Bridges and Tunnels Maintenance Manual

( Part 1 )
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Bridges and Tunnels
Maintenance Manual

(Part 1)
The kingdom of Saudi Arabia prides an extensive urban and rural road network that is the largest road network in the Middle East and that ranks among the world’s largest road network. This road network encompasses a great number of bridges and tunnels of various purposes: bridges that span flood courses, bridges in areas of high traffic volumes, bridges at crosswords with multiple arms, pedestrian bridges, tunnels crossing mountains and tunnels in crossings of high traffic volume. Hence, the owner (Ministry of Municipal and Rural Affairs, Ministry Deputy for Technical Affairs, General Directorate for Operation and Maintenance) prepared this manual that covers urban areas in the Kingdom. The Bridges and Tunnels Maintenance Manual consists of three parts: Part 1 of nine chapters adequately covering inspection, evaluation and maintenance works for bridges, underpasses, tunnels and culverts and part 2 of the manual encompasses contracts and bills of quantities for the maintenance works of bridges, underpasses, tunnels and culverts. This manual aims to provide a precise system that would enable the concerned officials to explore and conduct in-depth inspections of bridges and tunnels in urban areas of the Kingdom. The manual will enable these officials to perform their work accurately, as it provides them with the necessary guidance for inspecting damaged bridges in the road network in the Kingdom. It should be noted that this manual has been prepared for informing bridge engineers on the potential defects and the correct methods of detailed evaluation of bridges and conduct of tests, in addition to the strategies of the rehabilitation of damaged components. The manual also includes the details pertaining to maintenance priorities and repair methods included in the maintenance strategies. Further, the manual includes an explanation of the specifics of execution required in the repair and reimplementation processes.

Best regards…..
Chapter 1

Introduction
Chapter One: Introduction

1-1 Preface

Bridges and tunnels are basic and important components in any of the various transportation networks, especially road networks. But, inspite of this known importance, bridges continue to receive lesser attention as though they never require maintenance and repair and can serve for long years in this condition. This method of thinking results in the speed of damage becoming greater than the speed of repair which leads to great future losses with the structure requiring replacement of some components and sometimes complete reconstruction in order to perform its function.

In all cities, municipalities and governorates in the Kingdom of Saudi Arabia, there are many bridge projects being implemented or there are plans for implementing a number of bridges and tunnels for satisfying the ever increasing transportation and traffic in addition to the large number of existing bridges and tunnels.

The Ministry of Municipal and Rural Affairs has taken into account all these facts when it issued a direction for the preparation of the (Bridges and Tunnels Maintenance Manual) as a scientific base and a complete methodology for dealing with the maintenance of these vital installations.

1-2 Purpose of the Manual

The purpose of this manual is to explain the methods of maintaining the different kinds of bridges and tunnels. The manual basically addresses itself to the engineers of governorates and municipalities to enable them to maintain bridges and tunnels in accordance with standardized principles. It also addresses itself to all who are concerned with the maintenance of bridges and tunnels, including consultants, contractors and authorities responsible for the management of these installations.

The manual encompasses all the aspects of bridge and tunnel maintenance namely, (classification of bridges and tunnels, bridge and tunnel damages, methods of bridge and tunnel inspection and rating, maintenance and repair of bridges and tunnels damages, basics and technical requirements for maintenance of electric and mechanical works, bridge and tunnel management system (computer, contracts and bills of quantities).
1-3 Scientific Terminology

The following scientific terminology assumes greater importance in regard of bridge and tunnel maintenance as these terms are used in all relative references and manuals and they are explained for general benefit. They are as follows:

- **Acrylic**: Acrylic paint
- **Advanced Inspection Techniques**
- **Air Compressor**
- **Air Conditioning Unit**
- **Alternating Current (AC)**
- **Ammeter**: Measure for the flow of electric current in amperes
- **Anchors**
- **Arch Bridge**: A bridge in the form of arches which may be above or below the deck of the bridge.
- **Arcing**
- **As-built drawing**
- **Automatic**
- **Axial fans**
- **Ballast**: Coarse gravel laid to form a bed for railroads.
- **Ballast cleaning/replacement**: cleaning or replacement of brakes
- **Beam**: It is of various types and varies with design.
- **Boilers**
- **Bolted**: Steel parts joined by a bolt
- **Bond Test**: Test of bonding strengths
- **Bored**
- **Bridge**: A concrete, steel, wooden or metal structure above the ground for the passage of vehicles, trains or pedestrians.
- **Bridge Inspectors Training Manual**
- **Bridge Type**: Type of bridge according to the used classification.
- **Buckles and kinks**: Bends and twists
- **Built-in Test**
- **Bushings**: Liners
- **Bus-Bar**: A general conductor, also called connection or distribution bar.
- **Cable-Stayed Bridge**: A type of bridge where the bridge parts are stayed with cables to the two towers at the beginning and end of the bridge.
Cast in Situ
Cast in Place
Catenary power system: Overhead power system
Cathodic protection
Centrifugal fans
Ceramic tiles
Check; Concrete segregation
Chillers
Clamp slippage: Inspection of slippage clamps
Clamped electrical connectors
Clamp-on Ammeter: A device for measuring current, potential and resistance
Classification
Clock system
Closed circuit TV: Cameras of the closed circuit TV
Coated cement board panels
Concrete Bridge
Condition code forms
Construction methods
Contact rail insulators
Contact wire wear
Contractor: Contact key for controlling current flow in the electric circuit.
Controller: Control system
Cooling tower
Core test: Test of concrete core
Cracks
Corrosion
Corrugated
Culvert
Cured: Cured concrete
Current: Electric current and it is measured in amperes
Cut and cover
Cut and Pull Out Test: Cutting of concrete and testing it on tension.
Damage Inspection: It is performed in case of any damage to the bridge.
Dampers
Debris
Deck: The surface of the bridge and the name may vary with the material used in construction.
Defect location forms
Deflection
Delineation: General description
Desalination
Destructive Tests: So called because some destruction is made in the test place.
Deterioration:
Dewatering pump
Direct Current (DC)
Disconnect switches
Distress: Fatigue of the structure
Documentation forms
Drill and blast
D-meter: Device for measuring the density of metal rails.
Efflorescence: Desalification
Ejector Pump
Electro Chemical Porosity: Electric potential test for measuring porosity.
Emergency eyewash: Emergency wash water sources.
Epoxy
Expoxy-coated concrete
Exhaust
Exposed reinforcement: Exposed reinforcement steel
Fan drives
Fastener
Fatigue
Filter
Fire damage
Fire hydrant: A discharge pipe with a valve and spout for drawing water for fighting fire.
Flexure
Flow neutralization basin:
Frequency: The number of repetitions in a time unit or amount of oscillations per second
FRP: Fibreglass
Full Transverse ventilation
Full overlap
Fuse
Fuse Box
General Aligning
Geotextile: Filling earth coat
Girder: It is larger than a beam
Ground: A wire or other object for electric connection with the earth, or electrical connection with the earth.
Gunite: Concrete sprayed on a mold
Hangar
Heel: Railroad switch joint
Highway assets
Hollow area
Honeycombing
Hum-Meter: Test of moisture content
Illumination
Immersed tube
Impact echo test
Impedence: Resistance in an electric circuit
Impregnation: Treatment with infiltration
Initial inspection
Injection: Treatment with injection
Inspection
Inspection forms
Inspection Report
Inspection Tools
Inspection Team: Usually consists of the manager of the inspection program, team leader and a number of workers.
Inventory: Inventory of the establishment (life in service, date of last inspection, etc).
Invert repair
Invert types
In-depth inspection: Detailed inspection
Jacked tunnels
Joint maintenance: Maintenance of the joints
Joint spall
Jumpers
Latex
Lattice girder
Leakage
Less ductile
Liffelstein: Liffelstein Block
Lighting systems
Liner types
Longitudinal ventilation
Luminaire
Mastic
Messengers support
Metal tiles
Minor
Miscellaneous finishes
Mobilization
Moderate
Mortar
Motors
Mudballs
Multitester or multimeter: An electric meter with multiple measurements (for the current resistance and potential)
Natural ventilation
Non-Destructive Test
Overhead power system
Overlap
Paint Deterioration
Patch Failure
Pedestrian Bridge
Pedestrian Tunnel
Physical Inspection: Manual inspection using simple tools
Placed concrete
Plinth pads
Polyaramide glass fiber
Polymer
Pop-out: Concrete segregation
Porcelain-enamed metal panels
Post-tensioned
Power
Pre-cast
Pre-cast concrete
Panel
Pre-stressed
Pre-tensioned
Protection board
Protection board brackets
Protection system
Rainbow Indicator: Device for measuring the carbon content in concrete (carbonization test).
Rail
Railway bridge: A bridge established to be used by trains only.
Rail grinding
Rail joint
Rail lubrication
Rapid Chloride Test: Test of salts content in concrete.
Rating: Evaluation of the structure using special codes such as numbers and letters.
Rebound Hammer: Test of concrete strength using Schmidt hammer
Regaging: Resetting of the regular distance between the two rails.
Registration assembly
Repair
Re-alkalization
Resistance
Ribbed System
Riprap: Stones used for riprap
Road Bridge
Rock reinforcement system
Rot
Routine Inspection
Scaling
Seal
Segmental lining
Semi-transverse ventilation
Septic system
Serviceability
Severe
Shapes
Shear
Shield driven
Shotcrete: Concrete sprayed on a metal mold
Signal / Communication system
Single-point extraction
Sky-jacker
Slab
Slabbing
Slurry wall
Snooper: Lifting apparatus for inspecting high bridges
Sound attenuator
Spalling
Span
Special Inspection
Spike replacement
Sprayed Concrete
Staining
Steel Bridge
Steel contact rail
Stray current protecting system
Strengthening
Substructure
Sump
Superstructure
Supplemental tunnel segment sketches
Supply air
Survey control
Suspended Bridge
Template Gauge: Measurement of cracks width
Temperature
Termie concrete
Thermal Imaging equipment
Third rail insulated anchor arms
Tie plates
Tie renewals
Track
Track and supporting structure
Track structure
Transformer
Transition area
Troubleshooting: Electronic troubleshooting guide
Truss
Tunnel
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Tunnel segment photo log sheet
Turnbuckles
Types
Underpass
Unit heaters
Unlined rock
Ventilation systems
Visual Inspection
Voltage
Wearing Surface
Welded

1-4 Units and Abbreviations

<table>
<thead>
<tr>
<th>AASHTO</th>
<th>American Association of State Highway and Transportation Officials</th>
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<tbody>
<tr>
<td>ASTM</td>
<td>American Society of Testing Materials</td>
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<tr>
<td>BS</td>
<td>British Standard</td>
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<tr>
<td>BMMS</td>
<td>Bridge Maintenance Management System</td>
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<td>NBIS</td>
<td>National Bridge Inspection System</td>
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<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
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<tr>
<td>SASO</td>
<td>Saudi Arabia Specifications Organization</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>SBC</td>
<td>Saudi Building Code</td>
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<tr>
<td>SI</td>
<td>International Unit System (Societe International)</td>
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<tr>
<td>UPVC</td>
<td>Unplasticized Polyvinyl Chloride</td>
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<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
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<td>MN</td>
<td>Mega Newton</td>
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<tr>
<td>MPA</td>
<td>Mega Pascal</td>
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<tr>
<td>GRMC</td>
<td>Galvanized Rigid Metal Conduit</td>
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<td>RMC</td>
<td>Rigid Metal Conduit</td>
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<tr>
<td>AC</td>
<td>Alternating Current</td>
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<td>DC</td>
<td>Direct Current</td>
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<td>IDB</td>
<td>Illumination Distribution Board</td>
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<tr>
<td>KVA</td>
<td>Kilovolt Ampere</td>
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<tr>
<td>IES</td>
<td>Illumination Engineering Society</td>
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Chapter 2

Types of Bridges and Underpasses
Chapter 2: Types of Bridges and Underpasses

2-1: Introduction

This chapter is a part of the Bridges and Tunnels Maintenance Manual the proponent of which is the Ministry of Municipal and Rural Affairs, Ministry Deputy for Technical Affairs, General Directorate of Operation and Maintenance in the Kingdom of Saudi Arabia. It generally consists of two parts: Bridges and Underpasses and Classification of Tunnels. This includes classification of bridges in the Kingdom in accordance with the shape, construction material, use and structural system of the superstructure of the bridge and classification of tunnels which includes vehicle tunnels, railway tunnels and pedestrian tunnels.

2-2 Bridges and Underpasses:

2-2-1 Introduction:

A bridge is a structure used for passing from one place to another with an obstacle between the two places. The obstacles may be a body of water, rough ground or a steep valley, or it may be a road, railroad or similar structure. Over the ages bridges were made of wood and stone and later from steel and concrete. It is not easy to have one classification method for bridges and tunnels in cities. Classification methods vary in accordance with the reasons and objectives of classification. Here we will set forth the main classification methods for bridges and underpasses.

2-2-2 Classification of bridges in the Kingdom:

2-2-2-1 Introduction:

In the Kingdom of Saudi Arabia there is a wide spread of concrete bridges and tunnels with some steel bridges for use by vehicles or pedestrians and it is noticed that there are no stone or wooden bridges. Thus this classification has to include these points. So the classification of bridges for the purposes of this manual is as follows:
2-2-2-2 Classification according to shape:

In this classification bridges are classified to arch bridges, suspension bridges, cable-stayed bridges, beam bridges that are made of concrete or stone (Figure 2-1) are considered the best type of bridge for they stand the loads that cause compressive stress and the arches may be above or below the roadway.

![Figure 2-1 Arch Bridge](image1)

The steel arch bridges, suspension bridges (Figure 2-2) and cable stayed bridges (Figure 2-3) are the best bridges as regards standing the loads that cause tensile stress.

![Figure 2-2 Suspension Bridge](image2)
Beam bridges (Figure 2-4) are the best type of bridge as regards standing both loads causing tensile stress and compressive stress. Beam bridges are classified into simple beam bridge, continuous bridge and cantilever bridge.
Sometimes beam bridges are uneconomic and in such case it is recommended to resort to truss bridges (Figures 2-5) with types varying according to truss type.

**Figure 2-5** Truss bridge

2-2-2-3 Classification according to construction material:

In this classification bridges are classified into bridges made of steel (Figure 2-6), bridges made of concrete (Figure 2-7), or composite bridges made of both concrete and steel (Figure 2-8). In the Kingdom of Saudi Arabia (except in rare cases) there are no stone or wooden bridges and all the bridges are of steel or concrete with the concrete bridges dominating.

**Figure 2-6** Steel Bridge
Concrete bridges

These are the ones with the major parts (superstructures and substructures) made of reinforced concrete. Concrete has many advantages over other construction materials. One of the advantages of concrete is its high compressive strength, its formability and its easy maintenance. Most existing bridges in the Kingdom of Saudi Arabia are
built using ordinary reinforced concrete or pre-stressed reinforced concrete. Concrete bridges include the following:

1. **In Situ reinforced concrete**

This is made of reinforced concrete that is cast in situ with the formwork made in the required dimensions, the reinforcement steel fit according to the design and the concrete cast. The technology required for building this type of structure is relatively simple and does not require complex technologies or well-trained workers (Figure 2-9).

![Figure 2-9: In situ reinforced concrete](image)

2. **In Situ pre-stressed concrete**:

Here the formwork is made in the required dimensions and the reinforcement steel and metal cable conduits are fit. The design of structural elements in this case are a mixture of reinforced concrete and pre-stressed concrete. After casting the concrete the metal cables are passed into the cable conduits and the pre-stressing force is applied. The minimum concrete strength is determined before applying the pre-stressing by the designing engineer.

3. **Pre-cast Reinforced Concrete**:

This method adopts casting the elements of reinforced concrete in the factory, processing them until the required strength is reached and then
transporting them for installation in the site. In this type of structure it is easy to insure the quality of the concrete in the factory but it requires executing the joints with extreme precision for insuring adequate installation in the site taking into consideration stresses on the different structural elements as they are transported, raised by the winch and installed and also taking into consideration secondary stresses resulting from manufacture error. The pre-cast reinforced concrete structures generally have joints that are weaker than those cast in situ (Figure 2-10).

![Figure 2-10: Pre-cast concrete bridge](image)

4. Pre-cast Pre-stressed Concrete

In this method the concrete is cast in the formworks in the factory with the metal cable conduits fixed inside the formworks. Pre-stressing is applied after casting the concrete and its reaching a certain strength that is specified by the designing engineer. Most often the reinforcement steel is completely replaced by pre-stressing cables in this kind of structure.

5. Ordinary Precast Concrete:

It is somewhat rare and is only used for secondary parts of the bridge frame, segments, side facets, covers of cable containers and utilities, etc.
b. Steel Bridges:

Steel bridges have the advantage of lending themselves to quick construction and controllability of the component segments to fit the design condition. In this type of bridge the superstructure and the substructure are made of steel. Steel bridges include:

1- Welded steel bridges:

Welded steel bridges have the advantage of not being subjected to any pre-stressing resulting from manufacturing error and freedom from the need for reinsuring the quality of the manufacture of the structural components because the necessary tests are already automatically performed on each structural component (Figure 2-11).

![Figure 2-11: Welded Steel Bridge](image)

2- Steel bridges with riveted or bolted joints:

This type of bridge has the advantage of being easily and quickly executed, but it entails strict precautions for insuring precise execution of the joints, especially when the joints are jointed using bolts. The openings for bolts and rivets are made in the factory. It is worth mentioning that all bridges in the Kingdom are of this type (Figure 2-12).
2-2-2-4 Classification in accordance with use:

a) Bridges for use by vehicles:

Bridges and tunnels are wide spread in the cities of the Kingdom of Saudi Arabia. No main street in Riyadh, for example, is hardly void of a bridge or a tunnel. Each of the two has its benefits and advantages. Bridges are not subjected to the problems of draining and ventilation, whereas water drainage has to be taken into consideration in the design of tunnels and ventilation has to be taken into consideration in the case of large extended tunnels. On the other hand, the construction of tunnels costs less than the construction of bridges. So, neither of the two can be preferred to the other but many factors are taken into consideration in choosing one of the two. Bridges and tunnels are usually established in the locations of major cross-roads which carry a large volume of traffic, at the intersection of two or more roads, sometimes as a continuous bridge over the road, (Figure 2-13) and at other times as a continuous bridge under the road. Selection of a bridge or a tunnel depends on a number of factors foremost among them are the following:

- The available area and nature of the location.
- Location topography.
- Geotechnical characteristics of the soil of the location.
- Type of intersecting roads.
- Traffic study and the recommendations it presents.
- Economic feasibility.

Based on the above selection is made.

Figure 2-13: A bridge for the use of vehicles

b) Pedestrian Bridges:

Pedestrian bridges in the cities are usually constructed for the safety of pedestrians during the crossing of heavy traffic streets the crossing of which poses a risk especially for children and old people. Pedestrian bridges are established in places with continuous pedestrian traffic as when there are two buildings belonging to an institution (such as a university), separated by a main street entailing presence of a safe path for pedestrians, (Figures 2-14 and 2-15). In many parts of the world there are bridges and tunnels for pedestrians but the Kingdom of Saudi Arabia’s experiment is focused on pedestrian bridges that are made of concrete or steel.
c) **Railway Bridges:**

These are usually established for the crossing of trains when valleys, plains or water bodies obstruct the railway path. These are usually truss bridges. Figure 2-16 shows a railway bridge.
2-2-2-5 Classification in accordance with the structural system of the bridge superstructure:

Bridges of this classification are classified into the following:

- Slab bridges: This type of bridge is characterized by that the nature of resting is unidirectional on the edge and intermediate piers and the stresses resulting from loading are shear stress, torsional stress and turning moments. There are different slabs for slab bridges such as hollow slabs and solid slabs. This type of bridge is very strong with non concentration of stresses on a specific point (Figure 2-17).
\begin{itemize}
    \item **Beam Bridges:** The superstructure of the bridge is designed in the form of linear beams on which the bridge slabs are placed. There are many types of beam segments including I shaped beam, T shaped beam, rectangular beam and trapezoid beam (Figure 2-18).

    \begin{figure}[h]
    \centering
    \includegraphics[width=\textwidth]{Figures/Beam_bridge.png}
    \caption{Beam bridge}
    \end{figure}

    \item **Box Bridges:** This type is used in bridges with large spans wherein a surplus in the segment height can be achieved compared with ordinary beam bridges. These bridges are also used when the bridge is subjected to turning moments, especially when the bridge is located at an acute curve and when there is an additional height in the road track. The largest volume of traffic can be taken in this type of bridge by a cantilever structure at the sides of the box segment (Figure 2-19).

    \begin{figure}[h]
    \centering
    \includegraphics[width=\textwidth]{Figures/Box_bridge.png}
    \caption{A box bridge}
    \end{figure}
\end{itemize}
- **Frame Bridges**: In this type of bridge the superstructure rests on the substructure in the form of complete joints which relieves the positive moments in the bridge type paths and gives the bridge greater strength. In this bridge there are no joints in the superstructure nor free rests on the substructure (Figure 2-20).

![Frame Bridge](image)

**Figure 2-20: A frame bridge**

- **Classification according to the slab suspension system**

In this classification bridges are classified into:

- Simple suspension on concrete supports.
- Cable suspension system.
- Suspension bridges.
- **Classification according to the number of spans in the bridge:**
  - In this classification bridges are classified into:
    - Bridges with one span
    - Bridges with two spans
    - Bridges with multiple spans
- **Classification according to the bridge components**
  Bridges may also be classified according to the shape of the segments making up the bridge as follows:
  1. Shapes designed on curvature and cast in place:

The common segments of reinforced concrete components are shown in figure 2-21 and they are:
- Structural slabs and bridges deck slabs
- Rectangular beams
- T-beams
- Reverse U or channel beams

The bridges with the above mentioned segments of beams reinforced with soft iron have been ideally executed through casting in place.

The concrete components of the aforesaid shapes are used in bridges with short and medium spans.

![Diagram of Slab, Channel, Rectangular beam, T-beam](image.png)

**Figure 2-21: Shapes of reinforced concrete segments**

Concrete slabs are used as concrete decks or as slab bridges. As regards the concrete decks the concrete spans are the distance between the members of the superstructure of the bridge structure with densities usually varying between 180 and 230mm. The spans of slab bridges are the distance between the intermediary or edge piers constituting the whole bridge deck and the whole superstructure, with densities usually varying between 300 and 600mm. The rectangular beams are used in the members of both the superstructure and substructure.

The beams of the intermediate piers are usually rectangular beams and they support the bridge superstructure. The T-beams are used on the beams superstructure only. These beams are merging of rectangular bridges and bridge slabs for forming the whole bridge deck and hence forming the bridge superstructure.
The inverse U-beams or channel beams are used only on the bridge superstructure. This shape of beam is pre-cast and is used in bridges with short spans.

2. Shapes of precast beams designed on curvature:

The most common shapes of pre-stressed concrete components are shown in figure 2-22. They are:

- I-beams.
- Bulb-Tee beams.
- Box beams.
- Box girders.
- Voided slabs.

All these types are used in the bridge superstructure.

Figure 2-22: Shapes of pre-stressed concrete segments

Pre-stressed concrete beams may be produced in the factory using concrete with high compression strength.
Increasing materials strength, using more efficient segment shapes and greater pre-stressing strengths and close observation during manufacture allow the structural members to stand greater loads and hence be capable of having larger spans and bearing greater live loads.

Pre-stressed and post-stressed concrete is generally more economic than ordinary reinforced concrete because the pre-stressing strengths under the neutral axis of the segment increases the area of the concrete subjected to compression in the concrete segment. This is coupled with the fact that the pre-stressing steel has a very high strength and so we only need a small quantity of steel, see Figure 2-23.

![Reinforced concrete and pre-stressed concrete](image)

**Figure 2-23: Concrete reinforced with soft steel and pre-stressed precast concrete**

I-beams have an I cross section and their role is that they are members of the bridge superstructure and support the bridge slab.

The bulb-tee beams have a T-cross section with a bulge similar to a bulb at the bottom of the cross section (similar to the lower wing of the I section).

Box beams have a square or rectangular shape. The height of the segment is usually equal to or greater than 430 mm. These beams can be in close contact or detached at some distance from one another. These beams are ideally used in bridges with short and medium spans.

Box girders have a square or rectangular sections and resemble the superstructure and slab together. This type of beam is used in bridges
with large spans or arched bridges and the beams may be precast or in the form of assembled pieces or cast in place.

Voided slabs have a rectangular section and inner voids and are usually precast units born on the substructure. The purpose of the inner voids is to reduce the dead load.

2-3 Tunnels:

2-3-1 Introduction:

A tunnel is an underground pass. Tunnels are dug through hills and mountains, below the cities, under waterways and even under the roads in the cities. Tunnels also provide roads and railways with safe and comfortable passageways for getting past natural and manmade obstructions. The term tunnel denotes underpasses with length many times their width and established for going past obstructions.

2-3-2 Classification of tunnels in the Kingdom of Saudi Arabia:

Tunnels are usually classified by use more than by any other classification. Accordingly, they are classified as follows:

2-3-2-1 Vehicle Tunnels:

The lengths of this type of tunnel vary. Some of them are passageways under an obstruction and in this case the pass is called an underpass with the length not exceeding two times the width as in figure (2-24) and it is the prevailing kind of tunnel in the Kingdom of Saudi Arabia. Others may extend for a long distance under the ground and here they are called tunnels, such as those in Makkah. The first type is considered to be a good option at intersections and it is mostly less expensive than bridges and free of ventilation problems. The only problem here is the draining of storm water, which entails installation of pumps.
These usually extend for a long distance under the ground and are called (underground railways). No railway tunnels are established for passing under the roads and other obstructions as the engineering design for railways entails using little longitudinal inclinations leading to great lengths of tunnels and hence great costs and so in the Kingdom of Saudi Arabia and other countries bridges are established on the other direction instead of railway tunnels, but all this of course is dependent on the nature of the location and whatever is the best technical solution. However, the global practice is that complete networks are built under the ground for the trains so the spaces above the ground are not affected allowing using them for other purposes (Figure 2-25).
2-3-2-3 Pedestrian Tunnels

Pedestrian tunnels (figure 2-26) perform the same purpose performed by pedestrian bridges. The only difference between the two is the cost in each type. Pedestrian tunnels are usually made of concrete or steel pipes.

Steel pipes of different diameters can be used in the different types of tunnels: vehicle tunnels, railway tunnels and pedestrian tunnels (figure 2-27).

The tunnel perform the same function performed by the bridge. Preference of one to the other depends on engineering factors such as available space, location nature and topography, geotechnical characteristics of the location soil, purpose of the tunnel and economic feasibility.
Figure 2-26: A pedestrian tunnel

Figure 2-27: A tunnel made of steel pipes
Chapter 3

Damages to Bridges and Underpasses
3- Damages to bridges and Underpasses:

3-1 Introduction:

This chapter is a part of the Bridges and Tunnels Maintenance Manual the proponent of which is the Ministry of Municipal and Rural Affairs, Ministry Deputy for Technical Affairs, General Department of Operation and Maintenance in the Kingdom of Saudi Arabia. It generally encompasses a number of main sections namely damages to underpasses, damages to the superstructures and substructures of concrete and steel bridges and damages to pedestrian bridges. The chapter also encompasses the details of these damages and the affected parts. We cannot touch on all the damages and defects that affect the bridges, tunnels, and pedestrian bridges because of the great number of their causes and variability of their types. Anyhow, we will try to cover the most serious damages that occur frequently in these structures and that are dealt with in accordance with the adopted engineering practices.

3-2 Damages to underpasses:

3-2-1 Cracking of the supporting walls of underpasses:

Supporting walls of tunnels in the cities hold back the soil that is saturated with moisture and ground water because the level of ground water is high in most of tunnels locations in cities since ground water is continuously fed with irrigation water from nearby farms, from nearby houses sanitary discharge, from leakage from nearby water and sanitary discharge networks and from storm water withheld behind those walls. And, since the main reinforcement bars of the supporting walls are in the front of the walls adjacent to the soil, the penetration of ground water through the concrete walls finds its way easily to the reinforcement bars which catalyzes the rusting and puffing of the reinforcement bars, especially when we know that the ground water contains high percentages of chloride and sulphate salts. Once the rusting process starts, it accelerates and may reach a state where the greater part of these rods may be lost with the loss of their structural capacity which may cause the failure of the locations of those supporting walls (figure 3-1).
3-2-2 Failure of storm water drainage in the underpasses

Heavy rainfall may cause water to accumulate so quickly in some tunnels that the capacity of water drainage systems fail to cope with the amount of water in these tunnels, which leads to the level of water raising beyond the levels that allow vehicle traffic. Among the causes of storm water accumulation in the tunnels may be some failures that affect the pumping stations in these tunnels, so it is opportune to intensity maintenance of pumps in the tunnels in anticipation of rainy seasons (Figure 3-2).

Figure 3-1: Cracking of the supporting wall

Figure 3-2: Inability to drain rain water
3-2-3 Differential settlement in the asphalt layer in the roads that are parallel to the supporting walls:

When the filling up and compaction operations in the soil layers behind the supporting walls are not executed properly according to the standards prescribed for compacting the filling up layers behind the supporting walls it is expected that there is a potential for a variation in the settlement of soil under the asphalt layer of the side roads parallel to the walls and so a difference in the settlement occurs between the filled part and the unfilled part and this phenomenon crystallizes by the presence of longitudinal cracks in the asphalt layer that goes parallel to the supporting wall.

This problem is remediated by creating a filter for draining water behind the wall and recompacting the filling layers regularly and then the asphalt layer can be scrapped off and remediated (Figure 3-3).

![Figure 3-3: Settlement in the asphalt layer parallel to the supporting wall](image)

3-3 Damages to concrete bridges:

The damages to concrete bridges are classified according to their position on the bridge structure as follows:
3-3-1 Damages to concrete bridges substructures:

These include abutments at bridge edges and intermediate piers at the lower part of the bridge structure.

3-3-2 Cracking of concrete caused by reinforcement rods rusting:

This is among the most common damages in cities bridges and is caused by plants irrigation method. There are other causes of concrete cracking, including the lack of concrete insulation and insufficiency of concrete coating. It is noteworthy that maintenance departments advise agriculture departments in the various municipalities about the importance of preventing irrigation water from getting to concrete bridges bases and piers but our requests do not get adequate attention (Figure 3-4).

![Figure 3-4: Damages of concrete cracking caused by reinforcement steel rusting (in the substructure)](image)

3-3-3 Damages affecting bearings:

Bridge Bearings are devices connections that transfer forces between the bridge superstructure (deck) and the substructures (pier or abutment) without overstressing the substructure elements, ensuring that the bridge functions as intended, the functions of bridge bearings could be summarized in the following three points:

1. Transfer the forces from the superstructure to the substructure.
2. Enables the rotational movement of the superstructure in reactions to Dead Load and Life Load.
3. Enables the horizontal movement (translational, longitudinal) of superstructure as a result of thermal expansion and contraction.

The Bridge Bearings classification is presented on AASHTO LRFD standard, which are classified in term of bearing function to six types, see figure (3-5):

1. The Moveable Bearings includes species described in the following figure:
2. Elastomeric Bearings consist of mild steel and neoprene rubber molded as one unit, includes the following types
3. Pot Bearings: as illustrated below
4. Disc Bearings: as illustrated below
5. Fixed Bearings: are functioned to prevent the horizontal movements in all directions and permits the rotation movement.

Figure 3-5: Bearings Types

The inspection and evaluation of Bridge Bearings will be conducted generally depending on bearing type, where the bearings are classified in this case according to the material to two types, Metal bearings and elastomeric bearings.
1) Malfunction of metal bearings:
   • Corrosion at the sliding surface.
   • Mechanical obstructions in the movement
• Obstructions to the movement due gravel and debris.
• Bending, torsion, and lack of integrity and the misalignment of concrete elements.
• Loss of coherence between the parts.
• Cracks on the welding places.
• Irregular distribution of load on the lower bearing plate.

2) Malfunction of elastomeric bearings:
• Occurring protrusions at the shims or fission between the bearing plates and the deficiency of coherence between them.

3-4 Damages to concrete bridges superstructure:

3-4-1 Concrete cracking resulting from reinforcement rods rusting:

These are rare in dry places but they may occur in the coastal salty places. Rain water draining system from the bridge deck may also be one of the causes of concrete cracking (Figure 3-6).

![Concrete cracking damages resulting from reinforcement rods rusting (in the superstructure)](image)

3-4-2 Damages due to bumping against high trucks:

These usually take place in low height bridges and on valley bridges that are not designed for vehicle traffic under the bridge structure. The
damage resulting from such collision is usually local and does not affect the bridge structure safety and is usually repaired with plastering without any remarkable negative results. These damages may occur despite cautioning and sign boards placed before low bridges (Figure 3-7).

3-4-3 Damages to concrete bridge joints:

These usually take place in bridges with traditional joints or bridges without joints where the gaps are filled with dust and gravel preventing the movement of the slabs and leading to the cracking of the asphalt layer above these expansion joints. Perhaps the best remediation for this kind of damage is the use of Thorma joints (Figure 3-8).

Figure 3-7: Damages due to bumping against high tucks.
3-4-4 Damages affecting guard rails:

These are common damages that can be controlled with continuous maintenance of bridges guard rails by replacing side guard rails with new ones or by increasing the side support of these side plates or rails (Figure 3-9).

Figure 3-8: Damages to expansion joints.
3-5 Damages to steel bridges:

3-5-1 Damages affecting the substructure:

3-5-2 Damage due to steel rusting caused by adjacent irrigation water:

This is noticed in most steel bridges in Riyadh, with dust, dirt and adjacent farms irrigation rain water accumulating in the beds of steel bridges footings causing occurrence of the indications of steel rusting in many steel bridges footings in Riyadh (Figure 3-10).

3-5-3 Damages in the form of scaling of the external paint layer of steel bridges:

This is a basic maintenance element is steel bridges. The external paint layer scales and starts to corrode within approximately 4 to 5 years then rehabilitation of the external paint layer of metal bridges by removing the...
old layer with a sand bath, addition of a primer and repainting of the whole metal bridge structure with brushes or mechanical spray is advisable (Figure 3-11).

Figure 3-10: Steel rusting due to irrigation water

Figure 3-11: Damages affecting the external coat.

3-5-4 Damages due to vehicle collision with metal bridges intermediate piers:

Although this is rare, some of these intermediate piers may not be sufficiently protected and so some vehicles collide with these piers.
3-6 Damages affecting metal bridges superstructure:

3-6-1 Damages due to vehicle collision with the bridges:

These damages are very common in most steel bridges in cities, especially with heights below 5.5 meters.

Unlike concrete bridges, damages to steel bridges structure are usually serious which entails dismantling and complete rehabilitation before putting them back in their places. Here, it is advisable to have readily available spare parts or segments for those steel bridges so that repair of the damages due to vehicle collision with the superstructures is done as fast as possible (Figure 3-12).

Figure 3-12: Damages due to collision of high vehicles

3-6-2 Damages due to collision of vehicles with side fenders:

This is inevitable in crowded cities and it applies to steel bridges and concrete bridges but the steel bridges side fenders may not be of the same strength as concrete bridges.
These damages are continuously repaired by replacing or rehabilitating the damaged pieces (Figure 3-13).

![Figure 3-13: Damages to side fenders.](image)

3-6-3 Scaling of epoxy protective layer:

This is one of the most common damage in steel bridges with repair and rehabilitation being the most expensive.

The epoxy layer used for protecting the steel bridge deck from rusting and for increasing the friction of vehicles wheels on the steel bridge deck usually corrodes within 5-7 years and when the percentage of epoxy layer corroded areas approximates 50% of the whole bridge area the decision to remove and rehabilitate this layer will be the last resort.

Removal of the old epoxy layer and cleaning of the steel bridge structure surfaces with a sand bath and fixing of a new epoxy layer reinforced with granite fragments for increasing the grip of vehicles wheels usually takes many weeks during which the bridge remains closed before vehicle traffic, which causes many problems and hinders public good, so these works are usually undertaken during the summer holidays when traffic on the bridge is light, allowing complete closure of the bridge.
3-6-4 The problems of bolts loosening and breaking:

The continuous dynamic vehicle traffic causes the tightening strength of some fasteners and bolts to loosen and in some cases some of these fasteners and bolts are completely cut and they fail and drop from the bridge structure. The maintenance teams attending these bridges perform periodic tensioning tests on these bolts and the defective items are replaced periodically (Figure 3-15).

Figure 3-14: Damages in the form epoxy protective layer scaling.

Figure 3-15: Problems of bolts loosening and breaking.
3-7 Damages to pedestrian bridges:

There is no denying that most of the damages affecting pedestrian bridges follow the same damage pattern that affect vehicle bridges and the repair methods used for pedestrian bridges are usually similar to those adopted for repairing vehicle bridges. However, some damages are specific to pedestrian bridges and we are going to address them in this paragraph.

3-7-1 Damages due to collision with the upper frame of pedestrian bridges:

Since the frames of pedestrian bridges are usually relatively light, the impact of the upper collision by high vehicles is more serious than that taking place in vehicle bridges, especially in three dimension bridge frames where collision usually leads to the loss of some components of the frame that support the bridge which entails the remanufacture of these components and their refixing in their place.

3-7-2 Damages in the form of wanton writings and intentional sabotage

All road establishments in cities are subject to wanton writing by children and teen-agers, such as spraying of paint and intentional fires. Pedestrian bridges are usually more subject to these acts as they are close to residential districts and used by people of all ages and races. So, this entails effective methods for preventing or reducing the impacts of these acts of sabotage and costs the authorities a lot of money and efforts spent in remedy of the damages.

![Figure 3-16: Damages in the form of wanton writings](image)
Chapter 4

Methods of Bridges and Underpasses

Inspection and Evaluation
Chapter 4: Methods of Bridges and Underpasses Inspection and Evaluation

4-1 Introduction:

This chapter is a part of the bridges and tunnels maintenance manual the proponent of which is the Ministry of Municipal and Rural Affairs, Ministry Deputy for Technical Affairs, General Directorate of Operation and Maintenance in the Kingdom of Saudi Arabia. It generally encompasses four main sections namely, the overview which encompasses the methods and types of inspection, stages of planning and preparation for the inspection, inspection reporting systems, qualifications and responsibilities of inspection teams, tests used in bridge inspection and the tools used in this operation.

4-2 General:

4-2-1 Introduction:

Bridge inspection has many requirements and important aspects that must be satisfied for insuring good outcomes of the inspection, given that the inspection results are used for determining the defects types and severity levels and consequently successful maintenance is based on accurate and careful inspection.

4-2-2 Inspection methods:

There are two inspection methods, namely inspection of concrete bridges and inspection of steel bridges.

a) Concrete bridges inspection methods:

There are three methods for inspecting reinforced concrete bridges and pre-stressed concrete bridges:

- Visual inspection; There are two methods of visual inspection to be used by the person who performs the inspection. The first method is called routine inspection which is a review of the previous inspection report and then visual examination of the bridge parts from below. The second kind of visual inspection is called in-depth
inspection. Here one or more elements are inspected above or under the water for detecting the defects which were not detected by routine visual inspection. There may be a need for more precise visual inspection for evaluating the concrete surfaces from a close distance and in this inspection nondestructive tests can be used.

- **Physical Inspection**: Physical tests are performed on the parts identified in the visual inspection using the inspection hammer for verifying the size and severity of the defect or using the metal wheel designed for this purpose instead of the hammer in large concrete surfaces and by means of the sound of the concrete we determine to what parts the defect extends.

- **Advanced inspection techniques**: In case the size of the defect cannot be determined by visual or physical inspection, advanced inspection techniques are used. These techniques include:
  - Acoustic wave sonic / ultrasonic velocity measurement.
  - Delamination detection machinery.
  - Rebound penetration methods.
  - Ultrasonic testing.

There is another set of testings, including:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Moisture content

**b) Steel bridges inspection methods:**

There are three basic methods for inspecting steel bridges. A person carrying out inspection of steel bridges may need one or all of the three methods. They include:

- **Visual inspection**: Visual inspection is carried out to check corrosion, cracks, segment reduction, flexion and cracks if any. Inspection should concentrate on the following:
Damaged parts (specifying the kind of damage, such as flexion, overloads and their remarkable effect as well as cracks and segment alignment etc.

- Corrosion
- Fatigue cracks and other cracks
- Any detachment points in the segments
- Segment reduction
- Welding places
- Previous places of repair with welding
- Parts subjected to shaking and flexion.

There are specific procedures to be followed for fatigue cracks during this kind of inspection encompassing the following:

- Writing of a report on fatigue cracks immediately upon their determination.
- Visual determination of limits of the cracks.
- Examination of the bridge parts that are similar to the cracked part.
- Examination of the places where there is scaling of paint and checking for the presence of rust.
- Application of nondestructive tests.
- Examination of the parts that are exposed to salt and moisture
- Examination of the parts that are usually difficult to access because they have been coated inadequately in the previous time.
- Examination of the parts exposed to wind and rain.
- It is important to examine the steel parts exposed to free air in the following parts (places subject to accumulation of rain water, places where dirt accumulates, places where salts accumulate, near joints and drainage systems).

The colour of the steel parts exposed to air is important for determining their condition as follows:

Yellow/Orange: Acceptable in new parts,

Brown/Purple: Acceptable for steel which has been in service for several years,
Black: Indicates failure. A part with a colour that is different from the surrounding area is an indication of a problem in this part that must be examined immediately.

The use of the brush and hammer for the inspection of steel surface texture also gives significant indications as shown in table 4-1 below:

<table>
<thead>
<tr>
<th>Appearance</th>
<th>Degree of Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coherent, stands hammering and</td>
<td>Protected</td>
</tr>
<tr>
<td>cleaning with wire brush.</td>
<td></td>
</tr>
<tr>
<td>Powdery</td>
<td>Initial indicator of losing protective layer and must be</td>
</tr>
<tr>
<td></td>
<td>changed in a few years.</td>
</tr>
<tr>
<td>Gravelly</td>
<td>Indicator of presence of problem.</td>
</tr>
<tr>
<td>Slightly scaled off</td>
<td>Initial indicator of losing protective layer</td>
</tr>
<tr>
<td>Severely scaled off</td>
<td>No protective layer</td>
</tr>
<tr>
<td>In the form of plates and small</td>
<td>No protective layer and indicative</td>
</tr>
<tr>
<td>nodules</td>
<td>of severe deterioration.</td>
</tr>
</tbody>
</table>

- Physical inspection: It is divided into:
  - Physical inspection of steel parts:

  After visual identification of the defect, physical methods must be used to identify the size of the defect, and for this the hammer and wire brush are used. They must be used carefully to avoid covering the cracks rendering seeing them difficult. A rule and measuring tape are used for determining segment reduction, if any, rust must be removed before performing the measurement. The inspector must measure all the dimensions comparing them with the plans. This is of utmost importance because the reduced segment pauses a risk in bearing and distributing the loads.

  - Protective layers:

    During inspection the degree of the protective layer corrosion must be identified. Also, we must distinguish between corrosion of the protective
layers and structural corrosion. Also, we must examine the constancy and coherence of the paint which is usually affected by the rays of the sun and the rust under it using a sharp tool (a knife). The thickness of the paint dry membranes must be examined using one of the following methods: (magnetic attraction, fixed probe, destructive testing). In case of repainting, the kind of paint to be used for insuring coherence must be specified.

➢ Use of advanced inspection techniques:

There are many advanced techniques and nondestructive tests that can be used on steel including the following:

- The smart dye for inspecting fatigue cracks.
- Penetrate dye
- Ultrasonic testing
- Tensile strength test

4-2-3 Inspection Types:

There are five of inspection types including:

A- Initial inspection: This is for inventorying, rating the structure, providing essential information on the bridge structural condition, assessing the bridge loading capacity and identification of the current bridge problems.

B- Routine (periodic inspection):

This is done in successive periods. It is the examination and measurement acts carried out for identifying the functional condition of the bridge components for finding out the discrepancy from what is recorded in the first inspection. The routine inspection will be carried out in no more than two years intervals.

C- Damage inspection: This is an unplanned inspection conducted when there is a damage on the bridge caused by natural factors or by man. This inspection includes determining whether there is a requirement for contingent measures for passing loads or for closing the bridge.
D- In-depth inspection: This kind of inspection is performed on one or more components for checking the defects not fully or adequately identified in the routine inspection. Field nondestructive testing may be used in this kind of inspection. It may also encompass rating of the loads for testing the loading capacity of certain components. In small bridges all critical components must be examined but in large bridges this inspection must be deliberately planned for examining certain bridge components.

E- Special Inspection; This kind of inspection is applied for checking a special defect such as settlement of the footings, soil rotting, fatigue damage. In this inspection the required tests and measurements are specified.

4-2-4 Planning for inspection:

For insuring conduct of systematic inspection, the inspection team leader must plan for the inspection. Planning is of great importance. It insures that inspection is effective, of a reasonable cost and done within a specific period specified during the planning. Planning must encompass the following:

- Specification of the kind of inspection.
- Selection of the inspection team. The team must include a team leader who is conversant in all kinds of inspection.
- Evaluation of the activities required in the inspection (nondestructive tests, inspection underwater …etc.
- Establishment of a specific sequence for inspection.
- Establishment of a schedule for inspection and evaluation of results.

4-2-5 Preparation for inspection:

Preparation for inspection should encompass the following:

- Review of the bridge file.
- Identification of the bridge parts and components.
- Preparation of memorandums and sketches required for work.
• Making arrangements for accessing the parts and components to be inspected.
• Verification of safety measures.
• Getting the tools and equipment ready.

### 4-2-6 Bridge inspection reports system:

The inspection report must include an inventory, rating and classification of the structure.

**A- Inventory items:**

- Definition: Definition of the structure using codes and description of the location.
- Structure type and the material of which it is made.
- Its age and service: Date of the establishment or reestablishment of the bridge, structure features, the area it spans, type of traffic on it.
- Structure engineering data (shape)
- Rating of loads: Bridge load capacity.
- Proposed improvements.
- Inspection: Date of last inspection, critical observations that require a special inspection.

**B- Rating items:** Rating must include the following:

- Comparison of the bridge condition at the time of inspection with its condition when it was established.
- Structural rating: Rating of the structure general condition based on the main defects and the ability of the bridge to bear loads.
- Slab geometric shape: Engineering rating of the road on the bridge and determination of the vertical clearance.
- Clearance below the bridge: Includes the horizontal clearance and the vertical clearance on the road below the bridge.
- Horizontal track of the road and the bridge. Comparison of the horizontal track of the road with the horizontal track of the bridge.
- Traffic safety: Lateral protection, central island, planning and markings, etc.
4-3 Inspection team, its qualifications and responsibilities:

4-3-1 Composition:
The team consists of inspection program manager, inspection team leader and workers, if need be.

4-3-2 Inspection team qualifications:
Inspection team qualification must be as follows:
A- Inspection Program Manager:
- Must be a specialized engineer or an engineer with no less than ten years experience in inspection.
- Has successfully completed the comprehensive training program on bridge inspection conducted by an accredited agency.

B- Inspection team leader
- Must have qualifications like those mentioned in (A) above, or:
- Must have no less than five years experience in the field of bridge inspection and shall have successfully completed the comprehensive training program on bridge inspection, or
- Must have an associate degree in engineering awarded by a college or university.
- Must have no less than four years experience in the field of bridge inspection.

4-3-3 Inspection Team Responsibilities:
The inspection official is generally responsible for the following:
- Guarantee of public safety and maintenance of confidence between bridge users and responsible authorities.
- Protection of public money by dealing with the small defects before they lead to major maintenance items such as part replacement and other kinds of maintenance of great cost.
- Provision of accurate records on the bridges.
- Accuracy in work taking into consideration that the inspection report is an official document.

4-4 Tests employed in bridge inspection:
Concrete and steel are the two main materials used in bridges. Hence, the standard common tests in the in-depth inspection of bridges areas are shown in table 4-2 below:
The tests used in bridge inspection are classified as destructive tests and nondestructive tests on concrete and steel as follows:

<table>
<thead>
<tr>
<th>Construction Materials</th>
<th>Serial</th>
<th>Tests</th>
<th>Test Purpose</th>
<th>Test Tool</th>
<th>Test Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>1</td>
<td>CAPO Test</td>
<td>Determination of concrete compressive strength</td>
<td>CAPO Test tools</td>
<td>ASTM C900-99BS 1881 Part 207</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Bond Test</td>
<td>Determination of Concrete tensile strength</td>
<td>Bond Test Tools</td>
<td>ASTM D 1144 BS 1881 Part 207</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>RCT Test</td>
<td>Determination of concrete purity</td>
<td>RCT Test Tools</td>
<td>ASTM C 114 AASHTO T260</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Hum-meter Test</td>
<td>Determination of the moisture content in the concrete</td>
<td>Hum-meter apparatus</td>
<td>ASTM C 1202-97</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Concrete Thinning Test</td>
<td>Determination of concrete areas with poor surface strength</td>
<td>Rebound hammer</td>
<td>ASTM STP 1073 RC</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Measurement of crack width</td>
<td>Determination of crack nature and its effect on the concrete</td>
<td>Template guage</td>
<td>____</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Concrete Homogeneity and Firmness</td>
<td>Determination of concrete firmness and honeycombing areas in it.</td>
<td>Pundit’s Ultrasonic Tester</td>
<td>ASTM C 597 BS 203</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Carbon content measurement test</td>
<td>Determination of the possibility of rust impact</td>
<td>Rainbow indicator</td>
<td>ASTM C 1202-97</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Concrete specimens testing (cubic weight, void ratio, moisture content, laboratory strength)</td>
<td>Determination of concrete physical properties</td>
<td>Coring machine</td>
<td>ASTM D 2829</td>
</tr>
<tr>
<td>Steel</td>
<td>10</td>
<td>ECP Test</td>
<td>Determination of the areas affected by rust in the reinforcement steel and the degree of being affected by rust</td>
<td>Half cell potential meter</td>
<td>ASTM G48</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Measurement of Reinforcement diameters</td>
<td>Determination of the design condition and amount of reinforcement rods corrosion</td>
<td>Vernier calipers</td>
<td>ASTM D 284 3 and 3863</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Measurement of the thickness of reinforcement protection layer</td>
<td>Determination of protection layer efficiency</td>
<td>Cover master</td>
<td>____</td>
</tr>
</tbody>
</table>
4-4-1 Nondestructive Tests:

(1) Rebound hammer

A- **Purpose of test:** Identification of weaknesses in the concrete such as the problem of thinning because of irregular distribution of concrete granules due to bad execution or concrete decomposition. This test is nondestructive.

B- **Test method:** The concrete surface to be tested is smoothed with a metal brush for removing all the protrusions that may be on the surface. The hammer is focused on the test point, the rebound key is released and the resultant reading is recorded. The test is repeated at least five times at the same point adopting the mean reading. The following should be taken into consideration:

- Identification of the units with which we obtain the results.
- Position of the hammer during the test (horizontal, vertical, oblique). This should be taken into consideration using the conversion tables that give the strength according to each position as regards the ordinary tools. As regards electronic tools it is sufficient to enter the test angle for making the conversion automatically.

C- **Tools for testing thinning in concrete:** The tool used for testing thinning in concrete is a simple tool called rebound hammer or Schmidt hammer. It is of two kinds: electronic and ordinary, the difference between the two is that the ordinary one needs conversion tables for converting the readings according to the test angle, whereas in the electronic type it is sufficient to enter the test angle to automatically conduct the conversations.

This test also requires a metal brush for cleaning the test surface in addition to papers for recording the data. In the electronic tool the data is automatically recorded and the tool can be connected with a computer.

D- **Ranges of concrete thinning test:** These ranges vary according to the original design strength of the structural component and structure age as in table 4-3 below:
Table 4-3 Ranges of concrete thinning test

<table>
<thead>
<tr>
<th>Tool reading (in Megapascals)</th>
<th>Condition</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-15</td>
<td>Poor concrete</td>
<td></td>
</tr>
<tr>
<td>15-25</td>
<td>Average concrete</td>
<td></td>
</tr>
<tr>
<td>25-35</td>
<td>Good concrete</td>
<td></td>
</tr>
<tr>
<td>&gt;35</td>
<td>Excellent concrete</td>
<td></td>
</tr>
</tbody>
</table>

(2) Template Gauge (for meaning crack width)

A- **Purpose of template gauge:** To show the distribution, severity and prevalence of cracks and hence their impact on structure functioning.

B- **Measurement method:** For measuring the width of cracks a special ruler is used for measuring the width of cracks. The ruler is placed on the crack measuring its width in accordance with the nature of the crack. For structural cracks reference is made to the type of cracks (moment or shear) and the extent of the impact of these cracks is recorded. For nonstructural cracks locations must be planned and remarks related to the probable causes of these cracks must be recorded.

C- **Crack width measuring ruler:** The following table 4-1 shows the ruler used for measuring crack widths, with each line designating the width correspondent to the crack.

Figure 4-1: Showing crack width measurement method
D- Crack classification ranges:

There is no internationally accepted standard that specifies the allowances for crack width. However, the crack ranges are generally as follows: small cracks are less than 0.3mm, average cracks are 0.3-0.5 mm and wide cracks are above 0.5mm.

(3) **Concrete homogeneity and firmness test**: (using ultrasonic waves):

A- **Purpose of the test**: This test is conducted for checking concrete homogeneity and firmness on the whole concrete component segment and hence determining weak areas in the concrete. It is noteworthy that this is a nondestructive test.

B- **Test method**: The sensors of the ultrasonic wave unit are placed on the two sides of the surface sending ultrasonic waves that penetrate the concrete from one side to the other and the necessary measurements express the sound wave transfer time and the wave form is displayed on the system screen. If the concrete surface has holes, caves, thinning or nonfirmness a change is observed in the length of the transmitted wave and the speed of its penetration of the concrete surface.

C- **Pundit’s Ultrasonic tester**: This tester consists of an electronic measurement unit which transmits ultrasonic waves through special sensors connected to the two sides of the concrete.

D- **Ranges of concrete homogeneity test**: There are no fixed ranges for the homogeneity test because of the difference in the concrete members thicknesses and the difference in the type of the used concrete. Determination and analysis of the test results depend upon the engineer experience and there are indicators that help him. He observes the change in wave length, performs the test in more than one location of concrete, comparing the results of various concrete members with various thicknesses.

(4) **Carbon content measurement test (using the rainbow indicator)**:

A- **Purpose of the test**: Study of the effect of the depth of carbonization in the concrete for:
- Determination of the causes of rust in the reinforcement steel.
- Determination of the life expectancy remaining for the concrete.
- Observation of the effect of elica compounds on concrete covering layer.
- Determination of concrete strength affected by the presence of carbon assuming the presence of a certain moisture in the concrete.
- When the carbon dioxide compound (CO₂) present in the air penetrates the concrete surface it reacts with calcium hydroxide Ca(OH)₂ producing calcium carbonates (CaCO₃) causing a reduction in the pH value of the concrete surface surrounding the reinforcement steel from 13 to about 9 and thus leading to the commencement of rust formation in the reinforcement steel in case there is moisture and sufficient oxygen content in the concrete.

B- Test method: The calibration fluid is sprayed on parts of the concrete (after breaking the surface for enabling occurrence of indicator reactions) the indicator here is a catalyst in the reaction, not a basic compound in the reaction. It indicates whether the reaction environment is acidic or alkaline according to the pH value and according to the change in the colour of the indicator (Figure 4-2) the pH value can be determined. Some permeative indicators are used to determine the depth of carbonization impact on concrete, figure 4-3.
C- **Test fluids:** A number of fluids are used for determining the change in pH value or for determining the depth of carbonization impact. These fluids are indicators that are capable of changing colour such as (phenolphthalein, rainbow indicator and they are coded as in figure 4-4 below:

![Indicator RI-7000](image1)

**Indicator RI-7000**
Penetrant indicator for measuring depth of carbonization

![Indicator RI-8000](image2)

**Indicator RI-8000**
For determining the pH value test

**Figure 4-4: Indicators used in carbon content test.**
D- Test ranges: The following ranges indicate the change of indicator colour according to pH value as shown in figure 4-5 below:

![Figure 4-5: Change of indicator colour according to pH value](image)

E- Carbon content reference: American specification ASTM C 1202-97 includes the test ranges, and kind of materials used and test conditions.

Note: Concrete compressive strength is affected by the presence of carbon.

(5) Concrete cover thickness measurement test:

A- Purpose of the test: Determination of concrete cover thickness for:

- Assessment of the efficiency of this thickness.
- A preliminary procedure before commencing other tests like the BOND Test, concrete samples test and CAPO test. It is noteworthy that this is a nondestructive test.

B- Measurement method: The principle of this test is the change in the magnetic field lines emerging from the testers. The length of the distance where the change in the magnetic field has occurred is measured by fixing the head of the tester on the concrete surface over the place where the reinforcement rods are.

C- Measurement tool: The measurement tool used here is Cover Master.

D- Measurement accuracy: The accuracy of this test ranges between 5-10% in densities up to 35 mm and 15-25% in densities from 60 to 70 mm.

- Methodology adopted in tests during in-depth bridge inspection: Following is the methodology adopted in carrying out tests according to defect types and type of member where the defects are prevalent. This methodology can be looked at as a plan
that affords the bridge engineer more flexibility in dealing with the tests in the location.

Following is an explanation of one of the tests that is the test of rust in the reinforcement steel. The remaining tests for various defects are carried out according to similar methodologies.

- **Reinforcement steel rust test** (using electromechanical potential)

This test is used in the following cases:

- Rust test in the bridge members that are directly exposed to external factors such as major and minor beams and below the bridge slab.
- This test is carried out on a proportion of areas affected by rust and a proportion of areas not affected by rust for comparing the results, determination of rust percentage and its impact on the affected areas and giving a visualization about the anticipation of future rusting of unaffected areas. It is carried out according to the following methodology:
  - Step 1: Randomly testing 10% of the areas affected by rust and 10% of the areas not affected by rust.
  - Step 2: Preparatory stages of the test:
    - A- Breaking of the covering layer.
    - B- Chloride test of samples of the broken layer.
    - C- Measurement of the moisture content in the broken layer.
  - Step 3: When the area and density of the samples are sufficient the electromechanical potential test may be started.
  - Step 4: Conduct of CAPO test, if required.
  - Step 5: In-depth inspection report.

