



Maintenance Guideline for Railway Concrete Bridges to the Ethiopian practice

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**Maintenance Guideline for Railway Concrete Bridges to the Ethiopian
Practice**

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ABBREVIATIONS

AASHTO: American Association of State Highway and Transportation Officials

AREMA: American Railway Engineering and Maintenance of way Association

ANSI: American National Standard Institution

ASR: Alkali Silica Reaction

ASTM: American Society for Testing and Materials

AWS: American Welding Society

BMS: Bridge Management System

CDE: Che-min de fer Djibouti- Ethiopien

ENRN: Ethiopian National Railway Network

ERA: Ethiopian Roads Authority

E-W: East-West

FDRE: Federal Democratic Republic of Ethiopia

FRP: Fiber Reinforced Polymer

GTP: Growth and Transformation Plan

ICE: Institute of Civil Engineers

LRT: Light Rail Transit

N-S: North- South

PC: Pre -stressed Concrete

RC: Reinforced Concrete

ABSTRACT

To perform any Engineering activity there should be a binding standard guideline with in one country. Ethiopia has established codes and guidelines for different Engineering design and construction which includes the Ethiopian Building Codes of Standards, for design and construction of buildings, Ethiopian Roads Authority manuals for design and construction of Highways and Bridges and also Addis Ababa City Roads Manuals for design and construction of urban roads and bridges. Now days the country is constructing vast railways in Addis Ababa and at federal level connecting the various regional states to each other and to neighboring countries. These constructions are handled mainly by foreign Contractors who make use of their own codes of standards, which may not account the local condition and the cultural makeup of our society. Thus, Ethiopia should have its own guidelines for the design, construction and maintenance of Railway system.

Bridge is one of the major components of railway system. This thesis will be concerned on assessment of governing guideline for maintenance of Railway Bridge. This guideline may be set up using detailed studies on geologic, topographic, weather, environmental, economic, social and cultural conditions of the country. Specifically concerning the bridge; Loading condition on the bridge, traffic volume, frequency of loading, type of bridge length of span, methodology during design and construction of bridges, track type based on number of track, tack type based on load transferring and bearing components, seismic events of the area will be considered to adapt the appropriate maintenance guideline to Ethiopian Railway Bridges. Therefore, the study will be concerned with preparation of the best guidelines of maintenance and rehabilitation Railway Bridges by incorporating the practice and experience of other countries.

Key words: rehabilitation, maintenance, Railway, bridges, guideline, standards

1. INTRODUCTION

1.1 BACKGROUND

Ethiopian government is constructing a lot of grand projects in its various regional states of the country. However the maintenance trend of the country is poor. As is the case of finished highways are failing due to lack of periodic inspection and proper maintenance. Other infrastructures are also damaged due to lack of maintenance. Maintenance does not only mean repairing some damaged or failed structure; but it is also keeping structures in good condition, detecting early defects and preventing from further damages. Engineering is usually about avoiding failures and investigating why failures occur and ways to fix the problem. There is a need to understand the conditions giving rise to past failures and ways to avoid such failures so that loss of life can be minimized, (4). Railway is one of grand projects that the country is constructing these days and bridge is one of major components of railway system. In this regard, this thesis is concerned on maintenance of railway bridges

Both the LRT and the national route of Ethiopian railway systems have numerous length of bridge due to interference with other transport systems and topographic reasons. Therefore, the design, construction and maintenance of bridges of the railway system should be done carefully. Bridges are the most expensive structure of railway system next to tunnels. Track irregularities on bridges could be created due to traffic load, temperature change and other reasons. Some of track irregularities are gauge, cross level, Alignment, longitudinal and Twist. These irregularities on bridges causes lateral vibration which in turn causes discomfort to passengers, damage freight, damage rolling stock and cause further failure of each components of the Bridge structure. This failure of Bridge structure will affect the economy of the country in two ways; one by being a reason for the expenditure of large amount of money for repairing the structure and the other by hindering the trade system due to blockage of the rail route. More than all, it may cause disastrous accidents which could be a reason to destruction of wealth and loss of irreplaceable human lives. Therefore, the need for routine inspection and periodic examination of bridge structures is unquestionable.

To perform any Engineering activity there should be a binding standard guideline with in one country. Ethiopia has established codes and guidelines for different Engineering

design and construction which includes the Ethiopian Building Codes of Standards, for design and construction of buildings, manuals for design of highway, pavement, bridges etc. by the Ethiopian Roads Authority and Addis Ababa City Roads Authority. Now days the country is constructing vast railways system in Addis Ababa and at Federal level connecting the various regional states to each other and to neighboring countries. These constructions are handled mainly by Foreign Contractors who make use of their own codes of standards, which may not account the local condition, the back ground and trend of the society handling infrastructures. Thus, Ethiopia should have its own guidelines for the design, construction and maintenance of railway system.

The maintenance system has to follow some standard guideline, in which the whole country would be bound. The guideline will ease the work by providing procedure of instructions on the frequency of inspection, methodology of maintenance, corrective measures of defects and other related issues. This thesis shall be made to address the development of these guidelines for railway bridge maintenance as practiced by other developed countries in the light of adapting to ours.

The research will investigate how frequent the inspections have to be carried as regular and major, and then the effects of regular maintenance on the life span of the bridge and its economic consequence. In addition, types of damages on bridges, their causes, methods and procedures of repair and rehabilitation will be studied in accordance with other countries guidelines and Ethiopian oldest railway system. Ethiopian Roads Authority experience will also be taken in to consideration to develop the guideline in an effective way.

1.2 OBJECTIVES OF THE STUDY

1.2.1 OBJECTIVES

To show maintenance guideline is necessary to perform maintenance activity.

Maintenance activity is very important for any kind of structure, machine or equipment to gain its intended service and function. Expensive structures such as Bridges need regular inspection and maintenance for safety issues, to maximize its life time and to minimize its life cycle cost. But the awareness of the authorized bodies of rail road network and the society about the need of maintenance activity is not satisfactory. Therefore this thesis shall discuss the importance of maintenance activity on the basis of experiences of different countries and our own past experience. The thesis also studies the effect of regular maintenance on bridge quality, safety, lifetime and its cost implications.

To describe basic concepts regarding railway bridge maintenance

To create the basic understanding of parameters of railway maintenance and rehabilitation works. It identifies different types of damages and defects, their causes and preventive measures which have to be taken. Once the cause of deterioration, defects and damages are known, specifically for Ethiopian condition, it is possible to take preventive actions. Even after damage/defect is identified the correct repair/ maintenance action have to be taken. These issues will be studied in detail in this thesis.

To develop maintenance guideline for Railway Bridges to the Ethiopian practice.

The main objective of this study is developing a manual for railway Bridge maintenance work in Ethiopia which is being constructed and will be constructed. The guideline could be referred during planning and scheduling of maintenance work; during inspection, maintenance, rehabilitation, repair and replacement activities. The study also targets at developing a leading code for the Engineering maintenance, type of action to be taken for each and every defects and damages noticed. Thus, the main objective of this study is developing a standard guideline of railway bridges within the Ethiopian boundary. Therefore, the administrative body of Ethiopian rail road, Ethiopian Railway Corporation, could make use of this study as a reference for maintenance activity of railway bridges with in the country.

✚ To serve as base for further studies

To provide the seed of maintenance concept for other research students, scholars and professionals who want to study about maintenance, in the Ethiopian context. Since maintenance activity is critical for the safe being of the railway network, it is worth value if it is studied in detail and in broader way. For those who want to study in this area the thesis could serve as a background.

1.2.2 SCOPE OF THE STUDY

Based on type of Bridges and Culverts the scope of study is limited to Concrete Bridges and culverts. Since most of Railway bridges in Ethiopia are Concrete bridges, the study does not concentrate on Steel, Arch, Suspension, Cable Stayed and Truss bridges. Both reinforced and pre-stressed concrete structures will be studied in detail. In terms of components of bridges and culverts both super structure and sub structure components will be dealt in the study though it is more focused on superstructure components. In this regard the study is made to develop maintenance guideline only for the railway bridges to the Ethiopian practice.

Thus, the thesis will be concerned to railway bridges and culverts made up of reinforced concrete and pre-stressed concrete and the study

- Does not cover those of highway bridges, and other purpose bridges
- Does not include components of railway track such as sleepers, ballast and sub grade
- Is also more focused on the super structure of concrete railway bridges
- Only covers the maintenance manual of Railway bridges; it does not include Policies, Strategies and Plans of maintenance activities.

1.3 WHAT IS IN THESIS

The thesis is organized in five chapters. Chapter one of the study include the background, objectives of the study, Scope and limitation and the general contents of the study. The Back ground describes general ideas about railway bridge; the necessity for maintenance and maintenance of railway bridges. The objective describes the general goals of the study and what to expect at the end of the study. The scope and limitation of the study describe the range of the study according to different parameters and also what the study does not include.

The second chapter is devoted to literatures survey on maintenance of bridges in general and railway bridges in particular. It addresses on types of damages of railway bridges, causes of damages, how to identify damages, damage and defect repair methods, tools and materials used for the repair purpose and existing practical system on the maintenance activities. These issues are described in detail based on the experience of different countries by referring different manuals, books, reports, publications and research studies on the railway and the highway industries.

The maintenance of railway bridges in according with the Ethiopian practice is addressed in the third chapter. Here, the past trend of maintenance of railway bridges in Ethiopia investigating the old Ethio-Djibouti railway network is revealed. The types of damages occurred, causes of failure, damage identification methods, materials and tools that had been used for repair of old railway network will be assessed. The current Ethiopia Highway bridge maintenance system is also studied; which will serve as base to develop the guideline for the railway bridge.

Chapter four discusses the preparation of formats and guideline of maintenance of railway bridges. This section will include important formats to precede the maintenance activity. The formats include inventory and inspection of railway Bridges, guideline for damage identification, materials and tools needed for repair and rehabilitation. Finally the technical specification for maintenance, repair and rehabilitation developed. The specification can serve as a guideline to precede maintenance and repair work of railway bridge of Ethiopia.

The study is then concluded with chapter five. It discusses idea based on the results of the study. Conclusion and recommendation based on the finding will be described in this section.

2. LITRATURE SURVEY

2.1 RAILWAY BRIDGES

2.1.1 GENERAL

A **bridge** is a structure providing passage over an obstacle. The obstacle may be a river, valley, road or railway. The passage may be for highway or railway traffic, pedestrian, canal or pipeline, (1). The opening must not less than 6100mm, (2).

A **culvert** is a structure which has its superstructure and substructure combined in to one entity and is generally erected over smaller obstacles when compared with a bridge; and characterized by lacking of sufficient abutment and foundation, (3).

A **railway bridge** is bridge which serve for the passage of railway traffic.

The overhead structure is a structure where the railway crosses over the natural obstruction or man-made facilities, (4), (See Figure 2.1-1).



Figure 2.1-1 A Railway Bridge at “Meskel Square”, Addis Ababa

A **railway culvert**: - The structure going across the railway sub grade and used for flood discharge, irrigation or as passageway, (4), (See Figure 2.1-2).



Figure 2.1-2 Railway Culvert at “Hayahulet”, Addis Ababa

2.1.2 TYPES OF RAILWAY BRIDGES

Railway Bridges can be divided based on different parameters

✚ According to length of span, (4).

Bridges are classified as follow in accordance with the length of superstructure as:

1. Super major bridge: - where, the bridge length is more than 500 m.
2. Major bridge: - where, the bridge length is between 100 m and 500 m.
3. Medium bridge: - where, the bridge length is between 20 m and 100 m.
4. Minor bridge: - where, the bridge length is 20 m or lower.

Note: bridge length means

- the length between the front ballast retaining wall of abutments for the beam bridge
- the length between outside ends of two expansion and contraction joints between the upper side wall of arch and side wall of abutment for the arch bridge
- The length between the outsides with the rigid frame along the span direction for the rigid frame bridge.
- Bridges less than 6m shall be considered as culverts.

✚ According to material of construction

Even though, it is common for a single bridge structure to incorporate each of the basic materials within its construction, the following classification is based on their primary construction material (5).

1. REINFORCED CONCRTE BRIDGE: - is a bridge which is made up with concrete and reinforcing steel. Concrete is a mixture of cement, sand aggregate and water in specific proportions that hardens to a strong stony consistency over varying lengths of time. Raw materials of concrete consisting of Water,

Cement, fine aggregate, coarse aggregate can be found in most parts of the world and can be mixed to form a variety of structural shapes. The great availability and flexibility of concrete material and reinforcing bars have made the reinforced concrete bridge a very competitive alternative. A reinforced concrete bridge may consist of precast concrete elements, which are fabricated at a production plant and then transported for erection at the job site, or cast-in-place concrete, which is formed and cast directly in its setting location, (6). Reinforced concrete can be classified, based on its structural form, as slab, beam (girder), Box girder (single, double or multiple).

2. **MASONRY BRIDGE:** - is bridge which is made with hard stone or brick and bonded with cement mortar. The strength of masonry construction is dependent on the material used; even different types of stone have different strengths. Stones can be cut in much larger sizes and more complex shapes than bricks. However, stone is very rigid and cannot deform to accommodate uneven bearing surfaces. Therefore, it requires good, even bearing to ensure that cracking does not occur due to uneven pressures. Brick can be stronger than some types of stone and, in specific instances, might be more readily available and easier to work with than stone. With good maintenance masonry structures can have a very long life; many masonry structures of the earliest construction are still in service today. Aside from steel reinforced concrete, masonry materials are limited to compressive loadings.

Masonry construction is generally very resistant to damage from fire and is not susceptible to attack by insects or animals. It is usually resistant to deterioration due to chemical attacks and water, although certain chemicals can have an adverse effect on specific types of stone and concrete. Arch bridges are the most common type of masonry construction, (5).

3. **TIMBER BRIDGES:** - is bridge which is made with using wood. Wood has been widely used for short and medium bridges. Although wood has the reputation of being a material that provides only limited service life, it can provide long-standing and serviceable bridge structures when properly protected from moisture, (6). The strength of timber varies widely with the species of wood which is being considered. Wood is also susceptible to fire, decay and attack by termites, marine borers and other insects. The main benefit of utilizing timber is, it's easily cut, drilled and handled. Timber deforms easily under load and, as a result, when there is uneven bearing pressure, it will crush until the bearing pressure evens out. This makes it a very useful and workable material.

Timber products possess tensile strengths between masonry and steel with most loadings designed to take advantage of wood's compressive strength. Timber does have a service life that will vary with species, climate, treatment, and other factors, (5).

4. STEEL BRIDGE:- is bridge which is constructed using steel as major part of construction. Structural steel is an extremely versatile material eminently suited for the construction of all forms of bridges. The material, which has a high strength-to-weight ratio, can be used to bridge a range of spans from short through to very long (15-1500 m), supporting the imposed loads with the minimum of dead weight. Steel bridges normally result in light superstructures which in turn lead to smaller, economical foundations. They are normally prefabricated in sections in a factory environment under strict quality control, transported to site in manageable units and bolted together in situ to form the complete bridge structure. Using this construction method the erection of a steel bridge is usually rapid, resulting in minimal disruption to traffic; a very important factor if traffic delays, be it road or rail, are properly assessed in the construction project, (7).

In the early years of railroad construction, metal structures were primarily of wrought or cast iron. Over time, the use of steel alloys and the improved control over the chemistry of steel has permitted rolling of a multitude of shapes and sizes of steel members. The improved workability of steel over masonry and the greater strength of steel over timber made it a desirable material for construction of railroad bridges at the height of railroad construction. With the progression of means of fastening from rivets to high strength bolts and welding and the availability of weather resistant and higher strength steels, use of steel as a material for bridge construction has remained predominant.

Steel is more susceptible to damage by fire than masonry and concrete but less than timber. And also Steel is susceptible to chemical attack by acids and will deteriorate due to rusting over time. Steel is generally less brittle than masonry but more brittle than timber; this makes it susceptible to fatigue failures due to repeated flexural (bending) loadings. The superior tensile strength of steel, when compared to masonry and timber, allows the design of structures which load members with both tensile and compressive loadings. More than masonry or timber, metal is subject to thermal expansion and contraction. The extent of this phenomenon is directly proportional to the

length of the member and the change in the temperature. The bearings of metal structures must take these thermal changes into account. In addition to thermal considerations, as the length of a span increases, the allowable deflection increases and the bearings must be able to transmit the vertical loads to the substructure evenly while accommodating the permissible deflection of the structure. More than concrete and timber, Steel members can be made up of multiple parts fastened and laced together to form a structural shape. Members can be made stronger by addition of cover plates at strategic points, (5).

✚ According to Structural form

According to their structural form (design) of Bridges, AREMA categorize in to two, *Beam Bridge* and *Arch Bridge*. Beam bridges transmit their loads vertically to the supports. This type includes trestles, beam spans, girder spans, and trusses. Arch type bridges transmit their loads diagonally to the supports. Arch bridges are commonly of masonry construction.

But below are described common types of bridges according to different writers, for wider understanding of types of bridges, (1).

1. ***Girder (beam) Bridge***: - Bridge formed of concrete slab and girder to transfer the traffic load. The girder could be T-girder, I-section, Box Girder. Girder Bridge is economical and long lasting solution for majority of bridges. It carries load in shear and flexural bending.
2. ***Arch Bridge***: - Bridge which has two moment resistant components: the deck and the arch rib. Arch bridge is preferable for valley with arch foundation on a dry rock slope.
3. ***Truss Bridge***: - Bridge formed with a network of truss members. Its primary force member is axial load; has reduced dead weight. Its high fabrication and maintenance cost made it less likely to be used compare to other types of bridges; instead it is being widely used as stiffening structure for suspension bridges due to its acceptable aerodynamic behavior.
4. ***Suspension Bridge***: - Bridge which transfers its traffic and dead loads through flexible cable, shaped and supported in such a way that it transfer the load to the towers and anchorage. The cable is constructed from high strength wires and the deck is hung from the cables by hangers constructed of high strength ropes in tension. It is the bold alternative for bridges over 600meters.
5. ***Cable Stayed Bridge***: - The basic structural form of cable-stayed bridge is a series of overlapping triangles comprising the tower, the cables and the

girder. All these members are under predominantly axial forces, with the cables under tension and both the tower (pylon) and the girder under compression. Axially loaded members are generally more efficient than flexural members, which contribute for the economy of cable-stayed bridge, (6).

- ✚ **Pre-stressed concrete Bridges:-** is a concrete in which internal stresses are introduced so that the stresses resulting from external loads are counter acted to a desired degree. The structure built mainly of concrete with prestressing tendon, (4). Prestressed concrete using high strength materials to improve serviceability and durability, are an attractive alternative for long-span bridges, (6).

2.1.3 COMPONENTS OF TYPICAL RAILWAY BRIDGE

Railway Bridge is one of the structures of railway system. When dealing with the railway bridges it is important to study about the approach track, components of conventional railway track are discussed as follows. Some of the components, such as sleeper, rail and fastener are also components of the bridge, (9), (See fig 2.1-3).

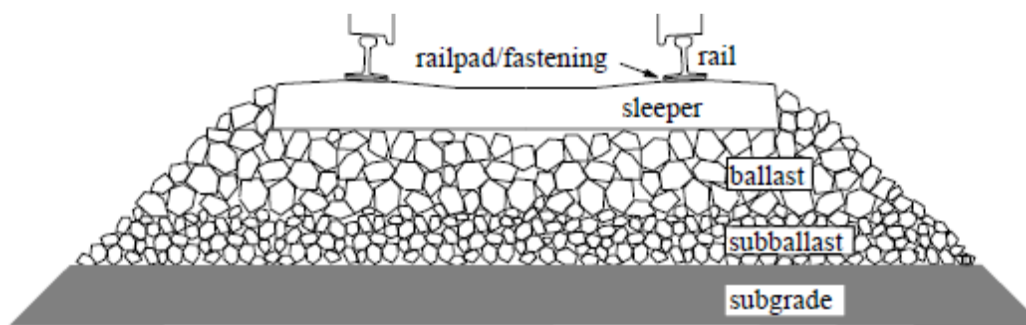


Figure 2.1-3 conventional ballasted railway track components

- ✚ **Rail:** - is component of railway track made up of high strength steel used to guide the wheels, provide a smooth running surface and transfer wheel loads to sleepers. In addition it distributes accelerating and braking forces by means of adhesion and conduct signal currents.
- ✚ **Sleeper:** - is used a component to distribute and transmit forces to the ballast bed or slab track and could be made up of concrete, timber or steel materials. It holds the rails, secure the track and establish and maintain track gauge.
- ✚ **Ballast:** - distributes the loads coming from the super structure to the structure supporting the ballast without failure. It also assists in drainage of water from the track and helps track stability by restraining sleeper forces from the rail.

- ✚ **Sub-ballast:-** is composed of well-graded crushed rock or sand gravel mixtures and sits between the ballast and the sub grade material. It transmits and distributes stress from the ballast layer to the sub grade over a larger area to reduce the magnitude of resultant stress.
- ✚ **Fastener/ Rail pad:-** is Elastic material between the rail and the sleeper which distribute load from the rail to the sleeper.

Railroad bridges, regardless of type, have some common elements. With some bridges, it may be difficult to clearly distinguish these major components because of the way the bridge was designed, as two or more major components may be combined together within the construction. AREMA classifies the components of Railway Bridge in to two major parts; Sub-structure and Super structure, (5).

a. **Substructure:-** The substructure transfers the entire load on the bridge superstructure to earth or rock which supports the bridge. Its two main components are abutments and piers, which vary with bridge design, and in turn, contain other components.

✚ **PIER:-** generally consist of footings, columns (or pile bents), and caps. The footing supports the rest of the pier, and in simplest form, rests directly on the rock. When a suitable layer of rock is not readily available, a spread footing which bears on earth can be used. The spread footing spreads the load over a greater area, allowing the weaker earth to support the bridge without settlement. Pile substructures can consist of piers or bents. A bent generally consists of piles that extend up to a cap on which the superstructure bears. A pier is typically made from stone or concrete which is supported on a timber or concrete mat on top of the piles and which, in turn, has a bridge seat at the top on which the superstructure is supported. Concrete pier column is shown below in figure.



Figure 2.1-4 Pier column of railway bridge

- ✚ **BEARING:-** is a mechanical device which permits expansion, contraction and rotation of beams. The bridge seat or bearing is the interface between the superstructure and the substructure. The loads from the superstructure are transmitted to the substructure either by direct bearing or through some type of bearing structure.

- ✚ **ABUTMENT:-** Every bridge will have an abutment each end. This is the interface area where the relatively flexible track structure connects with the relatively stiff bridge structure. This area is susceptible to greater impact and compaction and will often require additional attention to ensure that a dip does not form at the end of the bridge. Abutments typically consist of a backwall and wingwalls. The backwall is built directly against the end of the embankment on which the adjacent track is built. The wingwalls are built on either side of the backwall help keep the end of the embankment in place. Stone or concrete abutments are most common for larger structures. Steel or timber end bents typically serve as abutments for shorter trestle-type structures. The abutment must not only support the vertical loads of the bridge but also accommodate any transverse or longitudinal horizontal loads imposed by the bridge or by the pressure of the earth behind the backwall and wingwalls.



Figure 2.1-5 Railway Bridge concrete abutment

b. Superstructure

The superstructure contains the components of the bridge supported by the substructure. Its purpose is to support the deck and transmit all vertical, longitudinal, and transverse loads through the bearings to the substructure and then to the supporting earth. Depending on bridge design, the superstructure may incorporate the deck as well.

✚ **DECK:-**The bridge deck is the support for the track structure on the bridge. Bridge decks generally fall into two basic types: open decks and ballast decks. An open deck has the track structure supported on ties that are directly supported by the bridge superstructure.

A ballast deck has a floor and curbs which retain a ballast section which provides lateral and longitudinal restraint to the track structure. An open deck generally makes it easier to inspect the top of the superstructure members whether masonry, timber or steel. A ballast deck, with its floor that supports the ballast, usually makes it impossible to view the top of the superstructure member that supports the deck.

Open decks have the advantage of providing good drainage, but as the ties are structural members, close attention must be given to the fastenings which hold the ties to the superstructure so that adequate transverse and longitudinal restraint is provided. Ballast decks use ordinary track ties which get transverse and

longitudinal restraint from the ballast. This makes it easier to maintain line and surface on the bridge since the same machinery that is used to line and surface the track on each end of the bridge can be used on the bridge itself. Over time, as track across the bridge is repeatedly raised, additional curbs must be added to retain the extra ballast depth, which puts more weight on the structure. Double box girder concrete deck is shown below in figure.



Figure 2.1-6 Double box girder concrete deck

- ✚ **AUXILARY BRIDGE MEMBERS:-** is part of the structure, usually do not assist in carrying the primary loading on the bridge and can include foot walks, railings, wire line supports, pipeline supports and, in some cases, roadways. These auxiliary members are fastened to and supported by the bridge structure in a wide variety of ways and must be considered in the bridge inspection since they not only impose additional loads on the structure but may also affect bridge safety or the safety of those who must cross of inspect the bridge.

2.2 WHAT IS DAMAGE AND MAINTENANCE OF BRIDGE

2.2.1 DAMAGE OF A BRIDGE

- ✚ **Damage:** - physical injury that makes something less useful, valuable or able to function.
- ✚ **Damage of bridge:** - any defect which can affect the regular performance, serviceability and functionality of the bridge.

A damage of concrete bridge classification system, allowing users to quantify the damage present was proposed. In accordance with reference [10] damage is classified damage into one of three categories:

- **Minor damage** is defined as concrete with shallow spalls, cracks, and some efflorescence, rust or water stains. Damage at this level does not affect member capacity. Repairs at this stage are for aesthetic or preventative purposes.
- **Moderate damage** includes larger cracks and sufficient spalling or loss of concrete to expose strands. Moderate damage does not affect member capacity. Repairs are intended to prevent further deterioration.
- **Severe damage** is any damage requiring structural repairs. Typical damage at this level includes significant cracking and spalling, corrosion and exposed and broken strands.

Different repair technique was evaluated to provide an overview of the processes and advantages and limitations of the method. Guidelines were proposed based on service load capacity, ultimate load capacity; overload capacity, fatigue life, durability, cost, user inconvenience and speed of repairs, aesthetics and range of applicability, (10).

- ✚ **Defect on bridge:** - any problem on the structure which prevents it from functioning correctly or hinders the structure from giving its intended service. Some defects may not reduce the efficiency of the bridge but it may lead to severe damages which could result functional inadequacy of the bridge and on worst cases failure of the bridge.

There are many common defects that occur on concrete bridges. The following definitions are provided as a guideline for consistency in reporting of defects, (5).

- **Abrasion:** – Abrasion damage is the result of external forces acting on the surface of the concrete member. Erosive action of silt-laden water running over a concrete surface and ice flow in rivers and streams can cause considerable abrasion damage to concrete.
- **Cold joint displacement or deterioration:** – is unbonded concrete resulting from intended separate concrete placement or by lack of consolidation.

