Government of Karnataka

Public Works, Ports and Inland Water Transport Department

BRIDGE INSPECTION MANUAL









Planning and Road Asset Management Centre (PRAMC) – PWP & IWTD

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PREFACE

Planning and Road Asset Management Centre (PRAMC) working under Public Works, Ports and Inland Water Transport Department (PWP & IWTD) Government of Karnataka takes immense pleasure in releasing **Bridge Inspection Manual**.

This manual has been prepared for the Engineers of the Public Works, Ports and Inland Water Transport Department (PWP & IWTD)- Government of Karnataka. This manualis not an engineering text book, nor a primer on fundamentals of bridge inspection. It has been prepared to assist and guide Bridge Inspectors, who need not be necessarily qualified engineers, for the Periodic Inspection and Condition Rating of bridges and their components.

The periodic inspection of Highway Bridges is one of the essential inputs for any Bridge Management System(BMS), in order to ensure safe and uninterrupted traffic movement over the State Highway network.

The manual outlines and explains the series of regulations and instruction which govern the Periodic inspection, Data collection, Documentation and overall rating of bridge structures.

PRAMC and PWP & IWT Department, Government of Karnataka do express indebted gratitude for co-operation and guidance received from Dr. H.C. Mahadevappa, Hon'ble Minister for Public Works, Ports and Inland Water Transport Department, Government of Karnataka for the support extended in procurement of advanced Bridge Inspection Vehicle and preparation and publication of **Bridge Inspection Manual.**

PRAMC Organisation expresses its gratitude to Sri.M.Lakshmi Narayana,I.A.S,Additional Chief Secretary and Principal Secretary- Public Works, Ports and Inland Water Transport Department, Government of Karnataka for his valuable guidance and inspiration in preparing and publishing the useful Bridge Inspection Manual.

PRAMC is immensely grateful to Secretary, PWD Sri. S.B. Siddagangappa, KES for guiding the organisation in preparation and release of manual.

Organisation is also grateful to all the Engineers of Public Works, Ports and Inland Water Transport Department, Government of Karnataka who have co-operated in the Inspection and the Consultants M/s. EGIS India Consulting Engineers Pvt. Ltd., in particular Mr. Mahendra Raj Urs, Bridge Engineer for their effort in preparation and release of the manual.

It is the hope of the Organisation that all the Engineers do follow the instructions and guidelines for conducting Bridge Inspection and implement the remedial measures so as to save the assets created over a period of time.

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Introduction

General Purpose

This manual has been prepared for the Engineers of the Public works, Ports and Inland Water Transport Department (PWD) - Government of Karnataka.

This part of the manual outlines and explains the series of regulations and instructions which govern the periodic inspection, data collection, documentation and overall rating of bridge structures.

The manual is not an engineering text book, nor a primer on fundamentals of bridge inspection. It has been prepared to assist and guide Bridge Inspectors, who are not necessarily qualified engineers, in the Periodic Inspection and Condition Rating, of bridges and their components.

Goals of the Manual

The periodic inspection of highway bridges is one of the essential inputs for any Bridge Management System [BMS], in order to ensure both the safe and uninterrupted traffic movement over the State Highway network. The overriding goal of this document is to present a collection of instructions and guidelines for conducting a bridge inspection programme. The purpose of this is to provide the user with the necessary understanding of the most relevant and basic items of the complex structure of a bridge. In so doing the elements identified have, wherever possible, been simplified, condensed, and organised in such a manner that it allows the user to located and deal with these in an efficient manner. The specific objectives of this document can therefore be identified as follows:

- To assemble in one document the primary guidelines and instructions need by bridge inspectors.
- To provide reference and guidance for the inspection items, condition rating and appraisal of bridge structures and miscellaneous components, using both examples and illustrations relevant to the common bridge types to be found in Karnataka.
- To enhance the understanding of PWD District offices and inspectors on the overall procedures for a bridge inspection programme.

Manual Structure

This Inspection Manual has the following structure:

- Chapter - 1: Structural Inspections and Basic Bridge Terminology
- Chapter - 2: Collection of Inventory Data
- Chapter - 3: Bridge General Types and Defects (Condition Data).
- Chapter - 4: Super Structure (Condition Data)

  - RCC Solid Slab
  - RCC T-Beam and Deck Slab
  - RCC Box Girder
  - Pre-stressed Concrete Super-Structure
  - PSC T-Girder and Deck Slab
  - PSC Box Girder
  - Voided Slab (RCC/PSC)
  - Balanced Cantilever
  - Bow String Concrete Arch
  - Masonry Arch Bridges
- Chapter - 5: Bearings
- Chapter - 6: Sub-structure, including:
  - Abutments
  - Piers
  - Piers/Abutment Caps
  - Wing Walls
- Chapter - 7: Foundations – Firstly the common foundation issues of Scour, Settlement and River bed protection are discussed and then, secondly, the following types of foundations are dealt with:
  - Open Foundations
  - Well Foundations
  - Pile Foundations

Chapter - 8: Miscellaneous – Bridge Elements

- Expansion Joint
- Drainage
- Footpath
- Railing and Crash Barriers
- Wearing Coat
- Service Line
- Seismic Restrainer

Chapter - 9: Overall Condition Rating, Other Inspection and Photographs

CHAPTER – 1

Structural Inspections and Basic Bridge Terminology

Chapter 1: Structural Inspections and Basic Bridge Terminology

This section sets out the goals and objectives of structural inspections. It identifies the types of inspections and the types of structures to which this manual applies.

1.1 Goal and Objectives of Structural Inspections

The goal of structural inspections is to ensure, within an economic framework, an acceptable standard for structures in terms of public safety, comfort and convenience.

The main objectives of Structural Inspections are:

- to maintain structures in a safe condition;
- to protect and prolong the useful life of structures;
- to identify maintenance, repair and rehabilitation needs of structures; and,
- to provide a basis for a structure management system for the planning and funding of the maintenance and rehabilitation of structures.

1.2 Inspections of Structures

To achieve the goal and objectives of structural inspections, detailed visual inspections of bridges should be performed regularly. A detailed visual inspection is an element-by-element "close-up" visual assessment of material defects, performance deficiencies and maintenance needs of a structure. "Close-up is defined as "a distance close enough to determine the condition of the element**". In many cases, the inspection should be conducted within arms - length of the element, possibly involving tapping with a hammer or making measurements, it may be possible to inspect a portion of the bridge close-up and then estimating the condition of the remaining inaccessible parts by visually comparing them to the partial close-up inspection. It is expected that in order to adequately assess the condition of all elements, the engineer should plan to spend sufficient at a typical bridge site**.

Appropriate special equipment (bucket truck, ladders, etc) should be used to facilitate this assessment.

In addition to detailed inspections, routine inspections by maintenance are essential, and should be performed regularly to identify sudden changes in bridge condition. This manual describes the procedures for carrying out detailed visual inspections only.

1.3 Frequency of Detailed Visual Inspections

General Information of Bridge: These details shall be collected during the month of April – May, only for the bridges where information has changed (such as reconstruction or widening) is done, the data entry shall be done in the month of June for the details collected.

Condition Inspection Data Collection: These details shall be collected twice a year preferably in Pre-monsoon i.e. during the months of April – May and Post monsoon i.e. during the months of September- October with updating / data entry to be done in month of June for details collected during Pre-monsoon inspection and in the month of November for the details collected during the post-monsoon inspection.

It is recognized that the level of effort involved in performing a detailed visual inspection will vary depending on structure type and age. For example, if a bridge is less than 5 years old, it is unlikely that there will be much change in bridge condition from one inspection to the next. Consequently, the inspection time may be relatively short. However, the engineer must be satisfied that everything possible has been done to determine the condition of the various bridge elements.

It is also recognized that one of the purposes of regular inspections is to identify changes in bridge condition.

The frequency of inspections given above, applies to all structures in good repair. The maximum inspection interval and the level of inspection may however vary for certain structures. Some structures may have to be inspected more frequently as directed by the Engineer. Such action can be justified based upon the type of structure, construction details, existing problems or restrictions, and material and performance condition history.

Structures or components requiring more frequent inspection include:

- Structures with a high proportion of elements in the Poor Condition State;
- Structures with load limits on them;
- New types of structures or details with no previous performance history;
- Structures with load or clearance restrictions;
- Single load path structures;
- Structures with fatigue prone details;
- Structures with fracture critical components;
- Pins and hangers in arch structures;
- Pins in suspended spans and pinned arches.

Often, more detailed investigations and non-destructive testing techniques are required to identify defects for the above cases. The engineer should recommend that these specialized additional investigations be performed regularly, where warranted.

1.4 Emergency Inspections

An emergency situation exists when a structural component contributing to overall stability of the structure has failed, or is in imminent danger of failure or public safety is in any way at risk. In such cases, a detailed visual inspection should be carried out immediately. Typical problems that may cause an emergency situation to develop are:

- Accident or vehicle collision with a structure;
- Spring run-off or major flooding;
- An earthquake;
- Cracks in steel components; and

- Loose concrete in an overhead structure.

1.5 Additional Investigations

If during a detailed visual inspection, the inspector feels that more detailed information is needed, additional investigations can be requested. Some of these investigations are:

- Non-destructive Tests
- Post-Tensioned Strand Investigation;
- Structure evaluation.

1.6 Basic Bridge Terminology

It is important to be familiar with the terminology and elementary theory of bridge mechanics and materials.

A thorough and complete bridge inspection is dependent upon the bridge inspector's ability to identify and understand the function of the major bridge components and their elements. Most bridges can be divided into three basic parts or components:

- Deck
- Superstructure
- Substructure and Foundation

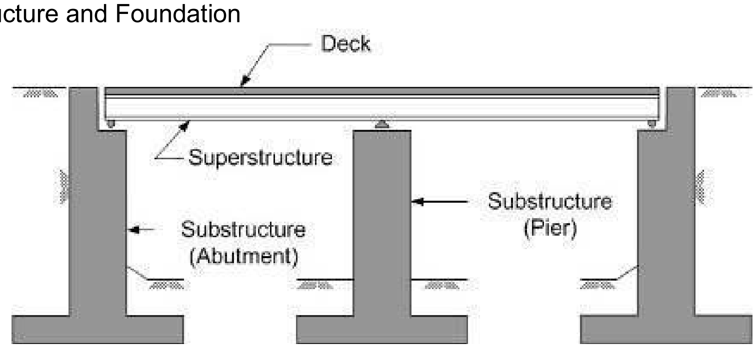


Figure 1-1: Major Bridge Components

1.7 Components of Bridge Structure

- **Bridge Deck:** The load bearing floor of a bridge which carries and spreads the loads to the main beams.
- **Superstructure:** Transmits the Load from Deck surface to the Sub-structure, It is either of reinforced concrete, pre-stressed concrete, steel etc.
- **Bearings:** These are supports on a bridge Abutment / pier, which carry the weight of the bridge superstructure and control the movements at the bridge supports, including the temperature expansion and contraction.
- **Bridge Cap (Abutment / Pier Cap):** The highest part of a bridge Abutment / Pier on which the bridge bearings are seated.