- **Rust testing on the upper side of the bridge slab** (where it is covered with an asphalt layer):

Sometimes it is noticed that there are cracks on the bridge surface asphalt layer that covers the bridge slab. These cracks may be due to defects in the asphalt itself or resulting from the development of the cracks in the bridge slab. So, this test is carried out on a proportion of areas affected by rust and another proportion not affected by rust for comparing the results, determining the rust percentage and its impact on the affected areas and giving a visualization about the anticipation of future rusting of
unaffected areas. The difference from the previous case is that here we take samples from the whole depth of slabbing and density of the slab. This test is carried out according to the following methodology.

- Step 1: Testing of two affected and two unaffected areas.
- Step 2: Preparatory stages:
  - Breaking of the covering layer.
  - Chloride test of samples of the broken layer.
- Step 3: When the area and density of the samples are sufficient the test may be carried out.
- Step 4: Testing of bearing strengths or taking of samples if required.
- Step 5: Final in-depth inspection report.

**Rust testing in intermediate and edge piers:**

The intermediate and edge piers are bridge members that are subjected most to the weathering agents. Rusting is the most prevalent defect in these members, therefore the electromechanical potential test is carried out by testing the affected and unaffected areas. The test is carried out according to the following methodology:

- Step 1: Selection of an affected area and an unaffected area.
- Step 2: Preparatory stages:
  - A- Breaking of the covering layer.
  - B- Chloride testing of samples of the layer.
- Step 3: When the area and density of the area are sufficient the electromechanical potential test may be started.
- Step 4: The in-depth inspection report.

### 4-4-2 Destructive tests

**Cut and pull-out test (CAPO):**

**A- Purpose of the test:**

Among the most important criteria for determining concrete quality is its compressive strength. The CAPO Test is an alternative option to the test of specimens laboratorially taken from concrete members. This is a destructive test but it is partial for the damaged area of the concrete does not exceed a diameter of 25 mm and a depth of 25 mm.
B- Test method:

This test is conducted by creating a hole with an adequate depth exceeding the concrete surface cover density perpendicular to the examined surface away from the reinforcing bars using a boring tool. Hence, the concrete will be penetrated to an adequate depth where the actual value of the concrete compressive strength can be obtained. Then a recess is created in the concrete with a 25mm diameter in the previous hole to a depth that exceeds the covering layer (no less than 25 mm), then a ring is inserted in the recess and expanded by a special tool that is connected to a hydraulic machine that is manually operated. A pressure tool with a 55 mm inner diameter disc is fixed on the concrete surface (Figure 4-6). Compression forces are applied so that the concrete between the disc and the ring is compressed and the ring is pulled out by a pull machine. The process continues until the concrete collapses. Hence, the pullout force F is a direct measure of the applied pressure force. For obtaining the compressive stress born by the concrete, special charts that convert the pressure force produced by the tool guage into compressive stress are used. The hole produced during the test may be repaired by injecting cement.

![Figure 4-6: How pressure and pullout forces are applied in the test recess](image)

C- Components of CAPO tester are given special names for easy handling during the test as follows (C#) with # indicating the tool number and hence its type or function.

D- CAPO test tools: All CAPO test tools are kept in three bags forming a pack of tools in addition to the rings and expansion tools. They are as shown in table 4-4 below:
### Table 4-4: CAPO test tools (Continued)

<table>
<thead>
<tr>
<th>Pack Code</th>
<th>Purpose of the pack</th>
<th>Pak components</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 101</td>
<td>Preparation for the test during creation of a recess in the concrete surface (Figure 4-2), insertion and expansion of a ring (Test preparation pack)</td>
<td><img src="image1" alt="Test preparation pack" /></td>
</tr>
<tr>
<td>C 102</td>
<td>Application of pressure (Figure 4-3) according to test conditions (pressure application pack)</td>
<td><img src="image2" alt="Pressure application pack" /></td>
</tr>
<tr>
<td>C 103</td>
<td>Hydraulic pulling out tool that pulls out the ring (Figure 4-4) (Pulling out pack)</td>
<td><img src="image3" alt="Pulling out pack" /></td>
</tr>
</tbody>
</table>

Figures 4-7, 4-8, and 4-9 show recess drilling, how to insert the ring and how to pull off the specimen, in order.
Figure 4-7: Recess drilling process using the diamond bit during CAPO test.

Figure 4-8: How to insert the ring in the recess and turn the wrench during the CAPO test.

Figure 4-9: How to pull off the specimen in the CAPO test
(2) Bond Test:
A - **Purpose of the test:** The purpose of the BOND test is:
- Measurement of the in-place bond strength between a newly cast concrete layer and another old concrete layer.
- Measurement of the in-place tensile strength of concrete or other construction materials.
- Evaluation of the compressive strength of the concrete using the approximate relationship between the concrete compressive strength \( f_c \) and tensile strength \( f_t \) as in the following (4-1) equation:

\[
\text{Equation 4-1: } f_t = \sqrt{f_t / 10}
\]

- The following figure (4-10) shows some forms of specimen failure in the various test cases with the yellow colour resembling new concrete and the (Shaded) resembling the old concrete. In case (a) we notice that the failure has occurred in the old concrete which means that the strength of the bond between the new concrete and the old one is stronger than the tensile strength of the old concrete itself. In case (b) we notice that the failure is in the bond area between the old concrete and the new concrete which gives us a direct measure of the bond strength between the two concretes. In case C we notice that the failure is in the new concrete which means that the bond strength between the new concrete and the old concrete is greater than the tensile strength of the new concrete.

![Figure 4-10: Showing different cases of specimen failure during the BOND test](image)

B - **Test method:** The Bond Test is a destructive test. It passes through the following stages:
• Preparation of the test surface: The surface is ground with a revolving grinding disc to expose the aggregates in the concrete and the tested surface is thoroughly cleaned as shown in figure 4-11 below:

Figure 4-11: Preparation of the surface to be tested in the BOND test

• Bonding the disc: A disc with a diameter of 50-70mm is bonded to the surface to be tested. For this purpose GRA bonding material with a tensile strength of up to 10 megapascal is used. The disc is left for 2 to 3 minutes in normal conditions. In cold conditions the test location is heated. Figure 4-12 below shows how to bond the disc.

Figure 4-12: How to bond the disc in the BOND test
• Coring the area surrounding the disc:
The area around the disc is cut using a revolving cylindrical coring tool to a depth of one and a half of the specimen (disc) diameter for measuring the bonding strength, and to a depth of 25mm for measuring the tensile strength of the concrete as in figure 4-13.

• Specimen pull off: The hydraulic pull off machine is fixed on the disc and the disc is pulled up by applying an increased tensile strength. The reading at which the failure occurs is taken, converting the reading into tensile stress or bonding strength as required by the test as in figure 4-14.

• Note: The person who conducts the test must record the specimen failure case (a,b,c) figure 4-5, as previously explained.

Figure 4-13: Showing how to cut the area around the disc for the BOND Test

Figure 4-14: Showing how to pull off the specimen for the BOND Test
C- Tensile (Bonding) strength Testing Equipment:

The BOND Test equipment are furnished in four bags each containing a pack of equipment. Each equipment pack is indicated by the letter B followed by the correspondent number as shown in table 4-5 below:

<table>
<thead>
<tr>
<th>Pack Code</th>
<th>Purpose of the pack</th>
<th>Pack components</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-10000</td>
<td>Preparation and grinding of the surface and stabilization</td>
<td></td>
</tr>
<tr>
<td>B-11000</td>
<td>Preparation for the test</td>
<td></td>
</tr>
<tr>
<td>CS-75</td>
<td>Coring around the disc before pulling off</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-5: Tensile strength testing equipment (continued)
(3) Rapid Chloride Test:

A- Purpose of the test: The main purpose of this test is to determine concrete purity, i.e., to determine the ratios of materials that are in the concrete mix, especially the chloride ratio, and hence their impact on its function, by performing some chemical analysis on the concrete. It is noteworthy that this is a destructive test. The rapid Chloride Test is considered to be the fastest method for determining the quantity of soluble acidic chloride in the concrete on the site.

B- Test Method:

- A quantity of concrete powder obtained from hardened concrete holes (weighing about 20 grams) is mixed with the chloride fluid indicator and the mixture is left for 5 minutes. After that the quantity of soluble chloride is determined as a ratio of the concrete weight directly via the RCT gauge that is connected to a sensitive electric chloride electrode which is in turn connected to an electronic screen operated by ordinary batteries and specially designed for this test.

- A diagram for the speed of chloride spread in the concrete is determined by taking a number of specimens at different depths at the same location. The depths are usually 30mm, 60mm and 90mm. Testing for each depth is performed separately.

Note: Usually, two specimens are tested and the mean of the two readings is taken.
C- **Rapid Chloride Test Tools:** All the RCT tools are kept in an adequate bag and are given a number according to table 4-6:

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCT-770</td>
<td>RCT chloride electrode</td>
<td>Inserted in the container of the chloride fluid indicator with the concrete powder.</td>
</tr>
<tr>
<td>RCT-900</td>
<td>An electric guage with 9 volt batteries</td>
<td>For showing the results</td>
</tr>
<tr>
<td>RCT-1000</td>
<td>Specimen drying tube</td>
<td></td>
</tr>
<tr>
<td>RCT-1001</td>
<td>Specimen mixing tube</td>
<td></td>
</tr>
<tr>
<td>RCT-1002</td>
<td>Metal brush</td>
<td>For cleaning the surface to be tested</td>
</tr>
<tr>
<td>RCT-1003</td>
<td>Plastic safekeeping tubes</td>
<td>No less than 10 tubes</td>
</tr>
<tr>
<td>RCT-1004</td>
<td>Bowl for collecting the concrete powder</td>
<td>Preferably of black colour</td>
</tr>
<tr>
<td>RCT-1005</td>
<td>Hollow metal rings</td>
<td>Encircling the drilling tool to prevent concrete powder scattering</td>
</tr>
<tr>
<td>RCT-1006</td>
<td>Pliers</td>
<td></td>
</tr>
<tr>
<td>RCT-1007</td>
<td>Drill bit with 8mm diameter and 80mm length</td>
<td></td>
</tr>
<tr>
<td>RCT-1008</td>
<td>Adequate securing nuts</td>
<td>No less than 20 pieces</td>
</tr>
<tr>
<td>RCT-1009</td>
<td>Electric drill</td>
<td></td>
</tr>
<tr>
<td>RCT-1010</td>
<td>Hammer</td>
<td></td>
</tr>
<tr>
<td>RCT-1011</td>
<td>Rubber rings for preventing leakage</td>
<td>With no less than 6mm diameter for covering the test tubes during tube shaking</td>
</tr>
<tr>
<td>RCT-1012</td>
<td>Concrete powder packing tube</td>
<td>Shaped like a test tube for packing the concrete powder within the test tube</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------</td>
<td>---------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>RCT-1013</td>
<td>Hole cutting wrench 10mm</td>
<td></td>
</tr>
<tr>
<td>RCT-1014</td>
<td>Standard calibration fluid (white)</td>
<td>Determines chloride percentage 0.005%</td>
</tr>
<tr>
<td>RCT-1015</td>
<td>Standard calibration fluid (purple)</td>
<td>Determines chloride percentage 0.02%</td>
</tr>
<tr>
<td>RCT-1016</td>
<td>Standard calibration fluid (Green)</td>
<td>Determines chloride percentage 0.05%</td>
</tr>
<tr>
<td>RCT-1017</td>
<td>Standard calibration fluid (Red)</td>
<td>Determines chloride percentage 0.500</td>
</tr>
<tr>
<td>RCT-1018</td>
<td>Test tubes marked weight 105 grams (red)</td>
<td>No less than 6</td>
</tr>
<tr>
<td>RCT-1019</td>
<td>Concrete powder extraction tubes</td>
<td>No less than 20 (yellow)</td>
</tr>
<tr>
<td>RCT-1020</td>
<td>Pieces of cloth for cleaning</td>
<td></td>
</tr>
<tr>
<td>RCT-1041</td>
<td>Calibration tables and charts</td>
<td></td>
</tr>
<tr>
<td>RCT-1042</td>
<td>Ruler</td>
<td></td>
</tr>
<tr>
<td>RCT-1043</td>
<td>Pencil</td>
<td></td>
</tr>
<tr>
<td>RCT-1043</td>
<td>Measuring tape</td>
<td></td>
</tr>
<tr>
<td>RCT-1044</td>
<td>Measuring guide</td>
<td></td>
</tr>
<tr>
<td>RCT-1045</td>
<td>Air bubble remover</td>
<td></td>
</tr>
<tr>
<td>RCT-1046</td>
<td>Tool bag</td>
<td></td>
</tr>
</tbody>
</table>

**D- RCT Ranges:** The Rapid Chloride Test ranges are values that reflect the extent of chloride impact on concrete. They are as shown in table 4-7 below:
Table 4-7: RCT Ranges

<table>
<thead>
<tr>
<th>Device reading (after conversion into tables)</th>
<th>Corresponding Indicator</th>
<th>Condition</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.005</td>
<td>White</td>
<td>No chloride content</td>
<td>Indicator colour indicates approximate chloride content. Indicators are used for calibrating the electronic gauge.</td>
</tr>
<tr>
<td>0.005-0.020</td>
<td>Purple</td>
<td>Little chloride content</td>
<td></td>
</tr>
<tr>
<td>0.020-0.050</td>
<td>Green</td>
<td>Average chloride content</td>
<td></td>
</tr>
<tr>
<td>0.050-0.0500</td>
<td>Red</td>
<td>High chloride content</td>
<td></td>
</tr>
</tbody>
</table>

(4) Moisture content test with Hum-Meter:

A- **Purpose of the test:** Determination of the moisture content in the concrete and hence determination of the extent of moisture impact on the concrete, especially reinforcement steel.

B- **Test Method:** This is a destructive test used for measuring relative moisture in the concrete (usually in the 100 outer mm). A 16 mm hole is created in the location to be tested. A plastic tube with a thin membrane closed on one side is inserted in the hole and left for about an hour, which is sufficient time for equalization of relative humidity and temperature. After that the test is conducted by breaking the closed end of the tube connecting the tube with a guage and recording the temperature and moisture content.

C- **Components of the Hum-Meter:** The Hum-Meter is a simple device consisting of the following:

- Electronic guage
- Sensitive plastic tube
- Drill, cleaning materials, recording paper etc.

Note: The device gives results directly without a need for converting the results via conversion tables.

D- **Hum-Meter ranges:** As in table 4-8 below:
Table 4-8: Hum-Meter Ranges

<table>
<thead>
<tr>
<th>Device Reading</th>
<th>Condition</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3%</td>
<td>No moisture content</td>
<td>Moisture impacts the reinforcement steel and the concrete</td>
</tr>
<tr>
<td>3-5%</td>
<td>Little moisture content</td>
<td></td>
</tr>
<tr>
<td>5-10%</td>
<td>Average moisture content</td>
<td></td>
</tr>
<tr>
<td>&gt;10%</td>
<td>High moisture content</td>
<td></td>
</tr>
</tbody>
</table>

(5) CORE SAMPLES Test (Semi destructive)

A- Purpose of the test:

Taking specimens of the concrete and studying them in the laboratory for:

- Determination of the physical properties of the concrete (cubic weight, void percentage, moisture content….).
- Determination of the chemical structure of the concrete and study of the possibility of occurrence of rust.
- Measurement of the concrete tensile strength and compressive strength.
- Comparison of the results of field tests and laboratory results (strengths, moisture content and firmness).
- This is a destructive test with concrete specimens taken for a number of laboratory tests on them.

B- Test Method:

- Cores (specimens) are pulled out from the concrete surface to be tested using carrot extraction, together with continuous moistening (Figure 4-15). Cores are usually taken at a diameter and depth adequate to the member to be tested (slab, beam, wall….).
- This method is usually resorted to when no satisfactory results are obtained from the previous tests. The number of cores should be corresponding with the number of bridge spans and length of each span and percentage of the prevalence of defects in the concrete. The experience of the engineer leading the inspection team plays a key role in determining the number of specimens.
During taking of specimens the following must be taken into consideration:

- No specimens should be taken from major or minor beams or intermediate piers.
- Specimens must be taken from locations that are away from Max B. Moments (Experience of the engineer leading the inspection team facilities determination of these locations).

Places from which the specimens are taken must be repaired immediately using a strong adhesive such as Epoxy.

**C- Test tools:**

A special device is used for pulling out specimens from the concrete. It is connected to a water pump and an electric generator as shown in the following figure:

![Figure 4-15: Concrete samples taking using carrot extractor](image)

(6) **Electrochemical potential for detecting rust:**

The test for detecting rust is conducted using the Half-cell potential.

**a) Purpose of the test:**

The main purpose of the test is to determine whether the reinforcement steel is affected by rust. The test is performed by passing an electric field in the reinforcement steel and measuring the uniformity of the flow of the
current in it, as the rust affects the speed, uniformity and strength of the electric current flowing in the reinforcement steel. The test is conducted in accordance with the following steps:

- Exposure of one of the reinforcing bars for conducting the electric current: The concrete is broken for exposing the edge of one of the reinforcement bars in a location where there are indications of rust occurrence (cracks or pigmentation in the concrete).
- Making sure that the electric circuit is closed: For conducting this test it must be insured that the electric circuit is closed with the first end of the circuit being a grip holding the exposed reinforcement bar (previous paragraph) and the second end of the circuit being an electric sensor in the form of a thin bar attached to the concrete surface as shown in figure 4-16 below.

![Image of rust detection](image.png)

**Figure 4-16: How to detect rust on the lower part of the bridge slab**

- Specification of a network on the damaged surface for conducting the test: when conducting this test in large areas it is advisable to select random parts of these areas, establish networks on them with 500x500 mm or at least 25x25 mm dimensions and conduct of the test on the squares of this network. In case of columns the test is conducted according to t vertical parallel lines.
• Observation of changes in the electric current: The change in the electric current travelling in the reinforcement bars is observed by following the following steps:
  ➢ Wettomg the concrete surface near the place where the test is conducted.
  ➢ Connecting the grip that resembles the first end of the circuit with the exposed bar.
  ➢ Wait until the electric current is steady then observe the speed of electric current over time.

We stress the importance of continuous wetting of the concrete near the test area.

The test is conducted by two persons, one responsible for the wetting and the other responsible for measuring.

• Specification of the test area and evaluation of the degree of rusting:

  Measurement of the speed of the passage of electric current is not the actual indicator of the impact of rust. This speed must be compared with the tables attached to the test device resembling an index for the impact of the rust as follows:

  Assuming that the reading of the speed of the passage of the current is the index \( X(\text{mv}) \) then the degree of rust impact will be as follows:

  \[
  \begin{array}{ccc}
    \text{First group} & X>0 & \text{No rust} \\
    \text{Second group} & -200<X<0 & \text{Rust in the first stages} \\
    \text{Third group} & -300<X<-200 & \text{Beginning of the appearance of the impact of rust (Beginning of reinforcement steel corrosion)} \\
    \text{Group four} & X<-300 & \text{Great impact of rusting and corrosion in reinforcement steel sections.}
  \end{array}
  \]
Colours are usually used for determining the above four groups as follows:

First group (White)
Second group (Green)
Third group (Yellow)
Four group (Red)

(7) **Reinforcement steel diameters measurement test:**

A- Purpose of the test: Measurement of the diameters of the reinforcement steel in the concrete for the purpose of:

- Knowing the internal arrangements and the distribution of the reinforcement steel.
- Identification of the actual remaining segment of the reinforcement steel that is affected by rust for making the calculations pertaining to the required steel.
- Giving an index of the correctness of the ECP test.

B- **Measurement method:** The concrete surface in the areas affected by rust is broken, the bars are cleaned and the diameter of each is measured after determining its direction (longitudinal or transverse) its function (tension bars, contraction, suspension, bracelets,…..) and position (upper reinforcement, bottom reinforcement) and these data are recorded after drawing a diagram of the concrete member to be examined.

C- **Measuring tools:**

Precise devices are used for measurement (with accuracy of parts of millimeter) such as the biacolis as shown in figure 4-17 below:
4-5 Tool used in bridge inspection

A number of factors determine the kind of tools required for bridge inspection. Key among these factors are bridge type, location and inspection type. The required inspection tools must be listed and checked before beginning the inspection based on these factors.

The inspection tools are classified as follows:

(1) **Standard tools** (Figure 4-18) including:
- Broom
- Wire brush
- Scraper
- Flat head screw driver
- Shovel
(2) **Inspection tools** (figure 4-19) encompassing:
- Pocket knife.
- Hammer with a plastic handle.
- Horizontal and vertical adjustment level.
- Belt with tool bag.
- Drawn chain.

![Figure 4-19: Showing inspection tools](image)

(3) **Optical aids** (Figure 4-20) including:
- Binoculars
- Electric lamp
- Magnifying glass
- Inspection mirror
- Penetrating die for exposing the cracks

![Figure 4-20: Showing optical aids](image)
4) Measuring tools including:
   • Measuring tapes of different lengths
   • Density measuring tool
   • Crack measuring tool
   • Indicator for determining coat density
   • Protractor for measuring the inclination in the substructure.
   • Thermometer
   • 4 foot ruler for measuring the inclination in the slab and the wearing surface.
   • Ultrasonic dense indicator for measuring the steel density.
   • Electronic distance indicator

5) Data recording materials, including:
   • Printed forms, support for writing, pens, rulers.
   • Recording pads (in case of the bridges).
   • Camera
   • Chalk and markers
   • Drill for making reference points in the steel.

6) Access tools: They include:
   • Ladders: These are used in the inspection of the members of the substructure on the land. Care must be practiced when using ladders for the possibility of falling off them. There are rope ladders that hang down, with the inspector secured on them.
   • Platform: A platform tied with cables used over watercourses, over crowded roads and over railways. They are used instead of the inspection vehicle.
   • Scaffold: Scaffolds are used in bridges that are no more than 12 meters high from the ground. When scaffolds are used there should be no traffic below the bridge.
   • Boatswain Chair: This is a seat for one person secured with ropes the movement of which is controlled by a special device as shown in figure 4-21 below.
• **Inspection vehicle:** A vehicle with a crane where the performer of the inspection sits and the crane is moved upward and downward. There are two types of these cranes:

• **Sky Jacker:** This crane is used in the cases where it is impossible to access all structure members by using ordinary ladders. This crane is used in bridges with up to 12 meters high, for at the end of the crane boom there is a cabin for the performer of the inspection or tests. The driver controls the upward and downward movement of the boom as shown in figure 4-22 below:
• **Snooper:** This type of crane is used in bridges higher than 12 meter and in bridges that are inaccessible from below (like bridges in mountainous areas). The boom can reach the lower part of the structure when the crane is on the surface of the road. The crane boom can be controlled by the driver or by the person in the cabin located at the end of the boom. In fact this crane has two cabins at the end of the crane boom where two persons can be in them at the same time as shown in figure 4-23 below:

![Snooper type crane](image)

**Figure 4-23: Showing Snooper type crane**
Chapter 5

Maintenance and Repair of Bridges and Underpasses Damages
Chapter 5: Maintenance and Repair of Bridges Damages

5-1 Introduction:

This chapter is a part of Bridge and Tunnel Maintenance Manual, proponent of which is the Ministry of Municipal and Rural Affairs, Ministry Deputy for Technical Affairs, General Directorate of Operation and Maintenance in the Kingdom of Saudi Arabia. It generally contains a number of main sections, namely: Factors affecting maintenance decisions, types of maintenance and techniques for maintenance, repair and rehabilitation of bridges and underpasses. This includes the different types of maintenance and methods of repair of the damages that affect the concrete, namely cracking, scaling and spalling, steel corrosion and methods of remediation according to the damaged member. Repair and rehabilitation strategies are also addressed.

5-2 Foreword:

For rating the performance of the bridge components table 5-1 is used in accordance with the international program for Bridge Rating (NPIB) which is used for rating the functional condition of bridge components with a generalized description of the cases where it is applied:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td><strong>Not Applicable:</strong> Applied to the required components in the inspection forms which are not present in the bridge currently being inspected or which can not be seen, for example some piers have and others support the supporting components directly.</td>
</tr>
<tr>
<td>7</td>
<td><strong>In new condition:</strong> No indication that any defect exists, maintenance is not necessary.</td>
</tr>
<tr>
<td>6</td>
<td><strong>In good condition:</strong> No need for maintenance works, but the component is old</td>
</tr>
<tr>
<td>5</td>
<td><strong>Functions as originally designed:</strong> There are some insignificant defects that do not reduce the structural capacity and functional ability such as a corroded bridge expansion joint which has not lost its function and still</td>
</tr>
</tbody>
</table>
allows required traffic and here little repair may be done for repairing the defect.

4  Of minimum efficiency (Acceptance): Immediate repairs are required for the affected component for maintaining the designed load capacity.

3  Does not function as originally designed: Severe deterioration resulting in a decrease in the structural capacity. When this classification is applied immediate actions must be taken to restore the required component strength.

2  Structurally inadequate: So severe defect that it dictates stopping of traffic. The classification applies to main components only.

1  There is potential risk: When this classification is applied to main components there is a risk of collapse under any other use of this structure and it must be immediately closed before traffic. When this classification is applied to secondary parts the condition may cause traffic accidents and must be immediately corrected.

0  Very dangerous: The bridge has already been closed: The condition is beyond repair, impending collapse or collapse has already taken place. Structure must be demolished and rebuilt.

There are four methods for the maintenance of bridges and tunnels as shown in table 5-2 below:

**Table 5-2: Maintenance Strategies**

<table>
<thead>
<tr>
<th>Serial</th>
<th>Maintenance Type</th>
<th>General Rating Score</th>
<th>Type of Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preventive Maintenance</td>
<td>Above 5</td>
<td>General</td>
</tr>
<tr>
<td>2</td>
<td>Remedial Maintenance</td>
<td>Above 4</td>
<td>General</td>
</tr>
<tr>
<td>3</td>
<td>Rehabilitation</td>
<td>Above 3</td>
<td>In-Depth</td>
</tr>
<tr>
<td>4</td>
<td>Replacement and Reconstruction</td>
<td>Below 3</td>
<td>In-Depth</td>
</tr>
</tbody>
</table>
Maintenance task vary according to various bridges components, various defects that affect the structure function and prevalence and severity of the defects. Sometimes remedial maintenance of some components may be listed under preventive maintenance of other components, for example treatment of slight concrete disintegration at the ends of main beams falls within remedial maintenance whereas treatment of the same defect in pavements or rails falls under preventive maintenance.

5-3 Types of Maintenance:

A- Preventive maintenance

Preventive maintenance is defined as maintenance tasks performed priorly for preventing occurrence of damage in the structure components. Preventive maintenance strategies stem from bridge general inspection functions and are applied directly without need for submission of bills of quantities or getting approval of the supervising engineer. According to the concept of the activities of bridges general inspection this maintenance will be performed on components with minor defects that give these components a rating score of 6 in accordance with bridge components score table.

The following group of maintenance tasks falls under preventive maintenance:

- Levelling of longitudinal and transverse inclinations of the bridge deck for insuring good water draining via draining installations.
- Cleaning of storm water traps and draining channels.
- Painting of the reflectors mounted on the railing which indicate the bridge margins at night to insure prevention of vehicle deviation or damage to the pavements and railings as a result of the collision of vehicles that move on the bridge.
- Examination of intermediate piers protection system by lifting the rail around the edge piers and painting it with reflective colours for preventing vehicle collision with the piers.
- Cleaning of the waterway in the bridges that intersect with valleys or waterways.
• In terms of expansion joints, cleaning of the joints openings from above by pumping a strong air current and reattachment and tightening of the fasteners of the joint and checking of evenness of the joint and that no parts of it are protruding upwards in a manner that impacts traffic.

• Cleaning of the area around the bearings from dirt and aggregates periodic greasing of movable bearings for preserving their flexibility and periodic checking of joint good fixing and insuring that it is not moved from its place.

• Continuous treatment of hair-line cracks with cement mixed with water in concrete components and insuring that concrete surfaces are insulated.

• Periodic anchorage of the land fills around the bridge making sure that they do not settle or deflect.

• Periodic cleaning of bridge deck from sands and maintenance of safety means on the deck, including lane division lines, cat’s eye and no overtaking lines.

B- Remedial maintenance:

Remedial maintenance is defined as maintenance tasks performed on the components of the structure to insure continuous function of these components within their designed and safety limits. According to bridge general inspection works concept this maintenance is for components with specific defects that give these components a rating score of 5 according to bridge components rating scores table.

The following set of maintenance tasks fall under the scope of remedial maintenance:

• Treatment of minor cracks and minor scaling in the asphalt wearing surface.

• Repair of cracks, spalling and settlement in the bridge pavement.

• Painting of pedestrian protection railings and posts.

• Repair of corroded draining channels and insulation of all drains, including manholes and storm water traps etc…

• Treatment of hair-line cracks, minor scaling, salification and moisture in the bridge slab.
• Removal of rust formed in the metal fingers in joints made or overlapping metal fingers and insuring that these joints do not protrude upward and treatment of the concrete surface on the sides of the joint, insuring leaving no space that allow leakage of surface water to the superstructure.

• Fastening of the plates covering the joints on a continuous basis.

• Treatment of minor and moderate disintegration and scaling in the main and secondary beams.

• Treatment of nonstructural cracks.

• Removal of rust in metal beams and coating of these segments with insulating materials.

• Fixing and tightening of fastening materials in metal joints.

• Bearings are rarely subjected to remedial maintenance works except in some of their accessories, such as fastening components and moving parts of the joint.

• Anchorage of bridge side slopes supporting means.

• Refilling of eroded earth above the footings in the bridges that intersect with valleys and water ways.

• Consolidation of intermediate piers with scuttles filed with heavy stones to be placed on the pier base and filled with earth in places with heavy rainfall and probably floods.

• Treatment of honeycombing in intermediate and edge piers.

• Treatment of nonstructural cracks (most often shrinkage cracks in the components).

• Treatment of leakage at the supporting wall in the contact area in the approach slab in the bridge.

• Anchorage of soil in the waterways with stones, gabions or concrete.

• Treatment of leakage in utilities accessory pipes.

C- Rehabilitation:

This stage is defined as the collection of maintenance tasks that aim to restore the structure components to their original design state after being subjected to a number of damages that have reduced the design condition or structural capacity of bridge components. According to the concept of bridge general inspection works this maintenance is for the components
with specific defects that give these components a rating score of 4 or 3 as per the table of rating scores for bridge components. Consolidation works are among these strategies. Consolidation techniques can be used for upgrading the performance of the structure for bearing greater loads when required. The following set of maintenance tasks fall under the scope of rehabilitation strategies:

- Treatment of longitudinal and reflexive cracks in the asphalt wearing surface.
- Treatment of settlement and rutting in the asphalt wearing surface.
- Treatment of scaling in the asphalt binder in the asphalt wearing surface.
- Treatment of undulations and displacements in the asphalt wearing surfaces.
- Repair of pedestrian protection railings and adjustment of their alignment.
- Treatment of severe concrete scaling (in the slabs, beams, columns ….).
- Treatment of concrete disintegration in main and subordinate beams.
- Treatment of different cracks in the concrete.
- Treatment of concrete salification (efflorescence).
- Treatment of reinforcement steel rust especially in main beams and pier caps.
- Treatment of reinforcement steel protrusion, especially in beams.
- Treatment of displacements and twirling in the piers due to pushing by the soil or major or differential settlements in the footings.
- Consolidation of the segments that appear to be incapable of standing stresses produced in them resulting from external loads or when there is a requirement for increasing loads on the structure due to a change in traffic or road service level by adding reinforcement bars or plates or by increasing the dimensions of concrete or metal segments.

**D- Replacement and Reconstruction**

Replacement is defined as a number of tasks that aim to re-execute some components or parts that have been subject to a number of defects that
caused damages that reduced the design state or structural capacity of bridge components and rendered it inserviceable. According to the concept of bridge general inspection works these works are for components with specific defects that give these components a rating score below 3 as per bridges components rating table. Sometimes this method is used when the structure is subjected to excessive loads or there is a change in the service level and design speeds on the road. Replacement may be for the whole component, part of it or one of its components. This depends on the engineer experience, the kinds of defects and prevalence and severity of these defects. It should be noted the decision to replace some bridge components affect some other components, for example when there is a need for replacing rectangular segments of the beams in the superstructure which box segments with entails changing the kind of bearings and review of the adequacy of the pier crest width. Replacement decisions are sensitive decisions as regards bridge maintenance works because of the great cost and execution techniques. Hence, the engineer and the supervising executing this strategy must have extensive experience for approving these works. These works must be subjected to value engineering studies for determining their feasibility. The following maintenance tasks fall under the scope of replacement strategies.

- Replacement of the bridge slab or parts thereof due to slab corrosion and unservicability.
- Replacement of some parts of expansion joints or replacement of the whole joint or fasteners of the joint.
- Replacement of bridge bearing due to a change in the nature of resting, inefficiency of the old bearing or increase of the loads on the bridge.
- Replacement of the two approach slabs at the bridge entrance or exit due to severe settlement at the bridge edges.
- Replacement of intermediate or edge piers to suit the new design status of the bridge.
- Replacement of the asphalt wearing surface due to the prevalence of severe alligator cracks or severe settlements, rutting and undulations.
- Replacement of some of the damaged parts of the railings because of the collision of vehicles on the bridge.
- Reconstruction of the whole bridge when it becomes inadequate for the passage of increased traffic and large loads.
- Reconstruction of the bridge when it is subjected to natural disasters, rainstorms and earthquakes.

5-4 Factors affecting maintenance decisions:

There are many factors that help in determining priorities pertaining to bridge maintenance and rehabilitation and preference of those works, such as:

- Strategic decision for determining the priorities pertaining to a specific type of maintenance.
- Strategic decision for determining maintenance priorities on a specific road.
- Strategic decision regarding finance of insufficient funds for implementing ideal maintenance strategy.

The last factor is the most prevalent factor in determining the priorities because the maintenance requirements and quantities required annually exceed the finance levels and therefore determining the maintenance budget makes it necessary to adopt the ideal maintenance priorities although it entails more complex calculations. Easier methods are adopted, one of which depends on decreasing the number of bridges that require major remedial maintenance. This entails classifying bridges according to their maintenance cost. Bridges costing less will be given higher priority and maintenance of bridges of higher maintenance cost will be deferred for some time. Due to this theory, bridges of higher maintenance cost may not be maintained at all. This method is not clearly favourable although it is based on a logical reasonable basis.

Any maintenance priorities program will be somewhat ideal in nature and will lead to the increase of maintenance life cycle costs and consequently failure to achieve a suitable service level. So, reducing the results will give better realistic results for determining maintenance priorities.
Following are the steps that encompasses maintenance priorities that are based on the ideal method for determining maintenance priorities:

- A detailed list of maintenance priorities for bridges will be prepared for a specific year, encompassing the bridges that require maintenance according to the ideal maintenance priorities program in accordance with the increase in the costs of maintenance life cycle.
- Assuming postponement of ideal maintenance works for each bridge in this list and calling the saving resulting from the bridge cost a ‘benefit’.
- Development of a maintenance priorities program for each bridge based on the above assumptions.
- Calculation of the increase in the costs of maintenance life cycle and traffic difficulty on each bridge resulting from the application of the above assumption “bridge priority cost”.
- Calculation of the ratio of cost to benefit for each bridge and ranking of bridges in a list according to this ratio increase.
- The bridge with the least maintenance cost and highest benefit will have the smallest ratio and hence will be given the highest maintenance priority. This bridge will be selected for maintenance in the specified year and will be removed from the list.
- The previous step will be repeated until the maintenance budget is used.
- Maintenance works for the remaining bridges of the list will be postponed when the maintenance budget runs out until they become ideal and then they are taken into consideration as regards maintenance. Practically, the above mentioned priorities concept is applied only on bridges that need maintenance that is not urgent or contingent due to critical or exceptional circumstances. All bridges that require consolidation or replacement will be awarded higher priority and this work will be implemented before determining the priorities for unurgent works.

Determination of maintenance priorities is based on an objective rule, therefore it is a useful procedures. This priorities concept depends on a logical principle and does not take into consideration the subjective
factors such as the environment and the environmental factors, social factors, continuity, beauty and historical values. These factors should be taken into consideration independently based on the experience of the responsible engineers to decide whether it is necessary to adjust the order of bridge priorities.

5-5 Maintenance Applications:

5-5-1 Introduction:

Many reasons present the need for developing methods for repairing, consolidating and replacing bridges, including the following:

- Many bridges have reached their life expectancy and there is evident continuing deterioration in them.
- There is a progressive increase in the weight of the trucks licenced to move in the cities and use their bridges.

There is now an urgent need to have more knowledge about bridge deterioration mechanisms and the best test for materials and design methods. Cost has always been the most important factor in determining adequate remedial actions and now there is a good attitude towards taking into consideration structure life cycle instead of adopting the least initial cost.

This section will concentrate on general guidelines for partial solutions and the outcomes of these solutions. The data will be presented in a tabular form as far as possible. While these tabular data will lead to the initial selection of the solution, financial and technical factors applicable to specific structures will constitute the key factor for assessing and comparing the alternatives. Cost considerations during the whole structure life will evaluate the results of alternative strategies and make objective comparison between them easy.

5-5-2 Repair of concrete structures:

Effective repair of concrete structures entails understanding the causes of deterioration and assessment of the effect of the selected repair technique on future survival. This must be based on a good test of the existing structure. Corrosion of the reinforcement steel is the most common reason
for repairing concrete structures. In this case the main agenda to focus on are:

- Reinforcement steel covering.
- Carbonization depth, the depth of carbon penetration into the concrete.
- The area contaminated with chlorides.
- Details of the concrete mixture.
- Concrete age
- The environmental factors that have caused the contamination and contamination condition.

The test program and its outcomes will lead to understanding the extent of the existing defect and the cause of deterioration. By taking these factors into consideration adequate repair can be selected, as shown in table 5-3 and table 5-4.

**Table 5-3: Repair of concrete corrosion resulting from chlorides**

<table>
<thead>
<tr>
<th>Damage Extent</th>
<th>Repair method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patching with mortar</td>
</tr>
<tr>
<td></td>
<td>Patching with concrete</td>
</tr>
<tr>
<td></td>
<td>Sprayed concrete</td>
</tr>
<tr>
<td></td>
<td>Cathodic protection</td>
</tr>
<tr>
<td></td>
<td>Desalination</td>
</tr>
<tr>
<td></td>
<td>Impregnation*</td>
</tr>
<tr>
<td>Disintegration over a small area</td>
<td>•</td>
</tr>
<tr>
<td>Disintegration over a large area with below 25 mm depth</td>
<td>•</td>
</tr>
<tr>
<td>Disintegration over a large area with above 25 mm depth</td>
<td>•  •  •  •</td>
</tr>
</tbody>
</table>

*Impregnation is injecting concrete with chemical materials (additives) for strengthening it or for improving its properties.
Concrete repair may be required for many reasons other than reinforcement steel corrosion. Among these reasons are damages resulting from fire, in which case the same general strategy will be adopted in the repair. The fact that there are multiple repair methods will render the most economic method which should be applied, as shown on table 5-5:

### Table 5-5: Concrete Repair – Application of repair materials

<table>
<thead>
<tr>
<th>Damage extent</th>
<th>Repair Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete replacement over small areas</td>
<td>Patching with mortar</td>
</tr>
<tr>
<td></td>
<td>Patching with concrete</td>
</tr>
<tr>
<td></td>
<td>Sprayed concrete</td>
</tr>
<tr>
<td></td>
<td>Cathodic protection</td>
</tr>
<tr>
<td></td>
<td>Alkalinity control</td>
</tr>
<tr>
<td></td>
<td>Painting with a carbon resistant coat</td>
</tr>
<tr>
<td>Concrete replacement over large areas below 25mm</td>
<td>Patching with mortar</td>
</tr>
<tr>
<td></td>
<td>Patching with concrete</td>
</tr>
<tr>
<td></td>
<td>Sprayed concrete</td>
</tr>
<tr>
<td>Concrete replacement over large areas above 25mm</td>
<td>Patching with mortar</td>
</tr>
<tr>
<td></td>
<td>Patching with concrete</td>
</tr>
<tr>
<td></td>
<td>Sprayed concrete</td>
</tr>
</tbody>
</table>

Concrete may be repaired by packing the cracks or repair of structural cracks. This type of repair will be performed when the cause of the cracking is known.
5-5-3 Materials used in repairing concrete structures:

The dimensions and measurements of repair will guide the method for applying repair materials. It remains to choose from a wide range of repair materials and the requirements to comply with the locally applicable specifications. Table 5-6 summarizes the key items that affect the selection of the repair material.

Table 5-6: Properties of the materials that affect concrete structures repair methods (continued)

<table>
<thead>
<tr>
<th>Material</th>
<th>Properties</th>
<th>Basic Applications and Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Flow and strength property has been designed to meet *BD 27/86 specification</td>
<td>Least flow depth is greater than 25 mm</td>
</tr>
</tbody>
</table>
| Sprayed concrete | • Sprayed concrete with a quantity above 10mm is called shotcrete and that which is lower in quantity is called dry mix concrete.  
• Concrete with 20-30 N/mm² is for wet use and concrete with 40-50 N/mm² strength is for dry use.  
• Good density and cohesion come with little porosity and dry mix. | • Least depth is 25mm.  
• There is a need for trained workers, especially for dry mixing.  
• Thick treatments are in the form of layers in the case of wet mixing  
• Excess concrete is removed from the treated surface which shall be treated with a smooth layer. |
| Cement mortar and cement with polymer used manually | Mortar modified with polymer ** must have:  
• Ratio of water to cement below 0.4  
• Cement quantity greater than 400Kg/m³. | • Density greater than 25mm.  
• Densities up to 12mm are suitable for cement polymer mixtures. |

* BD 27/86 specifications pertain to the specifications of repair materials used in the repair materials used in the repair and renovation of concrete members in road structures such as bridges and culverts and are usually used in the slabs and vertical surfaces of edge and intermediate piers and columns.

** Polymer is a liquid made up of small organic molecules that are capable of linking and forming a solid plastic material.
Table 5-6: Properties of the materials that affect concrete structures repair methods (continued)

<table>
<thead>
<tr>
<th>Mortar of Epoxy and polyester adhesives</th>
<th>• Produces great strength within 24 to 48 hours.</th>
<th>• Depends completely on impermeability for protection.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Constitutes an insulating layer covering the reinforcement bars.</td>
<td>• Requires good materials and workforce.</td>
</tr>
<tr>
<td>Epoxy for grouting cracks</td>
<td>• Of high strength</td>
<td>• Used for dormant cracks.</td>
</tr>
<tr>
<td></td>
<td>• Available with little viscosities</td>
<td></td>
</tr>
<tr>
<td>Acrylic paint</td>
<td>• Has little viscosity.</td>
<td>• Suitable for narrow cracks.</td>
</tr>
<tr>
<td></td>
<td>• Distributes in the surrounding concrete leaving an elastic mass.</td>
<td>• Repeated layers for wide cracks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Functions as an insulating layer in case of limited movement.</td>
</tr>
</tbody>
</table>

5-5-4 Methods of preventing corrosion:

Concrete replacement is an expensive measure and may not be economical in case chloride contamination extends to great depths. Further, placement of provisional strengtheners may not be practicable nor economical.

Table 5-7: Shows methods for preventing reinforcement steel corrosion without a need for removing the concrete.

Table 5-7: Comparison of various methods for preventing corrosion

<table>
<thead>
<tr>
<th>Method</th>
<th>Method Principle</th>
<th>Advantages and Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection with (negative cathode electrode)</td>
<td>• Corrosion caused by chlorides causes a reduction in the materials in the area of the positive electrode and from there it spreads to other areas. • A constant current between the positive electrode and reinforcement steel has the effect of preventing the spread of corrosion.</td>
<td>• This is an effective and proven method. • It is expensive.</td>
</tr>
</tbody>
</table>
### Desalination
- The surface to be treated is covered with positive electric electrodes with a tank connected with electrolyte for catalyzing chloride irons to move away from the reinforcing bars.
- This method reduces salts that cause corrosion.
- The treated concrete is that between the reinforcing bars and treatment electrodes.
- The desalination process takes 8 to 13 weeks.
- This method is more expensive than the cathodic protection.

### Realkalization
- This method is similar to the above mentioned desalination method.
- In this case the basic ions move to form a protective layer around the reinforcement steel.
- This method is effective in preventing future carbonization.
- This process takes 7 days.

### Protection from carbons
- The carbonization phenomenon is caused by the entry of carbon dioxide into the concrete and reaction with calcium hydroxide and thus reducing the alkalinity of the medium.
- The surface is coated to prevent carbon dioxide entry for reducing this phenomenon.
- This is a low cost method.
- Treatment can not be effected if the concrete is cast up to the reinforcement steel surface.

### Prohibitors of corrosion penetration
- The concrete surface is covered with a coat of protective paint.
- The substance penetrates through a liquid and a gas and forms a layer around the surface of the reinforcing steel.
- A new method under experimentation.
- A high cost method but still cheaper than some other methods.

### Impregnation
- When concrete is impregnated with some materials like xylene, this prevents penetration of water in the liquid state but permits exit of gas and hence entry of chlorides in the liquid state is prevented.
- A low cost solution.
- Also effective in preventing penetration of water from other concrete sides.
5-5-5 Strengthening of concrete structures:

Strengthening of concrete structures is a difficult matter because changing the reinforcement steel or pre-stressed steel is not effective after the concrete is cast and has become hard. So, the adequate strengthening option can be determined as follows:

- Increasing the depth of the beams and slabs and addition of bars in the added concrete, and addition of shear joints by drilling and securing.
- Increasing the width of the beams or addition of intermediate beams, as is usually done.
- Insertion of additional reinforcement by drilling the concrete and then grouting it after insertion of the new bars. This may also be achieved by driving the bars into hole.
- Addition of additional strengtheners or densities to the walls.
- Binding of composite materials on the surface or securing them in grooves made for this purpose.

The development of new techniques and materials recently has provided new potentials. Special among these is the epoxy resin adhesive which enables the addition of new reinforcing bars externally. This means further durability and low cost at the same time. The new applied methods can be classified as follows:

- Fixing of steel sheets.
- Fixing of unstressed composite sheets.
- Fixing of stressed composite sheets.
- Encasing of composite columns.

This section will focus on the most recent developments because they will gain extensive prevalence. Other strengthening methods will certainly be applied sometimes and will probably be combined with the addition of external reinforcing steel but this depends on the specific details pertaining to the structure.
5-5-6 Fixing of steel sheets:

The Fixing of steel sheets furnishes the concrete segment with additional tensile strength on the farther leaf, where it is very effective. With this method structures that entail removal are preserved. However, there is some reservation regarding this method and its disadvantages are shown on table 5-8.

Table 5-8: Factors affecting selection of steel strengthening sheets for concrete elements.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengthening can be achieved by a minimum increase in the dimensions.</td>
<td>• Requires a surface that is free of cracks resulting from the corrosion of reinforcing bars.</td>
</tr>
<tr>
<td>Strengthening in the fastening area</td>
<td>• The sheet will be subject to corrosion. • Risk of losing binding between the surfaces of the sheet and the concrete. • The segment needs a pressing power for avoiding brittle failure.</td>
</tr>
<tr>
<td>External strengthening elements</td>
<td>• Need extensive temporary support. • Risk of indentation because of pressure.</td>
</tr>
</tbody>
</table>

5-5-7 Practical Characteristics for fixing the steel sheets:

The effectiveness of fixing the steel sheets depends totally on the composite action of the sheets and the old concrete and hence on the used adhesive strength. Thus, the ability of the workers and observers is a basic matter. The surfaces of the concrete and the steel sheet must be treated with sand paper for achieving better adhesion. All surfaces must be completely dry and free from dirt and dust.

Steel will deteriorate quickly after its surface is treated with sandpaper, so it must be bound within no more than 4 hours. Alternatively, the steel sheet surface may be treated with sandpaper, cleaned and greased for keeping away from the work location, after that the sheets may be moved
to the work location and fixed after removing the greasing materials and drying.

5-5-8 Fixing of unstressed FRP composite sheets:

The use of steel sheet for repair and strengthening has been abolished and substituted by composite fibre reinforced polymers. All the above mentioned advantages are incorporated in these sheets while the disadvantages are reduced. Figure 5-1 indicates how to apply the adhesive and the sheets on test beams on a ruined bridge with 18m spans.

Figure 5-1: Application of the adhesive and sheets on the beams

The potential advantages of these plates can be summed up as follows:

- Strength: FRP sheets may be designed with components of different ratios.
- Weight: The density of FRP plates constitutes 20% of steel density and the weight of FRP sheet is 10% of the weight of a steel sheet of the same strength.
Transportation: The transportation of FRP polymers is easy because of their light weight and the fact that it has little density facilitates its folding and transportation.

Multiple design: The little density of polymer sheets enables stacking them, so a plate with a specific density can be bound with other sheets.

Surface preparation: Steel sheets must be mounted quickly after preparation, but the FRP sheets have a protective layer adhered to the prepared surface and removed before bounding the FRP sheet.

Mechanical fixing: The constant need for fixing for repairing scaling is less because of the little density in comparison with steel sheets and the low weight facilitates quick mounting and bounding.

Durability: The polymer sheets do not get rusted or corroded and therefore are not subjected to the same corrosion risks as steel at the line of attachment between the concrete and the external surface, which leads to lowering the maintenance cost.

Fire resistance: The mounted systems have good fire resistance compared to steel, because of their low heat conductivity, but in bad conditions they must be protected.

Low cost and short execution time: The low weight of the polymer sheets and easy handling and fixing reduces execution time and material costs.

5-5-9 Fixing of stressed composite sheets:

There is a very advanced development in the form of advanced composite sheets. This will expand the scope of strengthening means where the bounding of the sheets is the key and more economical solution. In this system anchorage elements are fastened to the structure with preshaped cables the lengths of which are determined priorly. They are stressed for incorporating their ends in the anchorage elements.

This method has been applied for the first time on a cast-iron bridge as shown in Figure 5-2.
Figure 5-2: Fixing of stressed composite sheets

Stressing is specially effective in FRP cables because this system focuses material strength in the areas under the neutral axis of the segment, leaving a large safety margin in the cable by stressing it with a force much less than its marginal strength.

Table 5-9: Compares the advantages and disadvantages of strengthening with stressed and unstressed polymer sheets

<table>
<thead>
<tr>
<th><strong>Table 5-9: Comparison between stressed and unstressed FRP sheets</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages of stressed polymer sheets</strong></td>
</tr>
<tr>
<td>• All dead loads can be neutralized before applying the live loads.</td>
</tr>
<tr>
<td>• The number of plates in this case is small compared with unstressed plates.</td>
</tr>
<tr>
<td>• Can be used for anchorage with limited cohesion lengths.</td>
</tr>
</tbody>
</table>
5-5-10 Summing up of the affixing of FRP sheets:

Affixing of the FRP sheets is the most comprehensive solution for strengthening bridge structures. The applications pertaining to this are summed up in table 5-10.

Table 5-10: Solutions for some structural defects through the use of FRP

<table>
<thead>
<tr>
<th>Structural defect</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion of reinforcement steel</td>
<td>Replacement of corroded steel by external polymer plates</td>
</tr>
<tr>
<td>Under tension elements strengthening</td>
<td>External reinforcement with polymer plates in the presence of pressure equalizing segment.</td>
</tr>
<tr>
<td>Prestressing wires are of no defined durability</td>
<td>Addition of an external network of FRP elements</td>
</tr>
<tr>
<td>• Cracks under loads</td>
<td>• Use of prestresed polymer for equalizing tensile stresses.</td>
</tr>
<tr>
<td>• Strengthening of the structures for shear</td>
<td>• External strengthening for the body.</td>
</tr>
</tbody>
</table>

5-5-11 Strengthening of built columns:

A system has been developed for the external strengthening of columns by using reinforcement with polyaramide glass fibers within the polymers. This system improves the behavior of the structure during earthquakes by increasing its flexibility and it increases the marginal strength and failure stresses. The system that coat the column will give it more protection against the penetration of water and chlorides.

5-5-12 Metal structures Repair and Strengthening:

Metal bridges structures are generally of great durability if adequately preserved. Also, the deterioration processes to which they are subjected
are well grasped and can easily be corrected if that is done early. The main causes of metal bridge deterioration are:

1. Corrosion
2. Fatigue and other cracks
3. Contraction and distortions resulting from loading and collision damages.

Corrosion and rusting occur when the protection system fails. This is the most common cause of deterioration. The chlorides that results from the salification of the road surface stimulate and aggravate corrosion.

The damage of fatigue and corrosion that are due to bad design details increases. The bad design details create areas that are subject to corrosion and concentration of stresses on the elements. Good inspection procedures will identify all forms of deterioration sufficiently early for acting before severe damages occur in adversely impacting the structure bearing capacity. An advantage of metal bridges that give it an edge over concrete is that deterioration occurs in the outer surfaces of the members in such a manner that it can be seen by the naked eye or by using minimum tools., an exception to this are buried structural members because they are difficult to access (especially in railway bridges) and also closed box members and their accessories such as load conveyance nails. Ultrasonic gauges may be used for measuring the plates during their inspection. They can also be used for identifying the location of cracking in the members that are difficult to access.

There are other methods for identifying cracking in the metal structures, such as x-ray photographing and magnetic fraction test. These technologies must be undertaken by specialized testing companies. Cracks that cannot be seen by the naked eye can be identified by dye penetrated testing which is a simple technique that can be undertaken by bridge inspectors. Acoustic emission techniques have been developed for identifying defects in metal members. However, at present there are no guiding manual addressing this technique.

If the mechanical properties of the metal structure are not known and its strength is known, we can take a specimen from a place of little stresses
or significance, such as segment wings and strengthening supports near the bearings. The specimen is tested in the laboratory for determining its composition and tensile strength.

If welding is to be used in the repair, then we should first check the metal composition and weldability. This can be determined in the laboratory.

Repair of metal structure deterioration resulting from one or more causes will only be initiated after determination and good understanding of the problem. In most cases the cause of the deterioration is readily apparent. On the other hand, the minor repair will only result in the reappearance of the defects if the main cause is not identified. The inadequate inspection and maintenance cycles may lead to a complete failure in the painting system and this can be avoided by early identification of paint defects and painting the bridge with a new protective layer. Local corrosion may be due to error or inefficiency in bridge drainage. The presence of areas that are subject to corrosion in the original design with accumulated dirt and waste may lead to damaging the paint and occurrence of many corrosions. The cracks resulting from fatigue and other causes may be due to unexpected loading or other environmental causes. In this case, the remedy and repair works must include, in accordance with practical and material capabilities, remedy of the original cause of damage of the structure to avoid repeating the repair. There are other examples involving fatigue cracks resulting from poor joints leading to vacuum flexure in the body sheet of the segment. Hence, minor repair of the damage without repairing the joint will lead to emergence of cracks once more.

5-6 Bridges and underpasses maintenance techniques:

5-6-1 Foreword:

Bridge maintenance techniques vary with the different defects that are prevailing in the bridge components in terms of the location where these defects are prevalent, the type, severity and impact of these defects. The maintenance and strengthening techniques are also influenced by the technical and scientific development in this arena as well as the modern synthetic materials which have created a revolution in the field of
structures maintenance and rehabilitation. It is not always required to resort to advanced techniques and modern technologies in the field of maintenance and treatment, but this is dictated by the adopted maintenance strategy, for some strategies depend on traditional technologies, others adopt advanced technologies and still other strategies adopt the technique of strengthening and replacement. Following is an explanation of the various techniques.

5-6-2 Crack Repair:

Cracks in concrete must be repaired if the rating engineer decides that these cracks reduce the strength and solidness to an unsatisfactory level or greatly reduce the function of the structure. The cracks must also be repaired if the engineer decides the need for improving the concrete surface. As per the precise evaluation of the cracks level and the cause of their occurrence one or more crack repair methods can be applied.

1- Epoxy Injection:

Cracks of a width below 0.05 mm are filled by injection with Epoxy. This is successfully used in repairing bridges and water tank cracks. This method can also be used for repairing most structural and nonstructural cracks taking into consideration that these cracks must be dormant or the causes of the occurrence of these cracks must be dealt with before applying this method. This method cannot be applied in cracks where the leakage is active or cracks that cannot be dried. It should be noted that this method requires a high degree of efficiency in execution.

2- Sealing:

This method is used for dormant and nonstructural cracks. It includes widening the crack along its exposed side. The crack is then filled and sealed with a suitable sealant and binder. This method cannot be used for active cracks and cracks undergoing hydrostatic pressure. It should be noted that this is one of the easiest maintenance methods and does not entail high level training. It is applied to both minor cracks and large isolated cracks.
3- Crack Stitching:

This method can be used when we need renewing tensile forces through major cracks. Crack stitching aims to strengthen and enhance the structure solidness, which leads to alleviating the problem at another location on this structure. Hence, it is important to conduct inspection and strengthen adjacent segments when there is a need for that. This procedure requires creating holes at the two slides of crack, cleaning of these holes and fixing the legs of the stitching veins in the holes either via nonshrinkable plaster or Epoxy adhesive with supporting resin substances. Stitching veins must be of variable length and direction and they must be available so that the tension conveyed through the crack is not applied at one level within the segment but prevailing in every location.

4- Drilling and Plugging:

Crack drilling and plugging is drilling under the crack and along it and then injecting the area and forming something like a key in a lock. This technique is only used in cracks that run in straight lines and can be accessed from one side only. This technique is usually used for repairing vertical cracks in supporting walls.