- **Cracking:** – a crack is a linear fracture that may extend partially or completely through the concrete member. When recording cracks, the inspector should describe the type, width, depth, length, direction, location and appearance of the crack as appropriate for the inspection.
- **Delamination:** – Delamination occurs when layers of concrete separate at or near the level of the top or outermost layer of reinforcing steel. The major cause of delamination is expansion of corroding reinforcing steel. Delaminated areas can generally be identified by a hollow sound when tapped with a hammer.
- **Efflorescence:** – Efflorescence is a white deposit on concrete caused by crystallization of soluble salts (calcium chloride) brought to the surface by moisture in the concrete.
- **Freeze-Thaw Damage:** – the deterioration of concrete, typically a crack or spall, due to introduction of moisture and the subsequent alternate freezing and thawing of the retained moisture.
- **Honeycombs:** – Honeycombs are hollow spaces or voids that may be present within the concrete. Honeycombs are caused by improper consolidation during construction, resulting in the segregation of the coarse aggregates from the fine aggregates and cement paste.
- **Pop-Outs:** – Pop-outs are conical fragments that break out of the surface of the concrete leaving small holes. Generally, a shattered aggregate particle will be found at the bottom of the hole, with a part of the fragment still adhering to the small end of the pop-out cone.
- **Scaling:** – Scaling is the gradual and continuing loss of surface mortar and aggregate over an area. When reporting scaling, the inspector should note the location of the defect, the size of the area, and the depth of penetration of the defect.
- **Spalling:** – a spall is a roughly circular or oval depression in the concrete. Spalls result from the separation and removal of a portion of the surface concrete, revealing a fracture roughly parallel to the surface. Spalls can be caused by corroding reinforcement and friction from thermal movement. Reinforcing steel is often exposed after spalling. When reporting spalls, the inspector should note the location of the defect, the size of the area, and the depth of the defect, (5).

2.2.2 MAINTENANCE OF BRIDGE

Maintenance: - is work that is done regularly to keep a structure or equipment in good condition and working order. It is routine or regular activities, which are intended to preserve and maintain a structure's original serviceability and functionality, (11).

Maintenance engineering is both an art and a science. Availing of the state of art and modern techniques in repair and rehabilitation will be required. It is an essential part of bridge engineering which comprises of a host of other tasks and disciplines, including Technical tasks such as analysis, diagnostic design, development of procedures, training, mentoring, continuing education, construction coordination, and construction supervision. It also deal with administration and related tasks such as bridge management, marketing, public relations, ethics, budgetary control, accounting, contract law, land acquisition, and right-of-way jurisdiction. Among the many facets of engineering, maintenance requires a more specialized approach than original design. Maintenance policy principles are basically governed by design codes and guidelines.

Maintenance is to a large extent based on the average daily traffic volume. Hence, all important and high volume bridges need increased inspections. Maintaining a healthy interstate and local transportation system requires diagnosis based on regular inspections by a team of qualified inspectors and repairing the bridge to an acceptable standard.

Engineering maintenance is need-based mitigation and reconstruction; It is a combination of both art and science for protecting, strengthening, upgrading and improving the performance of bridges through repairs and retrofits. Timely maintenance helps to correct things that may have gone wrong during the design or construction phase. Therefore, Bridges need to be maintained regularly for safety and security reasons, (11).

Bridge maintenance is one of the most critical works which is directly related to its lifetime, overall cost and most of all safety. But before few years it has been given less attention. For concrete bridges in particular, it was for many years believed by many bridge owners and designers, that reinforced concrete did not deteriorate and that realization of a 120 year life with little or no maintenance, was achievable. In practice, this has been shown to be wrong and many bridges have required major maintenance, strengthening and even early replacement as a result of deterioration. The concept of 'functional obsolescence', where structures require planned maintenance/upgrading during their life, until they reach a point where they need to

be replaced, has been accepted practice. Many concrete bridges are now showing signs of deterioration and this trend can be expected to continue unless repairs and preventative measures are carried out. There are a number of factors which can substantially reduce the durability and result the need for repairs and maintenance on bridges at a relatively young age. The challenge is to design and build bridges that do not contain defects which can reduce their durability. But there are should be works that can be done during the service life of a bridge to maintain and improve its durability, (12).

✚ **Inspection** is one of the major activities done on the process of maintaining any structure. The inspection of bridges is the primary method for monitoring the condition of the stock, detecting defects and providing assurance that bridges are safe and serviceable.

✚ **Railway bridge inspection:-**is the process of examining a bridge to determine the type and severity of any defects or deterioration which may be present. The observations made during an inspection should be thoroughly documented, and records of past inspections should be kept and reviewed prior to future inspections, (5).

Periodic inspections should be made to detect deterioration and damage before the structure becomes irreparable. The engineer in charge of maintenance and inspection should be experienced in determining the parts of structures in need of repair and the extent of deterioration or damage, (5).

PURPOSE OF INSPECTION

The purpose of bridge inspection is to find and document flaws or defects in a bridge structure. Once these are documented, their affect on bridge operating safety and load-carrying capability can be determined.

Then, the required repairs or component replacements can be scheduled and budgeted. In addition to describing bridge condition, records from past inspections can help to determine the rate of degradation of the structures. This deterioration or degradation rate will be most helpful in finalizing the work or action plan, as it will indicate how soon action is needed and what type of action to take. For example, defects or deterioration which are not yet serious and appear stable from recent past inspections may be allowed to remain if watched more frequently, allowing other work to be included in the current budget.

- ✚ **INSPECTION REPORTING:-** The results of the inspection should be recorded while still at the site on a form intended for that purpose. Available information gathered on previous inspections and information on repairs or maintenance performed since the last inspection should be taken to the field for reference and to ensure that any repairs or changes since the last inspection can be recorded.

- ✚ **RESULTS OF INSPECTIONS:-** The results of a bridge inspection should be reported to the responsible party so that bridge condition can be properly evaluated and the remaining steps in the bridge management program followed, ending in a work or action plan.

- ✚ **THE INSPECTION PLAN:-** To ensure that all necessary items are observed, a plan should be made to inspect the bridge in an orderly sequence. Usually, an inspection from top to bottom, near end to far end with the deck being inspected on the return will serve well. The importance of inspection items varies with different types of structures, and each type of structure will require different observations to be made.

Dealing with maintenance, rehabilitation and repair are the words which are used repeatedly. Therefore it's needed to discuss in brief about Rehabilitation and Repair of Bridge.

- ✚ **Rehabilitation** is defined as comprehensive repair of a bridge structure's most deteriorated elements that are intended to restore and significantly extend its original serviceability and functionality.
- ✚ **Repair** is activities, usually isolated to a portion of one element of a structure, that are necessary to restore serviceability or functionality due to distress from things such as vehicle impact damage, observed scour or severe localized deterioration.

The primary reasons for the need to rehabilitate and repair are Safety of the transport system, continuity of use, and failure prevention. Although the following considerations are of paramount importance:

- Correcting deficiencies of the bridge.
- Addressing environmental concerns.
- Increasing load carrying capacity.
- Providing for possible future widening.
- Minimizing lifecycle costs.

Rehabilitations and Repairs should directly follow the recommendations presented in inspection reports. Evaluation of defects should be confirmed by in-depth inspection or nondestructive testing. Emergency repairs are generally required immediately after an emergency or after extreme events, after high impact loads, earth quack, and collision. An experienced or licensed professional engineer has to oversee the delicate tasks.

Regarding with location and component of bridge, localized component repairs are needed. Selective criteria can be applied based on location and on a priority basis. Deck, deck joints, or bearings are subjected wear and tear and need the greatest attention. Usually the substructure is to some extent over designed and is less likely to need repairs, except for repairs resulting from erosion or earthquakes.

Another way of looking at maintenance is defining it as “mitigation.”

Mitigation technology is an alternate to rehabilitation, providing alternate solutions through one or more of the following approaches:

- Minimizing the impact by limiting the degree or magnitude of the action and its implementation
- Rectifying the impact/deterioration by restoring the impacted environment
- Eliminating the impact/deterioration over time by preservation and maintenance operations during the life of the action
- Compensating for the impact/deterioration by replacing or providing substitute resources, alternate solutions, and environmental controls.

The last option of maintenance process is replacing Bridge as a whole or component of Bridge with new one. This is done when the bridge or part of it has failed to provide its original service and function.

Replacement or reconstruction: These works are required to be carried out when the whole structure or at least its major components are required to be replaced, being beyond the economic level of repairs/rehabilitation, (13).

Finally let’s summarize the above maintenance terminologies according to AREMA, with respect to management. This will help to have clear understanding on the concepts of maintenance and other related terms.

Management actions resulting from the bridge management process may be generally grouped into the categories described in the following paragraphs. The intent of a bridge management program is to produce the most cost effective combination of these actions within the allowable budget level and with proper consideration of operating requirements to carry traffic over the line. In practice, there is often no

clear dividing line between some of the action categories, particularly between maintenance, repair, and rehabilitation. Typically the action category is based on the amount and type of work to be done, and sometimes a bridge project may include action in more than one category on a single bridge. Once action is taken, bridge inventory (plans, drawings) and repair history should be updated accordingly.

- ✚ **Observation:**-The action plan may include making a list of bridges or components which, while still in acceptable condition, warrant more frequent inspection to prevent unacceptable conditions from occurring before the next regular inspection is performed. It may also be advisable to increase the inspection frequency for any bridges on which operating restrictions have been placed.

- ✚ **Maintenance:**-Generally, this is work to keep a bridge in its current, safe condition so it can continue to carry loads at the required capacity. This work includes necessary housekeeping such as cleaning structures to retard deterioration of members subject to rusting or decay, patch painting, applying preservatives to the bridge, approach maintenance, and cleaning debris from bearings. It also includes removal of nearby drift, debris, and unwanted vegetation to reduce the likelihood of fire starting or spreading to the bridge and to prevent scour from occurring around supports of bridges over waterways or drainage pathways.

- ✚ **Repair:**- Generally, this is work on a bridge which is overall in sound condition, but has a few defects or deficiencies which may actually or potentially threaten its desired load-carrying capacity. Repair work typically involves replacing or strengthening defective or deteriorating members, replacing broken or nonfunctional fasteners, posting critical piles or posts, pointing and grouting of masonry structures, and repair welding of steel components.

- ✚ **Rehabilitation:**- More extensive than repair work, it involves restoration of a bridge which has serious defects, or in overall condition, only barely allows handling its desired load and traffic requirements. It may also involve restoring a bridge so that operating restrictions may be removed. Generally, the intent of rehabilitation is to extend the service life of a bridge by many years.

- ✚ **Upgrading:**- This work involves increasing a bridge's load-carrying capability by the addition of members (such as stringers) or by strengthening currently sound members with cover plates or by other modifications so that additional load can be safely handled.

- ✚ **Replacement:-** When a structure cannot be economically repaired or strengthened to permit continued safe operation or desired upgrading, replacement is the next option. In many cases, some or all of the supporting components (the piers) may be saved and a new deck and superstructure can be built on top of them. Otherwise, an entirely new structure may be needed.

- ✚ **Operating Restrictions:-** When needed bridge work exceeds allowable budget levels, one option is to place operating restrictions on a bridge which is still in overall sound condition, but does require repair, or possibly, rehabilitation. These restrictions may be: required slower speeds for trains while traveling over the bridge, limits on loads allowed over the bridge, or limits on the type of engines or (loaded) cars permitted on the bridge. The ability to continue safe operation over a bridge if operating restrictions are applied should be determined only by an experienced railroad bridge engineer. Recommendations for the appropriate restrictions should come from the bridge engineer who will consider bridge condition and railroad operating requirements in producing an appropriate recommendation.

2.3 CAUSES OF DAMAGES TO RAILWAY BRIDGES

Bridges have failed all over the world over and continue to do so. Most failures can be avoided with efficient monitoring and timely maintenance. Some of *General causes* of railway bridge damage which could further lead to bridge failure include the following, (11).

- Temperature change: - causes expansion and contraction of materials, which could lead to defect of different components of the bridge, especially the steel materials of bridge are more susceptible to damage of temperature change.
- Collision: - collision of under passing vehicle with the bridge due to limited vertical under clearance could damage the girder and other structures of the bridge. Train collision and other accidents is one of major causes of railway bridge damage, since it could destruct the rail and other components of the bridge.
- Fire and excessive heat.
- Excessive wind and hurricane.
- Scour: - Failure due to foundation scour and settlement from soil erosion is a threat to bridge structures.
- Flooding: - flooding could damage bridges constructed on rivers if it exceeds the clear height
- Design Error:-Failures result when assumptions do not truly represent the behavior of the superstructure in the field.
- Fatigue: - Cumulative fatigue damage of uncracked members and fasteners that are subjected to repeated variations or reversals of load-induced stress needs to be assessed.
- Blast load: - blast and impact load could also be the causes of railway bridge damage if not properly designed for such loads. Bridges provide vital links for the nation's economy, defense, and quality of life. In addition to natural hazards, the transportation infrastructure is vulnerable to physical, biological, chemical, and radiological attacks. Multiple hazards affect the stability and service life of bridge structures. To keep the system safe and operational under all circumstances systems and technologies should be developed to prevent, detect, respond to, and remediate all attacks.
- Damage due to Earth quack: - Railway bridges could be damaged by earth quack movements. Special attention should be given to sub structure of the bridge, as it is more prone to earthquake damage.
- Lack of Effective Inspection and Rehabilitation Systems:-Regular inspection of transportation facilities, especially Bridge, is critical to public safety.
- Construction error
- Debris, drift and unwanted vegetation on/around bridge components

- Social effects such as, improper use of the railway track, e.g. throwing away garbage.

The above discussed causes of Bridge damage are general and work for most types of bridges. As this study is more concerned with concrete railway bridges, some of the causes of concrete Bridge damage (deterioration) are discussed in sub-section below.

2.3.1 CAUSES OF DETERIORATION OF CONCRETE BRIDGES

In order to select the proper repair procedure for concrete, the cause of the deterioration must first be established. And it is important for the bridge inspection and maintenance Engineer to have understanding of the types of defect that often lead to deterioration since this can aid diagnosis and cure. AREMA categorize factors that may contribute to the deterioration of the concrete according to one or more of the following, (5).

- (1) Lack of quality in the original concrete and/or its placement.
 - (a) Quality of materials such as: improperly stored or handled cement; reactive, porous or soft aggregates; contaminated water; or inappropriate admixtures or combinations of admixtures
 - (b) Mix design and proportioning
 - (c) Workmanship, placing, finishing or curing
- (2) Deficiency of reinforcement.
 - (a) Design deficiencies
 - (b) Inadequate or improper details
 - (c) Damaged coating on epoxy coated reinforcement
 - (d) Insufficient concrete cover
- (3) Properties of surrounding environment.
 - (a) Use of deicing agents
 - (b) Alkali soil or water
 - (c) Industrial chemicals
 - (d) Marine environment
- (4) Inadequate structural capacity.
 - (a) Excessive loads
 - (b) Design deficiencies
 - (c) Inadequate or improper details
 - (d) Inadequate consolidation
- (5) Physical damage.
 - (a) Impact
 - (b) Abrasion from ice, stream flow, traffic
 - (c) Settlement of the foundation

- (d) Freeze-thaw cycles
- (e) Fire
- (f) Seismic activity
- (g) Wind
- (h) Storm

On the other hand [12] revealed the main reasons deterioration of concrete as:

- Reinforcement corrosion (caused by chloride and carbonation);
- Alkali-silica reaction;
- Freeze-thaw attack;
- Sulfate attack ;
- Cracking including settlement, plastic and early thermal cracking.

Reinforcement corrosion:- occurs when the passivity of the steel provided by the concrete is broken down. The alkaline nature of concrete (pH ~13) results in the formation of a passive film on the reinforcement surface that protects it against corrosion.

Carbonation is likely to be the cause of reinforcement corrosion on bridge concrete not exposed to chlorides. Once reinforcement corrosion has initiated it proceeds at a rate largely governed by the ambient temperature and the resistivity of the concrete which in turn depends on its moisture and chloride content.

Corrosion caused by carbonation results in general corrosion and leads to cracking, spalling and delamination of the concrete before significant reductions occur in the cross sectional area of the reinforcement. This type of damage reduces the steel-concrete bond which can affect the flexural strength of the element and spalling concrete from overbridges is a hazard to traffic. Corrosion caused by chlorides can also result in cracking, spalling and delamination but, in addition it can cause intense pitting corrosion of the steel, substantially reducing its cross sectional and strength.

Alkali silica reaction (ASR):- is a chemical reaction between aggregate particles and the alkali in cement. This reaction product is a silicate which swells when it absorbs water causing stresses which fracture the concrete. The reaction product is a white precipitate which is often, through not always, seen emanating from the cracks in the concrete. ASR requires three substances to be present simultaneously:

- reactive aggregate particles
- concrete with alkali content greater than 3kg/m³;
- concrete with a high moisture content

The cracks which result from ASR tend to form a map pattern in lightly or unreinforced concrete. In heavily reinforced and prestressed elements the cracks are more likely to be coincident with the main reinforcement and prestressing steel, respectively. The cracking can be quite severe and certainly detracts from the appearance of a bridge, but in most cases the structural effects are limited. The cracks caused by ASR can increase the risk of secondary reinforcement corrosion occurring at a later date. Modern bridges should not suffer from ASR since the alkali content of the cement and aggregate reactivity were controlled and now incorporated in the Specifications.

Sulfate attack:-usually occurs on concrete buried in soil with a high sulfate or sulphide level (sulphide can be oxidised to sulfate). It can also occur in concrete above ground and in seawater where the sulfate content of the cement is abnormally high. Sulfate attack starts at the concrete surface and moves progressively inwards. The rate of attack is usually much higher than for frost attack and substantial damage can occur which could have structural consequences. Sulfate attack can be prevented by the use of special cements such as sulfate resisting Portland cement.

The Guide does not specifically address concrete repairs to reinforced concrete below ground level. However, as with all repairs it is essential to determine the cause of any defects or deterioration in the concrete before deciding on the options for remedial work. It is also important to determine the effects and influence of the prevailing or anticipated ground conditions. An important issue is the prevention of recurrence of the concrete deterioration. Measures such as the use of protective membranes, improved drainage, replacement with non-aggressive backfill and the use of protective layers produced in low carbonate concrete should be considered.

Plastic settlement and early thermal cracks:- These cracks occur very early in the life of a structure but rarely cause any immediate problems. Plastic settlement cracks are formed due to restraint between the concrete and the reinforcement or the formwork. As the concrete, particularly with high bleeding water, settles under the process of settlement, it tears and cracks between the restraints. Early thermal cracking is a consequence of the heat of hydration of the mix with high cement content in a mass concrete. In thicker sections with a large volume, the concrete becomes insulating at outer edges as it hydrates. This results in substantial increase in temperature in the central core of the element. The temperature difference leads to early thermal cracking. Normally, these types of cracking would have been sealed at the construction stage. These cracks, if not sealed, can increase the risk of corrosion occurring later.

Other Factors affecting concrete deterioration:- Deterioration caused by material, design and construction problems can only be reduced by improvements made before and during construction. Deterioration due to environmental factors should be allowed for in the design but can also be controlled to some extent during service by adopting a range of preventative maintenance approaches. The performance of these protective measures is, however, significantly reduced if the bridge has shortcomings in material, design and construction.

Most deterioration processes involve water in some way and much could be achieved by improving the detailing of kerbs, joints, parapets, upstands, drainage systems and waterproofing membranes and avoiding the formation of sinks where water can accumulate and persist for considerable periods of time. Regular routine maintenance such as cleaning drains and vegetation control and removal may avoid more serious maintenance at a later date.

Some forms of deterioration and defects, although often not producing serious consequences immediately can result in corrosion occurring sooner because the transport, through the concrete, of aggressive substances in the environment is facilitated, (12).

2.3.2 CAUSES OF RAIL DAMAGE OF RAILWAY

Another critical component on the process of maintenance of Railway Bridge is rail maintenance and its damage and causes of the damage will be discussed in this section.

Having known the cause of the defects, it can be prevented or diagnosed if once the defect has appeared. Also it will be useful to avoid further damage of the rail. According to AREMA rail defect classification and their causes are described as follows; (5)

1, Head Defects - Transverse

Transverse defects are any progressive fractures occurring in the head of a rail and have a transverse separation, however slight. Present hand test methods classify defects in track using known defect characteristics. While these methods are generally accepted, only after rail is broken for examination can an accurate identification be made as one of the following:

- Detail Fracture (from Shelling, Head check or other surface defect)
- Compound Fissure
- Transverse Fissure
- Engine Burn Fracture
- Welded Burn Fracture

Most of these defects found in the head of the rail and are sometimes grouped with other fatigue defects which appear over time as the rail ages. Causes to include:

Steel impurities or process problems

- Fatigue (train tonnage over time)
- Rail surface (slivers, shells or damage, etc.)
- Track Geometry (vertical, horizontal and ballast/tie modulus)
- Temperature swings (compression and tension)

✚ **Detail fracture** is a progressive fracture that typically originates from a separation close to the running surface of the rail head. This separation turns down and progresses transversely at right angles to the running surface of the rail. This defect is usually associated with shelling but can also develop from head checking, sliver or flaking.

Cause: Separations normally originate on the gage side of the rail head from loading stresses associated with rail/wheel interfacing. However, the detail fracture can also be found on the field side of the rail. The separation progresses longitudinally (normally at a slight angle) until transverse separation initiates. No nucleus will be present, as the origin will always be associated with mechanical development.

✚ **Compound fissure** is a progressive fracture in the rail head that originates as a horizontal separation which turns up or down, or in both directions to form a transverse separation substantially at right angles to the running surface. Compound fissures may include multiple horizontal or vertical planes.

Cause: Usually a horizontal separation originating from an internal longitudinal seam, segregation, or inclusion. Conditions from which the horizontal separation originates can exist throughout the rail length. The separation will progress longitudinally for an unspecified distance, then will turn upward, downward, or both, and transverse progression will initiate. Seams or segregations can occur in multiple planes.

✚ **Transverse fissure** is a progressive crosswise fracture originating from a center or nucleus located inside the rail head, developing outward substantially at right angles to the running surface of the rail.

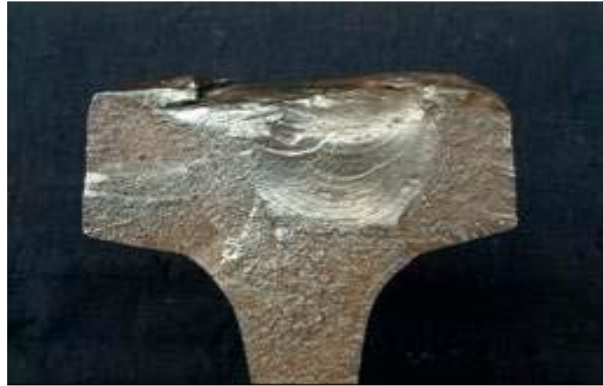


Figure 2.3-1 Transverse fissure

Cause: The internal nucleus from which the transverse fissure develops is an imperfection inherent from the steel manufacturing process, such as a shatter crack, or a minute inclusion or blowhole. Failure to effectively remove hydrogen is the most common cause of shatter cracks that develop in to transverse fissures. These inherent internal imperfections can be located in several places in the same rail length and can exist in multiple rails from the same heat. Loading, impacts from wheels and the bending stresses initiate the transverse separation around the internal imperfection

✚ **Engine burn fracture** is a progressive fracture in the head of the rail that initiates from overheating generated by slipping locomotive wheels. Rapid cooling results in thermal cracks. Its appearance in track is of a round or oval area with slivers from metal flow where metal has flattened or separated just below the surface. Usually fatigue is at right angles to the running surface, but may occur in several directions into the rail head.

Cause: The defect originates from overheating of the rail surface produced by the friction. Rapid cooling creates thermal cracking. The pounding of wheels over time at the burned area result in a horizontal separation of the burned metal from the parent metal and a noticeable flat spot will develop. Transverse separation can then initiate from the burn and progress into the rail head.

✚ **Transverse separation** associated with a weld repair is a progressive fracture in the head of the rail that initiates from an inclusion or stress crack resulting from a weld repair rail re-surfacing. The defect will typically initiate at the interface between the weld filler metal and parent metal of the rail section. It then

progresses transversely into the rail head. No evidence of a transverse defect is visible until the defect reaches the rail surface.

Cause: The defect is a result of improper welding techniques, usually during the cleaning phase, associated with the repair of engine burn or electrode burns. It can also be a result of improper cooling which may create martensite and thermal cracks. Transverse separation will initiate from inclusions or heat affected zone (under-bead cracking) of the weld.

- ✚ **Plant weld and in-track welds containing discontinuities or pockets**, usually oriented in or near the transverse plane. Weld defects may originate in the rail head, web, or base, and in some cases, cracks may progress from the defect into either or both adjoining rail ends.

Cause: Weld or weld process problems, shearing, finish grinding and rail handling following welding. Also it can be caused by rail handling during transportation to field track location and installation irregularities. Discontinuities or pockets may be due to incomplete penetration of weld metal between the rail ends, lack of fusion between weld and rail end metal, entrapment of slag, other shrinkage cracking, or fatigue cracking. Defects can also be associated with normal rail fatigue

- ✚ **Field Welds, containing discontinuities or pockets**, usually oriented in or near the transverse plane. This may be due to incomplete penetration of weld metal between the rail ends, lack of fusion between weld and rail end metal, entrapment of slag or sand, underbead or other shrinkage cracking, or fatigue cracking. Weld defects may originate in the rail head, web, or base. In some cases, cracks may progress from the defect into either or both adjoining rail ends.

Cause: Initial failures can be caused by improper rail end alignment, mold (or mold alignment) improper preheat, charge material, moisture or introduction of impurities, shearing, grinding and other process issues. Extended service life failures may be associated with normal rail fatigue, casting fatigue factors, hot tear (rail movement while weld is being made) and poor track support in the weld area.

- ✚ **Progressive horizontal defect** originating inside of the rail head, usually below the running surface and progressing horizontally, and generally accompanied by a flat spot on the running surface. The defect appears as a lengthwise crack, when it reaches the side of the rail head.



Figure 2.3-2 Progressive horizontal crack

Cause: The horizontal split head is usually caused by a manufacturing defect, which could be an internal longitudinal seam, segregation or inclusion. This segregation may be confined to a particular rail heat.

- ✚ **Lengthwise crack** (longitudinal or angled) on the side of the rail web extending into or through width of the web.
Cause: Can be present from steel mill or develop with time and train traffic. Split webs can originate from indentations, gouges in web during installation or maintenance, corrosion or welding processes.
- ✚ **Broken base** means a break in the base of the rail.
Cause: Rail damage due to handling and maintenance or inclusions inherent in rail from steel mill.
- ✚ **Damaged, deformed, bent or kinked rails unfit for track**, not because of any defect previously discussed, but because of accident or abuse. Justification for removal of damaged rail under this classification depends on the policy of the particular railroad. This general classification includes four types of damage, all of which can be identified in track. Other rail defects developing from damaged rails would be identified according to the type of defect.
- ✚ **Cause:** Derailments, rail handling or damage occurring during track maintenance
 - Kinked Rail:-twisted rail
 - Nicked Rail (Head, Web or Base):- small cut of the rail
 - Wheel impact rail breaks

- ✚ **Defects or cracks** originating from processes used for attachment of signal bond wires to head, web or base of rail.

Cause: Cracks can be caused by the drill bit overheating due to a dull bit or excessive pressure on the bit while drilling. Cracks can also be associated with rail fatigue

- ✚ **Rail end batter** consists of surface deformation, flattening and widening of the head of the rail in the immediate vicinity of the end of the rail

Cause: There are many causes of rail batter, not limited to the alignment and surface (joint support structure) of the rail joint. Bolts in the joint bar must be maintained and properly tightened

2. **HEAD CHECKING:-** are shallow surface or hairline cracks that appear in the gage corner of rail head, at any angle with the length of the rail.



Figure 2.3-3 Sever Head checking

Cause: Head checks are a result of cold working of surface metal, due to the interaction between the wheels and the rail, usually associated with the gage corner. This is also referred to as a form of rolling contact fatigue (RCF).