- **Abutment:** The End Supports of the Deck (Superstructure) of the Bridge, which also retains earth, fill of approaches behind.
- **Pier:** Intermediate supports of the Deck (Superstructure of the Bridge).
- **Retaining wall:** A wall designed to resist the pressure of earth filing behind.
- **Foundation:** The Part of Bridge in direct contact with and transmitting all the above loads to the Ground / Earth.
- **Expansion joints:** These are provided to accommodate the translations due to possible shrinkage and expansions due to temperature changes. These make the deck joint leak proof, protect the edges of slab / girder and also allow smooth passage of loads from one span to another by bridging the gap.
- **Crash Barrier / Railings:** Traffic barriers (called as crash barriers) keep vehicles within their roadway and prevent vehicles from falling off the bridge.
- **Wearing coat:** A layer of Bitumen / Concrete provided over the Deck to prevent the damage to the deck.
- **Approach Slab:** These are provided behind the dirt wall at approaches of the bridge structure to allow smooth passage of vehicular loads on to the main bridge structure.
- **Protection Works:** These are provided for ensuring the safety of bridges and their approaches on either side.

Figure 1-2: Various Components of Bridge

1.8 Tools and Equipment Required

Several factors play a role in determining what type of equipment is necessary to undertake a bridge inspection. The bridge location and the type of bridge are two of the main factors in determining equipment needs. A further factor influencing the choice of equipment is the type of inspection to be undertaken. A few minutes spent reviewing the bridge inspection manual and preparing a checklist of the necessary / required equipment can save inspection time in the field and ensure that the correct / required equipment is to hand.

Standard Tools

In order that the inspector can undertake an accurate and comprehensive inspection, the correct tools for such must be used. Standard tools that an inspector should have available at the bridge site are:

- Cleaning tools
- Inspection equipment
- Visual assessment aids
- Measuring equipment
- Documentation equipment
- Equipment to assist access
- Miscellaneous equipment

Cleaning tools

- Wisk broom for removing loose dirt and debris.
- Wire brush for removing loose paint.
- Scrapers for removing corrosion.
- Flat bladed screwdriver for general cleaning and probing.
- Shovel for removing dirt and debris from bearing areas.

Inspection Equipment

- **Pocket knife** for general duties.
- **Plumb line** to measure the vertical alignments of elements of super-structure or sub-structure.
- **Tool belt with tool pouch** for the convenience of 'having to hand' and storing all small tools.
- **Range pole / probe** for probing for scour holes.
- **Chipping hammer** for the loosening of dirt and rust, sounding of concrete and, the checking for sheared or loose fasteners.

Figure 1-3: Inspection Tools

Visual assessment aids

- **Binoculars** to provide the user the means of inspecting from a distance when close inspection is not possible.
- **Flashlight** for illuminating dark areas and areas with no natural light.
- **Back lit magnifying glass** to provide the means for closer examination of cracks and areas prone to cracking.
- **Inspection mirrors** for inspection of inaccessible areas, for example, the underside of deck joints.
- **Dye penetrant** for identifying cracks and their length.

Figure 1-4: Visual Assessment Aids

Measuring equipment

- **Pocket tape** for measuring defects, bridge elements and, joint dimensions.
- **Measuring tape (30m)** for measuring the dimensions of components.
- **Callipers** for measuring the thickness of an element beyond an exposed edge.
- **Optical crack gauge** for precise measurement of crack widths.
- **Resistivity meter**

- **Rebound hammer**
- **Tilt meter and protractor** for determining the tilt of sub-structures and for measuring the angle of tilt.

Documentation equipment

- **Inspection forms, clipboard and pencil** for recording data at site
- **Field books** for additional record keeping for complex structures.
- **Straight edge** an aid for drawing sketches.
- **Camera** to provide visual evidence of the bridge site and condition.
- **Chalk, paint sticks, or markers** for element/defect identification and photograph documentation.

Equipment to assist in access

There are two primary methods of gaining access where it is too hard to reach areas of a bridge namely, portable equipment and vehicle mounted access equipment. Common access equipment includes ladders, rigging, and scaffolding. In the case of vehicular equipment this includes, person lifts, bucket trucks and snoopers. In most cases, using a person lift or bucket truck will be less time consuming than using a ladder or rigging to inspect a structure. The purpose of access equipment is to position the inspector close enough to the bridge component so that a "hands-on" inspection can be performed. The following are some of the most common forms of access equipment:

- **Ladders:** Ladders can be used for the inspecting of the underside of a bridge or sub-structure units. However, a ladder should be used only for those portions of the bridge that can be reached safely and without undue 'leaning'.

Figure 1-5: Inspection with the help of Ladder

- **Boat:** A boat may be needed for structures over water. A boat can be used for some inspection, as well as for taking photographs. A safety boat is also required when performing an inspection over water.

Figure 1-6: Inspection with the aid of a Boat

Under bridge inspection vehicle

Bucket vehicle - An under bridge inspection vehicle is a specialised bucket vehicle with an articulated boom designed to reach under a structure while parked on the deck or under the bridge. A rotating turret provides maximum flexibility, with outriggers with wheels allowing the vehicle to be moved during use.

Figure 1-7: Bridge Inspection Vehicle

Survey equipment

For collection of dimension data a level, an incremental rod, or other survey equipment required. This equipment can be used to establish components exact location relative to other components, reference points, as well as being available to measure other required detail.

CHAPTER – 2

Collection of Inventory Data

Chapter 2: Collection of Inventory Data

Collection of the Inventory data is the first step of the data collection process. Once Inventory data is available in the BMS database, only updating and verification of data will be required. Condition data is collected at regular intervals.

Hence the data required for BMS can be split into 2 Inspection Categories - General Inventory Inspection Data and Condition Inspection Data.

General Inventory Inspection Data : This data generally includes the general information as it applies to any particular bridge and is unlikely to change until a physical change (such as reconstruction or widening) is done.

The general bridge inventory module data can be split into;

- Administrative / General Data
- Geometrical Data
- Technical Data (includes Structural details, Geotechnical details and Hydraulic details)
- Structural drawings (if any) and Photographs

2.1 Administrative / General Data

Administrative / General data contains the following

Kilometric Point (PWD Chainage): The Centre-line chainage of the Bridge with respect to Existing PWD kilometer Stone.

Bridge Identification Number / Structure Number: The Structure Number has two components, first one indicating the next increasing chainage and the following number indicates the serial number of the structure in that particular kilometer. For example structure Number 18/2 indicates that the structure is in between kilometer 17 and 18 and this is the second cross drainage structure in that kilometer (i.e. between 17 and 18) in the direction of increasing chainage.

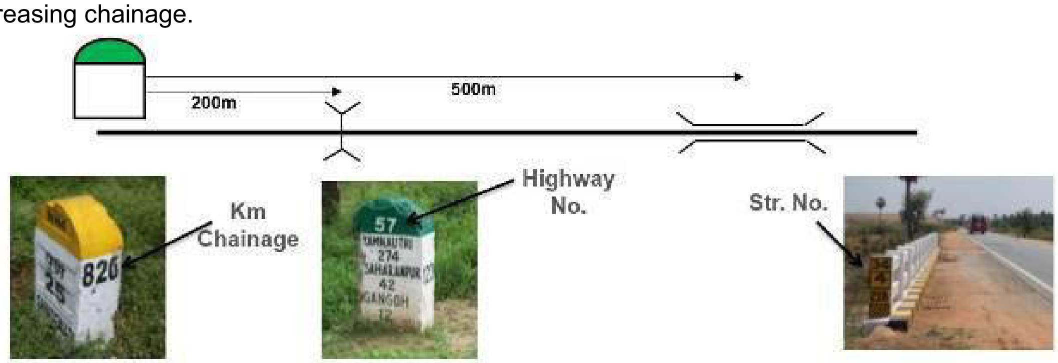


Figure 2-1: Typical Km Stone and the Structure Number

Name of Bridge: The Name of River / Stream / Nala across which the Bridge is built.

District / Taluk: Name of the District /Taluk in which the Bridge is located

Division / Circle: PWD Divisional office / PWD Circle responsible for Maintaining the Bridge

Category of Road: Category of Road on which the Bridge is located (such as NH / SH / MDR)

Road Number: Road Number on which the Bridge is located, such as National Highway Number / State Highway Number

Road Name: Nomenclature of Highway on which the Bridge is located

Location: Name of nearby place / settlements to the Bridge

Year of construction: The year in which the bridge was built.

Repairs done prior to the inventory: A list / details of previous repair work carried before inspection.

Name of Builder / Contractor /Consultant: The contractor/firm who constructed the bridge and the name of the consultant associated with the design or supervision of construction (if any).

2.2 Geometric Data

Most of the geometrical data for bridges are described as below. It should be noted that all widths are measured perpendicularly to the bridge centre line, and all lengths are measured along the bridge centre line

Bridge Roadway Width / Carriageway width: The width between the inner face of kerb to kerb. This is the total width of the area designed for road traffic.

Bridge Deck Width out to out (m): the Total width of Bridge (including Footpath, kerb, Railings), is the total width of the superstructure measured perpendicular to the bridge structure

Details of Footpath: The total widths of the left and right footways, respectively (as viewed in the direction of ascending chainage), including kerbs, measured to the nearest part of parapet or railing.

Parapet / Railings: The minimum height of either parapet measured above footpath, where there is no footpath or rubbing strip, the height shall be taken above the adjacent carriageway level.

Flow Direction: Generally L to R or R to L, in the increasing chainage of the road.

Skew Angle: The skew of the bridge is the angle between the line perpendicular to the bridge carriageway centre line and the centre line of the bridge's end supports.

Width of median: The total width of the median (central reserve) in metres including kerbs

Gradient / Curve: Whether the Bridge is in curve /Gradient or not.

Spatial Details: Details of Latitude, Longitude and Altitude.

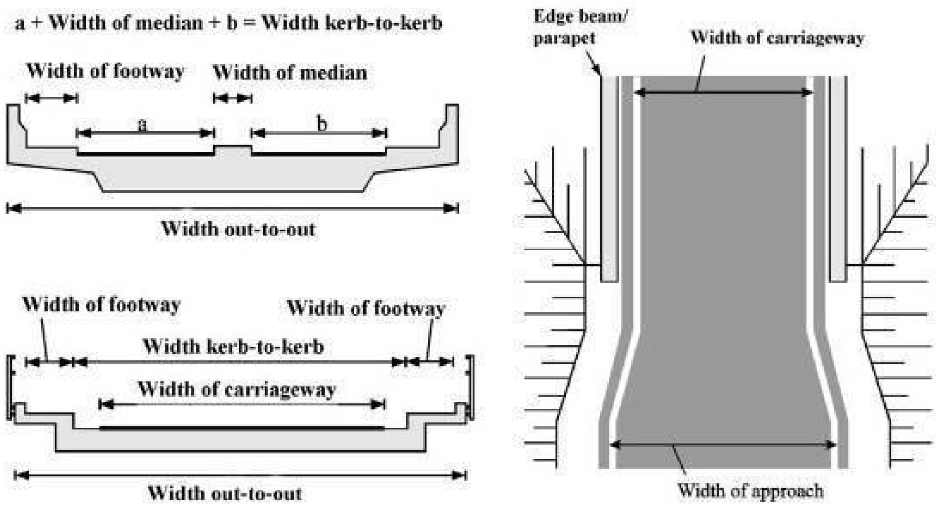


Figure 2-2: Typical Geometric details of Deck Surface for Bridge

2.3 Technical Data

Type of the Bridge: The appropriate type of bridge to be selected, namely; Major Bridge, Minor Bridge, ROB (Road Over railway line), RUB (Road Under railway line), High Level Bridge, Submersible Bridge / Causeway

Number of spans: The total number of bridge spans.