5- Flexible sealing:

The cracks are cleaned by a sand or water gun and then filled by a suitable mold of a flexible sealing material. A sticking preventer must be secured at the lower part of the crack for allowing changing the shape of the sealant as well as concentrating stress below. The sticking preventer may be made from polyethelene or another material that does not stick to the sealant before or during the treatment.

6- Grouting

A- Cement grouting

Wide cracks, especially in mass structures, thick walls and concrete walls, are repaired by grouting with Portland cement. The concrete is removed along the crack and then seats are mounted at equal distances across the crack sealing the crack between the seats with a cement coat, a sealant or
grouting. Then running water is used to clean and test the crack and the whole area is grouted. A manual grouting gun may be used in small cracks but for large cracks a pump is used for some minutes for ensuring good penetration.

**B- Chemical grouting:**

In chemical grouting two or more kinds of chemical solutions are mixed together to form a gel or a solid precipitate or a foam corresponding to the binding cement. It is formed of solid molecules suspended in a liquid. This chemical binder can be used in moist environmental conditions, can be controlled while it is turning into a gel and can be applied to very thin cracks.

**7- Dry Packing:**

Dry packing is manual placement of a low water content mortar followed by the packing of this mortar producing a deep contact between the mortar and existing concrete. The low ratio of water to cement leads to minor shrinkage in the material and helps in patching the remaining narrow cracks and increases the strength and water resistance of the material. The dry packs may be used for filling narrow cuts for repairing dormant cracks. It is not advisable to use dry packs for filling active cracks.

**8- Crack Arrest:**

During execution of mass concrete cracks may develop and increase in the new concrete because the surface is subjected to shrinkage or because of other reasons during execution. These cracks can be stopped by preventing cracking and spread of tensioning stresses in wider areas. Crack arrest is done by placing an anti sticking membrane or a steel net over the crack during concrete hardening. A semi circular tube may also be placed over the crack.

**9- Polymer Impregnation:**

A polymer is a liquid made up of small organic molecules that can cluster and form a solid plastic material. Polymers volatilize at different levels
and they have the characteristic of transformation and unmixability with water, and so they permeate dry concrete, being very liquid, and fill the cracks as water does. Polymers are used in polymer impregnation in addition to chemical media. Upon heating, polymers come together forming a strong solid polastic material that improve the properties of concrete greatly. Polymers are not used for repairing thin cracks.

10- Healing

Some polymers are added to concentrate in the forming stage reducing the internal tensile stresses that result from concrete reactions and increased heat in the stage of concrete hardening. Sometimes a special cement, such as Altimix cement is used for giving evenness to the concrete surface and acting to release internal tensile stresses. And it can permeate cracks, giving a high degree of healing. This kind of cement is used in mass concrete, especially in the piers of large bridges.

5-6-3 Repair of Scaling and Honeycombing:

Scaling and minor cracking in concrete is repaired by using polymers of low permeability for modifying the mortar of cement repair. The damaged areas are identified and marked. The concrete in damaged or honeycombed areas is removed until we reach the reinforcement level or good original concrete. Before beginning application of concrete mortar, the prepared concrete surface is totally saturated with water and free surface water is removed before the first coat. A good mix of polymers and cement putty (polymers to cement ratio is 1 to 2) is applied to the dry and saturated concrete surface and steel reinforcement bars to provide adhesion between the new cement and sand mortar. Then, repair mortar is applied (cement ratio to fine sand silicate is 1:3) over the previous cement and polymers putty. If scaling is deep a light metal net may be used before the application of the sand cement mortar and then a sand and cement mortar modified by polymers at the ratio of 1, polymers, 2, cement and 6, sand is applied, ending up with the smoothing of the existing concrete surface.
5-6-4 Repairs of Spalling:

First, the areas affected by spalling are cleaned and then the exposed reinforcement is coated with a basic PMC coat for preventing corrosion in the spalled areas. The exposed reinforcement is covered by a suitable mortar of good concrete. A basic coat of zink and epoxy is used as an anti corrosion coat. The basic coat prevents occurrence of corrosion within the area to be repaired preventing formation of positive electrode in the adjacent location.

5-6-5 Steel Corrosion Repair:

The corroded reinforcement steel (in places where corrosion has reduced reinforcing bars diameters by above 20%), repair is performed by adding new reinforcing bars to be strongly attached to the old reinforcing bars with an adequate method. Steel is used as reinforcement in the places where the diameters of the main reinforcing bars are reduced to 80% of the original diameter. However, British reinforced cement cloth must also be used for consolidating imbrication. The exposed reinforcing bars showing corrosion must be cleaned using a sand gun. If it is found that the reinforcing bars are reduced to 80% of the original diameter then new reinforcing bars free from corrosion with diameters equal to those of the old reinforcing bars must be attached with any suitable method and tied adequately.

5-6-6 Repair / Reconstruction of Wearing Surface:

Early detection and repair of minor defects on the asphalt wearing surface is the most important issue in bridge rehabilitation. Other cracks and defects are not observed in early stages, and if not repaired early, they may lead to severe defects. Hence, it is inevitable to perform periodic and in depth inspections of the wearing surface. Holes filled with dirt and lime debris and some cracks are repaired for facilitating prevention of water leakage to the slab surface and improving the asphalt wearing surface on the bridge for facilitating driving.
5-6-7 Surface Slab Treatment:

Cracks in the surface slabs can be repaired by adhesive covers in case the slabs are not moved. Adhesive covers can be used effectively for repairing slabs with multiple dormant cracks even if they are thin and resulting from dryness. Sometimes, the lower part of slab bridges can be effectively covered by a thick coat of resin Epoxy. For successful application of this method in highway bridges it is advisable to use covers of a minimum density of 40 mm.

- **Preventive measures for surface slab maintenance**
  1- Prevention of scaling by using high quality materials and adequate construction methods in addition to maintenance of good drainage, especially in places of flow. Scaling can also be reduced by applying a regular washing and cleaning program.
  2- Prevention of cracks by adopting the same measures pertaining to scaling. For limiting cracks in the surface joints connected with pavement pushing, measures are taken that would give a sufficient space for expansion and approximation. Structural cracks are precluded by good design and execution and avoidance of structure overloading.
  3- Scaling and cracking can be much reduced by the following measures which contribute to avoiding occurrence of reinforcement steel corrosion:
    - Coating of the reinforcement steel.
    - Use of better concrete that is more impermeable.
    - Provision of a waterproofing system for the surface during execution.
    - Provision of sufficient coverage over the reinforcement.
    - Adequate design for reducing vibrations and distortions resulting from large live loads.
    - Provision of negative electrode protection.
    - Use of sound execution techniques and quality control during execution.
    - Use of polymer impregnated concrete.
As regards reinforcement corrosion on the bridge deck, the use of negative electrode protection is a remedial and preventive measure at one and the same time.

Following is a presentation of remedial measures for defects that occur to the reinforced concrete deck (scaling, cracking, spalling or corrosion):

1. **Scaling:** It is repaired wherever it occurs by using a device that forms a light Epoxy coat that seals the location and prevents water penetration and access to the reinforcing steel. Fast hardening cement can also be used in addition to high quality cement of low precipitation.

2. **Cracking in concrete surface:** This can be treated through evaluation which may call for repairing the crack or use of another method, depending on the nature of the crack. When stresses are relieved and a stable condition is attained the cracks can be easily repaired through injection of a low viscosity epoxy.

3. **Spalling** is repaired by patching, covering or replacement. Areas of minor spalling are patched by a polymer modified concrete and unshrinking cement. In some places, during patching, a decision may be taken to cover all the lower surface with a thick cover that acts as a moisture repellent. The most important purpose of this is to remove water from the surface, for water is the most important factor among all the factors that contribute to concrete surface deterioration. The oxygen that is dissolved in water causes oxidization which leads to the corrosion of reinforcement steel. Sometimes, an alternative solution to coating is replacement. This is from an economic perspective for replacement is less costly. Corrosion of reinforcement steel can be prevented by cathodic protection which is effected by electrochemical techniques by including an additional positive electrode in the form of a metal net inside the concrete surface. The positive electrode is connected with the positive electrode of the electric supply unit and thus the reinforcement cage becomes a negative electrode and oxidation stops.
5-6-8 Maintenance of major beams:

The preventive measures used in the major components in the superstructure include the following:

1. Box beams – water and chlorides are prevented from leaking to the lower slab by placing a sealing coat on the surface of the box girder.
3. Laying of ground drainage below the girders and beams for reducing deterioration in concrete and the potential of corrosion in the reinforcement steel leading to a damage in surface draining.
4. A common method for protecting metal structures from rust and corrosion is keeping them coated with paint.

Existence of a constant schedule for scraping and removing chemical materials from structure bearing areas, tops of piers and bottom wings of girders and other areas of structural elements where dirt and debris may accumulate. Periodic cleaning and coating of leaking and seepage in the joints will prevent corrosion and extend the life of metal structures.

The following remedial measures are taken for main elements of the bridge superstructure:

1- Remedy of the exposed reinforcement in the bottom slab in the concrete box girder by adding a cement coat that restores bonding among unbound reinforcement bars. It is necessary to mount a wooden formwork under the structure at the start of the repair when there is a great loss of the bonding between the reinforcing bars due to high vehicles collision and in I or T beam.
2- Girders are much affected by this condition and the surface requires patching by high strength concrete for restoring the coat to its correct condition. Cracked girders with no broken reinforcement are remediated by the injection of Epoxy in them. There are various methods available for repairing concrete cracks. Application of any
of these methods depends on the cause of the occurrence of these cracks, their extension and their location.

3- Strengthening of concrete structures externally by adding reinforcing plates or bars or applying post tensioning.

4- Metal girders require immediate remediation measures in case of cracking or spalling. The cracking is an indication of a very grave damage. If the crack is major or in a critical location of the girder the traffic would be restricted on the bridge or the bridge would be closed until this element is replaced.

5-6-9 **Maintenance of minor members and beams:**

Preventive and remedial measures are taken similar to those used for major members. In addition to this, vertical clearance must be checked after repavement of the road.

5-6-10 **Maintenance of cushions and pier caps:**

The first remedial measure for preventing damage to bridge cushions and pier caps is the reduction of the quantity of leakage from the joints or deck drains.

Debris and chemical materials loaded with dust must not be allowed to accumulate on these decks. It is very important to scrape and remove accumulated materials every year after the end of the rainy seasons. The deck must be covered accumulated materials every year after the end of the rainy seasons. The deck must be covered with materials that are resistant to water and chemicals. In case of failure of the cushions directly supporting the bearings, a remedial measure is implemented by mounting temporary piers that transport the superstructure loads instead of the bearings. The cushions are replaced and reinforced at different layers so that they form a flexible support that relieves the dynamic load transported from the superstructure to the substructure. The pier cap usually requires consolidation in case that wide cracks appear in the cap. The width and thickness should be taken into consideration during consolidation, for this width plays an important role in reducing direct and indirect shear stress of penetration and in providing a sufficient space
for resting. As regards broken solder it should be scraped and replaced by a high quality solder. Loose and broken bolts and pins must be replaced.

### 5-6-11 End and intermediate piers:

The following preventive measures must be used for end and intermediate piers:

1. Checking whether differential settlements have occurred. This is determined by in-depth examination and careful evaluation of the foundation soil.
2. Use of leak-proof concrete compounds for preventing formation of defects above the water level. The concrete can also be protected at the water level by building a water proof uncorradable dike.
3. Building of a strong dike in front of the side facing the flow in the end pier in places where existence of much aggregate is expected. Damage at the water level can be prevented by protecting the concrete by steel sheets. However, the sheets must be well bonded and have sufficient density for protection from expected types of aggregates. Navigation platforms will form protective partitions against mechanical damages caused by boats and ships.

The following remedial measures should be taken for end and intermediate piers:

1. Identification and correction of settlement problems which may occur because of the inadequacy of the supporting soil strength or because of the slide of the bottom surface.
2. Repair of longitudinal and vertical cracks resulting from differential settlement by closing them with the Epoxy gun or by shotcrete. If the reverting wall moved much in relation to the structural member mass, then the reverting wall is brought down and rebuilt.
3. Complete removal of the damaged concrete through use of various air tools. Bonding of the fresh concrete with the old concrete depends on the depth and volume of the repair. Use of shotcrete for bonding fresh concrete with the old one is considered a suitable method.
4- Deflection of the soil adjacent to the revertin wall is attributable to the deterioration of the surface joint allowing draining of road water behind the revertin wall and consequently soil deflection. This problem is solved by replacing the joint after filling the void behind the wall and soil impaction when there is a need.

5-6-12 Repair / Replacement of Bearings:
The inspection and evaluation of Bridge Bearings will be conducted generally depending on bearing type, where the bearings are classified in this case according to the material to two types, Metal bearings and elastomeric bearings. Table (5-11) and table (5-12) explain the evaluation methodology.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>New Bearing or appears as new</td>
</tr>
<tr>
<td>6</td>
<td>The bearing is old construction, the condition is good no need for maintenance work</td>
</tr>
<tr>
<td>5</td>
<td>Minor defects, will not hinder the bearing function</td>
</tr>
<tr>
<td>4</td>
<td>The bearing situated in the minimum acceptance, immediate repairs are needed to maintain the bearing</td>
</tr>
<tr>
<td>3</td>
<td>Clear deterioration or bearing displacement, has become not functioning.</td>
</tr>
<tr>
<td>2</td>
<td>Advanced defect condition, suspension of traffic is required</td>
</tr>
<tr>
<td>1</td>
<td>The bearing is incoherently and unable to work</td>
</tr>
</tbody>
</table>
Table (5-12): Example for Assessment of the Bridge Bearings

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Frozen the bearings</td>
</tr>
<tr>
<td>3</td>
<td>Cleaning and painting</td>
</tr>
<tr>
<td>2</td>
<td>Lubricating</td>
</tr>
<tr>
<td>1</td>
<td>Replacement of worn out components</td>
</tr>
<tr>
<td>7</td>
<td>Jacking and resetting</td>
</tr>
<tr>
<td>6</td>
<td>Retrofitting</td>
</tr>
<tr>
<td>5</td>
<td>Replacement of the bearings</td>
</tr>
</tbody>
</table>

5-6-12-1 Bearing maintenance and repair:
After a detailed bearing inspection has been made, the decision to repair or replace bridge bearings can be made with respect to the report on the inspection. The main bearing repair and preservation methods are by:

1. Cleaning and Painting.
2. Lubricating.
3. Replacement of worn out components.
4. Jacking and resetting.
5. Retrofitting.
6. Replacement of the bearings.

The table (5-13) describes the most commonly defect experienced by bridges bearings and appropriate repair methods.

Table (5-13): the most commonly defect experienced by bridges bearings and appropriate repair methods

<table>
<thead>
<tr>
<th>Defect Description</th>
<th>Repair Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frozen the bearings.</td>
<td>Temperature control, cleaning and lubricating.</td>
</tr>
<tr>
<td>Mild Corrosion and rust Leakages in superstructure allowing flow of dirt, deicing salt, rain water etc. to the bearing area.</td>
<td>Cleaning and painting with corrosion protection paints, Sealing deck joints that allow leakage of rainwater and maintaining the superstructure drainage system.</td>
</tr>
<tr>
<td>Failure in connections and anchoring</td>
<td>Replacement of worn out components</td>
</tr>
</tbody>
</table>
components (rivets, bolts, welds). and Retrofitting.

| Massive corrosion of the bearings causing section loss. | Bearings Replacement. |
| Displacement of the bearing, visible misalignment and loss of components. | Jacking and resetting Replacement of worn out components. |
| Torn out or clearly bulged rubber in elastomeric bearings, Delamination of steel, wear of PTFE | Bearings Replacement. |
| Tilted bearing as a result of high load from the superstructure. | Jacking and resetting. Or Retrofitting. Or Replacement. |
| Damaged bearings from seismic activities. | Replacement with bearings with seismic capabilities. |
| Accumulated dirt, plant growth, animal activities (e.g. bird nest) | Cleaning Environmental control, sealing of bearing area. |
| Concrete spalling around bearing seat. | Jacking, removal of concrete and repair the concrete defects. |

**5-6-12-2 Cleaning and painting:**
Cleaning and painting is the most common repair and maintenance method for bridge bearings as virtually all kinds of bearing have steel components. Cleaning is done to remove all kinds of rust, dirt, and mill, and prepare the surface of the steel for corrosion protection treatments. Cleaning methods are by:

1. Painting with special rust removal paints.
2. Solvent cleaning by mineral spirits or turpentine.
3. Wire brushing.
4. Pickling with sulphuric acid, phosphoric acid or iron phosphate.
5. Flame cleaning with oxyacetylene flame.
6. Sand blasting or grit blasting.
7. Water jetting.

**5-6-12-3 Retrofitting:**
Retrofitting is the process employed in improving the functions of bearing such as, load capacity, seismic capabilities, and movement capabilities Retrofitting can be done by the following:

1. Use of restraining bars.
2. Use of dampers.
3. Use of shock transmission units.
4. Use of shear keys and restraining brackets.
5. Installing additional bearings.
Figure 5-3: Retrofitting using restraining bars or and restraining brackets

Figure 5-4: Retrofitting bearing

Figure 5-5: Retrofitting using Shock transmission units
**5-6-12-4 Replacement:**
Bearings that are damaged beyond repair or that can no longer carry out its functions should be replaced. Replacement is done by using hydraulic jacks in jacking up the bridge deck, supporting the bridge deck on temporary bearing, taking out the damaged bearing and replacing it. Where there is sufficient space around the bearing seat area or top of the pier, an auxiliary beam is erected across the top of the pier to support the temporary bearing, jacking device and to give sufficient work area. In the absence of sufficient space on top of the bearing seat area/ pier top, an auxiliary pier can be mounted from the pile cap, ground or by attachment to the bridge pier to support the temporary beam, jacking device and temporary bearing to effect the replacement. It is a risky process that requires skill, innovation and technique in handling effective load transfer, stability, bearing pressures, deck balancing etc. during the replacement hence only experienced and certified contractors should be contracted to carry out bearing replacement.

![Jacking of bridge deck to effect bearing replacement](image)

**Figure 5-6: Jacking of bridge deck to effect bearing replacement**

It is advisable to always design for bearing replacement in new bridges, which is by providing area for jacking around the bearing seat/ pier top. To design the deck so that it is possible to jack during maintenance easily. In addition, the bearing connection should be such that it can be easily repaired.
5-6-12-5 Jacking Tips before attempting to lift the Superstructure:
1. A heavy lifting equipment manufacturer must be contacted to determine what type of system is needed to do the lift. These manufactures can supply information on jacks, gauges, pumps, valves etc.
2. The bridge weight and the number of lift points will determine the jack capacity.
3. Generally, all the beams in the cross section shall be lifted at the same time and height to prevent excessive stresses to the bridge.
4. Establishing lift points longitudinally is also extremely important. The engineer shall be consulted when establishing the lift points. For example, simple span bridges may be lifted on one side of the span at a time. Continuous spans, on the other hand, need a jacking system to raise all the beams at all ends at the same time and height. The engineer will specify a differential beam lift tolerance to prevent excessive stresses to the continuous bridge during the operation.
5. Typically, the jack cylinder capacity should be twice the weight at the lift point.
6. Placing jacks directly under the beams may lift bridge ends. Alternatively, jacks may be placed under the diaphragms.
7. Hydraulic jacks cannot be active for long periods of time while the bridge work is in progress. Usually, the bridge is lifted and lowered on to blocking until the work is complete.
8. Traffic should preferably be taken off the bridge while jacking the bridge. Once the bridge is lowered onto safe blocking, traffic can resume.
9. Advanced hydraulic jacking systems offer synchronized lifting to help lift loads smoothly.
5-6-12-6 Jacking procedures:
1. Construct a necessary auxiliary pier to support the jacks when it is not possible to locate the supports on the existing substructure. An adequate foundation to prevent differential settlement is very important.
2. Reinforce bridge members as necessary to withstand the force of the jacks. Disconnect railing and utilities if necessary.
3. Place jacks snugly in position.
4. Restrict traffic on the span while jacks support it.
5. Raise the span by jacking. Pressure gauges should be used to ensure that all the jacks are lifting the span evenly.
6. Use observers placed at strategic points to look for signs of structural distress. Jack, block, and rejacking until the required position are achieved.
7. Check periodically to ensure that there is no differential settlement.
8. Remove the blocks using the jacks after the repairs are complete.

Figure 5-8: Lifting of the bridge girders in same time using auxiliary beam
Figure 5-9: Advanced hydraulic jacking system - controlled by computer software

Figure 5-10: Auxiliary pier attached to bridge foundation supporting the jacks and temporary bearings

5-6-13 Repair/Replacement of expansion joint:

a) Joints made of overlapping metal fingers:
The rust formed on the metal fingers is removed, insuring that the fingers do not protrude upward for fear that they may pierce the tyres of vehicles passing quickly on them. The asphalt layer placed on the sides of the joint must be treated insuring that there are no voids that cause surface water leakage to the superstructure. Also, there must be continuous cleaning of the joint opening by pumping of a strong air current.
b) **Solid joints:** The plates covering the joint must be maintained on a constant basis and it must be insured that they are well fixed.

c) **Flexible joints:** These joints are maintained by replacing the neoprene and good refixing of the joint edges. The concrete layer placed on the joint sides must be treated insuring that there are no voids to cause surface water seepage to the superstructure. This must be coupled with continuous cleaning of the joint opening by pumping a strong air current.

Note: Sometimes joint closure leads to a transverse movement of the bridge deck. If the case is so the correct condition must be restored with the provision of suitable conditions for the joint function.

**5-6-14 Repair of Railings:**

The procedures of the repair of the isolated cracks must be observed. Concrete of the railing’s elements must be broken in a similar manner to what was mentioned in the “Cracks paragraph”. The obviously damaged elements of the railing must be rebuilt; this procedure must include the poles of the railing but keeping the existing reinforcement intact. In case of the corrosion of the reinforcement and the loss of more than 10% percent of the portion, new reinforcement steel must be welded to the existing reinforcement, and an additional reinforcement must be installed consistent with the existing reinforcement. The free concrete pieces must be removed and the concrete surface completely cleaned out. The reinforcement and the cast must be placed in their proper places. Before starting to pour the new concrete, the old concrete surface must be dampened with water and covered with cement mortar.

**5-6-15 Pavements:**

The corrective procedures required for the repair of pavements include the following:

1. Corrective action relies on the type of defect of the pavement (crack, deterioration, loss in the portion, corrosion of the reinforcement)
2. Regain the loss in the structural capacity and compensate the deterioration of the pavements (cracks chopping, flaking, scaling)

3. The deferential movement of the partitions may need simple curing. The damage resulting from the collision must be compensated as needed.

5-6-16 Maintenance of Drainage Spouts & Service Lines:

Work includes the preparation and installation of drainage spouts with the upper grid in addition to the pipes. In certain places, the drainage spouts may be present, but may not extend to the required depth. Such pipes must be extended well under the railings. To avoid the potential of water leaking in areas of contact of extensions, the internal diameter of the steel pipe must be slightly larger. Cleaning and washing are two of the most effective corrective actions for the drainage systems especially in removing sand and debris carried by wind. Corroded metallic pipes must also be replaced as needed. Short drainage spout pipes must be extended to prevent the running drainage water from reaching the elements of the bridge. The free or suspended service lines must be kept in a safe operational condition until the Agency responsible for its maintenance restores them to their proper condition.

5-6-17 Maintenance of the Waterway under the Bridges:

Protective Procedures:
It is important to conduct accurate hydraulic studies in the main valleys known for their local flooding. The only actual protection for the effect of flow bed and banks is the adequate protection during the design and execution phases. Generally, the corrective procedures are several times costlier than the protective measures.

The following corrective procedures must be taken for defects of banks and waterways:

1. If corrosion is at an advanced stage, the affected or damaged area must be carefully plotted to determine the extent of damage through the Clean Analysis. Based on the findings, the size of soil
1. Works or the need for using gabion baskets, or stone/concrete cladding, must be determined in order to preserve the original shape of the waterway.

2. Precipitation is somewhat linked to corrosion. Anyway, if there is precipitation, earth sediments and debris must be removed to remote areas away from the active runway of the valley.

5-7 Repair and Restoration:
5-7-1 Introduction:

Concrete has multiple uses and is widely available for various purposes in various environmental conditions. Concrete may be used in conditions that require a type of repair works in order to increase its expected life cycle. All structural materials deteriorate one way or another over time and are subjected to the surrounding elements and the effects of vibrations and breakage. Designers must pay special attention to the extent the materials are repairable. In this respect, concrete must exhibit good restorability.

The service conditions for the concrete structure include cases that are vulnerable to harsh conditions to all parts of the structure (tiles etc). Often, the concrete structure suffers from cracks and deterioration as a result of such harsh conditions. Furthermore, there are conditions that include: impacting loading, moveable loading, overloading, shrinkage, temperature fluctuation, faulty designs, structural errors.. etc. Small cracks of acceptable widths can be tolerated in conditions of light vulnerability but are totally rejected in severe environmental conditions such as those that prevail in some parts of the Kingdom of Saudi Arabia. Such conditions are characterized by excessive temperature, seasons of humidity, and the alkalinity of surrounding soil.

The structure’s concrete components that exhibit stress in the form of excessive deflection, cracking, or deterioration in such an environment require immediate repair to prevent any further deterioration and to restore the structural cohesion to them. For example, cracks allow the chloride ions to enter into the steel; under certain conditions, this could lead to the corrosion of the reinforcement steel, which in turn may lead to
more cracking in the surrounding concrete and so the problem is complicated. So, if the deterioration is caused by a continuous phenomenon, actions must be taken either by dealing with the phenomenon or by protecting the concrete. If the deterioration is caused by isolated or by a series of events, the repair works are usually initiated immediately.

The information about the data of strength, hardness, and plasticity for the structural elements that have been repaired are to an extent limited and incomplete. There are a number of dependable repair materials and approaches available for treating all conceivable deteriorations. A unique characteristic of concrete structures is that they cannot be un-repairable.

There are certain instances where the repair approach may be difficult to apply or use as in another place. For example, the resin epoxy doses are used generally to patch large cracks while smaller cracks remain as a source for more deterioration to the structure in tough environments unless the problem is solved. Depending on the type of damage, the proper repair material and the proper method must be used otherwise the damage will complicate.

5-7-2 Categorizing the Damage:
5-7-3 Definition:

Before discussing the types of damage that may inflict a concrete structure, the following cases are determined:

1. The problem starts when a part of the structure is subjected to stress or severe conditions on a permanent basis that exceed the loading capacity, resistance or the strength of the structure’s material.

2. While the damage resulting from this defect appears usually in the surface of the concrete, it might however remain concealed under the surface of the unaffected concrete surface.

3. Repair means restoring the strength of the defective part of the structure to its original state. Repairing damage is not enough by
itself to eliminate the defect that caused it. Therefore, actions must be taken to prevent the damage occurring again on the concrete. As an example, correcting the corrosion-induced thin concrete is not enough because if the corrosion of the surface reinforcement steel is not stopped, the problem may continue.

5-7-4 Tests to Diagnose the Damage:

One stage of carrying out the repair of structures is to diagnose the causes and extent of the damage. The probable causes of the damage are:

a. Corrosion of the reinforcement steel
b. Succession of seasons
c. Chemical attack
d. Poor design of the structure /plan
e. Effects
f. lack of quality control
g. Overloading
h. Corrosion factors
i. Contaminated mixture components, and
j. Alkaline reaction

The type of repair depends on the type of damage. The damage may or may not be structural. Categorization of the damage may be determined by carrying out the following tests (refer to chapter 4 paragraphs 4-4-1 (destructive tests) and 4-4-2 (Non-destructive tests).

1. Visual inspection: this test could detect cracks, surface disintegration, rust spots, swelling (Refer to chapter 4, paragraph 4-4-2 Detection Methods).
2. Scanning with a test-device that covers the layer to detect the problems of inadequate concrete covering [less than as specified]
3. Carbonization test to determine whether the reinforcement steel is still protected by the alkaline concrete.
4. Chlorine test to detect the graduation of chlorine in the concrete
5. Mid-cell stress test to determine the possibility of steel corrosion
6. Concrete thinning due to the corrosion of the reinforcement bars
7. Permeability test
8. Test to check whether the strength of the concrete is less than the design strength or not
9. Resistance test to determine whether the concrete is contaminated with chlorine and other substances

5-7-5 Approaches for Repair & Restoration:

Once the cause and type of damage have been established, it is imperative to determine the most effective and cost-effective method of repair. In severe cases, this may require demolition and replacement of the entire structure. However, this is not the case of most damaged concrete structures. Some or all repair approaches will do the job and restore the structure. Most of these repair approaches includes replacing the defective concrete, the defective steel, or injecting cracks with joint materials as well as patching the concrete surface with coat.

5-7-6 The Size of the Damage and Speed of Repair:

When the concrete is damaged by excessive stress or overloading the owner in charge who was informed of the fact must look into the matter and see whether he has to repair the damage immediately or in the foreseeable future, or whether the repair works are something of his own.

The policy should be to accelerate and not to delay repair in case there is damage because of the following reason.

1. May be over time, the damage might threaten the strength or capacity of the structure
2. At certain stages, it might jeopardize the safety of the surrounding buildings or structures
3. If not immediately treated, it might cause the spread of the damage at an accelerated rate hence the repair costs will increase.
Basically, all corrosion cases of the reinforcement steel fall within this category. The physically affected reinforcement may contribute to the structural strength or significantly weaken it later if the corrosion is allowed to continue. If left untreated, the corroded reinforcement steel though by itself it may not affect the structural strength, could lead to the spread of the damage. For example, the corrosion may over time spread to the reinforcement steel bars that have been affected when the damage was noted for the first time. The reinforcement transverse areas of the sectors may decrease as a result of corrosion. The loading strength of the structure may be severely affected if the problem is not corrected or the reinforcement approaches are not carried in a proper way.

With all other types of symptoms of the damage, the owner may by himself look into the condition of the repair learn when and how the damage started in interfering with the function or service of the structure either in terms of decreased comfort and money returns, or increased risk to the traffic or for any other reason. In addition, the aesthetic considerations may play a part in this vision.

However, if the damage neither interferes with the function of the structure nor affects the aesthetic sensitivities, nevertheless, the owner must determine the causes of the damage and determine whether more damage, which could be severe, is probable to occur as a direct result. Here again it is recommended to call a specialist for service in order to conduct a detailed small or large inspection based on the nature and extent of the damage before he can give a dependable evaluation. The type of tests that he must make is necessarily (though it may be less comprehensive), essential in any event to determine the cause and extent of damage before making any corrective action.

5-7-7 Objectives of Repair - is it an Option?

If a decision to go ahead with the corrective action on the basis of these investigations is taken, it is necessary to start with determining the purposes of the curing, and the extent of the required works to achieve these objectives. Resulting costs must also be evaluated.
The basic objectives of any corrective actions may ideally be defined as the restoration of the structure to restore it to its original state and preventing further damage resulting from the same reason. Restoration means removing the damage be it overt or covert, return the affected part to its original portion by utilizing new concrete or patching mortar. Prevention means removing the defect by reinforcing the affected part and protecting the concrete surface, reinforcement steel, or reducing the stresses that cause the damage.

The only satisfactorily method to achieve these objectives is by carrying out a corrective action on a comprehensive scale. This could be highly costly. The owner of the structure is usually interested in the cost of the corrective action rather than the consequences of damage. The owner would mostly like to agree with the repairs that cost the least. As a result, a significant part of the corrective action is carried out by contractors who only carry out the repair or patching of obvious damages. Even if the corrective action is carried out in a proper manner, a similar damage may occur in another point in the structure if it is caused by a fault that was not considered at the time of the design. Further, the repetition of the same fault could be expected if the contractor does not determine the underlying cause or if he forgot to provide adequate protection to the structure against the stress(s) that cause the damage. The excessive costs resulting from determining, evaluating and repairing all damaged areas and taking the necessary actions are in most cases little in comparison with the incurred cost if the defect reappears. The provision of services, installation of scaffoldings and blasting equipments, and the special curing materials and others make a significant part of the total cost in several of the repair contracts. All these items must be provided and paid for once again. Much time will be wasted during carrying out of the repairs; this clearly hinders the use of the structure and causes further inconvenience.

Several owners do not even want to spend money or evaluate the damage in a professional manner. They usually do with a hasty visual inspection. They think they have carried out the repair only to be surprised when the damage repeats during two years and at times in the same place.
Sometimes, the first signs are ignored and mistaken as simple aesthetic distortions; no further attempts are made to discover the cause or determine the basic defect. Such behavior could prove to be costly in the long run.

In order to minimize the total cost of removing the defect and maintain the structure in the best possible condition afterwards, it is imperative to:

1. Carry out the corrective action as quickly as possible i.e. once the defect has been detected. To detect any damage well in advance, structures must be inspected at regular and constant intervals. Depending on the cause and extent of the damage, it is possible after accurately evaluating the situation, to postpone repair works for a while if it is not feasible for any reason to carry it out immediately.

2. Carry out proper evaluation for the scope of the required corrective work. The restorative curing supported with a guarantee from the contractor is undoubtedly reassuring to the owner of the works. However, the incorporated high costs are not always justified. So, in certain cases it is economically feasible to carry out a limited repair program to give an allowance for costing more corrective works at a later time.

In case of the damage caused by corrosion for example, the owner might decide that he will repair the damage every year and charge the costs to the ordinary maintenance expenses. In this case, the concrete will not tolerate excessive corrosion. In addition; the highly resistant-to-corrosion floor covers are not cheap. In such cases, relative costs and benefits must be assessed very carefully to assist in taking the proper financial decision. Even in the case of damage caused by the corrosion of the reinforcement steel, it is possible under certain conditions to limit the corrective works to removing the obvious defects and apply the protective coating designed to inhibit carbonation on the surface of the concrete and/or the entry of harmful chemical materials. In such case, the owner must accept the possibility that the concealed defects will show themselves at a later stage, which in turn necessitates more works over time.
5-7-8 Types of Repair Approaches:

One or more of the following approaches may be used as corrective work for most concrete deterioration and damages, which inflict structures. If the listed approach seems inapplicable, new opinion from a specialized body must be sought.

5-7-9 Replacing Concrete Completely:

In certain cases, the environmental conditions are so varied that complete removal of concrete and replacement with new one seems the only measure that appears to solve the problem. In case of severe fire for instance, it might be necessary to completely remove the concrete and replace it with new one.

Complete replacement of concrete is also preferable when the cost of repairing the existing concrete exceeds the replacement cost, or if satisfactory repair work in the long run cannot be achieved for some reason. It’s always a good idea when major repair works are contemplated, to determine first the cost of replacing the concrete. This helps the contractor evaluate all possible repair approaches. It is equally important to ensure that the person in charge of the original concrete must not take part in determining which type of corrective action to take.

5-7-10 Repairing Corroded and Chopped Reinforcement Concrete:

1. Patching and Coating of Corroded and Chopped Concrete Surfaces:

Patching is the term used usually to repair relatively small areas of a local damage by applying mortar or grout the damage existing in the area restored to match the surrounding areas and damaged concrete. In most cases, the patched surface is given a protective coating.

Coating of the concrete surface refers to applying mortar or coating to larger surface areas with the aim of restoring the concrete to its original portion (or at times increasing its original portion as is the case when contemplating overloads). The bonding materials upon which the repair
mortar or grout is based are: cement products, and types of mortar made of epoxy resin.

Special approaches must be used to prepare the substrate before patching. The type of approach depends on the type mortar and other materials used for the repair. Some of these approaches are sand blasting, high pressure water current, blasting with the use of sandstone/water, lime mortar coating, mortar polishing, abrasion tools, surface etching, hammering, vapor cleaning, wetting by water in case of patching with cement mortar. (Observe that for patching with epoxy mortar, the material must be as dry as possible). In some cases, there might be a need to line the concrete substrate with certain products (bonding system) before starting repairing.

During patching or coating of the surface, it may be possible to apply the repair material either manually or by pouring concrete under pressure or pumping. During pouring concrete by pressure, the ready mix mortar might reach the nozzle or pump water in the tube and mixed at the nozzle with dry materials. This approach is quick and suitable and may be used for vertical or horizontal work. This approach is very suitable when the repair is not deep and irregular in shape. However, it is neither practical nor economical for small repair works, which are preferably done by hand. Pressure concrete pouring requires a person has experienced with the nozzle in order to carry out good work.

2. **Repairing Reinforcement Steel:**

The main consideration in any corrective work on reinforced steel is the condition of the reinforcement steel. Long term and successful repair may be done only if the reinforcement is free from corrosion. Unless the rust forming on the surface of the reinforcement steel is removed or fixed by special treatment, the corrosion cycle will continue even if the surface is protected by a coating, that is resistant to air and water. On the short or long term, this will lead to the repetition of the damage. During the preparation of the concrete substrate for patching, the following procedures must be followed at the time of repairing the corroded steel and after the removal of the eroded concrete:
a. If the reinforcement steel is severely damaged, it is necessary to expose the reinforcement bars and remove the concrete behind the bars.

b. Expose the reinforcement bars by rough sand blasting or any other mechanical method such as grinding, or stainless wire brush.

c. Ensure all steel has been thoroughly cleaned.

d. After cleaning the steel to a polished finish, remove the dust and any other chlorine contamination then apply a corrosion erosion resistant coating or a base coat such as the base zinc rich epoxy coating.

e. It may be possible to add additional preliminary bars coated with epoxy or galvanized bars if the original reinforcement steel had corroded to the extent that the cross sectional area is depressed. Additional reinforcement may be calculated on the basis of the percentage of the depression in the original reinforcement area.

3. Using the Protective Coating:

Paints are chemical substances made of liquids or plastic; they penetrate directly to the concrete to protect it or add new characteristics not available in the existing concrete. It is not recommended to use an absorbent coating for protecting the concrete surface to seal the surface. Some of the materials used as a sealant are epoxy resins, bitumen products and products such as linseed oil, phyllo-silicates, and silicon preparations.

Coatings can be fixed on the surface of concrete either with a binding material, dripping in the pores of the concrete, or by a chemical reaction with the concrete at the surface. Using a combination of paintings on the surface of concrete may lead to a better resistance. The use of paints will provide an excellent aesthetic treatment for the repaired structures; as well it will conceal the non-harmonious colors, and provide additional resistance to specific aggressive environments.
5-7-11 Repairing Cracks:

Good repair of cracks depends on identifying the causes and selecting the repair steps that put such causes in consideration otherwise, repair will only be temporary. The successful long term repair procedures should take the causes of the cracks and the cracks themselves in consideration. So, and based on the accurate evaluation of the extent and causes(s) of the crack, it is possible to select the steps to achieve one or more of the objectives:

- Regain or increase the strength
- Regain or increase the hardness
- Improve the functional performance
- Seal the cracks to prevent water leakage
- Improve the appearance of the concrete surface
- Improve the permanency of concrete and prevent the entry of the corroding elements in the reinforcement

Based on the nature of the damage it is possible to select one or more of the repair methods. For example, it is possible to restore the tensile strength of a crack by injecting it with the epoxy. However, it might be necessary to provide additional strength by adding reinforcement or using subsequent tension. Injecting epoxy only can be used to regain surface hardness if more cracks are not anticipated. Cracks that cause leaking, lead to an unacceptable appearance, and cause corrosion of the surface must be repaired by sealing them. The following are the methods of repairing the cracks:

1. **Epoxy Injection:**

Narrow cracks up to 0.002 inch (0.05 mm) may be bonded by epoxy injection. The method consists generally of drilling adjoining holes and sometimes entry ports are made, then epoxy is injected under pressure. For larger structures the procedure consists of drilling a series of holes (usually 1/7 inch or 22 mm) that intersect with the cracks in a number of points. Holes are usually 5 feet (15 m) apart from each other.

Epoxy injection has been used successfully for repairs in buildings, bridges, tanks, and other types of concrete structures. However, if the crack is dormant (inactive) (or the cause of the crack has been eliminated
thus rendering the crack dormant (inactive), it is possible that the crack repeats elsewhere in the structure. If the cracks are active, and it is required to seal them while continuous movement is allowed in the site, it is necessary to use a sealant or another material that allows such crack to serve as a joint.

Except for certain types of epoxy, this approach is not applicable if the cracks leak actively without being able to dry them. While it is possible to inject wet cracks, however, the contaminants in the crack (including water) will decrease the effectiveness of the epoxy in structurally repairing the surface.

Epoxy injection requires a high degree of skill to achieve satisfactory results. The application of the approach could be limited by the ambient temperature. The general steps included in the epoxy injection are as follows (figure 5-3):

- Clean the surface
- Seal the surface
- Place entry ports
- Mix the epoxy
- Inject the epoxy
- Remove the surface tension
Figure 5-3: Epoxy Injection Method
2. Routing & Tight Sealing:

Routing and tight sealing may be used on dormant (inactive) cracks that have no structural significance. This method includes widening the crack on its exposed face, fill it and seal it with a suitable bonding material (figure 4-5). This process may be eliminated; however this will be at the expense of the repair appearance.

This is the simplest and most widely used method for repairing cracks. It may be carried out by a relatively inexperienced worker in comparison to epoxy injection. It is applicable to sealing cracks of minute forms and larger isolated defects. The method will not be effective on active cracks. It is also not applicable to sealing cracks that are subjected to an apparent hydrostatic pressure except when sealing the pressure face. In this case, it may be possible to gain a decrease in the flow. This process consists of inducing a large split in the surface large enough to accommodate the tight sealant. The split is induced by a concrete saw, manual tools, or electric tools. A minimum width of ¼ inch (6 mm) is preferred because repairing smaller splits is difficult. The surfaces of the routed joint must be cleaned by an air current and allowed to dry before applying the tight sealant. The aim of tightly sealing the crack is to prevent water from reaching the reinforcement steel, and the hydraulic pressure from building up in the joint, concrete surface stains, or causing humidity problems on the furthest side of that part. The sealant may be one of many materials depending on the level of tightness and permanence; both being highly demanded. An example is the epoxy compounds that are used a lot. Hot-poured sealants work well when a water-resistant accurate tight sealing is not required and the appearance does not matter. The urethane, which remains flexible during large temperature fluctuations, has been used successfully in cracks up to 4/13 inch (19 mm) wide and a large depth. There several commercial products; manufacturers need to be consulted regarding the type and the most suitable degree for application for a specific purpose as well the inspection condition.
3. Fixing the Grooves:

This method consists of drilling holes on both sides of the crack and injecting inside them fixing anchors (metallic unit – shaped with short legs). Fixing can be used when tensile strength is to be reintroduced in larger cracks. Fixing the grooves makes the structure hard; this forces the concrete to break somewhere else. Therefore, it is necessary to reinforce the adjacent sector by the use of external reinforcement in a suitable cover. Fixing steps consist of drilling holes on both sides of the crack, cleaning the cracks then inserting the anchors’ legs in the holes either by a shrinkage-resistant grout or a resin based epoxy bonding system. Fixing anchors should be variable in lengths and direction or both. They must be placed so that the tension directed through the crack does not lie on one surface in the portion but spread over the area. Fixing anchors’ intervals must be shortened towards the ends of the cracks. In addition, consideration should be given to drill a hole at each end to reduce its sharpness and lessens the focus of the tension. Wherever possible, both sides of the concrete must be fixed to prevent further movement of the structure. Bent parts must be stitched on one side only usually the tension side where there is movement. If the portion is in axial tension, anchors must be placed in a similar manner even if the drilling or demolition is required to gain access to the opposite sides of the portion. Fixing does not seal the crack but it can prevent it from spreading further. When there is water problem, the crack must be waterproof. It must be fixed to

![Diagram](image-url)
prevent the erosion of the anchors. This repair must be complete before beginning to fix the grooves. An exception could be made in the case of active cracks where the structure is to be used before making it waterproof because movement at the crack may break the material inside the crack. Anchors are relatively long and thin and cannot sustain high compression strength. Based on this, the anchors must be hardened and strengthened at points where the crack may open, for example by containing it in a cover.

![Figure 5-5: Sixing the Grooves](image)

**Figure 5-5: Sixing the Grooves**

### 4. Tension:

This method is one degree further than the stitching method. When there is a complete area of concrete that needs to be reinforced and any forming crack to be sealed, the tension method is usually the preferred solution. The method employs conventional tension cables or bolts to apply tensile strength (figure 5-6). This seals the crack and increases the power if applied accurately. Tension is a professional approach for an experienced engineer in his field and a contractor aware of applying.

Adequate fixing must be provided for the tension bolts making sure that the problem does not move to another part of the structure. Less tensile strength may be obtained either by injecting an expansive material into the concrete(s) or by driving a wedge in the concrete.
The beams of the concrete structure have successfully been repaired by the use of epoxy injection and the insertion of reinforcement bars. This approach consists of sealing the concrete and drilling 3/4 inch (19 mm) holes at 45° on the upper surface and passes the concrete surface at approximately 90° and fill both the concrete and hole with epoxy by pumping it under low pressure (50-80 Pascal (342 – 548 kilopascal) and placing the reinforcement bar in the drilled hole. Typically, number 4 or 5 bars (13 or 16 mm) are used and should extend at least 18 inch (0.46 mm) on both sides of the corrective work the crack. The epoxy bonds the bars to the walls of the hole. The crack should be filled to its top level and the surfaces of the cracked concrete should be bonded together in an integrated manner and thus the portion is reinforced.

The temporary external plastic concrete sealant is required for a successful repair. The gelatin epoxy crack sealant works very well within the limits of its flexibility. The silicon rubber gap sealant materials work well; they are particularly attractive in cold weather or when the time is short. The sealant material must be applied on a 1/16 – 1/32 inch (1.6 –
2.4 mm) thick homogeneous layer and must cover the crack by ¾ inch (19 mm) at least on both sides. The epoxy used to re-bond the crack should have a low viscosity and high flexibility index. It should be able to bond with concrete in the presence of humidity and be 100% interactive.

The reinforcement bars can be spaced to suit the needs of the repair. They can be placed in any pattern required based on the design criteria, and the existing reinforcement location.

### 6. Drilling and Boring:

The drilling and boring method consists of drilling down the length of the crack and applying mortar to form a groove (figure 5-7).

This approach is applicable if the cracks go along reasonably straight lines and can access to one end. This approach is used often in repairing vertical cracks of the retaining walls.

A hole (typically 2-3 inch (50-70 mm) in diameter must be drilled. The hole must focus on and follows the crack. The hole must be large enough to overlap along the entire length of the crack and provides enough repair material to structurally sustain the loads applied on the groove. Then, the drilled hole must be cleaned, tightly sealed and filled with grout. The grout groove prevents the opposite movement of the concrete portions adjacent to the crack. As well; it will decrease heavy leaking through the crack and prevents the loss of the soil behind a leaking wall.

If waterproofing is necessary and the transfer of the structural load is not, the drilled hole must be filled with a low index flexible material instead of the grout. If the effect of grooving is necessary, the flexible material may be placed in a second hole because the first one is grouted.

### 7. Flexible Tight Sealing:

Active cracks may be routed and cleaned by sand blasting, pressurized air or both then filled with a field prepared flexible sealant. Whenever
practical, the opening of the sealant formed by routing must comply with the requirements of the width and shape of an equal movement joint.

Figure 5-7: Maintenance of cracks by drilling and sealing

8. Grouting:

*Grouting with Portland Cement:*
Wide cracks especially in gravity dams and thick concrete walls can be repaired by grouting them with Portland cement grout. The steps consist of cleaning alongside the crack and establishing foundations (cement joints) at intervals on both sides of the crack (to secure a tight pressure contact with the injection tools), sealing the crack between the foundations with a cement coating, a sealant or grout then finish the crack to clean it and test the sealing and finally grouting the entire area. Grout mixture may include cement and water, or cement, sand and water based on the width of the crack. As much as it is practically possible, the water cement ratio must be kept to increase strength and decrease shrinkage. Water dilutants or other added materials may be used to improve the characteristics of the grout. For smaller sizes, it is possible to use a
manual injection gun. For larger sizes however, a pump must be used. After filling the crack, pressure must be maintained for several minutes in order to ensure good penetration.

**Chemical Grouting:**
Chemical grouting materials are solutions of two or more chemical substances that combine to form a gelatin material, solid sediment material or foam as opposed to the grouting materials that consist of solid particles suspended in a liquid. The 0.002 inch (0.05 mm) cracks in the concrete have been filled with cement grout.

The characteristics of the chemical grouting materials are that they are applicable in most environments (in presence of excess humidity) and the wide limits for watching the time it transforms to gel, and its application to hairline cracks. Disadvantages are that they require high degree of skill to give satisfactory results, loss of strength, and that the mortar is not required to dry during the service.

**9. Substrates and Surface Curing:**

Cracks in structural slabs and pavement can be repaired by the use of surface layers if the slabs are not subjected to movement (note that it is possible to use unconnected surface layers as coating but not necessarily to repair the slabs). However, most cracks in the slabs are subjected to movement resulting from changes in loading, temperature, and humidity. These cracks manifest through any connected surface layer slabs as multiple hairline cracks caused as a result of drying shrinkage or other causes can be repaired effectively by the use of surface coating.

Slabs at the level of the ground in freezing weathers should not receive surface coating or surface curing that constitutes a barrier against steam. The steam barrier will make the humidity passing from the lower layer show under the barrier the matter, which leads to severe saturation of the concrete and the quick dismantling by cyclic freezing and thawing.

The low hardness epoxy resin systems have been used to seal the concrete surfaces (including the hairline cracks). They are more suited for use on
surfaces that are not subjected to wear and tear. Typically, 17-25 of the epoxy resin dissolved solutions that conform to the viscosity degree ASTM C 881 TYPE 1, 11 or 111. The effectiveness of these materials has not yet been fully established yet.

Bridges, parking structures and internal slabs can be effectively painted by using heavy epoxy resin paint. This curing should include spreading aggregates on the un-wetted resin. This method seals dormant (inactive) cracks even if the surfaces of slippery resistant aggregates are eroded because the traffic cannot abrade the resin, which penetrates the cracks. Slabs and surfaces that have dormant (inactive) cracks can be repaired by executing a surface coating from concrete or polymer modified Portland cement mortar. In the application of roads’ bridges, the minimum coating thickness of 1½ inch (38 mm) has been successfully employed. The polymer materials that fit for such applications are styrene butadiene emulsions, acrylic emulsions and the non emulsified polyvinyl acetate as well as certain water accepting epoxy resin systems. The minimum solid resin materials must be 15% water to Portland cement; 20% to cement is considered ideal.

Before applying the coating, the surface must be cleaned to eliminate contaminants such as grease and oils. A connecting layer consisting of the finished emulsion mortar or an epoxy adhesive must be applied directly before placing the coating. Since the emulsion generally solidifies rather quickly, patching and mixing materials must be used continuously. The modified polymer coating must be mixed, applied and finished quickly (within 15 minutes in hot weather). Etching the coating after the emulsion starts to solidify will result in the cracking of the coating. These covers must be wetted for 24 hours.

10. Automatic Curing:

A normal process may occur that repairs cracks; this process is known as the automatic curing. This method has several practical applications to seal dormant (inactive) cracks in a humid environment such as those found in concrete facilities.
Curing occurs through the carbonation of the calcium hydroxide in a cement paste by carbon dioxide present in the ambient water and air. Calcium carbonate and calcium hydroxide crystals precipitate, accumulate and grow inside the crack. The crystals overlap, gather and produce an integrated mechanical bonding effect with a chemical bondage between neighboring crystals, and between the crystals and the surfaces of the paste and the aggregates. As a result, some tensile strength of the concrete is lost through the cracked portion; this could seal the crack. Curing will not take effect if the crack is active and subjected to movement during the curing period. Curing will not occur also if the water flow is slow to an extent that it leads to complete evaporation in the exposed face, which re-eliminates dissolved salts.

The saturation of the crack and the adjacent concrete during the curing process is important to develop any tangible strength. Submerging the cracked portion is preferable. Water bonds may also be created on the surface of the concrete until the crack is saturated. Saturation must be continued throughout the entire curing process. The drying and re-submerging cycle will result in significant reduction in the amount of the curing strength. Curing must start as quickly as possible after the appearance of the crack. Delayed curing will result in regaining less strength than that of the immediate curing.

5-7-12 Other Structural Repair Approaches:
1. Encasement:

Encasement is placing and bonding the material over the concrete thus providing the characteristics of the required performance. Materials used are metals, rubber, plastic and concrete. When water and ice corrode the bridge support for an example, the remaining material is sometimes encased with high strength concrete. This leads to regaining the structural values and protecting the reinforcement steel elements from being exposed. As well, it improves the appearance of the original concrete. If the water flow is too fast, or if the shape of the part indicates significant depression, it might be necessary to use metal or rubber encasement. Reinforcing materials or materials similar to mortar of various makes are widely used by contractors to encase the stained concrete or concrete with
mild surface disintegration. Materials may be floated or sprayed on the surface. They achieve a certain degree of water resistance.

Encasement materials may be secured by bolts, screws, adhesives and by bonding to the existing concrete or by gravity. The fixing method used depends on the exposure, the material used, and the placing of the encasement material.

2. Slabs’ Bonding Approach:

The slabs’ bonding approach can be defined as the approach in which the relatively small thickness (few centimeters) steel boards are bonded with the adhesive epoxy on the beams and reinforced concrete slabs to improve its structural performance (figure 5-8). For example, this approach may be used to watch over the concretes and deflection, and to increase the hardness and strength of the reinforcement concrete beams and slabs. Although the epoxy resin is costly, however this approach is preferable because of its simplicity and speed of application. Surface etching is at minimum. It also increases the size of the structural parts by approximately a few centimeters of its original size and so it will not create a problem with the head. In the past, the bending strength of a few structures in Europe, South Africa, and Japan have been reinforced using this approach. Several researchers have conducted research work to investigate its performance, how practical are the externally bonded steel boards on the bottom of the bridges. The steel reinforced beams bonded with epoxy to a thin tape of steel on the tension face have demonstrated an improved strength up to the level of service loading. However, at the level of the final load, these beams demonstrated sudden deficiency at the ends when the thickness of the board exceeded a certain limit, therefore it exhibited a loss of being retractable. The structural portions must have enough ability to be retractable in order to give a warning before collapse.
C. Details of anchorage at the ends

Figure 5-8: Reinforcement by Board

3. Slab Jacking:

Slab jacking is used to raise a depressed slab to the required level with the aim of providing a stable substrate. This approach is used a lot on pavements but it is equally effective on the floor slabs.

By following a predetermined pattern, holes are drilled through the concrete slab to be jacked. Each hole is equipped with a pressure fitting. A thin mortar is injected under the slab to raise it. When the thin mortar material solidifies, the structural strength of the base layer is strengthened. The thin mortar material may consist of cement, mud or ash.
based materials. If the loading strength is required, it may be possible to add emulsified cement to the mortar.

Some contractors are specialized in slab jacking. It’s an approach that requires extensive experience to place the correct number of the required holes, and to determine the amount of mortar to be pumped in the base layer.

Slab jacking is not a suitable method for heavy slabs where the pumping pressures are limited. We must anticipate back depression of about 5% from the level of slab jacking.

4. Cathodic Protection:

This is one of the repair approaches available to repair corrosion. The basic principles of the corrosion cell may be used to understand the cathodic protection theory. Cathodic protection is defined as the removal of corrosion by making the metal a cathode by passing a direct current connected on the surface of the concrete or connected by the use of galvanic (sacrificial) anodes or galvanizing tools. Since the areas have been transformed to cathodic areas, becomes cathodic and corrosion is removed.

The basic method that achieves cathodic protection is to pass a direct current from an external anode through the electrolytes to the metal. As long as the current flows from the electrolyte to the metal are correct, it will be a cathode. The directed current cathodic protection rates provide the modifications for the continuity of the proper levels of the impressed direct current.

It is possible to use a galvanized anode system to produce the electric current. This system consists of using an interactive metal such as zinc, ammonium or magnesium to create the flow of the current. The electric current is generated by the difference in the voltage of the metals when they are connected. The electric current flows from the anode (zinc, ammonium or magnesium) through the electrolytes to the abrading metal.
When the current flow is enough to change all the areas on the metal cathodic, cathodic protection is achieved.

The direct current produced by the use of the galvanized anode system is not sufficient to reinforce the reinforcement steel in the concrete.

In the corrosion cell, the oxygen and hydrogen in the anode and cathode are expelled respectively. When the cathodic protection is used, the areas of the abrading metal become cathodic. When there is enough quantity of hydrogen in the cathode, there is a polarized state.

5-8 Underpass Restoration Works:

1. Treatment of support walls
2. Installation of steel protective bars in the drainage spouts
3. Installation of open steel covers on the side drainage channel
4. Installation of protective grid on the ground pump tank

5-8-1 Support wall Treatment Method:

1. Inspection of damaged areas by the use of a light hammer on the axis in both directions at 20 mm intervals. The removal areas must swing by about 100 mm around the damaged areas.
2. Determine the limits of the damaged areas by a saw that cuts regular boundaries of the breaking and removal areas
3. Remove all damaged concrete areas by the use of a light jackhammer (not more than 15 kg in weight) and 80-100 mm deep, or about 25 mm behind the reinforcement steel (whichever is larger).
4. Remove the reinforcement steel that exhibits shortage in the cross-sectional area by 10% or more.
5. Clean all debris by the clean sand bath.
6. Connect new bars instead of the removed ones. Connect with the old bars by welding. The welding area must be less than 250 mm.
non-welding joint ranges between 900 mm for bars of 25 mm in diameter to 550 mm for bars of 20 mm in diameter.

It is preferable that welding be directed downwards only when it becomes difficult to obtain adequate length for connectivity.

Vertical reinforcement subjected to tension must be welded or connected in one place. Welding or connection of steel should be in a staggered manner at intervals not less than 500 mm.

7. The reinforcement steel bars that includes no less than 10% rust of the steel bar section must be cleaned by the use of short-blast until the rust is completely removed.