3. **FLAKING:** A condition where conjoining of head checks results in surface metal separation. It is indicated by small chipping and cavities. It is a progressive horizontal separation on the running surface of rail near the gage corner, with scaling or chipping of small slivers. Flaking should not be confused with shelling, as the flaking takes place only on the running surface, usually near the gage corner of the rail, and is not as deep as shelling.

Cause: Flaking is the result of surface metal friction, flow and plastic deformation. It is caused by the concentrated wheel loads, resulting in severe compressive shear deformation of the rail surface.

4. **SPALLING** is cracking and chipping of the rail surface. Spalling is a progression of head checking and flaking.

Cause: High horizontal wheel-rail creeping forces, transverse friction forces and extreme wheel-rail contact stresses result in micro-cracking, head checking or chipping.

5. **SHELLING:** is a rail head condition consisting of progressive subsurface horizontal separations that may crack out on the gage side of the rail head. Shelling normally occurs on the upper gage face of the rail head, and extends longitudinally. Shells originate under the surface of the rail head.

Cause: High contact stresses from wheel-rail interaction, especially when severe non-conformal wheel-rail contact occurs.

6. **CORRUGATION:** Repetitive longitudinal pattern of shallow wavelike depressions along the rail surface. There is short wave (2 to 3 inches) and long wave (10 to 12 inches or more) corrugation. Corrugation is sometimes called "washboard rail".

Cause: Corrugation can be caused by sliding wheel action, tractive forces, braking forces or lateral motion across the rail surface. In curves, it is caused by high and low rail rolling radius differences at each wheel/axis set transverses the curve. This may be most prevalent in or near curves or on some downgrades at restricted speed locations. Any anomaly in track geometry that sets up repetitive car motion issues can cause corrugation.

7. **CORROSION:** is disintegration of the rail starting at the surface, from chemical decay, mainly oxidation (rusting). As it progresses, it often forms irregular pits, cavities, or develops cracks in the rail web or base.

Cause - Corrosion usually occurs in wet or damp areas such as tunnels, grade crossings (filled-in with soil or contaminated with salt), and other areas where ballast or debris covers the rail base and web for long periods. In the past, salt brine dripping from refrigerator cars also caused rail corrosion. Base corrosion can occur where deteriorated rail pad centers on concrete cross ties hold water against the base. The effects of abrasion, alkali, lime in concrete, salt near coast lines and electrolysis in electrified areas are other causes and contributing factors to corrosion, (3).

2.4 RAILWAY BRIDGE DAMAGE INSPECTION AND IDENTIFICATION

Damage Identification is necessary to precede the actual maintenance activity. The investigation should try to determine the possible cause(s) and then select a repair procedure which will correct the existing condition and prevent further deterioration by any and all of the suspect cause(s), (5).

2.4.1 METHODS OF EVALUATION OF DETERIORATION AND DAMAGE

2.4.1.1 Visual Inspection

For surface conditions of concrete railway bridge, visual inspection can be used to identify the location and size of cracks, voids, scaling, spalls, delaminations, and exposed (corroded) reinforcement. Inspection of concrete structures which includes concrete Bridge structures is discussed as follows according to AREMA.

Periodic inspections should be made to detect deterioration and damage before the structure becomes irreparable. The engineer in charge of maintenance and inspection should be experienced in determining the parts of structures in need of repair and the extent of deterioration or damage. All Bridge and culvert structures and their components should be given thorough, detailed condition inspections at scheduled intervals. The scope and detail of the inspection should be based on the condition and age of the structure, traffic type and tonnage in order to determine that the physical condition of each structure is suitable for the imposed loading and to determine maintenance or rehabilitation needs. A record of physical conditions should be kept.

A special inspection may be required when the bridge is subjected to abnormal conditions which may affect the capacity of the bridge such as: floods, storms, fires, earthquakes, collisions, overloads and evidence of recent movement.

The inspector should review prior inspection reports before making the inspection. Previously noted defects should be examined in the field and any changes in conditions recorded. Field book, sketch pad, inspection form, camera, monitoring gages, etc., should be used to record the inspection data. Appropriate personal safety equipment should be used throughout the inspection.

The inspection of concrete structures should be carried out in a methodical manner. Of primary importance in all bridge structures is evidence of distress, misalignment, deflection, settlement, cracks, and general deterioration. Evidence of deterioration of concrete such as width and length of structural cracks, size and location of spalling

and scaling, and location and extent of water-saturation of concrete should be recorded. Cleaning of component parts may be necessary prior to inspection.

The inspector should report indications of failure in any portion of the structure and any conditions which could contribute to a future failure. Reference points should be established for monitoring misalignment, deflection, settlement, and cracks. The amount of tilt, separation between components, width and length of cracks, efflorescence and rust-staining and other measurements necessary for future checking should be recorded and the inspection should include the structure and all related features.

Inspection of major structural components is described separately as follows.

1. Waterway Crossing Bridges

Where a bridge crosses over a waterway, the inspector should note the condition and alignment of the waterway. The condition of the slopes and any slope protection (such as riprap) should be noted along with any indication of debris accumulation. The inspector should note any indication of damage from marine collision or debris. Where scour is possible, the channel bottom at piers and abutments should be checked by sounding, probing or other means.

The inspector should note any changes in the alignment of a waterway both upstream and downstream and the resulting effect that they may have on the structure. A major change in the alignment of a waterway may place it outside the spans intended for the crossing. Sedimentation deposits may fill scour holes after high water events. Structures located downstream of spillways or locks may be subject to increased scour potential.

2. Foundations: Piers and Abutments

The type of foundation and type and condition of material used in the various structural components should be noted. The inspector should note any settlement and/or rotation of foundations, piers, abutments or their component parts. Reference points should be established for monitoring of structural movement if appropriate.

Location and extent of exposed and/or corroded reinforcing steel should be reported. The condition of the structure at the bridge seats, bearings and near the waterline should also be investigated. Crack width, orientation and location should be noted. Widths and lengths of structural cracks should be marked and dated to monitor crack progression. On masonry structures note cracked, shifted, or missing stones, and condition of mortar.

Location, size and description of unsound areas, spalling, scaling or other deterioration should be noted. Condition of retained fill, drainage and slope protection at abutments should be inspected. Water-saturated concrete and extent of efflorescence and rust-staining should be noted. Check drains for proper function.

Concrete and masonry structures are placed on foundations of earth, piling, cribbing, rock or other similar material. Cracks may be evidence of settlement which has occurred during consolidation of the foundation. Settlement may occur without cracking. Noticeable changes in track surfaces and alignment, plumbness or elevation may indicate foundation settlement. Changes in backwall alignment or cracks in the earth embankment parallel to the backwall may indicate movement. Constant wetting may indicate swelling, premature loss of mortar, deterioration of facing or excessive water pressure behind backwalls.

3. Pile and Pile Bents

Alignment and condition of piling should be recorded. Impact damage from debris, vessels or vehicles should also be noted. Condition of piles should be investigated for soundness. Loss of section and cracking should be noted. These may be especially severe in a marine environment, particularly in the tidal zone. Condition of connections between cap and piling should be noted. Condition of bracing members and their connections should also be noted.

4. Underwater Inspections

The need and frequency for underwater inspections should be evaluated for every structure having submerged components. These inspections should identify the channel bottom conditions and presence of any scour, extent of foundation exposure and any undermining, and all deterioration and damage below water.

Inspection data should be recorded by written description, sketches, reports, photography and/or video. During high water events when scour conditions may be expected, channel activity should be monitored, which may include the use of sonar readings, until inspections can be made.

In evaluating the need for an underwater inspection, consideration should be given to type and depth of foundation, depth of water, normal and peak flow rates, nature of channel bottom and susceptibility to and history of scour, type of aquatic environment, typical extent of drift and ice accumulation, and amount and type of

watercraft traffic. The inspections should be performed with sufficient frequency to provide early detection of any detrimental conditions, and between inspections, the measuring of water depths should be considered to monitor channel bottom activity. In the event of a high water and/or flow occurrence, an excessive accumulation of ice or drift, a watercraft collision, a significant change in channel bottom configuration, or any submerged component movement, consideration should be given to performing an emergency inspection as soon as conditions will safely permit.

5. Slabs and Beams

Inspector should note if prestressed or conventionally reinforced concrete is used in the structure. Method of construction, cast-in-place or precast, simple or continuous, should also be recorded. Any cracks that open and close under traffic, diagonal cracks near supports, or wide or numerous cracks in any location should be reported immediately to the proper authority. Acute corners of skewed bridges should be examined for cracks, delaminations and spalls. Structural members should be inspected for excessive deflection, misalignment or collision damage. Curbs, ballast retainers, walkways and handrails should be inspected, noting the condition as to soundness and security of fastening devices. Soundness, uniformity and condition of bearings and bearing areas should also be noted. Areas exposed to drainage should be checked for spalls and cracks.

Transverse cracks in the bottom of simple span slabs and beams can indicate overload, particularly if cracks open and close during passage of a train. Hairline cracks on the tops of simple span prestressed beams are generally due to shrinkage of the concrete. Hairline cracks in the top or bottom of simple span reinforced concrete slabs and beams are generally not significant. Diagonal cracks running up the sides of the slab or beam from near the supports may indicate excessive shear stress in the member or the beginning of shear failure.

Transverse cracks in the top of continuous beams over support locations or in the bottom of continuous beams within the span can indicate overload. Sagging or excess deflection may indicate a loss of prestress. Loss of prestress may be caused by strand slippage, which may be visible at the ends of beams. End spalling can lead to a loss of bond in the prestressing tendons. The inspector has to note any deterioration on slabs and beams that has exposed or damaged prestressing tendons.

6. Box Girders

Type of box construction (precast, cast-in-place, segmental, pre-tensioned, post-tensioned, simple or continuous spans) should be recorded. Top flange, bottom flange and web walls should be inspected when accessible. Chamfers of boxes should be inspected for cracking which may extend along the sides or bottom of the girders. Shear transfer devices between adjacent box girders should be inspected, where accessible. Condition of grout, hardware, tie rods, and other materials used in tying together adjacent box girders should be noted.

Evidence of differential box deflections or misalignments should be recorded.

Condition of void drain holes and evidence of leakage between adjacent boxes should be noted. Horizontal or vertical cracks in the top of girder ends are frequently due to stresses created at the transfer of prestressing forces. Flexural cracks in the lower portion of the girders, particularly at mid-span, may indicate a problem resulting from overload or loss of prestress. Individual girder deflection under live load may indicate that shear keys between boxes have been broken and that boxes are acting independently of each other.

7. Inspection of culverts

Inspection of a concrete culvert in general should be in conformance with inspection of concrete bridge. Inspector should note any settlement, variations in cross-sectional shape and misalignment along the horizontal axis of a culvert. All joints between end treatments and within the culvert itself should be examined for differential movement, and all transverse or longitudinal cracking within a culvert should be noted.

A culvert should be inspected for any scour or undermining at either end. Any embankment damage around the culvert openings and debris or vegetation within the culvert should be noted. All submerged portions of a culvert should be inspected underwater based on the recommendations set forth for underwater structures inspection.

Horizontal alignment of a culvert can be inspected by sighting along one of the culvert walls. Sag in the culvert axis may be identified by a location of sediment buildup on the culvert floor. Spalls or cracking in the vicinity of a joint may be a sign of movement at the joint. Both longitudinal and transverse cracking may be an indication of differential settlement. Longitudinal cracks can also be caused by a structural overloading of the culvert. Holes appearing in the track structure may be

an indication of open culvert joints. For culvert extensions, integrity of connection should be noted.

Insufficient hydraulic capacity, either by design or due to obstructions, may cause upstream pond and lateral flow movements which can erode the embankments and supporting material around the culvert end treatments. Culverts often convey short-term, high volume flows, and consequently, all culverts should be carefully inspected for scour and undermining. Tipping, cracking or separation of the headwalls, wingwalls or apron may indicate the presence of undermining. For arch and frame type culverts with earthen floors, undermining beneath the wall foundations along their full length should also be investigated.

2.4.1.2 Reporting of damages observed by Inspection

When the inspector finds defects that appear to be of such a nature as to make the passage of traffic unsafe, the condition should immediately be reported. After steps have been taken to protect traffic, the train dispatcher and appropriate officers should be notified, consistent with established policies, recommending a speed limit and briefly describing the conditions which prompted the action. The inspector should follow this immediately with a report so that a detailed investigation and recommendation for repair can be made.

Upon completion of the inspection, a written record covering the inspection should be forwarded to the engineer or other officer in charge of maintenance. Upon receipt of the report, a review should be made to determine the need for remedial action.

2.4.1.3 Non-Destructive Tests

There are several common test procedures available to determine the in-place condition of the structure. The most appropriate test should be determined by the Engineer. For internal conditions and subsurface deterioration, conventional testing methods include:

- **Audio methods** for detection of cracks, voids and delaminations require the use of hand tools, including hammers, steel rods and chains, which are used for striking the structure to detect sound differentials between good and defective ("hollow" sounding) material.
- **Electrical methods** for evaluation of reinforcement corrosion activity include the use of half-cells or multiple electrode systems, which measure resistance and potential differences. The method requires connection be made to an exposed section of steel reinforcement.

- **Impulse radar** uses electromagnetic wave (radar) reflection to detect voids, measure material thickness, and evaluate presence and location of embedments (reinforcement) in structures. This method is affected by moisture in the concrete or masonry, and relative measurements should be correlated to known dimensions.
- **Infrared thermography** uses heat flow through structures to determine anomalies such as voids and delaminations.
- **Magnetic methods** for determining location, size and depth of reinforcement include the use of pachometers or R-meters that make measurements based on the principles of induction.
- **Stress wave reflection/refraction methods**, including pulse-echo, impact-echo and stress wave refraction, introduce a stress pulse into the structure, and reflections of the stress waves denote material flaws or interfaces such as voids, cracks, and delaminations.
- **Rebound (impact) hammers** use a spring-loaded weight impacted against the structure, with the amount of rebound being a measurement of material hardness and strength. This commonly used method is inexpensive, but results can be affected by surface conditions, material moisture content and aggregate type.
- **Ultrasonic pulse velocity methods** use measurements of the time for a sound wave to travel to and from a reflection surface (backside of a structure or internal discontinuity) to determine material thickness and to identify the presence and location of voids, cracks or delaminations. This method is affected by material density and component make-up, and relative measurements should be correlated to known dimensions.

2.4.1.4 Sampling and load test

- ✚ **Sampling** consists of removing samples of material, usually by coring, in order to analyze physical and chemical characteristics of concrete and reinforcing.
- ✚ **Load Test** method involves the instrumenting of a structure to measure strains or deflections as a means of determining the capability of the structure to sustain service loads. A prescribed test load is permitted to cross the structure at a given speed. Often it is desirable to stop the test load on the structure at a predetermined position and take measurements under static conditions.

The test should be monitored as the loading progresses to verify that the observed data compares favorably with the theoretical calculations. If a significant difference is observed the test should be stopped and further evaluated before proceeding.

This method should be used only if calculations indicate a reasonable margin of safety against collapse under the test load. Loads considerably below the desired service load level may be used initially to make a preliminary evaluation and to predict the reaction of the structure under a full test load.

2.4.2 REPORTING RESULTS OF IDENTIFICATION

Based on the evaluation, one or more of the following determinations can be made regarding the present condition:

- a. Requires no action.
- b. Requires action to arrest or minimize deterioration.
- c. Requires action to repair or strengthen the structure.
- d. Requires reconstruction or replacement of the structure.
- e. Requires restricting traffic speed and/or weight or closing the structure to traffic.

Both cost-effectiveness of the repair and the business costs of the time impacts on rail operations should be considered in evaluating a course of action.

2.4.3 SPECIAL CASES AND REEVALUATION

In special cases (i.e. windstorm, flooding, scour, seismic activity, fire damage, etc.), the resulting damage to the structure may not be apparent to the inspector in a visual examination of the surface. Care should be exercised in these cases to properly evaluate all defects using, where necessary, special inspection and nondestructive testing techniques.

Reevaluation: - During repair or rehabilitation of a structure it may be found that the extent of the damage or deterioration is greater than originally determined. This further damage should be reviewed for the effectiveness of the proposed repair under these conditions.

2.5 MATERIALS AND TOOLS FOR DAMAGE REPAIR

The materials needed for repair of railway bridges in this study are adapted from materials used for repair of railway concrete structures from AREMA manual. Since railway concrete bridge is one of railway concrete structures it will be appropriate to use it as a reference, (5).

2.5.1 CEMENT

Cement is one of the major materials used in modern construction technology. Whether a new construction or maintenance work use cement for bonding and strengthening purpose. The ratio of cement needed for the work depends on the required strength of the concrete. Cement used in the work shall be the same as that required by the mix design.

2.5.1.1 Specifications

Cement shall conform to one of the following Standard Specifications

- ASTM C150 Standard Specification for Portland cement as shown in [Table 2.5.1](#)
- ASTM C595 Standard Specification for Blended Hydraulic Cements.

The use of slag cement Types ‘S’ and ‘S(A)’ as defined in ASTM C595 are not included in this recommended practice as this .

Table 2.5-1 Portland cement ASTM C150

Type	Description
Type I	For use when the special properties specified for any other type are not required.
Type IA	Air-entraining cement for the same uses as Type I, where air-entrainment is desired.
Type II	For general use, especially when moderate sulfate resistance, or moderate heat of hydration is desired.
Type IIA	Air-entraining cement for the same uses as Type II, where air-entrainment is desired.
Type III	For use when high early strength is desired.
Type IIIA	Air-entraining cement for the same use as Type III, where air-entrainment is desired.
Type IV	For use when a low heat of hydration is desired.
Type V	For use when high sulfate resistance is desired.

2.5.1.2 Quality, sampling and testing

The quality of the cement and the methods of sampling and testing shall meet the requirements of the appropriate ASTM Standard Specification or Method of Test.

2.5.2 OTHER CEMENTITIOUS MATERIALS

When using cementitious materials other than portland cement, reference should also be made to the provisions of AREMA of Proportioning, Mixing, Depositing Concrete, Concrete in Sea Water, Concrete in Alkali Soils or Alkali Water, Curing and Unformed Surface Finish.

2.5.2.1 Acceptability

Cementitious materials other than portland cement will be permitted only if approved in writing by the Engineer of the Railroad Company.

2.5.2.2 Specifications

The above specifications apply to the use of other cementitious materials, either supplied in blended form with portland cement or added separately at the time of mixing. ASTM standard specifications shall be used for different types of cementitious materials, according to AREMA.

2.5.2.3 Materials not included in this recommended practice

The following materials are not included in this recommended practice:

- Pelletized silica fume:- consisting of hard pellets, not presently being used as an additive for concrete.
- Types of slag not produced in the iron making process.
- Types 'S' and 'S(A)' blended hydraulic cements containing ground granulated blast-furnace slag, as defined in ASTM C595.
- Blended cements containing ground granulated blast-furnace slag blended with hydrated lime.

2.5.3 AGGREGATES

2.5.3.1 General

I. Specifications

Except as specified otherwise herein, all aggregates shall conform to the requirements of ASTM C33, Standard Specification for Concrete Aggregates.

II. Sampling and Testing

Representative samples shall be selected and sent to the testing laboratory at frequent intervals as directed by the Engineer. Aggregates may not be used until the samples have been tested by the laboratory and approved by the Engineer.

Sampling and testing shall be in accordance with ASTM C33 and the Standard Specifications and Methods of Test of ASTM - International found in [Table 2.5.2](#).

Table 2.5-2 Sampling and Testing Methods in Addition to those of ASTM C33

Type	ASTM Designation
Surface Moisture in Fine Aggregate	C70
Specific Gravity and Absorption of Coarse Aggregate	C127
Specific Gravity and Absorption of Fine Aggregate	C128
Standard Sand	C778

The required tests shall be made on test samples that comply with requirements of the designated test methods and are representative of the grading that will be used in the concrete. The same test sample may be used for sieve analysis and for determination of material finer than the No. 200 (75 µm) sieve. Separated sizes from the sieve analysis may be used in preparation of samples for soundness or abrasion tests. For determination of all other tests and for evaluation of potential alkali reactivity where required, independent test samples shall be used.

The fineness modulus of an aggregate is the sum of the percentages of a sample retained on each of a specified series of sieves divided by 100, using the following standard sieve sizes: No. 100, No. 50, No. 30, No. 16, No. 8, No. 4, 3/8 inch, 3/4 inch, 1-1/2 inches (150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 4.75 mm, 9.5 mm, 19.0 mm, 37.5 mm) and larger, increasing in the ratio of 2 to 1. Sieving shall be done in accordance with ASTM Method C136.

III. Soundness

Aggregate subjected to five cycles of ASTM C88 Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate shall show a loss weighed in accordance with the grading procedures, not greater than the percentages found in [Table 2.5.3](#).

Table 2.5-3 Aggregate Soundness

Aggregate	Sodium Sulfate	Magnesium Sulfate
Fine	10	15
Coarse	12	18

Aggregate failing to meet the above requirements of may be accepted provided that concrete of comparable properties, made with similar aggregate from the same source, has given satisfactory service when exposed to weathering similar to that to be encountered.

2.5.3.2 Fine Aggregates

Fine aggregate shall consist of natural sand or, subject to the approval of the Engineer, manufactured sand with similar characteristics. Lightweight fine aggregate shall not be used.

I. Grading

Sieve Analysis-Fine aggregate, except as provided in ASTM C33, shall be graded within the limits found in [Table 2.5.4](#).

Table 2.5-4 Fine Aggregate Grading

Sieve Size	Total Passing Percentage by Weight
3/8" (9.5mm)	100
No. 4 (4.75 mm)	95-100
No. 8 (2.36 mm)	80-100
No. 16 (1.18 mm)	50-85
No. 30 (600 µm)	25-60
No. 50 (300 µm)	10-30
No. 100 (150 µm)	2-10
No. 200 (75 µm)	0

The minimum percentages shown above for material passing the No. 50 (300 µm) and No. 100 (150 µm) sieves may be reduced to 5 and 0, respectively, if the aggregate is to be used in air-entrained concrete containing more than 420 lb of cement per cubic yard (250 kg per cubic meter), or in non-air-entrained concrete containing more than 520 lb of cement per cubic yard (310 kg per cubic meter). Air-entrained concrete is here considered to be concrete containing air-entraining cement or an air-entraining admixture and having an air content of more than 3%.

The fine aggregate shall have not more than 45% retained between any two consecutive sieves of those shown in [Table 2.5.4](#) and its fineness modulus shall be not less than 2.3 nor more than 3.1. For walls and other locations where smooth surfaces are desired, the fine aggregate shall be graded within the limits shown in [Table 2.5.4](#), except that not less than 15% shall pass the No. 50 (300 µm) sieve and not less than 3% shall pass the No. 100 (150 µm) sieve.

To provide the uniform grading of fine aggregate, a preliminary sample representative of the material to be furnished shall be submitted at least 10 days prior to actual deliveries. Any shipment made during progress of the work which varies by more than

0.2 from the fineness modulus of the preliminary sample shall be rejected or, at the option of the Engineer, may be accepted provided that suitable adjustments are made in concrete proportions to compensate for the difference in grading.

The percentages listed above do not apply when using pozzolans or ground granulated blast-furnace slag. Such percentages shall be determined by tests as outlined in this recommended practice.

II. Mortar Strength

Fine aggregate shall be of such quality that when made into a mortar and subjected to the mortar strength test prescribed in [ASTM C87](#), the mortar shall develop a compressive strength not less than that developed by a mortar prepared in the same manner with the same cementitious materials and graded standard sand having a fineness modulus of 2.40 ± 0.10 . The graded sand shall conform to the requirements of [ASTM C778](#).

III. Deleterious Substances

The amount of deleterious substances in fine aggregate shall not exceed the limits found in [Table 2.5.5](#).

A fine aggregate failing the test for organic impurities may be used provided that, when tested for mortar making properties, the mortar develops a compressive strength at 7 and 28 days of not less than 95% of that developed in a similar mortar made from another portion of the same sample which has been washed in a 3% solution of sodium hydroxide followed by thorough rinsing in water. The treatment shall be sufficient so that the test of the washed material made in accordance with [ASTM C40](#) will have a color lighter than the standard color solution.

Table 2.5-5 Deleterious Substances in Fine Aggregate

Item	Maximum Limit Percentage by Weight
Clay Lumps	1.0
Coal and Lignite	0.5(Note 1)
Material finer than No. 200 sieve (75 μ m): Concrete subject to abrasion All other classes of concrete	3.0 (Note 2) 5.0 (Note 2)

Note 1: Does not apply to manufactured sand produced from blast-furnace slag.

Note 2: For manufactured sand, if the material finer than the No. 200 (75 μ m) sieve consists of the dust of fracture, essentially free from clay or shale, these limits do not apply.

Fine aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalis in the cement in an amount sufficient to cause excessive expansion of mortar or concrete, except that if such materials are present in injurious amounts, the fine aggregate may be used with a cement containing less than 0.6% alkalis as measured by percentage of sodium oxide plus 0.658 times percentage of potassium oxide, or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction.

2.5.3.3 Coarse Aggregate

I. Normal weight Coarse Aggregate

Coarse aggregate shall consist of crushed stone, gravel, crushed slag, or a combination thereof or, subject to the approval of the Engineer, other inert materials with similar characteristics, having hard, strong durable pieces, free from adherent coatings, and shall conform to the requirements of ASTM C33 except as required by this Part. Crushed slag shall be rough cubical fragments of air-cooled blast-furnace slag, which when graded as it is to be used in the concrete, shall have a compact weight of not less than 70 lb per cubic foot (1100 kg per cubic meter). It shall be obtained only from sources approved by the Engineer.

Grading

Coarse aggregate shall be graded between the limits specified ASTM C33. The maximum size of aggregate shall be not larger than one-fifth of the narrowest dimension between forms of the member for which concrete is used, nor larger than one-half of the minimum clear space between reinforcing bars.

Deleterious Substances

The amount of deleterious substances in coarse aggregate shall not exceed the limits found in ASTM C33.

Abrasion Loss

Coarse aggregate to be used in concrete when subjected to test for resistance to abrasion (ASTM C535 or ASTM C131) shall show a loss of weight not more than the following:

- a. For concrete subject to severe abrasion such as concrete in water, precast concrete piles, paving for sidewalks, platforms or roadways, floor wearing surfaces, and concrete cross or bridge ties, the loss of weight shall not exceed 40%.
- b. For concrete subject to medium abrasion such as concrete exposed to the weather, the loss of weight shall not exceed 50%.
- c. For concrete not subject to abrasion, the loss in weight shall not exceed 60%.

Rubble Aggregate

Rubble aggregate shall consist of clean, hard, durable stone retained on a 6-inch (150 mm) square opening and with individual pieces weighing not more than 100 lb (45 kg).

Cyclopean Aggregate

Cyclopean aggregate shall consist of clean, hard, durable stone with individual pieces weighing more than 45 kg.

II. Light weight Coarse Aggregate for structural concrete

This recommended practice covers lightweight coarse aggregates intended for use in lightweight concrete in which prime considerations are durability, compressive strength, and light weight. Structural lightweight concrete shall only be used where shown on the plans or specified.

Aggregates for use in non-structural concrete such as fireproofing and fill, and for concrete construction where capacity is based on load tests rather than conventional design procedures, are not included in this recommended practice.

General Characteristics

The aggregates shall conform to the requirements of ASTM C330 Standard Specifications for Lightweight

Aggregates for Structural Concrete, except as otherwise specified herein.

Unit Weight (Mass Density)

The dry weight (mass density) of lightweight aggregates shall not exceed 55 lb per cubic foot (880 kg per cubic meter), measured loose by accepted ASTM practice. The unit weight (mass density) of successive shipments of lightweight aggregate shall not differ by more than 6% from that of the sample submitted for acceptance tests.