Overall length: The total length of the superstructure of the bridge measured along the centre line, it is the total length from inner face to inner face of dirt wall

Span Lengths: The length of each span of the bridge as measured from expansion joint to expansion joint.

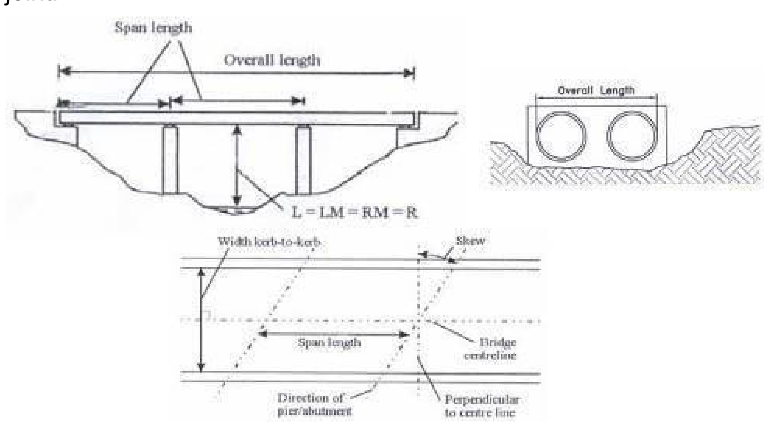


Figure 2-3: Typical Span details of Bridge

Superstructure: The structural system which supports a carriageway and a pedestrian footpath is called super-structure. A bridge may have different types of superstructure, an appropriate type of structure as per site should be recorded. Distinction shall also be made between simple span, continuous superstructure, cantilever superstructure, frame, box, arch, cable stayed bridge, suspension bridge etc

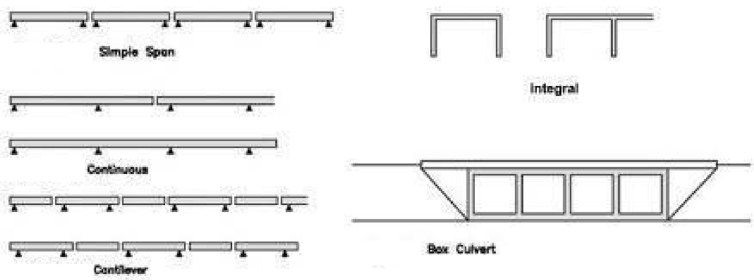


Figure 2-4: Super structure span arrangement of Bridge

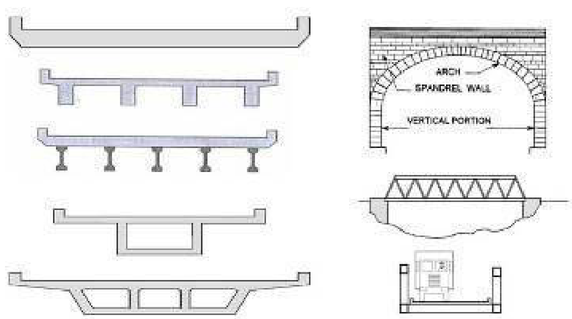


Figure 2-5: Type of Super structure arrangement for Bridge

Type of bearings: The type of bearings (such as Metallic, Elastomeric, POT / PTFE, Roller Bearings) provided with number of bearings at Abutment / Pier location shall be noted.

Figure 2-6: Bearing arrangement for Bridge

Substructure: The substructure of a bridge consists of the supports. The supports are the abutments (end supports) and the piers (intermediate supports).

Abutment: The type of Abutment (such as Solid Abutment, Spill Through, Slope Protected, other types) shall be recorded with the material used for construction (such as Stone Masonry / Brick Masonry, PCC, RCC)

Pier: The type of Pier (such as Wall Type, Circular (Single / Multi), Cellular, other types) shall be recorded with the material used for construction (such as Stone Masonry / Brick Masonry, PCC, RCC)

Return wall / Wing wall: The type of wall (such as Return wall / Wing wall, other types) shall be recorded with the material used for construction (such as Stone Masonry / Brick Masonry, PCC, RCC)

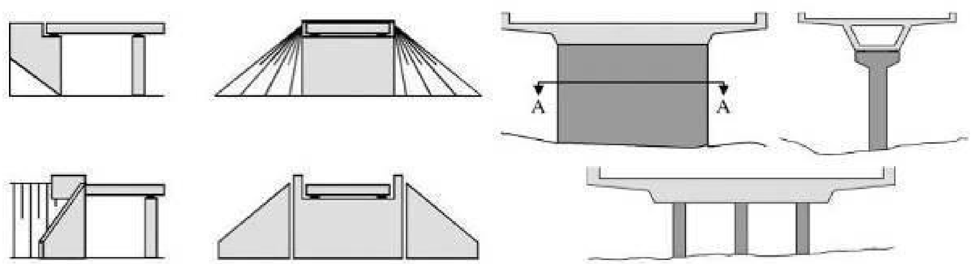


Figure 2-7: Abutment and Pier arrangement for Bridge

Foundation: The type of Foundation (such as Raft Foundation, Open Foundation, Pile Foundation, Well Foundation) shall be recorded with the material used for construction (such as Stone Masonry / Brick Masonry, PCC, RCC)

Figure 2-8: Foundation Arrangement for Bridge

Geo-technical and Hydraulic: which includes Type of Bed Material (such as Sandy, Gravelly, Boulders, Rocky) and hydraulic details such as waterway details, type of nalla / stream, HFL, details of Protection works shall be recorded.

Miscellaneous Details: such as type of wearing coat, type of expansion joint, Details of railing / parapet, drainage spout, footpath if provided, if there is any service line crossing over bridge and whether any sign board is provided on the bridge or at bridge approaches shall be recorded.

CHAPTER – 3

Bridge General Types and Defects

Chapter 3: Bridge General Types and Defects

The most commonly types of Bridges found on road network in Karnataka is as below

- Hume Pipe / MCPC Bridge
- Stone Slab Bridge
- Stone Masonry / Brick Masonry Arch Bridge
- RC Multi-Cell Box Bridge
- RC Solid Slab Bridge
- RC Girder Bridge
- RC Box Girder Bridge
- Composite I Girder Bridge
- Steel Truss Bridge

3.1 Hume Pipe (HP)

- These are generally provided with 900mm, 1000mm or 1200mm dia pipes.
- These type of structures are generally proposed where the design discharge is less.
- Pipe Structures Constructed 15 to 20 years back were with NP2 pipes which are designed for Light Traffic.
- Recently Constructed Pipe structures are with NP4 pipes which are designed to carry Heavy traffic (such as Present day vehicle loads / Railway loads).
- Structures with NP2 pipes will have to be replaced based on the condition as these are not designed for the present day loading conditions.

Most Common Defects observed

- **Cracks in Pipes:** Cracks may be defined as separating media in the body of concrete, this may be caused by overloading, vibration due to traffic loads, settlement of foundations Inadequate Cushion above Pipe, etc.

Headwall: is generally constructed with Stone / Brick Masonry or PCC, The main defects observed are

- Loosening of Pointing in between the stones / Bricks.
- Deterioration of bricks, stones or concrete blocks and
- Cracking due to failure or settlement of Foundations.

Table 3-1: Different Class of Non-Pressure (NP) Pipes

Class	Description	Conditions where Normally used
NP1	Unreinforced concrete non-pressure pipes	For drainage and irrigation use, above ground or in shallow trenches
NP2	Reinforced concrete, light-duty, non-pressure pipes	for drainage and irrigation use, for cross drains/culverts carrying light traffic
NP3	Reinforced and also unreinforced (in case of pipes manufactured by vibrated casting process) concrete, medium-duty. Non-pressure pipes	For drainage and irrigation use, for cross drains/culverts carrying medium traffic
NP4	Reinforced and also unreinforced (in case of pipes manufactured by vibrated casting process) concrete, heavy-duty, non-pressure pipes	Fur drainage and irrigation use, for cross drains/culvert carrying heavy traffic

Table 3-2: How to Differentiate between NP2 and NP4 Pipes

Pipe Dia (Inner)	NP2 (Thickness of Pipe)	NP4 (Thickness of Pipe)
900	55	100
1000	60	115
1200	70	120

Figure 3-1: Showing Difference between NP2 and NP4 pipe

Hume Pipe - Observations

- Check whether the pipe is **NP2 or NP4**.
- Check for any signs of settlement on road surface, this may be due to settlement of Pipes.
- Check for cracks in the Pipe barrel, this may be due to insufficient Cushion, Lesser load carrying capacity of Pipes or due to settlement (to be quantified in no. of pipes cracked).
- Check of any loss of Pointing / Plastering in headwall (to be quantified in sqm)
- Check for any Tilt in the Headwall, Any spalling / Deterioration of Stones from Headwall.
- Check for Cracks in Headwall (this may be due to Settlement).
- Check for Scour at Inlet and out let.

Figure 3-2: Showing Various condition of Pipe Structure

Hume Pipe - Overall Rating

Overall rating for Pipes

S. No.	Defects	Condition rating	BCI Valves
1	Cracks in Pipes	Reconstruction	< 30
2	Cracks in pipes at edges	Moderate Repairs Required	65-45
3	Pipes in good condition	Minor Repairs Required	80-65

Overall rating for Headwall

S. No.	Defects	Condition rating	BCI Valves
1	Serious weathering of stones, adjoining stones split, signs of slight tilt in Headwall, Severe scour at inlet or Outlet	Reconstruction	< 30
2	Loss of a significant amount of mortar with between 40 to 60 percent of mortar missing, slight scour at inlet / outlet	Moderate Repairs Required	65-45
3	Minor cracks being observed in the headwall, up to 10-20 percent of mortar may be missing	Minor Repairs Required	80-65
4	No sign of deterioration in masonry or mortar	Routine Maintenance Required	100-80

3.2 Mass Concrete Pipe Culvert (MCPC)

- These are generally with higher diameter varying from 2000mm to 3000mm in diameter
- These are generally proposed where the foundation soil has less bearing capacity.
- These type of structures are Constructed 15 to 20 years back.
- These types of structure needs to be proposed for Reconstruction if the structure is narrow or if the cracks in the pipes are beyond repair.
- These types of structures cannot be widened and hence these have to be proposed for Reconstruction
- Presently these type of structures are not proposed, as an alternative RC Box structure are proposed.

Most Common Defects observed

- **Cracks in Pipes:** Cracks may be defined as separating media in the body of concrete, this may be caused by overloading, vibration due to traffic loads, settlement of foundations, etc.
- Concrete cracks are due to thermal gradients (the difference between internal and external temperatures) in massive sections immediately following placement, and for a period of time thereafter
- **Headwall:** There is no separate headwall constructed for these type of structures as the entire structure is constructed monolithic with pipes.

Observations

- Check for any signs of settlement on road surface, this may be due to settlement of Pipes.
- Check for cracks in the Pipe barrel, this may be due to thermal variation in Concrete, Lesser load carrying capacity of Pipes.
- The Cracks in the Pipes have to be carefully observed (whether the Cracks are minor or Wider cracks.