8. Holes 12 mm in diameter and 150 mm deep shall be drilled every 500 mm in both directions. The joint reinforcement bars must be placed in these holes after filling them with epoxy.

9. The cracked concrete surfaces must be cleaned of dust using a water bath followed by a dry air bath.

10. All old and new reinforcement bars must be coated by a rust resistant material (zinc paint).

11. All clean concrete surfaces must be painted with a material to join between the old and new concrete as per the specification of the material.

12. A temporary wooden formwork must be placed in such a way as to allow the concrete cover to be within 70-75 mm on top of the reinforcement steel.

13. New concrete mixed with suitable low shrinkage chemical materials must be poured. Pouring must be from the top; the vibrator must be placed on top of the wooden formwork to ensure the penetration of the concrete in all voids and around the new and old bars.

14. The new concrete must be wetted and treated for five (5) days by fresh water; wetted canvas must be to ensure that humidity is retained.

15. After 28 days from pouring the concrete the entire concrete surface from the side of backfilling the soil including the upper surface of the wall foundations must be prepared by the removal of the dust,
remaining backfilling materials, organic components, and any other materials must be removed in preparation for placing the wall’s insulation materials.

16. The dryness of the concrete surface must be ensured. The degree of humidity of the concrete surface must not exceed the allowed limits specified for the insulation materials used.

Ready made concrete special mix for the purpose of repair deteriorated concrete may be used. Salt resistant cement concrete together with silica foams as an additive (5%) to concrete; sulfate resistant cement (type 5) may be used.

5-8-2 Installation of Steel Protection Bars in the Openings of the Side Drainage Spouts in the (curbstones):

During the rainy season, a lot of debris and trees clog the openings of the subsidiary drainage spouts that are fixed in the (curbstone) inside the stones, dusts and waste materials coming with water from outside the tunnel. Protection may be achieved by installing reinforcement steel bars.

5-8-3 Installation of Open Steel Bar Covers on the Subsidiary Drainage Spouts

In most tunnels there are concrete covers placed on top of the side flood discharge channels. It is difficult to carry out periodic maintenance and cleaning works because the concrete covers may be damage during transportation, opening and returning them after the maintenance work. They may also be damaged because a lot of dust settle on the covers when water flow over them during the rainy season. Therefore, this requires the provision of a system that protects and restores the side discharge lines.

5-8-4 Installation of Protection Grid in the Ground Pumps’ Reservoir:

In most ground tanks in the tunnels, there is precipitation reservoir; tanks are divided into two parts with a barrier wall of a height not exceeding 1.5 m. When there rains become heavy and reach to the reservoir in large
quantities with some small waste materials through the side discharge spouts and the vertical (curbstone) openings and consequently entering directly into the pumps, this requires the provision of a system to protect and filter as a final protection line before waste materials enter into the pumps. This is done by installing a grid on top of the barrier wall in the ground reservoir.
Chapter 6

Principles and Requirements for the Maintenance of the Electrical & Mechanical Works
Chapter 6: Principles and Requirements for the Maintenance of the Electrical and Mechanical Works of the Bridges and Tunnels:

6-1 Introduction:

This chapter is part of the [Bridges & Tunnels Maintenance Guide] of the Technical Affairs Agency, Directorate General of Operation and Maintenance, Ministry of Municipal and Rural Affairs, Kingdom of Saudi Arabia. The guide generally includes several main parts, which are:

- Overview of the chapters
- Light poles’ footings
- Ground connection pipes
- Cables
- Anchor bolts
- Fuses’ box
- Lighting distribution boards
- Transformers
- Lamps
- Policies observed in maintenance
- Traffic department, and
- Inspection & maintenance of the mechanical works

The guide includes the various inspection methods (visual, physical & advanced), common defects, various maintenance methods, how to inspect cables, methods of inspection and maintenance of the poles and the anchorage bolts, methods of the inspection of and the fuses’ box, methods of inspection and maintenance of the lighting distribution boards, methods of inspection and maintenance of the electric transformers, methods of inspection and maintenance of the lamps, policies observed in maintenance, safety plans, traffic control, signs used during maintenance, and methods of inspection and maintenance of the mechanical works.
6-2 General:

6-2-1 Objective:

The objective is to ensure the adequacy and safety of the methods of Maintenance of the Electrical & Mechanical Works of the bridges and tunnels.

6-2-2 Description:

These are the technical specifications of the Electrical & Mechanical Works for inspection and technical requirements to be followed by inspectors and contractors on the bridges and tunnels.

6-2-3 Scope of Work:

The Electrical & Mechanical Works that have relevance with the principles and requirements include the inspection and evaluation in the field of bridges and tunnels. These works include the following components:

1. Light poles’ footings
2. Ground connection pipes
3. Cables
4. Anchor bolts
5. Poles
6. Fuses’ box
7. Distribution boards
8. Transformers
9. Poles’ lights diameter
10. Others

6-3 Poles’ Footings:
6-3-1 Introduction:

Bridges and tunnels are natural extensions of the roads and consequently lighting. In this case, additional lighting poles should be fixed. The footings of the poles must be installed in the edges of the
bridge slab. The aesthetic aspects of the structure must be observed as indicated in the figure number 6-1.

Figure 6-1: A pole’s footing in the edge of a bridge’s slab

6-3-2 Methods of Inspection:

There are three methods to inspect the concrete footings of the lighting poles depending on the required method of inspection. It may be possible to select any or all of these methods. The methods are:

1. Visual inspection.
2. Physical inspection
3. Advanced inspection

6-3-2-1 Visual Inspection:
Visual inspection can be periodical and includes a review of previous inspection reports and inspection of column bases and recording of any defects or damages there.

6-3-2-2 Physical Inspection:
Any observed defects in the concrete poles’ footings must be checked physically with the use of a hammer to identify the extent of the damage. Focus must be put on the high stress areas in these footings. The inspection hammer also helps identify the thin areas and weakness in the concrete.

6-3-2-3 Advanced Inspection:
Some available advanced inspection methods may be used for inspection of the concrete poles’ footings (non-destructive test method). An example is the infrared thermal imaging. The idea of this experience
is making thermal imaging of the concrete surface to inspect the thinning of the concrete poles’ footings. Refer to figure number 6-2.

**Figure 6-2: Thermal Imaging of a Concrete Element**

**6-3-3 Most Common Defects:**

The most common defects of the concrete poles’ footings are:

1. Cracks, dissociation
2. Deformations of the anchor bolts and their fittings, and the footing’s plate
3. Destruction resulting from collision
4. Loose anchor bolts
5. Corrosion of the anchor bolts and their fittings, and the footing’s plate
6. Destruction resulting from excessive loading

**6-3-4 Methods of Maintenance:**

- To avoid critical damages in the poles’ footings, the following steps may be taken:
1. Remove all dirt and debris from the poles’ footings. Remove corroded parts such as the anchor bolts and their fittings, and the footing’s plate. Fix slack bolts.

2. Clean the poles’ footings at least once every two years
   - The elements sued in the cleaning process are:
     1. Skilled labor
     2. Water
     3. Equipments, water trailer, high pressure water pump, water hose
     4. Personal safety tools
     5. Manual tools

6-4 Ground Connection Pipes:
6-4-1 Introduction:

Ground connection pipes free from cracks and corrosion must be used for the electrical works. Connections must be tight. The materials of the pipes must be highly resistant, suitable for external connections, and suitable for the surrounding environment under the ground including continuous overflow of water. After completion of the ground connection pipes, the pipes must be left clean and free from any obstacles and obstructions.

6-4-2 Types of the Ground Connection Pipes:

1. **Un-plasticized Polyvinylchloride (UPVC):**
   They may have the following characteristics:
   a. Suitable for burial under the ground
   b. Minimum tensile strength MN 400/sq m
   c. Minimum torque MN 40/sq m

2. **Polyvinyl Chloride (PVC):**
   These are used also for ground connections’ they must be of high resistance
3. **Galvanized rigid metal (GRM or RMC)**

Galvanized rigid metal pipes are suitable for external uses under the bridges and the sides of tunnels (figure 6-3). All galvanized rigid metal pipes used above or under the bridge slab must be covered with a 0.3 maintenance plastic tape with a 50% overlap from the covering tape.

![Figure 6-3 a. Galvanized steel pipes](image)

![Figure 6-3 b. Pipes with elbows under the roof of a bridge](image)

![Figure 6-3 c. Pipes are prepared in the supporting walls before pouring concrete](image)

![Figure 6-3 d. Straight connection pipes under the bridge’s slab](image)

![Figure 6-3 e. Connection pipes beside the abutments](image)
6-4-3 Methods of Inspecting Ground Connection Pipes:

The ground connection pipes are inspected visually or routinely. Visual inspection includes routine inspection; it contains reviewing the previous and inspection reports, inspecting the parts and surfaces of the ground connection.

6-4-4 Most Common Defects:

The most common defects that inflict the pipes and their connections in bridges and tunnels may be summarized as follows:

1. Voids of incomplete filling
2. Transverse cracks
3. Longitudinal cracks
4. Dry connections
5. Destruction resulting from excessive loads
6. Corrosion
7. Slackness of the pipes’ support
8. Entry of debris and humidity
9. Accumulation of objects from wreckages

Follows are the causes of these defects:

1. Voids in filling:
   This defect occurs because of the presence of air entrapped inside the pipes, water sprinkling, and incomplete filling as indicated in figure 6-4.
2. Transverse cracks:
These types of cracks result due to local loads

3. Longitudinal cracks:
These types of cracks manifest as longitudinal splits parallel to the longitudinal axis of the pipes

4. Dry connections:
Connections become dry as a result of the lack of treatment with the epoxy or inadequate treatment with epoxy.

6-4-5 Methods of Maintenance of the ground connection pipes:

The ground connection pipes works are carried out to minimize damages such as corrosion, cracks, and splitting. The maintenance of such works must be carried out before the damages can aggravate and stay longer thus causing more and more damage.

Maintenance methods observed in this field are as follows:

1. The Connection Pipes Collection Point’s Boxes Method:
The inspection is carried out visually. The box cover must be tight and free from any defect or corrosion (refer to figure 6-5)
The damaged or broken covers must be replaced. It is important to repair the damages inflicting the boxes in the side walls in the tunnels and abutments of the bridges.

A. Electrical collection boxes in the surface of the tunnel
B. Electrical collection boxes in the side wall
Figure 6-5: Electrical collection boxes points’ boxes

2. The maintenance of the drainage spouts and the ground connection boxes includes but not limited to:
   a. Ensuring the adequacy of water discharge
   b. Replacing the or broken or damaged covers of the drainage spouts
   c. Treating the collapsed drainage spouts’ sides
   d. Treatment, cleaning and levelness of the surface of the location of the drainage spout

6-5 The Cable:
6-5-1 Introduction:

Electrical cables and their connections must be done to take the shortest route to the electric outlet from which they take their power. Under normal operation conditions the life cycle of cables is more than 25 years. However, there are some factors that may decrease their efficiency and life cycle. Therefore, to maintain them and make function efficiently and for a longer time, it is important to inspect, test and periodically maintain them.

6-5-2 Methods of Inspecting Cables:
Maintenance must be carried out immediately after the inspection each time they are inspected. The inspection works include two types: (1) Visual inspection, and (2) Physical inspection.

6-5-2-1 Visual Inspection:

Previous inspection reports if any must be reviewed, then inspection be carried out on the connection pipes above and under the bridges and tunnels to determine any defects that may show on them.

6-5-2-2 Physical inspection:

Some defects cannot be detected by visual inspection, therefore it is necessary to employ the suitable equipments and experiments for each
type of defects and then determine the extent and size of the defect. The inspection involves the connectors, insulation, electric current, voltage, and defects in general. One type of equipments is the thermal imaging equipment that and the current, voltage and resistance meter.

1. **Thermal Imager**

The thermal imager can be employed practically and cost-effectively for early inspection of the points of high resistance in cables and the connection wires (refer to figure 6-6). The use of an attached camera with the thermal imager can check over the bad connections and cables.

![Thermal Imager](image)

C. Cable inspection

**Figure 6-6: Thermal Imager**
2. Clamp on Ammeter:

This ammeter makes it easy for engineers to use. It operates on batteries or power; it can also be charged. It operates by being placed on the cable to be measured by tightening its grip on the cable. It can measure the direct and alternating current and the resistance (figure 6-7).

![Ammeter](image)

Figure 6-7: Ammeter

6-5-3 Most Common Cable Damages

The following are the damages that must be included in the inspection:

1. Connections
2. Corrosion
3. Areas that show humidity
4. Corroded insulation areas
5. Exposed cables
6. Thin cables
7. Indication of the presence of rodents and insects
8. Wear & tear
10. Areas of cable bending

Therefore, inspection must be at times determined by the competent engineer. The inspection results must be recorded on order to make use of them in the maintenance programs.

6-5-4 Methods of Repair of Cables:

1. When the temperature of the cable increases markedly as a result of bad electrical connections, the insulated material is affected; this certainly leads to inflammation. Therefore, it is imperative to ensure that the surface of the cable is cleaned, lubricated and then insulated.

2. If the surface of the cable is not properly insulated, the entry of water into the cable may pose a problem that may lead to the deterioration of the cable and decrease its efficiency.

3. It is imperative to ensure the integrity and safety of the cable’s sheath and its insulation material.

4. Replace all bad insulators

5. Delicate insulators lead to the attack of rodents and insects. This causes openings in the surface of the cable. As a result, water may enter the cable, deteriorates it over time, and decreases its efficiency.

6. Any of the cable’s parts plays an important role. So, the periodic maintenance maintains the efficiency of the cable and prolongs its life cycle.

6-6 Light Poles and Anchor Bolts:

6-6-1 Introduction:

This work includes the inspection and maintenance of the light poles, the footing’s plate, the anchor bolts and their fixtures as well as the cable footing of the pole.
Large poles require inspection outlets in their footing. Figure 6-8 shows the components of installing the footing of the pole with the footing before pouring the concrete.

Figure 6-8 a.
The footing of the pole ready for pouring concrete after fixing the installation bolts
6-6-2 Most Common Defects of the Light Poles:

Often the most corroded places of the light poles are their internal areas because water and humidity enter inside them. To avoid this type of damage, carefully studied discharge spouts must be made for the discharge of water and humidity that gather inside the poles. Figure 6-9 a. shows the collapse of a steel light pole as a result of corrosion.

Care must be taken when the light poles are erected in the bridges in case they are to be in the following environmental media.

1. Poles subjected to highly contaminated air that leads to corrosion
2. Poles in the coastal areas with high content of water and humidity of a salty nature
3. Poles in areas of heavy rains or high humidity, or those which are continuously wetted (refer to figure 6-9 b.)
Figure 6-9 b. Samples of the corrosion of the light poles and their footings

Figure 6-9 c. samples of the corrosion of the light poles’ anchor bolts

6-6-3 Inspection Methods:

The following items must be inspected visually and physically. These are:

1. Steel poles erected on the bridges
2. Light supports and lamps in the underpasses and tunnels
3. Elevated light poles
4. The tensile resistance of the sliding anchor bolts of the footing
5. The anchor bolts and their fixtures at the bottom of the pole with the concrete footing

The abovementioned elements must be inspected within ten (10) years in the first period after installation, and every five (5) years thereafter.

These intervals are observed in normal circumstances. In case there are factors that accelerate the appearance of damage such as flooding in coastal areas and contamination, the inspection intervals may be made shorter. A detailed evaluation and maintenance must be made after the inspection. A tight plan must be prepared to carry out this task. Figure 6-10 shows the bolts and fasteners with their fixtures.

![Bolts fixing tools](image)

Figure 6-10. Bolts fixing tools

6-6-4 Maintenance of the Poles:

After the erection of light poles in the bridge, at least the following items must be inspected:

1. Test the galvanized plate of the pole’s footing and other places in accordance with the following specifications: [ASTM A123/A123M (2000), ASTM A156/A153M (2000)]
2. Check the vertical alignment of the pole
3. Evaluate the surrounding area
4. Inspect the damages resulting from traffic accidents and replace damaged poles immediately
5. Inspect any horizontal rupture in the pole that exceeds 20% of the pole’s perimeter
6. Identify any deformations in the pole that results from the impact and exceeds 20% of the pole’s diameter

Therefore the following must be done:

a. Maintain the poles and lamps; change in case of severe damage
b. Straighten bent poles and their support arms.
c. Paint the poles

Poles with sharp dents resulting from being run over or other but do not need to be replaced completely, may be treated & used. Ground handholes may also be treated without the need of replacing the entire pole. The use of welding in light poles in the bridges must be in the manufacturing phase only.

6-7 Fuse Boxes:
6-7-1 Introduction:

The fuse boxes are the electrical components that contain the fuses. They are used as a short circuit device for protecting the electrical elements. Figure 6-11 shows the fuse boxes.

![Figure 6-11: Fuse boxes](image)

6-7-2 Methods of Inspecting Fuse Boxes for the Purpose of Evaluation and Carrying Out the Suitable Maintenance Works:
There are two methods namely the visual inspection and the physical inspection.

6-7-2-1 Visual Inspection:

![Figure 6-12: Inspecting the fuse box](image)

This type is done visually to inspect the components of the fuse boxes to and check their conditions to see if there is any damage or defect in them. Figure 6-12 shows a picture of a fuse box. The technician must record the remarks of the inspection.

6-7-2-2 Physical Inspection:

Some damages and defects in the fuse boxes may not be detected by the eye (visual inspection), therefore, the physical inspection is carried out to detect the damage and deterioration in these boxes. The physical inspection is done with the use of the inspection equipments and devices. Figure 6-13 shows an inspection device and a type of fuses.
a. Multi use inspection device

B. Fuse

Figure 6-13: Advanced inspection device and a fuse

6-7-3 Most Common Defects of the Fuse Boxes

The most common defects of the fuse boxes may be summarized as follows:

1. Improper setup of the fuse box
2. Burnt out fuse as a result of overload rather than breaking and disconnecting the circuit
3. Loose cables inside the fuse box
4. Corrosion of the holder of the fuse box
5. Entry of humidity

In case of periodic inspection, the fuse boxes must be checked and cleaned at least once every two years. The damaged or corroded parts must be maintained, repaired or replaced. Figure 6-14.

![Figure 6-14: inspecting the fuses](image)

6-8 Light Distribution Board:

6-8-1 Introduction:

Light distribution boards must be contained entirely within housing or a case to protect them from dust, rain, sunrays, and the from being fixed outside. Figure 6-15.

![Figure 6-15: Light distribution boards](image)

6-8-2 Components of the Light Distribution Boards:

The light distribution boards must contain all that is required for the setup and installation in addition to a knob that controls the electric current. A light distribution board must include the following:

1. Electrical voltage indicator
2. An electric current control knob
3. Power transformer
4. Electric circuit indicator
5. Electric current connectors
6. Gauges
7. Internal cables
8. Control devices for electronic imaging and timing

6-8-3 Methods of Inspecting the Light Distribution Boards
Light Distribution Boards are inspected visually or physically or by both of methods.

6-8-3-1 Visual Inspection:
This method inspects the components of the light distribution board such as current inhibitors, electric circuit breakers, connectors, and cables.

6-8-3-2 Physical Inspection:
When the need arises to conduct a more thorough inspection the visual one, the physical inspection is employed. This method carries out the required tests with the use of test equipments. It identifies the extent and spread of the damage. An example of the equipments used is the thermal imager, which detects bad connections. Refer to figure 6-2.

6-8-4 Most Common Defects:
The most common defects of the light distribution boards may be summarized as follows:

1. Corrosion of the cable insulating material inside the boards
2. The burning out of fuses as a result of overloads
3. Loose connections
4. Cables not secured
5. Dirty control board
6. Entry of humidity
6-8-5 Methods of Maintenance of the Boards:

Maintenance works are carried out after the inspection works. Some of the most important maintenance works are:

1. Entry of water
2. Worn out parts such as the components and the insulation material
3. The damages that are affected by the impact actions
4. Defects of connectors
5. Earthling circuit
6. Protection against the direct and indirect low electric currents
7. The validity of the components of the board

All inspection and maintenance works as well as the results of tests must be recorded for future references.
6-9 Transformers

6-9-1 Introduction:

The transformers are three-phase and filled with oil. Transformers are kept inside boxes with tight covers for opening and closing when needed. Transformers must be provided with measurement devices that are fixed in at the sides. Figure 6-16.

![Image](image_url1)

6-9-2 The Components:

The characteristics and components of the transformers as those mentioned below depend in their evaluation on the temperature.

They are as follows: 50° C:
1. Ammeter
2. Voltmeter
3. The transformer core connectors
4. Currents and lines control keys
5. Line coding
6. Noise level
7. Allowable temperature
8. Cooling system
9. Fixtures

![Image](image_url2)
6-9-3 Methods of Inspection:

Inspecting the transformers must be carried out on daily or weekly basis to test the level of oil and measure the temperature. There are other methods for supervision and data recording by the use of remote control systems. Oil level must not be relinquished or changed except after consulting with the manufacturing company or the agent.

6-9-4 Intervals of Periodic Inspection:

1. Monthly Inspection
   a. If there is no need to open the transformers, inspect them from the outside to learn of their general conditions.
   b. Check if there are signs or the indications of leakage of oil and damage of the paints.
   c. Check the noise level. If the level is high, this may be an indication of a fault. A report must be sent to the competent authorities. Shut down the transformer immediately until it has been thoroughly inspected.
   d. Oil, pressure and temperature indicators must be checked as indicated in table 6-1.

   Table 6-1: Necessary measurements for transformers work

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Alert</th>
<th>Danger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil temperature</td>
<td>&lt;85°C</td>
<td>&lt;85°C</td>
<td>95°C</td>
</tr>
<tr>
<td>Core temperature</td>
<td>&lt;95°C</td>
<td>&lt;95°C</td>
<td>105°C</td>
</tr>
<tr>
<td>Oil level</td>
<td>Yellow</td>
<td>Yellow</td>
<td>NA</td>
</tr>
<tr>
<td>High pressure indicator</td>
<td>No color</td>
<td>No color</td>
<td>No color</td>
</tr>
</tbody>
</table>

   h. The values indicated in table 6-1 above are approximate; they may change according to the requirements of the design, or the conditions of the site.
   i. The abovementioned measurements must be taken on regular basis to ensure that the evaluation is within the allowable limits.

2. Annual Inspection:
The transformers’ protection devices must be inspected annually.
3. Inspection Every 5 years:

The lock keys must be checked at their various locations. Necessary measures must be made to ensure that the internal connections are functioning properly. This inspection is done after completely shutting down the transformer. Upon completion of the inspection, the keys must be put back to their normal position once again.

4. Inspection Every 10 years:

It is recommended to carry out a complete inspection by the agent or the manufacturing company.

6-9-5 Methods of Maintenance

Transformers require accurate and integrated maintenance works when needed. Check the oil level to ensure it reaches the cover so that no voids or ventilation are present inside; this ensures the absence of contaminants from the environment or the surrounding air. To ensure the safety of the operation and the transformer’s connectors, the following must be done:

1. Make sure that the keys are in their proper positions
2. Make sure that the measurement devices are clear and effective
3. Make sure that the leakage-proof discharge openings are well insulated
4. Make sure of the earthing circuits
5. Check the continuity of the electric loops

6-9-6 Transformers’ Collapse Indicators:

Refer to the table number 6-1.

1. High pressure
2. High temperature (for oil or the transformer’s sore)
3. Low oil level

6-10 Lamps:

6-10-1 Introduction:
Lighting the bridges and tunnels improve the visibility and achieves traffic safety. Tunnels need continuous follow-up due to the need for lighting, this is particularly true for tunnels with long lanes. Inconsistent visibility in tunnels during the day in the entrances and exits necessitate quick maintenance works for all faults in the lines and lamps (refer to figure 6-17).

**6-10-2 Methods of Inspection:**

Periodic inspection of lamps and fixtures must be given special attention in order to guarantee the continuity of lighting the bridges and tunnels. The interval of cleaning the lighting fixtures (figure 6-18) must not exceed three years. In case there is an obstruction that may accelerate the damage of such fixtures, the cleaning intervals need to be shortened according to the affecting factors. When carrying out inspection works, the following factors should be taken in consideration [Federal Roads Administration, United States of America, (LM-50,IES RP-22 (IES)].
1. Measure the levels of lighting in the bridges and tunnels
2. Measurements must be carried out at regular intervals
3. Measure the level of lighting at the emergency exits
4. Inspect all lighting fixtures and devices on top of the road surface to identify damage such as corrosion, loose fixtures, and broken or burnt lamps. Ensure that the lamp lenses are clean. Figure number 6-17.
5. Make sure the lighting devices for the various levels during night lighting or during the day.

![Sample of a lighting device](image1)

6-10-3 Methods of Maintenance:

1. The team carrying out the maintenance works must be experienced and knowledgeable, or be trained according to the specifications of the lighting devices manufacturers.
2. Replace all burnt out lamps immediately after detecting them
3. Clean the lamps completely
4. Decrease the cleaning intervals for tunnels and bridges that are subjected to natural conditions such as flooding. Refer to figure 6-19
5. After completing the maintenance works, make sure that the lighting units are insulated as this will prolong the cleaning intervals.
6. Non-insulated lighting units especially in places stormed heavily by insects may require continuous cleaning works at closer intervals.
7. Burnt out lamps may lead to disparity in the intensity of light. This may lead to compromising the traffic safety. Therefore, put this as a priority in the maintenance works.

Figure 6-19. Water covered underpasses

6-10-3-1 Lamps Maintenance:

The maintenance works include the following:
1. Clean the lamps’ lenses from the inside and outside (refer to figure 6-20)
2. Check the worn out filaments and change them when necessary
3. Replace the damaged light reflectors (refer to figure 6-21)
4. Check the electrical components that the increase in temperature.
5. Ensure that the anchor bolts and fittings are fastened well. Fasten as required. Refer to figure 6-21.

Figure 6-20. Lighting lamps

Figure 6-21. Replace lighting devices

6-10-3-2 Replace Lighting Lamps:

High pressure sodium lighting lamps must be replaced every three years. Lamps must be replaced after this interval irrespective of their performance.
6-10-3-3 Replace Lighting Units:

Lighting units must be replaced every 20 years. Replacing the lighting unit with different lighting units may affect their performances. The lighting units mean the entire lighting system including the frame, lenses, lamps, and the means of insulation and fixing.

6-10-3-4 Wastes of Maintenance:

The wastes of the lighting must be disposed of in a manner that does not affect the safety of the surrounding environment.

6-11 Policies Observed in Maintenance:

When carrying out maintenance works for the lighting of bridges and tunnels, the contractor or the engineer has to observe the following:

1. Maximum response in case of risks
2. Check the layouts to identify the routine & periodic inspection works
3. Always make sure of the integrity of lighting
4. Repair all damages that occur suddenly as result of the impact of collision or other
5. Make a maintenance program based on the inspection works

The maintenance options depend on the following.

1. Public safety
2. Traffic
3. Costs incurred in case the maintenance works have not been carried in due time

6-12 Traffic Directorate:
6-12-1 Safety and Traffic Control Plans:
Safety and traffic control plans have to be approved by the competent authorities before beginning the maintenance works. The Terms and Conditions of the Manual on the Unified Traffic Control Devices (MUTCD) (as per the Federal Roads Department Specifications) must apply to the signs that are used in the maintenance location.

If the maintenance works are to continue for more than three days as of the day the damage is detected, a guide sign as that indicated in figure number 6-22 should be used.

![Street Light Under Repair Sign](image)

**Figure 6-22: A sign with the sentence [Street light under repair]**

The inspection works might indicate the presence of serious damage in the bridges or tunnels; these damages may affect the safety of the working team, or the public. They may be categorized as critical works. Therefore, the following procedures must be taken:

1. The bridge or tunnel has to be shut down until the damage is completely removed or repaired
2. Prevent the public from entering the damaged area
3. Support the elements if that is possible
4. Consult with the owner in order to take the proper decision
6-12-2 Signs used in the Case of Emergency Works:

Figure 6-23 shows the various signs for the safety and traffic control plan.

![Figure 6-23 a. Beware of risks](image)

![Figure 6-23 b. Plastic cones](image)

![Figure 6-23 c. Do not enter](image)

![Figure 6-23 d. Diverted traffic](image)

**Figure 6-23. Signs used in the safety and traffic control plans**

6-13 Inspection and Maintenance of the Mechanical Works:

The inspection works include identifying the condition, and operation of the mechanical equipments and systems that are in use in the tunnels. This includes reviewing the equipment to look for damages that result from the operation or the surrounding environmental conditions. The inspection must include the following works:
1. The ventilation system
2. The air conditioning systems
3. The heating systems
4. The plumbing systems
5. The sewage works
6. Fire fighting
7. Water storing and discharge systems

6-13-1 Ventilation of Tunnels:

Inspecting the tunnel ventilation (refer to figure 6-24) includes the following works;
   1. Checking the previous maintenance works
   2. Checking the components of the ventilation systems (fans, openings, air outlets etc)
   3. Ensure that the fans are operational when the motor is operated
   4. Make a vibration test for the fans and the motor on the loading equipments
   5. Make sure that the air outlets are free from any obstructions and debris

![Tunnel ventilation equipment](figure624a.png)

![Ventilation equipment](figure624b.png)

6-13-2 Air Conditioning:

Air conditioning inspection works include the following:

1. Check the previous maintenance works to identify whether there are repeated malfunctions
2. Note the general condition of the ventilation units, the air conditioning units, coolers, pumps cooling towers, exposed air distribution, cooling pipes, and peripheral units
3. Ensure that the system works and record the temperature at the time of operation
4. Carry out the vibration tests (BS ISO 10816-3: 2009)
5. Carry out the analysis tests of the lubrication oils according to the specifications [ASTM D6224-98 (2009)]

6-13-3 Heating:

Inspection works of the heating system include the following:
1. Check the previous maintenance works and record the repeated faults.
2. Note the operational condition of the treatment units, pumps, steam & distribution systems, peripheral units, boilers, air distribution system, heating pipes, and steam convertors.
3. Enter into contracts with competent bodies that are specialized in conducting tests, or may be deal with bodies such as the National Boiler Inspectors & Pressure Pipes Association if any, to specify the degree of operational efficiency and inspection of the boiler seat to see if there is corrosion or opening in it.
4. Measure the temperature upon operation.

6-13-4 Control:

The devices controlling the equipments operating in the tunnels must be equipped with a panel that indicates the operational conditions of such equipments, and consequently the performance of the equipment through which it becomes easy for the inspection team to identify the situation just by looking at them. The informational control system (SCADA) can completely control the equipments used. These systems work with minimum maintenance works possible except for the sensors. They require a computer to work effectively.

6-13-5 Plumbing Works:
The plumbing works must be based on local or international specifications and include:


1. Check the previous maintenance works and record any specific or repeated malfunctions
2. Note the normal condition i.e. water heaters, channels
3. Make sure that the channels are free of obstructions or leakage
4. Note the presence of water on the surface of the tunnel to identify the leaking areas in the plumbing systems

6-13-6 Tunnel Discharge Spouts:
The tunnel discharge spouts include water withdrawal depression by the use of pumps. Therefore, make sure these channels are free from any obstructions that prevent the flow of the discharge water.

6-13-7 Protection from Fires:
1. Check the previous maintenance reports
2. Take note of the normal conditions regarding the protection systems in the tunnels and annexed places, which include the fire extinguishers, hose connections, water pumps, pipes, treatment pumps, and hose reels.
3. Ensure the correct position of the fire extinguishers, alarm systems, and the water level handles in the tanks
4. Test the control panel to look for any malfunctions in the detectors, signals and wires.
Chapter 7

Tunnels
Chapter 7:  
Tunnels: 
7-1 Introduction: 

This chapter is part of the [Bridges & Tunnels Maintenance Guide] of the Technical Affairs Agency, Directorate General of Operation and Maintenance, Ministry of Municipal and Rural Affairs, Kingdom of Saudi Arabia. The guide generally includes three main parts, which are: Inspection, Maintenance, and the Safety requirements. It also includes the types and shapes of tunnels, the lining types, methods of construction, the qualifications and responsibilities of the inspection team for all specializations, models of inspection, types of maintenance (preventive, rehabilitative), and last the aspects of safety in tunnels and their applications.

7-2 Inspection: 
7-2-1 Introduction: 

The purpose of preparing this guide is to give the owners of the roads and tunnels the direction and guidance to establish the procedure and application of the inspection, documentation, and the advanced categorization of the various elements in the tunnels. This guide is used as a part of the comprehensive inspection and maintenance program.

The inspection includes several paragraphs that explain most of the elements present in the tunnels such as the shape, the ventilation systems, lighting, communication, signal, and the tunnel lining methods. As such, it assists the inspection team in their general understanding of the tunnels and how to deal with them. In addition, it gives directions to the inspection team regarding the utilization of the specialized equipments and how to deal with them. The inspection also includes the method of documentation for the outcomes of the inspection process and how to write the respective reports.

This section has been developed for the purpose of inspection and checking of the structure of the tunnel and to conduct non-destructive visual tests for the lining of the tunnel.
7-2-2 Construction of Tunnels and Associated Systems:
7-2-2-1 Types of Tunnels:

This section describes in detail the various types of highway and rail transit tunnels. These tunnel types are described by their shape, and construction method by looking to the existing tunnels or those anticipated to be constructed in the future. The purpose of this section is to look at the types that are most commonly used in tunnel construction to help the inspection team skillfully deal with, differentiate, and properly classify any given tunnel. As a general guideline a minimum length of 100 meters was used in defining a tunnel.

7-2-2-2 Shapes of Tunnels:
This section deals with two types of tunnels:

a. Highway tunnels
b. Rail Transit Tunnels

a. Highway Tunnels:
There are four main types of road tunnels: circular (figure 7-1), rectangular (7-2), horseshoe (figure 7-3), and oval/egg (figure 7-4). These shapes depend on the method of construction, the soil condition on which the project is established, the outside shape of the tunnel defines its type. Some tunnels may be constructed using combinations of the aforementioned types due to different soil conditions along the length the tunnel.

2. Rail Transit Tunnels:
This type of tunnels has the same shapes of road tunnels and the same factors influencing the shape. These shapes typically change at the transition between the station structure and the typical tunnel cross-section. However, the change in shape may also occur between stations due to variations in ground conditions. Refer to figures 7-5 and 7-6 a, 7-6 b, 7-7, and 7-8.
Figure 7-1: Two traffic lanes circular tunnel
Figure 7-2: Double box tunnel

Figure 7-3: Two lanes horseshoe tunnel
Figure 7-4: Three lanes oval tunnel
Figure 7-5: Single lane train track tunnel

Figure 7-6 a. Single railroad track double box tunnel
Figure 7-6 b. Single railroad track single box tunnel
Figure 7-7: Single railroad track horseshoe tunnel
Figure 7-8: Single railroad track oval tunnel
7-2-2-3 Liner Types:
Tunnel liner types can be described using the following classifications:

A. Unlined Rock
B. Rock Reinforcement Systems
C. Shotcrete
D. Ribbed Systems
E. Segmental Linings
F. Placed Concrete
G. Slurry Walls

a) Unlined Rock
These are the tunnels constructed from the inside with rocks that are irregular in shape in the majority of the length of the tunnel. This type of tunnels is often the tunnels that pass through the mountains.

b) Rock Reinforcement Systems
Rock reinforcement systems are used to add additional stability to rock tunnels in which structural defects exist in the rock.

Reinforcement systems include the use of metal straps and mine ties with short bolts, un-tensioned steel dowels, or tensioned steel bolts. To prevent small fragments of rock from falling off the lining and into the streets, wire mesh, shotcrete, or a thin concrete lining may be used.

c) Shotcrete
Shotcrete is appealing as a lining type due to its ease of application in a relatively short time. Shotcrete is primarily used as a temporary application, during the construction of the tunnel, or as a final liner where it is typically placed in layers. It can have metal or fiber straps as reinforcement.

d) Ribbed Systems
The ribbed system consists of placing a lining of timber, steel, or pouring precast concrete. Concrete block are used placed between the layers then concrete is poured to fill the gaps.

e) Segmental Linings
Segmental linings are primarily used in conjunction with a tunnel boring machine in soft ground conditions. The prefabricated lining segments made of steel, concrete or cast iron and are usually bolted together to compress gaskets for preventing water penetration.
f) Placed Concrete

Placed concrete linings are usually the final linings that are installed over any of the previous initial stabilization methods. Placed concrete is the most important for waterproofing as they make a good surface to work on. They may contain reinforcement steel or not. They may be designed as a main structural support for the tunnel.

g) Slurry Walls

This method is used to stabilize the sidewall of the tunnel by the use of delicate grout or slurry wall for the insulation and fixing the soul during excavation.

7-2-2-4 Invert Types:

The invert of a tunnel is the slab on which the roadway or track bed is supported. There are two main methods for supporting the roadway or track bed.

The first method is used in most rail transit tunnels because their ventilation systems rarely use supply ductwork under the slab. This method is also employed in many highway tunnels over land where ventilation is supplied from above the roadway level.

The second method is commonly found in both types of circular highway where there is void under the slab that includes the ventilation system and the services. In the inspection and maintenance operations it is important to identify the type of the slab used for the tunnel and whether the slab is placed directly on the ground or if there is a slab under it. Figures (7-9), (7-10), and (7-11) indicate the type and position of the slab.
Figure 7-9: Circular tunnel with a structural slab that provides space for an air plenum below.

Figure 7-10: Single box tunnel with a structural slab that provides space for an air plenum below.
Figure 7-11: Horseshoe tunnel with a structural slab that provides space for an air plenum below.
7-2-2-5 Construction Methods:

A) Cut and Cover
This method involves excavating an open trench in which the tunnel is constructed and subsequently covered with various compacted carefully selected earthen materials and soils. Several technologies employ this method according to the type of soil agreed upon in the project.

B) Shield Driven
This method involves pushing a shield into the soft ground ahead. The material inside the shield is removed and a lining system is constructed before the shield is advanced further.

C) Bored
This method refers to using a mechanical tunnel boring machine TBM that excavates the full face of the tunnel cross section at one time. The TBM is designed to support the adjacent soil until the linings tunnels are installed.

D) Drill and Blast
This is an alternative to using a TBM in rock situations. The rock is manually drilled and blasted without causing significant damages. Then the blasted rocks are removed using various. This method is commonly used when it is determined cost effective or in difficult ground conditions.

E) Immersed Tube
When a canal, channel, river, etc., needs to be crossed, this method is often used. A trench is dug at the water bottom and prefabricated tunnel segments are made water tight and sunken into position where they are connected to the other segments. Afterward, the trench is backfilled with earth to protect the tunnel from the passingships and boats.

F) Sequential Excavation Method (SEM)
If the soil is sufficiently strong, equipments are used to excavate the face of the soil in small increments without direct support; the method is called the (Sequential Excavation Method). The tunnel sides may be supported using shotcrete and the excavation is safely continued. The cohesion of the rock or soil can be increased by additive materials into the ground prior to excavation.

G) Jacked Tunnels
When excavation of tunnels may be obstructed by facilities they could not be removed or diverted anyway, the jacked method is used. The tunnels
are constructed to support the obstructing facility so it is not affected by the construction.

7-2-2-6 Tunnel Finishes:
The interior finish of a tunnel is very important to the overall tunnel function. The finishes must meet the following standards to ensure tunnel safety and ease of maintenance:

1. Be designed to enhance tunnel lighting and visibility
2. Be fire resistant
3. Be precluded from producing toxic fumes during a fire
4. Be able to attenuate noise
5. Be easy to clean.

A) Ceramic Tile
This type of tunnel finish is the most widely used especially for tunnels with a concrete inner lining because these materials are conducive to tile placement. Ceramic tiles are extremely fire resistant, economical, easily cleaned, and good reflectors of light due to the smooth, glazed exterior finish, and good sound attenuators. Ceramic tiles have various colors and sizes that suit all requirements.

B) Porcelain-Enamed Metal Panels
Porcelain enamel is a combination of glass and inorganic color oxides that are fused to metal under extremely high temperatures. The Porcelain Enamel Institute (PEI) has established guidelines for the performance of porcelain enamel through the following publications:

1. Appearance properties
2. Mechanical and physical properties
3. Resistance to corrosion
4. High temperature properties
5. Electrical properties

Porcelain enamel is typically applied to either steel or aluminum panels. For ceilings, the panels are often filled with a lightweight concrete; for walls, fiberglass boards are frequently used.

C) Epoxy-Coated Concrete
Epoxy coatings are used on many tunnels during construction to reduce costs. Epoxy coatings are characterized by their toughness, strong adhesion, reflective ability, and low shrinkage.
D) Miscellaneous Finishes
There is a variety of other finishes that can be used on the walls or ceilings of tunnels. Some of these finishes have improved sound absorptive properties, and ease of replacement. Some of the finishes are listed below:

(1) Coated Cement board Panels
These panels have limited use though they are light in weight, and are reinforced by fiber that is coated with baked enamel.

(2) Pre-cast Concrete Panels
This type of panel is often used as an alternative to metal panels. A combination of the two is possible. The ceramic tile is cast underside of the panel as the final finish.

(3) Metal Tiles
This tile system is uncommon, but has been used successfully in certain tunnel applications. Metal tiles are coated with porcelain enamel and are set in mortar similarly to ceramic tile.

7-2-2-7 Ventilation Systems:
7-2-2-8 Types of Ventilation:
It should be noted that ventilation systems are more applicable to highway tunnels due to high concentration of contaminants. Rail transit tunnels often have ventilation systems in the stations or as intermediate fans. During normal operations ventilation relies mainly on the piston effect of the train pushing air through the tunnel to remove stagnant air. Many rail transit tunnels have emergency mechanical ventilation that only works in the event of a tunnel fire.

A) Natural Ventilation
The movement of air is controlled by meteorological conditions and the piston effect created by moving traffic pushing the stale air through the tunnel. This effect is minimized when bi-directional traffic is present. Naturally ventilated tunnels over 180 m long have mechanical fans installed for use during an emergency (such as fire).

B) Longitudinal Ventilation
Longitudinal ventilation is similar to natural ventilation with the addition of mechanical fans. Longitudinal ventilation is often used inside rectangular-shaped tunnels that do not have the extra space above the ceiling.
Figure 7-12: Shows a longitudinal cross-section of a naturally ventilated tunnel.

Figure 7-13: shows a longitudinal cross-section of a Longitudinal ventilation system

C) Semi-Transverse Ventilation
   1. Exhaust
   2. Supply air
Semi-transverse ventilation also makes use of mechanical fans for movement of air, but it does not use the roadway envelope itself as the ductwork. A separate ductwork is added either above or below the tunnel, which is mostly circular; refer to figure 4.14.
Some tunnels combine between the two types. In all cases, air enters or exits from both ends of the tunnel and from one end in case of one direction.

Figure 7-14: The upper figure shows an exhaust system, the lower the air supply system

D) Full-Transverse Ventilation

Full-transverse ventilation uses the same components as semi-transverse ventilation. This method is used primarily for longer tunnels that have large amounts of air that need to be replaced or for heavily traveled tunnels that produce high levels of contaminants. Refer to figure 7-15.

Figure 7-15: Longitudinal cross section of full-transverse ventilation system
E) Single-Point Extraction
This Type of Ventilation is used to increase the quantity of air in an event of an emergency.

7-2-2-9 Equipments used
a) Fans
There are two of fans: axial and centrifugal

(1) Axial fans:
There are two main types of axial fans - tube axial fans and vane axial fans. Both types move air parallel to the impellor shaft, but the difference between the two is the addition of guide vanes on one or both sides of the impellor for the vane axial fans. These additional vanes allow the fan to deliver pressures that are approximately four times that of a typical tube axial fan. They are mounted horizontally or vertically to renew the air. Refer to figure 7-16.

(2) Centrifugal fans
This type of fan outlets the air in a direction that is $90^\circ$ to the direction at which air is obtained. Air enters parallel to the shaft of the blades and exits perpendicular to that. Centrifugal fans are commonly selected over axial fans due to their higher efficiency with less horsepower required and are therefore less expensive to operate.

Refer to figure 2-17.

![Figure 7-16: Axial fans](image-url)
b) Supplemental Equipment

(1) Motors
Electric motors are typically used to drive the fans. They can be operated at either constant or variable speeds depending on the type of motor.

(2) Fan Drives
A motor can be connected to the fan either directly or indirectly. Direct drives are where the fan is on the same shaft as the motor. Indirect drives allow for flexibility in motor location and are connected to the impellor shaft by belts, chains, or gears.

(3) Sound Attenuators
Some tunnel exhaust systems are located in regions that require the noise generated by the fans to be reduced. This can be achieved by installing cylindrical or rectangular attenuators either mounted directly to the fan or within ductwork along the system.

(4) Dampers
Dampers are typically used in a full open or full closed position, but can also be operated at some position in between to regulate flow or pressure within the system.
7-2-2-10 Lighting Systems:
7-2-2-11 Types of Lighting Systems:

a) Highway Tunnels
There are various light sources that are used in tunnels to make up the tunnel lighting systems. These include fluorescent, high-pressure sodium, low-pressure sodium, metal halide, and pipe lighting. Systems are chosen based on their life-cycle costs and the amount of light that is required for nighttime and daytime illumination. Shorter tunnels will require less daytime lighting due to the effect of natural light entering the portals on both ends, whereas longer tunnels will require extensive lighting for both nighttime and daytime conditions. Highly reflective surface on the walls and ceiling, such as tile or metal panels, may be used to enhance the lighting system.

b) Rail Transit Tunnels
Rail transit tunnels are similar to highway tunnels; they require additional and sufficient light for passengers and train operation caners. The tunnel owners usually stipulate the required level of lighting within the tunnel for clear visibility. As a minimum, the light level should be sufficient to allow inspectors and workers to clearly see the elements of the road without the need to use torch light.

7-2-2-12 Other Systems:
The track systems contain the power, signal and communication.

7-2-2-13 Track:
The track system contains the following critical components:

1. Rail
The rail is a rolled, steel-shape portion of the track to be laid end-to-end in two parallel lines to facilitate the movement of trains or vehicles wheels on top of them.

2. Rail Joints
Rail joints are mechanical fastenings designed to unite the abutting end of contiguous bolted rails.

3. Fasteners/Bolts/Spikes
These fasteners include a spike, large bolt more than 10 cm long or another mechanical device used to tie the rail to the crossties.

4. Tie Plates
Tie plates are rolled steel plates designed to protect the timber crosstie from localized damage under the rails by distributing the wheel loads over
a larger area. They assist in holding the rails to gage, tilt the rails inward to help counteract the outward thrust of wheel loads, and provide a more desirable positioning of the wheel bearing area on the rail head.

5. **Crossties**

Crossties are usually solid timber, but may be made of precast reinforced concrete or fiber reinforced plastic. The many functions of a crosstie are to:

a) Support vertical rail loads due to train weight.
b) Distribute those loads over a wide area of supporting material.
c) Hold fasteners that can resist rail rotation due to laterally imposed loads.
d) Maintain a fixed distance between the two rails making up a track.
e) Help keep the two rails at the correct relative elevation.
f) Anchor the rails against both lateral and longitudinal movement by embedment in the ballast.
g) Provide a convenient system for adjusting the vertical profile of the track.

6. **Ballast**

Ballast is a coarse granular material forming a bed for ties, usually rocks. The ballast is used to transmit and distribute the load of the track and railroad rolling equipment to the sub-grade; restrain the track laterally, longitudinally, and vertically under dynamic loads imposed by railroad rolling equipment and thermal stresses exerted by the rails; and provide adequate drainage for the track.

g) **Plinth Pads**

Plinth pads are concrete support pads or pedestals that are fastened directly to the concrete invert. These pads are placed at the joints.

### 7-2-2-14 Power:

1. **Third Rail Power System**

A third rail power system consists of the following elements:

a. **Steel Contact Rail**

Steel contact rail is the rail that carries power for electric rail cars through the tunnel and is placed parallel to the other two standard rails.

b. **Contact Rail Insulators**

Contact rail insulators are made either of porcelain or fiberglass and are installed at each supporting bracket location.
c. Protection Board  
Protection boards are placed above the steel contact rail to protect personnel from making direct contact with this rail. These boards are typically made of fiberglass or timber.

d. Protection Board Brackets  
Protection board brackets are mounted on either timber ties or concrete ties/base and are used to support the protection board at a distance above the steel contact rail. Refer to figures 7-18 a, and 7-18 b (system supplements).

Figure 7-18 a. Components of the third rail power system

Figure 7-18 b. Third rail power system anchor arm

Figure 7-18 of the third rail insulated anchor arm
f. Third Rail Insulated Anchor Arms
Third rail insulated anchor arms are located at the midpoint of each long section, a maximum length for any section limited to 1.6 km.

g. Catenary Power System
The catenary system is an overhead power system whereby the rail transit cars are powered by means of contact between the pantographs on top of the rail car and the catenary wire. A typical catenary system consists of components such as: contact wires, insulators, first ids and recorders etc

7-2-2-15 Signal/Communication Systems

1. Signal System
The signal system is a complex assortment of electrical and mechanical instruments that work together to provide direction for the trains within a transit system. A typical signal system may consist of some or all of the following components: signals, signal cases, relay rooms, switch machines, switch circuit controllers, multi-purpose cables, and local control facilities.

2. Communication System
The communication system consists of all devices that allow communication from or within a tunnel. Examples of these systems would be emergency phones that are located along a highway tunnel and radios by which train controllers correspond with each other and central operations. The communication system also includes the cables, wires, or other equipment that is needed to transport the messages.

7-2-3 Basics of Tunnel Inspection:

7-2-3-1 Qualification of Inspectors:
Inspection of tunnels is carried by inspection teams; each team consists of two members at least. Each of the members must have a minimum of general and special qualifications. In addition, members of the inspection teams must be approved by the owners of the tunnel to ensure they have the required qualifications.

The team members are categorized to the team leader and the team members. Each must be knowledgeable in the components of tunnels, the function of each segment and element of a tunnel, and how utilize that segment or element.

The general qualifications of the inspection team that must be met are as follows:
a) The ability to climb to high places to inspect them and use the various tools to help them achieve that.
b) The ability to evaluate and determine the type of tools that determine the efficiency of the structural element
c) The ability to understand the readings of instruments, print them, and make clear and understandable graphs from them
d) The ability to read and interpret engineering sketches
e) The ability to use the computer for all data and information
f) The ability to discover the problems and find suitable solutions for them

The special qualifications of the inspection team that must be met according to the specialization are:

7-2-3-1-1 Structurally:

1. Team Leader
   a. Must be registered as a specialist engineer
   b. Must be experienced in the design of tunnels
   c. Must have a minimum of five years experience in the field of tunnel inspection and the ability to identify and evaluate the defects of the structural element in the tunnel
   d. The ability to evaluate the degree of deterioration of the structural element (concrete, steel, rock or wood).

2. Team Members:
   a. Must be trained on the requirements of the tunnel inspection
   b. Must have a minimum of one year experience in the field of inspection of concrete, steel, rock or wood structure,

7-2-3-1-2 Mechanically:

1. Team Leader
   a. Must be registered as a specialist engineer
   b. Must be experienced in the design or well experienced one of the mechanical systems that are used in the tunnel that include but are not limited to the following:
      - Ventilation
      - Air conditioning
      - Supervision
      - Plumbing
      - Water discharge
      - Fire fighting
c. Must have a minimum of three years experience in the field of inspection of tunnels and the ability to evaluate the physical and operational of the mechanical equipments.

d. Must be familiar with the guides of practices and directions applied in the construction of tunnels and the method of operation according to the mechanical characteristics.

2. **Team Members:**
   a. Must be trained on the requirements of the tunnel inspection
   b. Must have a minimum of one year experience in the field of inspection of mechanical systems, pipe plumbing and discharge

**7-2-3-1-3 Electrically:**

1. **Team Leader**
   a. Must be registered as a specialist engineer
   b. Must be experienced in the design or well experienced one of the mechanical systems that are used in the tunnel that include but are not limited to the following:
      - Power distribution
      - Lighting
      - Emergency staff
      - Fire detectors
      - Communications
   c. Must have a minimum of three years experience in the field of inspection of tunnels and the ability to evaluate the physical and operational of the mechanical equipments.
   d. Must be familiar with the guides of practices and directions applied in the construction of tunnels and the method of operation.

2. **Team Members:**
   a. Must be trained on the requirements of the tunnel inspection
   b. Must have a minimum of one year experience in the field of inspection of electrical systems.

3. **Test Competent Bodies:**
   Test competent bodies are referred to in order to test the power distribution systems, and fire fighting. These bodies must meet the following requirements:
a) Must be a member of the International Electrical Testing Association  
b) Must be internationally approved in the field of electrical testing  
c) Must have a minimum of five years experience in the field of testing the electrical systems and equipments  
d) Must have the adequate number of calibrated equipments and instruments that are ready for work to do the required test  
e) Must have the means to inspect the calibration of the testing equipments of the National Specifications Organization

7-2-3-1-4 The Communication, Signals, Track, & Third Rail Specialization:

1. Team Leader  
a. Must be registered as a specialist engineer  
b. Must be experienced in the design of the components of the system to be tested  
c. Must have a minimum of three years experience in the field of inspection with the ability to identify and evaluate the conditions of the equipments to be inspected  
d. Must be well-experienced in the testing equipments to evaluate the operational capability of a specific element of the structure.

2. Team Members:  
a. Must be trained on the requirements of the tunnel inspection  
b. Must have a minimum of one year experience in the track systems, third rail, signal and communications.

7-2-3-2 Responsibilities of the Inspection Team:

a. Team Leader:
   1. Coordinate the tasks of the team members to carry out the inspection on the said tunnel, supervise their work, and direct them  
   2. Schedule the operation of equipments  
   3. Determine the required degree of inspection according to the condition of the tunnel  
   4. Evaluate all types of deficiencies  
   5. Ensure that all forms of inspection are complete, legible and fulfilled  
   6. Draw the attention of the team members to any underlying risks that may confront them in their work and pose any hazards to them
b. Responsibilities of the Team Members:
The responsibilities of the team members is to help the team leader in the inspection such as carrying the equipments, prepare the inspection forms, provide copies, take photographs of the sections required to be inspected, and make graphs.

c. Responsibilities of the Owners of Tunnels:
The owners of the tunnels are responsible for closing the tunnel before traffic in order to complete the inspection.

7-2-3-3 Equipments:
The following equipments and tools are used in the inspection of the tunnels:

a) Upper work platform: these are used to raise the inspectors to upper places that are difficult to reach by other normal means such as stairs, ladders and hands

b) Railroad carriage used in inspecting the defects in the track. These are usually provided by the owners of the tunnels

c) Boring machines: these are used to determine the extent of destruction in the wood of the railroad track

d) Steel plate thickness measurement devices

e) Chalks, and highlight pens to put reference marks on the surface of the tunnel

f) Tapered end hammer to be used for scratching and scraping

g) Paper holder with a clip at the upper end to hold paper and allow the inspector to write while standing up without the need for a table

h) Crack measurement device

i) D-meter to measure the thickness of the steel bars

j) Electric cables to connect electricity to the inspection area

k) Field forms to document the remarks and draw sketches for the various structures

l) Pocket torch light to help see far areas during the inspection

m) Ladders for high places that cannot be seen from the ground

n) Light meter to measure the intensity of light inside the tunnel

o) Halogen lamps to be used when the original lighting inside the tunnel is not enough during the inspection

p) Pencils

q) A tool to ensure the alignment of the faces of the poles and walls
r) Pocket knife to test the disengaged materials
s) Sample bottles
t) Scrape knife to scrape off the excess materials from the surface of the structural elements
u) Screwdriver
v) Wire brush to clean the surface before scraping it
w) Simple electronic gadget to record the remarks and notes and draw sketches
x) Measuring tapes of various sizes and measures

There are also safety equipments that must be provided for the inspection. Some of them are:

a) Traffic control safety equipments (reflective clothes, barriers, etc)
b) First aid box
c) Pocket torch light
d) Head safety helmet
e) Leather gloves for work
f) Safety jackets
g) Protective safety goggles for the eyes according to the nature of the work
h) Protective gears fro the ankles
i) Safety belts to protect from the falling from high places
j) Protective safety shoes for the feet according to the nature of the work
k) Protective respiratory equipments to protect against the leakage of gas or inhaling poisonous fumes inside the tunnel
l) Air purification equipments

7-2-3-4 Preparations:

7-2-3-4-1 Mobilization:

Before beginning the inspection, there is a preparation and mobilization period. This period includes planning and organizing for the inspection. This period is of importance because it assists carrying out the inspection effectively.

In case inspection requires a consultant, the following is needed:

a) Coordinate with the owners of the tunnel to specify the times for the inspection during which the tunnel will be clear of any traffic and so it will be possible to carry out the inspection
b) Initiate the required communications to close the suction fans and ventilation during the inspection, and make schedules for that.

c) Schedule a time to close all electrical systems in preparation for testing them.

d) Discuss all problems and preparations related to the inspection.

The most important and vital part of the preparation and mobilization is to provide the detailed engineering sketches and the inspection reports in order to study and discuss them. This saves time and effort to start from where others have stopped.

The inspection forms must take the final shapes during the phase and before entering the field phase and start the inspection. Finally, planning for the inspection and scheduling it during the preparation and mobilization phases, must augment the effectiveness of the inspection. This is beneficial to the inspection teams and the owners of the tunnels.

7-2-3-4-2 Survey Control:

It is necessary to establish a system that determines and records the defects. This allows the inspection to be reference for subsequent inspections. This augments the effectiveness of the inspection.

The majority of highway tunnels and rail transit tunnels have stations established along the length of the tunnel. They have equipments to record the defects at the time of their occurrence. Some owners have panels to identify faults up to certain distances.