Concrete Making Properties

Concrete specimens containing lightweight coarse aggregate under test shall conform to ASTM C330 and shall meet the following requirements. A magnesium sulfate soundness test shall be conducted for 10 cycles in accordance with ASTM C88. Loss thus determined shall not exceed 15%. Loss of individual gradation size shall not exceed 20% of that size.

2.5.4 CONCRETE ADMIXTURES

The selection of admixtures to be used in concrete, if any, shall be subject to the prior written approval of the Engineer of the Railroad Company.

An admixture shall be shown capable of maintaining essentially the same composition and performance throughout the work as the product used in establishing concrete proportions in accordance with proportioning specification of AREMA.

Admixtures containing chloride ions shall not be used unless approved by the Engineer. Special purpose admixtures may be used if approved in writing by the Engineer of the Railroad Company.

However, before an admixture can be approved for use, it must be shown that its use will not adversely affect the placement, strength and/or durability of the concrete. Admixtures used in combination may be incompatible and their performance should be verified by prior testing.

2.5.4.1 Types of admixtures and standard specifications

The following specifications listed apply in the use of admixtures.

✚ Air Entraining Agent - ASTM C260 Air-Entraining Admixtures for Concrete.

✚ ASTM C494 Standard Specification for Chemical Admixtures for Concrete:

- (1) Accelerating Admixture
- (2) Retarding Admixture
- (3) Water-Reducing Admixture
- (4) Water-Reducing Admixture, High-Range
- (5) Water-Reducing and Accelerating Admixture
- (6) Water-Reducing and Retarding Admixture

2.5.5 REINFORCEMENT

Reinforcements shall be deformed reinforcement, except that plain bars and plain wire shall be permitted for spirals or tendons, or for dowels at expansion or contraction joints. Reinforcement consisting of structural steel, steel pipe, or steel tubing shall be permitted for composite compression members.

Reinforcement may consist of one or more of the following materials: Deformed steel bars, prestressing tendons, wire mesh or reinforcing fibers consisting of steel, glass, or plastic. When increased protection from corrosion is required, coatings or cathodic protection of steel reinforcement may be considered.

2.5.5.1 Welding

Welding of reinforcing bars shall conform to “Structural Welding Code-Reinforcing Steel” (ANSI/AWS D1.4) of the American Welding Society. Type and location of welded splices and other required welding of reinforcing bars shall be indicated on the plans or in the project specifications. The ASTM specifications for reinforcing bars, except for ASTM A706, shall be supplemented to require a report of material properties necessary to conform to welding procedures specified in ANSI/AWS D1.4.

If welding of wire to wire, and of wire or welded wire fabric to reinforcing bars or structural steel is to be required on a project, the Engineer shall specify procedures or performance criteria for the welding.

2.5.5.2 Specifications

I. Reinforcement

Bars, wire, welded wire fabric, prestressing tendons, structural steel, steel pipe and tubing shall conform to one of the ASTM specifications found in [Table 2.5.6](#).

Table 2.5-6 ASTM Specifications for Reinforcement

Type	Designation
Bars, Wire and Fabric	
Deformed and Plain Billet-Steel Bars	A615
Deformed and Plain Low-Alloy Steel Bars	A706
Deformed Rail-Steel and Axle-Steel Bars	A996
Deformed and Plain Stainless Steel Bars	A955
Welded or Forged Headed Bars	A970
Steel Wire, Plain (wire shall not be smaller than size W4 (0.226 inch (5.74mm) dia.))	A82
Steel Welded Wire Fabric, Plain	A185
Steel Wire, Deformed (wire shall not be smaller than size D4 (0.225 inch (5.72mm) dia.))	A496
spaced farther apart than 16 inches (400 mm) in direction of primary flexural reinforcement)	A497
Prestressing tendons	
Uncoated Seven-Wire Steel Strand	A416
Uncoated Stress-Relieved Steel Wire	A421
Uncoated High-Strength Steel Bar	A722
Structural steel, Steel pipe and Tubing	
Structural-Steel	A36, A242, A529, A572, A588 or A709 (Grade 36, 50 or 50W)
Steel Pipe	A53 (Grade B)
Steel Tubing	A500, A501 or A618

II. Coated Reinforcements

Coated reinforcement, when specified or shown on the plans as a corrosion-protection system, shall conform to one of the ASTM specifications found in [Table 2.5.7](#).

Table 2.5-7 ASTM Specifications for Coated Reinforcement

Type	Specification
Epoxy-Coated Steel Reinforcing Bars	A775
Epoxy-Coated Prefabricated Steel Reinforcing Bars	A934
Epoxy-Coated Steel Wire and Welded Wire Fabric	A884
Epoxy-Coated Seven-Wire Prestressing Steel Strand	A882
Zinc-Coated (Galvanized) Steel Reinforcing Bars	A767

Repair all damaged epoxy coating on reinforcing bars due to shipping, handling and placing with patching material conforming to ASTM A775 or A934. Repair shall be done in accordance with the material manufacturer’s recommendations.

Repair all damaged epoxy coating on wire or welded wire fabric due to shipping, handling and placing with patching material conforming to ASTM A884. Repair shall be done in accordance with the material manufacturer’s recommendations.

Repair all damaged zinc coating on reinforcing bars due to shipping, handling, and placing in accordance with ASTM A780. The maximum amount of damaged areas shall not exceed 2% of the total surface area in each linear foot (300 mm) of the bar. Equipment for handling epoxy-coated reinforcing bars shall have protected contact areas. Bundles of coated bars shall be lifted at multiple pickup points to prevent bar-to-bar abrasion from sags in the bundles. Coated bars or bundles of coated bars shall not be dropped or dragged. Coated bars shall be stored on protective cribbing. All damaged coating due to handling, shipping, and placing shall be repaired. The maximum amount of damage areas shall not exceed 2% of the surface area of each linear foot (300 mm) of the bar. If the damaged areas exceed 2% of the total surface area in each linear foot (300 mm) of the bar, the bar shall be replaced. After installation of mechanical splices on epoxy-coated or zinc-coated (galvanized) reinforcing bars, any damaged coating shall be repaired. All parts of mechanical splices used on coated bars, including steel splice sleeves, bolts, and nuts shall be coated with the same material used for repair of damaged coating on the spliced material. Remove coating for two inches (50 mm) back from the mechanical splice to bright metal before repair.

After completion of welding for welded splices on epoxy-coated or zinc-coated (galvanized) reinforcing bars, coating damage shall be repaired. All welds, and steel splice members when used to splice bars, shall be coated with the same material used for repair of damaged coating. Remove coating for six inches (150 mm) back from the

welded splice to bright metal before repair. Plants applying fusion-bonded epoxy coatings to reinforcing bars shall maintain certification by the Concrete Reinforcing Steel Institute.

2.5.6 BONDING

Before new concrete is placed against hardened concrete, the surface of the hardened concrete shall be cleaned and all laitance removed. Immediately before new concrete is placed, the existing surfaces shall be thoroughly wetted and all standing water removed. Prior to placing fresh concrete, apply a bonding layer of mortar, usually 1/8 inch to 1/2 inch in thickness, which is spread on the moist and prepared hardened concrete surface. In lieu of mortar, a suitable commercial bonding agent may be used, when applied in accordance with manufacturer's recommendations.

2.5.7 EPOXY MATERIALS

Epoxy materials are manufactured with a wide range of properties for various applications and should be chosen to provide for the requirements (i.e. viscosity, strengths, flexibility, adhesion, etc.) of the specific repair. In addition, they should meet the requirements of ASTM Specification C881, Type 1, Epoxy Resin Base Compounds for Concrete. Epoxy materials are used for a variety of purposes including bonding new concrete to old, repair of cracks, sealing and patching. Selection is subject to approval of the Engineer.

2.5.8 NON-SHRINK GROUTS

Non-shrink grouts consist of either portland cement based grouts with an expanding agent added to counter the shrinkage from the hydration of the portland cement grout or non-cementitious based grouts such as epoxy grouts. Non-shrink grouts are generally used for setting and leveling bearings. Selection of the grout is subject to approval by the Engineer.

Non-shrink grouts should conform to ASTM C1107. Design and use of portland cement non-shrink grouts should be in conformance with ACI-223 - Standard Practice for the Use of Shrinkage Compensating Concrete.

Non-shrink grouts are available in a wide variety of compositions for special purposes. This results in highly variable properties of the products. The variables include flowability, resistance to chemical attack, set time, rate of strength gain, ultimate strength and impact resistance. No single product is applicable for all cases. Product should be checked for suitability of application.

2.5.9 FIBER REINFORCED POLYMERS (FRP COMPOSITES)

Fiber reinforced polymers may be considered for strengthening or repairing existing reinforced or prestressed concrete. Polymer resins are manufactured with a wide range of properties for various applications and should be chosen to provide for the requirements of the specific repair. Selection is subject to the approval of the Engineer.

Reinforcement typically consists of carbon, glass or fiber. Reinforcement is manufactured with a wide range of properties for various applications and should be chosen to provide for the requirements of the specific repair. Selection is subject to approval of the Engineer. Fiber-reinforced polymers are typically applied in alternating layers of polymer resin and woven-fabric fiber reinforcing. Concrete underlying repairs should be cleaned and checked for soundness prior to surface application. Design and application for FRP repairs should conform to manufacturer's recommendations and sound engineering principles.

2.6 METHODS AND PROCEDURES OF MAINTENANCE

This part applies to the repair and rehabilitation of concrete structures by the following methods: patching, encasement with concrete, shotcrete, pressure grouting, injection grouting of preplaced aggregates, tremie placement, bagged concrete, epoxy injection, external post-tensioning, splicing of damaged reinforcement and component replacement. They are intended to provide means of accomplishing repairs both above and below water using a variety of materials.

Repair of a structure usually consists of five basic steps:

- (1) Identifying the deterioration.
- (2) Determining the cause.
- (3) Evaluating the strength of the existing structure.
- (4) Evaluating the need for repair.
- (5) Selecting and implementing a repair procedure.

The above steps are described in the previous sections; now let's discuss the repair methods used for concrete bridges according to AREMA, (5).

2.6.1 SURFACE REPAIRS USING PORTLAND CEMENT MATERIALS

Repairs should consist of removal of soft, disintegrated, broken, or honeycombed concrete or stone; cleaning and preparing the bonding surface and exposed reinforcement; placing of anchors and reinforcement; placing of concrete by shotcreting, hand patching, forming and placing, tremieing, grouting of preplaced aggregate, or as specified. Such concrete is to be finished to true line and surface as shown on the plans and properly cured. Concrete in the repaired area below the neutral axis in prestressed members should be repaired under an externally applied preload. Preload may be applied by means of jacks or a known load.

2.6.1.1 Preparation

Proper preparation of the surfaces to be repaired is critical to the success of the repair. Failure to provide a sound, clean surface prior to application of repair material is a common cause of failure of repairs.

All loose, soft, honeycombed and disintegrated concrete or stone should be removed from the areas to be repaired by proper tools, to expose a bonding surface of sound material. Appropriately sized equipment should be used so as not to damage sound underlying material. Following the removal of all loose, disintegrated or otherwise

defective concrete, the entire exposed surfaces of the structure should be carefully inspected for locations of seepage, internal honeycombed areas, cracks or voids.

In prestressed concrete, extreme care should be taken to avoid any damage to prestressing strands. Exposed strands should be chemically cleaned by an approved method.

Thin or feathered edges should be avoided and the boundaries of the areas to be repaired should be square cut or slightly undercut to a depth of 2.54 cm. For shotcreting, the boundary edges should be 45-degree bevel cuts to a depth of at least 2.54 cm. The maximum depth of removal shall be determined based on an analysis of the existing structure and its condition. The bonding surface should be rough, clean, sound concrete or stone. Oil or film of any sort that may reduce the bond should not be permitted. Loose particles, dust and dirt, should be removed.

2.6.1.2 Anchorage

Concrete repairs applied less than 1-1/2 inches thick will not require anchorage, unless specified by the Engineer. A bonding compound may be specified. Where new concrete greater than 1-1/2 inches thick and less than 4 inches thick is to be placed, 1/4 inch diameter galvanized expansion hook bolts should be spaced not more than 18 inches center to center on vertical surfaces and not more than 12 inches center to center on overhead surfaces. Each bolt should have sufficient engagement in the sound concrete to resist a pull of 150 pounds. When pried from the wall with a bar inserted under the bend of the bolt, the bend should straighten out without pulling the bolt.

The specified spacing of expansion bolts should be based on supporting three times the total weight of suspended concrete and two times the weight of concrete on vertical surfaces. Facilities should be provided for testing the supporting value of the bolts. Each bolt should be set in sound concrete and should be capable of supporting, without loosening.

Any expansion bolt failing to support such load should be reset and tested. Where the thickness of concrete is more than 12 inches, the size, length, spacing and embedment of expansion bolts should be determined or approved by the Engineer. The exposed end of each expansion hook bolt should have a right angle, or greater, bend for engaging reinforcement. No isolated area greater than 2 square feet should have fewer than 3 bolts. Dowels made of deformed steel bars, grouted in, may be used instead of expansion bolts. When dowels are used, the size, spacing and bond capacity shall be the same as that required for expansion bolts. Horizontal dowel holes should be drilled downward on a slope of approximately 1 inch per foot.

2.6.1.3 Placement of Reinforcement

Reinforcement should be securely wired to the anchors. The clear distance from the existing concrete to the first layer of reinforcing should be 1-1/2 times the maximum aggregate size, but not less than 1/2 inch. Cover of reinforcement should meet the requirements of reinforced concrete design.

Shotcrete; No reinforcement is required for shotcrete encasement less than 1-1/2 inches thick unless specified by the Engineer.

A layer of reinforcement shall be provided for each 4 inches (3 inches for suspended encasement) thickness of encasement or fraction thereof. For encasement thicknesses in excess of 4 inches (3 inches suspended), an additional two-way system of reinforcing bars spaced the same as the anchors in both directions should be provided. The last layer of wire mesh should be secured by wiring to the bars.

Each layer of mesh must be completely encased in the shotcrete or concrete which has taken initial set before the succeeding layer of mesh is applied. Mesh extending around corners or reentrant angles should be bent to a template before securing to anchorage and not sprung or forced into position. At corners, double reinforcing mesh should be provided and extended a minimum distance of 6 inches beyond the intersection of the 2 planes. When splicing wire mesh is necessary, a lap of 1-1/2 mesh spacing should be required, wired together at intervals of not more than 18 inches. Where special reinforcement is required for structural strength, engineering plans should be furnished.

Concrete; Reinforcement should meet the requirements of Reinforced Concrete Design, Shrinkage and Temperature Reinforcement.

2.6.1.4 Bonding

When using bonding agents, timing can be critical. Extended exposure of the bonding agent prior to application of the new material may cause failure of the bond.

I. Slurry Bonding

After the bonding surfaces of the old concrete have been prepared as outlined in the above sections, the bonding surface should be kept constantly wet for a minimum of 1 hour immediately prior to application of the bonding coat. In no case should fresh material be applied to a dry surface. The bonding coat should be applied to the damp bonding surface and should be vigorously brushed on to completely fill all surface pores immediately prior to placing the body of the new concrete. The bonding coat should be composed of cement or one part cement to one part fine sand and sufficient water to make a creamy mixture. If required by the Engineer, an approved

shrinkage reducing material should be added. The bonding coat should not be troweled, screeded, disturbed or allowed to dry before the next layer of new concrete is applied.

II. Other Bonding Agent

At locations where positive bond is mandatory, an approved bonding compound should be specified. Since a large variety of bonding products are available, surface preparation and compound application should be in accordance with the manufacturer's recommendations.

2.6.1.5 Hand Patching

Immediately after the bonding coat has been applied, the entire cavity should be filled and finished to true line and surfaced with an approved patching material suitable for hand patching vertically, horizontally or overhead.

Application should be in conformance with manufacturer's recommendations.

2.6.1.6 Cast-in-Place

When restoration or encasement is accomplished by placing concrete in between forms and the old surface by gravity or pressure placement, the forms should have sufficient strength to withstand the pressure of the new concrete without yielding appreciably. The concrete should be proportioned per mix design. The new concrete should completely fill the space provided and present a surface comparable to the original. And the concrete has to be compacted per standard specification of AREMA.

2.6.1.7 Shotcrete

Shotcrete is a mixture of Portland cement, fine aggregate and water, shot into place by compressed air. There are two different processes in use, namely the "dry mix" process and "wet mix" process. The successful application of shotcrete requires experience and knowledge. The use of an experienced, qualified crew is recommended; especially in the nozzleman position. The following methods are practiced for shotcreting.

Dry Mix Method

Shotcrete should be made of a mixture of portland cement and sand in the proportion of one bag of cement for every 4 cubic feet of sand by volume. The amount of sand should be based on dry, loose measurement with proper correction in quantity for effect of bulking due to moisture content. The sand and cement should be thoroughly mixed dry, passed through a 3/8 inch screen before being placed in the pneumatic apparatus, and placed by pneumatic pressure through shotcrete equipment with proper amount of water applied in the mixing nozzle for the necessary placement consistency. The screened sand and cement should be applied on the surface within

one hour after combining them. To avoid voids and reduce shrinkage cracks, shotcrete should be applied as dry as practicable. Suitable prepackaged materials may be used as approved by the engineer. Shrinkage reducing and/or bonding compounds are to be applied as specified by the manufacturer. The air pressure in the pneumatic apparatus should be maintained uniform and not less than 35 psi while placing the mixed material, with necessary increase in pressure for horizontal delivery distances of more than 100 feet or vertical distances of more than 25 feet. The water pressure applied through the nozzle should be not less than 10 psi greater than the air pressure in the shotcrete machine.

Wet Mix Method

The wet mix method varies from the dry mix method only in that the materials are mixed in a vessel prior to pumping the mix to the nozzle, whereas the mixing with water occurs at the nozzle in the Dry Mix Method. This method may therefore require variations in pressure from those required for dry mixing.

Application

Shooting strips should be employed to ensure square corners, straight lines and a plane surface of shotcrete, except as otherwise permitted by plans or approved by the Engineer. They should be so placed as to keep the trapping of rebound at a minimum. Where no separate bonding agent is used, the surface, particularly porous brick, to which shotcrete is to be applied should be thoroughly wet, without free water, to facilitate bond. At the end of each day's work, or similar stopping periods requiring construction joints, the shotcrete should be sloped off to a thin edge. No square joints will be allowed. In shooting vertical surfaces, care must be taken in general to begin the shotcrete area at the bottom and complete at the top.

A sufficient number of coats should be applied to obtain the required thickness. The thickness of each coat should not be greater than 1 inch, except as approved by the Engineer, and should be so placed that it will neither slough nor decrease the bond of the preceding coat. Where a successive coat is applied on shotcrete, which has set more than two hours, the surface should be cleaned and water blasted.

When placing shotcrete, the stream of flowing material from the nozzle should impinge as nearly as possible at right angles to the surface being covered, and the nozzle should be held from 2 to 4 feet from the working surface. Deposits of rebound from previous shooting, whether loose or cemented, should be removed and not covered up. Should any such deposits be covered, they should be cut out and the area reshot.

The final surface of shotcrete should be given either:

(1) A thin finishing or flash coat;

- (2) A screeded finish;
- (3) A rubbed finish; or
- (4) A brush finish, as specified.

2.6.1.8 Preplaced Aggregate Grouting

Grouted Aggregate: - Installed by placing coarse aggregate in the forms, then injecting cement grout through pipes which extend to the bottom of the forms. The pipes are withdrawn as grouting proceeds. The grout forces the water from the forms and fills interstices in the aggregate.

Grout insert pipe system shall be designed and installed to deliver grout to the entire mass. Vent pipes shall be required to relieve entrapped water or air. Sounding wells should be provided to determine the location of grout surface during the grout injection. The coarse aggregate shall be placed in horizontal layers of such maximum thickness as will provide a dense fill without segregation and shall be well compacted. The grout mixture shall be applied under such pressure and at such consistency as will insure complete filling of voids, and grout pipes shall be properly spaced to be consistent with this requirement.

Mineral fillers and admixtures may be added to the grout mixture if approved by the Engineer. The grout mixture required for this class of work necessitates the use of special mixers and agitators to deliver suitable grout in place. This equipment and all grout lines shall be maintained in good operating condition. After every shift or work stoppage, they shall be cleaned of all grout.

2.6.1.9 Tremie Placement

Tremie; when concrete is to be deposited under water by means of a tremie; the top section of the tremie shall be a hopper large enough to hold one entire batch of the mix or the entire contents of the transporting bucket, when one is used. The tremie pipe shall be not less than 8 inches in diameter and shall be large enough to allow a free flow of concrete and strong enough to withstand the external pressure of the water in which it is suspended, even if a partial vacuum develops inside the pipe. Preferably, flanged steel pipe should be used, of adequate strength to sustain the greatest length and weight required for the job. A separate lifting device shall be provided for each tremie pipe with its hopper at the upper end. Unless the lower end of the pipe is equipped with an approved automatic check valve, the upper end of the pipe shall be plugged with an approved material, before delivering the concrete to the tremie pipe through the hopper, which plug will be forced to and out of the bottom end of the pipe by filling the pipe with concrete. It will be necessary to slowly raise the tremie in order to cause a uniform flow of the concrete, but the tremie shall not be emptied so that water enters above the concrete in the pipe. At all times after

the start of placing the concrete and until all concrete is placed, the lower end of the tremie pipe shall be below the top surface of the plastic concrete. This will cause the concrete to build up from below instead of flowing out over the surface thus avoiding formation of laitance layers. If the charge in the tremie is lost while depositing, the tremie shall be raised above the concrete surface, and unless sealed by a check valve it shall be replugged at the top end, as at the beginning, before refilling for depositing concrete.

NOTE: Experience has shown that tremie concrete can be placed as above specified, so that it will flow as much as 50 feet horizontally from the discharge end of the tremie with a slope of less than 3 feet in 50 feet.

2.6.1.10 Pumping Concrete

The pump and all appurtenances shall be so designed and arranged that the specified concrete can be transported and placed in the forms without segregation. The pump shall be capable of developing a working pressure of at least 300 psi and the pipeline and fittings shall be designed to withstand twice the working pressure. Where it is necessary to lay the pipe on a down grade, a reducer shall be placed at the discharge end of the pipe to provide a choke and thus produce a continuous flow of concrete. When the type of pump is such that it discharges the concrete in small batches, or “belching,” a baffle box shall be provided into which the concrete shall be discharged. This box should preferably be of metal, about 2 feet square, with open sides so as to permit the concrete to flow into the forms at right angles to line of discharge. The pipe shall be not less than 6 inches or more than 8 inches outside diameter, and the line shall be laid with as few bends as possible. When changes in direction are necessary they shall be made with bends of 45 degrees or less, unless greater bends are specifically permitted. If greater bends are permitted in special cases, they shall be long-radius bends. The maximum distance of delivery of concrete by pumping shall be 1000 feet horizontally and 100 feet vertically, unless otherwise specifically permitted by the Engineer. (A 90-degree bend is figured as equivalent to 40 feet of horizontal piping. A 45-degree bend is equivalent to 20 feet. A 22.5-degree bend is equivalent to 10 feet.) When pumping is completed, the concrete remaining in the pipeline if it is to be used, shall be ejected in such a manner that there will be no contamination of the concrete or separation of the ingredients. The pipeline and equipment must then be thoroughly cleaned. The pipeline can be cleaned by either water or air. If water is used, a pump shall be provided with a capacity of at least 80 gpm and capable of developing a pressure of 400 psi. Cleaning of the pipe can also be accomplished by the use of a “go-devil” which is propelled through the line by water or air pressure. (The “go-devil” is a dumbbell shaped piece with a rubber cup on each end. The cups are turned toward the liquid, or air, and the seal is the same as in a simple plunger pump.) If water is used, it must be discharged outside of the forms. On

important work duplicate pumping equipment and additional pipe shall be provided to prevent delay due to breakdown of equipment.

2.6.1.11 Curing and Protection

Curing of cast-in-place concrete and shotcrete repairs may be more critical than for concrete in new construction.

Where there is an existing concrete or masonry substrate, shrinkage is limited to the repair material only and cracking may result. In addition, the substrate may pull water from the repair material, reducing the available water in the mix. In the case of shotcrete, which has a low water cement ratio, there is no form to reduce moisture loss further increasing the need for protection from drying during the curing process.

In freezing weather, or when there is likelihood of freezing temperatures within the specified curing period, suitable and sufficient means must be provided before concreting, for maintaining all concrete surfaces at a temperature of not less than 50 degrees F (10 degrees C) for a period of not less than 7 days after the concrete is placed when Type I, IA, II or IIA portland cement is used, and not less than 3 days when Type III or IIIA portland cement is used. The temperature of concrete surfaces shall be determined by thermometers placed against the surface of the concrete. Provision shall be made in form construction to permit the removal of small sections of forms to accommodate the placing of thermometers against concrete surfaces at locations designated by the Engineer. After thermometers are placed, the apertures in forms shall be covered in a way to simulate closely the protection afforded by the forms.

In determining the temperatures at angles and corners of a structure, thermometers shall be placed not more than 8 inches (200 mm) from the angles and corners. In determining temperatures of horizontal surfaces, thermometers shall rest upon the surface under the protection covering normal to section involved. Temperature readings shall be taken and recorded at intervals to be designated by the Engineer, over the entire curing period specified, and the temperatures so recorded shall be interpreted as the temperature of the concrete surfaces when the thermometers were placed. When protection from cold is needed to insure meeting these specification requirements, all necessary materials for covering or housing must be delivered at the site of the work before concreting is started and must be effectively applied or installed, and such added heat must be furnished as may be necessary without depending in any way upon the heat of hydration during the first 24 hours after concrete is placed when Type I, IA, II or IIA portland cement is used, or the first 18 hours when Type III or IIIA portland cement is used. The methods of heating and protecting the concrete shall be approved by the Engineer. Chemicals or other foreign

materials shall not be mixed with the concrete for the purpose of preventing freezing, unless approved by the Engineer.

When heat is supplied by steam or salamanders, covering or housing of the structure shall be so placed as to permit free circulation of air above and around the concrete within the enclosure, but to the exclusion of air currents from without, except that where salamanders are used, sufficient ventilation shall be provided to carry off gases. Special care shall be exercised to maintain the specified temperature continuously and uniformly in all parts of the structure enclosures, and to exclude cold drafts from angles and corners and from all projecting reinforcing steel. All exposed surfaces in the heated enclosure shall be kept continuously wet during the heating period unless heat is supplied in the form of live steam.

From different curing circumstances according to AREMA specification, hot weather curing and wet curing is discussed below taking Ethiopian weather condition in to consideration.

Hot weather curing

The temperature of concrete at times of placement shall not exceed 32 degrees C. When the temperature of the concrete approaches 32 degrees C, special efforts to prevent too rapid drying out must be made.

Continuous wet curing is preferred and shall commence as soon as the concrete has hardened sufficiently to resist surface damage. Curing water shall not be much cooler than the concrete to avoid temperature-change stresses resulting in cracking. Exposed, unformed concrete surfaces shall be protected from wind and direct sun.

Wet curing

All concrete surfaces when not protected by forms, or membrane curing compounds, must be kept constantly wet for a period of not less than 7 days after concrete is placed when Type I, IA, II or IIA Portland cement is used, or not less than 3 days when Type III or IIIA portland cement is used. The wet curing period for all concrete which will be in contact with brine drip, sea water, salt spray, alkali or sulfate-bearing soils or waters, or similar destructive agents, shall be increased to 50% more than the periods specified for normal exposures. Salt water and corrosive waters and soils shall be kept from contact with the concrete during placement and for the curing period. When wood forms are left in place during the curing period they shall be kept sufficiently damp at all times to prevent openings at the joints and drying of the concrete.