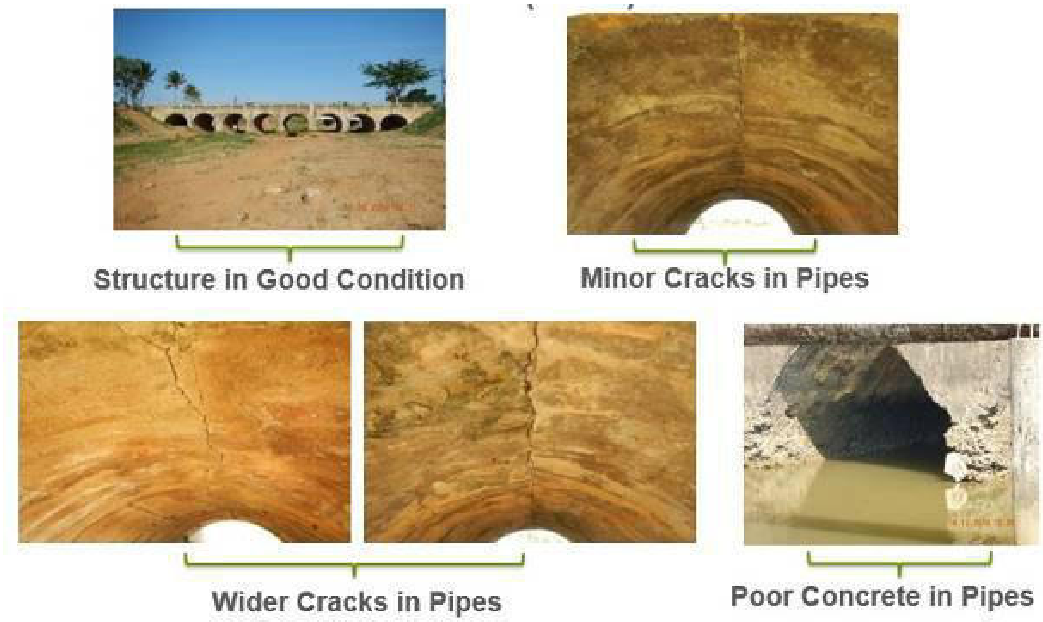


Figure 3-3: Showing various condition of MCPC Structure

Mass Concrete Pipe Culvert (MCPC) - Overall Rating

S. No.	Defects	Condition rating	BCI Valves
1	Wider Cracks more than 3 to 4mm all along the length of the Pipes which is beyond repair, severe scour at inlet / outlet	Reconstruction	< 30
2	Wider Cracks which can be arrested by further grouting and Minor Cracks at substantial locations, slight scour at inlet / outlet	Moderate Repairs Required	65-45
3	Minor cracks being observed in the Pipes, up to 1mm crack at few locations	Minor Repairs Required	80-65
4	No sign of deterioration / cracks in pipes	Routine Maintenance Required	100-80

3.3 Super Structure – Stone Slab

- These type of structure were constructed in earlier days, presently these are not proposed for any highway project.
- Stone slabs approximately of 200 mm thick have been used as superstructure in some bridges.
- Many were cracked and displaced as these type of slabs are not capable of withstanding IRC Class AA, Class A and Class 70 R live loading.
- The stress at the superstructure base, which is tensile in nature, is very high especially where the earth cushion is either negligible or non-existent.
- ***These type of structure are to be proposed for Re-construction or the stones slabs can be replaced with RC Slabs if the sub-structure is in good condition.***

Figure 3-4: Showing various condition of Stone Slab Structure

3.4 Concrete structures

Common reinforced concrete structures will not fail without an early warning such as coarse cracks and visible deflections, while connections in steel structures exposed to repeated loads may fail in fatigue without any other warning than very fine cracks. Therefore, potentially "dangerous" details of steel structures should be pin pointed in advance of the Principal Inspection in order to give these details a closer inspection

There are three ways in which concrete is used in bridges:

Types of concrete structures

- Plain cement concrete structures (PCC)
- Reinforced cement concrete structures (RCC)
- Prestressed cement concrete structures (PSC)

Concrete defects

The following main defects are associated with the concrete elements of bridges.

- Cracking
- Scaling / leaching / efflorescence
- Spalling
- Honeycombing / exposed reinforcement
- Concrete surface erosion
- Porosity
- Efflorescence, dampness, leakage

Cracking

Cracks may be defined as separating media in the body of concrete. Most concrete elements develop cracks. Fine and short cracks, like shrinkage and thermal cracks, may not pose significant problems but wide and long cracks can always be dangerous and indicative of serious defects and distress in concrete. This may be caused by overloading, over-stressing, vibration due to traffic loads, settlement of foundations, etc.

Structural cracks

A crack is a linear fracture in concrete. It may extend partially or completely through the member. There are two basic types of cracks, namely structural and non-structural cracks. Structural cracks are caused by 'dead' and 'live' load stress, foundation settlement, exceptional loading due to earthquakes, wind impact of vehicles, jammed bearings, etc. Cracking is considered normal, for mildly reinforced concrete, (e.g., in cast-in-place tee-beams), provided the cracks are small and there are no rust stains or other signs of deterioration present. Larger structural cracks indicate potentially serious problems as they are directly related to the structural capacity of the member. When cracks are observed opening and closing under loading, they are referred to as "working" cracks. Major structural cracks can be categorised as:

- Flexure cracks
- Shear cracks
- Bearing cracks
- Tensioned cracks
- Compression cracks
- Torsional cracks
- Splitting cracks

Flexure cracks: Flexure cracks are caused by tensile forces induced in concrete elements due to bending and therefore develop in the tension zones. Tension zones occur either on the bottom or the top of a member, depending on span configuration. Tension zones can also occur in substructure components. Tension cracks terminate when they approach the neutral axis of the member. If a beam is a simple span structure, flexure cracks can often be found at the mid-span and at the bottom of the member where bending or flexure stress is the greatest. If the superstructure is continuous over adjacent spans, flexural cracks occur at the top of members near their supports.

Shear cracks: Shear cracks are caused by diagonal tensile forces that typically occur in the web of a member near the supports where shear stress is the greatest. Normally, these cracks initiate near the bearing area, beginning at the bottom of the member and extending diagonally upward toward the centre of the member. Shear cracks with similar patterns also occur in abutment dirt walls, stems and footings, pier caps, columns, and footings.

Although structural cracks are mainly caused by ‘dead’ and ‘live’ load forces, they can also be caused by overstress in members resulting from unexpected secondary forces. Restricted thermal expansion, contraction (such as that caused by frozen bearings), forces due to the expansion of an approach slab, or failure of a dirt wall, can induce significant forces which may result in cracks.

A flexural shear crack is a combination of a flexural crack with a straight angle, turning into a 45 deg shear crack.

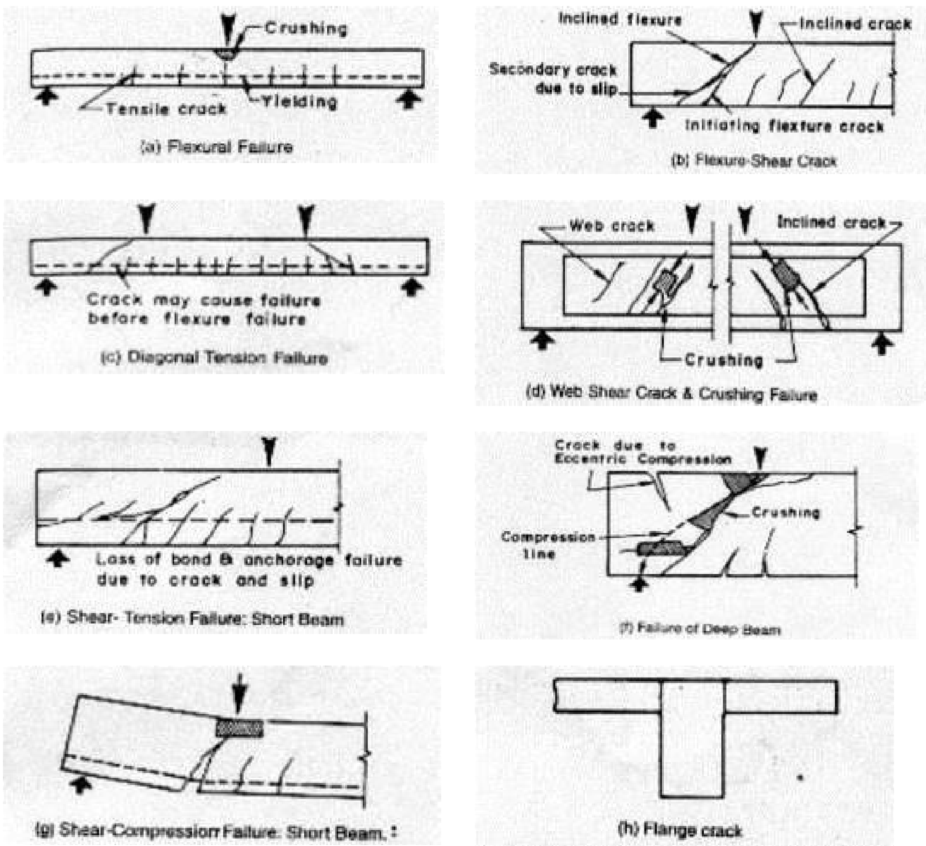


Figure 3-5: Types of Crack in Reinforced Concrete Beams

Figure 3-6: Flexural crack on T-Beam and Shear crack on Solid Slab

Bearing cracks: Bearing cracks occur at bearing locations in 'T' and 'box' girders. The failure of concrete at a bearing location under direct compression, or due to faulty construction, are the prime reasons for bearing cracks. Some typical examples of bearing cracks are shown below.

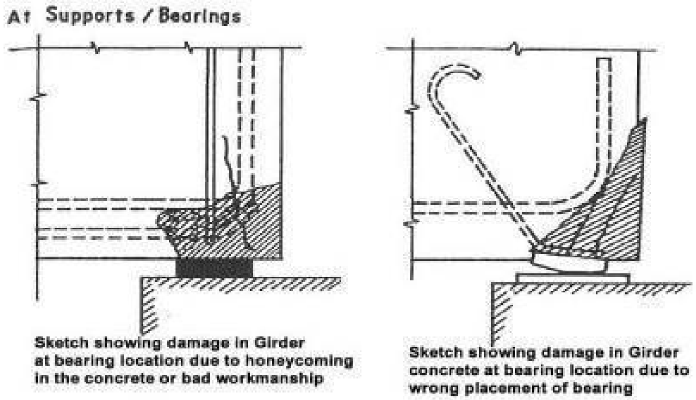


Figure 3-7: Bearing Cracks

Tension cracks: Tensile stress (pure or bending induced) will lead to cracking. Normally the tensile cracking of a concrete section, under loading, occurs when the tensile stress acting on a section is larger than its tensile strength or, when tensile strain exceeds the tensile strain capacity. Due to the very low tensile strength of concrete (less than 1/10 of its compression strength), it tends to crack under relatively low tensile stress.

Since in all reinforced concrete elements,'re-bar' is provided to carry the tensile force and stress, the development of tensile cracks provide good evidence of the lack of sufficient cross section reinforcement.

Compression cracks: In many instances, compression cracks occur as a result of honey combing, wrong placement of bearing, bad workmanship but are primarily due to economic compression in deep beams.

Torsional cracks: Where elements sustain torsion, torsional cracks occur. This normally happens in girders and diaphragms of highly 'skewed' superstructures. This type of crack develops at a 45 deg angle with respect to the members longitudinal axis and wraps around the element.