The defects in tunnels of circular sections that are free from air ductworks and the construction slabs are determined by the clock system. For the horseshoe and rectangular tunnels and other circular tunnels, they are divided into cross sectional parts as in the following figures:
Figure 7-19: Upper Projection of the Divisions of the Tunnel’s Inspection
Figure 7-20: Clock system circular tunnel

Figure 7-21: Signal system circular tunnel
Figure 7-22: Signal system rectangular tunnel
Figure 7-23: Signal system horseshoe tunnel

7-2-3-4-3 Inspection Forms:
In order to efficiently collect and record the inspection data, it was incumbent to develop inspection form to facilitate entering data, and understanding and dealing with it easily. These forms are previously prepared and the domains are completed later by hand, or are entered electronically through the already programmed palmtop computer so that they are ready when needed in the future.

The inspection forms in use are of two types:
   a) Documentation forms
   b) Defect location forms
The first type will be discussed in this chapter in addition to the forms used for tunnel inspection. The second type is used for the main components of the sections of the tunnels and the annexed facilities such as the control rooms and stations. This type will be discussed in the next chapter. The following are examples of the inspection forms:
## 1. **Highway Tunnel Forms:**

### a) **Condition Code Forms:** Figure 7-24.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel name</td>
<td>enter the agreed upon name given to the tunnel</td>
</tr>
<tr>
<td>Begin station</td>
<td>enter the name of the station of the tunnel segment from which the inspection begins</td>
</tr>
<tr>
<td>End station</td>
<td>enter the name of the station of the tunnel segment at which the inspection ends</td>
</tr>
<tr>
<td>Plate number</td>
<td>enter the plate number predetermined for the segment</td>
</tr>
<tr>
<td>Year built</td>
<td>enter the year the tunnel is constructed</td>
</tr>
<tr>
<td>Liner type</td>
<td>enter the abbreviated name of the type of lining</td>
</tr>
<tr>
<td>Inspector</td>
<td>enter the first &amp; last names of the inspector</td>
</tr>
<tr>
<td>Inspection date</td>
<td>enter the day, month and year of the inspection</td>
</tr>
<tr>
<td>Condition code</td>
<td>enter (-) for all elements not present in the tunnel segment. A numerical rating is allocated to each element according to the numerical rating table</td>
</tr>
<tr>
<td>Comments</td>
<td>add any comment necessary to indicate anything relevant to the practice guide in the tunnel segment</td>
</tr>
</tbody>
</table>

### b) **Supplemental Tunnel segment Sketches:** Figure 7-25.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel name</td>
<td>enter the agreed upon name given to the tunnel</td>
</tr>
<tr>
<td>Begin station</td>
<td>enter the name of the station of the tunnel segment from which the inspection begins</td>
</tr>
<tr>
<td>End station</td>
<td>enter the name of the station of the tunnel segment at which the inspection ends</td>
</tr>
<tr>
<td>Plate number</td>
<td>enter the plate number predetermined for the segment</td>
</tr>
<tr>
<td>Year built</td>
<td>enter the year the tunnel is constructed</td>
</tr>
<tr>
<td>Liner type</td>
<td>enter the abbreviated name of the type of lining</td>
</tr>
<tr>
<td>Inspector</td>
<td>enter the first &amp; last names of the inspector</td>
</tr>
<tr>
<td>Inspection date</td>
<td>enter the day, month and year of the inspection</td>
</tr>
<tr>
<td>Sketches</td>
<td>provide details of sketches for the defects that still exist and have not been covered in other inspection forms</td>
</tr>
</tbody>
</table>
Figure 7-24: Highway Tunnel Condition Code Form
Figure 7-25: Forms of the Sketches of the Alternative Segments for Highway Tunnels
c. Tunnel Segment Photo Log Sheet

**Figure 7-26.**

- **Tunnel name:** enter the agreed upon name given to the tunnel
- **Begin station:** enter the name of the station of the tunnel segment from which the inspection begins
- **End station:** enter the name of the station of the tunnel segment at which the inspection ends
- **Plate number:** enter the plate number predetermined for the segment
- **Year built:** enter the year the tunnel is constructed
- **Liner type:** enter the abbreviated name of the type of lining
- **Inspection date:** enter the day, month and year of the inspection
- **Inspector:** enter the first & last names of the inspector
- **Photos:** provide details related to the photos log

2. Railway Transit Tunnel Forms:

a. Condition Code Forms

**Figure 7-27.**

- **Railway:** enter agreed upon railway name
- **Track:** enter a description of the track to be inspected
- **Previous station name:** enter name of station behind of the train direction
- **Next station name:** enter name of station coming after the train direction
- **Begin station:** enter the begin station of the tunnel segment from which the inspection begins
- **End station:** enter the station at which the inspection ends
- **Plate number:** enter the plate number predetermined for the segment
- **Year built:** enter the year the tunnel is constructed
- **Liner type:** enter the abbreviated name of the type of lining
- **Inspection date:** enter the day, month and year of the inspection
- **Inspector:** enter the first & last names of the inspector
- **Condition code:** enter (-) for all elements not present in the tunnel segment. A numerical rating is allocated to each element according to the numerical rating table
- **Comments:** add any comment necessary to indicate anything relevant to the practice guide in the tunnel segment
### General Information

Tunnel Name _____________________________

Begin Station __________________________ End Station __________________________

Or

Panel Number ___________________________

Year Built _____________________________ Liner Type ___________________________

Date of Inspection ___/___/______ Inspector(s) ________________________________

<table>
<thead>
<tr>
<th>Roll No.</th>
<th>Counter No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
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</tr>
</tbody>
</table>

Figure 7-26: Forms of the photos log for the highway tunnel segments
### Figure 7-27: Form of the Practices Guide for the Railway Transit Tunnel

**TUNNEL AGENCY NAME**

**RAIL TRANSIT TUNNEL FIELD INSPECTION FORM**

**TUNNEL SEGMENT CONDITION CODES**

---

**General Information**

- **Line**: ____________________
- **Track**: ____________________
- **Name of Station Ahead**: ____________________
- **Name of Station Behind**: ____________________
- **Begin Station**: ____________________
- **End Station**: ____________________
  
  Or

- **Panel Number**: ______
- **Year Built**: ______
- **Liner Type**: ____________________
- **Date of Inspection**: __/__/____
- **Inspector(s)**: ____________________

---

**Condition Codes** *(0=Worst → 9 = Best, See Chapter 4 for Ratings Schedules)*

<table>
<thead>
<tr>
<th><strong>Track Area</strong></th>
<th><strong>Rating</strong></th>
<th><strong>Miscellaneous Appurtenances</strong></th>
<th><strong>Rating</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Underside of Roof</td>
<td></td>
<td>Safety Walks</td>
<td></td>
</tr>
<tr>
<td>Concrete Track Supports</td>
<td></td>
<td>Railings</td>
<td></td>
</tr>
<tr>
<td>Right Wall</td>
<td></td>
<td>Utility Supports</td>
<td></td>
</tr>
<tr>
<td>Left Wall</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Comments**

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

---

237
b. Supplemental Tunnel Segment Sketches for the alternatives segments of the tunnel

**Figure 7-28**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway:</td>
<td>enter agreed upon railway name</td>
</tr>
<tr>
<td>Track:</td>
<td>enter a description of the track to be inspected</td>
</tr>
<tr>
<td>Previous station name:</td>
<td>enter name of station behind of the train direction</td>
</tr>
<tr>
<td>Next station name:</td>
<td>enter name of station coming after the train direction</td>
</tr>
<tr>
<td>Begin station:</td>
<td>enter the begin station of the tunnel segment from which the inspection begins</td>
</tr>
<tr>
<td>End station:</td>
<td>enter the station at which the inspection ends</td>
</tr>
<tr>
<td>Plate number:</td>
<td>enter the plate number predetermined for the segment</td>
</tr>
<tr>
<td>Year built:</td>
<td>enter the year the tunnel is constructed</td>
</tr>
<tr>
<td>Liner type:</td>
<td>enter the abbreviated name of the type of lining</td>
</tr>
<tr>
<td>Inspection date:</td>
<td>enter the day, month and year of the inspection</td>
</tr>
<tr>
<td>Inspector:</td>
<td>enter the first &amp; last names of the inspector</td>
</tr>
<tr>
<td>Sketches:</td>
<td>provide details of sketches for the defects that still exist and have not been covered in other inspection forms</td>
</tr>
</tbody>
</table>

c. Tunnel Segment Photo Log

**Figure 7-29.**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway:</td>
<td>enter agreed upon railway name</td>
</tr>
<tr>
<td>Track:</td>
<td>enter a description of the track to be inspected</td>
</tr>
<tr>
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<td>Plate number:</td>
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<tr>
<td>Year built:</td>
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</tr>
<tr>
<td>Liner type:</td>
<td>enter the abbreviated name of the type of lining</td>
</tr>
<tr>
<td>Inspection date:</td>
<td>enter the day, month and year of the inspection</td>
</tr>
<tr>
<td>Inspector:</td>
<td>enter the first &amp; last names of the inspector</td>
</tr>
<tr>
<td>Photos:</td>
<td>provide details of photos log</td>
</tr>
</tbody>
</table>
Figure (7-28): Sketches form for supplemental segments in rail transit tunnels
Inspection Methods:

To reach the different construction elements to perform visual inspection this requires special equipment such as crane, rail inspection vehicle, ladders, building equipment (scaffold) and field glasses (used where it is difficult to access) also non-destructive inspection tests must be used.

Safety Applications:

Safety application during work is important and it is the responsibility of inspection team thus it is important to use warning signs to all people, those who are using the tunnels & the rest of team members. It is better to close the tunnel during inspection with coordination with the owning party. Each type of tunnel has its own application as follows:
a) Road tunnels: the suitable safety methods should be used when using ladders and elevators and when using inspection tools on the road. It should conform to safety documents issued by the party responsible for road management.

b) Rail transit tunnels: the inspection team should take more caution to avoid contact with the third rail or hierarchy order. It is better to disconnect power from such systems when performing inspection; upon coordination and pre-planning with the owning parties.

7-2-4 Inspection Performing Methods:

7-2-4-1 Inspection of structural components:

7-2-4-1-1 Periodical inspection:

Tunnel owners shall establish a periodical inspection for structural components in the tunnel depending on the age & conditions of the tunnel; for newly constructed tunnels the time period for the periodical inspection shall be for five years as maximum; old tunnels would require a less 7 more close time period. Inspection might be daily, weekly or monthly and shall be in all cases comprehensive.

7-2-4-1-2 What are we looking for during inspection?

This part introduces us to the methods & procedures of inspection in addition to the known defects in concrete, steel, stone and wood constructions; this can be done through visual inspection and nondestructive tests. Visual inspection shall be made to all exposed surfaces of structural components. These clear damages and defects shall be subject to measurement and documentation process and after that classified according to the degree of damage: great damage, medium, or non effective damage as we shall see later. Of these defects and damages are:

a) Retaining stones for the roof of the concrete of hard unsuitable edges and shall be measured in length, width and depth.

b) Clear and big cracks should be measured in length and width.

c) In iron members the rusted part shall be measured in length, width and rust thickness.
Inspection team shall clean the surface to be inspected of all debris and unwanted protrusions and that do not form part of the structural component before starting inspection process.

Transition areas are the areas where the retaining system in the tunnel changes as those between rock sections and soil, between the tunnel and the ventilation system or the station buildings. Their locations are identified from as built drawings.

Partial slide causes such damages a thing that explains why we spend more time to inspect such areas.

Back to the visual inspection, the structural components should be subject to voice recoil test using a special hammer which detects hidden defects that cannot be seen by the eye. As a result of hammering the structural component shows certain sounds that indicate the availability of hidden defects and damages. High sounds resulting from hammering the indicate the absence of defects in the materials under the related surface contrary to the hammering that result in sounds of a drum that indicate defects hidden under the surface. Also the hollow sound in wood refers to advanced defect. The surface which shows such defects or damages must be marked until the completion of all inspection for all the area to identify the damaged areas.

There are tests that are applied to accessible stone & concrete surfaces and are usually are non-destructive tests or ultrasound test such as impact-echo test which is an audio-test that determine the existence of and location of defects and voids and the thickness of the concrete. This method helps early detection of the damage a thing that allows treating the same in the early stages.

It is important for detection team members to be acknowledged of any water insulation systems that can be used in tunnels during construction.

Of the common structural damages we mention the following:

a) Concrete installations:

1- Scaling

- Minimum degree: loss of surface mortar up to 6 mm in depth with exposure of the surface and the appearance of coarse stack.
• Medium degree: loss of surface mortar to a depth of 6mm to 25mm with the loss of part of the mortar added between the parts of the coarse stack (the aggregate)

• Maximum degree: loss of the aggregate in addition to the loss of the surface mortar and that surrounding the aggregate where the depth is more than 25mm.

2- Cracks:

Cracks are linear break in the concrete because of straining power that results from the concrete resistance to straining. cracks happens because of structural & non-structural reasons.

Structural cracks happen as a result of excess external loads, but the nonstructural happen upon curing (a problem in maintaining concrete humidity after pouring results in contraction that leads to the appearance of cracks).

Types and forms of cracks:

a) Traverse cracks: they are straight and perpendicular to the direction of the concrete component; it appears in tiles and beams in addition to curbs and retaining walls.

b) Longitudinal cracks: they are straight and parallel to the concrete component.

c) Horizontal cracks: generally happens in walls and beam sides it resembles the traverse cracks.

d) Vertical cracks: generally happens in walls it resembles the longitudinal cracks that appear in tiles and beams.

e) Diagonal cracks: appear parallel with each other in tiles with inclination and differ in length, width and spaces between them; and when appear on beams then this means there is a real problem.

f) Map cracks: they are the cross cracks which are different in their extent and their network form; mainly found in tiles and walls.

g) Capillary cracks: they are a series of cracks in random way.

h) Random cracks: They are non-uniform cracks on concrete surface; it has no definite form or classification.

All cracks in non pre-stress concrete can be classified as follows:
• Small: up to 0, 8 mm.
• Medium: between 0,8 -3,2 mm
• Mature: more than 3,2
But in non pre-stress concrete the cracks that are more than 0,1 mm should be classified as mature and any crack less than or equal to 0,1 should be classified as small not effective.

3- **Spalling** :
They are the concrete debris that either circular or oval that appear on concrete surface cause by removal of part of concrete surface causing parallel cracks to the surface.

Usually there is part of these debris that appear perpendicular to the surface and appear therein the reinforcement iron; these cracks are classified as follows:

• Small: protrusion is less than 12 mm or diameter from (75-150) mm
• Medium: protrusion from (12-25) mm or for diameter about 150 mm.
• Mature: protrusion is more than 25 mm and diameter more than 150 mm and in this case the reinforcement iron appears.

4- **Joint spall**
Concrete debris extending along the structural joints and is classified as the previous.

5- **Concrete pop-out**
They are concrete compounds broken from the concrete surface leaving a small pit on the roof. The degree of damage of this pit is classified as follows:

• Small: the diameter of the pit is up to 10 mm or equivalent.
• Medium: the diameter of the pit is between 10-50 mm or equivalent.
• Mature: the diameter of the pit is between 50-75 mm or equivalent.

6- **Mudballs**:
Small pits on the surface due to non melting of mud and other soft granules; the degree of damage here is classified as the previous.
7- **Efflorescence**
This is a mixture of calcium carbonate that comes out of the cement mud and some of carbonates and chlorine compounds all are formed on the concrete surface after water evaporates.

8- **Staining**
Removal of the concrete color due to some non melted materials through the cracks and remain on the surface after water evaporates. This case means there is corrosion in the reinforcement iron layer.

9- **Hollow areas:**
The areas in the concrete surface that give hollow areas when hammered. mainly relates to bad sort of concrete.

10- **Honeycombing**
These are areas in the surface of the concrete that are not filled properly during pouring. Here the debris are clear leading to a bad concrete that resembles the honeycomb.

11- **Leakage:**
Happen in the concrete surface from which water comes out.
- Few: the concrete surface is wet although no drops of water available.
- Medium: active flow at the rate of less than 30 drops /minute
- Much: active flow at the rate of more than 30 drops /minute.

b) **Iron installations:**

1- **Corrosion**
Iron corrosion differs in its color from dark red to dark brown. In the beginning it would be soft granules then it becomes scales. Corrosion causes digging in the component; that is why all the places of corrosion should be referred to as damages with the measurement and recording of the size of the digging. Corrosion is classified as:
- Light: is not more than digging in the surface.
- Medium: formation of the scales and coarse layers and the corroded areas can be seen.
• Mature: Cause digging in the component and gradually the iron component loose part of its section, it generally happen with water leakage.

2- **Cracking:**

It differ in the iron components form capillary cracks to large cracks through which light pass; all must be considered, recorded in the report and classified as mature.

3- Buckles& Kinks: happens mainly due to thermal stresses and excess load; also the damages resulting from collision may cause them.

4- Leakage: happens on iron surfaces from which water emerges through cracks & joints.

• Few: iron surface is wet although no drops of water available
• Medium: active flow at the rate of less than 30 drops /minute
• Much: active flow at the rate of more than 30 drops /minute.

5- **Protection system:**

Usually iron is protected using certain putty, galvanization or using resisting iron. Using putty would fail when there are scales, cracks and corrosion on the surface area.

The degree of damage shall be classified by referring to the physical conditions of the putty and the amount of corrosion as follows:

• Light: all signs of putty damage but no corrosion yet.
• Medium: putty reaches its worst cases, corrosion start to appear, no decay in the section size.
• Mature: failure in the putty system, availability of severe corrosion in addition to decay in the section.

7-2-4-1-3- **Safety-critical repairs:**

In many cases damages are great to the extent it is dangers for the tunnel users, workers or inspection team.

These damages are classified under critical repairs and in this case the following procedures shall be taken:
- Close the tunnel until such damages are removed or repaired in case they are accessible.
- Fence the place to be repaired using warning tape until the defect is removed or repaired.
- Support the structural element as much as possible to facilitate its repair.

The inspection team should coordinate with the owning parties and be ready to face critical issues and take the necessary measures that are needed in case the concrete is very thin a thing that would lead to its collapse. Repair process is the responsibility of the inspection team, the tunnel owners, and the concerned contractors; such activities are very dangerous and all safety precautions should be taken to prevent injuries.

7-2-4-1-4 Case Coding:

Structural elements of what sort they may be are to code using the directives shown below. Coding is referred to by the numbers from 0-9 will be assigned to each element. Zero refers to the worst status while 9 refer to the better status. This coding system was developed by international parties like FHWA (Bridge inspectors training manual).

In case tunnel owners wish to use this system for the mechanical or electrical works then it will be amended to show the coding of the cases such as(excellent, good, acceptable, weak, dangerous) so as to be connected to the computer programs of the tunnel management, the following table these grades:

<table>
<thead>
<tr>
<th>The code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Newly completed construction</td>
</tr>
<tr>
<td>8</td>
<td>Excellent case- no damages</td>
</tr>
<tr>
<td>7</td>
<td>Good, no need for repairs</td>
</tr>
<tr>
<td>6</td>
<td>Different between 5-7</td>
</tr>
<tr>
<td>5</td>
<td>Acceptable – some small repairs are required but the basic functionality of the construction is not affected by these different damages but there is no loss in section.</td>
</tr>
<tr>
<td>4</td>
<td>Different between 3-5</td>
</tr>
<tr>
<td>Grade</td>
<td>Status Description</td>
</tr>
<tr>
<td>-------</td>
<td>-------------------</td>
</tr>
<tr>
<td>3</td>
<td>Bas status - the construction needs main repairs &amp; its basic functionality is affected by these severe damages.</td>
</tr>
<tr>
<td>2</td>
<td>Dangerous status – the construction needs urgent basic repairs to keep the construction usable</td>
</tr>
<tr>
<td>1</td>
<td>Critical case- needs quick closure and a comprehensive study for the correct repair</td>
</tr>
<tr>
<td>0</td>
<td>Very critical case- requires the closure of the tunnel and the prompt start of the repair process.</td>
</tr>
</tbody>
</table>

These grades depend on the quantity, type, size, and location of the damages in the construction and the extent to which the construction would bear being used under such defects.

7-2-4-1-5 The tunnel sections:

1- Cut & cover of the box type concrete using the pumped concrete for the internal lining:

In most tunnels & passenger stations, the covering of the concrete surface is done through many ways mentioned in (7-1-2). The general conditions of such concrete should be evaluated depending on the status of cracks and leakage. The inspector needs to make an equitable engineering judgment when evaluating all the conditions of the sectors inspected. In case the sectors here showed the lack of damage except mature cracking plus much leakage then it is considered a bad status as it still requires urgent repair.

2- Tunnel lining of soft soil

These applications include iron and precast concrete, cast iron and stone lining in addition to joint screws & rings in manufactured linings.

The inspector shall be knowing inspection requirements for such type of lining as follows:

a- Lining edges of precast concrete may include other metal plates instead of rivet screw for fixing, corrosion extent in such metal, plates must be inspected. The rivet screws in the precast concrete and cast iron may change color due to humidity and water inside the tunnel; this should be take in consideration especially in place of leakage and ensure no lack of the size of section, if this is the case all these screws must be noted for replacement.
b- The regular cross section of the tunnel should be noted which can be affected by the pressure of the soil. This regularity should be noted every 60m form the internal face of the horizontal line and from the top of the tunnel's ceiling up to the surface of the rail for rail way tunnels or up to the surface of pedestrian tunnels. As for coding process it will be as mentioned in table (7-1).

3- Stone lining of the tunnel:
These applications include precast concrete in addition to shot concrete. The internal part of the tunnel should be inspected and ensure it is free of the common damages that happen to the concrete that are mentioned in the beginning of the chapter. Also the cross section regular form should be noted as regards the lining which should be inspected every 60m in the same previous way. As regards the coding system it will be the same as in table (7-1)

4- Track supports:
This part is concerned with direct fixing with concrete base supports and the rolled over slab.
The concrete structural elements must be inspected and ensure it is free of the common damages that are mentioned in the beginning of the chapter. As for the coding system it will be the same as in table (7-1).

5- Finishing:
The assessment degrees mentioned previously from 0-9 are not used to assess finishing instead degrees like (excellent, good, acceptable, bad) are used. For ceramic tiles it should be inspected by the inspection team using a thin stick to hit the tiles' surface to test the voids in the lower layer and depending on the sound heard the existence of voids is determined; the solid voice indicate the fullness of such layer while the hollow voice indicate the existence of a void. The inspector should record the amount and distance of such voids as damages and should note the status of the tiles and whether it is good or not.
As for the glazed porcelain of metal and precast concrete plates, the dangerous plates would expose the tunnel to danger. Metal plates should be free from corrosion especially at the edges of the tile. The precast concrete plates should be free of cracks at the tile bends.
The evaluation system mentioned in table (7-1) may be used.
6- Drainage systems:
It is important to inspect the drainage system inside the tunnel to ensure it drain water whatsoever its size may be. The source of such water may be underground water coming from outside the tunnel or may be rain water that leaked inside the tunnel or water from firefighting. The existence of a problem in such system means the formation of big pond of water a thing that would forbid the use of the tunnel. Rail way tunnels are more sensitive to such problems due to the many equipment involved therein. Such ponds would lead to the closure of these systems.

The inspection team for such systems will use a descriptive evaluation such as excellent, good, acceptable, and bad. This evaluation must depend upon the ability of the mentioned system to drain water and ensure it did not come as a result of blocking or leakage. As regards the evaluation process will be the same as the previous mentioned in table (7-1).

7- Miscellaneous tunnel accessories:
Safety passages which include CCTV and the fence for the track. Inspection of these elements is to know the degree of damage and whether it can perform its function effectively.

7-2-4-2- Inspection of the mechanical systems:
Inspection process id done periodically depending on the need of the system for inspection and maintenance which will include inspection of pumps, fans, motors, Inspection differs from daily, weekly, monthly and annual inspection or every two tears, three years or seven to ten years sometimes.

Inspection would include the following systems:

1- Tunnel ventilation system.
2- A/C system
3- Heating system
4- Control system
5- Pipe connection system
6- Drainage system
7- Fire fighting system
7-2-4-2-1- Tunnel ventilation system

Inspection in this system should include the following:

a- Review maintenance instructions for each item of the equipment and seek to avoid future problems.

b- Note the physical status of the accessories such as fans, air passages, air openings and dampers that are in motors and ensure they are working properly.

c- Ensure performing the required tests and to follow up the work of the companies responsible for such tests to submit the results properly.

d- Ensure that air passages are free of blockings and debris that cause its closure.

7-2-4-2-2- Cooling & air conditioning system

This system includes the following points:

a- Review of the previous maintenance records of every equipment and to seek to avoid the potential problems or problems that happened actually.

b- Noting and follow up of the physical status of system accessories such as (air handling units, air conditioning units, filling units, coolers, pumps, cooling towers and their accessories) and ensure them working.

c- Contracting with the companies concerned with the required tests (vibrations analysis) and to inspect coolers, cooling towers and pumps and also analysis of oil cycle and lubrication materials in the supports.

7-2-4-2-3- Heating system:

It contains the following points:

a- Review of the previous maintenance records of every equipment and to seek to avoid the potential problems or problems that happened actually.

b- Noting and follow up of the physical status of system accessories such as (air handling unit, pumps, water & vapor distribution system, separation unit, boilers, heating joints, vapor transformers)

c- Contracting with the companies concerned with tests to analyze boilers to determine their operational efficiency and to inspect the boiler rear for corrosion and holes.
7-2-4-2-4 - Control system:
This system depends on using the Supervisory control and data acquisition-SCADA system. It is a central system for the systems that supervise and control all locations or group systems that are distributed on wide areas and mostly in electrical power stations or communication stations; the operation of these systems is with the least effort of maintenance operational accessories.

The control and periodical update for the programs is required to maintain the flexibility and effectiveness of system operation.

7-2-4-2-5 - Pipe connection system
This system includes the following points:

1- Review of the previous maintenance records of every equipment and to seek to avoid the potential problems or problems that happened actually.

2- Noting and follow up of the physical status of system accessories such as (water cycle equipment, drainage system) and ensure they are operating and free of leakage.

3- Review the places of water flow on the tunnel surface to determine the places of leakage and defect in the connection system.

7-2-4-2-6 - Drainage system:

1- Mechanically the centrifugal pumps should be inspected and ensure they are operating properly.

2- Drainage should be ensured clear from debris and dirts.

7-2-4-2-7 - Firefighting system:

This system includes the following points:

1- Review of the previous maintenance records of every equipment and to seek to avoid the potential problems or problems that happened actually.

2- Noting and follow up of the physical status of system accessories such as (fire extinguishers, fire hose pulley joints) in addition to system reservoirs, warning devices and ensure they are working efficiently.

3- Inspection system control board for fire detectors, indicators, wires and warning system and ensure they are working properly.
7-2-4-3- Inspection of electrical systems:

Inspection process is done periodically according to the system needs for inspection and maintenance which includes the following systems:

- Power distribution, emergency power, lighting, fire alarm & detection.

Detection should be according to the following requirements:

- Visual inspection for wiring systems and cables to protect against damage & corrosion.
- Ensure that electric boxes are secured and also their covers.
- Ensure that power is cut off during inspection.
- Consideration of safety precautions and procedures during the inspection of electrical systems and shall be published to abide by the same.

7-2-4-3-1- Power distribution system:

This system is composed of electrical equipment, wires, ventilation pipes and the cables carrying the main current from the main distributor and the main transformer.

It may also include the following accessories:

Transformers, switchboards, branch units, distribution boards and operators.

For inspection of this system the following should be followed:

a- Take the readings of the voltage and electricity load on electrical instruments.

b- Checking the transformers and ensure that the temperature degree and pressure are all within the allowed limit.

c- Ensure the operation of alarm devices and the engine temperature.

d- Ensure the existence of empty space in-front of the equipment and no items are stored around them especially in-front of them this is according to the recommendations of the national society for fire fighting (NFPA 70).

e- Evaluation of channels status and locks and ensure that all the boxes' covers are in place and in a sound condition.

f- Visual inspection for system wires and ensure that they are free of corrosion and sabotage.
g- Ensure that power distribution system is conforming to the specifications of the international association for fire fighting NFPA70, 130

h- Inspection of all motor control units to ensure their efficiency

i- Performance of the required system tests that are stipulated in the manual of the international association for electricity tests NETA.

7-2-4-3-2- Emergency power system

This system is composed of electrical devices, wires, cables and his used when the power is cut off from the facilities in the tunnel. Such electrical devices are emergency power generators, systems to forbid power cutoff.

Inspection to this system should include the following points:

a- Ensure the ability to operate emergency system in case the ordinary system fails.

b- Perform the required tests according to the international Association for electrical tests NETA to inspect hot points.

7-2-4-3-3 Lighting system

This system is composed of electrical devices, wires, channels, cables, bulbs and control devices used to control lighting the tunnel.

Inspection in this system includes the following points:

a- Ensure the proper work of electrical equipment, wires, channels, cables, bulbs and control devices to provide sufficient lighting for the tunnel.

b- Measurement of lighting level throughout the tunnel and at emergency exit and joints by getting help from light engineering Society LES for comparing the readings with the Society requirements.

c- Inspection of visual damage that include corrosion, loss of accessories in addition to broken or dirty lenses.

d- For rail way crossing tunnels the operation of emergency lighting devices should be ensured and also continuous suitable lighting inside his the tunnel.

e- Ensure emergency lighting switch that is connected to the third signal bar when such bar is disconnected off service and such switches are to be located every 240m.
7-2-4-3-4 Fire detection system
This system is composed of control panels, smoke detectors, heat detectors, wires, channels and cables.
Inspection in this system includes the following points:
- Ensure existing documents that show that the system has been inspected on stages and regular periods according to the conditions of the international society for fire fighting NFPA 72 as the society when it conducts a test requests copies of such documents for the last seven years.

7-2-4-3-5 Communication system
This system is composed of communication devices (televisions, radios, close TV Cameras, SCADA system) used to perform communication in the tunnels.
Inspection in this system includes the following points:
- Ensure the operation of SCADA system and the rest of communication system.
- Inspection of traffic signs

7-2-4-4 Inspection of other accessory systems
7-2-4-4-1 Track elements inspection
- The rail: inspect any vertical or horizontal cracks in iron, cracks in the stem, in screw openings and distortion of welding.
- Rail width: it is the distance between the head of the rail center for the other center measured in vertical angle. This distance is insured according to TSS-Track Safety standard according to the following categorization of the track:

<table>
<thead>
<tr>
<th>Categorization</th>
<th>Width not less than</th>
<th>Not exceeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1400mm</td>
<td>1450mm</td>
</tr>
<tr>
<td>2&amp;3</td>
<td>1400mm</td>
<td>1444mm</td>
</tr>
<tr>
<td>4&amp;5</td>
<td>1400mm</td>
<td>1438mm</td>
</tr>
</tbody>
</table>
- Regularity: track regularity must be a ensured that it shall not exceed the allowed deviation and mentioned in TSS-Track Safety standard
• Bending: maximum increase in rail bending from outside shall not exceed 200mm for categorization tracks (1&2) and 175mm for categorization tracks (3&4&5).

• Screws & fasteners: this is considered a high importance in safe operation for railway system and to keep the width of the track; must be ensured as tight free from fracture and damage and to perform certain tests for the same.

• Fastening plates: ensure that the regular load is achieved.

• Sectional supports: its function is to support and maintain track rails and are made of wood, pre-cast concrete or plastic supported fiber. As for wood supports they must be inspected to ensure that they are free from damage resulting from insects. But the pre-cast concrete supports must be inspected to ensure they are free from cracks.

7-2-4-4-2 Power system inspection (the third rail / the chain)

a- Third rail system:

• Iron joint rail: must ensured to be free from cracks, breaks and are not weak in their tie.

• Joint rail insulators: ensure they exist with all accessories and are free from breaking.

• Protection plate: ensure well cover to the joint rail and also ensure the existence of related bows and the perfect placing of the same.

• Protection plate bows: to be inspected and ensure they are in their correct places on the sectional supports and that they are fixed using screws on concrete rails and they are insulated using polyethylene paint between iron and concrete.

• Third rail insulation arm: inspect all screws, insulators, connection fasteners, support plates and must be ensured that they are free from breaking and that these accessories do exist.

b- Catenary power system (the chain)

This system is known as overhead power system where the vehicles passing along the track receive their power from this system depending upon contact between pantograph device above the vehicle on rails and system wiring.

Below we give description of inspection process to this system by reference to the main components of the system using two methods: visual inspection and precise inspection.
1- Visual inspection

The location should be stated, the speed of the train, number & type of pantograph devices, movement direction, climactic conditions in addition to stating unusual conditions. To perform the inspection the following should be adopted:

- Inspect insulators, ensure the ceilings are free from breakage; iron supports for insulators must be inspected to ensure they exist and are fixed firmly.
- Hangers: ensure they are vertical; prompt inspection must be done when any change in direction happen and inspection of connector wire fastener against any external exposure.
- Jumpers: inspection of the jumpers in the shape of C for correct overlapping, ensure correct tying against movement and are not exposed to fire.
- Clamp slippage inspection, ensure the heel is higher than the connector wire and the descending bow is vertical.
- Anchors: ensure they fix the system inside the tunnel, any damages must be noted.

2- Precise inspection

It is used in addition to giving tunnel employees the chance to compete corrective maintenance and repair program to execute the following tasks; to perform inspection the following must be adhered to:

- Contact wire wear: ensure the thickness of the wire; it should not be less than 11mm.
- Clamped electrical connectors: it should be randomly removed and expected at C jumpers, feeding points and overlapping points of such joints.
- Hangers: should be inspected to ensure it is free from mechanical wear or arching.
- Messenger support: check electrical route through insulators and inspect stainless iron wires for indications of any wear and must be replaced if necessary.
- Registration assembly: inspect recording components at the same site in addition to opening wire fasteners and inspect for wear and re-grease.
- Overlaps: ensure overlapping of connection wires to ensure good transfer from pantograph
• Disconnect switches: to be opened and closed to ensure good operation.

7-2-4-4-3- Inspection of signal /contact systems:

Signal: steps to perform inspection to these systems is in-Federal Railroad administration for the different components of signal system where the periods of periodical inspection differ from one month 10 years sometimes; these periodical inspection periods can be summarized as follows:

<table>
<thead>
<tr>
<th>Operation circuit control device</th>
<th>Three months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corporation switches</td>
<td>Monthly</td>
</tr>
<tr>
<td>Information devices</td>
<td>Six months</td>
</tr>
<tr>
<td>Exchanges</td>
<td>Two years</td>
</tr>
<tr>
<td>Timing devices</td>
<td>annually</td>
</tr>
<tr>
<td>Traffic signs:</td>
<td>Monthly</td>
</tr>
<tr>
<td>Height and regularity operation</td>
<td>six months</td>
</tr>
</tbody>
</table>

As for contact systems periodical inspection periods can be summarized as follows:

<table>
<thead>
<tr>
<th>emergency telephones</th>
<th>Monthly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial cables</td>
<td>Before operation</td>
</tr>
<tr>
<td>Main cables</td>
<td>Continuously</td>
</tr>
<tr>
<td>Communication devices</td>
<td>For each manufacturing process</td>
</tr>
</tbody>
</table>

Signal system inspection includes the following:

• Ensure the operation of automatic signs and control points.
• Ensure that all transfer lines operate on not less than 750 volt which must be put in height not less than 1.2m on the nearest pole that bear communication sign a contact circle.
• Ensure rail joints insulation is maintained against any problems.
• Ensure recording results of all required tests and that they are printed on the assigned forms submitted from the owner party.

Inspection of communication system includes the following:
- Visual inspection of basic cables upon appearance of deterioration signs.
- Testing signal force of radiation cables.
- Ensure availability of emergency telephones along the road in the suitable places and in each station.
- Testing signal force of radiation cables.
- Following all the instructions and recommendations by manufacturers during inspection and maintenance of communication equipment.

7-2-5- Inspection process documentation:

7-2-5-1 Field data:

7-2-5-1-1 Tunnel structure:

Structural inspection for the tunnel must be documented precisely; to document dangerous damages this needs planning stating the location and size of these damages with complete description and it must be photographed and enclosed with the report.

These drawings are to be put in forms that were developed during mobilization fase. They should show the vertical and front elevation that show the details of the structural element. Also documentation of inspection output as any inspection team should use the following classification and initials system to state the defects:

<table>
<thead>
<tr>
<th>Code</th>
<th>Classification</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not dangerous</td>
<td>Minor</td>
</tr>
<tr>
<td>2</td>
<td>Medium</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>Dangerous</td>
<td>severe</td>
</tr>
</tbody>
</table>

Table 7-3: Description of defects with their codes (continued)

<table>
<thead>
<tr>
<th>Damages</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracks</td>
<td>CR</td>
</tr>
<tr>
<td>Scaling</td>
<td>SC</td>
</tr>
<tr>
<td>Spalling</td>
<td>SP</td>
</tr>
<tr>
<td>staining</td>
<td>ST</td>
</tr>
<tr>
<td>Exposed Reinforcement</td>
<td>E</td>
</tr>
<tr>
<td>Corrosion</td>
<td>C</td>
</tr>
<tr>
<td>------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Honey Comb</td>
<td>H</td>
</tr>
<tr>
<td>Patch failure</td>
<td>PF</td>
</tr>
<tr>
<td>Hollow areas</td>
<td>HA</td>
</tr>
<tr>
<td>Debris</td>
<td>D</td>
</tr>
<tr>
<td>Buckle</td>
<td>B</td>
</tr>
</tbody>
</table>

Table 7-3: Description of defects with their codes (continued)

<table>
<thead>
<tr>
<th>EF</th>
<th>Efflorescence</th>
</tr>
</thead>
<tbody>
<tr>
<td>LK</td>
<td>Leakage</td>
</tr>
<tr>
<td>CK</td>
<td>Check</td>
</tr>
<tr>
<td>RT</td>
<td>Rot</td>
</tr>
<tr>
<td>FD</td>
<td>Fire damage</td>
</tr>
<tr>
<td>PD</td>
<td>Paint deterioration</td>
</tr>
</tbody>
</table>

These abbreviations and classifications should be placed in the drawings and reference is made for them for identification.
Figure (7-30): Tunnel inspection form (Tablet PC Data Collector)
Figure (7-31): Tunnel inspection form (Pre-Printed form)
Figure (7-32): Portal Inspection form (Pre-printed form)
7-2-5-1-2 Track structure
Documentation of this part requires going back to (TSS-Track safety standard) which require from rail road tunnel owners to maintain previous records of inspection processes. Also the owners sometimes have special forms for inspection process.

7-2-5-1-3 Specialized tests reports:
To inspect the different systems this requires special parties to perform the required tests and to provide equipments used and the reports. Such type of reports should be included in inspection documents of such period.

7-2-5-2 Identification of repairs having priority:
When we summarize inspection data and recommend future maintenance and repair works, it is important to specify groups that have priority in such repairs. Such recommendations may be included in the inspection report or enter the same in structural data base to schedule repair processes. Below we mention classification of repair works:

7-2-5-2-1 Critical repairs
As mentioned in the previous chapter, these defects need a special processing and quick action including closing the construction for maintenance.

7-2-5-2-2 Repairs having priority:
They are top of the list as they are very important in developing the expected life of the construction and relieve of the cost of future maintenance.

7-2-5-2-3 Routine repairs
It is part of maintenance schedule, projects schedule or maintenance procedures when occurrence of a certain incidence. Also all the items mentioned in the preventive maintenance program should be also enlisted in this sort of repairs.

7-2-5-3 Reports
Upon completion of inspecting all the required elements, the owning parties should request an official report that summarizes the findings of the inspection team. This report will help, such parties to know the defects in the tunnel and thus make them able to schedule repair works and assign the required finance.
Here are the main items that should be available in the inspection report:

- **Transfer letter:** an official definition of the report.
- **Index:** a table containing the report contents.
- **List of tables:** showing the name of each table and in what section.
- **Figures & illustrative drawings:** showing the name and number of each figure and in what section.
- **Photos list:** showing the name & number of each photo and in what section. They show the defects found.
- **Executive summary:** gives precise summary of the inspection process, its outputs and recommendations of repair.
- **General description:** for the tunnels inspected; it includes the tunnel location, year of construction, general engineering description and any technical or descriptive data.
- **Inspection procedures:** procedures used for inspection process on all tunnel systems (mechanical, electrical, structural …etc.) the parties responsible for the required tests must be notified by the works entrusted to them.
- **Inspection outputs:** structural: the report must include structural elements mentioning all the defects, their locations, degree of danger and performing the required tests.
  
  Mechanical: operational conditions for all equipments for the system and the required tests.

  Electrical: operational conditions for all equipments for the system and the required tests.

  Other systems: for track inspection, the tests required for draw power of the track, signals & communication systems,

- **Recommendations:** recommendations for repair and maintenance of the tunnel components; according to the owner's desire a statement of costs of required prices for maintenance and repair process will be included. Maintenance works must be breakdown for each system separately according to the previous division: important repairs, repairs having priority and routine repairs.

- **Appendixes:** should be used to show the details of inspection process and shall include test reports done during inspection. This report will give us a document that shows the tunnel status. In the future it will be used to evaluate the construction's performance in the past period.
7-3 Tunnel maintenance:

7-3-1 Introduction

7-3-1-1 Background

To avoid problems in operation process resulting from deferred maintenance, MOM has adopted the project of developing inspection tasks and tunnel maintenance directives in addition to development of database computing.

The first stage starts by development of the existing data base that includes the tunnel location, name, year of construction, shape, length, height, width, used construction methods, types of lining, and types of mechanical & electrical systems.

The main reason of deterioration in tunnel elements is underground water leakage, thus it is important to develop a regular maintenance program to repair defects in tunnels.

7-3-1-2 General view

The purpose of creating this section is:

a- Giving preventive maintenance directives and applications to owning parties of road and railway tunnels for tunnels structure and the systems included (mechanical, electrical and the track).

b- Giving recommended repair methods for tunnel structure and its systems regarding the different existing defects.

c- These repair methods include directives to limit ground water leakage to the tunnel which is considered the main reason for deterioration.

7-3-1-3 The content

This section include different sections showing the different components of the tunnel and the manner to maintain and repair the same. They are mentioned in paragraphs to help the owning parties to train and qualify in section teams according to the system needing maintenance.

7-3-2 Preventive maintenance:

7-3-2-1 Preventive maintenance for the tunnel structure

The aim of regular preventive maintenance for the tunnel structure and its systems is to provide safe environment for workers in the tunnel and its users and also to increase the supposed age of the tunnel. As it is not
possible to know the places of defects in full it is necessary to perform a precise inspection periodically to schedule maintenance works according to the degree of danger of the existing defects. Structural preventive maintenance is summarized in the following:

- Tunnel washing
- Water drainage
- Removal of ice and snow
- Removal & replacement of defected tiles.

Below we mention the details of these processes:

7-3-2-1-1- Tunnel washing:
This process is recommended for tunnels that uses tiles in finishing such as ceramic and galvanizes porcelain; it is done according to the following steps:

1- Spray the tunnel with mixed soap & water and brush with a certain brush.
2- Washing the tunnel with compressed water (about 140-200 bar) using compressors. There are some other elements that must be maintained and washed with compressed water such as protection barriers, lighting unit’s covers, concrete barriers, side plates.
3- The main reason for washing is to have good lighting that depend on tile convexity.
4- This process is not applied on tunnels with concrete or stone lining nor to railroad tunnels that do not depend on tile convexity for lighting
5- This process is repeated to the environment conditions of the area of the tunnel.

7-3-2-1-2- Water drainage
It must be ensured that water drainage is free from debris and dirt; it is better that maintenance be half yearly, for road tunnels it is better to be at the time of tunnel washing.

7-3-2-1-3- Snow & ice removal
This process is performed in area whose temperature degree is less than zero; snow is abundant in areas where leakage is recurrent. When snow is much it creates hazard to traffic a thing that require daily inspection and seek to stop leakage which is the cause of this.
7-3-2-1-4-Removal and replacement of the defective tiles:
During the detailed inspection the location of the defective tiles must be known; also inspection must be done every three months to ensure the status of the remaining tiles. Inspection and maintenance process is better to be at the time of washing due to the effect of brushing and water pressure of the status of tiles.

7-3-2-2- Preventive maintenance for mechanical systems:
Mechanical systems of the tunnel include several components that should work with one system to execute its tasks effectively. To avoid faults that happen suddenly a routine and regular preventive maintenance program must be developed that include inspection & maintenance of each piece of the system equipment.

When using computer for the data base of the system, then it will be able to store previous information of repairs and maintenance in addition to the estimated costs and the required financing.

Table 7-4 shows a list of preventive maintenance tasks for each part of the mechanical system in the tunnel:
Table 7-4: Preventive maintenance tasks for mechanical system in the tunnel:

<table>
<thead>
<tr>
<th>Process description</th>
<th>Maintenance cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekly</td>
</tr>
<tr>
<td>1- Air compressor</td>
<td></td>
</tr>
<tr>
<td>- Filter cleaning or replacement if necessary</td>
<td></td>
</tr>
<tr>
<td>External cooling fans cleaning</td>
<td></td>
</tr>
<tr>
<td>Manual operation of safety valves and drainage tanks</td>
<td></td>
</tr>
<tr>
<td>Oil inspection, ensure it is free of pollution and change if necessary</td>
<td></td>
</tr>
<tr>
<td>Inspection of the belt, motor cleaning and valve operation</td>
<td></td>
</tr>
<tr>
<td>Inspect air leakage</td>
<td></td>
</tr>
<tr>
<td>Inspect all screws and lubrication of motor supports</td>
<td></td>
</tr>
<tr>
<td>Inspect and clean compressors' valves</td>
<td></td>
</tr>
<tr>
<td>Inspect all pressure gauges and control devices</td>
<td></td>
</tr>
<tr>
<td>2- Air conditioning unit</td>
<td></td>
</tr>
<tr>
<td>- Filter cleaning or</td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Process description</th>
<th>Weekly</th>
<th>Monthly</th>
<th>Bimonthly</th>
<th>Quarterly</th>
<th>Half yearly</th>
<th>Annually</th>
<th>Every two years</th>
<th>Every three years</th>
</tr>
</thead>
<tbody>
<tr>
<td>replacement if necessary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspect pipe joints and coils and replace if necessary</td>
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<td>Inspect control devices and ensure effective operation of the unit</td>
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<td>- Inspect chimney and its pipe, ensure no obstacles and that all joints are</td>
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<td>Pumps &amp; motor lubrication when necessary</td>
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<td>Clean all surface of boiler inside &amp; outside</td>
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<td>Replace chimney filter</td>
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<td>Inspect the level of hot water and fill if necessary</td>
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<td>Re-operate the boiler, check performance of combustion chamber, smoke, heat</td>
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<td>Test safety valve, be more keen about safety</td>
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<td>- Inspect &amp; grease compressors</td>
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<td>Inspect control devices</td>
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<td>Adding chemicals according to requirement</td>
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<td>- Inspect sensation equipment (calibrate or replace if necessary)</td>
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<td>- Perform leakage test in air ballast</td>
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<td>Calibrate central sensation devices</td>
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<td><strong>6- Cooling tower</strong></td>
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<td>- Inspect &amp; lubricate pumps &amp; fans</td>
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<td>- Ensure safety controls</td>
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<td>- Clean sump</td>
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<td><strong>7- Service water tanks &amp; pumps</strong></td>
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<td>- Visual inspection for pumps</td>
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<td>Grease pumps &amp; motors</td>
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# Maintenance Cycle

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<th>Monthly</th>
<th>Bimonthly</th>
<th>Quarterly</th>
<th>Half Yearly</th>
<th>Annually</th>
<th>Every Two Years</th>
<th>Every Three Years</th>
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<tbody>
<tr>
<td>Inspect pump operation and connect with ground tanks</td>
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<td>Grease ejector pump</td>
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<td>Ensure operation of pressure adjustment key, the difference should not be more than 172KPa</td>
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<td><strong>8- Drainage system</strong></td>
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<td>- Precise check for system components</td>
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<td>Control of drainage process at the entrance and the rest of the joints</td>
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<td><strong>9- Dewatering pumps:</strong></td>
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<td>- Good cleaning &amp; visual inspection</td>
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<td>Pump greasing (before usage in case of movable pumps)</td>
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<td><strong>10-Emergency eye wash</strong></td>
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<td>- When non bacteria solutions are not used, cleaning with clear water is the solution</td>
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<td><strong>11-Extract fans and dampers</strong></td>
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## Chapter 7: Tunnels

### Process description

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<tbody>
<tr>
<td>-operation of fans and dampers and listen carefully for unusual sounds</td>
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<tr>
<td>Inspect supports &amp; tie belts ensure they are secure</td>
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<tr>
<td>Clean entrances and all movable parts</td>
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<tr>
<td>Grease supports , handles and all that facilitate movement and operation</td>
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</table>

**12- Fire extinguishers**
- Inspect every fire extinguisher existing in the tunnel and ensure it is operating

**13- Fire hydrants**
- Grease the front of the hydrant

**14- Fire fighting system joints**
Freezing fighting pumps: clean & **visual inspection**

Grease pumps

---

273
## Process description

<table>
<thead>
<tr>
<th>Maintenance cycle</th>
<th>Weekly</th>
<th>Monthly</th>
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<tr>
<td>Heat detection equipment: ensure the system is working effectively</td>
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<td><strong>15- Fire fighting water pumps</strong></td>
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<tr>
<td>- visual inspection</td>
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<tr>
<td>Inspect supports &amp; tie belts ensure they are secure</td>
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<td>Clean entrances and all movable parts</td>
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<td>Grease supports, handles and all that facilitate movement and operation</td>
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<td><strong>16- Fire pump controller</strong></td>
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<td>- Testing insulator switch and current operation switch</td>
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<td>- Performance of the annual test including current in the connections according to NFPA72 manual</td>
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<td><strong>17- Fire tanks filling pumps</strong></td>
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<tr>
<td>- Visual inspection for the pumps</td>
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<td>- Greasing motors and</td>
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<td>- Inspect tanks upon defects, <strong>corrosion</strong> or leakage at the inside &amp; outside of the tank</td>
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<td>- Follow up <strong>maintenance</strong> steps mentioned in boilers</td>
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<td>19- Hot water pumps:</td>
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<tr>
<td>- Visual inspection of pipe joints and ensure they are free of <strong>corrosion</strong></td>
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<td>- Outside visual inspection for water boiler and ensure it is free of any leakage</td>
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<td>Greasing motors &amp; pumps according to the requirement</td>
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<td>20- Septic system</td>
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<td>- Pump outside the tank as required</td>
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<td>visual inspection for ejector pumps</td>
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<td>Inspect local indicators and ensure they are effective.</td>
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<td>21- Tunnel fans</td>
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<td>- listen to any vibrations or sounds that are unusual upon operation on normal speed.</td>
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<td>Monthly</td>
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<td>Half yearly</td>
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<td>General cleaning of motors (internally &amp; externally)</td>
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<td>Disconnect motors from electrical source and re-grease them, ensure they are full of grease up to 75%</td>
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<tr>
<td>- Inspect all greases and oils</td>
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<td>Ensure all dampers are operable in all conditions and grease when required.</td>
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<td><strong>22-Unit heaters</strong></td>
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<td>- Cleaning condensers and coils and repaint corrosion places</td>
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<td>Ensure fan screws are tight.</td>
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<td>Check the control side wires and ensure they are tight</td>
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<tr>
<td>Grease the motor when necessary</td>
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<td><strong>23-Ground fuel tank:</strong></td>
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### 7-3-2-3- Preventive maintenance for tunnel electrical systems

Electrical systems of the tunnel encompass several components that work together to perform their functions effectively as they are interconnected and interdependent in performing their functions.

Electrical systems are of great importance as other systems (mechanical systems or others) depend on them for effective performance. Also, the preventive maintenance system applied on the mechanical systems may include electrical systems. Further, not all tunnels use the components that will be given below for a number of reasons that are related to the tunnel age, location and size. Newly constructed tunnels have high operational technology that exceeds what will be mentioned in the

<table>
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<tr>
<th>Process description</th>
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<tr>
<td>- Removal of fluid level sensation device in the tank to ensure the least level of warning device</td>
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<td>- Immerse sensation device in the water to activate measurement of the higher level of the warning device</td>
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<td><strong>24- Water tank:</strong></td>
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<td>- Visual inspection for the outer surface of the tank</td>
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<tr>
<td>Drainage of residues</td>
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<tr>
<td>Inspect air pressure inside the tank and correct when necessary</td>
<td></td>
</tr>
</tbody>
</table>

- Remov 24.

- Immerse 24.

- Visual 24.

- Drainage 24.

- Inspect 24.
preventive maintenance tasks. Hence, it is important to refer to the manufacturer’s manual of each piece of the system’s equipment for the maintenance procedure to be followed. Hence, National Electrical Testing Association (NETA), Maintenance Testing Specification (MTS) gives detailed data and explanations on the maintenance of tunnel electrical system.

Table 7-5 shows list of preventive maintenance tasks for each part of the electrical system in the tunnel.

<table>
<thead>
<tr>
<th>Process description</th>
<th>Maintenance cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekly</td>
</tr>
<tr>
<td>1- Closed Circuit TV</td>
<td></td>
</tr>
<tr>
<td>- Clean, alignment and concentration of all cameras after tunnel cleaning</td>
<td></td>
</tr>
<tr>
<td>2- Emergency lighting</td>
<td>•</td>
</tr>
<tr>
<td>- Operation of test controls under stable light in case of emergency.</td>
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</tr>
<tr>
<td>- Operation of battery group for emergency lighting for 90 min.</td>
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</tr>
<tr>
<td>3- Electrical switch board</td>
<td>•</td>
</tr>
<tr>
<td>- Inspect switch group and joints through scanning and infrared rays.</td>
<td></td>
</tr>
<tr>
<td>- Performance of ultrasonic inspection for connection rails that are assistant to medium voltage switches and also insulators and barriers.</td>
<td></td>
</tr>
<tr>
<td>- Inspect all equipment in unusual cases using visual</td>
<td></td>
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</tbody>
</table>
### Process description

<table>
<thead>
<tr>
<th>Maintenance cycle</th>
<th>Weekly</th>
<th>Monthly</th>
<th>Bimonthly</th>
<th>Quarterly</th>
<th>Half yearly</th>
<th>Annually</th>
<th>Every two years</th>
<th>Every three years</th>
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</thead>
<tbody>
<tr>
<td>inspection.</td>
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<tr>
<td>- Review the strength of all connections.</td>
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<tr>
<td>- Removal &amp; replacement defected lighting units</td>
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<tr>
<td>- Review the latest results of the visual inspection and infrared rays and ultrasonic waves</td>
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<tr>
<td>- After disconnecting power the switch group is to be cleaned completely from inside</td>
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<tr>
<td>Cleaning and lubricating devices &amp; control switches and ensure its operation</td>
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<td>●</td>
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</tr>
<tr>
<td>Clean and lubricate and adjust and add anti oxidation to all switch units that are not connected</td>
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<td></td>
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<td>●</td>
</tr>
<tr>
<td>Clean and test insulation resistance for all lighting ballasts.</td>
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</tr>
<tr>
<td>Test insulation resistance for every connection rail</td>
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<tr>
<td>Perform calibration test for measurement devices ensure correct operation</td>
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<td>●</td>
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<tr>
<td>Air circuits breakers for low voltage:</td>
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<tr>
<td>Process description</td>
<td>Maintenance cycle</td>
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<td>Half yearly</td>
<td>Annually</td>
<td>Every two years</td>
<td>Every three years</td>
</tr>
<tr>
<td>- Remove covers and clean breakers completely</td>
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<tr>
<td>Add anti oxidation material for main breakers</td>
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<td>●</td>
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<tr>
<td>Lubricate machinery and ensure operation</td>
<td></td>
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<tr>
<td>Pass 90%-110% of disconnect current rated to ensure the suitable disconnection</td>
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<tr>
<td>mechanism</td>
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<tr>
<td>Record disconnection time for long periods, short periods and short moments and</td>
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<tr>
<td>ground faults at double loads of the rated loads for every emergency circuit.</td>
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<tr>
<td>Measure contact resistance and adjust</td>
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<tr>
<td>Perform and record insulation resistance test between each pole and the ground one.</td>
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<tr>
<td>Lubricate and clean breaker stands</td>
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<tr>
<td><strong>Molded breakers:</strong></td>
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<tr>
<td>Check the breaker for correct insulation</td>
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<tr>
<td>- Remove cap if possible and clean from outside and inside</td>
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<tr>
<td>- Check combustion,</td>
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<tr>
<td>Process description</td>
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<td>temperature increase and suitable alignment</td>
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<tr>
<td>Perform contacts resistance test and insulation resistance measurements</td>
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<tr>
<td>Pass 300% current of the rated breaker current to test long period element</td>
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<tr>
<td>Test the resistance of breakers resistance breaking with checking manufacturing party characteristics.</td>
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<tr>
<td>- Automatic transfer switches: clean contacts surfaces and add anti oxidation material and measure &amp; record contact resistance and adjust if possible</td>
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<tr>
<td>lubricate the pins and cams</td>
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<tr>
<td>Test voltage and frequency and time relays</td>
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<tr>
<td>Insulated low voltage cables: ensure correct tying of cable terminals</td>
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<tr>
<td>- Performance of insulation resistance test between each phase &amp; the other and the grounding for one minute using 1000 volt test of DC and recording the results &amp;</td>
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</tbody>
</table>
### Process description

**4- Electric transformers:**

- Inspect transformer connections using scanning through infra red rays.
- Inspect assistant connector rail using sound waves for medium voltage, insulators and barriers.
- Inspect all equipment visually in unnatural conditions.
- Inspect transformer and insulation oil in the breaker.

**Dry type:** remove cap, inspect visually the cables and connection rails if it shows evidence of combustion or increased temperature and ensure tight connection and clean coils.

**The immersed type in fluid (oil):** inspect transformer to ensure lack of holes or spoiled seal and suitability of oil.