2.6.2 SURFACE REPAIRS USING POLYMER CONCRETES AND POLYMER PORTLAND CEMENT CONCRETES

Polymer concrete mixes may contain unpolymerized chemicals that can be hazardous. Particular attention should be given to the ingredients and handling instructions. Many of these materials have a very rapid strength gain, high strengths and high impact capacity. These features make these materials useful where load bearing concrete must be replaced in short time frames. The particular characteristics of the materials vary from product to product. The characteristics of the product should be evaluated before use, (5).

Repair should consist of removal of soft, disintegrated or honeycombed concrete; cleaning and preparing the bonding surface; placing the Polymer Concrete or Polymer Cement Concrete; and finishing to true lines and surface.

Preloading: - Concrete in the repaired area below the neutral axis in prestressed members should be repaired under an externally applied preload. Preload may be applied by means of jacks or a known load.

Surface Preparation, Materials and Application

Surface preparation materials and application should be in accordance with the manufacturer's recommendations.

2.6.3 INTERNAL STRUCTURAL REPAIRS

Internal structural repair of concrete consists of the filling of internal voids and/or restoring the cracked sections to meet original strength with Portland cement grouts or epoxies and reinforcement where required. Care should be taken in the choice of whether to use portland cement grouts or epoxy for injection. The two materials have different characteristics and costs. Cement grouts are generally thicker and considerably less expensive, making them appropriate for applications where large internal voids, large cracks and a pathway to the earth fill behind the member are present. Where high strength is important, cracks are thin and the material can be well contained in the crack, epoxy materials are appropriate, (5).

2.6.3.1 Cement Grouts

Preparation

Before the grouting operation is started, all defective materials should be removed and the entire surface should be thoroughly inspected for points of leakage and indications of voids. Inserts for grouting should be so located and set that the pressure grout will reach all voids and paths of leakage. All defective exposed joints and cracks in the structure should be chipped out, and then thoroughly cleaned of all foreign materials by means of high pressure air or water. The joints, cracks and disintegrated areas should be restored to the original surface with hand pointing or shotcrete.

Grout Holes in Stone

Before drilling of the grout holes is started, the test drillings should be made completely through the masonry to determine the thickness of the masonry. From the test drillings, the proper depth of grout holes should be determined in order that grout holes are not drilled completely through the masonry. Grout holes should be drilled at regular intervals, staggered to include approximately 25 square feet of surface area per hole or at such other locations as may be specified. In cases of arch rings, the holes should be drilled diagonally to intercept the longitudinal joints (parallel to the barrel) and staggered at such intervals as to include approximately 12 square feet of surface area per hole. Holes should be 1-1/2 inches minimum diameter for Portland cement grout and should be drilled to such a depth, and in such manner, as necessary to intercept joints and internal voids, to completely consolidate the structure. Holes which have been drilled completely through the structure should not be used for pressure grouting and these holes must be completely plugged before grouting begins.

On structures, or parts of structures, of one stone thickness, the grout holes should be drilled in such a manner as to intercept the horizontal joints where possible; however, if, due to insufficient clearance, the holes cannot be drilled through the horizontal joints, they should then be drilled so as to intercept the vertical joints. The holes in the courses of masonry below ground line should be drilled diagonally downward at various angles to the natural foundation below the masonry, so that the bottom courses and any underlying cavities, including cavities in or under timber grillages, should be completely filled.

Grout Holes in Concrete

For Portland cement grout 1-1/2 inches diameter grout holes should be drilled to a depth and spacing as necessary to provide maximum dissemination of the pressure grout throughout the repair areas. Prior to pressure grouting, the chipped areas should be restored as previously specified, provisions being made to extend the grout holes through the replacement material for grouting after the exposed surfaces are sealed.

Portland cement Grout Mixture

For stone masonry the pressure grout mixture should consist of one part of cement, one-half part of sand and, if required, an approved type of shrinkage reducing material. The amount of sand to be used in the grouting mixture should be determined by starting the grouting operation with neat cement grout and which will give a free flowing grout. If it is found through application of the above that the addition of sand retards the free flow of the grouting material, the sand should be

omitted. For concrete, the pressure grout should consist of neat cement grout only, and, if required by the Engineer, an approved type of shrinkage reducing materials.

Polymer grouts may be used for concrete or stone masonry, as specified by the Engineer. Other suitable prepackaged materials may be used if approved by the Engineer.

Grouting Procedures for Portland cement Grouts

Grout inserts should be set in drilled holes and the interior voids cleaned with water, prior to the application of the pressure grout. The grout should be pressure induced into the internal voids and joints of the structure to fill them completely.

Grout should be applied by pumping or gravity pressure. Excessive pressure should be avoided to prevent damage to the structure. Grouting should be started at the lowest row of holes and at the hole nearest the center line of structure. If grout appears in adjacent holes at the same elevation, these holes should be temporarily plugged and grouting continued in the original hole until grout appears at the next adjacent hole at the same elevation or at the next line of holes above the one being grouted. When this condition occurs, grouting of the original hole should be discontinued and the grout line moved to the last hole at the current elevation at which grout appeared, and the same procedure followed until all holes in the current line have been grouted, at which time grouting should proceed in a like manner along the next line of holes above, etc., until the entire structure has been completely filled.

During the course of all grouting operations, extreme care should be given to observing the surrounding ground, track subgrade, ballast and the stream bed for the breaking out of grout, and when such breaking out occurs, the grout line should be moved to some other part of structure. Grouting may be resumed in the original location after the elapse of 24 hours. In grouting foundations, pressure grout should be applied to the various holes in rotation. The above program should be followed until the grout is brought up into the masonry. When grouting foundations founded on rock, care should be taken to watch for movement of the track structure caused by the lifting of all or a portion of the structure.

2.6.3.2 Epoxy Injection

Epoxy injection is generally applicable to cracks ranging in width from 0.075mm to 6.35mm. Injection of epoxy into cracks wider than 6.35mm should be approved by the Engineer. Certain members, especially prestressed members, may require preloading during injection. Cold weather epoxy injection may require special procedures and materials.

Preparation

The area surrounding the crack should be cleaned of efflorescence, deteriorated concrete and other contaminants that may be detrimental to adhesion of the epoxy gel. If unsound or deteriorated concrete is located adjacent to the crack, which could prevent the complete injection of the crack, the unsound or deteriorated concrete should be removed prior to the injection. Cracks should be flushed with water under pressure to remove debris and other contaminants.

Injection Ports

Install the injection ports at appropriate intervals to accomplish full penetration of the injection resin. The spacing of the injection ports should be determined by the size of the crack and the depth of the concrete substrate. Injection ports should be designed for the intended use and should be acceptable to the epoxy manufacturer.

Injection ports should have the capability of being positively capped and sealed following the injection work. Care should be taken to prevent concrete dust generated during drilling from plugging the crack. A vacuum attached to the drill and hollow drill bits should be used to remove the dust as drilling occurs and prevent it from blocking the flow of the epoxy.

The injection ports should be installed using one or more of the following methods:

- ✚ Surface Mounted Injection Ports: Center the injection port over the crack and secure in place using the epoxy gel. Completely seal the exposed crack located between the injection ports and other area, as required to prevent leaking of the resins, using epoxy gel. If the crack extends through the member, and is accessible, install telltale injection ports on the opposite side and seal all exposed areas of the crack. Generally, the spacing of the telltale injection ports should be between 12 inches and 24 inches.
- ✚ Drilled-In Injection Ports: The holes should be drilled a minimum of 5/8 inch deep. Exercise care so as not to drill beyond a crack which may be running at an angle to the surface. The injection ports should be inserted into the drilled holes about 1/2 inch, allowing for a small reservoir below the injection port. Secure the injection ports into position using epoxy gel. Seal the exposed crack using the same procedures as described above.
- ✚ Injection Ports Mounted Against a Head of Water: For cracks that have water running from them, use a hydraulic cement (fast setting) to set the injection ports, and seal the crack. After the hydraulic cement has cured, seal the cracks and injection ports by overlapping the hydraulic cement about 1 inch on either side using epoxy gel.

Curing of Epoxy Crack Surface Sealer

Allow all bonded ports and sealed cracks to cure overnight at temperatures of 50 degrees F or above. Should temperatures below 50 degrees F exist, additional cure time may be required. Under these circumstances, it will be necessary to consult the manufacturer for proper cure times. In any event, pressure injection operations should not commence until the epoxy gel has adequately cured and has been deemed capable of sustaining pressures of the injection process.

Materials and Equipment

The following minimum properties should be required of all epoxy used in the repair of the damaged concrete:

- Epoxy injection material should meet requirements of ASTM C881, Type IV, Grade 1, Class A, B or C.
- Epoxy crack surface sealant gel (paste type) should meet the requirements of ASTM C881, Type 1, Grade 3, Class A, B or C.
- It is recommended that the ratio of the components should be between 1:1 and 2:1 by volume, with similar viscosities of components.
- The colors of the components should be distinctly different, and when mixed in proper ratio yield a distinctly different third color.
- All injected epoxies should be wet bonding agents.

Epoxy injection equipment should be the automatic mixing and dispensing type. The equipment should include positive displacement pumps inline pressure gauges, pressure gauges on the mixed materials at the point of injection, and positive connection to the injection ports. The unit should be capable of delivering 125 psi dynamic fluid pressure at the point of injection at a minimum flow rate of 2 gpm. The equipment should indicate when the supply of one component has been exhausted to prevent injection of only a single component.

Injection of Epoxy

After proper curing of epoxy bonded ports and crack surfaces, commence pressure injection operations. Take ratio checks as follows: The mixing head of the injection equipment should be disconnected and the two adhesive components should be pumped simultaneously into separate calibrated containers. The amounts discharged into the calibrated containers simultaneously during the same time period should be compared to determine the mix ratio. After the test has been completed at a 200 psi discharge pressure the procedure should be repeated for 0 psi discharge pressure. The ratio test should be run for each injection unit at the beginning of each day that unit is used. Samples of the mixed epoxy should be taken before commencing work each day, at least once every hour during injection work, and each time the mixing head is

flushed with solvent. Time, dates and curing of the samples are to be noted. The samples before work and after flushing should be from the injection nozzles. Samples during work should be from injected ports.

Commence pumping at the lowest point possible, or first injection port in a line, whichever is applicable. Continue pumping until the epoxy appears at one or more of the next ports in line. When this occurs, stop pumping, cap the port through which liquids were being injected and move up to the next port in line from which liquids were observed to flow. Repeat this operation until all cracks have been filled to refusal. During installation pressures should normally be limited to a maximum of 100 psi. Injection pressures above 100 psi (0.7 MPa) are not recommended as the pressure could cause further damage to the member. If the normal pressures are not sufficient to cause penetration of the materials into the cracks, a lower viscosity epoxy should be considered.

Cure

Allow injected epoxies to cure overnight, or in accordance with the manufacturer's directions for those temperatures prevailing during application. Generally, at temperatures above 50 degrees F, overnight cure is adequate.

Port Removal and Clean Up

After adequate curing of injection epoxy, all ports and the epoxy gel should be ground smooth to eliminate any sharp edges or protrusions. No epoxy materials or injection ports should extend beyond the surface of the existing concrete.

Record Cores

Obtain record cores of sufficient diameter (2 inches to 4 inches), and length (10 inches to 30 inches) from each member to determine the completeness of the injection and the bond. Each core should be identified. All core holes should be filled prior to completion of the work at the structure. Location of the core should be at the discretion of the Engineer.

2.6.3.3 Reinforcement of Cracks

The following methods, to reinforce cracks, are obtained from AREMA

I. Stitching

The integrity of a cracked concrete section can at times be restored by stitching. The process involves the application of steel reinforcing bars (stitching dogs or staples) across a cracked section (see [Figure 2-6-1](#)) on the surface of the members. Where surface appearance is a consideration, the stitches may be installed below the finished surface. The stitching dogs should be of various lengths, spacing and orientation so that a single plane is not overstressed. Their spacing should decrease

near the ends of the crack to avoid stress concentration. The ends of the stitching dogs should be grouted with a non-shrink or expanding mortar so that a proper anchorage is achieved. It should be realized that repairs of this type may cause the cracking to migrate to another portion of the structure.

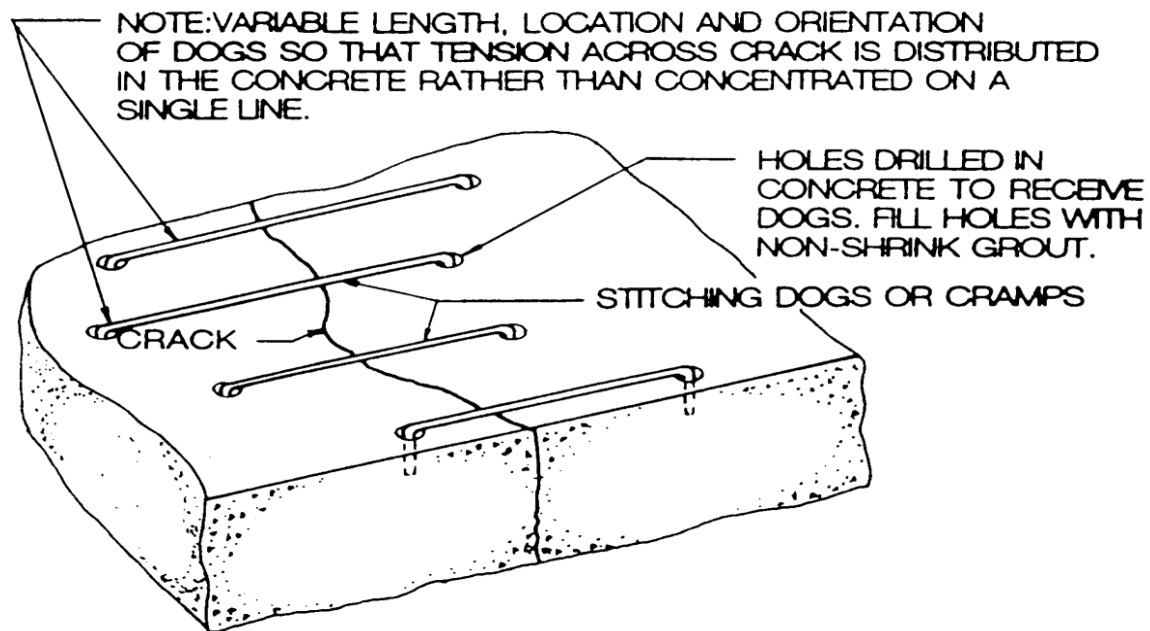


Figure 2.6-1 Repair of Cracks by Stitching

Injection of materials into a crack should not be considered to restore the tensile capacity of the concrete. Where tension is to be transferred across the crack, reinforcement should be installed to carry the tension. The selection of the type of reinforcement should consider where the tension forces are to be transferred. The reinforcement should continue to a point where the existing capacity of the structure can resist the forces, with proper consideration to development of reinforcement.

II. Pinning

Cracks may be immobilized by drilling holes through the concrete so as to intercept the crack and grouting reinforcing into them as specified by the Engineer. (See [Figure 2-6-2.](#))

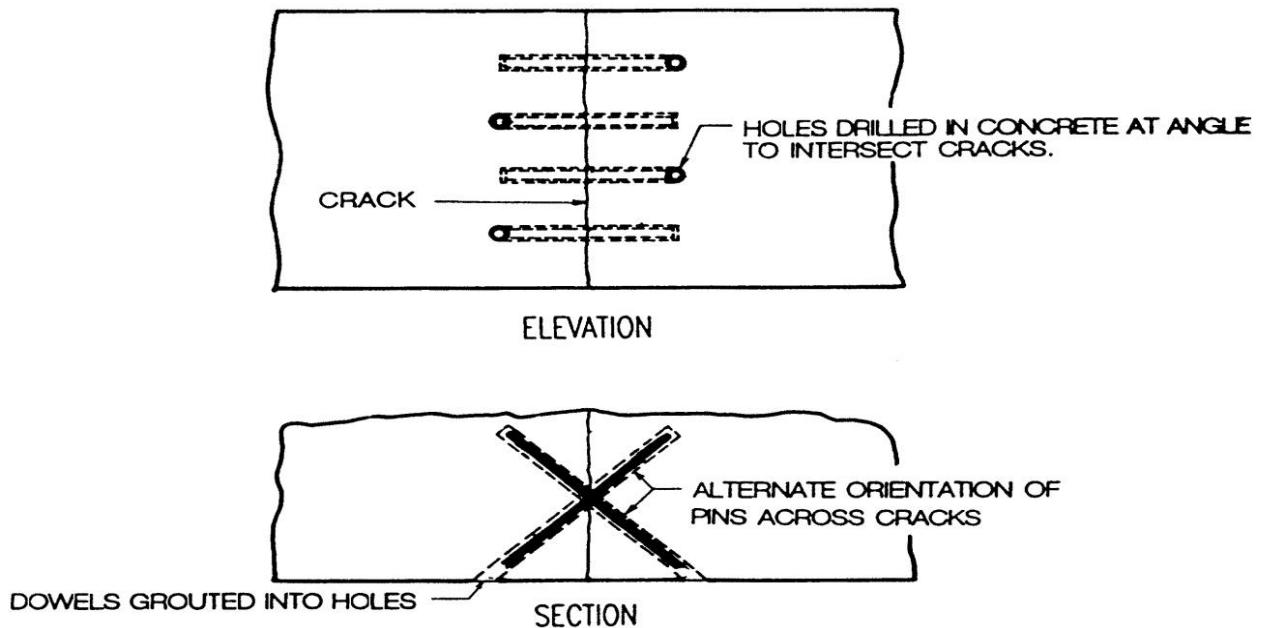


Figure 2.6-2 Repair of Cracks by Pinning

III. External Reinforcing

Placing external reinforcing across the crack and extending for a substantial length can distribute the stresses causing the crack. The stresses at the ends of such reinforcing should be considered to eliminate simply relocating the cracked condition. Tensile stress cracks can be arrested by removing the stresses by tensioning the external reinforcement, thereby compressing the member. Cleaned cracks can be closed by inducing a compressive force sufficient to overcome the tension and to provide a residual compression. The principle is similar to stitching and the problem of crack migration must be considered in this process also. Anchorage is required for the external post-tensioning. Some form of abutment is needed such as a strong back bolted to the face of the concrete.

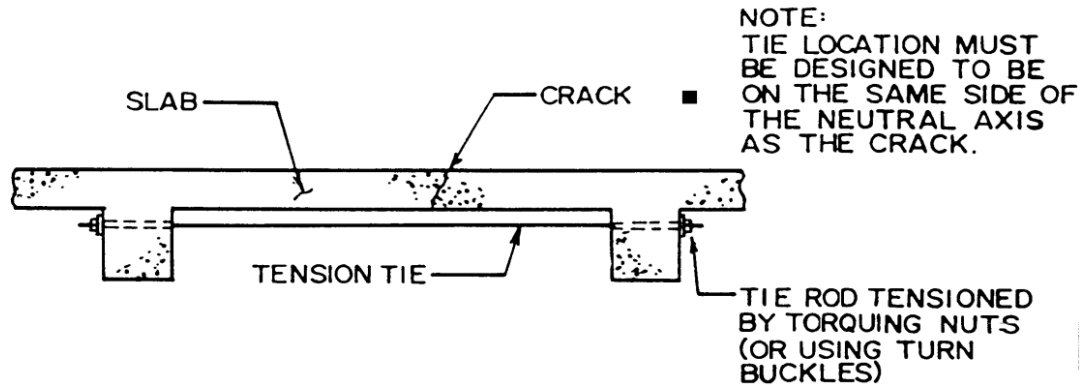


Figure 2.6-3 External Stressing to Correct Cracking of Slab

IV. Banding

Members which are exposed around their perimeter may have steel members placed around them to arrest movement in the crack. These bands should be anchored at regular intervals to the member.

2.6.4 NON-STRUCTURAL CRACK REPAIR

2.6.4.1 Sealing Cracks or Joints

Where there may be movement in the structure, by reason of expansion, contraction or vibration, structural joints subject to leakage may be sealed by using a water stop such as a 10 inch, 16 ounce, cold-rolled copper expansion plate, preformed along the longitudinal centerline of the copper to produce a modified “V”-shape, or a half round 2 inches diameter PVC pipe, secured in place with straps and anchors, or similar noncorrosive materials with the necessary flexibility as approved by the Engineer, (5).

The concrete or stone should be chipped out sufficiently to provide space for installation of a watertight joint between the water stop and concrete and also for a channel for water seepage, properly drained at the base of crack or joint, or as otherwise specified by the Engineer. The expansion joint between the finished surface and the water stop should be filled with a flexible joint sealing material. The patch should be reinforced and placed as previously specified. Non-leaking cracks or joints where movement in the structure by reason of expansion, contraction or vibration is apparent, may be sealed with a flexible joint sealing material. Where it has been determined that no movement exists, a rigid compound can be used.

2.6.4.2 Surface Crack Repairs

Routing and sealing may be used to make surface crack repairs where surface appearance is not a consideration.

This method consists of enlarging the crack along its exposed face with a concrete saw or hand pneumatic tools to open the crack sufficiently to receive the sealant. Minimum surface width should be 6.35mm. The surface of the routed joint should be clean and dry before placing the sealant. Sealant and installation should be according to the sealant manufacturer's recommendation.

2.6.5 REINFORCEMENT SPLICES

Severely damaged reinforcing in members may be repaired by splicing. Where damaged reinforcement is spliced, the repairs should be designed so that there is no change in stress due to the damage. Preloading of the member may be required to achieve this, depending on the repair method used. The strength of the splice should meet the required ultimate strength of the member, (5).

2.6.5.1 Internal Splicing of Prestressing Tendons or Conventional Reinforcement

Strands or bars should be spliced by attaching a coupling device to the severed ends. The ends should be trimmed to sound, undamaged material prior to splicing. The strand or bar should be stressed by tightening the coupling device until the desired stress is reached. Consideration should be given to fatigue and space limitations in selecting this method of repair for multiple strands or bars. Splices in conventional reinforcing may be accomplished by lap splices. Sufficient bar length must be exposed for development of the splice and preloading may be required.

2.6.5.2 External Post Tensioning

External post tensioning should consist of threaded bars or prestress strands applied to the member. The applied post tensioning force should be calculated based on the internal stresses required under live and dead loads. Location of the anchorage for the post tensioning system should be based upon the stresses at the transfer of load into the original member. Anchorages typically consist of corbels attached to the concrete with expansion bolts and bonding agents.

Care should be taken to ensure that existing tendons or bars are not damaged in the placement of anchor bolts.

2.6.5.3 External Metal Splice Sleeves

Metal sleeve splices consist of bonding steel plates across the damaged area with sufficient bond length to develop both the damaged reinforcing and the metal plates. Concrete surfaces in the bond area must be clean. Metal plates are galvanized steel with the contact surface scored vertically by wire brushing. The plates are bonded to the concrete by pressure injection by epoxy resin. A 1/16 inch gap should be left between the concrete and the steel. The gap should be maintained by use of metal spacers. The edges of the splice sleeve should be bolted to the concrete taking care

2.6.6.1 Crack exist with no significant section loss and no tendon damage

Cracks should be repaired by epoxy injection. Cracks in the precompression zone should be repaired under preload if live load alone applied to the section produces a tensile stress exceeding the bond strength or the base concrete allowable tension.

The application of preload should be investigated in conjunction with concrete repairs. Applying preload prior to epoxy injection can result in live load stresses no greater than original.

2.6.6.2 There is minor section loss, but no tendon damage Minor concrete nicks, spalls, or scrapes (*Adequate cover remains and there was not significant section loss*)

Clean and seal minor defects with penetrating sealer to prevent moisture intrusion.

The application of two coats of a penetrating sealer is recommended to prevent moisture intrusion or other corrosive elements to the prestressing steel.

Gouges across bottom flange with loss of cover (No Significant Section Loss)

Gouge patches should attain required strength prior to removal of preload.

Girder designed for zero tension in bottom flange concrete under live load. Clean and seal minor defects with penetrating sealer to prevent moisture intrusion. Additional protection may be provided by patching with an acceptable concrete patching material.

Girder designed for tension in bottom flange concrete under live load, Clean and seal minor defects with penetrating sealer to prevent moisture intrusion. If patching is used to provide additional protection, the patch should be applied under preload. If under preload it is found that a crack has propagated from the gouge either the cracked concrete should be removed or the crack repaired by epoxy injection. The gouge should be patched with an approved concrete patching mortar and the preload removed after the patch has reached adequate strength. (This applies to existing girders that may have tension in the bottom flanges. Current standards do not allow this design).

2.6.6.3 Shattered concrete and significant section loss, but no tendon damage

Replacement of lost concrete should be executed under preload if the repaired section would be subject to tensile stresses when live load is applied. In preparation of the surface for placement of repair material and in removal of damaged concrete extreme care must be taken to avoid any damage to prestressing tendons. Tendons should be chemically cleaned.

2.6.6.4 There is section loss and tendon damage

Repairs should be designed so there is no change in stress due to the damage. Preloading the member may be required to achieve this end. The ultimate strength of the splice should always meet or exceed the required ultimate strength.

Impact damage may cause sweep (lateral curvature in the bottom flange) or abrupt lateral curvature caused by the combination of torsional and transverse flexural stress induced by tendon eccentricities when strands are broken on one side of a girder. It may be possible to jack the tension flange into alignment and hold it using an additional diaphragm.

Few Tendons Are Damaged

Tendons should be repaired by internal splicing. After tendons are repaired the concrete is repaired, usually under preload. Repair of more than 2-4 tendons by this method is usually difficult. One advantage of internal strand splices is that they restore strength internally. Combined with preloading, the girder should be restored to its original condition.

Several Tendons Are Damaged (6-8 Tendons)

The span may be repaired with external post-tensioning. Due to the externally applied tensioning, preload may not be required. The damaged concrete may be repaired utilizing appropriate patching methods. Protection of the posttensioning system must be considered.

Jacking corbels may be used to secure the ends of post-tensioned rods. The strength of the corbels will generally control the number of severed strands that can be spliced by post-tensioning. Between corbels, the post-tensioning rods should be grouted after post-tensioning inside of a conduit to protect the rods.

Multiple Tendon Damage with Large Section Losses

Repairs can be accomplished with metal splice sleeves. The damaged concrete areas within the splice area are filled with concrete. Preloading is not required if the stresses at the top and the end of the sleeve are within the allowable.

The use of metal splice sleeves does not restore prestress unless preloading is used. Intermediate cracks which are covered by the splice should not reduce structure integrity or durability.

3. MAINTENANCE OF RAILWAY BRIDGES TO THE ETHIOPIAN PRACTICE

3.1 RAILWAY BRIDGES IN ETHIOPIA

3.1.1 THE OLD ETHIO-DJIBOUTI RAILWAY NETWORK

Short History

Ethiopia is one of the first countries to start railway network in Africa. It was during Emperor Minilik II that the first Ethiopian Railway is constructed between the end of nineteenth century and the beginning of twentieth century. The construction of the railway network started in 1897 from Djibouti and in 1901 it started to give first commercial service from Djibouti to Dire Dawa. The line reached at Addis Ababa in 1917 by the Compagnie de Chemin de Fer Franco-Ethiopien de Djibouti after facing different challenges which hindered the progress of the project. The railway is 1000 mm gauge and diesel traction. It is owned and administered by the governments of Djibouti and Ethiopia. The network suffers from old-age, lack of spares, high operating cost, worn out track, no Locomotives, low capacity. Now days the network is giving service only between Djibouti and Dire Dawa after rehabilitation is made in 2007 by Italian company, (8).