Torsional cracks will develop in the absence of sufficient longitudinal and transversal torsional reinforcement.

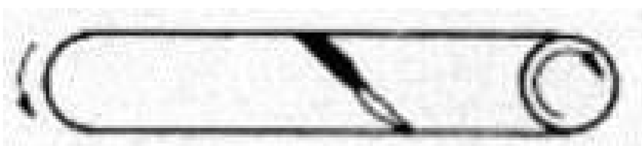


Figure 3-8: Torsional Cracks

Splitting cracks: Splitting cracks are due to highly concentrated loads on concrete, for example; at bearing points and in the anchorage zones for pre-stressing cables. Normally two types of splitting cracks are probable. The first type of splitting is located very close to the concentrated force which tries to split the concrete section locally. This is normally prevented by providing meshes of reinforcing bars. The second type is caused by the trajectory distribution of the force into the cross section, which will normally take place over a certain distance and is dependent on the geometric condition.

Non-structural cracks

Non-structural cracks result from internal stress due to dimensional changes. Non-structural cracks are divided into four categories:

- Temperature cracks
- Shrinkage cracks
- Mass concrete cracks
- Corrosion cracks
- Sulphate and chemical attack cracks

Whilst these cracks are non-structural and relatively small in size, they do provide an opening for water and contaminants which can lead to serious problems.

Temperature Cracks: Temperature cracks are caused by the thermal expansion and contraction of the concrete. Concrete expands or contracts as its temperature rises or falls. If the concrete is prevented from contracting, due to friction or because it is being held in place, it will crack under tension. Inoperative bearings and 'clogged' expansion joints can also cause this to occur.

Shrinkage Cracks: Shrinkage cracks are due to the shrinkage of concrete during the curing process. Volume reduction due to curing is also referred to as plastic shrinkage. Plastic shrinkage cracks develop on the finished surfaces of concrete, and in some cases even before finishing, due to the rapid drying of the surface whilst the body of the concrete is still 'plastic'. In non-reinforced concrete surfaces, cracks are diagonal as well as short and do not extend to the free edge. In reinforced concrete surfaces, the pattern of cracks may be different.

Mesh pattern drying shrinkage cracks develop in walls and slabs due to loss of moisture and the drying of the concrete surface. Development of drying shrinkage cracks may take a few weeks from the time of concreting and may continue for many years.

Mass Concrete Cracks: Mass concrete cracks are due to thermal gradients (the difference between internal and external temperatures) in massive sections immediately following placement, and for a period of time thereafter.

Corrosion Cracks: Corrosion of reinforcement is the primary, and possibly the most frequent cause, of the development of cracking in concrete structures. Corrosion is the rusting or oxidation of metal through contact with oxygen and chemicals in a damp atmosphere.

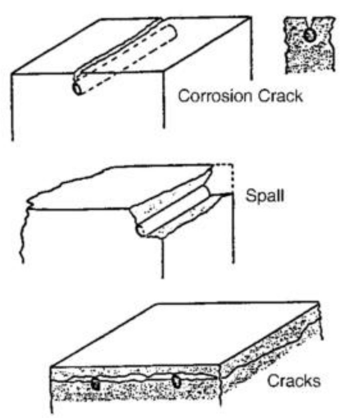


Figure 3-9: Development Procedure of Corrosion Cracks

Corrosion Cracks are caused by the "Rust pressure" of reinforcing bars. When steel corrodes, its volume increases and the resulting pressure start the cracking of the concrete cover of there-bar.

Sulphate and chemical attack cracks: Cracking due to sulphate attack occurs near or below ground level and is due to the sulphate salts found in damp ground. This type of cracking is severe and can gradually cause the total disintegration of concrete. These types of cracks can also be caused by chemical attack from pollutants found in water and affect parts of both piers and abutments that are in direct contact with polluted water.

Notes on non-structural cracks: Temperature, shrinkage, and mass concrete cracks typically do not affect the structural strength of a concrete member significantly.

Figure 3-10: Temperature Cracks and Shrinkage Cracks

In concrete bridge decks, temperature and shrinkage cracks can occur in both the transverse and longitudinal direction. In retaining walls and abutments, these cracks are usually vertical, whilst in concrete beams, these cracks can occur either vertically or transversely over the member. However, since temperature and shrinkage stress exists in all directions, the cracking could have other orientations.

Engineers must therefore exercise care in distinguishing between non-structural and structural cracking. However, regardless of the type of crack, water generally 'seeps' in and causes corrosion of the reinforcement. The corroded reinforcement then expands and exerts pressure on the concrete. This resultant pressure can then cause de-lamination and spalling.

Orientation of cracks

In addition to both classifying cracks as either structural or non-structural and, recording their lengths and widths, inspectors must also describe the orientation of the cracking. The orientation of the crack, with respect to the load and supporting members, is an important feature that must be recorded accurately to ensure the proper evaluation of the cracking. The orientation of cracks can generally be described using one of the following four category types:

- Transverse cracks
- Longitudinal cracks
- Diagonal cracks
- Map cracking

Transverse cracks: Fairly straight cracks that is roughly perpendicular to the centreline of the bridge or a bridge member.

Longitudinal cracks: Fairly straight cracks that run parallel to the centreline of the bridge or a bridge member.

Diagonal cracks: Cracks that are skewed (at an angle) to the centreline of the bridge or a bridge member, either vertically or horizontally.

Map cracking: Inter-connected cracks that form networks of varying size. They vary in width from barely visible fine cracks to cracks with a well-defined opening. Map cracking resembles the lines on a road map.

Figure 3-11: Pattern or Map Cracks

Figure 3-12: Longitudinal Cracks

Classification and measurement of cracks

Crack size is very important in assessing the condition of an 'in-service' bridge. Cracks may extend partially or completely through the concrete member. Where there is reinforced concrete, cracking will usually be large enough to be observed with the naked eye.

Cracks can be classified as hairline, narrow, medium, or wide. Hairline cracks are small and cannot be measured with normal equipment, such as a six-foot rule. Medium and wide cracks are cracks that can be measured by simple means or, a crack gauge. On conventionally reinforced structures, hairline cracks are usually insignificant. All other crack widths may be significant and should be monitored and recorded in the inspection notes.

On pre-stressed structures, all cracks are significant and an optical crack gauge is the correct instrument required to measure and differentiates the cracks.

When reporting cracks, the length, width, location, and orientation (horizontal, vertical, or diagonal) should be noted. Both large and small cracks in main members, especially in pre-stressed members, should be carefully recorded. The presence of rust stains or efflorescence or, evidence of differential movement on either side of the crack, should be noted.

An important identification, which is of direct importance for structural safety, is to identify whether or not the crack is a 'through' crack, given that 'through' cracks are extremely dangerous as they destroy the integrity of the concrete element.

For many years, the highest authorities accepted, in an arbitrary manner, the values of 0.1 mm for a crack in an extremely aggressive environment (marine atmosphere for example), 0.2 mm for a normal external atmosphere and 0.3 mm for a sheltered structure. In fact, to comply with these values -especially the first one -is tantamount to limiting the steel stress to an excessively low value of about 100 MPa, this figure being adjusted according to the diameter and the bond qualities of the reinforcement; however, numerous experiments have established that the corrosion risk was far more likely to be linked to concrete perviousness than to the opening of cracks; up to an opening of a few tenths of a millimetre, cracks do not constitute a real hazard, as was often believed.

Table 3-3: Classification of Cracks with respect to their Width (as per Federal Highway Administration of US Department)

Definition	Reinforced Concrete	Prestressed Concrete
HAIRLINE (HL)	< 1.6mm	< 0.1mm
NARROW (N)	1.6 to 3.2mm	0.1 to 0.23mm
MEDIUM (M)	3.2 to 4.8mm	0.25 to 0.76mm
WIDE (W)	> 4.8mm	> 0.76mm

The cracks should be measured using:

- Crack film
- Crack gauge

- Glass tell-tale
- Optical crack gauge

Scaling/leaching/efflorescence

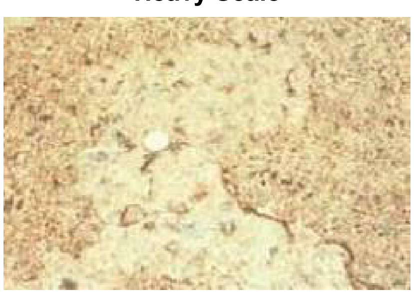
Scaling is the gradual and continual loss, over an area, of surface cement paste and aggregate due to the chemical breakdown of the cement bond. Scaling is accelerated when the member is exposed to a harsh environment. Scaling is classified under the following four categories:

- **Minor scaling -** loss of surface cement paste up to 6 mm deep, with surface exposure of coarse aggregates.
- **Medium scaling -** loss of surface cement paste from 6 to 13 mm deep, with cement paste loss between the coarse aggregates.
- **Heavy scaling -** loss of surface cement paste from 13 to 25 mm deep; coarse aggregates are clearly exposed.
- **Severe scaling -** loss of coarse aggregate particles, as well as surface cement paste and the mortar surrounding the aggregates; depth of the loss exceeds 25 mm; reinforcing steel is usually exposed.

Light Scale

Medium Scale

Heavy Scale



Severe Scale

Figure 3-13: Various types of Scaling

Spalling

A spall is a 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 corrosion of reinforcement, friction from thermal movement, and over stress in concrete. Reinforcing steel is often exposed in a spall, and the common shallow pothole found in a concrete deck is often considered as a spall. Spalls are classified as follows:

- **Small spalls –** not more than 25 mm deep or approximately 150 mm in diameter
- **Large spalls –** more than 25 mm deep or greater than 150 mm in diameter

Figure 3-14: Small Spalling to Large spalling on a Concrete Deck

When concrete is over-stressed, it flexes or fractures. Over time, the fracture widens from debris, freeze/thaw cycles, or further over-stressing. This cycle continues until a spall is formed. Spalls caused from over-stress are very serious and should be brought to the immediate attention of the Chief Bridge Engineer. Most spalls are caused from corroding reinforcement but, if the spall is located at or near a high moment region, over-stress may be the cause. Examples that might indicate a spall has been caused by over-stress include:

- A spall that is at or near flexure cracks in the lower mid-span portion of a beam
- A spall that is at or near flexure cracks in the top of a continuous member, over a support

Similarly, when concrete is over-stressed in compression, it is common for the surface to spall.

When reporting spalls, the inspector should note the location of the defect, the size of the area, and the depth of the defect.

Honeycombing / Exposed Reinforcement

Concrete is made from course aggregates, sand, cement and water, in a pre-selected proportion. The quality of concrete depends upon many factors, the major ones being, water/cement ratio and workmanship. An improper water cement ratio leads to porous and honey combed concrete. In general, honey combing in concrete may occur due to: grout loss; inadequate compaction; congestion of reinforcement; the using of course aggregate not properly graded and, the using of less fine aggregates resulting in less mortar being available to fill the voids between the course aggregates. In some cases, honeycombs are the result of insufficient vibration, where the entire concrete mix does not physically reach the form surface.

Honeycombing in concrete allows diffusion of moisture, carbon dioxide and oxygen inside the void space. The moisture carries chloride salts from the atmosphere and creates a favourable condition leading to corrosion of reinforcement, which is one of the basic reasons for cracking.