**Check transformer's tank and cooling fans for breakage, or erosion and for proper grounding.**

<table>
<thead>
<tr>
<th>Process description</th>
<th>Maintenance cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekly</td>
</tr>
<tr>
<td>compare them with the previous</td>
<td></td>
</tr>
<tr>
<td>4- Electric transformers:</td>
<td></td>
</tr>
<tr>
<td>- Inspect transformer connections using scanning through infra red rays.</td>
<td></td>
</tr>
<tr>
<td>- Inspect assistant connector rail using sound waves for medium voltage, insulators and barriers</td>
<td></td>
</tr>
<tr>
<td>- Inspect all equipment visually in unnatural conditions.</td>
<td></td>
</tr>
<tr>
<td>- Inspect transformer and insulation oil in the breaker</td>
<td></td>
</tr>
<tr>
<td>Dry type: remove cap, inspect visually the cables and connection rails if it shows evidence of combustion or increased temperature and ensure tight connection and clean coils.</td>
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</tr>
<tr>
<td>The immersed type in fluid (oil): inspect transformer to ensure lack of holes or spoiled seal and suitability of oil</td>
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</tr>
<tr>
<td>Check transformer's tank and cooling fans for breakage, or erosion and for proper grounding</td>
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</tr>
</tbody>
</table>
### Process description

<table>
<thead>
<tr>
<th>Maintenance cycle</th>
<th>Weekly</th>
<th>Monthly</th>
<th>Bimonthly</th>
<th>Quarterly</th>
<th>Half yearly</th>
<th>Annually</th>
<th>Every two years</th>
<th>Every three years</th>
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</thead>
<tbody>
<tr>
<td>Check bushings to ensure lack of cracks, ensure tight connection and no evidence of increased heat.</td>
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<tr>
<td>Inspect all instruments and warning devices</td>
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<tr>
<td>Clean coils, internal contents and filter inspection</td>
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<tr>
<td>Perform insulation resistance test for primary and secondary coils if possible.</td>
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<tr>
<td>Test polarization indicators for transformers of 500 KVA and above</td>
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<td>Test the rated number of rounds</td>
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<tr>
<td>Perform rating test and ensure proper operation for all instruments</td>
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</table>

#### 5-Fire warning system:
- Perform all tests and inspections and their conformity to NFPA72
- Create a stable record file for all results of and inspections made
- Open the initial power source to connect warning plate and note warning sound and the emitted sound if there
<table>
<thead>
<tr>
<th>Process description</th>
<th>Weekly</th>
<th>Monthly</th>
<th>Bimonthly</th>
<th>Quarterly</th>
<th>Half yearly</th>
<th>Annually</th>
<th>Every two years</th>
<th>Every three years</th>
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<tbody>
<tr>
<td>is a problem</td>
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<tr>
<td>- Activate fire hole using a key in fire warning plate, ensure visual and audio signs are making sound and that scada system or any other system has received the warning</td>
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<tr>
<td>- <strong>Visual inspection</strong> for all control warnings and warning about water flow in all piping systems</td>
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<tr>
<td>Test all fire detectors using a standard heat source, change all defected units</td>
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<tr>
<td>Test all smoke detectors by measuring and recording sensitivity and changing defected units</td>
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<tr>
<td>Clean fire and smoke detectors and ensure that battery voltage is under the load.</td>
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<tr>
<td>Ensure suitability of operation of warning device to the primary circle.</td>
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<tr>
<td>Ensure that the remote warning is operating in a good condition</td>
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<tr>
<td>Ensure that all bulbs and warning devices works in a</td>
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## Process description

<table>
<thead>
<tr>
<th>Maintenance cycle</th>
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<tbody>
<tr>
<td>Weekly</td>
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<tr>
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</tr>
<tr>
<td>proper manner.</td>
</tr>
<tr>
<td>Conduct the test of battery unloading for operation for 24 hr system.</td>
</tr>
<tr>
<td>6- Generators:</td>
</tr>
<tr>
<td>- Operate the unit under load for 4 hrs. and then ensure standard levels.</td>
</tr>
<tr>
<td>Oil change, cooling fluid and strainers</td>
</tr>
<tr>
<td>Compare information on tag and connections with drawings &amp; specifications</td>
</tr>
<tr>
<td>Check the suitable fixing on the ground</td>
</tr>
<tr>
<td>Conduct insulation resistance for generator coils and polarity indicator.</td>
</tr>
<tr>
<td>Conduct phase rotation test for conformity with load requirements</td>
</tr>
<tr>
<td>Practical test for engine and warning controls stopping due to low oil, increase in heat and speed, or any other characteristics</td>
</tr>
<tr>
<td>Vibration test conducting, chart diagram for the apex of vibration against frequency for every main stand</td>
</tr>
<tr>
<td>Process description</td>
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<tr>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Conducting the test for load</strong> and recording voltage, frequency, load current, oil pressure, cooling fluid temperature periodically and regularly during test.**</td>
</tr>
<tr>
<td><strong>Ensure proper operation, voltage time, relays, engine sequence, delay time, operation of auto transfer, delay time re-transfer to restore power and reduced temperature of the engine</strong></td>
</tr>
<tr>
<td><strong>7- Disconnect high voltage:</strong></td>
</tr>
<tr>
<td>- Inspect the key for disconnecting connection rails through scanning by infrared rays.</td>
</tr>
<tr>
<td><strong>Inspect using ultrasound waves for connection rails assisting medium voltage, insulators and barriers</strong></td>
</tr>
<tr>
<td><strong>Visual inspection</strong> for all equipment in unnatural conditions</td>
</tr>
<tr>
<td><strong>Inspect connection rails: review results of visual inspection and ultrasound scanning.</strong></td>
</tr>
<tr>
<td><strong>Review good tying to connection rails</strong></td>
</tr>
<tr>
<td>Process description</td>
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<tr>
<td>------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Review cracks in connection rails and clean</strong></td>
</tr>
<tr>
<td><strong>Clean &amp; lubricate control switches, assistant relays and devices and ensure operation</strong></td>
</tr>
<tr>
<td><strong>Clean &amp; lubricate and adjust all disconnected switches add no oxidation material to the contacts of these switches.</strong></td>
</tr>
<tr>
<td><strong>Clean lighting ballasts and conduct insulation resistance test</strong></td>
</tr>
<tr>
<td><strong>Conduct insulation resistance test for all connection rails</strong></td>
</tr>
<tr>
<td><strong>Closed service breaks switches: complete cleaning &amp; and inspection for the switch operation mechanism after closure &amp; disconnection</strong></td>
</tr>
<tr>
<td>-Ensure switch contacts are in one line and add anti oxidation material to the main contacts</td>
</tr>
<tr>
<td><strong>Inspect fuses and record the size and type used</strong></td>
</tr>
<tr>
<td><strong>Clean insulators of all phases and review pollutants and corona defect if any</strong></td>
</tr>
<tr>
<td><strong>Complete cleaning and ensure lack of cracks in all insulators</strong></td>
</tr>
<tr>
<td>Process description</td>
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<tr>
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</tr>
<tr>
<td>Cleaning and conducting insulation resistance test to all lighting ballasts</td>
</tr>
<tr>
<td>Inspect all ground connections</td>
</tr>
<tr>
<td>Conduct resistance test and insulation resistance of the contacts and record the results</td>
</tr>
<tr>
<td>8- Motor control center:</td>
</tr>
<tr>
<td>- Inspect joints &amp; connection rails by scanning through infrared rays</td>
</tr>
<tr>
<td>Conduct inspection using ultrasonic waves for connection rails that supports low voltage, insulators and barriers</td>
</tr>
<tr>
<td>Visual inspection for all equipment in unnatural conditions</td>
</tr>
<tr>
<td>Review the recent results of the visual inspection and that of infrared rays and ultrasonic waves</td>
</tr>
<tr>
<td>After disconnection the power clean well internal control elements</td>
</tr>
<tr>
<td>Ensure correct tying to all exposed connection rails</td>
</tr>
<tr>
<td>Process description</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Clean insulators of connection rails and ensure cracks if any</td>
</tr>
<tr>
<td>Clean and lubricate control switches, support relays and devices and ensure their</td>
</tr>
<tr>
<td>operation</td>
</tr>
<tr>
<td>Clean, lubricate, and adjust contacts of all non connected switches and add anti</td>
</tr>
<tr>
<td>oxidation material to the contacts</td>
</tr>
<tr>
<td>-Conduct insulation resistance test and polarity for connection rails and feeding</td>
</tr>
<tr>
<td>pumps during connection</td>
</tr>
<tr>
<td>Test increase of load at 1255 and 600% of the rated load against break curve</td>
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<tr>
<td>Conduct evaluation test and ensure the proper operation of instruments</td>
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<tr>
<td>Connectors and lighting devices: clean all connectors and replace the defective</td>
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<td>ones.</td>
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<tr>
<td>-Check the correct tying of contacts</td>
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<tr>
<td>Measure load current and ensure proper operation</td>
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<tr>
<td>Process description</td>
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<td>9- Traffic signs:</td>
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<tr>
<td>- Inspect and ensure operation track control devices</td>
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<tr>
<td>Inspect and ensure operation of the changing sign message</td>
</tr>
<tr>
<td>10- Tunnel control system:</td>
</tr>
<tr>
<td>- Ensure that all control devices in switch board are working properly in tunnel lighting and fan operation</td>
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<tr>
<td>Test warning and lighting of the suitable feedback of devices.</td>
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<tr>
<td>- Review correct tying of connections</td>
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<tr>
<td>- Cabin cleaning</td>
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<tr>
<td>11- Tunnel lighting</td>
</tr>
<tr>
<td>- Ensure good operation of tunnel lighting</td>
</tr>
<tr>
<td>- Counting and recording lighting units day &amp; night</td>
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<tr>
<td>Replace the defective bulbs by another and increase efficiency</td>
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<tr>
<td>Clean external lighting lenses in the tunnel</td>
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<tr>
<td>Clean internal lenses when necessary</td>
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### 7-3-2-4- Preventive maintenance for track systems:
#### 7-3-2-4-1 Track & supporting structure

Inspection & preventive maintenance in this section mostly coincide creating optimum usage of inspection & maintenance teams and the equipment of each of them this do not reduce the importance of good documentation of inspection process but allows quick execution steps after discovering the defects. This prevents the development of defects in the track. Below are several step of preventive maintenance:

- **Rail lubrication:**

It is known that periodical lubrication of rails would increase its supposed age, oil should be placed on the face of the rail with keenness to adjust oil quantity to prevent ions from traveling from along the head of the rail. Lubrication can be done manually or through lubricating the outer surface of train wheels facing the rails or through rail vehicle (it has lubrication stick) that places a thin layer of lubrication on rail surface during train operation.

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<table>
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<tr>
<th>Process description</th>
<th>Maintenance cycle</th>
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| Replace all bulbs with new ones of the same type.                                   | 12- **Observation and follow up ground tanks and their connections:**  
- Conduct built in test when necessary and ensures operation of all electrical circuits; if not possible another configuration is to be used using trouble shooting manual. |                  |
|                                                                                     | Weekly Monthly Bimonthly Quarterly Half yearly Annually Every two years Every three years |
|                                                                                     |                  | •                  |                  |                  |                  |                  |
- **Rail grinding:**
  In addition to removal of defects that are found using specialized equipment in detecting rail defects, this is done for the outer surface of rails to prevent development of existing defects. Periodical maintenance through this process depends on the total amount of carriage on rails which is between one year for the track of large carriage to five years for the track of few carriage.

- **Ballast cleaning / replacement**
  Ballasts in tunnels are not exposed to residues due to weeds growth but in spite of this if water leakage happen this would transfer residues to ballasts and expose them to defects. For ballast maintenance should be removed and cleaned and in other cases they are replaces successively instead of cleaning.

- **Tie renewal:**
  The routine program for replacement of cross tie should be executed to ensure the number required and the correct placing of the same along rails.

- **Joint maintenance:**
  All joints must be riveted with good screws. Screws must be reviewed for good tying as required with (9070-13610kg) for each new screw and with (6800-11400kg) for used screws, tying interval for used screw is from one to three months from the start of tying them then yearly after that. There is primary paint layer for these that must be reviewed and repainted if required.

- **Regaging:**
  In detection section we talk about defects that happen to the regularity of the distance between the two rails and its maintenance would be urgent in case there is great change therein.

- **General aligning:**
  Track structure must be fixed directly; generally the vertical & horizontal alignment must be ensured periodically that they are in conformity with specifications and is done through automatic equipment or manually using simple equipment.
• **Spike replacement**
  They are to be replaced routinely; expected lifetime of these spikes is 6 months

**7-3-2-4-2 Power systems (third/ upper rail):**

a- Third rail system

It is useful to conduct routine inspection for this system according to what is mentioned in inspection section in addition to conducting preventive maintenance to its elements according to the following steps:

- Total alignment to the third rail to ensure stability with the regular movement rail.
- Clean rail insulators regularly to stop increased corrosion especially in wet positions near water leakage in tunnels.
- Repair or replace protection plates and bows and ensure that they are not in contradiction with joints to provide safety for workers in the tunnel.
- Repair or replace joints that are exposed to current flow on rail connections.

b- Catenary system: follow the same steps mentioned previously in the third rail; it represents an important factor in the suitable operation to the crossing systems and the train. For this reason it is important to conduct preventive maintenance program in addition to the visual inspection to reduce defects in the system according to the following steps:

- Replace broken insulators and their caps
- Alignment of hangers when they vertically and avoid cases that spoil alignment of these hangers.
- Replace joint wires by others of 10,7mm vertical thickness.
- As for jumpers and feeding points they should be removed cleaned and tied firmly and there should be full overlapping in the corroded joints.
- Ensure that electrical pipes include points to extend wires.
- Place joint wires regularly.
- Place turnbuckles on insulator stands to maintain unit level.
7-3-2-4-3- Signal communication systems:
These systems are directly related to safety reasons in rail crossing. Whenever traffic increases in the need for effective methods for communication increases during emergency; and as these one mostly composed of electrical or electronic systems they should continuously tested.

These systems include mechanical equipment that are manually or electrically operated; they must be maintained continuously. A routine maintenance program must be conducted to lubricate all moving parts in this system, clean and replace lighting bulbs in important equipment.

7-3-2-5- Preventive maintenance for accessory systems:
7-3-2-5-1 Corrosion protection systems:
Used in the two types of tunnels: roads and rail crossing; there are two types detailed as follows:

a- Cathodic protection system:
Designed to protect any metal parts in the tunnel and underground piping, grill system against defects due to corrosion. Effective maintenance is recommended for this part as it changes from tunnel to the other depending on design and also any tests for the efficiency of this system should be according to national Association of corrosion engineers (NACE).

This system is to be maintained annually and is inspected using electrical instruments as follows:

- Conduct the required adjustment to deal with variables
- Determine areas that needs protection against corrosion
- Determine area that are likely to be defected or are under construction
- Conduct tests and periodical inspection to reflect changes from economic or safety aspect.
- Determine areas that needs more follow up.
- Provide more equipment to maintain system efficiency

Half yearly inspections & tests shall be conducted for the equipment of this system as follows:

- All sources of current (transformers and power sources).
• All current protection devices (circuit breakers plates, wires and lightning arrester)
• Review current switches and wires

There are some routine procedures that are usually followed in dealing with this system:
• Repair or replace any defected parts in the protection system
• Clean & paint as required for making the required insulation
• Repair or replace jumpers.
• Replace defected wires
• Replace or repair any defected insulation devices,

**b- Stray current protection system:**

Stray current happens when supplying the rail system with DC when it be at the time of humidity and this will cause great corrosion.

The danger of this corrosion can be reduced through increasing insulation of rails and reducing humidity. In spite of this old tunnels will require updating DC systems to prevent corrosion.

**7-3-2-5-2 Safety passages, barriers and exit ladders:**

It is important to ensure that these elements which are used by workers in the tunnel in emergency cases are equipped to bear them during usage; benefit of these elements can be achieved by applying preventive maintenance as follows:

• Maintaining the area clean and free of wastes and dirt and abstaining from using pedestrian passages and ladders as storage areas.
• Preventing collection of water and ice on the surfaces of these components so that falling and slipping may be avoided.
• Insuring that all metal components are well coated for avoidance of rust.
• Coating the concrete or metal surfaces with non-skid materials.
• Insuring that all metal parts are adequately insulated against any electrical system.

**7-3-2-5-3 Ventilation facilities emergency exits:**

Preventive maintenance program must include the following:

• Keeping the area clean and free of sediments and dirt.
7-3-3- Re却ulation of structural elements of tunnels:

7-3-3-1 Introduction:

This section describes different methods for repair of certain defects in the tunnel. Water leakage is the most common cause of defect. Anyhow defects may result from non standard design or construction or unforeseen geological conditions in the land on which the tunnel is located. Of the other common causes of defects is that when the tunnel age exceeds the medium expected design age, the construction materials themselves start decaying. The repair method differ according to the reason of decay.

This section provides discussions and recommendations for tunnel repairs that comes due to water leakage paragraph (7-2-3-2) also in Para 7-2-3-3 there is detailed description of the cases of concrete failure and the methods of repair. Para (7-2-3-4- ) deals with repair of certain types of lining.

7-3-3-2 Water leakage:

7-3-3-2-1 The problem

As most tunnels are constructed deep in the soil beneath the ground water level, control of water leakage is great concern to tunnel owners. Water leakages can happen in all types of constructions of tunnels. Even tunnels that are designed to be waterproof, such as tunnels of immersed pipes that are place in water can have residues due to unsuitable joints designs, nonstandard construction, and deterioration due to chemical or biological factors in water. Water is prevented from entering the tunnel by drainage mechanisms outside the external linings or to be left in the joints. With the passage of time, the manner of water flow changes the drainage becomes closed and water finds its way through joints or cracks.

There is another scenario that could happen in urban areas that the level of ground water increases due to effects of surrounding buildings bases a thing that would make the tunnel which is designed to be above ground water level faces hydrostatic powers that it can not resist and thus water leakage becomes a problem.
Owing parties should start setting tolerance levels to be used as reference to determine design standards and start methods of repair and treatment when leakage of water exceeds the tolerance level which recently assessed as 3, 8 liter/min for every longitudinal meter.

7-3-3-2-2- consequences of water infiltration:

As expected no positive thing would happen when water leaks in the tunnel. Defects differ from surface deterioration to major defects in the structure. Most tunnels suffer problems between these limits. Below are some of the possible forms of defects that result from water leakage:

- Erosion would happen to concrete and in some cases to the aggregate leading weakening the structure of the tunnel.
- Corrosion happens I the supporting steel leading to breaking of the concrete cover.
- Screws that tie sectoral linings can decay and fall down.
- Building and mortar units can be exposed to deterioration and can inflate or break according to the chemicals in the water.
- Steel linings or plates can lose parts thereof if exposed to humidity & air.
- Small particles of soil can move with water along cracks, leaving voids behind the linings causing residues to from neighboring structures and / or causes decentralized loads on the tunnel which can lead to non-visual stresses and can also close drainage in or behind linings.
- Fixtures in internal finishes or other accessories can decay and causes danger to cars or trains.

7-3-3-2-3- Remediation methods

Generally, owners of tunnel have three options to consider when dealing with water leakage, they are: short term repairs, long term repairs, or as final solution, reconstruct all tunnel linings or parts thereof using water insulation methods that include more modern technologies.

a- Short term repairs

For certain situations, it might be necessary to redirect infiltrated water to the tunnel drainage system on a temporary basis until further investigation can be performed and a more long term solution implemented. It should be noted that certain tunnels, whether due to deficiencies in design or construction or a change in the ground water
table, will not be able to stop the water infiltration completely without a total restoration or reconstruction of the tunnel lining or at least significant portions.

Where water infiltration is a problem. Therefore, some tunnels may have to rely on a long term system that conveys the water rather than prevents the water from entering the tunnel. Long term systems will be discussed more in-depth in the next section of this chapter, but the following paragraphs cover a few methods for temporarily diverting the infiltrated water.

(1) **Drainage Troughs**

If leaks are occurring in joints at the tunnel crown in a direction perpendicular to the tunnel length, then neoprene rubber sheets can be attached to the tunnel lining with aluminum channels. The sheets can be directed to channel the water to the side of the tunnel where it can flow into the tunnel drainage system (Figure 7-33). A similar method utilizing metal drainage troughs is sometimes used to redirect isolated areas of infiltration to the drainage system.

![Figure 7-33](image1.png)

**Figure 7-33:** Temporary drainage systems comprised of neoprene rubber troughs and 25 mm (1 in) aluminum channels.

(2) **Plastic Pipe Network**

Another rather rudimentary method is to use plastic piping with one end inserted into the concrete at the main concentration of the leak. The piping can be hooked together in a network that conveys the water to the primary drainage system (Figure 7-34).

![Figure 7-34](image2.png)
Figure 7-34: Temporary drainage system comprised of 50 mm plastic pipe.

b) **Long Term Repairs**

Since water infiltration is an ongoing problem for tunnel owners, there have been a wide variety of methods and materials used to prevent the water from entering the tunnel and causing undesirable degradation. Multiple techniques have not performed favorably over the long term, but that does not necessarily mean that the method utilized was the problem. Many different factors are involved in determining which method should be used that are site specific in that the cause and volume of the water infiltration will help determine how to properly prevent it. One method might work very well for one tunnel but not another. Therefore, it is suggested that a detailed study be performed on major leaks to determine the source and amount of water leakage, and the cause and exact location of the leak. This, along with knowing the type and condition of the materials that make up the tunnel lining structure, will help determine how to address the problem. Also, the method of preparing the surface and the procedure for installing the waterproofing system should be investigated to help determine which system should be used. The following paragraphs describe a few methods that have been used to address water infiltration problems for the long term.

(1) **Insulated Panels**

Insulated panels have been successfully used to line exposed rock tunnels to allow the water to flow behind the insulation down to the primary drainage system, while being insulated to prevent water from freezing.
2.4 m by 9.6 m (8 ft by 32 ft) panels of Ethafoam insulation of 5 cm thickness that was secured to the rock using 12 mm (1/2 in) diameter galvanized steel pins set into the rock on a .9 m (3 ft) square grid (Figure 7-35). It should be noted that use of this type of system would reduce the interior clearances within the tunnel.

Figure 7-35: Insulated panels used as a waterproofing lining to keep infiltrating water from freezing.

(2) **Waterproofing Membrane**

As an addition to the method given above, a continuous, flexible membrane can be used as the waterproofing layer that allows the water to flow towards the main tunnel drainage system. The specific process that has been effectively used involves placing a geotextile material against the existing tunnel interior, then a PVC waterproofing membrane, followed by a layer of material that will protect the membrane, such as shotcrete or other fire-retardant and protective materials. The term geotextile stands for a wide variety of materials which are normally synthetic and whose main purpose are to provide a drainage gallery outside the waterproofing membrane through which the infiltrating water can freely pass. The geotextile layer also provides a physical protection of the waterproofing membrane. Refer to Figure 7-36 for a detail of this system.

This system requires a relatively smooth surface to attach the membrane, without projections that could potentially puncture the membrane. It is suggested that mock-up trials be performed to ensure that the components
of the system achieve adequate bond to each other, especially the application of a protective layer on the inside of the membrane. If shotcrete is used a minimum membrane thickness might be required as well as limiting the aggregate size in the shotcrete. If a fire retardant protective material is applied in sheets then the connection of this material through the membrane must be properly sealed to prevent water infiltration through this joint.

Figure 7-36: Section of membrane waterproofing system

This system can also be supplemented by inserting pressure relief holes into the surrounding soil/rock that provide a path of least resistance for the infiltrating water, so that adverse hydraulic pressures are not allowed to build up behind the liner. Additionally, a temperature controlled heat strip can be attached to exposed drainage pipes that prevents freezing of water in pipes and subsequent back up of water.

It should be noted that material types other than those stated have been used successfully, which include both preformed sheet materials and liquid applied materials for the waterproofing membrane layer. Therefore, research of current material technology should be performed prior to selecting the individual components of the waterproofing membrane system. The system chosen may need to be site specific given the possible presence of hydrocarbons or other chemicals that could adversely affect the membrane material. Some of the other materials available include...
polyolefin, which includes polyethylene and polypropylene, and sprayable polymer membranes. The manufacturer of the materials should be consulted and they should be able to supply material specifications and case histories of where the material might have been used successfully.

The success of this system is primarily dependent on the ability to install a continuous membrane and whether a proper connection of this membrane to the tunnel drainage system is achieved. The membrane chosen must also be able to withstand any future movement of the structure without reflective cracking and must be resistant to chemical or biological attack from the infiltrating ground water.

(3) **Crack/Joint Injection**

The most common method for preventing water infiltration in concrete linings is to inject the crack/joint with a particle or chemical grout. Particle grouts are very fine cementitious grouts that produce nonflexible fillers that prevent water from penetrating the crack/joint. Since these grouts are nonflexible, they are not recommended for any location that might experience structural movements in the future. Chemical grouts on the other hand can be highly flexible and also have low viscosities that enable them to be injected into very thin cracks. Chemical grouts are expensive, sometimes toxic or flammable and require a high degree of skill for proper application; therefore, an understanding of the chemical properties and their suitability for the desired application is essential.

Even with the drawbacks of some chemical grouts, their performance in stopping water infiltration is significantly superior to particle grouts; therefore, they are used more frequently. It is important to note that if chemical grouts are allowed to dry out they may not be as effective. This could happen if the source of the water infiltration is diverted or the ground water elevation drops below the crack location. In the event of a dry crack, repair methods discussed in Section B of this chapter should be considered.

Of the chemical grouts developed to date, the polyurethane, reactive grouts have performed the best for tunnel applications. This type of grout expands into a foam at the presence of water and subsequently seals off the crack, not allowing water to pass through. This foam is also moderately resistant to tensile forces; therefore it can expand when and if a crack/joint continues to open further. Figure 4.6 shows and explains
the procedure for properly injecting a vertical or overhead crack/joint with a chemical pi grout. It has been found that when applying pressure to inject the grout that low pressure for an extended period is better than high pressure for a short period. The latter can result in further damage to the concrete.

In addition to polyurethane chemical grouts, acrylate esters are also being used to inject cracks. The esters have an advantage over the polyurethanes in that they form a gel upon reaction with the water and serve as a barrier to water penetrating a crack. The esters will also not dry out as can occur with polyurethane grouts as described earlier. For this reason, a site specific investigation will need to be conducted to determine which material is most cost-effective over the long term.

It should be noted that cracks in masonry liners can also be injected, but often times other methods of repair are more effective for masonry over the long term. These methods will be discussed in Section C of this chapter.
Figure 7-37: Leaking Crack Repair Detail

(4) Soil/Rock Grouting (Back-Wall Grouting)

As an alternative to injecting a crack/joint (which is generally successful for stopping the leak through the injected crack/joint, but can force the water along the path of least resistance towards another crack/joint), similar materials can be injected through the lifter into the soil/rock beyond. The goal of this method is to provide a protective barrier on the outside of the tunnel lining either in specific crack/joint locations or over an entire segment of the tunnel. The material that is injected can form this
protective barrier or the injected material can introduce cohesion into the soil, which makes the soil itself impermeable.

The procedure for this method consists of drilling holes perpendicular to and through the liner on a predetermined pattern (based on ground conditions and amount of water present), and installing mechanical injection packers. Then, a grout is injected into the soil/rock and maintained at a constant pressure for a prescribed amount of time to allow the grout to penetrate small cracks in the soil/rock. There are different grouts that are available and a site-specific investigation is necessary to determine which one is best suited for the particular conditions. Some of the available grouts are:

- **Microfme cement grouts**
  Most of these grouts are used in permeable bases that includes small breaks or openings supposing that they are able to fill such openings and are used as protective mortars; it is also used to reduce permeability and increase resistance to pressures of base materials.

- **Polyurethane chemical grouts**
  These grouts are injected when they are compresses and fluid to be able to deal with leakage; upon contact of this grout with water there happens a chemical reaction then it become foam that fill the voids.

- **Acrylate ester resin chemical grouts**
- **Acrylamide-based chemical grouts (highly toxic).**

Typically the chemical grouts are more expensive; therefore, the cement grouts can be used for areas where voids exist behind the liner and large volumes of grout are required.

In the case of a steel or cast iron liner, the existing grout plug holes should be used as the location for the new grout placement, since the liner would not have been designed to handle additional holes being drilled through it.

It should be noted that this system could be used in conjunction with other systems. An example would be to back-wall grout a particular area and therefore force water to flow to a predetermined point where a drainage system could be installed. More details for installing drains within the liner are given in the next method.
(1) **Crack/Joint Repair**

If water infiltration through cracks/joints in concrete linings cannot be stopped by injecting the crack/joint as described previously because of excessive movement which surpasses the tensile strength of the grout material used, then another approach is to convert a crack into a joint that allows differential movement of the concrete, and add waterproofing components to the existing joints. Figure 7-38 portrays a method of routing out the crack or joint to a specific depth and then properly sealing off the water infiltration with successive layers of different impervious materials. The finished product will look and behave like a joint in that it will allow for some differential movement and will be watertight. As with the other repair techniques, a registered professional engineer should review and approve the application of this method to the specific site location. This is especially true for this method due to the possible weakening of the structural capacity of the lining depending on where and what direction the crack is located.

Figures 7-39 and 7-40 deal specifically with cracks and joints respectively and begin by routing or cleaning in the case of a joint.

The difference with this method is the addition of a semi-perforated pipe that is inserted into the crack/joint, which enables the infiltrating water to be collected from the exterior side of the pipe and exported into the tunnel drainage system at the bottom of the crack. The pipe can be covered with a neoprene rubber sheet (liquid neoprene is also applicable) on the exterior of the concrete or mastic and impervious mortar can be used to make the repair look just like a normal joint.

(2) **Segmental Joint Repair**

Segmental liners can be made of either precast concrete, steel, or in the case of older tunnels—cast iron. Water infiltration generally occurs at the joint location where the original lead, mastic, or rubber seal has failed. This can be corrected by repacking the joint with new sealing material and installing new gaskets at bolt holes. Cracks and joints can also be injected with particle or chemical grouts as discussed previously. In the case of precast concrete segments, the cracks are injected similar to method mentioned in Para (3). In addition, for single-pass liner systems
with any of the three segmental liner types, the processes described in method (4) can be implemented on the exterior of the liner with the precautions noted. See figures 7-38, 7-39, and 7-40.

c) **Reconstruction and New Construction**

If the tunnel degradation has advanced to a point where repairing numerous localized areas of the liner becomes cost prohibitive, it may be necessary to reconstruct larger areas using different techniques. This could include shotcrete or pumping plasticized concrete within a form liner. There are several relatively new technologies that are being used for new tunnel construction that can also be incorporated into reconstruction procedures, with some modifications. These methods generally attempt to prohibit the water from infiltrating the final liner and thus entering into the tunnel space. This is accomplished by collecting the water and draining it away either within the liner or on the exterior of the tunnel. The latter method is less common because the drains can become clogged with fine soil particles. In addition, using an exterior drainage system in a tunnel below the ground water elevation is normally not effective over the long term because of the ability for water to penetrate very small cracks that develop between drains.
Figure 7-38: Repair of a Concrete Joint or Crack By Inclusion of a Neoprene Strip
Figure 4-8: Treatment Of Cracks By Membrane Covering
There are various detailed techniques that will only be explained briefly, although many of these are complex in nature. Furthermore, should an extensive repair be needed, it is recommended that a specialized consultant be obtained to develop possible solutions that are specific to the tunnel in question. The following paragraphs describe available systems for extensive lining reconstruction or that are also applicable for new tunnel construction.

(1) **Shotcrete Applications**

The use of shotcrete in tunnel construction has greatly increased since the advent of the Sequential Excavation Method (SEM) and the improvement of the shotcrete materials and application processes used. A few of the general material classifications for shotcrete are cementitious, latex/acrylic-modified, or two-component epoxy. Shotcrete can also be used in tunnel rehabilitation in various forms. One method is to simply coat the entire interior of the tunnel walls and ceiling with a mix design that makes the cured shotcrete relatively impervious to water. This method has some drawbacks that include decreasing the tunnel clearances and trapping the moisture inside the original liner. Trapped moisture can
lead to deterioration due to chemical reactions between the water and the liner material, especially in masonry.

Another more in-depth procedure is to remove all or portions of the existing liner, replace it with a structural layer of shotcrete, then place a geotextile layer and waterproofing membrane (either sheet membrane or sprayable polymer membrane), and finally provide a protective, non-structural finish liner of shotcrete on the inside that initially adheres to the waterproofing membrane during curing. As mentioned previously, the membrane thickness and shotcrete aggregate size may have restrictions placed on them in order to ensure that the membrane is not damaged during the shotcreting procedure. It is possible to place another geotextile layer or other protective material on the inside of the membrane, but attachment of this layer is difficult since the attachment mechanism has to puncture the membrane. The thickness of this liner is dependent on the tunnel size and shape and the amount of water infiltration that is expected. It is recommended that a detailed site investigation be performed to determine if this final lining will need to resist any hydrostatic loadings. This method allows water that penetrates the initial liner to be directed down the tunnel along the waterproofing membrane to the primary tunnel drainage system. The existing liner can be removed with traditional demolition techniques or, depending on the depth of removal desired, a modern laser-controlled cutterhead mounted on a boom as shown in Figure 7-41 can be used to remove precise depths of masonry, concrete or rock.
Figure 4-10: Laser controlled cutter for removing portions of existing tunnel liner.

(2) **Joint Control**
Deteriorated joints can be repaired as described previously in this chapter, Para 7-2-3-1, Part 3b (5). It is not often that there is an opportunity to completely reconstruct a joint in an existing tunnel. However, when there is a complete tunnel reconstruction or new tunnel construction, the joints can be fitted with a new system that allows the joint to be initially injected with chemical or particle grouts and to be reinjected at any future time that the joint might begin to leak due to settlement of the structure. Also, products exist that can be inserted at anticipated crack locations that actually facilitate crack development at that location. Once the crack occurs, the product can be injected with a chemical or particle grout to stop water infiltration.

(3) **Concrete Design**
One of the most effective methods of preventing water infiltration in reconstruction or new construction is to properly design the concrete or shotcrete mix to approach impermeability and to not be as susceptible to cracking. This is primarily done by ensuring adequate reinforcement and limiting the water/cement ratio to 0.45. Other considerations include the use of water reducing and shrinkage reducing admixtures. Another admixture that is increasing in usage is a waterproofing additive. This admixture reacts
with the fresh concrete to produce crystalline formations throughout the cured concrete that resist the penetration of water.

When major repairs or reconstruction is required, a detailed site-specific investigation should be undertaken to determine what methods and materials can be applied based on current research and experience.

7-3-3-3 Concrete Repairs:

As concrete deteriorates, it is important that proper repairs be made to avoid further degradation of the structure. The repairs must be durable, easy to install, capable of being performed quickly during non-operating hours, and cost-effective. The repairs included in this manual are commonly used and have been performed in various tunnel locations.

The defect must first be evaluated to determine the cause and the severity of the deterioration, in order to select the best repair method. Factors affecting the repair are the severity to which the concrete has deteriorated, whether water infiltration is the cause, location of the repair to be completed, and the structural impact of the defect. Repairs should not be made until the cause of the defect has been determined and the situation remedied, or the same problem may repeat itself in the newly repaired concrete.

It should be noted that many concrete linings in highway tunnels have an additional tunnel finish that covers the concrete and therefore may hide the extent of the deterioration. This finish commonly is porcelain tile or prefabricated metal or concrete panels. Therefore, a repair analysis will need to account for the replacement or repair of the finish as well. Concrete deterioration in tunnels may be caused by any of the various factors listed below.

• Water Infiltration - Refer to Para 7-2-3-2 for a discussion of the negative effects of water infiltration and suggested methods of repair.

Corrosion From Embedded Metal - Several factors contribute to accelerate the HJ corrosion of embedded steel, such as oxygen, water, stray electrical currents, chemicals, chlorides, and low pH (acidity). Once the corrosion has begun, a signs of this problem are delamination (a separation of the concrete from the embedded steel), surface spalling, or cracking. Cracks may have existed previously that permit deleterious elements access to the reinforcement steel.
Disintegration of Material - Certain chemicals like acids, alkaline solutions, and salt solutions are common enemies of concrete. Acid attacks concrete by reacting with the calcium hydroxide of the hydrated Portland cement. This reaction produces a water-soluble calcium compound, which is then leached away.

Porous concrete will absorb water into small capillaries and pores. Once there, the water freezes, then expands and exerts tension forces on the concrete. Near the surface small flakes of concrete will break away causing further exposure and eventual spalling and removal of aggregate with the process continuing inward.

Thermal Effects - Thermal loads cause the concrete to expand and contract putting undue stress on the concrete. This expansion and contraction can lead to cracking. However, due to the relatively uniform environment within a tunnel, this form of degradation of the concrete is limited to areas near portals and possibly within air plenums where temperature fluctuations are more likely.

Loading Conditions - Load placement will have varying effects on concrete. For continuous concrete spans in roadway slabs over air ducts, cracks may develop over the underlying steel support on the slab topside. In the center of the span, cracks will develop on the underside of the slab. Shear cracks may also develop near the support.

Poor Workmanship — Workmanship is critical to overall concrete performance. If the reinforcement steel is placed improperly, if there is insufficient vibration to consolidate the concrete, if the concrete is permitted to segregate when placing, or if the concrete is not finished or cured properly, then the strength and long-term durability of the concrete will be affected.

Once the defect has been evaluated and the cause determined, one of the following potential repairs should be implemented:

7-3-3-3-1 Crack:

The most common defect found in concrete is a crack. For cracks where water infiltration or moisture is present, see Para 7-2-3-2 for methods of repair. For cracks that are void of water, and movements are not expected, the crack can be filled with an epoxy resin. For cracks on a horizontal surface, the crack may be gravity filled with epoxy by constructing a temporary dam (see Figure 7-43). However, the underside of the concrete surface may need to be sealed, if it is accessible, to prevent the resin from
running completely through the crack. For vertical and overhead cracks, a paste gel is placed on the surface of the crack, around the injection ports to contain the resin that fills the crack. See Figures 7-42 and 7-43 for examples of this repair.

7-3-3-3-2 Spall:

A spall is an irregular shaped depression in the concrete in which the fracture is parallel, or slightly inclined, to the surface. It is caused by the separation and removal of a portion of the surface concrete, typically due to corroded reinforcement steel, where the tensile stresses in the concrete exceed the tensile capacity. However, some spalls may occur that do not have any exposed steel. Depths of spalls vary and for repair purposes can be classified as either shallow or deep. A shallow spall typically penetrates less than 50 mm (2 in) into the concrete, whereas deep spalls penetrate 50 mm (2 in) or more into the concrete and usually expose the reinforcement steel within. Reinforcement steel can also be exposed in a shallow spall if it was originally placed too close to the surface of the concrete, resulting in a pop off of the concrete cover.

Special attention needs to be given to determining the cause of any corrosion on the reinforcement steel. If corrosion is due to water infiltration from the exterior of the tunnel, then the methods and materials given in this section may not be adequate to resist the effects of future infiltration. For this situation, it is necessary to address the water infiltration using methods given in Para 7-2-3-2. But, if a complete restoration of the original concrete surface is desired, the following methods can be used.

If the inspector recommends that the spalls should be repaired to preserve the integrity of the concrete, the following procedures may be utilized:

a) Shallow Spall With No Reinforcement Steel Exposed (See Figure 7-44)

This repair is typically performed for aesthetic reasons and not necessarily for structural integrity of the lining. Suggested steps include:

• Remove all loose or delaminated concrete on the spall surface.
Provide temporary dam each side of crack to control flow of gravity. Feed epoxy resin into crack

Type CR-2 cracks

Top of existing concrete

Temporary dam each side of crack

Fill crack with epoxy resin

Seal underside of concrete if accessible and if needed to retain resin in crack

Figure 7-42: Horizontal surface crack repair detail (for cracks 0.8 mm (1/32 in) wide and greater)
Figure 7-43: Vertical/Over Head Crack Repair Detail

- Clean the concrete surface of deleterious materials.
- Sawcut around the spalled area on a 20-degree angle.
- Place polymer repair mortar in the spall to original concrete depth.

b) Shallow Spall with Reinforcement Steel Exposed See Figure 7-45)

If the exposed reinforcement steel is only slightly corroded with no significant section loss, then this repair method can be used. If, however, the corrosion appears to be deeper than the current spall depth, or if the spall extends behind the reinforcement steel, it is recommended that the extent of the corrosion be determined and the spall be repaired by the method given in Para 7-2-3-3-2). Suggested repair steps include:

- Remove all loose or delaminated concrete around the exposed reinforcement steel.
• Clean the reinforcement steel of any corrosion.
• Coat the reinforcement steel and the concrete surface with an anti-corrosion coating.
• If replacing the spalled concrete is recommended, then, prior to application of anti-corrosion coating, perform sawcut as described in Part a) and place polymer repair mortar as final step. Make sure that anti-corrosion coating and polymer repair mortar are chemically compatible.

c) Deep Spall With Reinforcement Steel Exposed See Figures 7-46 and 7-47)

Generally, any exposed reinforcement steel in a deep spall will be corroded. The extent of this corrosion should be determined and the
concrete should be removed around the affected reinforcement steel to a width of at least one half the existing reinforcement steel spacing and to a depth of at least 25 mm (1 in) behind the back of the reinforcement steel. It is recommended that the sawcut around the perimeter of the spalled area be at least 25 mm (1 in) deep to accommodate a repair material with aggregate. If the material being used does not include aggregate, that depth can be reduced to 6 mm (1/4 in), given that a proper bonding agent is used. As for bonding agents, experience has shown that separate, manual application is often not performed correctly and insufficient coverage is obtained. Therefore, a bonding agent admixture can be substituted for a certain percentage of the water in the mix. Specific repair recommendations are as follows:

- Remove all loose or delaminated concrete from the spalled surface and face of the reinforcement steel.
- Clean the concrete and steel surfaces of deleterious materials.
- Sawcut around the spalled area.
- Provide new reinforcement steel where necessary and overlap with existing steel according to standards.
- Coat the reinforcement steel with an anti-corrosion coating.
- Place polymer repair mortar in the spalled area unless the area is very large such that the use of shotcrete or plasticized concrete pumped with a form is more cost-effective. Where shotcrete is used, additional welded wire fabric is recommended to help support the shotcrete.

7-3-3-4 Liner Repairs:

A general note that applies to all the liner repairs suggested in the following sections, is that a registered professional engineer should evaluate and approve suggested repairs and methods used. Particular attention should be directed to determining if structural components need to be temporarily shored so that the component to be repaired is unloaded.

7-3-3-4-1 Cast-in-Place (CIP Concrete)

CIP concrete liners are common in both highway and transit tunnels because of strength, cost, adaptability to site conditions, durability and resistance to corrosion (if designed and constructed properly), and ability to obtain a smooth surface for the final tunnel finish (tile, metal panels,
etc.) application. Although there are many benefits for using CIP concrete liners, they may also have extensive repair needs to remedy.

![Image of shallow spall repair detail](https://example.com/spall_repair.png)

**Without Polymer Mortar**

Cracking, spalling, and reinforcement steel deterioration. These effects could be due to water infiltration, inadequate design/construction, age, or unforeseen changes in ground conditions surrounding the tunnel.

The methods for repair of CIP concrete liners are the same as those given for general concrete in Para 7-3-3-3-1 and 7-3-3-3-2, but will briefly be reiterated below for reference.

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**Figure 7-45: Shallow spall repair detail**

*(Shallow spall with reinforcement steel exposed)*
Figure 7-46: Deep Spall With Exposed Adequate Reinforcement Steel (Using Polymer Repair Mortar, Plasticized Concrete Or Shotcrete)

- If water infiltration is occurring, then methods of water redirection, crack injection, soil grouting, or membrane application should be performed prior to actual concrete repair.

- If dry cracks need structural repair, epoxy resins can be injected, but a determination must be made if there are active movements at the crack. If actively moving cracks are epoxy grouted, then subsequent cracks adjacent to original crack may occur depending on the elastic capacity of the epoxy material. Other materials with cellular structures can be used for active cracks.
- Spall repair is dependent on the size and depth of the spall and can be repaired with a polymer mortar for smaller spalls or with a plasticized concrete or shotcrete for larger spalls. Care must be given to cleaning or replacing exposed steel that has experienced corrosion and section loss.

Figure 7-47: Using Polymer Repair Mortar, Plasticized Concrete or Shotcrete

Oftentimes in highway tunnels, the CIP concrete liner is covered with a reflective material such as tile or metal panels; therefore, the repair
technique must take into account the attachment requirements of the final tunnel finish.

Another retrofit method that is being used more often for strengthening concrete tunnel linings is carbon fiber, polyaramide glass fiber sheet products. This method is performed by first completing crack and spall repairs, and then the concrete surface is prepared as per the manufacturer's instructions. An epoxy coating is applied to the concrete surface and the fiber sheets are installed in two layers, the sheets with fibers in the transverse (circumferential) direction are installed first followed by sheets with fibers in the longitudinal direction. The sheets are impregnated with epoxy.

This type of retrofit can be used to increase the load capacity of the tunnel arch when there is increase in the weight of overburden, this will also help to prevent further cracking and exfoliation of the concrete lining.

**Caution:** This method should not be used in areas where fires or excessive heat may occur, due to the possible flammability and toxicity of the materials used. In the event of a fire, these materials will fail and therefore the concrete lining will lose any structural improvements provided by the carbon fiber sheets. Also, this method is not recommended in areas of the tunnel that might experience water infiltration.

7-3-3-4-2 **Precast Concrete:**

Precast concrete liners are often used as a primary liner that is placed by the TBM or manually within the shield of a driven tunnel. They are used because of their easy adaptability to site conditions, and speed of erection. In highway tunnels, the precast concrete liners are often covered with an interior cast-in-place concrete liner for supporting the tunnel finish as described previously. Conversely, transit tunnels, which do not have the same visibility constraints, sometimes use a single precast concrete liner with no interior finish; therefore repairs are made to the precast directly. Generally precast segmental liners are bolted together to compress gaskets in the joints to prevent water infiltration and to provide overall structural stability to the liner.

Repair of precast segmental concrete liners is often related to degradation of the joints, especially in tunnels subject to water infiltration. The joint material can fail and corrosion of the bolts can lead to spalling of the
concrete, which can expose the reinforcement steel, subsequently subjecting it to corrosion effects as well. Obviously, the ideal is to repair the joint before the corrosion becomes too extensive; therefore a routine inspection is crucial. As mentioned previously in the water infiltration section, the method of repairing a joint consists of repacking the joint with new gasket material and replacing any bolts that have lost their structural capacity. Also, the joints can be injected with grout to help seal them off to water.

Other defects such as cracks and spalls that can occur within a precast panel can be repaired using the same methods given in either Chapter 4, Section A or B depending on whether water infiltration is present.

7-3-3-4-3 Steel:

Within a tunnel, structural steel is used for two main purposes: as segmental steel liners and as structural columns or beams. Structural columns and beams are mostly found in transit tunnels although steel beams are also used in structural slabs for support of roadway or overlying buildings and tunnels. As with structural steel in other uses such as bridges and buildings, the primary method of failure is by corrosion caused by moisture, which in transit tunnels can be enhanced by the presence of stray current from the rail electrification system. It is also possible for steel to develop cracks due to improper design/erection, fatigue, or from defects in the material.

To repair these defects, it is necessary to determine the cause and actual extent of the damage. Typically this will be done during the inspection process and will be recorded for reference in determining the type of repair. One general note is that for older structures the weldability of the steel must be determined due to the wider range of chemical composition allowed in their fabrication.

If the existing steel utilizes welded connections, then it is safe to assume that the steel is weldable. But, if there is any doubt, then the steel should be tested according to American Welding Society (AWS) standards.

Below are examples of repair procedures that can be used for steel defects:

• If beams or columns made from W-shapes, T-shapes, or channels have significant section loss (greater than 20 percent), then consider welding or
bolting plates to flanges or webs to increase the capacity in the area of the section loss.

• For steel segmental liners that have section loss or considerable corrosion of the panels, then plates can be welded on the interior surface to replace the area of section loss.

• If liner joints and bolts are corroded, then new joint material must be installed along with new bolts. If stray current is suspected, then install an insulating sleeve over the bolt to prevent current from passing between dissimilar metals.

• Painting the steel is the best method for preventing corrosion. Research should be conducted to determine the best paint type for the given situation. Traditionally, epoxy paints have performed well for steel. Prior to painting, existing steel should be blast cleaned of all present corrosion - down to white metal.

• If clearance is adequate, headed studs may be welded to the liner and then a layer of reinforced concrete or shotcrete can be constructed inside the steel liner. If welding is not practical, threaded rods that anchor the rebars may replace steel bolts that connect the liner segments.

7-3-3-4-4 Cast Iron:

Cast iron is similar to steel in the extent of its use for tunnel construction, such as the primary tunnel liner segments and columns (usually tubular) in open areas of transit tunnels. Cast iron differs from steel in that it is not as susceptible to corrosion. Generally cast iron is far less ductile than steel and therefore brittle failure and cracking can be more common.

Repair of cast iron defects is much more difficult than for steel and therefore a detailed, site-specific investigation is required to determine the proper method for repair. However, there are some general comments that can be made about repair methods that can be used.

a) Bolting

It is possible to bolt new cast iron members over existing cracks, or areas of corrosion. When doing so, a watertight connection must be accomplished. If the repair is at a joint between liner segments, then the joint itself could be made watertight by inserting gasket material or by injecting the joint with a chemical grout. If the repair is the addition of a plate over a crack or area of section loss in the panel, then a
waterproofing material will need to be applied between the new piece and the existing lining.

b) **Welding**

In general cast iron that is used in tunnels should **not** be considered weldable. Depending on the type of cast iron (gray, nodular, white, malleable, etc.) and the accessibility of the item to be repaired, some welding techniques can be attempted. Significant expertise is required and preheating is necessary, which is difficult since the cast iron components in a tunnel are not usually removable. Therefore, other methods of repair will usually be recommended.

c) **Concrete Liner**

Similarly to steel liners, if clearance is adequate, a layer of reinforced concrete or shotcrete can be added inside the cast iron liner. However as mentioned above welding is not usually an option, so replacing bolts or rivets that connect the liner segments with threaded rods to anchor the rebar is suggested.

d) **Metal Stitching**

Technology does exist to stitch the cast iron in a manner illustrated in Figures 7-48 to 7-50. It is recommended that if the cast iron cannot be repaired using other methods, that this method be investigated. Currently, this method is being used with much success on high-pressure castings such as water pumps, valves, compressors and pipes, which demonstrate that the method provides a high strength, watertight repair. This process can restore the original strength to the casting without the problems associated with on-site welding such as stress, distortion, hardening and additional cracking because heat is not used in the repair process.
Figure 7-48 - Metal Stitching Detail

Figure 7-49: Metal Stitching Procedure
Shotcrete:

Shotcrete is a material that is gaining increasing usage for tunnel construction as materials and methods of application continually improve. Another terminology that is sometimes used is "gunite," which refers to fine-aggregate shotcrete. There are various uses for shotcrete in tunnel construction and each use may require a different mix design and application method. Primarily it is used as a primary support liner for the excavation prior to the construction of the final liner. This procedure can be supplemented with rock bolts, lattice girders, or wire mesh for additional strength. More recently with the addition of steel or synthetic fibers and fine-aggregates, shotcrete has been able to be used as a final liner, which can achieve significant strength in thin, smooth layers. Shotcrete can be used to cover and protect a waterproofing liner or as a repair liner for tunnel rehabilitation.

Generally, cured shotcrete will behave similarly to standard cast-in-place concrete and will be susceptible to cracking, spalling and delamination, even though the mix designs were intended to reduce those effects. If repairs need to be made to shotcrete liners, they can be performed in the same manner as the methods given in 7-3-3-4-1- and 7-3-3-4-2-, depending on whether water is present at the defect.
7-3-3-4-6 Masonry:
The term "masonry" refers to materials such as stone or brick that are connected together in the field with mortar, which in the case of brick tunnel liners could be five or more courses thick. In older tunnels—generally those built in the 19th century—masonry was the construction material that was most readily available and economically possible for construction of the liners. Oftentimes, even after concrete and steel began to be used as construction materials for cut-and-cover tunnels, masonry was still used as a protective liner for the mastic waterproofing that was used on the outside of the finished lining. Masonry liners that are still in existence today range from very good condition to very poor condition, depending on the severity of any ground water presence. If they were constructed within geologic conditions that kept them relatively free from the presence of ground water, the masonry itself could last without much attention for a very long time. This is proven by the fact that most of the world's historic tunnel structures were constructed with masonry and still exist today.

Another reason that masonry tunnel liners remain in good condition is that the original method for waterproofing against, or draining of, the ground water was and remains very effective. The original waterproofing system typically consisted of a timber primary support lining and void space between the timber and masonry that was filled with tunnel debris, which formed a drainage channel for ground water. Over time, the timber lining rots and the water erodes the material that filled the void, causing the masonry itself to be exposed to the water.

When masonry is exposed to water, it and the mortar can swell and become brittle depending on the firing temperature of the brick and the chemical make up of the mortar. This, in conjunction with possible ground collapse in the space behind the brick lining, can induce stresses into the lining that cannot be resisted and therefore, structural cracking occurs, which further exacerbates the water infiltration problem.

If it is determined that repairs are needed, then the actual cause of the deficiency needs to be determined in order to select the proper repair method. If the problem is caused by extensive water infiltration, then methods given in 7-2-3-2-3 should be considered, otherwise the following are suggested:
- Inject cementitious grout into known large voids behind liner to stabilize ground material. If waterproofing is needed, use methods described in Para 7-2-3-2-3(b)(4).
- Replace cracked or brittle masonry units in localized areas.
- Repoint mortar by removing existing mortar to depth of twice the joint thickness or 18 mm (1/4 in) minimum and replacing with new mortar of equal strength and color but increased water impermeability.
- Provide horizontal reinforcement steel embedded in the joint across the crack prior to repointing, for added strength.
- Inject cracks with chemical or particle grouts (take care to use grouts that are suited for the moisture content present in the crack).
- Apply a shotcrete lining if vertical and horizontal clearances can be reduced. However, underlying causes of cracks and water infiltration must be addressed first. One repair that is not recommended is to apply an impermeable coating—such as a paint or epoxy—to the interior surface of the masonry. This practice is discouraged because any moisture or water that enters the masonry will be trapped and cause swelling; inevitably the face of the masonry will delaminate and fall off.

7-3-3-4-7 Exposed Rock

Many older tunnels that were constructed through dry, sound rock conditions, were left unlined except for zones near the portals or where the rock was incompetent to carry the loads. These tunnels may function without need for repair long into the future, but it is more likely that ground movements will either cause pieces of rock to fracture and fall to the invert, thus endangering the tunnel occupants, or they will open up cracks in which water will eventually infiltrate into the tunnel space. For the latter situation, some type of waterproofing liner, membrane, or pipe network will most likely need to be installed at the location of the leak to divert the water towards the tunnel drainage system.

If water infiltration is not a concern, then there are methods that can be used to structurally support the exposed rock, so that it does not pose a threat to the tunnel occupants. Listed below and shown in Figure 7-51 are some examples of those methods:
• Metal plates attached with short anchor bolts can be used to support surface defects. The plates can vary in width and length as needed to cover fractured rock.

• Rock bolts can be used to secure thicker sections of fractured rock to a competent layer behind. Examples of rock bolts are standard rock bolts, cable bolts, or friction bolts (dowels). They can sometimes be pre-stressed, but normally the stress is induced during future ground movements. Also, they are normally grouted into the drilled hole using chemical or particle grouts, but can be anchored mechanically for short-term applications.

• To protect from small spalls or pieces of fractured rock, wire mesh (chain link) can be attached to the surface using rock bolts.

• To completely protect against falling debris and to increase the structural capacity of the liner, shotcrete or a thin cast-in-place liner can be installed. However, this process does reduce the interior clearances.

## 7-4 Safety requirements in tunnels:

### 7-4-1 Introduction

The aim of this part is to achieve steady, regular and high standard of protection to all tunnel users. Safety standards should be able of the following:

• Qualify safety team to protect themselves during rescue operations.

• Allow them to act quickly to prevent more of the consequences of the accident with ensuring the effectiveness of application

• Protect environment and limit the spoilage of its resources.

Also owning parties should seek to execute safety levels similar to those in tunnels constructed in the concerned area. There are five pivots connected to safety procedures in tunnels, they are:

• Administrative power

• Tunnel manager

• Safety officer

• Construction inspection

• Risk analysis
7-4-2 Safety pivots in tunnels:

1- Administrative power
This power may be at a national level, regional or local and means the owner parties of the tunnels. The tunnels under the responsibility of the administrative power is represented in municipalities and all are under the responsibility of MOM for the tunnels inside towns; for tunnels on highways between towns they are under the responsibility of the Ministry of transport. the administrative party has the authority to supervise the operation of the channel and should be keen about inspection, testing and maintenance of the tunnels periodically on scientific bases.

2- Tunnel manager:
This is an administrative power responsible of tunnel management. In case of a big accident the tunnel manager prepares an accident report that is passed to the safety manager and then to owners of the tunnel and lastly to emergency services.

3- Safety officer
This is the first to be approved in the tunnel hierarchy and his tasks are as follows:

- Coordination with emergency services
• Participate in inspection tasks, execution and evaluation of emergency operations.
• Participate in determination of safety projects and drawings and establishment specifications.
• Ensure that operation 7 emergency services teams are trained properly.
• Participate in evaluating any serious accident.

4- Establishment inspection

Owning parties should ensure that inspection; evaluation and test operations are done as required with high quality procedures and should be functionally independent of tunnel management.

5- Risk analysis

It is the study of knowing the risks of any tunnel taking in consideration design and traffic conditions that affect safety in addition to the length of the tunnel, its engineering shape and the expected number of cars passing through it.