Bridges and Culverts of the Old railway Network

The old railway network uses narrow gauge (gauge length of 1000mm) track system which implies the Bridges were also designed for metric (narrow) gauge railway system. With respect to material of construction the types of bridges are predominantly steel bridges with spans ranging from 4.00m to 150.00m. But most of the culverts are concrete culverts. The steel bridges are all together about 217 in number.

There was no major accident of failure of bridge throughout the history of the railway bridges. This is due to proper inspection and maintenance activities taken by the department of infrastructure. The Department of Infrastructure had been responsible for the operation and maintenance/repair of the network guided by the maintenance policies and procedures thus implementing the preventive and corrective maintenances methodologies along with their basic corresponding activities. The inspections and maintenances have, more or less, been taken regularly; so there was no failure to the superstructure as such because of the stress due to passing (dynamic) load on the steel structure.

But there were previous devastating incidents to most of the bridges between Meiso and the border with Djibouti by explosives during the Ethio-Somalia War where

eventual rehabilitation actions to restore the bridges at least temporarily were taken, although not to a high level and that even today some signs of the then events are visible.

There have also been frequent sub-structure failures due to flooding; to the extent of the wash away of the parts or the whole, (15).

3.1.2 THE CURRENT RAILWAY SYSTEM OF ETHIOPIA AND ITS BRIDGES

Background of the new Railway system (14)

The Government of the Federal Democratic Republic of Ethiopia (FDRE) has for many years recognized the need to improve and expand the existing transportation network throughout Ethiopia. In its national Five Year Plan (2010/11 - 2014/15), referred as the “Growth and Transformation Plan” issued in September 2010, FDRE has confirmed its commitment to improve the country’s transportation infrastructure with the proposed development of a standard gauge railway network for Ethiopia. The target for construction of new rail infrastructure during this period consists of a 2046 km National Railway Network of Ethiopia (NRNE), which will be constructed in seven corridors, and a 34 km Light Rail Transit (LRT) system for the capital city of Addis Ababa.

The priority corridor for the NRNE will be the construction of a new standard gauge railway line from Addis Ababa (Sebeta) to Djibouti (Djibouti and Doraleh Ports), which will have an estimated length of 756 km (656 km inside Ethiopia and 100 km inside the territory of the Republic of Djibouti). This will replace the dysfunctional existing line between the capital cities of Ethiopia and Djibouti. Both the NRNE and LRT new standard gauge railway infrastructure will utilize the vast renewable energy resources which are also available in Ethiopia, and for which major infrastructure projects are also being developed in parallel by FRDE as part of its ongoing GTP.

The following are general important information about Ethiopian National Railway Network (ENRN) and Addis Ababa Light Rail Transit (AALRT)

ENRN

- 5000 km of national railway line
- Standard Gauge (1435 mm)
- Electric Traction
- High capacity (25 ton/axle)

- High speed (120 -160 km/hr for passenger and 80 -120 km/hr for freight), though later reduced
- Concrete sleeper (160cm X20.5cmX22cm)

LRT

- 34km of Fully electrified LRT for Addis Ababa
- Standard Gauge (1.435 meters) and double track for the whole route
- Capacity: 80,000 PPH (Passenger/hr)

Bridge and culverts of the current Railway Network

Bridges and culverts are one of the major structures of the new Ethio-Djibouti railway line and Addis Ababa Light rail Transit, which are under active construction.

The LRT has two main lines, the East-West (E-W) and the North-south (N-S). E-W route has the total length of 17.4Km, 2.73Km of which are elevated section, BRIDGES. Including elevated sections for stations which are about 340m length, the total elevated structure has the length of 3.07Km, which takes 17.644% of the whole route. N-S route has the total length of 14.17Km (2.8 kilometers of shared section are not included), 2.345m of which are elevated road section. All the elevated stations have the total length of 240m. And the total elevated structure has the length of 2.585m; this takes 18.243% of the whole route. The Addis Ababa Djibouti railway line also has a vast number of bridges, more than 180 major and medium bridges are under construction through the line.

Based on material of construction the current railway bridges under construction are Concrete bridges. Most of the Girder and Decks are prestressed reinforced structures where as the piers are reinforced cast in place concrete, (14).

3.2 CAUSES OF DAMAGES AND CLASSIFICATION IN ETHIOPIAN PRACTICE

3.2.1 DEFECTS AND DAMAGES OF CONCRETE BRIDGES

The following defects have predominantly existed in Ethiopian Bridges, according to ERA, (16).

I. Cracking

Cracking is linear fracture of concrete. Concrete is a brittle material by nature, so reinforced concrete structures are destined to suffer cracking. Since concrete is compressive material, its strength to resist tensile strength is weak. That's why cracking is one of the common defects of Ethiopian concrete Bridges. However, not all types of concrete cracking pose a problem; some are detrimental to structures but others not. Damaging cracking includes those types that cause water leakage due to cracking throughout the member, excessive deflection, aesthetic concerns and defect to the durability of the structure. Cracking can be an important indicator of deterioration taken place in concrete and possible corrosion of reinforcement steel depending on the size, extent and location of cracks.

Cracks can be classified structural and Non-structural

- ✚ **Structural Cracks:-** are those cracks which result from insufficiency of the section to withstand the flexural, shear, settlement and other stresses developed in the section due to dead and live loads applied on it. This type of cracks occurs in Ethiopia in areas where bridges are overloaded than their load carrying capacity (design load); this crack is common on Bridges which exists from Adama to Djibouti. Structural cracks caused by loads can be divided in to flexure and shear cracks. **Flexural cracks** are vertical and start from maximum tension zone and proceed towards the compression zone. **Shear Cracks** are found near the bearing area and begin at the bottom of the member and extend diagonally upward. Structural cracks will usually be substantial in width, and the opening may tend to increase as a result of continuous loading and creep of the concrete.
- ✚ **Non structural cracks:-** are cracks which result from workmanship problem, shrinkage of concrete and other minor cases. They can be categorized as caused by temperature, shrinkage and mass concrete cracks. These cracks are relatively minor and generally do not affect the load carrying capacity of the member. They can however provide openings for water and contaminants, which can lead to serious problem.

II. Delaminating and Spilling

Delaminating occurs when layers of concrete separate at the level of outer most layer of reinforcing bars. Delaminated areas give a hollow sound when tapped with a hammer. Expansion beneath the surface of concrete, for example as a result of reinforcement corrosion, produces tensile stress, which exceed concrete strength and areas of the concrete surface break away, which is delaminating. The resulting depression by delaminating is called spill. A spill is a roughly circular or oval depression in the concrete resulted from separation and removal of portion of surface concrete. Spilling means the breaking away of concrete flakes. Separation of concrete flakes defects the structure.

III. Spoiling, Wearing and Scaling

Spoiling is loose of quality appearance of the concrete due to many external reasons. Wearing is removal of concrete material from the surface of the concrete.

Scaling is gradual and continuing loss of surface mortar and aggregate over an area of concrete. Improper finishing and curing operations and materials cause surface scaling. If additional water is added at the time of delivery of concrete in order to increase the workability of concrete it causes an increase in the water cement ratio of concrete leading to a reduction in strength and durability of concrete. This can lead to defects such as scaling and dusting.

III. Honey comb and void

Honey comb is voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles. This may be due to leakage of mortar through formwork joints which is not well prepared. Honey combing occurs where the spaces between coarse aggregate particles are inadequately filled, with the result that the hardened concrete has an open structure. Honey combing is always an aesthetic problem, and depending on the depth and extent may reduce both durability performance and structural strength of the member.

IV. Bridge Scour

Bridge scour is removal of sediments such as sand and rocks from around bridge abutments or piers. Bridge scour is one of main causes of bridge failure in Ethiopia. Bridges in the southern and western parts of the country has damaged from scour and related hydrological problems in the past. Scour occur when floodwater passes around obstructions in the water column. As the water flows around an object, it must change direction and accelerate. Soil can be loosened and suspended by this process

or waves striking the object, and be carried away. Piling, piles capes, columns, walls, footings, slabs and other objects under a bridge can lead to localized scour. Scour effects increase with increasing velocity and turbulence and with increasing soil erodibility.

V. Efflorescence and Water leakage

Efflorescence is defect of concrete bridges, white deposit on concrete caused by crystallization of soluble salts (calcium chloride) brought to the surface by moisture in the concrete. Efflorescence mainly appears on expansion joints and between approach road and the bridge due to the area prone for water leakage. Water leakage is unwanted movement of water through cracks or voids of concrete structure of the bridge, which may lead to efflorescence and other defects. Serious and wide range of water leakage may progress and cause a reduction in loading capacity; therefore it is critical to take proper maintenance measure after evaluating the cause.

VI. Reinforcing steel Corrosion: - is destruction of reinforcing steel by chemical action; a process by which the steel is affected progressively by chemical action, reaction with water and oxygen or with salts.

VII. Damage to guard rail/Parapet: - is destruction of the guard rail due to external factors, such as accident.

3.2.2 CAUSES OF CONCRETE DEFECTS

Defects that appear on the surface of concrete during construction or within a relatively short time after completion are usually caused by poor quality materials, improper mix design, poor workmanship and curing procedure. It is often difficult to establish the causes of defects when the visible evidence gained from inspection is limited. Design and construction records may assist the maintenance activity they are available. Structures may overstressed by conditions outside the control of the designer and contractor, such as overloading, changes to the flow of river, failure of adjacent structures and various natural causes.

In the following paragraphs causes of defects of bridges to the Ethiopian practice is discussed, (16).

1. Causes for Concrete Cracking

✚ Causes of structural cracks

One of the basic causes for structural cracks in Ethiopian high way Bridges on reinforced concrete member is Heavy traffic loads and increment of the load acting frequencies that may occur through time after construction of bridge structures. Overloading is the most common cause to damages of bridges to the eastern part of Ethiopia. Due to it is the only commercial line of the country, the Addis Ababa Djibouti road is suffering with heavy and frequent traffic loads, which lead to the bridges of the line to flexural and shear cracks. Insufficient structural design and errors in interpreting the drawings during construction, large impact forces caused by defect of road surfaces and aging of concrete are also main causes of the structural cracks.

Causes of Non structural cracks

Shrinkage of concrete due to lack of proper curing mechanism, defect on concrete surface formwork removal, absence of proper expansion joints, other workmanship problems are among the most common causes of non structural cracks. Some of general causes of this type of cracks are variation of temperature and moisture, differential settlement of foundation, lack of curing, corrosion of rebar for lack of covering, chloride damage and carbonation.

2. Causes of delaminating and concrete Spilling, Peel off

The major cause of delaminating is expansion of corroding reinforcement bars. This is commonly caused by intrusion of chlorides or salts. An inadequate drainage system can severely limit the life span of concrete deck to deterioration by leakage of corrosive deicing mainly.

Spill can be caused, by corroding reinforcement and friction from thermal movement due to which reinforcing steel is often exposed. Insufficient cover is hardly detected at the time of casting concrete, however the reinforcement bar will gradually rust and swell and concrete cover start to be peeled off. Expansion beneath the surface of concrete, for example as a result of reinforcement corrosion, produces tensile stress, which exceed the concrete strength and areas of the concrete break away.

3. Causes for Spoiling, Wearing and Scaling

Wearing and abrasion of concrete surface are caused by being exposed to traffic and water flow. It is a result of external forces acting on the surface of concrete member. Some aggregates used in concrete react chemically with high alkali cements, causing disruption of the concrete. This form of spoil is called alkali reaction and results in extensive cracking.

A comprehensive evaluation factors responsible for concrete surface scaling according to Ethiopian case are

- Quality of concrete materials, proportions and properties
- Poor construction practices, finishing, curing, drainage, surface treatment
- Concrete maturity
- Deicing salts, salt type, concentration and timing exposure on scaling

4. Causes for Honey Comb and Void

Honey comb forms when mortar fails to fill voids between coarse aggregate particles. The most common causes of honey combing are

- Use of dry mix that was not properly consolidated, mix design which do not provide workable mix
- Compaction not having been adequate to cause the mortar to fill the voids between the coarse aggregate
- Loss of cement grouts b, leaking of cement paste, where form work is inadequately sealed
- The member shape and detailing or placement of reinforcement compounds
- Uncontrolled setting rate, slow placement rate and high concrete temperature

5. Causes of scouring

General scour occur over a long period of time and is initiated by an alteration in channel flow patterns. This mainly caused by a change in supply of sediments to a large area.

One of major causes of scour is Channel Constriction. Typical situations which lead to scour problem are sediment deposits, Pier scour, loose riprap, Lined banks, Horizontal and Vertical channel constrictions that creates a high velocity, flooding, protruding abutments, debris and river beds. Most foundation movements are caused by movement of the supporting soil. Soil deformations are caused by volume changes in the soil or by a shear failure. Slope slides and bearing failures are good examples of shear failure.

Another cause to scour is poor design, inadequate study of the area of bridge. Waterways should be inspected in order to determine whether any condition exists that could defect to the bridge or the area surrounding the bridge.

6. Cause of Water Leakage

Water leakage under concrete may be caused due to cracks, voids, concrete porosity, absence of impermeable wearing course, defect to joint sealants or blockage of

drains. Accumulation of debris compounded by design oversights is principal cause for surface drainage inlet-clogging. The ponds and puddles of water that form on the bridge deck pose the problem which constitute a safety hazard and can cause extensive deterioration problem. Down spouts and horizontal pipe-runs, which are poorly designed with inadequate slopes and sharp directional changes at elbows, are conducive to plugging drains.

7. Cases of Reinforcement corrosion

Reinforcement corrosion may come from pitting, loose rust, mill scale, paint, oil, grease, adhering earth, ice or any other materials that may impair the bond between the concrete and the reinforcement. Reinforcing steel corrodes either where cracking induces the corrosion of reinforcing steel or where carbonation or salt defect corrodes reinforcing steel. Cracking which happens before reinforcement corrosion initiates reinforcement corrosion due to leakage of water which reacts with the steel to produce rust (iron oxide), in reverse the corrosion of reinforcement steel causes cracking due to less tensile resistance of the concrete. Salt defect of reinforcement is caused by intrusion of Chloride ions, which can reach the reinforcing steel through cracks or diffusion within the concrete voids.

8. Causes for Guard rail, parapet Damage:

Accident is one of the main causes of guard rail damage. In Ethiopian cases Bridges on curved areas are more prone to accidents of collision, misalignment and overturning and results on demolition of the guard rail and other structures.

The above discussed causes of concrete defects can be generally categorized as follows:

Design error;

- Specification of insufficient concrete cover to reinforcement, which results in cracking and spalling;
- Failure to allow for effects of creep
- Inappropriate structural form
- Incorrect movement joint spacing and location
- Drawing or/and detailing errors
- Poor detailing of expansion joint
- Omission of design consideration
- Poor drainage detail which results leakage or clogging

Construction Errors

- Inadequate supervision during construction
- Incorrect concrete mix proportions

- Failure to adequately support reinforcement, resulting in movement during concreting
- Failure to provide the specified concrete cover to reinforcement
- Insufficient compaction of concrete
- Inadequate form work support
- Lack of curing concrete elements
- Generally poor material and workmanship

External effects

- Accidental damages such as collision, falls, fire,
- Overloading or increased traffic levels
- Natural Phenomena like flood, subsidence, heave, earth quack
- Chemical actions of sea water, polluted water de-icing salt, air born pollution
- Failure of adjacent structures and influence of bridge approaches

Note: War could be one of the external causes for the damage of Bridges, even complete failure of the bridge. The practical example in Ethiopian case is there were devastating damages to most of the railway bridges between Meiso and the border of Djibouti by explosives during the Ethio-Somalia war in 1970th, (15).

3.3 DAMAGE IDENTIFICATION IN ETHIOPIAN PRACTICE

In this section damage identification in Ethiopian practice in the past is assessed. Ethiopian roads Authority practice of damage identification is studied to see possible application to railway bridges, (17).

Bridge damage Identification in Ethiopia according to ERA is based on *Inspection* and inspection results. The inspection technique used is visual inspection and using local tools. Advanced Inspection techniques, Non-destructive testing and destructive load testing, has not been used for Ethiopian concrete Bridges.

Damage identification by inspection is the initial and major step of bridge management system of ERA. Ethiopian roads Authority have a department called “Bridge Management Branch” which is responsible for performing all activities regarding bridge management and maintenance. The branch has developed manual for bridge inspection which helps to inspect, record results and repair based on the result found using software called “ERA-BMS”. In the following paragraphs Inspection trend, classification, rating method and other related concepts are described according to bridge inspection manual of Ethiopian roads Authority.

Bridge inspection is an action to assess correctly the bridge conditions in a standardized manner and is the most important element in the Bridge Management Cycle that is the systematic maintenance process of inspection, assessment, selection of measures, prioritization and repair to keep bridges in satisfactory levels. The purpose of bridge inspection is not simply to collect the latest information about the present bridge conditions but, more importantly, it should be understood that the inspection is to provide essential information for Bridge Management Cycle. The road administration sometimes must take the critical decisions such as closure and reconstruction of the bridge based on the inspection results.

Bridges cannot keep good conditions forever. Bridges start deteriorating soon after their completion because of the actions of weather, traffic and other various causes. If the bridge inspections are not carried out at all lots of bridges would collapse frequently across the county and would invite social and political troubles without doubt. One bridge collapse can cause casualties and require considerable amount of money and time to reconstruct the new bridge. It is important to understand that a bridge consists of lots of members and elements that have different durability in nature due to the difference of materials, locations, and sensitivities against weather and loads. This indicates that in order to keep the appropriate functions of bridges expected in design, appropriate maintenance is

essential in response to the actual deteriorations. Service life of a bridge is usually expected as long as fifty years and longer.

To do bridge inspection in the standardized manner can provide:

- Basic information to assess the safety of bridges
- Data and information to all the activities of Bridge Management Cycle
- Information on any potential trouble spots
- Information on a consistent maintenance strategy
- Information on the effect of any changes in traffic loads
- Information on the behavior of repair and new strengthening techniques
- Hard facts on the results of new constructions and measure

3.3.1 CLASSIFICATION OF INSPECTION

According to bridge inspection manual of there are three types of inspection in terms of purposes and frequencies, (17):

1. Regular Inspection

The regular inspection is a planned, periodic, and superficial inspection to confirm the structural safety and safe traffic condition as frequently as possible. It is also expected that the regular inspections can detect the major/serious defects and damages as soon as possible. The inspections are to be carried out by not only bridge inspection staff but also road inspection personnel.

Inspectors must develop the annual plan for the regular inspection work to cover all the bridges in the District to meet the frequency requirement of once a year.

2. Major Inspection

The major inspection is a planned, periodic inspection to be conducted once in every three years by close visual inspection method. The results of the major inspections are core information of the Bridge Management System and bridge inspectors of the District must conduct the major inspections. Inspectors must develop the annual plan for the major inspection work to cover one third of the bridges in the District to meet the frequency requirement of once three years.

3. Emergency Inspection

The emergency inspection shall be conducted when needed. After natural disasters and severe traffic accidents the emergency inspection may be needed. The purpose of this inspection is to provide information on structural safety and safe traffic condition. If needed, bridge inspectors must do the emergency inspection without delay so as to judge necessity of emergency measures.

The classification is summarized as follows.

Table 3.3-1 Bridge Inspection classification according to ERA

Classification	Type	Purpose	Frequency	Method	Inspector
Regular Inspection	Periodic Superficial	Assessing traffic safety and structural safety. Finding major defects.	Once a year	Visual inspection from ground level. Report on check list	Road inspector, or Bridge Inspector
Major Inspection	Periodic Detail	Assessing conditions of all the structural components.	Once in 3 years	Close visual inspection with equipment. Detailed report with damage ratings	Bridge inspector or Bridge Engineer
Emergency Inspection	Non-periodic	Assessing traffic Safety and structural safety	When Needed	Visual	Bridge inspector Or Bridge Engineer

3.3.2 PROCEDURE OF INSPECTION

The standard inspection procedure is as shown below. However, sometimes inspectors may follow the different procedures due to actual traffic conditions and seasonal conditions. Before going out for inspection, the inspector shall check the availability of past inspection records using ERA-BMS and obtain the necessary information on the target bridges. Inspectors shall bring the necessary equipment to manage the appropriate inspections, (17).

- 1) Arrive at the target bridge
- 2) Park at the safe space with necessary traffic safety measures
- 3) Check the location data and name of the bridge using the required BMS data
- 4) Check the GPS indication

- 5) Examine the entire carriageway condition from the abutment side(s)
- 6) Examine the approach road section
- 7) Examine the expansion joint
- 8) Examine the pavement
- 9) Examine the parapet and railing
- 10) Examine the drainage inlets
- 11) Examine the surrounding land condition
- 12) Move down to underneath the bridge (channel, opening)
- 13) Examine the abutments
- 14) Examine the bearing(s) at the abutment(s)
- 15) Examine the piers
- 16) Examine the bearing(s) at the piers
- 17) Examine the high water level
- 18) Examine the river condition (river bank, sedimentation)
- 19) Examine the girder(s)
- 20) Examine the deck
- 21) Take the pictures of defects/damages
- 22) Check all the inspection records are correctly filled in the standard form
- 23) Leave the bridge

3.3.3 COMMON DEFECTS AND DAMAGES TO THE ETHIOPIAN CONCRETE BRIDGES

ERA bridge management branch has developed a manual which shows types of defects and most prone components of the bridge to which the defect could appear based on past experience. The list could help the inspector and the bridge Engineer to suspect most prone components for Ethiopian concrete bridges. This could be important to the railway concrete bridges too. The table below shows the typical defects/damages frequently observed in reinforced girder concrete girder bridges in Ethiopia, (17).

Table 3.3-2 Common defects to the Ethiopian concrete bridges

Component	Defect/Damages	Principal Causes
Girder	Flexural Crack	Excessive load
	Shear Crack	Excessive load, poor design
	Spilling, De lamination	Insufficient cover, Excessive load
	Re-bar Exposure	Insufficient cover, Re-bar corrosion, Concrete deterioration
	Material Deterioration	Poor construction
	Honey come	Poor construction
	Water leakage	Excessive load, poor design
Deck Slab	Flexural Crack	Excessive load, poor design
	Spilling, De lamination	Insufficient Cover, Excessive Load
	Re-bar Exposure	Insufficient Cover, Re-bar Corrosion, Concrete Deterioration
	Material Deterioration	Poor Construction
	Honeycomb	Poor Construction
	Water Leakage	Excessive Load, Poor Design
Bearing	Break Failure	Poor design, poor construction, Abrasion
	Dislocation	Poor design, poor construction
Expansion Joint	Abrasion	Aging
	Distortion	Aging
Pier, Abutment	Crack	Poor construction
	Spilling, De lamination	Insufficient cover
	Re-bar Exposure	Insufficient cover, Re-bar corrosion, concrete deterioration
	Material Deterioration	Poor construction
	Settlement, Inclination	Poor design, poor construction, Earth pressure
	Scouring	Poor design
Parapet, Guard rail	Deformation	Vehicle collision
	Break Failure	Vehicle collision
Clearance	Sedimentation	Poor planning, Lack of maintenance

Superstructure

Inspectors shall examine the defects/damages of girders, deck slab, and other transverse beams, deterioration of materials, straightness and flatness of members, abnormal noise and vibration, and deflection of girders.

Substructure

Inspectors shall examine the settlement and inclination of substructures, defects/damages of materials, deterioration of materials, bulging and missing of masonry materials, and scouring.

Ancillary

Inspectors shall examine the defects/damages of pavement, expansion joints, drainage, railings/parapets, and bearings.

Approach

Inspectors shall examine the settlement of backfill behind the abutments, displacement and erosion of embankment, and surrounding land condition.

Note: Inspectors shall examine the water level, sedimentation of rocks and sand, other debris, vegetation, rip-raps, and condition of levee.

3.3.4 RATING METHOD

Every defect and damage found shall be rated based on the following rating system. Because the rating system reflects the specific conditions and desirable interventions taken into account the present situations in Ethiopia, inspectors shall strictly follow the rating (ranking) description table, (17).

Table 3.3-3 Ranking of damages to the Ethiopian Highway Bridges

Rating (Ranking)	Condition	Desirable Intervention
A	Serious/major damages, defects, and deterioration causing reduction of load carrying capacity	Urgent repair
B	Major damages, defects, and deterioration affecting reduction of durability	Repair but not urgent.
C	Minor/no damages, defects and deterioration.	Routine maintenance.

3.4 MATERIALS AND TOOLS FOR REPAIR OF CONCRETE BRIDGES IN ETHIOPIA

3.4.1 MATERIALS USED FOR REPAIR OF CONCRETE BRIDGES

Materials for repairing cracks, voids, peel off and de lamination on concrete, (16).

- ✚ **Mortar and concrete:** - the material needed for maintenance by dry-packing is a slurry bond and a low water-content mortar. The cement slurry bond coat consists of equal parts of cement and fine sand and the mortar consists of one part cement and three parts of sand passing a No. 16 sieve and only enough water so that the mortar will stick together when molded into a ball by slight pressure of hands and will not exude the water but will leave the hands dry. If the patch must match the color of surrounding concrete, a blend of Portland cement and white cement can be used. About one-third white cement is adequate for blending. Dry pack mortar shall consist of type I or II Portland cement, clean sand that will pass a 1.18mm (No. 16) sieve, and clean water.
- ✚ **Cement mortar:** - used for repair of cracks and voids by shotcreting, patching and caulking. All ingredients of mortar, the epoxy resin, cement based polymer and concrete materials shall fulfill the Standard Technical Bridge Repair Manual.
- ✚ **Epoxy concrete:** - material used for patching used for repair of cracking and resurfacing delaminated or/and Honey combed areas concrete bridge.
- ✚ **Flexible epoxy filler:** such as Epoxy resin, polyurethane resin, Acrylic and others; used for effective repair of non structural cracks observed on RC or plain concrete components of bridges. The application is done with injection.
- ✚ **Rigid epoxy filler:** Epoxy injection fluid shall confirm the following requirements. The resins for crack injection system shall have a two part: solvent free low viscosity, polymer and; the flexible, low viscosity, polymer, crack injection resin system when mixed in the proportions specified by a supplier, supplied and injected in to cracks in concrete, the resin shall form a slightly flexible and impermeable barrier in both dry and damp condition, and thus, shall form permanent seal in cracked seal.
- ✚ **Cement grout:** Mixture of neat Portland cement and water, Portland cement. Other additives and admixtures (siliceous residue, diatomite) may be added on approval of the Engineer. The proportions of ordinary Portland cement to sand will depend upon the size of the spaces to be filled and will vary from a neat grout to about mix containing one part of cement to two parts of sand. The sand used in 1:2 ratios can be successfully pumped if all sand passes the No. 16 sieve and 15 percent or more passes the No. 100 sieve. Where necessary and approved by the Engineer, admixtures to Portland cement grout mixtures may be added for

delaying the setting time, increasing flow ability minimizing segregation and shrinkage. Materials shall conform to AASHTO M6-81, M85-01 and M154 for fine aggregate, Portland cement and Air-entraining admixtures respectively. Water shall be fresh, clean and free from sewage, oil, acid, alkali, salts or organic matter.