Figure 3-15: Honeycomb of Concrete

Concrete surface erosion

Wherever water at high velocity carries suspended gravel, sand or silt, then erosion of the concrete surface can be expected. Less than perfect work or poor concrete materials produce a layer of friable material on the surface; which is particularly susceptible to erosion. The friable material consists mainly of cement laitance and fine sand, which is eroded rapidly. Thereafter, the rate of erosion is usually constant.

Where the coarse aggregate is a hard material, such as flint aggregate or granite, the rate of erosion is related directly to the quality of the matrix surrounding the aggregate. The higher quality of this matrix increases the resistance to erosion. Where the coarse aggregate is of a weak material, such as poorly cemented sandstone, then this material, not the mortar, will control the rate of erosion.

In hot arid regions, the outer skin of concrete may be eroded by sand storms with the effect being comparable to sand-blasting.

The consequences of erosion, when this is deep and/or exposes the reinforcement, will be similar to that of "Spalling".

Porosity

Porosity in concrete may occur due to high water loss, inadequate compaction, congestion of reinforcement, the use of coarse aggregates not properly graded or, the use of non fine aggregates thus leaving less mortar to fill the voids between the coarse aggregates, etc.

The porosity in concrete allows diffusion of moisture, carbon dioxide and oxygen inside the void space. The moisture carries chloride salts from the atmosphere and creates a favourable condition for the corrosion of reinforcement, which is the primary cause for the development of cracks in concrete structures.

Figure 3-16: Exposed and Corroded Reinforcement in Sub Structure

The porosity in concrete allows diffusion of moisture, carbon dioxide and oxygen inside the void space. The moisture carries chloride salts from the atmosphere and creates a favourable condition for the corrosion of reinforcement, which is the primary cause for the development of cracks in concrete structures.

Efflorescence, Dampness, Leakage

Efflorescence is the formation of whitish porous powder on a concrete surface. This indicates that the concrete is porous or cracked and provides for an increase in the acidity in the moisture content of the concrete due to a reduction of PH value, which is caused by the reaction of atmospheric carbon dioxide with calcium hydroxide in hydrated cement. Corrosion of steel can begin at such places.

Dampness of concrete surfaces at the soffit of a structural element and, signs of water leakage are also evidence of concrete defects such as deterioration, voids, cracks, etc.

Chemical attack

Aside from accelerated rebar corrosion, the use of salt or chemical de-icing agents contributes to weathering through re-crystallisation.

Sulphate compounds in soil and water are also a problem. Sodium, magnesium, and calcium sulphates react with compounds in cement paste and cause rapid deterioration of the concrete.

Alkali-silica reaction (ASR) is a reaction between the alkalis in cement with the silica molecules of various aggregates. When the reaction takes place, a gel-like substance is formed. Once exposed to moisture, the gel expands and causes cracking in the concrete.

3.5 Masonry

Figure 3-17: Masonry Bridge

Since bricks and stones are durable and low maintenance materials, they have been both previously and frequently used in the construction of: spread footings (open foundations); piers; gravity abutments; retaining and wing walls, as well as, arch bridges and culverts, primarily due to their wide availability from rock cuts or local brickyards. Well maintained masonry bridges and culverts have lasted for more than a century.

The amount of durability that a stone or brick has, depends on how well it can resist rain, wind, dust, frost action, heat, fire, and air borne chemicals. Some stones are so durable that they may be maintenance free for more than two hundred years, whilst others may require maintenance after about ten years.

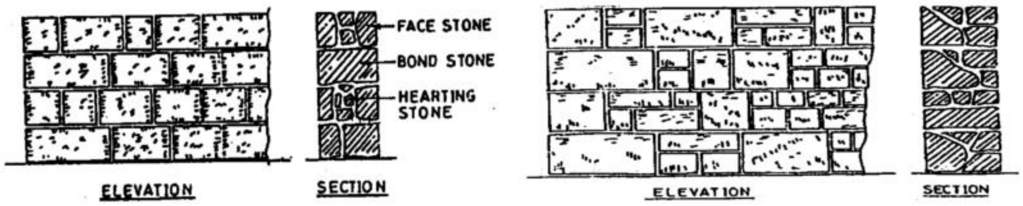
Porosity in a stone or brick member depends on the amount of open or void spaces within that member. All stones and bricks have some degree of porosity. Those which are less porous can resist environmental effects better than stones or bricks with a higher degree of porosity. Water absorption is directly related to the degree of porosity.

Masonry has a good strength in compression, but weak in tension. Although stone, brick or concrete blocks have shear resistance capacity, the mortar joints make the masonry structure less strong in the carrying of shear forces.

Types of masonry works

The following major types of masonry work can be used in bridges:

- Stone masonry: Using the following two types of coarse rubble masonry;
- Face stones are dressed and all stones are normally laid in courses of equal height
- Courses may be of different heights, but each course shall be of equal height throughout.
- Brick masonry
- Concrete blocks



First Sort **Second Sort**

Figure 3-18: Coursed Rubble Stone Masonry

Protection of Masonry by Pointing / Plastering

Pointing is the compacting of mortar into the outmost portion of a joint and the towelling of its exposed surface to secure water tightness or a desired architectural effect, as well as, the replacement of deteriorating or deteriorated mortar.

In order to provide a protective cover to masonry, the surfaces of masonry in contact with water or air are sometimes plastered to protect the structure against fast flowing rivers, and a severe and/or aggressive environment. Plastering is more frequently used on brick masonry than stone masonry.

Type of Defects

Normally the following defects are associated with masonry work:

- Cracking
- Bulging
- Loss of pointing
- Deterioration of stone, concrete blocks or bricks
- Defects in plaster
- Cavities

Cracking

Cracking is an indication of distress in masonry. It can be caused by over-loading, vibration or impact from traffic. Failure or settlement of foundations, change in temperature or, alternate wetting and drying can also cause cracking.

Cracking weakens the masonry and allows the ingress of water and soil. Plants and small trees can also grow in cracks. This causes the cracks to further widen. It is not easy to determine the cause of cracking. Masonry expands and contracts with changes in temperature and moisture content. The resulting cracks normally pass only through mortar joints. However, cracks which cross bricks, stones or concrete blocks, are usually serious. These cracks can be caused by either over-loading or by failure in foundations. All large cracks should be meticulously mapped.

Figure 3-19: Cracks, Loss of Mortar at Joint in Masonry Substructure

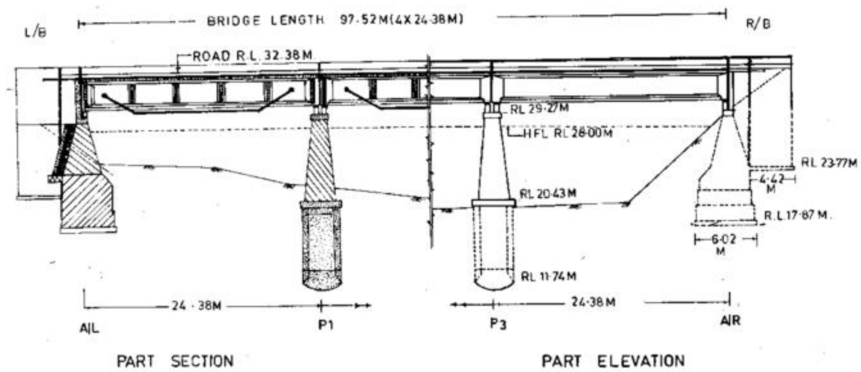


Figure 3-20: Typical Masonry Abutment and Pier

Cracks should be considered `serious' when:

- Cracks cross the masonry element (i.e. Stones, bricks, or concrete blocks)
- Cracking occurs near bearings
- A step occurs in the face of masonry
- Cracks are about 5mm and wider
- The crack crosses the entire thickness of the structural component (e.g. through the pier wall)

Bulging

Bulging is a change in the shape or curving of the face of the masonry element. It is usually caused by excessive back-pressure. Bulging of masonry parapets can be caused by vehicular impact. The force/pressure exerted by the soil behind such a structural masonry element can increase due to the saturation of the fill, if the drainage is inadequate or blocked. In order to drain a fill, weep-holes are provided in the abutments and earth retaining structures e.g. return walls. Weep holes sometimes get choked thus causing the saturation of the fill. Saturation may also be caused by vibration or compaction caused by heavy vehicles or, by shaking caused by earthquakes. The height of fill may also increase over the years and the mortar usually becomes weaker with age, thus causing bulging. Bulging should be mapped and measured with the help of a plumb-line, or other measuring devices, where possible.

Loss of pointing

Pointing is the mortar between bricks, stones or concrete blocks and is generally exposed. The mortar can be eroded or deteriorated through the action of a river or by rain. Pointing is usually weaker than the stones or bricks and deteriorates with age. The loss or weakening of pointing can cause stones or bricks to loosen, move or even fall off. Re-pointing should be done periodically.

Deterioration of bricks, stones or concrete blocks

Many weaker types of bricks or stones have a shorter life. They can be worn away by weathering, rainwater or river flow. 'Peeling Off' or 'De-lamination' can be caused by alternate heating and cooling and changes in the moisture content of the air.

Tapping the stone or brick face lightly with a hammer can cause pieces to break off. This indicates the presence of deterioration or weathering. It may then be necessary to protect the surface with a hard mortar, gunite or shotcrete.

Defects in plaster

The plaster covering of masonry structures may suffer from two different categories of defect, namely:

- those originating from the main masonry structural components and,
- those associated with the plaster cover
- The plaster cover normally shows non-structural defects which are not serious, e.g. surface cracks, loss from masonry surface, erosion, spalling, etc. However, the defects which affect and
- deteriorate the plaster cover (such as bulging, spalling, through cracks, etc.) should be deemed "serious" structural defects.

Cavities

The presence of cavities in masonry work is normally a construction defect. This occurs due to poor workmanship. Improper pointing can also result in missing and / or splitting of stones or brick units.

Other defects

Chemicals: Gases or solids dissolved in water often attack stones, concrete blocks, bricks and the mortar cementing compounds between such. The oxidisation and hydration of some compounds found in rock can also cause damage.

Volume changes: Seasonal expansion and contraction can cause tiny seams to develop, which weaken the stones and bricks.

Erosion / Abrasion: This is primarily due to wind or waterborne particle abrasion of the exposed surfaces of the masonry structure.

Vegetation Growth: Roots and stems of vegetation growing in crevices or joints can exert a wedging force, which can result in bulging or spalling of the masonry. Some plants may also produce chemicals which attack the stone surface.

Measurement of defect

Cracking

All cracks wider than 3mm should be mapped with the cracks being measured with the use of:

- Crack film
- Creak gauge
- Crack comparator card
- Scales

Bulging

Bulging should be mapped and measured with the help of tape, scale, etc. The bulge area is of major concern. Bulges observed in abutments are more serious than these observed in return walls. When a bulge has a horizontal crack, precise notes are required as this is a serious problem.

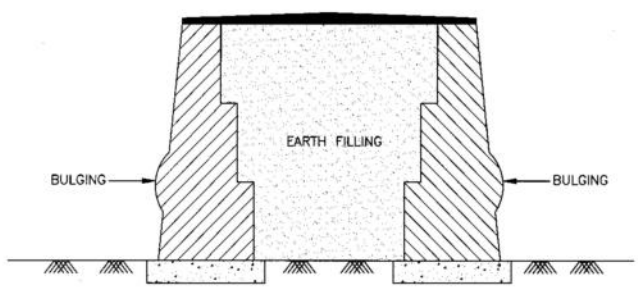


Figure 3-21: Bulging of a Masonry Retaining Wall

Loss of pointing

This can be visually inspected. Areas affected by loss of pitching can be measured using a tape.