Risk analysis include:

• Structural measurement alternatives
• Tunnel characteristics
• Longitudinal ventilation of the tunnel that extend up to 1000m in the two directions
• Identification of by-laws and the requirements regarding transfer of goods through the tunnel.
Below is the hierarchy that takes over safety operations

Organizational hierarchy of safety operation in tunnels
7-4-3 Safety applications & related issues:
There are some issues that concerns safety which must be discussed, they are:

- No of tracks and longitudinal slopes
  Two compulsory tracks should be made in case of traffic is more than 10000 car / day according to the evaluation of the last fifteen years; regarding longitudinal slopes it will be less than 55 according to the geographical nature of soil.

- Tunnel closing equipment:
  They are barriers in front of the tunnel; they are compulsory for tunnel of more than 1000 meter length. Consultant recommend placing of traffic signs every 1000m in tunnel of more than 3000m with control center.

- Emergency stations:
  They are composed of a box placed near the tunnel wall or an opening in the wall is made for it. It should be provided with two fire extinguishers and be distributed every 150m in new tunnels and every 250m in already constructed tunnels (fig 53).

- Side platforms:
  Compulsory every 1000m for two way tunnels whose length exceeds 1500m without emergency tracks and before constructing them the feasibility and effectiveness study should be evaluated, fig 7-54.
Emergency exits should be constructed in new tunnels provided that the distance between each one should not be more than 500m; regarding emergency exits in old tunnels, the feasibility study must be evaluated for the construction of the same. Also the doors of such exits must be anti smoke and heat and forbid them entering the tunnels, fig 7-55.

- Emergency corridors for pedestrians:
  They are compulsory in two way tunnels which shall be of the same level, fig 7-56.

- Transit passages for rescue services:
  Shall be compulsory for double tunnels which are on the same level, Fig 7-57.
Figure 7-55: Emergency exits

Figure 7-56: Pedestrian emergency passages

Figure 7-57: Passages for rescue services
• Tunnel lighting
Supply and install lighting systems of different forms: ordinary, safety lighting and emergency lighting (evacuation) that shall be at 1.5m height, the nearest exit shall be distinguished by wall lighting bulbs and shall be at distances not exceeding 25m Fig 7-58.

Figure 7-58: Tunnel lighting

• Water sources
Shall be compulsory in tunnels whose length exceeds 500m and shall be at distances of 250m, Fig 7-59

Figure 7-59: Water sources
• **Drainage system:**
  Shall be compulsory in case there are dangerous goods to be transported.

• **Tunnel ventilation**
  Shall be compulsory in tunnels whose length exceeds 1000m and the traffic size therein exceeds 2000 car/track; longitudinal ventilation shall be applied in two-way tunnels. Regarding two-way tunnels where traffic size exceeds 2000 car/track and their length exceeds 3000m, cross-ventilation is used; it should be noted that air and smoke exhaust fans can work separately or in groups; follow-up must be performed for the air speed in longitudinal ventilation and that the equipments are in their proper situation, fig 7-60.

![Figure 7-60: Ventilation system in the tunnel](image)

• **Follow up and observation systems:**
  Video systems are able to discover tunnel accidents and fire and this would need control center; in case this is not available automatic systems for fire detection shall be provided and installed, fig 7-61.

• **Communication system:**
  Wireless broadcasting equipment to be installed in tunnels whose length exceed 1000m with traffic size exceeds 2000 car/track; in case there is control center wireless broadcasting can be stopped to send an emergency message; in case of emergency evacuation loud speakers are used to notify the users of the danger, fig 7-62.
Control center shall be supplied and installed for all tunnels whose length exceeds 3000m with traffic size of more than 2000car / track; control of many tunnels can be centered in one tunnel, fig 7-63

Design stage:
Description of the construction drawing and manner of dealing with the same.

- Study of traffic expectations to specify expected conditions of transporting dangerous goods with analysis of such risks.
- Investigation of accidents that may happen that affect the safety of tunnel users.
- Opinion of safety and security consultants or the specialized companies.
Figure 7-63: Control center.

- **Testing stage**
  - Safe documentation of design stage.
  - Description of the company (organization), human resources, materials, instructions of the tunnel manager that show tunnel operation & maintenance.
  - Emergency plan that takes in consideration the handicapped persons.
  - Description of the feedback system that is specialized in specifying which type of accident to be recorded and analyzed.

- **Operation stage:**
  - Secure documentation of design stage.
  - Secure documentation for testing stage
  - Preparation of reports and analysis for important accidents
  - Preparation of a list of executed safety trainings and the lessons learnt.

- **Periodical training**
  Tunnel manager & emergency services section shall with coordination with safety officer organize periodical exercises for the team working in the tunnel to avoid risks every four years at least; it should be extensive and factual; safety officer with emergency services section shall evaluate these trainings and prepare reports about the same.

- **Traffic signs inside the tunnel**
  Traffic signs that are for safety means must be used inside the tunnel as follows:
• Side pavements
• Emergency exits
• Exit ways
• Emergency stations
Chapter 8

Culverts
Chapter eight: Culvert

8-1 Introduction:
This section is part of tunnels maintenance manual that belongs to MOM in the kingdom of Saudi Arabia, department of technical affairs, operation & maintenance directorate; generally it includes two main parts which are culverts inspection & maintenance, this included types of culverts, contents of the forms used in inspection operation, defects of materials used in construction, evaluation of level of defects, methods and maintenance strategies and methods of updating.

8-2 Definitions:
A culvert is a structure under a road having only clear openings of less than or equal to three meters measured between the faces of piers and/or abutments and pipe shaped structures of any diameter. They are for the drainage of rain and flood water.

Culverts are an important component of road network. Compared to bridges, culverts are smaller and less critical structures buried beneath the road embankment However, failure of culverts can be a hazard to traffic. They constitute an asset that is subject to deterioration and therefore they must be managed appropriately. The total investment in culvert structures is considerable.

8-3 Culvert Inspection Procedure:
The culvert inspection process is essentially visual in nature. All defects must be noted and photographed as they may be the first indications of underlying problems. Where the condition of critical components is not clear during the culvert detailed visual inspection, engineering support or further investigation may be necessary to confirm the condition and identify any problems. The need for additional inspections must be noted in the inspection report. Where there is no visible defect, the form shall be marked and completed appropriately.

8-3-1 Types of culverts:
Types of culverts as regards the engineering shape, type of material used in construction according to their location in roads network and geographical nature of the area, below is a statement of common culverts types:
a- Arc culvert
Fig (8-1)

![Figure 8-1: Arch culvert](image)

b- Wooden culvert
Fig 8-2

![Fig 8-2: Wooden culvert](image)

c- Box culvert
Fig 8-3

![Fig 8-3: Box culvert](image)

d- Circular type of culvert
Fig 8-4
e- Bed log type of culvert

Fig 8-5

**Figure 8-5: Bed log culvert**

### 8-3-2 Culvert inventory data
The most important of these information:

1- Culvert number
2- General information
3- Culvert type
4- Culvert material
5- Number of barrels
6- Barrel length
7- Skew
8- Horizontal & vertical size
9- Diameter

### 8-3-3 The Detailed Visual Culvert Inspection
The Detailed Visual Culvert Inspection Report is compiled on a standard form. Inspection items include the delineation, waterways, walls and aprons, and culvert units.

The structural components of a culvert are:
1. Side walls of the culvert units;
2. Top (or overt) of the culvert units or link slabs, the culvert's superstructure or spanning component;
3. Base of a culvert or invert;
4. Headwalls if they are in the adjacent area of the formation of a road and are thus load bearing; and
5. Wing walls if they are in the area of the formation of a road and are considered tall enough to cause stability issues if failure occurs.

Detailed visual culvert inspection form includes:

**8-3-3-1 General Information:**

Certain general information heads the Culvert Detailed Visual Inspection Report form. Most of this data does not change over time and can be entered from drawings or previous inspections prior to the site visit but shall be checked on site to confirm.

**8-3-3-2 Walls & Aprons:**

Separate comments are required for headwalls (LHS, RHS), wing walls (LHS 1, LHS 2, RHS 1, and RHS 2), abutment and pier walls, and aprons where these items are present. Exception reporting is required for defects such as material defects, impact damage, cracking, spalling, honeycombing, corrosion, coating defects, undermining and settlement/movement.

**8-3-3-3 Delineation:**

The condition of the delineators (e.g. width markers, guide posts) includes identifying any missing, damaged or obscured culvert delineator items. The condition of any barriers at a culvert location should also be recorded.

**8-3-3-4 Culvert Units:**

Comments for defects are required for each barrel and joint making up the culvert. Each barrel will be made up of a series of connecting culvert units and all units within that barrel should be inspected, where possible, with any defects encountered documented including detail of what unit number the comment refers to. Exception reporting is required for defects such as material defects, impact damage, cracking, and spalling, honeycombing, corrosion, coating defects, welds, fracture, buckling, warping, undermining and settlement/movement.
8-3-3-5 Severity Level:

A severity level shall be assigned to inspection item components for the condition of the waterway scour, waterway flow, headwalls, wing walls, pier walls, aprons, each culvert barrel and base slab. The seventy level is a broad scale of indication of the condition and can be related to the importance and timing of identified work.

<table>
<thead>
<tr>
<th>Severity Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The item is in <em>excellent</em> (as-new) condition.</td>
</tr>
<tr>
<td>2</td>
<td>The item is in good condition. No noteworthy deficiencies that affect the condition of the culvert. Insignificant damage and defects only with negligible misalignment No work required. No deficiencies.</td>
</tr>
<tr>
<td>3</td>
<td>The item is in <em>fair</em> condition. All primary structural components are functional and fit for purpose but may have minor section loss, cracking, spalling or scour. Moderate deterioration or disintegration and minor settlement or misalignment.</td>
</tr>
<tr>
<td>4</td>
<td>The item is in poor condition and requires attention within the next few years. Without repairs there is potential for failure leading to a critical situation. Advanced section loss, deterioration, significant spalling or scour have affected primary structural components. Considerable settlement or misalignment.</td>
</tr>
<tr>
<td>5</td>
<td>The item is in <em>critical, imminent failure</em> condition and requires immediate attention. Major deterioration or section loss present in primary structural components affecting structural stability.</td>
</tr>
</tbody>
</table>

8-3-4 Common Material Defects:

This section describes typical defects that can be found in the various materials used to construct culverts. The key items outlined below should provide enough guidance as appropriate.

8-3-4-1 Concrete:

Concrete is used in culverts as mass concrete or normally it is combined with steel reinforcement. Defects in concrete are often related to the lack
of durability resulting from the composition of the concrete, poor placement practices, poor quality control, insufficient curing or the aggressive environment in which it is placed. (pouring in hot weather or dusty…)

**Cracking** - It is recognized that in reinforced concrete some cracks will form. As long as these cracks remain hairline they may be considered harmless structurally but may open up and progressively spread to longer and wider cracks becoming a durability issue. Cracks should be photographed to enable historical recording of crack propagation and growth.

**Scaling** — Scaling is the localized flaking or loss of surface concrete to a depth of approximately 5mm. Scaling is prone to occur in poorly finished or overworked concrete where too many fines and not enough entrained air is found near the surface. Scaling is generally rather superficial and does not extend to the reinforcement but may lead to a reduction in overall durability.

**Spalling** — It is a local spalling or loss of concrete to the depth of 5mm approximately. There is potential spalling in badly made concrete such as greater percentage of sand in its formation; generally spalling is on surface and do not extend to reinforcement steel but may lead to reduction of total bearing strength.

**Delamination** — Delamination is a discontinuity in the surface concrete which is substantially separated but not completely detached from the adjoining concrete. Visibly it may appear as a solid surface but can be identified by the hollow sound when tapping with a light hammer. Delamination begins with the corrosion of reinforcement and subsequent cracking of the concrete parallel to the exterior surface.

**Dampness** - Areas of the concrete surface that are wet or damp without any obvious cause may be an indication of moisture penetration through the concrete. If this is the case, then it may eventually lead to the corrosion of the steel. Such features should be noted and further investigation undertaken.

**Surface Defects** - Surface defects are not necessarily serious in themselves but are indicative of a potential weakness in the concrete. These include segregation, cold joints, honeycombing, deposits such as
efflorescence, exudation, rust stains, erosion caused by the action of flowing fluids and general wear.

**Patching or Other Repairs** - The condition of the repair or patch will indicate whether the underlying problem has been solved or if it has been merely covered up and is actively continuing under the patch. Cracking, delamination, rust stains or spoiling around the patch indicates further investigations and repairs are needed.

**Corrosion of Reinforcement** - The concrete alkalinity protects the reinforcement from corrosion but when moisture, air and/or chloride ions above a certain concentration penetrate through the concrete to the reinforcement, this protection breaks down and corrosion commences. In the initial stages, corrosion may appear as rust stains on the concrete surface. In the advanced stages, the surface concrete cracks, delineates and spalls off exposing heavily corroded reinforcement. Spalling and delamination are indications of advanced corrosion.

**8-3-4-2 Steel:**

Steel as a structural material when not encased *in* concrete has defects related to poor quality control or the aggressive environment in which it is placed.

**Corrosion** - Corrosion, or rusting, will only occur if the steel is not protected or if the protective coating wears or breaks off. Corrosion on carbon steel is initially fine grained but as rusting progresses it becomes flaky and exposing a pitted surface. The process continues with progressive loss of section.

**Permanent Deformations** - Steel pipe culvert permanent deformations can take the form of bending, buckling, twisting or elongation, or any combination of these. Bending generally occurs in the direction of the applied loads whereas buckling occurs in a direction perpendicular to the applied load.

**Cracking** - Cracks represent a linear fracture in the steel and are generally caused by fatigue and can lead to brittle fracture. Brittle fracture usually occurs without prior warning or plastic deformation and represents complete material disintegration through the component. Cracks in steel should never be treated lightly and although not common for steel pipe
culverts, all details must be recorded with recommendation of urgent additional investigations.

8-3-5 Defects Unrelated To Materials:
A number of items need to be inspected which are not related to defects in construction materials used in the culvert but which, if not checked and rectified, could be a cause of future deterioration.

8-3-5-1 Damage Due to Accidents:
The most common components affected by vehicle impact are delineators and less frequently wing walls, which can be severely abraded, spalled or damaged. Damage is usually self-evident.

8-3-5-2 Drainage:
Inadequate collection of runoff water from the approaches can cause erosion, piping and washout or scour of the approach embankment and batter slopes, particularly in areas where flows are concentrated at the ends of barrel openings. These areas should be inspected, particularly after heavy rain or flooding.

8-3-5-3 Debris:
The build-up of debris on the upstream side of a culvert over a flood prone waterway can cause high loads being imposed on the culvert. Build-up of debris can also cause: blockage of the waterway which can exacerbate problems of scour; undermining; flooding; and in extreme cases, total blockage and diversions of the watercourse.

The build-up of debris is dependent on upstream catchment conditions and is usually most severe in culverts with small openings or low freeboard.

8-3-5-4 Vegetation
Uncontrolled and excessive growth of vegetation under or adjacent to the culvert does not in itself generally cause damage. Some vegetation is beneficial to the stability of the embankments and surrounding soil and can help to prevent siltation of the culvert and scour. Vegetation can however create a fire hazard, blockage to the waterway and build-up of debris and moisture and for these reasons should be reported.
8-3-5-5 Scour:
Scour of foundations caused by excessive stream flows or changes in the alignment of the stream channel can result in progressive settlement or movement of culvert units, which if not rectified may ultimately cause total failure.

Where evidence of scour, degradation or aggradations of the stream bed exists, this shall be noted by the Inspector as a record of the existing condition which may then be compared with the relevant data from past and future inspections. Changes between inspections in conditions of the stream bed on the upstream and downstream sides of the culvert shall also be noted.

8-3-5-6 Movement/Settlement:
Movement of the culvert units or wall supports may result from scour, movement of the ground itself, and poorly compacted embankment, excessive earth pressure caused by movements or settlements of the approach fill, or erosion, piping, washout or scour of the approach.

8-3-6 The assignment of severity level ratings:
Is an important part of the inspection process as it gives a qualitative and quantitative measure of the culvert component's individual condition and an indication of the timeframe for required maintenance works. The severity level rating is on a scale of 1 to 5. The following descriptions and photographs shall be used as a guide to the allocation of the appropriate severity level rating.
8-3-6-1 Waterways:

Table 8-2 a. Scour

<table>
<thead>
<tr>
<th>Severity level</th>
<th>Description</th>
<th>Photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No waterways issues identified with no scour</td>
<td><img src="image1.jpg" alt="No scouring present" /></td>
</tr>
<tr>
<td>2</td>
<td>Minor scouring may be present at either the inlet channel, outlet channel, on the road embankment either side of the wing walls or on the road shoulder behind either headwall.</td>
<td><img src="image2.jpg" alt="Minor scour on the road embankment" /></td>
</tr>
<tr>
<td></td>
<td></td>
<td><img src="image3.jpg" alt="Minor scour under the outlet apron" /></td>
</tr>
</tbody>
</table>
Table 8-2. Scour (continued)

<table>
<thead>
<tr>
<th>Severity level</th>
<th>Description</th>
<th>Photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Noticeable scouring is present at either the inlet channel, outlet channel, on the road embankment either side of the wing walls or on the road shoulder behind either headwall. The level of scouring is not likely to develop into a potential hazard to stability or cause significant structural damage in the short-term.</td>
<td><img src="image1" alt="Noticeable scouring under the inlet apron" /> <img src="image2" alt="Scouring of the downstream riverbed" /></td>
</tr>
<tr>
<td>4</td>
<td>Significant scouring is present at either the inlet channel, outlet channel, on the road embankment either side of the wing walls or on the road shoulder behind either headwall. The level of scouring is likely to develop into a potential hazard to stability or cause significant structural damage to the culvert.</td>
<td><img src="image3" alt="Severe scouring under the pipe culvert" /></td>
</tr>
</tbody>
</table>
### Table 8-2 a. Scour (continued)

<table>
<thead>
<tr>
<th>Severity level</th>
<th>Description</th>
<th>Photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Advanced scouring is present that is currently causing stability issues or will very quickly cause significant structural damage to the culvert.</td>
<td><img src="image1.png" alt="Water is no longer flowing through the culvert but is flowing underneath with structural failure of the base" /></td>
</tr>
<tr>
<td>1</td>
<td>No waterways issues identified with no impediments to the flow condition of the culvert units.</td>
<td><img src="image2.png" alt="No obstruction to water flow" /></td>
</tr>
<tr>
<td>2</td>
<td>Minor silting or obstruction of the waterway up to 10% of entry/exit.</td>
<td><img src="image3.png" alt="Minor (&lt; 10%) silting of the waterway" /></td>
</tr>
<tr>
<td>3</td>
<td>Silting or obstruction of the waterway of between 10% and 25% of entry/exit. Silting is evident along the length of the culvert.</td>
<td><img src="image4.png" alt="Vegetation blocking the culvert entrance" /></td>
</tr>
<tr>
<td>Severity level</td>
<td>Description</td>
<td>Photographs</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>4</td>
<td>Silting or obstruction of the waterway of over 25% of entry/exit.</td>
<td><img src="image" alt="Culvert opening is blocked by vegetation" /></td>
</tr>
<tr>
<td>5</td>
<td>Silting or obstruction of the waterway at entry/exit is so severe that water flow is likely to cause structural damage to the culvert</td>
<td><img src="image" alt="Box culvert is almost completely blocked" /></td>
</tr>
</tbody>
</table>
### Table 8-3: Walls and Aprons

<table>
<thead>
<tr>
<th>Severity level</th>
<th>Description</th>
<th>Photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All structural components are in good condition with little or no deterioration.</td>
<td>As-new condition of headwall, wing walls and apron</td>
</tr>
<tr>
<td>2</td>
<td>Minor deterioration or damage only in structural components. Defects are more surface in nature and do not affect the structural integrity</td>
<td>Cracks and minor damage to concrete wing wall (non-primary structural component)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Construction joint on headwall and minor cracking</td>
</tr>
<tr>
<td>Severity level</td>
<td>Description</td>
<td>Photographs</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| 3              | Medium deterioration or damage in structural components. Defects are not yet affecting the structural integrity. | Cracking in masonry wall  
|                |                                                                              | Badly cracked apron  
|                |                                                                              | Wing wall is cracked and is tilting over (caused by tree growth Headwall (structural component) has honeycombing and medium crack |
Table 8-3: Walls and Aprons (continued)

<table>
<thead>
<tr>
<th>Severity level</th>
<th>Description</th>
<th>Photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Significant deterioration or damage in structural components. Defects are starting to affect the structural integrity.</td>
<td>Headwall has separated from pipes and is collapsing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Headwall has concrete sections missing, pipes in danger of being undermined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The end of the wall has major abrasion damage</td>
</tr>
<tr>
<td>5</td>
<td>Structural components are showing signs of distress or have already failed. Defects affect the structural Integrity.</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
</tbody>
</table>

Culvert pier wall is severely cracked and abraded

Major spalling of wall due to salt attack of reinforcement

Walls have major abrasion and have been propped to maintain structural stability
Table 8-4: Culvert Units

<table>
<thead>
<tr>
<th>Severity level</th>
<th>Description</th>
<th>Photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All structural components are in good condition with little or no deterioration.</td>
<td><img src="image" alt="No timber deterioration" /></td>
</tr>
<tr>
<td></td>
<td>Barrels – the line and invert of the culvert is straight with no water being retained in the culvert.</td>
<td><img src="image" alt="No concrete spalling or cracking" /></td>
</tr>
<tr>
<td></td>
<td>Concrete – any cracking is only hairline (≤ 0.1 mm) and cracks are widely spaced and very infrequent; no spalling; minor efflorescence on the underside of the link slab or near unit joints.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steel – no evidence of corrosion.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Masonry – any cracking is only hairline or fine (≤ 0.3 mm) and contained within the mortar joints. Timber – may have very minor splits only.</td>
<td></td>
</tr>
</tbody>
</table>

(Note: Silting is severity level 3)
| 3 | Medium deterioration or damage in structural components. Defects are not yet affecting the structural integrity or ability to withstand significant water flows.  
Some evidence of fill or water leakage passing through the culvert barrel cell joints.  
Barrels – there may be some deviation of the line of the culvert due to local buckling, separation or differential settlement (> 5 mm and ≤ 30 mm) which may have resulted | Exposed reinforcement in outside leg of box culvert  
Evidence of leakage through the barrel joints |
in water ponding in the culvert.

Concrete – infrequent medium cracking (> 0.3 mm and ≤ 0.7 mm); fretting and spalling may be present; extensive rust staining; patches of dampness and efflorescence of 0.25 m² to 1 m² may be visible in any one unit.

Steel – steel corrosion; surface pitting may be evident especially at normal water level.

Masonry – heavy cracking (> 1.0 mm and ≤ 2.0 mm) of the mortar or loss of mortar between blocks; mortar may be starting to lose strength and crumble.

4 Significant deterioration or damage in structural components. Defects are starting to affect the structural integrity or ability to withstand significant water flows. There is a likelihood that a major water flow will result in loss of pavement and/or culvert.
Evidence of fill or water leakage passing through the culvert cell joints.

Barrels – there may be a large deviation of the line of the culvert (> 30 mm) which may have resulted in an excessive amount of water being retained in the culvert.

Concrete – heavy cracking (> 0.7 mm); fretting and spalling along large delaminated areas; exposed reinforcement exhibits signs of severe corrosion over large areas resulting in substantial loss of section; patches of dampness and efflorescence may be > 1 m² in any one unit.

Steel – extensive steel corrosion; surface pitting is evident resulting in localised areas of complete loss of steel section.

Masonry – very heavy cracking (> 2.0 mm) of the mortar or loss of mortar between blocks; blocks may have started
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>slipping; mortar has become powdery. Timber – little solid timber remaining; timber has become fully friable; splits may be severe.</td>
<td></td>
</tr>
<tr>
<td>Major heavy longitudinal crack in the pipe invert</td>
<td></td>
</tr>
<tr>
<td>Heavy longitudinal crack in the top of the pipe</td>
<td></td>
</tr>
<tr>
<td>Heavy longitudinal cracks through the pipe</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Structural components are showing signs of distress or have already failed. Defects affect the structural integrity or ability to withstand water flows. Water flow is likely to result in loss of pavement and/or culvert.</td>
</tr>
<tr>
<td>Severe corrosion damage of the pipe</td>
<td></td>
</tr>
</tbody>
</table>
The road surface is uneven.

 invert with complete loss of section in some locations

 Spalled concrete and widespread delamination

 Joints badly cracked with propping to reinstate stability

 Misalignment of pipe culverts (repair needed to prevent scour and subsidence)
8-4 Maintenance of Culverts:

8-4-1 Introduction:
This section, which deals with the maintenance of culverts, complements the inspection of culverts. It’s an important part of the Dams and Bridges’ Maintenance Guide of the Ministry of Municipal Affairs, Kingdom of Saudi Arabia. This section provides a number of brief and adequate solutions for the works of the maintenance and qualifications that can be used when the inspection works indicate the need to carry out repair works for the culverts.

This section contains the evaluation of problems, and methods of repair, rehabilitation and replacement.

8-4-1-1 Objectives:
The objectives of this section are to provide information that assist the users in carrying out the following works:

- To recognize the causes of problems and how to determine solutions
- To check and carry out the maintenance in order to limit the ongoing deterioration of the culvert
- To select the procedures of repairing of the individual components of the culvert for the various types of damages
- To select the procedures of rehabilitating the culvert in order to carry out its intended function
- To select the procedures for enhancing and readjusting the culverts after completing the improvement carried out to correct the design or the defects of construction, and to improve the serviceability and functional capabilities of the culvert.
- To select the procedures for replacing the functionally deteriorated and old culverts.
- To follow the guidelines and criteria for testing the most cost effective procedures for dealing with the current problems to prolong the serviceability and expected life cycle of the culvert.

8-4-1-2 General Problems of Culverts:
There is a wide variety of types of culvert problems. These can be categorized according to the strength capabilities. The following are the general problems of culverts:

A. Serviceability Problems:
   - Scour and erosion of the streambed and embankments
Inadequate flow capacity
Corrosion and abrasion of the metallic parts of the culvert
Corrosion and abrasion of concrete and masonry components of the culvert
Detachment and/or collapse of parts of the culvert (culverts are made up of various components)
Inadequacy of the length of the culvert

B. strength-related problems:
- Cracking of the rigid culverts
- Undermining and loss of structural support
- Loss of the invert of culverts due to corrosion and abrasion
- Over deflection and shape distortion of the flexible culverts
- Stress cracking of plastic culvert

8-4-2 Structural Foundations of Culverts:
To identify the shapes of concrete pipes and corrugated steel pipes, please refer to tables 8-5 and 8-6.

Table 8-5: Standard Shapes of Concrete Pipes

<table>
<thead>
<tr>
<th>Shape</th>
<th>Range of size</th>
<th>Common uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>circular</td>
<td>30.5-122 cm</td>
<td>Culverts, storm drain and sewer</td>
</tr>
<tr>
<td></td>
<td>10-91.5 cm reinforced concrete</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-91.5 cm non-reinforced concrete</td>
<td></td>
</tr>
<tr>
<td>Pipe arch</td>
<td>38-335.5 cm Equivalent diameter</td>
<td>Culverts, flood drain and sewer</td>
</tr>
<tr>
<td></td>
<td>Used where head is limited</td>
<td></td>
</tr>
<tr>
<td>Horizontal ellipse</td>
<td>Span x rise 45.7-365.7 cm Equivalent radius</td>
<td>Culverts, flood drain and sewer</td>
</tr>
<tr>
<td></td>
<td>Used where head is limited</td>
<td></td>
</tr>
<tr>
<td>Vertical ellipse</td>
<td>Span x rise 91.5-365.7 equivalent diameter</td>
<td>Culverts, flood drain and sewer</td>
</tr>
<tr>
<td></td>
<td>Used where lateral clearance is limited</td>
<td></td>
</tr>
<tr>
<td>Rectangular (box)</td>
<td>Span</td>
<td>Culverts, flood drain and sewer</td>
</tr>
<tr>
<td>Sections</td>
<td>Span</td>
<td>Use</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------------</td>
<td>---------------------------------------------------------------------</td>
</tr>
<tr>
<td>Arch</td>
<td>731.5-1249.7 cm</td>
<td>Culverts, under drains, sewer, service tunnels etc. Uses closed low and wide water channels</td>
</tr>
<tr>
<td>Surface leveled three-sided</td>
<td>426.7-1066.8 cm</td>
<td>Culverts, under drains, sewer, service tunnels etc. Low-wide waterway enclosures, culverts, storm sewers.</td>
</tr>
<tr>
<td>Arch surface three sided</td>
<td>487.7-1097.3 cm</td>
<td>Culverts, sub-drains, service tunnels, etc. Uses closed low and wide water channels</td>
</tr>
<tr>
<td>Round</td>
<td>15.3-792.5 cm</td>
<td>Culverts, sub-drains, service tunnels, etc. All plates same radius. For medium or high fills (or trenches).</td>
</tr>
<tr>
<td>Vertical enlarged (ellipse)</td>
<td>122-640 cm</td>
<td>Culverts, sewers, service tunnels, recovery tunnels. Plates of various radii; shop fabrication. For appearance and backfill compaction is only moderate.</td>
</tr>
<tr>
<td>Pipe arch</td>
<td>Span x rise</td>
<td>Where headroom is limited. It has hydraulic advantages at low flows. Corner plate radius. 18 inches or 31 inches for structural plate.</td>
</tr>
<tr>
<td>Underpass</td>
<td>Span x rise</td>
<td>For pedestrians, livestock, or vehicles (structural plate).</td>
</tr>
<tr>
<td>Arch</td>
<td>Span x rise</td>
<td>For low clearance large waterway opening, and aesthetic</td>
</tr>
</tbody>
</table>

*Span* refers to the horizontal distance across the opening, while *rise* is the vertical height.
Culverts, grade separations, storm sewers, tunnels.

Table 8-6: Standard shapes of corrugated steel culverts (continued)

<table>
<thead>
<tr>
<th>Shape</th>
<th>Range of size</th>
<th>Common uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pear</td>
<td>Span</td>
<td>Grade separations, culverts, storm sewers, tunnels.</td>
</tr>
<tr>
<td></td>
<td>762 cm x 914 cm</td>
<td></td>
</tr>
<tr>
<td>High profile arch</td>
<td>Span</td>
<td>Culverts, grade separations, storm sewers, tunnels, ammo ammunition, earth covered storage.</td>
</tr>
<tr>
<td></td>
<td>310 cm x 1370.6 cm</td>
<td></td>
</tr>
<tr>
<td>Low profile arch</td>
<td>Span</td>
<td>Low-wide waterway enclosures, culverts, storm sewers</td>
</tr>
<tr>
<td></td>
<td>610 cm x 1524 cm</td>
<td></td>
</tr>
<tr>
<td>Box culverts</td>
<td>Span</td>
<td>Low-wide waterway enclosures, culverts, storm sewers</td>
</tr>
<tr>
<td></td>
<td>305 cm x 792.5 cm</td>
<td></td>
</tr>
<tr>
<td>Special shapes</td>
<td>Various</td>
<td>For lining old structures or other special, special fabrication.</td>
</tr>
</tbody>
</table>
8-4-3 Problem Identification and Assessment:

1. **Scope:**
   This section discusses how culvert problems are determined and culvert appurtenances.

2. **Determining Culvert Problems:**
   The process of determining culvert’s problems is a three-step effort. The first step is to recognize visually in the field whether the culvert as a whole or one of its components does not function properly, or shows signs of distress that may lead to prevent the culvert from performing its intended functions. Culverts may be classified based on its capacity to control the inlet water, water flowing through it and outlet water, or the capacity to safely sustain the traffic loads on the lanes and intersections.
   The second step is to assess the cause and identify the basic type of the problem. In certain cases, the underlying cause or the cause of the problem is obvious. In other cases however, determining the cause of the problem may require more research either by inspection with the use of general means, or it require the use of hydraulic, structural, geographic/technical or other detailed engineering studies. If this does not work, the third step is to conduct a thoroughly detailed research.

3. **Regular (Routine) Maintenance:**
   The culvert and appurtenances must be inspected during the periodic maintenance works to determine the defects and repair the minor faults. Records must be maintained to report the faults, treatments, and recommendations regarding conducting further inspection and repair works. Inspection works in the periodic maintenance allow the opportunity to determine and repair simple faults before they become more serious. The protective maintenance is a major prevention against early deterioration of culverts and the resulting hindrance to their functions.

4. **Recognizing the Problems and Solutions:**
   The process of evaluating the problems and putting alternative solutions consists of four steps.

   1) Determine the type and cause of the problem
   2) Select possible repair methods
   3) Obtain all required information for evaluating the alternatives
   4) Analyze the alternatives
Figure 8-6: Illustrates this process in clear steps

1. **Review initial report**
2. **Perform inspection. Record data**
3. **Is detailed inspection required?**
   - Yes: **Perform detailed inspection**
   - No: **Determine cause, type and extent of the problem**
4. **Gather other relevant information**
5. **Classify repairs**
   - Minor/limited repair correctible with the routine maintenance
   - Major repairs
7. **Analyze the alternatives**
8. **Make decisions on types of repair, who to perform**

Figure 8-6: Analysis of problems and solutions. Overall process
5. **Determine the Cause and Type of Problem:**

The graph illustrates the process of identifying the problem

![Flowchart](image)

**Figure 8-7: Process for identifying problems**
6. Analyze Alternative Solutions

The following figure depicts this process of analyzing the alternative solutions:

- Gather basic data
  - Cause
  - Type of problem
  - Urgency
  - Maintenance history
  - Overall condition

Determine and classify repair options

Routine/limited alternatives

Major/multiple alternatives

Analyze alternatives:
- Gather data
- Gather data (Geographical, hydraulic, cost, time, traffic)
- Analyze alternatives
- Determine repair method
- Classify implementation

Common/limited alternatives

Special extensive repair

Implement. Analyze resources:
- Expertise
- Equipments
- Personnel
- Funds

In-house

Contract

Figure 8-8: Process for analysis of potential solutions
7. **Approaches:**
The condition of roadway approaches could be indicative of currents or future problems of culverts. Defects in the approach roadway can signify possible structural or hydraulic distortions. Inspection of the approach roadway should include an evaluation of both roadway condition, and its functional adequacy.

Table 8-7 shows the symptoms that occur on approaches that may be indicative of problems of the culvert.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Possible cause</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Embankment:</strong></td>
<td></td>
</tr>
<tr>
<td>Deterioration of the roadway shoulders and embankments</td>
<td>Settlement, possible deterioration of the culvert barrel</td>
</tr>
<tr>
<td>Piping, undercutting, and eventual rotation of the culvert footing, or severe differential settlement</td>
<td>Erosion</td>
</tr>
<tr>
<td>Retraction and corrosion of the parts of the culvert</td>
<td>Slope slipping</td>
</tr>
<tr>
<td><strong>Guardrails:</strong></td>
<td></td>
</tr>
<tr>
<td>Bend, sags, or depression of guardrails</td>
<td>Settlement, possible deterioration of the culvert barrel</td>
</tr>
<tr>
<td><strong>Pavement</strong></td>
<td></td>
</tr>
<tr>
<td>Cracking in rigid pavement</td>
<td>Settlement of material under pavement caused by poorly compacted embankment material; displacement of soft material; piping along barrel; deteriorating culvert; erosion, slope slippage</td>
</tr>
<tr>
<td>Irregular settlement in flexible</td>
<td></td>
</tr>
<tr>
<td>Pavement</td>
<td></td>
</tr>
<tr>
<td>Pavement patches</td>
<td></td>
</tr>
<tr>
<td><strong>Functional evaluation</strong></td>
<td></td>
</tr>
<tr>
<td>Safety hazard:</td>
<td>• Width of roadway surface is too narrow, culvert ends are too close to travelled way</td>
</tr>
<tr>
<td></td>
<td>• Steep embankments</td>
</tr>
</tbody>
</table>

8. **End treatment and Appurtenants Structures:**
Several types of end treatments are commonly used at culverts inlets and outlets. This ranges from no treatment at all to a constructed in-place end structure. Table 8-8 shows the causes and potential causes of the
problems of final treatment and the structures of the channel appurtenances.

**Table 8-8: Determining the Final Treatment Problems & the Distribution of the Culverts**

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Potential cause</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Projecting pipes:</strong></td>
<td></td>
</tr>
<tr>
<td>- Piping</td>
<td>- Seepage along exterior culvert barrel</td>
</tr>
<tr>
<td>- Uplift of culvert ends</td>
<td></td>
</tr>
<tr>
<td>- Flexible culvert’s operating in inlet control</td>
<td>- Seepage through open joints</td>
</tr>
<tr>
<td>- A flexible culvert with submerged outlet</td>
<td>- Hydraulic uplift forces not balanced by a counter weight</td>
</tr>
<tr>
<td><strong>End walls and Wing-walls</strong></td>
<td></td>
</tr>
<tr>
<td>- Cracking, tipping, separation of the culvert’s barrel from the headwall</td>
<td>- Undermining and settlement</td>
</tr>
<tr>
<td>- Voids behind the walls</td>
<td>- Loss of backfill materials</td>
</tr>
<tr>
<td>- Toe out of base</td>
<td>- Scour in front of the wall</td>
</tr>
<tr>
<td>- Outward motion at the top</td>
<td>- Damage of anchor rod</td>
</tr>
<tr>
<td><strong>Mitered of beveled ends:</strong></td>
<td></td>
</tr>
<tr>
<td>- Deformation of ends</td>
<td>- Buoyant force damage due to reduced structural integrity of beveled ends</td>
</tr>
<tr>
<td><strong>Aprons:</strong></td>
<td></td>
</tr>
<tr>
<td>- Underpinning, settlement, or movement of concrete slabs</td>
<td>- Scour</td>
</tr>
<tr>
<td>- Displacement of stones in riprap</td>
<td>- High velocities</td>
</tr>
<tr>
<td>- Displacement of partially full baskets, wire deterioration</td>
<td>- head cutting</td>
</tr>
</tbody>
</table>

9. **Waterways:**
The primary function of most of the culverts is to carry surface or stream water from one side of a roadway to the other side. Usually, the hydraulic design of culverts involve the determination of the most cost-effective size and shape of the culvert necessary to carry the designed discharge without exceeding the allowable headwater depth. It is essential that the culvert be able of to handle the designed discharge. Figure 8-9 shows the possible problems often found in waterways.
### Table 8-9: Determining the problems of the water channels

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Potential cause</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal alignment:</strong></td>
<td></td>
</tr>
<tr>
<td>- Erosion</td>
<td>Abrupt changes in stream alignment, obstructions in the streambed, or intersection of excessive velocities into stream banks</td>
</tr>
<tr>
<td>- Retarded flow</td>
<td></td>
</tr>
<tr>
<td>- Sedimentation</td>
<td></td>
</tr>
<tr>
<td><strong>Vertical alignment:</strong></td>
<td></td>
</tr>
<tr>
<td>- Scour</td>
<td>Excessive velocities</td>
</tr>
<tr>
<td>- Accumulation of sediment</td>
<td>Low velocities</td>
</tr>
<tr>
<td><strong>Scour</strong></td>
<td></td>
</tr>
<tr>
<td>- Local scour</td>
<td>Obstruction that causes a constriction of flow</td>
</tr>
<tr>
<td>- General scour or head cutting</td>
<td>Downstream lowering of the channel</td>
</tr>
<tr>
<td><strong>Sediments and debris:</strong></td>
<td></td>
</tr>
<tr>
<td>- Blockage of the culvert</td>
<td>Deposited debris or settlement</td>
</tr>
<tr>
<td>- Local scour in the stream channel</td>
<td></td>
</tr>
<tr>
<td>- Scour of the streambed roadway embankment</td>
<td></td>
</tr>
<tr>
<td>- Changes in the channel alignment</td>
<td></td>
</tr>
<tr>
<td>- reduced capacity of the culvert</td>
<td></td>
</tr>
<tr>
<td>- Increased chances of damage because from buoyancy forces</td>
<td></td>
</tr>
</tbody>
</table>

### 10. Pre-cast Concrete Culverts:

There are certain important considerations related to concrete used in culverts. Machine-made, round concrete pipe is manufactured in a plant rather than in the field. The entire manufacturing process is under controlled conditions enabling the production of a uniform quality, high-density concrete product. Both cast-in-place and precast concrete culverts are somewhat protected by the soil backfill from rapid fluctuations in surface temperature and direct-application chloride salts used for deicing. As a result they are generally more resistant to surface deterioration than concrete bridge elements. Concrete culverts are classified as rigid
structures because they do not deflect appreciably under the applied loads. However, uneven or excessive loads will cause such structures to crack rather than bend. Inspections must, therefore, concentrate on defects in the alignment, joints, and walls of the structure.

11. Environmental Impacts
Off-site erosion, flooding, and pollution due to urban development and land-disturbing activities in a watershed have become significant problems to environmental control. The development of storm water management standards to protect streams and other bodies of water from the effects of erosion and sedimentation are among the first priorities of transportation and environmental agencies.

8-4-4 Culvert Maintenance Applications:

1. General:
The functions of the maintenance include:
   A. To preserve the waterways clear from debris, wastes, vegetations, and other obstructions.
   B. To correct and treat the parts that fail to perform their functions such as corrosion, structure breaks or displacement, waterways, sewers, and pavements.
   C. To expect the problems and to make limited changes or modifications.

2. Benefits of the Periodic and Preventive Maintenance:
Most culvert problems regarding operation and the service capabilities occur gradually with time where the structures or appurtenances deteriorate slowly with time. If the culverts deterioration continues without inspection, the deterioration will inflict other parts of the waterway.

3. Maintenance Procedures:
A. Debris Removal:
At culvert sites where experience or physical evidence indicates that the watercourse will transport a heavy volume of debris during high flows, consideration should be given to debris-control structures. The need for debris-control structures will be more prevalent in steep or mountainous areas and where the culvert is under a high fill. In addition to blockage, rock debris may cause moderate to severe abrasion damage to culverts.
B. Flushing/Sediment Removal
Clogging of culverts with silt and sediment is a common occurrence, especially in areas undergoing continuous construction activities drastically altering or destroying protective vegetative cover and soil mantle, the probability of the accumulation of sediment in culverts increases.

C. Ditch Cleaning and Repair
Ditches and open channels that carry water from roadways and adjacent land and drainage facilities to culverts should be maintained so that they have a uniform flow line with sufficient depth and grade to ensure free drainage to and from culverts, roadways, and other roadside areas and drainage facilities, such as under drains. Unpaved channels should be kept free of obstructions with proper depth and width to provide adequate drainage. Paved channels should be maintained free of all vegetation and debris.

D. Maintenance of the Streambed:
Streambed Maintenance
Regardless of how stable a stream is perceived to be, its bed and banks are in a constant state of change. Placement of a culvert in this environment presents yet another factor in the interplay or erosion, sedimentation, and debris movement.

A culvert barrel usually constricts the natural channel and forces water to flow through a reduced opening. As the flow is constricted, eddies or areas of high velocity are formed that strike the upstream slopes and tend to scour away the embankment adjacent to the culvert.

Scour hole repair - Attention should be given to detection, maintenance and repair of scour holes that develop in streambeds in the vicinity of culverts before they become a major problem. The scour hole is usually deepest during passage of peak flows; suspect locations should be inspected after major storms.

Scour holes may be filled with crushed stone, rubble, or riprap. Since prediction of scour at culvert outlets is difficult and protection is expensive, a practical approach is to provide a minimum amount of protection that is monitored by periodic site inspection. The installation should be inspected to assess its performance after a number of storm events.
H. Control of Vegetation:
The objective of roadside and waterway vegetation management is to provide utility, economy, and beauty to the roadside. Utility is provided by stabilizing roadside and embankment soils, preventing erosion, and by growing and encouraging desirable vegetation in place of undesirable and future problem vegetation. Economy is provided by the selection of vegetation, such as Crownvetch, that needs no mowing or fertilization, or by the type of vegetation that can withstand roadside environmental contaminants such as salt. Beauty is provided by green and well-maintained turf, by spring flowering roadside plants, and by screening unsightly areas adjacent to the highway.

8-4-5 End Treatment and Appurtenant Structure Repairs and Retrofit Improvements:

1. General:
The rationale for selecting and carrying out repair and/or retrofit procedures for the wide range of types and sizes of culverts, which may have an even wider range of problems or deficiencies, will depend on many factors. These factors include:

- The type, size, and length of the culvert;
- The degree of deterioration of the culvert;
- The age of the culvert;
- Other deficiencies of the culvert;
- The type and amount of work to be done;
- The location of the culvert: depth of fill, classification of roadway, etc.;
- The general location: urban or rural;
- The area of the Kingdom (Riyadh, East Region etc); and
- Whether the work will be done by contract or in-house personnel.

Although the primary focus of this manual is on culvert repair practices, some of the procedures presented may be used to correct design and operational problems and to increase the strength and hydraulic efficiency of culverts. Procedures used to correct design problems should be referred to the engineer. The following are considered to be retrofit improvements, since they would not be considered either maintenance or repair work:

- Adding slope erosion protection;
- Paving approach channels for scour protection;
- Adding headwalls, tail-walls, and wing-walls;
• Strengthening for increased load capacity;
• Lengthening for roadway widening;
• Adding grates for vehicle safety; and
• Retrofitting to facilitate fish passage.

Table 8-10 provides a summary of the types of problems and repair options available for correcting the upstream and downstream channel deficiencies. Table 8-11 provides similar information for the inlet and outlet ends of the culvert.

### Table 8-10: Problem and corrective action options, upstream and downstream channels

<table>
<thead>
<tr>
<th>General location</th>
<th>Type of problem</th>
<th>Repair options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Action required</td>
<td>Specific options</td>
</tr>
<tr>
<td>Upstream &amp; downstream</td>
<td>Erosion, slopes</td>
<td>Vegetation</td>
</tr>
<tr>
<td>channels</td>
<td></td>
<td>Grass/ground cover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geo-textiles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Several types available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Barriers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rubble/riprap</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gabions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retaining walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modular or cast-in place concrete</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loffelstein block</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timber</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pave slopes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete, cast-in place or shotcrete</td>
</tr>
<tr>
<td>Scour, streambed</td>
<td>Fill holes</td>
<td>Rubble or riprap</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pave apron</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rock or concrete, CIP or shotcrete</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy dissipaters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Several types</td>
</tr>
<tr>
<td></td>
<td>Re-align</td>
<td>Modify channels</td>
</tr>
<tr>
<td>Fish passage</td>
<td>Retrofit</td>
<td>Modify channel</td>
</tr>
</tbody>
</table>
Table 8-11: Problem and corrective action options, inlets and outlets ends.

<table>
<thead>
<tr>
<th>General location</th>
<th>Type of problem</th>
<th>Repair options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Action required</td>
<td>Specific options</td>
</tr>
<tr>
<td>Inlet and Outlet (Head and wing walls &amp; general)</td>
<td>Erosion behind wings</td>
<td>Backfill</td>
</tr>
<tr>
<td></td>
<td>Undermining</td>
<td>Fill hole</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Underpin</td>
</tr>
<tr>
<td>Masonry/mortar</td>
<td>Re-point</td>
<td>Mortar</td>
</tr>
<tr>
<td>Loss of masonry</td>
<td>Replace</td>
<td>Masonry block</td>
</tr>
<tr>
<td>Concrete spalling &amp; deteriorating</td>
<td>Patch</td>
<td>Mortar or concrete</td>
</tr>
<tr>
<td>Strength loss</td>
<td>Jacket</td>
<td>Reinforced concrete</td>
</tr>
<tr>
<td>Alignment</td>
<td>Re-construct</td>
<td>Reinforced concrete</td>
</tr>
<tr>
<td>Displacement</td>
<td>Underpin</td>
<td>Concrete</td>
</tr>
<tr>
<td>Safety</td>
<td>Retrofit</td>
<td>Widen or add grates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Change from inlet to outlet control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Add sections to reduce slope</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eliminate</td>
</tr>
</tbody>
</table>

8-4-6 Culvert Barrel Repair and Rehabilitation Procedures:
This chapter presents information on procedures that may be used to repair and rehabilitate the barrels of a wide range of culvert types. The types of problems range from those associated with corrosion and abrasion to those of joint leakage, deformation and loss of structural integrity and hydraulic capacity. The repair and rehabilitation techniques
include use of traditional materials as well as innovative techniques to line the culverts by sliplining, inversion lining, and cement mortar lining.

**8-4-6-1 Precast Reinforced Concrete Culverts:**
The culvert problems may be categorized into groups associated with (1) joint defects, (2) cracking, (3) spalling, (4) scaling (5) slabbing and (6) invert deterioration. Under each of these categories there are many individual types of problems and possible courses of remedial action. For example, scaling may be due to freeze-thaw action or sulphate attack. The proper course of action will depend on the type and severity of the problem as it relates to the type, size, and location of the structure.

**a. Joint Defects**
Precast concrete culverts have problems that are associated with a variety of conditions that are focused on behavior at the joints between the individual segments, which is a natural plane of weakness. As an example, reinforced concrete pipe bells with O-ring gaskets may break if the gaskets are too large or poorly installed.

**b. Cracking:**
Circumferential cracking at the joints of precast concrete culverts is somewhat rare because tensile stresses that create cracking will tend to open the joints rather than cause cracking. Under certain circumstances it may be possible to develop compression or shear cracks due to rotation and displacement of sections, commonly caused by poor foundations with differential settlement. Repair of such cracks will normally be cosmetic in nature, unless more involved procedures are undertaken to correct the problem that caused the distress.

**c. Spall Repair**
Spalling is generally the result of corrosion of reinforcing bars that initially causes horizontal (or in plane) cracking of the concrete and then subsequent delamination and spalling of the surface concrete off of the reinforcing bars.

**d. Slabbing Repairs**
The terms slabbing, shear slabbing, and slab shear refer to a problem of radial failure of the concrete over the inner layer of reinforcement, due to excessive deflection and straightening of the reinforcing cage. The deformation causes radial tension and diagonal shear tension in the concrete that splits the concrete at the level of the interior layer of reinforcement. It is characterized by large slabs of concrete “peeling”
away from the reinforcement. Slabbing is a serious problem that may occur under high fills with reinforced concrete pipe of inadequate D-load strength and/or on an inadequately deep bedding on a rock foundation. Slabbing is a phenomena that occasionally occurs during installation of precast concrete culverts as well as the result of bad soil conditions and a high water table.

The corrective action that should be undertaken will depend upon the amount of bending and distortion that has taken place in the concrete section and the likelihood that additional movement and slabbing will occur. If it is determined that the cause of the slabbing has been corrected (during construction) or that additional distortion and slabbing is unlikely, then the corrective action is rather simple and straightforward. If this is the case, and it may be determined that the culvert is structurally stable, then the primary concern is protection of the inner (and exposed) layer of steel reinforcing against corrosion.

e. Invert Deterioration

The inverts of precast concrete culverts are normally quite durable and resistant to damage or progressive deterioration. However, under special conditions of high flow velocity water flow they are sometimes subject to deterioration due to abrasion and cavitation related loss of concrete. In areas of acid water runoff they may also be subject to chemical attack that deteriorates and removes concrete. In mountainous country they may be subject to severe impact by large rocks and boulders that are transported down steep slopes by high flow velocity. Such boulders may be several feet in diameter. Continued loss of concrete may lead to a reduction in structural strength of the culvert. This may be particularly critical since precast concrete culverts are considered rigid culverts that are designed to withstand structural loads without deformation. Thus, loss of section strength may lead to cracking, deformation and collapse of the culvert. The following addresses specific aspects of the problem and associated remedial action.

f. Concrete repair

Deteriorated inverts in precast concrete culverts generally require paving to restore them to an acceptable functional condition. In order to accomplish such paving it is necessary to divert all water flow so that the invert may be dried, deteriorated concrete may be removed and other necessary work be done to prepare the invert for paving. A variety of
Portland cement-based concretes may be used for such paving including conventional concrete, high strength concrete, and steel fiber-reinforced concrete as well as latex modified or low slump concretes of the type used for bridge deck overlays. Regardless of the materials selected for the paving it should be reinforced and securely anchored to the existing/remaining invert.

In areas where there is acidic water it may be necessary to coat the concrete surface with a epoxy sealer or a polymer concrete.

g. **Flow neutralization basin**

Since abrasion and rock-impact damage to culvert inverts is the result of fast moving water, elimination of the cause of the damage will thereby eliminate, or minimize, such problems. Specifically, this would be to reduce the velocity and energy of the water flowing through the culvert. The subjects of flow neutralization basins and other forms of energy dissipators are discussed in Chapter 5.

Nonetheless, it should be recognized that although such concepts may be very effective in reducing the velocity and energy of the water they also cause the water to drop sand, rocks, and boulders that are being carried, which thereby causes a buildup of these materials in the channel ahead of the culvert entrance. This may not only reduce the effectiveness of the energy dissipator system but also constrict the channel and cause an increase in water velocity and other associated problems. Thus, they should be designed to facilitate regular or scheduled maintenance.

h. **Crown Deterioration**

Precast concrete culverts may sustain damage in their crown section due to the depth of cover being too shallow to adequately support and distribute vehicle live loads. The result may be cracking, spalling and distortion in the crown area. Some information on procedures that may be used to repair such problems is provided in appendix B-37.

8-4-6-2 **Cast-In-Place Concrete Culverts:**

Cast-in-place concrete culverts are normally not circular or elliptical, but rather box or arch shaped. Their size ranges from perhaps as small as 3 foot square for a single cell box to as large as 12 feet high by 40 feet wide for multi-cell boxes. Their attributes include the fact that they may be constructed by highway agency personnel or general contractors. They are generally easy to construct and may be less expensive than precast.
concrete culverts, particularly in remote areas that are a long distance from a pre-casting plant.

A. Joint Defects
The joints of cast-in-place concrete culverts are oriented longitudinally, rather than transversely. They run the length of the structure, rather than across it. Also, as noted above, reinforcing steel and waterstop seals are built into (and across) the joint. Thus, joints in cast-in-place concrete culvert construction can transfer (or carry) tensile, compression and shear forces but possibly not bending or rotational forces. Joint problems can occur because of differential settlement, unbalanced soil forces, or because of chemical and environmental conditions.

a. Repair or replacement of seals
Waterstop seals may be damaged because of excessive differential displacement of the sections of the culvert or because of freeze-thaw action that damages the surrounding concrete and then the water-stop. Water-stop seals are flat strips of material that run the length of the culvert. They are frequently about eight inches wide with half of the width cast into the adjacent sections of concrete. Repair of damaged seals is quite difficult and time consuming, and there is some question of whether they may be effectively repaired. The most practical solution will probably be to replace the damaged section of the seal unless another repair or protection procedure may be effective. The replacement procedure involves removal of the facing concrete in the damage zone and insertion of a replacement section of water-stop. This then requires removal of at least four inches of concrete on both sides of the joint to access the water-stop seal. The damaged seal is then removed and a replacement section is installed and the facing concrete is then replaced.

b. Cracks and Spalls
Cracks and spalls are almost to be expected in cast-in-place type culvert construction because of a variety of factors including:

- The structures are relatively large or, at least, long. Any appreciable bending or deformation will cause cracks, whereas, precast concrete sections may rotate at the joints to relieve excessive local stresses.
- The cast-in-place sections are cast at somewhat different ages. Differential drying shrinkage will cause stresses between the sections that may cause cracking.
- There may also be differential drying shrinkage between the bottom half and the top half of the culvert because the lower half may be continuously wet whereas the top half may be continuously dry.

c. Sealing
d. Patching
e. Underpinning the footings

Cast-in-place concrete arch culverts are supported on concrete footings that carry and resist compression thrust forces from the arch. Differential forces that are applied to the arch through the embankment must be resisted without cracking of the footing. If cracking occurs, then there may be displacement of the footing with an associated shift in stresses in the arch of the culvert. Cracking of a footing may also occur because of scour and undermining of the footing. In either case, the footing must be repaired or strengthened so that it can reliably carry the required structural loads without cracking or being displaced. This strengthening can only effectively be done by underpinning the footing.

Underpinning involves dewatering the construction zone, excavation of the soil under portions of the footing, installation of reinforcing steel (in most cases), and then placing concrete to develop a structural reinforced concrete “footing” under the existing footing. If there is a scour problem, then the depth of the underpinning must certainly extend a considerable distance below any possible future scour line. Depending on the site of the culvert and the nature of the water and debris that may pass through it, it may be necessary to protect the footings with riprap or to pave the invert.

Repair of deteriorated inverts in cast-in-place concrete culverts generally requires paving to restore them to an acceptable functional condition. In order to accomplish such paving it is necessary to divert all water flow so that the invert may be dried, deteriorated concrete may be removed and other necessary work be done to prepare the invert for paving. A variety of Portland cement-based concretes may be used for such paving including conventional concrete, high strength concrete, and steel fiber reinforced concrete. Regardless of the materials selected for the paving it should be reinforced and securely anchored to the existing/remaining invert. In areas where there is acidic water it may be necessary to coat the concrete surface with an epoxy sealer or a polymer concrete.
8-4-7 General:
There are now thousands of culverts in use today that are showing signs of wear. While some types of deterioration may not, for the present, endanger the traveling public or affect the capacity of the culvert to perform, many of these culverts may need to be either repaired or replaced.