- ✚ **Elastomeric sealer and fast setting mortar:** - materials used for repair of crack by caulking.
- ✚ **Latex modified concrete and highly dense concrete:** - are materials used for repair of cracks of concrete bridges by grinding and overlay.
- ✚ **Steel plate, Post-tensioning steel and steel pins:** - used for crack repair by methods of stitching and external pre-stressing.
- ✚ **Reinforcement:** - high yield strength reinforcement bar reinforcing steel should rely on specification of AASHTO M31. Reinforcement can be used for repair methods of stitching and external pre-stressing.

In addition materials used for replacing concrete surface, a method used for repairing Delaminating/ Honeycomb, are Portland Cement Concrete, Low-Slump, High Dense Concrete, High Alima cement Concrete, Epoxy mortar cement and concrete, Polymer concrete and Latex-modified concrete.

3.4.2 TOOLS USED FOR CONCRETE BRIDGE REPAIR

The following are tools and equipments used for repairing concrete defects and damages in Ethiopia. Most of the tools are used for cleaning, calibration and application of repair. Advanced inspection equipments are not included since it is not applicable in Ethiopian Highway Bridges, (17). Below are listed inspection tools;

Tools used for **measurement** are Tape measure, pocket measure, caliper, level, staff, rope, straight line and crack gauge.

Tools used for **inspection** are Hammer, pen knife, Scraper.

Tools used for **Visual aid** are Binocular, magnifying glass, handy torch, goggles and ladder.

Tools used for **documentation** are digital camera, clip board, pen and pencil, chalk, paint, information board, area map and As-built drawings.

Tools used for **Cleaning:** - Shovel, stiff hand and brush.

Tools used for **Safety:** - Range pole, hard hat, safety traffic cones

4. GUIDELINE FOR MAINTENANCE OF RAILWAY CONCRETE BRIDGES

4.1 FORMATS FOR INVENTORY AND INSPECTION OF RAILWAY BRIDGES

Periodic inspections should be made to detect deterioration and damage before the structure becomes irreparable. The engineer in charge of maintenance and inspection should be experienced in determining the parts of structures in need of repair and the extent of deterioration or damage. All Bridge and culvert structures and their components should be given thorough, detailed condition inspections at scheduled intervals. The scope and detail of the inspection should be based on the condition and age of the structure, traffic type and tonnage in order to determine that the physical condition of each structure is suitable for the imposed loading and to determine maintenance or rehabilitation needs. A record of physical conditions should be kept.

A special inspection may be required when the bridge is subjected to abnormal conditions which may affect the capacity of the bridge such as: floods, storms, fires, earthquakes, collisions, overloads and evidence of recent movement.

NAMING

The two Addis Ababa LRT lines, which are the East- West and the North-South, and the eight ENRN lines shall be named “route” for inventory purpose. This will ease the documentation process and help to identify and/or classify railway bridges and culverts based on their routes. The route shall further classify in to “section” and “rail segment”. Then the bridges and culverts in the specified rail segment shall have specific name and number.

BRIDGE INVENTORY FORMAT

Location and Naming of the Bridge

Route: _____

Section: _____

Rail Segment: _____

Bridge Name: _____

Bridge Number: _____

General Information

1. Location from Addis: _____
2. Bridge width and length: _____
3. Present water level: _____
 - Highest water level _____
4. Construction data:
 - year _____
 - Contractor _____
 - Consultant _____
 - Cost of the bridge _____
5. Load capacity _____
6. Average daily traffic _____

Super Structure

- Type of the structure: _____
- Number of Span: _____
- Span composition: _____
- Total span length: _____
- Span support type: _____
- Deck Slab Type: _____
- Girder/Box data: Depth: _____
 - Width: _____
 - Number: _____
 - Spacing: _____

Sub structure and Foundation

- Abutment type _____
 - Height: _____
 - Width: _____

- Wing wall dimensions: _____
- Pier data: Number of piers: _____
 Height: _____
 Width and length: _____
 - Foundation data: Abutment foundation depth, size: _____
 Pier foundation depth, size: _____
 Number of abutment piles: _____
 Number of pier piles: _____
 Soil Type: _____

Other components

- Type of expansion joint: _____
- Type of abutment bearing: _____
- Type of pier bearing: _____
- Type of guard rail: _____

Note: - Inspector name, signature and date have to be registered at the end of inventory format.

BRIDGE INSPECTION FORMAT

Location and Naming of the Bridge

Route: _____ Weather: _____
 Section: _____ Temperature: _____
 Rail Segment: _____ Inspector: _____
 Bridge Name: _____ Date: _____
 Bridge Number: _____

PRESTRESSED AND REINFORCED CONCRETE SUPERSTRUCTURE
1. General:
Type of construction (pre-stressed or reinforced concrete)
Cracks (location, size and description)
Spilling and crazing (location, size and description)

Condition of reinforcing steel (exposed, corroded, rust around cracks - location and description)
Condition of drainage (pipe damage, blockage, each inlet damage)
Condition of bearings (main damage, parts missing, anchor damage, bed damage, unusual movement)
Condition of expansion joints (Noise, water leakage, deformation, peel off, missing)
Condition of curbs (cracks, spalls, rebar exposure, deformation, corrosion, missing)
Condition of handrail (fastenings)
Indications of movement
Other deterioration (location and description)
Changes apparent since last inspection
2. Remarks

SUBSTRUCTURE
1. General:
Alignment of unit (horizontal, vertical)
Evidence of settlement
Evidence of scour (wing walls, abutments, piers)
Condition of retained fill (drainage, slope protection)
Alignment of waterway and evidence of debris
Changes apparent since last inspection

2. Piers and Abutments: Material (brick, stone, concrete)
Condition of back wall (plumb, clearance of structure) Indications of wing wall movement
Evidence of scour
Condition of embankment (spilling over, drainage, cavities)
Concrete: Cracks (location, size and description) Spilling and crazing (location, size and description)
Condition of bridge seat
Condition of bearings (level, bedding)
Concrete structures: Cracks (location, size, description)
Condition of retained fill (drainage, slope protection)
Alignment of waterway and evidence of debris
Changes apparent since last inspection

Bridge inspection report should also include comments and remarks of the Bridge inspector, Bridge history and repair history, special recommendation of the inspector such as replacement, rehabilitation and regular inspection. In addition pictures and figures shall be included to clearly show the extent of the defects.

CULVERT INVENTORY FORMAT

Location and Naming of the culvert

Route: _____

Section: _____

Rail Segment: _____

Culvert Name: _____

Culvert Number: _____

General Information

1. Location from Addis Ababa: _____
2. Culvert width and length: _____
3. Present water level: _____
 - Highest water level _____
4. Construction data:
 - year _____
 - Contractor _____
 - Consultant _____
 - Cost of the Culvert _____
5. Load capacity _____
6. Average daily traffic _____

Structural Information

- Type of the Culvert: _____
- Number of Openings/Barrel: _____
- Opening width composition: _____
- Head wall length: _____
- Total culvert width: _____
- Culvert Height: _____
- Abutment type _____
 - Average height: _____
- Pier Type and height: _____
- End wall type: inlet and out let): _____
- Wing wall average length: _____
- Soil Type: _____

Note: - Inspector name, signature and date have to be registered at the end of inventory format.

CULVERT INSPECTION FORMAT

Location and Naming of the Culvert

Route: _____ Weather: _____
Section: _____ Temperature: _____
Rail Segment: _____ Inspector: _____
Culvert Name: _____ Date: _____
Culvert Number: _____

CULVERTS
1. General:
Type of the culvert and Material of construction
Hydraulic damages (over topping, obstruction, scour, constriction)
Culvert superstructure damage (cracking, deformation, peel off, Honey comb, void, water leakage)
Abutment (failure, crack, Tilting) Guard/parapet (deformation, tilting, other defects)
Indications of settlement
Cracks or open joints (location and description)
Condition of embankment (spilling over, drainage, cavities)
Condition headwalls and wing walls (cracks, bulge out, failure, honey comb, void, tilting, scour) Indications of wingwall movement
Water leaking into embankment
Changes apparent since last inspection
Remarks

Culvert inspection report should also include comments and remarks of the inspector, culvert history and repair history, special recommendation of the inspector such as replacement, rehabilitation and regular inspection. In addition pictures and figures shall be included to clearly show the extent of the defects.

4.2 FORMAT FOR FLOW OF INSPECTION AND DAMAGE IDENTIFICATION

To identify any damage of concrete bridge and culverts of railway, inspection is the major activity to be taken. To perform inspection activity there has to be strategies and plans at a national level for Ethiopia. The plan will help for budgeting purpose, and preparing the necessary materials, tools, logistics and Professionals. It facilitates the inspection process and it is also important to cover all of bridges and culverts, by inspection, with in the country.

Ethiopian government prepares plans for each sector of governmental offices for long, medium and short term. Major plans are set each five years based on existing conditions and future forecasting. Railway is one of the broad sections, among the transport sector and it is under construction based on the five years growth and transformation plan set on 2010. The administrative body of railway, Ethiopian Railways Corporation, shall have maintenance department which manages overall inspection and maintenance activity. The department shall be responsible for preparing schedule to perform the inspection of bridges and culverts. Annual and Five year plan also helps for budgeting, to decide type of inspection, to identify defects and take measures at the right time.

There are three types of inspection: Major inspection, Regular inspection and Special inspection. Major inspection is a planned, periodic inspection by a close visual inspection method and using advanced inspection techniques. For Ethiopian railway bridges, it shall be conducted twice within each five year plan. On this manner two fifth of the bridges and culverts of the country can be inspected each year. Regular inspection is planned, periodic inspection using visual inspection method. All bridges shall be inspected regularly each year. Special inspection is inspection performed after manmade disaster like war, natural disaster such as earth quack, floor, volcanic eruption etc. and traffic accident like collision. Contingency budget shall be budgeted for Special inspection and repair. Schedule should be prepared to cover all bridges and culverts of the country by Major and Regular inspection.

After inspection is performed and the necessary action has to be taken based on the result of the inspection. If the bridge or component of a bridge inspected have sever damages, defects and deterioration causing reduction of load carrying capacity, it needs urgent repair. And if the bridge is damaged and deteriorated causing reduction of durability, it needs repair but not urgent. Routine maintenance is necessary for bridges with minor defects. The inspection shall be performed by trained or experienced Professionals of inspection, damage identification and bridge Engineering.

General flow of inspection and damage identification is shown in the figure below.

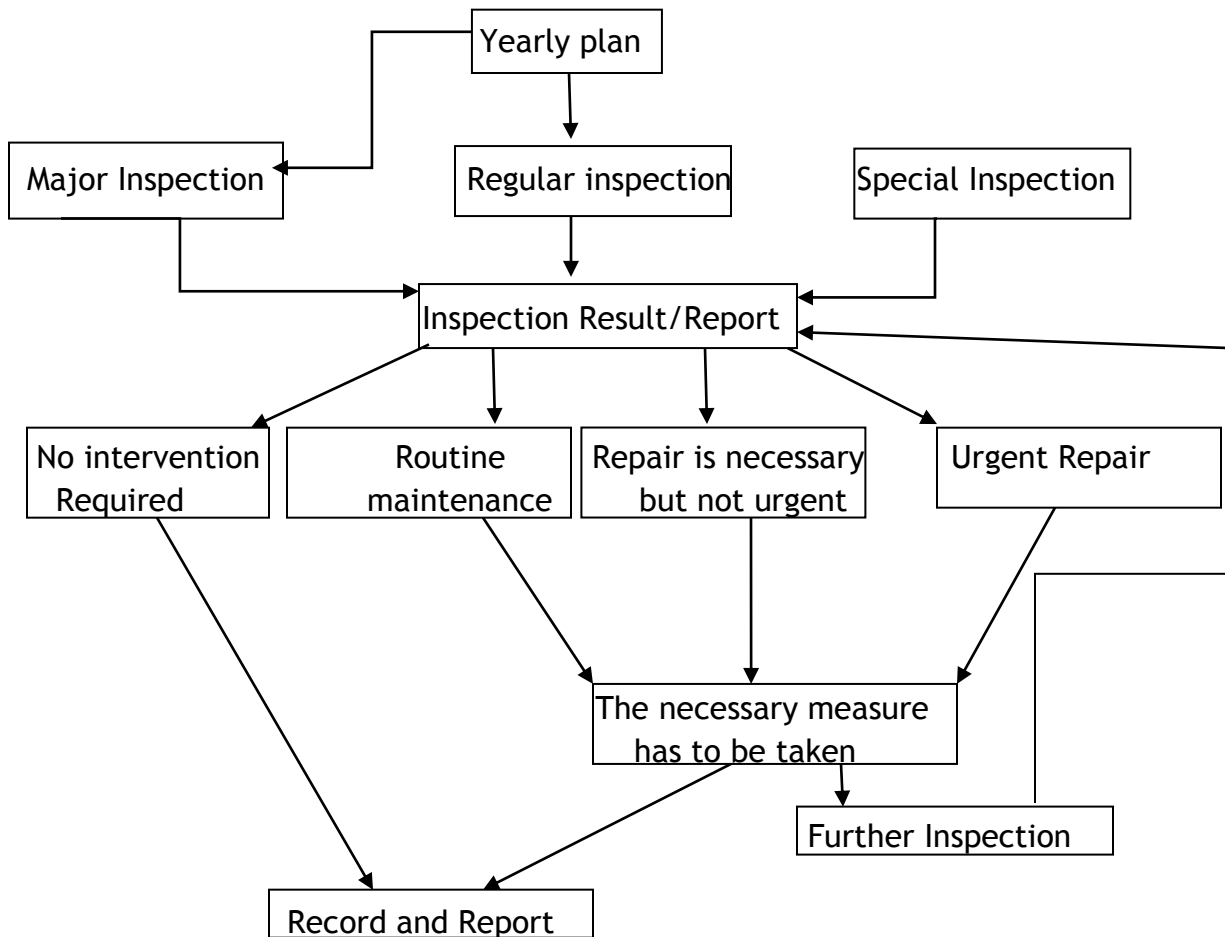


Figure 4.2-1 Work flow of Inspection and Damage Identification

4.3 MATERIALS AND TOOLS FOR REPAIR OF CONCRETE RAILWAY BRIDGES

4.3.1 MATERIALS FOR REPAIR OF CONCRETE CRACK

- I. **CONVENTIONAL PORTLAND CONCRETE:** - is used for *jacketing* of dormant concrete cracks. It is also recommended for repair of concrete defects such as peel off, spalling and scalling by *shotcreting*. It shall also be used for repair of concrete peel off, spalling or scalling by resurfacing using *concrete overlays*. *Patching* with cement concrete is repair method which repairs exposed concrete rebar. It shall conform to conventional Class “A” concrete mix 24 Mpa cylindrical compressive strength at 28 days. Sufficient air-entraining agent shall be added to maintain an air content of about 8 percent. The slump shall be the minimum practical for placing and in no case shall it exceed 50 mm. The mix shall be placed in the area to be jacketed while the bonding grout is still wet, a slightly overfilled and struck off with a vibrating screed drawn slowly across the area, (3 & 8).
- ✚ **Cement** is one of the major components of concrete as it is used for binding and gives strength to the concrete mix. To produce conventional class “A” concrete the cement shall be ordinary Portland cement. It shall be in a dry, fresh condition and be the consistency powder when used. If lumps are developed, the cement may only be used if these can be crushed between the fingers, otherwise the whole sack will be rejected. Generally Cement shall conform to American Society for Testing and Materials (ASTM) C150 Standard Specification for Portland cement.
 - ✚ **Steel reinforcement** shall be deformed high yield steel bar. All reinforcement shall be new and shall be free from rust, dirt, paint, oil or other contaminants. Generally Section 4.3.1.IV of this document can be referred for Specification for reinforcement. Tying wire shall be 0.6 or 1.25mm diameter.
 - ✚ **Coarse aggregate** shall be hard crushed stone with no trace of clay or other contaminants. Aggregate shall be cubic in appearance with no excess of flaky particles. Not less than 95% by weight of the aggregate shall pass a 26.5mm sieve and be retained on a 9.5mm sieve. All material retained on a 37.5mm sieve shall be rejected. Generally coarse aggregate shall conform to ASTM C33, Standard Specification for concrete aggregates.
 - ✚ **Fine aggregate** shall be clean sand with 95% by weight passing a 4.75mm sieve and retained on a 0.075mm sieve. In addition, sand shall be free from excess silt. Silt should not be greater than 7% of sand volume. Generally fine aggregate shall conform to ASTM C33, Standard Specification for concrete aggregates.
 - ✚ **Water:** Water shall be fresh, clean, and free from injurious amounts of sewage, oil, acid, alkali, salts, or organic matter.

- ✚ **Air Entraining Admixture** shall comply with ASTM C260, Air-Entraining Admixtures for Concrete.
- ✚ **Chemical Admixtures** for Concrete shall follow ASTM standard specification C494.
- ✚ **Steel fibers:** -Where directed by maintenance Engineer, the Contractor shall furnish steel fibers for reinforcement of shotcreting. The amount of steel fibers used shall be 40 kg of fiber per 0.75 square meter of shotcrete. Steel fibers shall be carbon steel deformed type I (cold drawn wire) or type II (cut sheet) to conform to the requirements of ASTM A820. Length of steel fiber shall be 2 cm minimum to 3cm maximum. The steel fiber shall have a minimum average tensile strength of 350 Mpa.


II. EPOXY MATERIALS

- ✚ **Rigid epoxy filler:** - used for injecting dormant cracks. The material for injection shall be low viscosity having the required characteristics bonding with concrete and resistance to moisture penetration the material for epoxy injection shall conform to the ASTM C 881. Type I, low viscosity grade. The two components will be mixed in the proportions specified by the producer without additional fillers and/or aggregate. The two-component epoxy adhesive shall have a mixed viscosity from (100 - 600 cps) at (25 +/- 16oC). And also an epoxy bonder shall be used to seal the cracks and ports during the injection process. A maximum of 2 mm thick by 25 mm shall be sufficient to seal the crack for injection. The sealing epoxy need not be removed from the concrete. Coverage of the seal coat 4-6 sq m per kg of mix depends on the temperature of application.
- ✚ **Reinforcement with Epoxy:** - used for repair of live concrete crack using conventional reinforcement using epoxy. Epoxy adhesives used to rebound the crack should conform to ASTM C 881, Type I, low-viscosity grade. The reinforcement could match section 4.3.1.1 of this document.
- ✚ **Epoxy concrete:** - is used for jacketing dormant cracks and for resurfacing honey combed and delaminated concrete structures. A variety of materials including conventional concrete and mortar, epoxy mortar, concrete etc. have been used as encasement materials. **Epoxy resins** shall conform to the American Society for Testing and Materials (ASTM) C 881. Type II. Used as the adhesive for bonding freshly mixed Portland cement concrete to hardened PCC. **Fine aggregate and coarse aggregate** of indicated sizes meeting the requirements of ASTM C 33 should be specified for epoxy resin concrete mixtures. Epoxy resin concrete proportions by weight may vary from 6 to 10 parts aggregate to 1 part epoxy resin binder, which is equivalent to a ratio of approximately 4 to 7 parts aggregate to 1 part epoxy resin binder by volume. The aggregate mixture (fine and coarse aggregate) should contain 55 ± 5 percent. Anchorage reinforcement bar shall conform to

specification given below for reinforcement. Fiberglass formwork shall use as permanent forms. Permanent fiberglass, rubber, and fabric forms have gained wide acceptance because they provide permanent resistance to chemical attack after the repair is complete, (5 & 17).

III. CEMENT GROUT/ CEMENT MORTAR: - Used for caulking of dormant concrete cracks and preventing water leakage. Cement mortar is also used to repair exposed concrete rebar by patching. Mixture of neat Portland cement and water, Portland Cement other additives and admixtures may be added depending on the existing condition. The proportions of ordinary Portland cement to sand will depend upon the size of the spaces to be filled and will vary from a neat grout to about 1:2 mix. Mix containing two parts sand to one part cement can be successfully pumped if all the sand passes the No. 16 sieve and 15 percent or more passes the No. 100 sieve. The amount of water to be added depends upon the consistency required. Grouts with as little as 16 liters of water per bag of cement could be handled and it should seldom be necessary to use more than 35 to 40 liters of water per bag of cement. Where necessary and approved by the Engineer, admixtures to Portland cement grout mixtures may be added for delaying the setting time, increasing flow ability minimizing segregation and shrinkage. Material specification of cement, sand, water and admixtures can be adapted from section 4.3.1.1 of this document. Cement mortar can be used for repair of Honey comb and delaminating but it has to be dry pack. The amount of water added for this repair method has to be as small as it is enough to make the mortar stick together and when molded into a ball by slight pressure of the hands and will not exude water but will leave the hands dry, (5 & 17).

IV. REINFORCEMENT: - Reinforcements shall be deformed reinforcement, except that plain bars and plain wire shall be permitted for spirals or tendons, or for dowels at expansion or contraction joints. Reinforcement may consist of one or more of the following materials: Deformed steel bars, prestressing tendons, wire mesh or reinforcing fibers consisting of steel, glass, or plastic. When increased protection from corrosion is required, coatings or cathodic protection of steel reinforcement may be considered. Specification for reinforcement of repair work of concrete bridges shall follow the AREMA standard which is described in section 2.5.5.2 of this document.

 **Reinforcement steel pins bonded with epoxy resin** can be used for stitching which helps to repair live concrete cracks. In this case the reinforcing steel has to be high yield strength and the epoxy resin shall comply with the specifications given above for epoxy materials.

V. OTHER MATERIALS:-

- ✚ **ELASTOMERIC SEALER:** - used for caulking of live cracks. Polymeric Joint Sealants are 2 parts "A" and "B" Components chemically cured elastomers.
- ✚ **Flexible filler:** - used for repair of live concrete cracks by injection. The materials are flexible sealant or mastic, polyethylene strip or pressure-sensitive tape bond breaker.
- ✚ **Latex Modified Concrete:** - can be used for repair of concrete rebar exposure by overlaying it on the exposed portion of the concrete structure. The mix shall contain Latex Emulsion Admixture (68% Styrene, 38% Butadiene), 121 liters/m³, 390kg/m³ of cement and 55% of fine aggregate. The material should have compressive strength of 21Mpa after seven days of cure.
- ✚ **Preplaced aggregate:** - cement, aggregate, admixtures and water shall comply with the specifications described in section 4.3.1.1.
- ✚ **Bonding materials:** - Before new concrete is placed against hardened concrete, the surface of the hardened concrete shall be cleaned and all laitance removed. Immediately before new concrete is placed, the existing surfaces shall be thoroughly wetted and all standing water removed. Prior to placing fresh concrete, apply a bonding layer of mortar, usually which is spread on the moist and prepared hardened concrete surface. In lieu of mortar, a suitable commercial bonding agent may be used, when applied in accordance with manufacturer's recommendations, (5 & 17).

4.3.2 TOOLS AND EQUIPMENTS FOR INSPECTION AND REPAIR

Inspection tools can be categorized as:

- ✚ Tools for cleaning
- ✚ Tools for Inspection
- ✚ Tools for Visual Aid
- ✚ Tools for measuring
- ✚ Tools for Documentation
- ✚ Miscellaneous and special Tools

1. Tools for Cleaning: - Cleaning tools are necessary for any inspection and repair activity. Cleaning the area under inspection or repair is the first and the most important activity of the respective activities. It helps to identify defects and damages easily and it also eases the repair process. The following cleaning tools shall be used for inspection and repair of Ethiopian Bridges.

- ✚ Whiskbroom: - a small short handled broom with stiff bristles, used to clean small area.
- ✚ Wire brush: - A brush made up of wire to remove materials from concrete surface.
- ✚ Scrapers: - used to remove hard, sharp or rough material across concrete surface.
- ✚ Shovel: - hand tool consisting of a broad, usually curved blade attached to a long handle, used for removing loose materials and digging.

2. Tools for inspection: - are tools which are used directly for inspection purpose. These tools help the inspector to identification of damages.

- ✚ Chipping hammer with leather holder: - used for sounding concrete removing unsound concrete, used to check whether or not there are internal voids, cracks and/or loosened bonding.
- ✚ Plumb bob (“Tumbi”): - weight, usually a conical metal one, at the end of a plumb. It uses to check the vertical alignment of a structure.
- ✚ Tool belt and pouch: - Used to holding tools and access.

3. Tools for Visual aid: - are tools which help to create clear vision of the inspection or repair area.

- ✚ Binoculars: - an optical instrument with a lens for each eye, used for viewing distance objects.
- ✚ Flash light: - used to give light in dark areas.

- ✚ Magnifying glass: - a convex lens in a frame with a handle, used to make objects viewed through it appears larger.
- ✚ Dye penetrant: - an equipment which encourages liquid to penetrate concrete surface.

- ✚ Inspection Mirror: - is mirror attached to long handle, used to see area where it is not accessible for visual inspection.

4. Tools for Measuring: - these are tools used to measure the dimensions of bridge components, defect or damage inspected and environmental condition during inspection or repair.

- ✚ Tape measure and pocket Tape: - a long roll or strip of fabric, plastic or thin metal that is marked off in inches or centimeters for measuring the length of something. Pocket tape is shorter in length, mostly limited to 5m.
- ✚ Caliper: - an instrument used to measure the internal or external dimensions of structures and consisting of two curved hinged legs.
- ✚ Tiltmeter and protractor: - used to measure tilting or any angular variation of a structure, component of a structure, or part of a component.
- ✚ Thermometer: - used to measure the temperature of structures and material of repair.
- ✚ Carpenter level: - used to measure horizontal alignment of structure and its components.
- ✚ Optical crack gauge: - for precise measure of length, used for relatively small length.

5. Tools for Documentation:-

- ✚ Inventory and inspection forms, clip board: - forms for inventory and inspection of bridges and culverts uses to record and report the existing conditions of bridge and culverts.
- ✚ Pen, ruler, chalk and note book: - these are additional stationary tools used to write, sketch and document.
- ✚ Digital Camera: - used to take picture of defects or damages and repair procedure.

6. Miscellaneous and Special Tools:-

- ✚ Safety tools: - includes safety hat, reflecting cloths and safety shoes, protects the inspection personnel from injury.
- ✚ Wasp and Hornet Killer: - used to avoid wasps, insects.
- ✚ First aid Kit:- used for helping injured personnel in case of accident

- ✚ Traffic warning signs: - used to warn others indicating the existence of maintenance activity.
- ✚ Non destructive equipment: these are advanced devices used to identify damage on the bridge.

Equipments for Repair includes

- ✚ Access equipment: - such as, Truck cranes, which helps to access to the defected area of elevated bridges.
- ✚ Concrete Pump: - used to pump concrete.
- ✚ Vibrator: - used for vibration of repair materials so that it can fill the void area.
- ✚ Mixer: - used for mixing repair materials to give the necessary mix design.
- ✚ Air compressor
- ✚ Injection pump: - used to inject the repair material in to the defected area of the concrete.
- ✚ Sand -blaster, air-water jet: - used to clean the damaged area of the concrete.
- ✚ Manual caulking gun: - used to fill the defected area of the concrete by caulking.
- ✚ Vacuum attached drill chuck: - used to drill the concrete so that injection ports can be mounted.
- ✚ Tampers: - used to compact material, which helps to fill the voids.
- ✚ Survey Equipment:- equipments used for surveying activities
- ✚ Equipments for under water inspection: - special equipments are needed for inspection and repair of underwater structures.

4.4 TECHNICAL SPECIFICATION OF MAINTENANCE/REPAIR OF RAILWAY CONCRETE BRIDGES

Defects identified during inspection have to be repaired to prevent further failure of the bridge structure and to maintain original situation of the bridge. To repair these defects and damages of concrete railway bridges standard procedures shall be followed for by the responsible party of the repair.