Deterioration of brick, stones and concrete blocks

The area affected by deterioration can be measured using a tape.

Cracks in plaster

Fine cracks are measured using a crack gauge. A simple metal gauge or crack-gauge film is all that is required to measure crack width.

However, cracks transferred from the stone masonry structure to the plaster, are “serious” defects and require to be measured as defects as a part of the main structural component.

Cavity / Porosity

By tapping on the stone concrete block or hammering on the brick face surface, where a cavity exists the sound will be different from that of solid masonry. The member should be tapped at different locations to find the weak spots. Areas that are affected should be marked with chalk and measured with the aid of a tape and/or scale.

Special considerations

Many older bridges have piers and abutments that are constructed of masonry. The types of stone commonly used are granite, limestone, and sandstone. Problems that are found to be prevalent in masonry structures include cracking, scaling, and deterioration of pointing.

Masonry is a naturally porous material and is susceptible to deterioration through weathering. The stone may fracture and break off in small pieces with the mortar deteriorating like concrete. Mortar joints near the waterline are the most susceptible to this type of damage. The abrasive action of sand in water may cause underwater masonry to experience losses in both the masonry and the pointing. Record the location, length, width, and penetration of defects in the areas of deterioration.

When appropriate, check the condition of the mortar between masonry elements. The mortar should be firm and intact and not soft, crumbling or missing. Examine the pattern of the masonry elements to determine if any movement has occurred. When inspecting masonry arches, determine if any stones appear to be “slipping”. Also visually inspect other masonry elements for deterioration and cracking.

Inspect any old repairs, specifically replacement of stones or bricks and carefully note and report on these.

Figure 3-22: Concrete Superstructure on Brick Masonry Substructure

Note:

Defects and notings in individual types of super structures, substructures, bearings and other miscellaneous items are dealt separately as below

CHAPTER – 4

Super Structure

Chapter 4: Super Structure

4.1 RCC Solid Slab

Basic concepts

A 'cast-in-place' reinforced concrete slab is the simplest type of bridge and is generally used for bridges with a span length of up to 10 metres. The Ministry of Surface Transport [MOST] standard designs for RCC slab bridges provide detailed drawings for a span range of between 6 to 10 meters with varying deck configurations. These are widely used in Karnataka.

A slab functions as a wide shallow rectangular beam and may directly rest on tar paper bearings at pier/abutment caps, or on elastomeric bearings. Simply supported single span slab bridges are the most common type, although, continuous multi-span bridges are also used.

Reinforcement: In single span slab bridges, the load only develops positive moment and the primary, or main tension reinforcement, is therefore required at the bottom of the slab. The reinforcement is placed longitudinally, from support to support, parallel to the direction of traffic. In continuous spans, additional primary reinforcement, at the top of the slab over the piers, is needed longitudinally in order to resist negative bending moments.

Secondary reinforcement, known as temperature and shrinkage steel, is located transversely throughout the top and bottom of the slab. In simple span slabs, nominal temperature/shrinkage reinforcement is also located longitudinally at the top of the slab.

In continuous span slabs, the primary reinforcement is often placed over the entire structural length, negating the need for longitudinal secondary reinforcement.

Nearly all slab bridges are provided with a grid or mat of steel reinforcement at the top and bottom of the slab.

Figure 4-1: A Reinforced Concrete Slab Bridge

Components of RCC solid slab

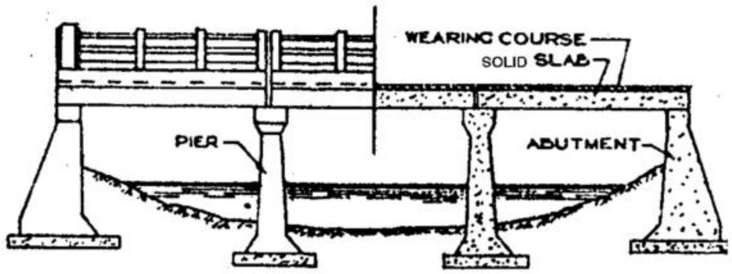


Figure 4-2: Simply Supported RCC Solid Slab

The only super-structural member in this type of bridge is the slab. Normally the slab has a uniform thickness throughout the span although in some bridges the slab thickness may be reduced at the edges.

Common defects

For the common defects of concrete and the evidence of such, reference should be made to ***Chapter - 3.*** However, additional information is given below, where required.

It should be noted that only the soffit and the side faces of the slab are visible as the wearing coat normally covers the top surface of the slab. However, based on the extent of the deterioration, the inspection results may call for additional investigations and tests of the top of the slab.

Defects related to Honeycombing of concrete, Spalls in concrete, Efflorescence, dampness, leakage, Cracking and Corrosion of exposed reinforcement shall be inspected and noted as explained in ***Chapter - 3***.

Honeycombing

Spalling at Soffit of Slab

Reinf. Exposed and Corroded

Figure 4-3: Showing various condition of RC Slab Structure

Deflection

Vertical movement of structural elements is known as deflection. In bridge decks, deflection is normally a combination of the effects of 'dead' and 'live' loads.

In slab bridges, as well as other reinforced concrete bridges, deflection due to dead loads occurs immediately after the load is applied and remains constant throughout the bridge life, other than very minor changes due to creep and shrinkage. It is common practice to rectify the dead load deflection by cambering the super-structure, during construction, equal to the calculated deflection. Almost no deflection due to dead load effects should therefore be observed in bridge super-structure. However, in some cases, improper scaffolding results in sag of the mid-span, which should be differentiated from deflection.

On the other hand, deflections always occur with live loads due to the 'elastic' behaviour of structural elements. These are, nevertheless, reversible. This type of deflection should not be excessive for reasons of aesthetics, user discomfort and, possible damage to the whole structure.

Limitations are generally expressed as a deflection to span ratio. IRC generally limits live load bridge deflection without footpath to 1/800, and for bridges with footpaths to 1/1000.

In simply supported single-span bridges, maximum deflection usually occurs in the mid-span. However, all spans should be observed with the passage of live loads (traffic). Any excess deflection, vibration or unusual noise with passage of vehicles must be noted as this can indicate overstress. A length of string can be used for checking vertical deflection.

Figure 4-4: Excessive Deflection at Mid-span

Inspection procedure

Visual: The inspection of concrete slabs for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer or will be revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical: The physical examination of a slab with a hammer is laborious and so in most cases a chain drag is used. A chain drag is made of several sections of chain attached to a pipe with a handle attached. The inspector drags this across a slab and makes note of the resonating sounds. A chain drag can usually cover about a 1.0m wide section of slab.

Many of the problems associated with concrete bridge slabs are caused by corrosion of the rebar. When the deterioration of a concrete slab progresses to the point where it requires rehabilitation, a detailed inspection of the slab is required to determine the extent, cause, and possible solution to the problem.

Where to look

Bearing Areas: Examine each of the bearing areas for spalling, this being where the friction from thermal movement, or bearing pressure, could cause the concrete to crack or spall.

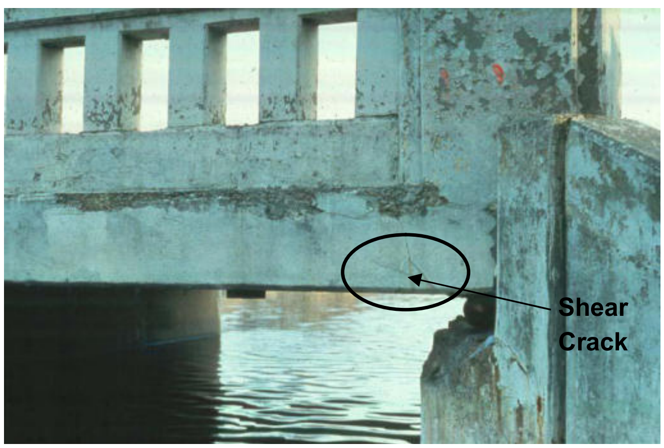


Figure 4-5: Shear Cracks at Ends

Shear zones: Investigate areas near the supports for shear cracking. The presence of transverse cracks at the slab soffit, near supports, or diagonal cracks at the sides of the slab indicates the onset of shear failure. These cracks represent low shear capacity and should be carefully measured.

Tension zones: Tension zones should be examined for flexure cracks which will be vertical on the sides and transverse across the slab. The tension zones are at the mid-span, along the slab soffit, for both simple and continuous span bridges. Additional tension zones are located on the top of the slab, and over the piers for continuous spans. Cracks wider than 4 mm are considered wide cracks and indicate extreme bending stresses. Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel may become exposed due to spalling.

Document the remaining cross section of reinforcing steel since section loss will decrease load carrying capacity.

Areas exposed to drainage: Inspect areas exposed to carriageway drainage for deteriorated concrete. This includes the entire riding surface of the slab, particularly around drains. Spalling or scaling may also be found along the kerb.

How to quantify the defects

Span, width, thickness

Centre to centre distance between expansion joints should be measured using a measuring tape to establish the span length. The width and thickness should also be measured using a measuring tape.

Honeycombing and the quality of concrete

Hit the slab with a hammer at a rate of 10 blows per 1 square meter area. Listen to the sound carefully. A hollow sound indicates poor concrete / honeycombing / voids, whereas, a metallic sound indicates good quality concrete.

Spalls in span

Number of spalls	Can be counted
Area of spalls	Can be measured with a measuring tape
Depth of spalls	Can be measured
Number of bars exposed	Can be counted
% of corrosion	Simple arithmetic calculation

Efflorescence, dampness and leakage

Number of affected locations at each span can be inspected visually and recorded.

Cracking in span

Nature of crack	Inspect to ascertain if the cracks, are horizontal, inclined, mesh or diagonal
Length of crack	Use a measuring tape
Width of crack	Use a crack gauge
Total area	Simple arithmetic calculation
Section of Super-structure	Locate visually

Corrosion of exposed reinforcement

Number of location	Can be counted
Location	Can be identified with respect to span length and width
% with respect to bar diameter	Simple arithmetic calculation
Pit corrosion	Visual inspection

Vertical deflection

No deflection	By observation
Moderate deflection	By observation/measurement and with the aid of a string line
Excessive deflection	By observation/measurement and with the aid of a string line

Water ponding

Number of locations where ponding of water occurs can be visually inspected. If the ponding occurs at mid span it is an indicator of span deflection.

Concrete discolouration

Number and location of where the concrete has discoloured, can be visually determined.

Overall Observation for rating of RCC Solid Slab

The elements detailed on the data form should be assessed, depending on the severity of damage at the time of inspection. The following should therefore be checked by the Engineer and Quantified for each element

- Inspect for honeycombing or disintegration, spalling etc.
- Inspect efflorescence, dampness and leakage if any. Any evidence of water passing through cracks in the slab.
- Inspect cracking, nature of cracks and location, should be explained, preferably by drawing a sketch, detailing whether these are longitudinal, horizontal, diagonal, etc.
- Report corrosion of reinforcement and reduction in bar diameter, if any.
- Report excessive deflection or loss of camber, if any.
- Observe ponding and also identify where the concrete has been discolored.
- In the case of an asphaltic wearing surface, the real condition of the slab may not be visible. In such cases, large cracking in the wearing surface are often indications of slab damage.