2. Repair Versus Replacement
The rehabilitation or replacement of a culvert, particularly a large one, can be an item of great significance in the budget of a local agency. County or state agencies, which are responsible for the construction and maintenance of many culverts, can be faced with enormous costs, especially as culverts in place begin to reach their life expectancy.
It is, therefore, important that all pertinent facts are considered and evaluated before decisions are made as to whether to rehabilitate, repair, or replace and how the work is to be performed. The development of available alternatives should include consideration of the following elements:

- The condition of the existing culvert and its suitability for rehabilitation;
- The current and future needs of the area served by the culvert;
- The capacity, alignment, and other characteristics of the culvert to meet
- Present and anticipated needs;
- The cost of repair versus the cost of replacement;
- Site conditions
  - Effluent characteristics;
  - Other considerations:
    - Life-cycle costs;
    - Funding availability;
    - Availability and expertise of in-house forces;
    - Availability and expertise of local contractors;
    - Availability and cost of materials and specialized equipment;
    - User costs or time out of service; and
    - Aesthetics

Table 8-12 illustrates the work alternatives for pipe shape
Table 8-12: Work options for each strategy

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Objective</th>
<th>Work options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine Maintenance</td>
<td>To keep a culvert in a uniform and safe condition by repairing specific</td>
<td>▪ Debris &amp; sediment removal</td>
</tr>
<tr>
<td></td>
<td>defects as they occur.</td>
<td>▪ Thawing frozen culverts</td>
</tr>
<tr>
<td>Preventive Maintenance</td>
<td>A more extensive strategy than routine maintenance intended to arrest</td>
<td>▪ Joint sealing</td>
</tr>
<tr>
<td></td>
<td>light deterioration and prevent progressive deterioration.</td>
<td>▪ Concrete patching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Mortar repair</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Invert paving</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Scour prevention</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Ditch cleaning &amp; repair</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>Takes maximum advantage of the remaining unusable structure in a culvert</td>
<td>▪ Repair of basically sound endwalls &amp; wingwalls</td>
</tr>
<tr>
<td></td>
<td>to build a reconditioned culvert</td>
<td>▪ Invert paving</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Repair of scour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Slope stabilization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Streambed paving</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Addition of apron or cutoff wall</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Improving inlet configuration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Installing debris collector</td>
</tr>
<tr>
<td>Upgrade to equal replacement</td>
<td>Upgrade to provide service that is equal to that provided by a new</td>
<td>▪ Addition, repair or replacement of appurtenant structures.</td>
</tr>
<tr>
<td></td>
<td>structure.</td>
<td>▪ Lining of the barrel.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Provision of safety grates or safety barriers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Lengthening of the culvert</td>
</tr>
<tr>
<td>Replacement</td>
<td>Provide a completely new culvert with a new service life.</td>
<td>Can be accompanied by:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Realignment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Hydraulic structural and safety improvements.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Change in culvert shape or material</td>
</tr>
</tbody>
</table>

Figure 8-6: Work sheet for recording the data collected on each culvert.
It is suggested that this tabulation be utilized as a summary sheet and placed at the front of calculations and sketches prepared for each culvert on which a decision is required.

**Figure 8-9: Work sheet for Recording the Data Collected on Culverts for Strategies and Work Options (continued)**

<table>
<thead>
<tr>
<th>General Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of culvert</td>
</tr>
<tr>
<td>Type material</td>
</tr>
<tr>
<td>Size &amp; length</td>
</tr>
<tr>
<td>Age of structure</td>
</tr>
<tr>
<td>Depth of cover</td>
</tr>
<tr>
<td>Roadway classification</td>
</tr>
<tr>
<td>Urban or rural</td>
</tr>
<tr>
<td>Roadway scheduled for repair?</td>
</tr>
<tr>
<td>Hydraulically adequate/future</td>
</tr>
<tr>
<td>Structurally adequate/future</td>
</tr>
<tr>
<td>Alignment adequate?</td>
</tr>
<tr>
<td>Safety adequate/future traffic</td>
</tr>
<tr>
<td>Deterioration</td>
</tr>
<tr>
<td>Light</td>
</tr>
<tr>
<td>Useable structure remaining</td>
</tr>
<tr>
<td>Little structural value remains</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategic &amp; work options (refer to table 8-12)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Routine Maintenance</strong></td>
</tr>
<tr>
<td>Remove debris and sediments</td>
</tr>
<tr>
<td>Thaw frozen culvert</td>
</tr>
<tr>
<td>Control vegetation</td>
</tr>
<tr>
<td><strong>Preventive Maintenance</strong></td>
</tr>
<tr>
<td>Clean and repair sediments</td>
</tr>
<tr>
<td>Seal joints</td>
</tr>
<tr>
<td>Patch concrete</td>
</tr>
<tr>
<td>Repair mortar</td>
</tr>
<tr>
<td>Pave invert (limited)</td>
</tr>
<tr>
<td>Prevent scour</td>
</tr>
<tr>
<td><strong>Replace</strong> (May include the following)</td>
</tr>
<tr>
<td>Re-alignment</td>
</tr>
<tr>
<td>Hydraulic, structural and safety improvements</td>
</tr>
<tr>
<td>Change in culvert shape or material</td>
</tr>
<tr>
<td>Alternative 1:</td>
</tr>
<tr>
<td>Rehabilitation</td>
</tr>
<tr>
<td>Repair scour damage</td>
</tr>
<tr>
<td>Repair end walls and wing walls</td>
</tr>
<tr>
<td>Stabilize slopes</td>
</tr>
<tr>
<td>Pave streambed</td>
</tr>
<tr>
<td>Add apron or cutoff wall</td>
</tr>
<tr>
<td>Improve inlet configuration</td>
</tr>
<tr>
<td>Install debris collector</td>
</tr>
<tr>
<td><strong>Upgrade to equal replacement</strong></td>
</tr>
<tr>
<td>Add, repair or replace appurtenants structures</td>
</tr>
<tr>
<td>Line the barrel</td>
</tr>
<tr>
<td>Provide safety grates or safety barriers</td>
</tr>
<tr>
<td>Lengthen the culvert</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Alternative 2</td>
</tr>
<tr>
<td>Alternative 3</td>
</tr>
</tbody>
</table>
Figure 8-9: Work sheet for Recording the Data Collected on Culverts for Strategies and Work Options

<table>
<thead>
<tr>
<th>Reinforcement of Options</th>
<th>Expertise available? □ Yes □ No</th>
<th>□ Yes □ No</th>
<th>□ Yes □ No</th>
<th>□ Yes □ No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment available?</td>
<td>□ Yes □ No</td>
<td>□ Yes □ No</td>
<td>□ Yes □ No</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Estimated cost:</td>
<td>-------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Present</td>
<td>-------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Annual</td>
<td>-------------------------------</td>
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<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Future</td>
<td>-------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Year applied:</td>
<td>-------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Estimated life:</td>
<td>-------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Present worth:</td>
<td>-------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Annual cot:</td>
<td>-------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
</tbody>
</table>

3. Replacement Systems
Not all culverts should be repaired or rehabilitated. Some should be replaced if they cannot be repaired or rehabilitated to meet the present and future needs of the area in which it is located. Therefore, if the physical requirements have changed, careful analysis and design should precede the selection of the type, size, and installation characteristics of the replacement culvert.

8-4-8 Repair and Upgrade Procedures
8-4-8-1 Repair and Upgrade Systems
Applications:
The following procedure is applicable to the removal of debris both at the mouth of the culvert and inside the culvert barrel, which causes blockage of the waterway and impedes the flow of the stream.
The need for removal of debris generally is based on reports from culvert inspectors or as reported by culvert maintenance personnel. However, debris is likely to collect during a period of high water and should be removed prior to succeeding periods of high water to help reduce scour problems. Debris can also hold moisture against a structure, accelerating corrosion. Abrasion is accelerated by the continual movement of stones and other material that are not cleared by the culvert barrel
Procedures:
The general procedure for removal of sediment includes the following steps:
1. Place traffic control devices. Observe the work area and decide where to place traffic control devices if they are required. Place advance warning signs and devices so that they can be seen by drivers in time to react. Keep tools off the roadway.

2. Assign the work. When cleaning culverts, position workers on both sides of the roadway to work as a team to minimize crossing the roadway.

3. Start by removing debris and obstructions in the channel around the mouth of the culvert and at the outlet end. Cut debris with a handsaw or chainsaw if necessary.

4. Clean inside the culvert barrel.
   a. If the culvert is large, send a crew inside to clean from each end, meeting in the middle.
   b. If the structure is a large box culvert, a small front-end loader can be used to remove the debris.
   c. If the structure is too small to go inside, tie a rope to a long stick or pole. Push the stick and the rope through the culvert to the other end. When the rope comes out the other end, tie it to a piece of wood or a metal bucket. Have the crew on the other end pull the rope and bucket through. This should clean out the debris.

5. It may be necessary to clean out debris from a channel or natural water course beyond the right-of-way line to keep rains from washing material into a culvert line. Written permission should be obtained from the property owner before entering private property to clean up debris.

6. Load all the waste inside a wheel-barrow and properly dispose of it.

**Safety precautions:**
Proper precaution should be taken to ensure the safety of workers. When air quality is questionable, test for oxygen content and the presence of hazardous gases should be conducted prior to entry. Confined spaces should be mechanically ventilated continuously during occupancy. Scour joules and flash floods present drowning hazards. Steep embankments, toxic chemicals in streams, animals, poison ivy, and insects all present a danger.
8-4-8-2 Procedures for Shotcrete/Gunite Paving, Lining, and Repairs

Applications:
Shotcrete may be used for the following types of works:

- Repairing damaged and/or deteriorated headwalls, end-walls, and wing-walls of culverts. Repairing and/or paving culvert inverts.
- Retrofitting inlet and outlet features to provide increased flow capacity, to inhibit abrasion damage, and to facilitate fish passage.
- Lining approach channels; and
- Lining corrugated metal culverts to increase flow capacity by reducing roughness of the inside surface.

The terms ‘shotcrete’ and ‘gunite’ refer to the process of pneumatically transporting and placing Portland cement-based mortar or concrete with compressed air. Although the term shotcrete may generally be used for all related processes, the term gunite frequently refers to a dry mix, whereas shotcrete may refer to both wet and dry mixes. As with conventional Portland cement concrete, the physical properties of wet and dry shocrete mixes depend upon many factors, including the relative amounts of water, cement, and chemical admixtures.

Shotcrete has advantages over conventional concrete for many types of repair works. It is especially advantageous where formwork is impractical or where forms can be reduced or eliminated, where access to the work area is difficult, and where thin or available thicknesses are necessary. Properly applied shotcrete is structurally sound and durable. It has excellent bonding characteristics with concrete, masonry, rock, and steel. However, these properties are very dependent upon the use of good materials and procedures by a knowledgeable and experienced nozzleman to adjust the amount of water added to the mix. Figures 8-7 to 8-10 illustrate the proper shooting positions and procedures to produce the best results from the shotcrete.

Figure 8-10: Correct shooting positions (aquaure or radial to wall)
Figure 8-11: Manipulating the nozzle to produce the best shotcrete
Figure 8-12: Correct shooting position for thick applications,

It should be noted that a variety of Portland cement-based materials may be pneumatically applied. The choice of materials will depend upon site-specific conditions and requirements for the materials. Typical materials include conventional concrete, high strength concrete and steel fiber reinforced concrete.

**Procedures:**
1. It is essential that the work area be properly prepared for the application of both dry and wet shotcrete mixes. Steel surfaces should be cleaned of loose mill scale, rust, oil, paint or other contaminants.
For concrete surfaces, it is imperative to completely remove all spalled, severely cracked, deteriorated, loose, or otherwise unsound concrete by chipping, scarifying, sandblasting, water-blasting, or other mechanical means. For solid concrete surfaces, it may be necessary to sandblast or otherwise remove the surface layer of cement paste to facilitate bond between the existing concrete and the shotcrete.

2. Steel reinforcement, consisting of welded wire mesh fabric or plain or deformed reinforcing bars is required for installations where shotcrete must carry structural loads or drying shrinkage cracking must be avoided. The amount, size, and distribution of reinforcing steel should be determined as for conventional reinforced structures. The enforcement should be rigidly secured in position with anchorage devices to assure structural interaction of the shotcrete with the existing structure.

3. Earth, concrete, masonry surfaces should be pre-dampened so as to minimize absorption of water from the shotcrete and the creation of a weak interface bond, however, the surface should be free of standing water.

4. The shotcrete should be mixed, pneumatically transported, and placed in accordance with recommendations and guidelines contained in documents of the shotcrete industry.

5. Immediately after finishing, shotcretes should be continuously moist for at least 24 hours by using ponding or sprinkling, (b) an absorptive mat, fabric, or other covering, or (c) a curing compound.

Safety Procedures:
The potential of problems and injury due to construction with shotcrete should be recognized and avoided. The materials are transported by high pressure air through hoses, which are difficult to control and which could break. The process is noisy, which can cause ear damage. The cement dust in the air can cause skin and eye damage.

8-4-8-3 Procedures for Installing Riprap

Application
Riprap can be installed on soil-water interface where the soil conditions, water turbulence and velocity, or expected vegetative cover are such that the soil may erode under design flow conditions. Riprap may be used, as appropriate, at storm drain outlets, on channel banks or bottoms, around
culvert appurtenants to prevent corrosion and scour, in roadside ditches, and along the toe of slopes.

The purposes fulfilled by the placement of riprap are as follows:

To protect the soil surface from the erosion forces of concentrated runoff;

- To slow the velocity of concentrated runoff while enhancing the potential for infiltration;
- To stabilize slopes with seepage problems and/or non-corrosive soils; and
- To stabilize streambeds and stream banks exposed to increased velocity and turbulence at culvert inlets and outlets.

Comments:

There are several types of riprap that are considered to be permanent flexible linings. These types are described as follows:

**a. Rock riprap**

Rock riprap is dumped in place on a filter blanket or prepared slope to form a well-graded mass with a minimum of voids. Rocks should be hard, durable, preferably angular in shape, and free from overburden, shale and organic material. It should be noted that hand-placed riprap is considered to be a rigid lining since it cannot accommodate even movement of the surface it protects.

**b. Gravel riprap**

Gravel riprap consists of coarse or crushed rock placed on filter blankets or prepared slope to form a well-graded mass with a minimum of voids. The material is composed of tough, durable, gravel-sized particles and should be free from organic matter.

**c. Wire-enclosed riprap:**

Wire-enclosed riprap, usually known as gabions, is manufactured from a rectangular container made of steel wire, woven in a uniform pattern and reinforced on the corners and edges with heavier wire. The containers are filled with stones, connected together, and anchored to the channel side slope. Stones must be well graded and durable. Wire-enclosed riprap is typically used when high quality rock riprap is either not available or not large enough to be stable.

Appendix B, section 9 contains further information on gabions. Methods discussed below refer to dumped rock riprap only.
Procedures:
1. Riprap and Geo-textiles Placement for Stream bank/Streambed Protection
   a) If a portion of the streambed is to be lined, construct a sandbag cofferdam to an elevation above the water level or divert the stream using temporary pipes.
   b) Install sediment control devices
   c) Prepare foundation by removing unsuitable material, sediment, vegetation, and debris
   d) Backfill with suitable material if required
   e) Select appropriate geo-textile according to the local specifications
   f) Place the geo-textile as described the local specifications
   g) Place the geo-textile so that it will not stretch or tear excessively
   h) Anchor the terminal ends by using the key trenches or aprons at the crest and toe of the slope as described in paragraph ‘e’.
   i) Overlap successive geo-textile sheets in such a manner that the upstream sheet is placed over the downstream sheet and/or upslope over down-slope. In underwater application, place the geo-textile riprap the same day. Begin the riprap placement at the toe and proceed up the slope.
   j) Overlap seams a minimum of 31 cm (12 inch) except when placed underwater where the overlap shall be a minimum of 92 cm (3 feet). Secure with anchor pins, 38 cm (15 inch) long every 92 cm (3 feet) along the overlap.
   k) Riprap and heavy stone filling should not be dropped onto the geo-textile from a height to exceed 30.5 cm (1 foot). Slope protection and smaller sizes of stone filling should not be dropped from a height exceeding 92 cm (3 feet). For larger stones 31 cm (12 inch) or greater, an 11 cm (4 inch) layer of gravity may be necessary to prevent damage to the cloth.
   l) Placement of stone should follow immediately after placement of the filter. The riprap should be placed so that it produces a dense well-graded mass of stone with a minimum of voids. It should be placed its full thickness in one operation, not in layers. The riprap should not be placed by dumping into chutes or similar methods that are likely to cause segregating of the stone sizes.
   m) Remove sediment control devices.
2. **Riprap and Geo-textiles Placement to provide scour protection**  

NOTE: This construction to be done in the dry condition only  

a. Construct a sandbag cofferdam to an elevation above the water level or divert the stream using temporary pipes.  
b. Install sediment control devices  
c. Probe the scour holes to determine its approximate size. Remove sediment, unsuitable material, and debris from the scour hole.  
d. Excavate the scour hole to a minimum of 92 cm (3 feet) deep to the natural streambed material  
e. The geo-textile should line the scour hole and be placed so that the fabric will overlap a minimum of 92 cm (3 feet) downstream as shown below.  
f. Placement of fabric and riprap should follow the process as specified in items ‘I’ through ‘M’.  

![Diagram](image)  

**Figure 8-14: Use of Geo-textile to prevent scour**  

**Safety Precautions:**  

1. Riprap for slope stabilization must be designed so that the angle of repose of the stone mixture is greater than the gradient of the slope being stabilized.  
2. Finished riprap should be free of pockets of small stones or clusters of large stones. Minimum hand placing may be necessary to achieve the required grades and a good distribution of stone sizes. However, excessive hand placement will result in a rigid lining that will be less resilient when movement occurs.
3. Care should be taken by workmen probing the stream for depth of scour because of the current and unknown depth of the hole.

8-4-8-4 Procedure for Repair and Replacement of Apron/Cutoff Wall

Applications
This procedure is applicable to the repair and replacement of all or portions of existing culvert concrete or masonry aprons and cutoff walls.

Comments
Aprons and cutoff walls help to protect the slopes and channel bed from scour. Undermining is one of the major causes of failure of the aprons. If caught early, voids below can be filled and cutoff walls added as necessary to prevent further undermining. Care should be exercised.

Procedures
1. Install sediment control devices
2. Construct sluices or other devices to divert stream and to protect freshly placed concrete from flowing water.
3. Remove deteriorated masonry or concrete.
4. Excavate unsuitable material. The apron should not protrude above the streambed elevation.
5. Place and compact base material.
6. Drill holes and set dowels with non-shrink grout or approved adhesive.
7. Construct formwork. Aprons should extend at least one pipe diameter upstream.
8. Place reinforcing steel.
9. Place concrete. Just prior to placing concrete, apply epoxy bonding agent to all existing concrete that is to come into contact with new concrete.
10. Remove formwork
11. Remove sluices and sediment control devices.
12. Grade streambed.

8-4-8-5 Procedure for Concrete Jacket Repair for End walls and Wing walls

Applications
This procedure can be used to repair the deteriorated face of concrete endwalls or wing walls when the deterioration of the concrete is not
related to lack of air in the concrete, inferior to inadequate aggregate, or another progressive concrete deterioration problem.

**Comments**

Agency specifications for materials and placement of concrete should be followed. Endwalls and wing-walls should be jacketed only when the existing material is deemed sound.

**Procedures:**

1. Remove deteriorating concrete and laitance by chipping and blast cleaning.
2. Drill and set dyscrus and lagstuds.
3. Set reinforcing steel and forms.
4. Just prior to placing concrete, apply epoxy bonding agent.
5. Place cement concrete, cure, remove forms, and provide erosion control as shown in figure 8-12.
New concrete coat 15.5 cm (6 inches) at least

Replace deteriorated portions of endwall or wing wall

Cross-ties and wedges ½” 61 cm

Cover 8 cm (3 inches)

Steel net No.6 gauge 15.5 X 15.5

Top of footing

Typical Section

Figure 8-15: Endwalls & Wing Walls
8-4-8-6 Procedure for Underpinning

Application

The following procedure have application to underpinning portions of hydraulic structures including footings, wing-walls, and the upstream end of culverts.

Comments

Underpinning is the process of increasing the support for structures that have deteriorating or inadequate sill support. The cause may be scour and erosion of soil from under the structural footings or the structure may have been constructed without adequate soil support. Although several concepts may be used for re-instating or increasing the structural support by underpinning, the most appropriate will depend on the site conditions and the type of repair or retrofit work that must accomplished.

Procedures

Several concepts and methods may be used for underpinning portions of hydraulic structures depending upon the nature and severity of the problems. The following are general guidelines that may be used as the basis for the work to be done.

1. General Procedure

   a. Construct a sandbag cofferdam to an elevation above the water level or divert stream using temporary pipes.
   b. Clean all exposed concrete of marine growth and remove loose or deteriorated concrete.
   c. Excavate to a depth of two feet below the bottom of the scour or as directed by the engineer as shown in figure 8-13.
   d. Drill required dowel holes, set and install dowels, set additional reinforcing, and place and anchor forms.
   e. Place and consolidate the concrete, making sure that the scour area is completely filled.
   f. Remove forms and as necessary protect against continued streambed erosion with gabions or stone riprap. Where the scoured-out material is fine-grained, a properly designed filter should be placed prior to placing the riprap.
Figure 8-16: Underpinning foundation with concrete

2. **Use of Tremie Concrete Procedures**
   Clean all exposed concrete of marine growth and remove loose of deteriorated concrete
   a. Excavate as required to sound material
   b. Place concrete riprap bags around scour area. Where the scoured-out material is fine-grained, a filter should be placed prior to placing the riprap as shown in figure 8-14
   c. Pump or tremie concrete into damaged area
   d. Protect against continued streambed erosion as required by rebuilding the streambed with properly designed riprap or by paving the streambed. Where the scoured-out material is fine-grained a properly designed filter should be placed prior to placing the riprap.
Figure 8-17: Repair of scour damaged wing-wall using concrete-filled bags or tubes and tremie concrete

Precautions:

1. Compliance with applicable permit and procedural requirements of fish and wildlife and conservation organizations may be required.
2. Caution must be exercised that the structure does not collapse during the repair period. Dewatering of wall structures eliminates water pressure on that side of the structure, which could allow active soil pressure on the back side of the wall to push the wall over, particularly if a large portion of the footing is undermined. It should also be recognized that dewatering for a period of time may allow soil under a footing to dry and shrink away from the underside of the footing.
3. If concrete is used to fill undermined sections of a footing, appropriate formwork should be used so that the void is completely filled. If possible, vibrators should be used to help consolidate the concrete and to eliminate pockets of entrapped air.
8-4-8-7 Procedure for Repairing Cracks in Concrete:

Applications:
The following discussion applies to the repair in Portland cement concrete.

Comments
The procedures and materials that should be used for repairing cracks in Portland cement concrete will frequently depend upon the cause of the crack, its location, and the environment surrounding it. Shrinkage cracks may be quite narrow and shallow and have little influence on the structural behavior, whereas wider and deeper cracks may have been caused by structural loading and may signify more serious effects on structural load carrying capacity. Both types of cracks may have an influence on long term durability of the structure.

Procedures
1. **Installation of a Flexible Sealant**
The following is a general procedure for filling a crack with a flexible sealant. The manufacturers of such sealants will have more specific recommendations for their particular materials if the highway agency has not established such procedures.
   a. Clean the surface of the concrete
   b. Route a groove into the surface of the crack, so that it will serve as a reservoir for the sealant.
   c. Clean concrete dust and debris out of the crack by sand-blasting, air-water jet, or both.
   d. Fill the crack with the sealant by pressure injection or toweling. If toweling is to be done a bond breakage should be first applied to the surface of the concrete on both sides of the crack so that the sealant will not have a wide width at the top of the crack.
   e. Scrape excess sealant off the concrete surface, so that the surface will be smooth. (For some types of cracks it may be desirable to trowel a shallow depression in the surface of the sealant).
2. **Installation of a Portland cement mortar or grout;**
Wide cracks may be repaired by filing with Portland cement grout as follows:
   a. Clean the surface of the concrete
b. Install built-up seats and grout nipples at intervals along and astride the crack to provide a pressure tight contact with the injection apparatus.

c. Seal the crack between the grout nipples, with a cement paint, sealant, or grout.

d. Flush the crack to clean it and to test the seal.

e. Grout the crack. The grout mixture may contain cement and water or cement plus sand plus water, depending on the width of the crack. However, the water-cement ratio should be kept as low as possible to provide maximum strength and low shrinkage. The grout may include a water reducer or other admixtures to improve the properties of the grout.

3. **Repair by injection of epoxy adhesive**

   **Equipment:**
   
   a. **Type** – the equipment used to meter and mix the two injection adhesives components and inject the mixed adhesive into the crack shall be portable, positive displacement type pumps with interlock to provide positive ratio control of exact proportions of the two components at the nozzle. The pumps should be electric or air powered and shall provide in-line metering and mixing.

   b. **Discharge pressure** – the injection equipment shall have automatic pressure control capable of discharging the mixed adhesive at any present pressure up to 200 psi plus/minus 5 psi and shall be equipped with a manual pressure control override.

   c. **Ratio tolerance** - the equipment shall have capability of maintaining the volume ratio for the injection adhesive prescribed by the manufacturer of the adhesive with a tolerance of minus 5 percent by volume at any discharge pressure up to 200 psi.

   d. **Automatic shut-off control** – the injection equipment shall be equipped with sensors on both the component A and B reservoirs that will automatically stop the machine when only one component is being pumped to the mixing head.
4. **Preparation:**
   a. Surfaces adjacent to cracks or other areas of application shall be cleaned of dirt, dust, grease, oil, efflorescence or other foreign matter to bond of epoxy injection surface seal system. Acids and corrosives shall not be permitted for cleaning.
   b. Entry ports shall be provide along the crack at intervals of not less than the thickness of the concrete at that location.
   c. Surface seal material shall be applied to the face of the crack between the entry ports. For through cracks, surface seal shall be applied to both faces, if possible.
   d. Enough time for the surface seal material to gain adequate strength shall pass through before proceeding with the injection.

**Epoxy injections**
   a. Injection of epoxy adhesive shall begin at lower entry port and continue until there is an appearance of epoxy adhesive at the next entry port adjacent to the entry port being pumped.
   b. When epoxy adhesive travel is indicated by appearance at the next adjacent port, injection shall be discontinued on the entry port being pumped, and epoxy injection shall be transferred to the next adjacent port where epoxy adhesive appeared.
   c. Perform epoxy adhesive continuously until cracks are completely filled.
   d. If port to port travel is of epoxy adhesive is not indicated, the work shall immediately be stopped corrective work the engineer notified.

**Finishing**
   a. When cracks are completely filled, epoxy adhesive shall be cured for sufficient time to allow removal of surface seal without any drainage or runback of epoxy material from cracks.
   b. Surface seal material and injection adhesive runs or spills shall be removed from concrete surfaces.
   c. The face of the crack shall be finished flush to the adjacent concrete showing no indentations or protrusions caused by the placement of entry ports.
8-4-8-8 Procedure for sealing culvert joints:

Application

The following applies to sealing the joints of corrugated metal and precast concrete culverts. Although the methods are used more commonly for metal (flexible) culverts, they may be used for the others, with same adaptation.

Comments:

Corrugated metal pipes and pipe arch as well as precast concrete culverts are subjected to a variety of external loads and changing soil conditions that may cause the circumferential joints to open. When this occurs infiltration and exfiltration frequently develop and cause a progressively worsening condition. Open joints lead to loss of the embankment material and creation of voids in the embankment surroundings and supporting the culvert. Uneven soil pressures may cause distortion of metal culverts and cracking and settlement of precast concrete culverts, with possible collapse of both types.

Procedures

1. Steel expansion ring gasket

   Several types of steel expansion rings are available for repair of culvert joints from inside of the culvert, as shown in figure 8-18.
   a. The type and width of band to be used is determined based on the amount of separation and the misalignment at the joint. For example, a corrugated band would be selected if there were no or very little misalignment.
   b. Based on the type and width of band selected, a gasket that will properly seal the joint is determined i.e. an O-ring type could be used with a corrugated band; a strip type with other types of bands where minor misalignment is determined; and a mastic type with a flat band where misalignment is greater. Strip gaskets should be wider than the band.
   c. Fabricate band(s) using 2 sections that conform to the existing pipe shape. Each section should conform as neatly as possible to ½ of the cross-section of the pipe, with the maximum being equal to the perimeter of the 2 sections. Shorter than ½ cross-section may be desirable if the two pieces are to be bolted together prior to placement at the joint. Size and location of angles are determined by design, space required for hardware
(nuts and washers), and space required to facilitate installation. The size of bolt should be ¾ inch minimum. It may be necessary to specify larger diameter bolts for some installations.
d. The peripheral area of the pipe where the band is to be placed must be cleaned and prepared. Dirt and debris should be removed. Localized dents and distortions should be smoothed out by hammering with hat applied as necessary to help in the straightening. All fins, burrs, and other imperfections in the pipe should be ground to a smooth surface.
e. Install the band with gasket either with the two sections bolted together or as single units. the bottom half should be installed first. On larger pipe, the top half may require temporary support prior to bolting the sections together. If a strip gasket is used, the lap should be as close to the top as practical. On pipe arches, it may be necessary to weld the bottom section to the pipe due to the possibility of buckling at the invert when the bolts are tightened.
f. Tighten the bolts evenly until a tight fit is realized. A tight fit may be determined by the distortion of the gasket or band-to-pipe contact. Caution: observe invert area of bank for buckling.
g. Seal the edges of the band with mastic.

Safety precautions
If galvanized metal is used for the ban, removal of the galvanizing is required prior to welding clip angles. Caution should be exercised when shop or field welding is performed on galvanized metals. Fumes can be toxic. The welder should wear a mask in case all galvanizing has not been removed.
a. Internal expandable band

b. Standard steel pipes rings

**Figure 8-18: Different shapes of gaskets**

<table>
<thead>
<tr>
<th>Types of bands</th>
<th>X-sections</th>
<th>Angles</th>
<th>Bar, bolt &amp; strap</th>
<th>Wedge lock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universe</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Corrugated</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Semi-corrugated</td>
<td>●</td>
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<tr>
<td>Channel</td>
<td>●</td>
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<td>●</td>
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</tr>
<tr>
<td>Flat</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Wing channel</td>
<td>●</td>
<td>●</td>
<td>●</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gaskets</th>
<th>O-ring</th>
<th>Sleeve or strip</th>
<th>Mastic</th>
<th>Angular plain</th>
<th>Plain</th>
<th>Reformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-Ring</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Sleeve gasket</td>
<td>●</td>
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<tr>
<td>Strap gasket</td>
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</tr>
</tbody>
</table>
8-4-8-9 Procedure for patching concrete

Applications

The following procedure may be used to patch spalled, delaminated and broken areas of Portland cement concrete.

Comments

Although there are materials that may be used for patching concrete, the overriding principle for such repair is that it be done carefully and with good workmanship. The cracked, spalled, or otherwise deteriorated area to be repaired must be properly prepared, good materials must be used, and the work must be properly protected until the materials have gained sufficient strength and other physical properties to withstand the expected environmental and loading conditions. The alternative to this produces a patch that will not endure and the patching work will be a total waste of time and money. Moreover, loss of the patch may create worsening or additional problems that may certainly require even more time, material, and funding to correct. Depending upon the site condition, even well-prepared and installed patches may not last very long, and it should be an established practice to periodically inspect critical patches to ensure that the structure is performing adequately.

The material that normally provides the most permanent patch for Portland cement concrete is Portland cement concrete. The closer the physical properties of the patch are to the existing material, the better. It is important to minimize shrinkage of the patching material. This may be done by using a low water/cement ratio material. A water reducing admixture may also be used. Inclusion of a latex additive to the concrete or mortar will also reduce the amount of water required for workability and also reduce the permeability of the patch material. Other performance-proven additives can be used to reduce setting time and to increase strength.

Proper curing is important for all concrete work and especially important for patching. Thin patches present a particularly difficult problem because they dry out quickly. The exiting concrete will tend to absorb the moisture in the patching material. If exposed to the sun or wind, moisture is lost even more readily. If possible, patches should be covered with moist burlap.

The following provides some guidance for patching Portland concrete.
Procedures

1. The first step is to determine the exact boundaries of the distressed concrete. Delaminated areas may be detected by tapping by a hammer or steel rod, with a hollow sound being produced in the delaminated area.

2. Remove delaminated and/or broken concrete from the distressed area. For some areas or structures it may be desirable to make a ¾ inch deep saw-cut around the area to be patched. For delaminated and spalling areas, the edge of the repair should be extended 12 to 18 inches into good concrete to ensure that all cracked concrete is removed. Deteriorated concrete may be removed with power-driven hand tools. If used, pneumatic hammers should not be heavier than a nominal 30 pounds. A 15 pound chipping hammer may be useful, particularly around reinforcing bars. Care must be taken to not apply heavy vibrations to reinforcing bars, to prevent breaking bond with the concrete.

3. The repair area should then be air- or sand blast cleaned to remove all dust and debris. Do not use water to clean the area.

4. Apply cement or cement-latex grout or an epoxy resin to the sides and bottom of the area to be repaired.

5. Place the patching material in the distressed area, in accordance with the local specifications or the guidelines of the manufacturing company. The material should be placed before the bonding layer (step 4) begins to set up. The patch material should then be struck off, finished, and edged as required.

6. The patch area should then be covered with wet burlap or a moisture barrier and allowed to cure without disturbance.

8-4-8-10 Procedure for grouting voids behind and under culverts

Application

The following discussion deals with the materials and procedures that may be used to grout voids behind and under culverts.

Comments

There have been substantial advances in the development of grout and grouting techniques. Much of this advancement is the result of the need for improved techniques for grouting underground construction, machinery bases, and segmental pre-stressed concrete and cable-stayed bridges. It has been well established that the primary objective of
grouting is to completely fill the required space with a material that will not shrink segregates, or otherwise create additional problems.

Critical reviews of previous grouting jobs have led to the development and use of special admixtures for Portland cement based grouts and mortars, and chemical and foaming grouts that foam and expand when they come in contact with water. In general, for concrete repair work Portland cement based grouts, with and without special admixtures, are adequate and much less expensive than the foaming and chemical grouts that are used to set machinery and to resist high external and internal fluid pressures.

The primarily objective of completely filling the void can be accomplished by adequately studying site conditions and properly planning and executing the grouting operation. The principal problem to be avoided is entrapment of air or water, in the void to be filled with grout. The procedures to be used for grouting must recognize this potential problem and provision must be made for air or water to be vented out of the void as grout is pumped into the void. Depending on the location of the void to be filled, the grout may be installed with a pressure pumping system or it may merely flow in by gravity.

Normally voids under corroded or undermined inverts may be filled by a gravity flow method. Voids behind the sides of culverts that are caused by piping or ex-filtration will have to be pressure grouted to ensure that the void is properly filled. However, for certain situations where the void can be accurately located, it may be possible to fill side voids by gravity feed from the roadway surface.

**Procedures**

There are basically three procedures for grouting.

2. **Gravity flow from above the void**

   This concept involves merely pouring the grout into the void from above it. It is assumed that the fluid grout will completely fill the void without entrapping air and that any water in the void will be displaced as the heavier-than-water grout displaces it.

   Although this technique may work for a water-filled void, the grout will be probably dispersed in the water with the result that the void will to be properly grouted. It is much preferred that any water in the void be pumped out prior to grouting.
2. **Grouting through a tremie pipe or tube**
   For this gravity feed concept the grout is introduced into the void by pouring it into a tremie tube, so that grout fills the void from the bottom with an upward flow of the grout. The procedure may be warranted for some site conditions where there is a potential problem of entrapment of air in the grout.

3. **Pressure grouting**
   This concept will normally be used to fill voids behind the sides of the culvert. If the void is behind an open joint, it will be necessary to seal the interior surface of the joint, normally with a concrete mortar, or a joint sealing system.

   The most effective procedure for grouting will then involve installation of grout tubes at the bottom and the top of the joint or void. The grout is then pumped into the lower tube. Air or water will, first, flow out of the upper tube, then a watery grout will flow out, and finally a pure grout will flow out of the upper tube. At this point it may be considered that the void is properly filled.

   **Precautionary**
   1. The grouting procedures should be designed so that air or water is not trapped in the void.
   2. The grouting pressure should be monitored to prevent burning of lines and/or displacement of the culvert walls if a blockage develops in the grout lines.
Chapter 9

Safety Precautions for the Inspection and Maintenance Works
Chapter 9: Safety Precautions for the inspection and Maintenance Works

9-1 Introduction:
This chapter is part of the Bridges and Dams Maintenance Manual of the Directorate General of Operation and Maintenance, Ministry’s Agency for Technical Affairs, Ministry of Municipal and Rural Affairs. It generally consists of two main parts (1) the main concerns for bridge and dams inspection for safety, and (2) traffic control. This includes the safety responsibilities, personal protection, causes of accidents, and inspection team safety procedures in the work site, traffic control equipments, and general safety.

9-2 Main Concerns for Bridge Inspection for Safety:
Five key motivations for bridge inspection safety:
- Injury and pain - Accidents can cause pain, suffering, and even death.
- Family hardship - A worker’s family also suffers hardship when an accident occurs.
- Equipment damage - The repair or replacement of damaged equipment can be very costly.
- Lost production - The employer loses revenues associated with the employee’s work, and also loses time and money spent on safety training and equipment.
- Medical expenses - Whether coverage is an employee benefit, personal insurance, or out of pocket, someone has to pay for medical expenses.

9-2-1 Safety Responsibilities
The employer is responsible for providing a safe working environment, including:
- Clear safety regulations and guidelines
- Safety training
- Proper tools and equipment

The supervisors are responsible for maintaining a safe working environment, including:
a. Recognition of physical limitations
b. Knowledge of rules and requirements of the job
c. Safety of fellow workers
d. Reporting an accident
9-2-2 Personal Protection
Proper Inspection Attire It is important to dress properly for the job. Field
clothes should be properly sized for the individual, and they should be
appropriate for the climate. For climbing of bridge components, the inspector
should wear boots with a steel shank, as well as leather gloves.

9-2-3 Inspection Safety
Equipment
Safety equipment is designed to prevent injury. However, the inspector must
use the equipment correctly in order for it to provide protection. The
following are some common pieces of safety equipment:

1. Hard Hat
   A hard hat can prevent serious head injuries in two ways.
   First, it provides protection against falling objects.
   Secondly, a hard hat protects the inspector’s head from accidental
   impact with bridge components (figure 9-1).

   Figure 9-1: An inspector wearing a hard hat

2. Reflective Safety Vest
   When performing activities near traffic, the inspector is required to wear a
   safety vest (figure 9-2)
3 Safety Goggles

Eye protection is necessary when the inspector is exposed to flying particles. Eye protection should be worn during activities such as:

- Using a hammer
- Using a scraper or wire brush
- Grinding
- Shot or sand blasting
- Cutting
- Welding

4. Gloves

Wearing gloves will protect the inspector’s hands from harmful effects of deteriorated members (figure 9-3)
4. **Life Jacket**

A life jacket should always be worn when working over water or in a boat (figure 9-4).

![Figure 9-4: Inspector Wearing a Life Jacket](image)

1. **Dust Mask / Respirator**

Conditions requiring a respirator include:

- Sand blasting
- Painting
- Exposure to dust from pigeon droppings
- Work in closed or constricted areas

![Figure 9-5: Inspector Wearing a Respirator](image)
2. **Safety Harness and Lanyard**
   The safety harness and lanyard is the inspector’s lifeline in the event of a fall (figure 9-6). Use this equipment as required by conditions, these may include the following:
   - At heights over 6.0 m (20 feet)
   - Above water
   - Above traffic

3. **Boats**
   When performing an inspection over water, it is required to have a manned boat in the water at all times.

![Figure 9-6: Safety Harness with a Lanyard](image)

### 9-2-4 Causes of Accidents

**General Causes**
Accidents are usually caused by human error or equipment failure.
Specific causes of accidents include the following:
- Improper attitude – distraction, carelessness, worries over personal matters.
- Personal limitations – lack of knowledge or skill, exceeding physical capabilities.
- Physical impairment – previous injury, illness, side effect of medication, alcohol or drugs.
➢ Boredom – falling into an inattentive state while performing repetitive, routine tasks.
➢ Thoughtlessness - lack of safety awareness and not recognizing hazards.
➢ Shortcuts - sacrificing safety for time.
➢ Faulty equipment – damaged ladder rungs, worn rope, frayed cables or access equipment not inspected regularly.
➢ Inappropriate or loose fitting clothing.

9-2-5 Safety Precautions
Safety precautions can be divided into four main categories:
General Precautions,
Climbing Safety,
Confined Spaces, and
Culverts.

1. General Precautions:
Some general guidelines for safe inspections are as follows:
   a) Keeping well rested and alert
   b) Maintaining proper mental and physical condition
   c) Keeping work areas neat and uncluttered
   d) Establishing systematic procedures
   e) Follow safety rules and regulations
   f) Avoid use of intoxicants or drugs
   g) Electricity – All Transmission lines on a structure should be identified prior to the inspection.
   h) Assistance – Always work in pairs.
   i) Inspection over water – A safety boat must be provided when working over water.
   j) Inspection over traffic – Equipments such as tools and clip boards, should be tied off.
   k) Entering dark areas – Use a flashlight to illuminate dark areas prior to entering as a precaution against falls, snakebites, and stinging insects.
   l) Homeless people – Caution should be exercised when approaching a bridge where homeless people are present.

2. Climbing Safety
There are three primary areas of preparation necessary for a safe climbing inspection:
1. Organization (figure 9-7 and 9-8)
2. Inspection Access Equipment (figures 9-9 and 9-10)
3. Mental attitude. Inspectors must:
   - Avoid emotional distress
   - Be aware of surroundings
   - Realize limitations

Figure 9-7: An inspection involving a lot of climbing

Figure 9-8: Bad weather makes some parts of the bridge slippery and limited visibility to divers
Figure 9-9: Proper use of a ladder

Figure 9-10: Truck with a lift
3. Confined Space Precautions

a. Safety Concerns

There are four major concerns when inspecting a confined space:

a) Lack of oxygen
b) Toxic gases
c) Explosive gases
d) Lack of light
Safety Procedures

Before entry, inspectors must:

a. Test for oxygen
b. Test for other gases,

**Basic safety procedures:**

a. Avoid the use of flammable liquids in the confined area.
b. Position gasoline powered generators "down-wind" of operations.
c. Operations producing toxic gases should be performed "down-wind" of the operator and the inspection team.
d. Carry approved rescue air-breathing apparatus.
e. Use adequate lighting.

4. **Culverts**

There are several hazards that can be encountered when performing a culvert inspection. The following are some of the hazardous conditions an inspector may encounter.

a) Inadequate Ventilation
b) Drowning
c) Toxic Chemicals
d) Animals
e) Quick sand conditions
f) Insufficient Number of Inspectors

**9-3 Traffic Control**

**9-3-1 Introduction:**

Bridge inspection usually only requires traffic control procedures for a relatively short term closure (only a day or two). Long term closures for construction activity which use concrete barriers are not included in this topic.
Bridge inspection, like construction and maintenance activities on bridges, often presents motorists with unexpected and unusual situations. Most state agencies have adopted the federal Manual on Uniform Traffic Control Devices for Streets and Highways. Some states and local jurisdictions, however, issue their own standard manuals or drawings.

When working in an area exposed to traffic, the bridge inspector should check and follow existing local agency standards. These standards will prescribe the minimum procedures for a number of typical applications and the proper use of standard traffic control devices such as cones, signs, and flashing arrow-boards (see Figure 9-13).

1. Inform the Motorists

Traffic safety in work zones should be an integral and high priority element of every inspection project, from the planning stage to performance of the inspection. The safety of the motorist, pedestrian, and worker must be kept in mind at all times.

The basic safety principles governing the design of traffic control for roadways and roadsides should also govern the design of inspection sites. The goal should be to route traffic through such areas with geometrics and traffic control devices comparable to those for normal highway situations. Notice of work site locations and guidance through these sites must be clearly communicated to the driver.
A traffic control plan, in detail appropriate to the complexity of the work project, should be prepared and understood by all responsible parties before the site is occupied. Any changes in the traffic control plan should be approved by an official trained in safe traffic control practices.

At times, after the initial installation, traffic control might need a revise in order to secure adequate protection for motorists, pedestrians or inspectors. Inspection time should be minimized to reduce exposure to potential hazards without compromising the thoroughness of the inspection. Principles and procedures, which have been shown to enhance the safety of motorists, pedestrians, and bridge inspection in the vicinity. These may include:

2. Control The Motorists
Traffic movement should be inhibited as little as practical. Traffic control in work sites should be designed on the assumption that motorists will only reduce their speeds if they clearly perceive a need to do so. Reduced speed zoning should be avoided as much as practical.

The objective is a traffic control plan that uses a variety of traffic control measures and devices in whatever combination necessary to assure smooth, safe vehicular movement past the work area and at the same time provide safety for the equipment and the workers on the job. Frequent and abrupt changes in geometrics, such as lane narrowing, dropped lanes, or main roadway transitions that require rapid maneuvers, should be avoided.

Provisions should be made for the safe operation of work vehicles, particularly on high speed, high volume roadways. This includes the use of roof mounted flashing lights or flashers when entering or leaving the work zone. This also includes considering the number of lanes that can be closed at one time for an operation.

While it might be most cost efficient to inspect a floor system from left to right, traffic control may dictate working full length, a few beams at a time.

3. Provide a Clearly Marked Path
A good traffic control plan provides safe and efficient movement of motorists and pedestrians and the protection of bridge inspectors at work areas. Adequate warning, delineation, and channelization should be provided to assure the motorist positive guidance in advance of and through the work area. Proper signing and other devices which are effective under varying conditions of daylight and weather must be used.
The maintenance of roadside safety requires constant attention during the life of the work because of the potential increase in hazards. All traffic control devices should be removed immediately when no longer needed.

To accommodate run-off-the-road incidents, disabled vehicles or other emergency situations, it is desirable to provide an unencumbered roadside recovery area that is as wide as practical.

Channelization of traffic should be accomplished by the use of signing, cones, barricades, and other lightweight devices which will yield when hit by errant vehicles.

Whenever practical, equipment and materials should be stored in such a manner as not to be vulnerable to run-off-the-road vehicle impact. When safe storage is no available, adequate attenuation devices should be provided.

9-3-2 Inspector Safety Practices in the Work Zone

Traffic represents as great, or even greater, threat to the inspector’s safety than climbing high bridges. The work zone is intended to be a safe haven from traffic so the inspectors can concentrate on doing their jobs.

As such, the work zone needs to be clearly marked so as to guide the motorist around it and, insofar as possible, prevent errant vehicles from entering (see Figure 9-14). The work zone should be as compact as possible to minimize traffic disruption, but must be wide enough and long enough to permit access to the area to be inspected and allow for safe movement of workers and equipment. The end of the work zone should be clearly signed as a courtesy to the motorist.
1. Vehicles and Equipment

Inspection vehicles and equipment need to be made visible to the motorists with flashing marker lights or arrow boards as appropriate (see Figure 9-15). Vehicles entering and exiting the work zone should use a roof-mounted flashing light or flashers to distinguish themselves from other motorists. Also, all vehicles should use extreme caution when moving in and out of the work zone. Allow traffic ample time to react to the vehicle's movements.

![Figure 9-15: Inspection car with flashing light](image)

2. Workers

Individuals in a work zone must wear approved safety vests and hard hats for visibility and identification. They also help make the inspector look “official” to the public. The inspectors should also stay within the work zone for their own safety.

9-3-3 Requirements of Traffic Control Devices

Each bridge inspection project is different and has traffic concerns that are unique to that location. Selection of the proper traffic control device's for each location is dependent upon many factors. Though there are several different types of traffic control devises, there are some basic requirements for efficient traffic control devices:

- Traffic control devices must be visible and attention getting.
- Bright colors make devices easier to see for motorists.
- All signs must be legible and color distinguishable at night as well as during the day. Nighttime sign visibility is provided
through electroreflectivity, which is accomplished by spherical glass beads or prismatic reflectors in the sign material.

- New sign messages such as “Slow Down. My Daddy Works Here” and “Give Us A Brake. Slow Down” causes the driver to think on a more personal level.

- Traffic control devices must give clear direction.

- Traffic control devices must command respect. They should be official.

- Traffic control devices must elicit the proper response at the proper time.

- The decision process includes the classical chain of sensing, perceiving, analyzing, deciding, and responding.

- The average perception-reaction time of a driver is 2.5 seconds. At 100 km/hr (60 mph), the 2.5 seconds translates to 67 m (220 feet). Additional time and distance is required for a specific action taken such as “hitting the brakes”.

- Traffic control must accommodate a wide range of vehicles (from small compact cars to large combination tractor-trailers) and driver skills, which may be impaired by alcohol, drugs, drowsiness, or use of cellular telephones.

All of these requirements for traffic control devices have been factored into the various agencies’ guidelines for work area traffic control. These guidelines represent efforts by trained people. Do not change traffic patterns without consulting agency standards or traffic control personnel.

**1) Types of Traffic Control Signboards**

Examples of traffic control signboards include the following:

- a. Regulatory - "Speed Limit 40 mph", "DO NOT PASS", may require special authority (see Figure 9-16)

- b. Warning - "Bridge Inspection", "Work Area Ahead", "Slow" (see Figure 9-1V)

- c. Guide Signs - Directional and destination signs; not used for bridge inspection traffic control unless a detour is established

- d. Changeable Message Signs – Can display more than one message
(2) Channelizing Devices
The functions of channelizing devices are to warn and alert drivers of hazards created by construction or maintenance activities in or near the traveled way and to guide and direct drivers safely past the hazards. Devices used for channelization should provide a smooth and gradual transition in moving traffic from one lane to another, onto a bypass or detour, or in reducing the width of the traveled way. They should be constructed so as not to inflict any undue damage to a vehicle that inadvertently strikes them.
Channelizing devices are elements in a total system of traffic control devices for use in highway construction and maintenance operations. These elements should be preceded by a subsystem of warning devices that are adequate in size, number, and placement for the type of highway on which the work is to take place.

Typical channelizing devices include the following:

a. Cones (see Figure 9-18)
b. Drums (see Figure 9-19)
c. Wands
d. Vertical panels
e. Portable concrete barrier sections (these are seldom applicable to bridge inspection due to the short duration of the work)

Figure 9-18: Traffic Control Cones

Figure 9-19: Traffic Control Drums
(3) Lighting
Another type of control device is lighting. Examples of lighting include the following:

a. Flashers - attached to signs or other devices to attract attention or for night visibility
b. Arrowboards - for lane control (see Figure 9-20)
c. Floodlights - to illuminate the work area at night and/or to assist motorists in negotiating a restricted area. Floodlights should only be required for bridge inspection in emergencies or in extremely high traffic volume areas where lane restrictions are only feasible at night. They should be aimed so that a driver’s vision is not impaired.
d. Message boards – for lane control. Message boards can be programmed remotely using a cellular phone (see Figure 9-21)

![Figure 9-20: Arrowboard](image)

![Figure 9-21: Message Board](image)
(4) **Flaggers**

A number of hand signalizing devices, such as STOP/SLOW paddles, lights, and red flags, are used to control traffic through work zones. The sign paddle bearing the clear messages "STOP" or "SLOW" provides motorists with more positive guidance than flags and is generally the primary hand signaling device. If permitted by the agency, flag use should be limited to emergency situations and at spot locations that can best be controlled by a single flagger. Since flaggers are responsible for human safety and make the greatest number of public contacts of all construction personnel, it is important that qualified personnel be selected. A flagger should possess the following minimum qualifications:

a. Good common sense  
b. Good physical condition, including sight and hearing  
c. Mental alertness  
d. Courteous but firm manner  
e. Neat appearance  
f. Sense of responsibility for safety of public and crew  
g. Training in safe traffic control practices

The use of hard hat and suitable clothing, such as an approved vest, shirt, or jacket, should be required for flaggers. For nighttime conditions, similar outside garments should be reflectorized.

Flaggers are provided at work sites to stop traffic intermittently as necessitated by work progress. They also maintain continuous traffic past a work site at reduced speeds to help protect the work crew.

For both of these functions, the flagger must, at all times, be clearly visible to approaching traffic for a distance sufficient to permit proper response by the motorist to the flagging instructions and to permit traffic to reduce speed before entering the work site. In positioning flaggers, consideration must be given to maintaining color contrast between the work area background and the flagger’s protective garments.
The following methods of signaling with sign paddles should be used (see Figure 9-22):

a. To stop traffic - The flagger should face traffic and extend the STOP sign paddle in a stationary position with the arm extended horizontally away from the body. The free arm is raised with the palm toward approaching traffic.

b. When it is safe for traffic to proceed - The flagger should face traffic with the SLOW sign paddle held in a stationary position with the arm extended horizontally away from the body. The flagger motions traffic ahead with the free hand.

c. Where it is desired to alert or slow traffic - The flagger should face traffic and slowly wave the flag in a sweeping motion of the extended arm from the shoulder level to straight down without raising the arm above a horizontal position.

Lights approved by the appropriate highway authority or reflectorized sign paddles or reflectorized flags should be used to flag traffic at night. Whenever practicable, the flagger should advise the motorist of the reason for the delay and the approximate period that traffic will be halted. Flaggers and operators of machinery or trucks should be made to understand that every
reasonable effort must be made to allow the driving public the right-of-way and prevent excessive delays.

Flagger stations should be located far enough in advance of the work site so that approaching traffic will have sufficient distance to reduce speed before entering the project. This distance is related to the approach speed and physical conditions at the site; however, 60 to 90 m (200 to 300 feet) is desirable. In urban areas, where speeds are low and streets are closely spaced, the distance necessarily must be decreased.

The flaggers should stand either on the shoulder adjacent to the traffic being controlled or in the barricaded lane (see Figure 9-23). At a spot obstruction, a position may have to be taken on the shoulder opposite the barricaded section to operate effectively. Under no circumstances should a flagger stand in the lane being used by moving traffic. The flagger must be clearly visible to approaching traffic at all times. For this reason, the flagger must stand alone, never permitting a group of workers to congregate around the flagger station. The flagger should be stationed sufficiently in advance of the work force to warn them of approaching danger, such as out-of-control vehicles.

![Flagger with Stop/Slow Paddle](image)

**Figure 9-23: Flagger with Stop/Slow Paddle**

Flagger stations should be adequately protected and preceded by proper advance warning signs. At night, flagger stations should be adequately illuminated.

At short lane closures where adequate sight distance is available for the safe handling of traffic, the use of one flagger may be sufficient.
One-way Traffic Control

Where traffic in both directions must, for a limited distance, use a single lane, provisions should be made for alternate one-way movement to pass traffic through the constricted work zone. At a spot obstruction, such as a short bridge, the movement may be self-regulating.

However, where the one-lane section is of any length, there should be some means of coordinating movements at each end so that vehicles are not simultaneously moving in opposite directions in the work zone and so that delays are not excessive at either end. Control points at each end of the route should be chosen so as to permit easy passing of opposing lines of vehicles.

Alternate one-way traffic control may be facilitated by the following means:

a. Flagger control
b. Flag-carrying or official car
c. Pilot car
d. Traffic signals

Flagger control is usually used for bridge inspection, where the one-lane section is short enough so that each end is visible from the other end. Traffic may be controlled by means of a flagger at each end of the section. One of the two should be designated as the chief flagger to coordinate movement. They should be able to communicate with each other verbally or by means of signals. These signals should not be such as to be mistaken for flagging signals.

Where the end of a one-way section is not visible from the other end, the flaggers may maintain contact by means of radio or field telephones. So that a flagger may know when to allow traffic to proceed into the section, the last vehicle from the opposite direction can be identified by description or license.

(5) Shadow Vehicles

Shadow Vehicles with truck Mounted attenuators are used to prevent vehicles from entering the work zone if the motorist drifts into the lane closure. Each agency has its own specific requirements, but a shadow vehicle should generally be employed any time a shoulder or travel lane will be occupied by workers or equipment.

a. The requirements for the truck itself vary, but high visibility with flashing lights, a striped panel, or an arrow board on the rear of a vehicle of a specified minimum weight are generally required.
b. Some agencies recommend the use of truck or trailer mounted attenuators (see Figure 9-24). This protects the motorist, as well as the inspectors.

Figure 9-24: Shadow Vehicle with Attenuator

(6) Police Assistance
On some inspection jobs, police assistance may be helpful and even required. The presence of a patrol car aids in slowing and controlling the public. At a signalized intersection near a job site, a police officer may be required to ensure traffic flows properly and smoothly.

9-3-4 Public Safety
Since the fundamental goal of bridge inspection is to enhance public safety, it would make little sense to endanger that same public by inadequate traffic control measures. Traffic control does take time, money, and effort. It is, however, a necessary part of the business of bridge inspection.

In the broadest sense, the motorist is the customer of everyone in the transportation industry. Like everyone else, bridge inspectors need to treat customers well by inconveniencing them as little as possible and protecting their safety. This means providing well thought out, clear, and effective traffic control measures.

Pedestrians also must be considered. If a walkway must be closed, it should be properly signed and barricaded. An alternate route for the pedestrian should be indicated, if necessary through or preferably around the work zone.
1. **Training**

   Each person whose actions affect inspection, maintenance and construction zone safety (from the upper-level management personnel to construction and maintenance field personnel) should receive training appropriate to the job decisions each individual is required to make.

   Only those individuals who are qualified by means of adequate training in safe traffic control practices and have a basic understanding of the principles established by applicable guidelines and regulations should supervise the selection, placement, and maintenance of traffic control devices in bridge safety inspection, maintenance, and construction areas.

2. **Responsibility**

   Legally and morally, it is the inspector’s responsibility to follow the regulations and guidelines of the agency having jurisdiction.

   The primary goal of good traffic control is safety – safety of the workers, motorists, and pedestrians. A secondary goal is to be able to defend yourself and your employer should there be an accident.

   Accidents bring lawsuits. Lawsuits bring inquiries about who is responsible.

   One thing investigated during a lawsuit will be whether or not the standards and regulations were followed. Anything not done in accordance with published standards, regulations, and directives could bring blame upon whoever violated the regulation. Being blamed for an accident is expensive and damaging.
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a. Non-Arabic References


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b. Arabic References


17. Ministry of Municipal and Rural Affairs in the Kingdom of Saudi Arabia, Municipality of Jeddah Province, Contract for the Maintenance of Concrete Bridges Project in Jeddah Province.

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