Generally, there are four basic procedures to be followed for repair work of concrete bridges; Removal of Concrete, Surface Cleaning, bonding agent preparation and Material Application.

- ✚ **Removal of concrete:** - All loose or defected concrete should be removed from the areas to be repaired by proper tools. Avoid defect to sound concrete and reinforcement steel. The entire area of reinforcement shall be exposed for full area of repair. Defect to bond of reinforcement steel outside the repair area should be avoided.
- ✚ **Surface cleaning:** - All loose particles, dirt, deteriorated concrete, or other substances that would impair the bond of the repair material shall be removed. The area to be repaired shall be cleaned by abrasive blasting, high pressure water blasting. Exposed reinforcement steel of concrete, rust and other contaminants shall be cleaned and this should be followed with a high pressure air blast for final cleaning.
- ✚ **Bonding agent application:** - Use a cement scrub or epoxy as bonding agent. Use bonding agent if cement or concrete is used for repair material. Follow the manufacturer's recommendation for epoxy bonding agent and if pre-packed repair material is used. For rapid setting repair materials epoxy bonding agents shall not be used. The bonding surface should be kept constantly wet for a minimum of 1 hour immediately prior to application of the bonding coat. In no case should fresh material be applied to a dry surface. The bonding coat should be applied to the damp bonding surface and should be vigorously brushed on to completely fill all surface pores immediately prior to placing the body of the repair material.
- ✚ **Material Application:** - The repair material shall be placed in a manner that repair material is in intimate contact with the bonding agent and free of voids.

The placement shall be performed so as to restore the original lines and surfaces of the structure.

For repair of concrete defects/damages the removal of defected concrete and cleaning of repair surface is generally similar. But there are different types and

procedures of material application depending on the type of defect/ damage and its severity.

Methods and Procedures of concrete bridge repair based on types of concrete defects are described below.

4.4.1 CONCRETE BRIDGE CRACK REPAIR

Typical repair systems for cracks are use of epoxy or cement based on the materials that can penetrate to deep inside the cracked area and to bond the exposed surfaces. There are two types of cracks repairs; Structural crack repair and non-structural crack repair.

- **Non- structural Cracks**

It is possible to repair non-structural cracks by filling the gap using high polymer special adhesive materials like epoxy resin. Two of most common Non-structural concrete railway bridges crack repair method is described below adapted from AREMA.

I. Sealing Cracks or Joints

Where there may be movement in the structure, by reason of expansion, contraction or vibration, structural joints subject to leakage may be sealed by using a water stop; cold-rolled copper expansion plate, preformed along the longitudinal centerline of the copper to produce a modified 'V'-shape, or a half round 5 cm diameter PVC pipe, secured in place with straps and anchors, or similar noncorrosive materials with the necessary flexibility. Non-leaking cracks or joints where movement in the structure by reason of expansion and contraction shall be sealed with a flexible joint sealing material such as epoxy resin. Where it has been determined that no movement exists, a rigid compound can be used.

II. Surface Crack Repairs

Routing and sealing may be used to make surface crack repairs where surface appearance is not a consideration.

This method consists of enlarging the crack along its exposed face with a concrete saw or hand pneumatic tools to open the crack sufficiently to receive the sealant. Minimum surface width should be 6.35mm. The surface of the routed joint should be clean and dry before placing the sealant. Sealant and installation should be according to the sealant manufacturer's recommendation.

▪ Repair Methods for Structural Cracks

Care has to be taken for the selection and application of repair method for structural cracks; since the main purpose of structural crack repair is to restore structural integrity across the crack, to increase load carrying capacity of the section and block access of water and harmful chemicals to reinforcing steel. Structural cracks can be effectively maintained if and only if the load carrying capacity of the section is improved by provision of sufficient reinforcement system.

Structural Cracks of Ethiopian railway concrete bridges can be repaired in the following methods

I. Injection With Cement Grout

Cement grouts are generally thicker and considerably less expensive, making them appropriate for applications where large cracks and a pathway to the earth fill behind the member are present.

This method can be used for repair of single cracks width of more than 5mm or multiple cracks width of more than 3mm, together with water leakage, free lime or salt. In bearing area, single crack width of more than 3mm and multiple crack width of 1 mm which cause reduction in loading. For cracks wider than 0.5mm caulking method of filling can be used. Caulking is a method of filling cracks by cutting the area in 'U' or 'V' shape and filling it with cement grout. Cutting the concrete along the cracks, and then fill the materials which are elastomeric sealer and cement grout or mortar.

Grouting Procedures for Portland Cement Grouts

Before the grouting operation is started, all defective materials should be removed and the entire surface should be thoroughly inspected for points of leakage and indications of voids. All defective exposed joints and cracks in the structure should be chipped out, and then thoroughly cleaned of all foreign materials by means of high pressure air or water. Then the cement grout material application can be preceded using injection ports.

The caulking method of grouting consists of cleaning along the crack, cutting the concrete following along the crack with concrete saw or with hand or pneumatic tools and opening the crack sufficiently into 'V' or 'U' shape to receive the cement grout or mortar installing injection ports. Then the sealing the crack between injection ports, flushing the crack to clean it and test the seal, and then grouting will be accomplished.

On completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

II. Injection with flexible/rigid Epoxy resin

A crack resulting from a rare load-application and which has ceased to propagate, (active crack), can be repaired by pressure injection with suitable epoxy formulation so that integrity is restored and any adverse influence on the service life of the structure is eliminated or minimized. Epoxy injection shall be applicable to cracks ranging in width from 0.3mm to 6.35mm. Where high strength is important, cracks are thin and the material can be well contained in the crack, epoxy materials are appropriate. This method can be used for single live cracks width of more than 1mm or multiple crack width of more than 1mm. This method also shall be applied in bearing area for single crack of less than 1mm with no water leakage in concrete bridge structures, such as deck slab and girder.

Preparation works

The area surrounding the crack should be cleaned of efflorescence, deteriorated concrete and other contaminants that may be detrimental to adhesion of the epoxy gel. If unsound or deteriorated concrete is located adjacent to the crack, which could prevent the complete injection of the crack, the unsound or deteriorated concrete should be removed prior to the injection. Cracks should be flushed with water under pressure to remove debris and other contaminants. This method involves routing out of active cracks; cleaning them by sand blasting, air water jetting; and filling them with flexible bonder or other suitable field-molded flexible sealant. Flexible Bonder is used for active cracks when a bond breaker is placed over the crack.

Procedure

Traffic warning signs shall be established at both ends of the work section

Access and platform shall be prepared on which workers shall stand and perform the crack maintenance operation.

The cracks shall be as clean as possible before injection. It shall be free from dusts using a proper brushing material like disc sander or wire brush. The crack should then be cleaned by sand blasting, air jetting, or both. By drilling holes at close intervals along the cracks, the epoxy resin will be injected under pressure.

Cracks at the surface shall be sealed to keep the epoxy from leaking out before it has gelled. The surface can be sealed by brushing an epoxy on the surface of the crack and allowing it to harden.

Entry ports for epoxy shall be provided, spaced far enough apart to assure that when the adhesive material shows at the adjacent port, it has completely filled the crack to its full depth.

The process used for epoxy injection shall fill the entire crack with liquid epoxy resin system and shall contain the resin system in the crack until it has hardened.

A bond breaker should be provided at the bottom of the slot to allow the sealant to change shape without a concentration of stress on the bottom.

The bond breaker may be a polyethylene strip, pressure-sensitive tape, or other material which will not bond to the sealant before or during cure.

Narrow cracks subject to movement, where aesthetics are not important, may be sealed with flexible surface seal.

By using a bond breaker over the crack, a flexible joint sealant may be troweled over the bond breaker providing an adequate bonding area.

To maintain hydraulic efficiency in some structures, it may be necessary to cut the concrete surface adjacent to the crack and to place the retaining cap flush with the original flow lines.

The crack should then be cleaned by sandblasting, air-water jetting. The mastic is placed into the routed crack slot and a retaining cap placed over the mastic to continue it. A sample retainer can be made by positioning a metal strip across the crack and fastening in to expandable anchors or grouted bolts installed in concrete along one side of the crack.

Cure and Removal of materials

Allow injected epoxies to cure overnight, or in accordance with the manufacturer's directions for those temperatures prevailing during application.

After adequate curing of injection epoxy, all ports and the epoxy gel should be ground smooth to eliminate any sharp edges or protrusions. No epoxy materials or injection ports should extend beyond the surface of the existing concrete.

On completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

III. Stitching with reinforcement steel pins bonded with epoxy resin

Stitching can be used for single live cracks width more than 5 mm or multiple cracks width of more than 3mm, together with water leakage, free lime or salt. In bearing

area, single crack width of more than 3mm and multiple crack width of 2 mm which cause reduction in loading capacity. The integrity of a cracked concrete section can at times be restored by stitching. The process involves the application of steel reinforcing bars (stitching dogs or staples) across a cracked section on the surface of the members.

Stitching a crack tends to stiffen the structure and stiffening may accentuate the overall structural restraint, causing the concrete to crack elsewhere. Therefore, it may be necessary to strengthen the adjacent section using external reinforcement embedded in a suitable overlay. Stitching across the cracks in reinforced concrete members is done either along the cracks or as a series of bands around the members. Reinforcement is placed across the cracks in suitable grooves which are suitable gunited (sprayed concrete structure) or shotcrete. Steel pins are used to stitch across the cracks.

Procedure

Drilling holes on both sides of the crack shall be the first step of stitching procedure. Cleaning the holes and anchoring the legs of the dogs in the holes, with either a non shrink grout or an epoxy-resin-based bonding system follows. The stitching dogs should be variable in length and orientation or both, and they should be located so that the tension transmitted across the crack is not applied to a single plane within the section but is spread over an area. Where surface appearance is a consideration, the stitches may be installed below the finished surface.

The ends of the stitching dogs should be grouted with a non-shrink or expanding mortar so that a proper anchorage is achieved. It should be realized that repairs of this type may cause the cracking to migrate to another portion of the structure.

Injection of materials into a crack should not be considered to restore the tensile capacity of the concrete. Where tension is to be transferred across the crack, reinforcement should be installed to carry the tension. The selection of the type of reinforcement should consider where the tension forces are to be transferred. The reinforcement should continue to a point where the existing capacity of the structure can resist the forces, with proper consideration to development of reinforcement.

Spacing of the stitching dogs should be reduced at the end of cracks. In addition, consideration should be given to drilling a hole at each end of the crack to blunt it and relieve the concentration of stress.

Both sides of the concrete section should be stitched so that further movement of structure will not pry or bend the dogs. In bending members, it is possible one side of the crack only. Stitching should be done on tension face, where movement is

occurring. If the member is in a state of axial tension, then the dogs must be placed symmetrically, even if excavation or demolition is required to gain access to opposite sides of the section.

The dogs must be stiffened and strengthened if there is a tendency for the crack to as well as to open since the dogs cannot take much compressive force as it is relatively thin and long.

✓ **External Reinforcing**

Another reinforcement repair method for structural crack is external reinforcing. Placing external reinforcing across the crack and extending for a substantial length can distribute the stresses causing the crack. The stresses at the ends of such reinforcing should be considered to eliminate simply relocating the cracked condition. Tensile stress cracks can be arrested by removing the stresses by tensioning the external reinforcement, thereby compressing the member. Cleaned cracks can be closed by inducing a compressive force sufficient to overcome the tension and to provide a residual compression. The principle is similar to stitching and the problem of crack migration must be considered in this process also. Anchorage is required for the external post-tensioning. Some form of abutment is needed such as a strong back bolted to the face of the concrete.

4.4.2 REPAIR METHODS FOR CONCRETE VOID, PEEL OFF AND DELAMINATING

I. Concrete void repair by using Dry-pack mortar

Dry packing is a process of ramming or tamping into a confined area a low water-content mortar. Because of the low w/c ratio, there is little shrinkage and the patch remains tight and is of good quality with respect to durability, strength and water tightness. No special equipment is required for this technique though the method require skilled man power.

Procedure

The area to be repaired should be undercut slightly so that the base width is slightly greater than the surface width.

After the area or slot is thoroughly cleaned and dried, a bond coat should be applied. Placing of the dry pack mortar begin immediately.

Dry-pack mortar should be placed in layers having a compacted thickness of about 1 cm. Each layer should be compacted. It is usually necessary to scratch the surface of

compacted layers to provide bond for the next layer. One layer shall be placed immediately after another.

After being finished, the repaired area should be cured. Procedures for curing and protection of dry pack are similar with those for concrete.

On completion of the works, the site shall be cleaned of surplus materials and wastes, left clean and tidy condition.

II. Concrete void repair by using Portland cement / sand mix mortar blended with epoxy resin

Wide range of voids which could affect the durability of the concrete bridge structures (volume less than 600 cm²) shall be repaired by Portland cement sand mix mortar mixed with Epoxy resin.

The plastering of Portland cement/sand mortar blended with epoxy resin shall be applied pressure grouts.

Procedure

Necessary safety preparations, such as traffic warning signs should be installed.

Remove the defective area by sounding using hammer or other tools, with approved method and level. Care must be taken to avoid defect to the surrounding concrete.

After properly cleaning the removed part of the old concrete surface, it shall be primed with epoxy resin. The concrete void will be repaired by a Portland cement/sand mortar blended with Epoxy resin. The plastering will then be applied either pressure grout or conventional hand tools. Patching method of repairing shall be used since it is simple and it can be applied using hand tools.

On completion of the works, the site shall be cleaned of surplus materials and wastes, left clean and tidy condition.

4.4.3 REPAIR METHOD FOR CONCRETE STRUCTURE HONEY COMB

The extent and depth of the honey combed area first needs to be defined. This can be done by chiseling out the affected area to expose sound concrete or by using non-destructive testing techniques. If the honey combed area is small in extent and depth does not significantly jeopardize the quality of the cover concrete protecting the reinforcement then, it can be repaired by patching with mortar. Mortar used for patching should be made from the same material to the original concrete.

If the honey combing is extensive and penetrates down to the reinforcement or even deeper then it is necessary to cut out the defective concrete and replace it with sound concrete.

Honeycomb can be repaired by using Dry-pack patching, shotcrete or Guniting preplaced aggregate.

Shotcrete (pneumatically applied cement concrete) and Guniting (pneumatically applied cement mortar) are suitable for forming new concrete (restoration concrete); and for strengthening and jacketing of various structural elements.

On completion of the works, the site shall be cleaned of surplus materials and wastes, left clean and tidy condition.

4.4.4 REPAIR METHODS FOR PRESTRESSED MEMBERS

The type of repair must be determined by the extent and type of damage, the time the structure will be out of service, the repair cost, durability, and the ultimate load capacity of the repair. Combinations of repairs such as internal splicing with external post-tensioning should also be considered, (5).

For independent precast members, replacement of the member may be the most effective solution. If member is damaged beyond reasonable damage; replacement of some severely damaged members may be the only solution.

If member has inadequate strength external post-tensioning and metal sleeve splices may be used to increase the strength of members.

- **Crack exist with no significant section loss and no tendon damage**

Cracks should be repaired by epoxy injection. Cracks in the precompression zone should be repaired under preload if live load alone applied to the section produces a tensile stress exceeding the bond strength or the base concrete allowable tension.

The application of preload should be investigated in conjunction with concrete repairs. Applying preload prior to epoxy injection can result in live load stresses no greater than original.

- **There is minor section loss, but no tendon damage Minor concrete nicks, spalls, or scrapes (Adequate cover remains and there was not significant section loss)**

Clean and seal minor defects with penetrating sealer to prevent moisture intrusion.

The application of two coats of a penetrating sealer is recommended to prevent moisture intrusion or other corrosive elements to the pre-stressing steel.

Girder designed for tension in bottom flange concrete under live load, Clean and seal minor defects with penetrating sealer to prevent moisture intrusion. If patching is used to provide additional protection, the patch should be applied under preload. If under preload it is found that a crack has propagated from the gouge either the cracked concrete should be removed or the crack repaired by epoxy injection. The gouge should be patched with an approved concrete patching mortar and the preload removed after the patch has reached adequate strength. (This applies to existing girders that may have tension in the bottom flanges. Current standards do not allow this design).

- **Shattered concrete and significant section loss, but no tendon damage**

Replacement of lost concrete should be executed under preload if the repaired section would be subject to tensile stresses when live load is applied. In preparation of the surface for placement of repair material and in removal of damaged concrete extreme care must be taken to avoid any damage to prestressing tendons. Tendons should be chemically cleaned.

- **There is section loss and tendon damage, (5).**

Repairs should be designed so there is no change in stress due to the damage. Preloading the member may be required to achieve this end. The ultimate strength of the splice should always meet or exceed the required ultimate strength.

Impact damage may cause sweep (lateral curvature in the bottom flange) or abrupt lateral curvature caused by the combination of torsional and transverse flexural stress induced by tendon eccentricities when strands are broken on one side of a girder. It may be possible to jack the tension flange into alignment and hold it using an additional diaphragm.

✓ **Few Tendons Are Damaged**

Tendons should be repaired by internal splicing. After tendons are repaired the concrete is repaired, usually under preload. Repair of more than 2-4 tendons by this method is usually difficult. One advantage of internal strand splices is that they restore strength internally. Combined with preloading, the girder should be restored to its original condition.

✓ **Several Tendons Are Damaged (6-8 Tendons)**

The span may be repaired with external post-tensioning. Due to the externally applied tensioning, preload may not be required. The damaged concrete may be repaired utilizing appropriate patching methods. Protection of the posttensioning system must be considered.

Jacking corbels may be used to secure the ends of post-tensioned rods. The strength of the corbels will generally control the number of severed strands that can be spliced by post-tensioning. Between corbels, the post-tensioning rods should be grouted after post-tensioning inside of a conduit to protect the rods.

✓ **Multiple Tendon Damage with Large Section Losses**

Repairs can be accomplished with metal splice sleeves. The damaged concrete areas within the splice area are filled with concrete. Preloading is not required if the stresses at the top and the end of the sleeve are within the allowable.

The use of metal splice sleeves does not restore prestress unless preloading is used. Intermediate cracks which are covered by the splice should not reduce structure integrity or durability.

5. DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 DISCUSSION

This study is done based on documental review methodology. The thesis is focused on preparing a maintenance manual to the Ethiopian railway bridges. This is done mainly by reviewing bridge maintenance documents of America, China and Europe and comparing it with Ethiopian experience of highway bridges and old railway bridges.

Bridge components, defects / damages of bridges and causes of the damages are studied by reviewing AREMA in detail so that it could help to set the guideline of Ethiopian Railway Bridges. The damages of concrete bridges and their causes are studied also from Ethiopian past experience by referencing highway bridges of the country and the old railway bridges. Common defects which are experienced in the past are concrete crack, concrete spilling, delaminating, concrete void, honey combing, rebar exposure and corrosion, water leakage, concrete scalling, bridge scour and sedimentation. The main causes of these defects are design errors, workmanship errors, poor construction material and equipment quality, improper design and construction of drainage system, over loading, external effects such as war and accidents. The other cause is one type of defect causing the other due to lack of maintenance, for example concrete crack causes water leakage and which in turn causes extended crack and corrosion of rebar.

Damage identification method and inspection schedule are studied from AREMA's standard. ERA's experience is taken in to consideration to obtain efficient damage identification method and inspection schedule after knowing what exact situations, trend appears in the country. Since inspection is the first and the major step of maintenance activity it should be done regularly with properly scheduled program. Inspection work needs formats prepared which shows how frequent the inspection should be, what components to inspect, how to inspect and what measures to take. These formats are prepared including inventory formats for Ethiopian Railway bridges and culverts. Inspection for railway bridges of Ethiopia is classified in to Major inspection, Regular inspection and Special inspection. Major inspection is a planned, periodic inspection by a close visual inspection method, using advanced inspection techniques and even, if possible by using non destructive testing methods. Major inspection shall be accomplished every two and half years. Regular inspection is planned, periodic inspection using visual inspection method. All bridges shall be inspected regularly each year. A special inspection may be required when the bridge is subjected to abnormal conditions which may affect the capacity of the bridge such

as: floods, storms, fires, earthquakes, collisions, overloads and evidence of recent movement.

The main objective of this thesis is to prepare standard of maintenance for Ethiopian concrete railway bridges. This is done by adapting the AREMA standard to the Ethiopian condition. But during setting up this standard the availability of advanced technology, materials and equipments and skilled workmanship is a big challenge. Therefore, to minimize these challenges, it is also necessary to adapt from highway bridge maintenance guidelines of Ethiopia. During development of the standard specifications of materials are also described including tools and equipments required for the action to be completed. The major materials which are used for maintenance activity are cement, fine aggregate, coarse aggregate, epoxy materials, reinforcing steel and different admixtures. Tools for cleaning, visual aid, measuring, recording and special tools have to be prepared discussed in detail in chapter four. Equipments used for access, preparatory works and actual maintenance work should also be delivered for the repair work. The other critical thing in maintenance activity is skilled manpower. The maintenance crew shall be organized including Bridge Engineer, Inspection Engineer, Construction foreman (trained for maintenance), Masons, Equipment Operators and Daily Laborers.

5.2 CONCLUSION

Maintenance is necessary to keep a system or a structure in a desired operation state or bring it back into that state. Bridges form an essential part of a railway system. The failure of a bridge may result more severe and long lasting negative effect than other section of the track, which makes bridges most important component of the railway infrastructure. The construction cost of a bridge is also more expensive than at grade components of railway track. Therefore, great attention has to be given for maintenance of bridges. From our country experience of handling highway bridges, the fact is that only very limited action taken towards maintaining the bridges. Many of the bridges deteriorated significantly over the past many years. This is mainly due to lack of inspection that is caused by shortage of skilled manpower and experience; absence of maintenance program, age of structures over design loading. Therefore to obtain the bridge's functional and operational quality throughout its life time maintenance is very important and necessary activity.

Maintenance guidelines lead the maintenance activity by outlining inspection frequency and method, the actions to be taken to after inspection report, materials and equipments to be used for repair and procedures to be followed to regain its original function. Maintenance standards provide limits for specific defects and should be used to determine when maintenance is desirable and should be accomplished. This allows for maintenance or repair before the condition exceeding safety standards limits. A conceptual framework of maintenance management can facilitate effective and efficient decision making in maintenance of railway bridges and will act as an essential component of a decision support system.

There are defects which appear in the Ethiopian concrete bridges and which are also common to other countries concrete railway bridges. So considering both situation, defects which could appear to Ethiopian Railway concrete bridges are concrete crack, concrete scaling, delaminating, concrete spalling, water leakage, corrosion of rebar, concrete void and honey comb. The major causes of the these damages are design consideration errors, less quality of construction materials and equipments, workmanship errors during construction, over loading (over design axle load), lack of proper and detailed inspection during and after construction, natural disasters and accidents.

Water related damages should be given prior attention to the Ethiopian case, since most of construction damages to the Ethiopian infrastructures are related to drainage problems. Proper drainage system has to be designed and constructed, water leakage has to be avoided as much as possible, drainage system should be inspected and

cleaned frequently to avoid clogging the system. In this case it is possible to avoid sever damages caused by water to concrete structures including bridges.

Thus, the study has come at works

- Preparing inventory and inspection formats for concrete railway bridges and culverts
- Developing defect/damage identification format
- Specifying the necessary materials, tools, equipments and skilled manpower
- Describing method and procedure of concrete railway bridge repair activity
- Showing the necessity of Maintenance work and maintenance guideline

5.3 RECOMMENDATIONS

I. Maintenance Policy and strategy

It is recommended that Maintenance Policy and strategy has to be developed for Ethiopian railway infrastructures in general and for Ethiopian railway bridges in particular. Maintenance policy, strategy and plan are the key factor for achieving objectives of railway infrastructures. Maintenance Policy and Strategy is a framework which outline how the maintenance and related activities has to be done with in a country. The maintenance policies are the set of technical and organizational actions required to achieve the maintenance objectives and they could be adopted according to the technical characteristics, of the various technologies. Maintenance policies shall have concepts about initial inspection, deterioration prediction, inspection evaluation, remedial measures and recording. Maintenance strategy comprehensively encompasses inspection, estimation of deterioration levels and rates, evaluation of performance of structure, remedial actions and recording. The combination of these steps differs to different maintenance category, considering the importance of the structure, hazards to the third parties and environmental conditions. The complexity and magnitude of repair procedure will depend on whether: only the cause of defect has to be removed; the structure must be restored to original condition; the structure needs upgraded for its load carrying capacity and/or its geometry.

Rail transport system is a complex system involving different techniques and technologies: civil, mechanical, electrical and telecommunications. Bridge is one of the major and critical civil structures of railway system, therefore the specific maintenance policies, strategies and plan has to be prepared Railway bridges, (18).

Based on the general idea of Maintenance Policy and Strategy maintenance manual can be developed. Maintenance manual is a document that classifies and describes the elements which compose the infrastructure, indicating times and methods for the maintenance operations. The manual discusses general outline of maintenance methodology, method of damage identification, inspection procedures and formats, materials and tools necessary for the maintenance and general procedure to be followed during repair process. This thesis is focuses on only developing railway bridge maintenance manual; but the maintenance policy and strategy of the railway infrastructure is not prepared. Therefore it is recommended to set policy and strategy for maintenance activity of railway network generally and also for railway bridges in particular.

II. Further Study for Adaptation of detailed maintenance guideline Bridges.

This document list general guideline and procedure for maintenance of railway bridge. But further study has to be done for establishment of detailed maintenance guideline

for each and every component of bridge components. And the studies shall adapt maintenance guideline from other experienced countries and Ethiopian manuals. Which could be modified depending on going situation of railway system.

III. Skilled Personnel, material and tools, devise equipment

Skilled man power has to be produced for maintenance of Ethiopian railway bridges with. To accomplish the task of maintenance it is must to work with highly skilled and experienced maintenance personnel. Maintenance of Railway Bridge requires personnel with detailed knowledge of the system, able to perform all the troubleshooting, verification and measurement activities, including through the use of specialized equipment and also recommendation of appropriate maintenance method. Therefore it is recommended that Ethiopia shall have skilled man power which can fulfill the above criteria for maintenance of railway bridges. This can be satisfied by giving training to existing bridge and maintenance Engineers, by letting transfer of knowledge from experienced countries.

It is also recommended the country to have materials, tools and equipments necessary for the maintenance activity. Lack of equipments should not be a barrier for maintenance work. Damaged structure has to restore its original function and operation unless, if the traffic keeps flowing on defected / Damages Bridge, the damage may increase and through time could result disastrous accident. Therefore necessary inspection equipments, detecting devices and materials for repair has to be provided.

IV. Design and construction has to take maintenance in to consideration

Maintenance shall be taken in to consideration at the planning stage of newly constructed structure, because the design concept and the construction method can be changed depending on the level of maintenance. The levels of maintenance applied to a concrete bridge structure are closely related to the levels of the design and construction of the structure. As it is seen in chapter three of this document design errors and construction faults are among the causes of bridge damage. Proper design and Construction can save excessive maintenance cost. Therefore it is recommended that planning, design and construction of concrete bridge has to be done considering future maintenance work.

V. Awareness creation for the society

The society shall be given awareness about safety, security and prevention to damage of the infrastructure. It has been observed that there is garbage on the railway track of LRT, Chemical wastage on the drainage lines, dumping of sewer in the drainage and other facilities and this trend may extend even during the operation of the network. This could cause damage to different structures including concrete structures and

even may lead to derailment of the train. Therefore, it is recommended that the society has to be properly aware of what to do and what not to regarding the well being of the railway infrastructure. Doing so it can be avoided excess maintenance cost and operational delay to accomplish the maintenance. More than all, it is better to prevent damage than curing it.

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