Table 4-1: Details of Defects for RCC Solid Slab

Types / Defects	Heavy	Moderate	Low
Spalling	More than 50% of total area spalled	Between 25% and 50% of total area spalled	Less than 25% of total area spalled
Deflection	Greater than 10mm	5mm to 10mm	Less than 5mm
Corrosion	Diameter of the bar reduced more than 20% of original diameter	Diameter of the bars reduced to 10% to 20% of original bar diameter.	Diameter of the bars reduced to less than 10% at the original bar diameter.

Condition rating of reinforced concrete solid slabs

Table 4-2: Guidelines for Condition Rating

Sl. No.	Defects	Condition rating	BCI Values
1	Excessive vertical deflection due to live load, Crack Width more than 4mm, heavily corroded reinf.	Re-construction / New Construction	< 30
2	Crack Width around 2 to 3mm	Requires Strengthening / Rehabilitation	45 - 30
3	Excessive spalling of concrete with moderately corroded reinforcement		
4	Moderate vertical deflection	Moderate Repairs Required	65 - 45
5	Moderate spalling of concrete		
6	Small spalling of concrete	Minor Repairs Required	80 - 65
7	Pit corrosion of reinforcement		
8	Efflorescence, dampness, discoloration of concrete		

4.2 RCC T-Beam and Deck Slab

Definition

The concrete tee-beam, a predominant bridge type for the last 50 years, is generally a 'cast-in place' monolithic slab and stem system formed in the shape of the letter 'T'. The 'cast-in-place' T-beam is the most common type of T-beams.

RCC T-beam and slab super-structure is widely used in Karnataka for span ranges of 12 to 24 metres, mainly in the form of simply supported single span bridges. In this case, T-girders are of constant depth and stem width throughout the span. The RCC T-beam and slab system is also adopted in continuous super-structures, in which the depth of T-girders may vary along the spans (normally longer than simply supported, single span types), in terms of being deeper close to piers and shallower at mid spans.

Figure 4-6: Simply-Supported T-beam and Slab Bridge of Constant Girder Depth

Basic concepts

The number and spacing of the T-beams depends on the overall deck width, as well as the span length, and may vary from 1 to 2.5 meters. MoST has produced standard designs for single-span simply supported T beam super-structure for a spans ranging between 12 to 24 metres and for various widths and deck configurations (with/without footpaths, different railing and crash barrier types, various widths, etc. The bottom portion of stem is normally slightly wider (girder bulb) to provide sufficient room for main longitudinal reinforcement of the girder.

The common practice is for the girders to be formed and 'cast-in-place', with the deck slab then being cast on top and integrated into the girders by means of shear bars protruding out of the girders. The slab and stem are constructed of the same class of concrete, hence, the system must not be deemed as "Composite". The slab portion of the beam is constructed to act integrally with the stem, thus providing greater 'stiffness' and thereby allowing increased span length. Figure below shows a schematic cross section of MoST standard RCC T-beam super-structure. Overall super-structure depth depends on span length and, in the case of

MoST standard designs, varies between 200mmto 250mm thicknesses of the slab and is a function of girder spacing but it is not normally less than 200mm.

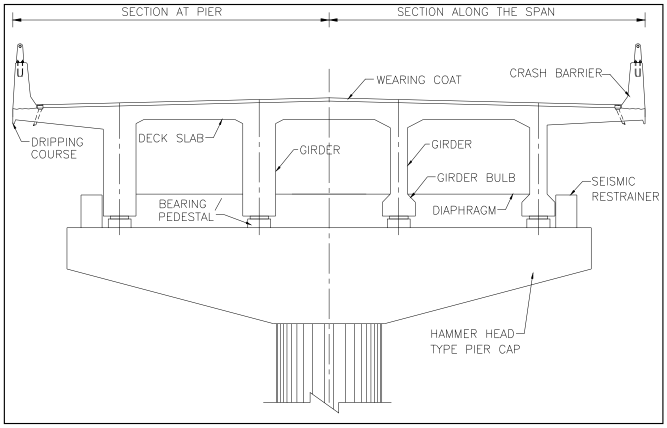


Figure 4-7: Schematic Cross Section of RCC T-beam & Slab Super-Structure System

Steel reinforcement:

The primary (tension) reinforcing steel consists of main tension reinforcement and shear reinforcement or stirrups. The main tension reinforcement is located in the bottom of the beam stem and oriented longitudinally. If the concrete T-beams are continuous, there will be longitudinal reinforcement close to the top surface of the slab over the piers. The sides of the stem contain primary vertical shear reinforcement, called stirrups, and these are located throughout the length of the stem at various spacing as required by the design. Stirrups are generally U-shaped bars and run transversely across the bottom of the stem.

The need for stirrups is greatest near the beam supports where shear stresses are the highest. The secondary (temperature and shrinkage) reinforcing steel for the stem is orientated longitudinally in the sides. The primary and secondary reinforcing steel for the slab portion of the beam is the same as for a standard concrete slab. Figure below shows a conceptual sketch of T-girder and slab super-structure system.

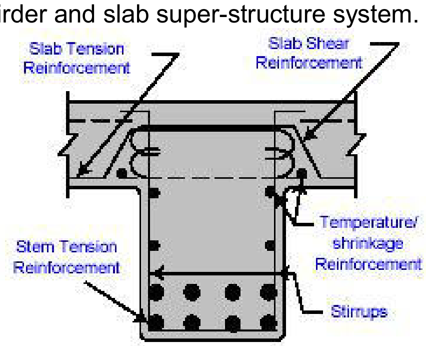


Figure 4-8: Schematic Steel Reinforcement Arrangement of Concrete T-beams

Components of RCC T-beam and deck slab

The main (primary) components of a T-beam bridge are the T-beam stem (web) and slab (flange). The only secondary members of an RCC T-beam super-structure are diaphragms (or cross-girders), which support the free edge of the beam flanges. An intermediate diaphragm may also be present in longer span bridges, usually at half or third points along the span.

However, in many older T-beam bridges, diaphragms are not used. In many of the old bridges, the diaphragms are not integrated with the deck slab, whereas in newer bridges the diaphragms, girders and deck slab are fully monolithic. The diaphragms are designed as simple beams and should be inspected for flexural and shear cracks, as well as, for typical concrete defects. Diaphragms are important in the distribution of live loads between the girders. The end diaphragms should also be able to carry the dead / live loads of the super-structure when the deck is 'jacked up' for the purpose of repair and or replacement of the bearings. The jacks will actually transfer the load between pier/abutment cap and the diaphragm.

Figure 4-9: End Diaphragm Monolithic with Deck Slab

Figure 4-10: T-beam and Slab Bridge without Diaphragm

Figure 4-11: End Diaphragm not integrated into Deck Slab

Common defects

The common defects of concrete and the evidence of such defects are detailed in ***Chapter - 3***. The defects associated with RCC T-beam bridges are listed below with any additional information being given wherever necessary.

Honeycombing

It should be noted that the top surface of slab is usually covered with a wearing coat and is therefore not accessible. The inspector should inspect the soffit of the slab and girders, and the girder sides and edges of the cantilevered portion of the slab, for any defects. However, based on the extent of defects identified, this may call for additional investigation and testing of the top of the slab.

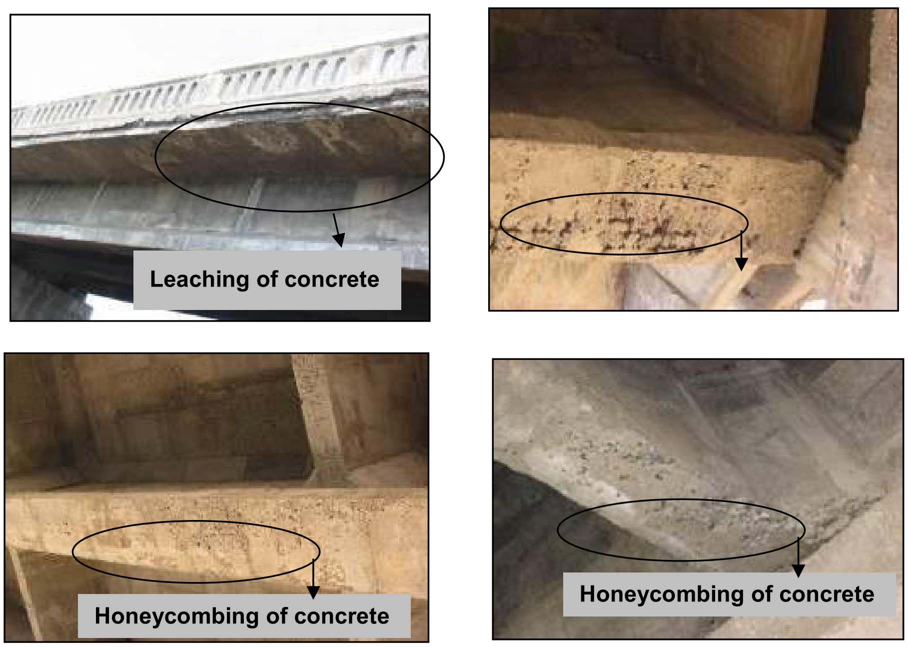


Figure 4-12: Leaching and Honeycombing of Concrete

Figure 4-13: Cavity and Spalling of Concrete

Figure 4-14: Exposed and Corroded Reinforcement

Cracking

As discussed in ***Chapter - 3*** of this manual, cracks are of different characteristics and origin. The nature of cracks in girders and slabs that have developed may therefore vary greatly. The inspector should inspect and record any cracks in the deck slab and girders carefully and report them on the inspection forms separately. It is also required that sketches be prepared of cracks that or of a critical nature and or location with these being attached to the forms with a clear description of the locations on the slab and / or girder.

Vertical deflection

Definition causes, measurement method and, overall deflection of the T-beam and slab super-structure are similar to that detailed of this chapter for RCC slab bridges.

In some cases, excessive local deflections may occur at the edge of cantilevered portion of slab due to the effect of heavy live loads. This type of deflection should also be noted and reported.

Inspection procedure

Visual: The inspection of a concrete T-beam and deck slab for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical: The physical examination of a T-beam and deck slab with a hammer is a lengthy process. In most cases therefore, a chain drag is used for physical inspection of the slab. A chain drag is made of several sections of chain attached to a pipe with a handle attached to it. The inspector drags this across a deck slab and makes notes of the resonating sounds. A chain drag can usually cover about a 1.0m wide section of deck slab.

Many of the problems associated with a concrete T-beam and deck slab bridge are caused by corrosion of the reinforcement. When the deterioration of a concrete slab progresses to the point where rehabilitation is required, an in-depth inspection should be undertaken to determine the extent, cause, and possible solution to the problem.

Where to look

Bearing areas: Examine the bearing areas for cracks and spalling, etc. This is the area where friction from thermal movement, or bearing pressure, could cause the concrete to deteriorate, crack or spall.

Shear zones: Investigate areas near the supports for shear cracking. The presence of transverse cracks at girder soffits near supports or, diagonal cracks at sides of the girders, indicates the onset of shear failure. These cracks represent lost shear capacity and should be carefully measured.

Tension zones: Tension zones should be examined for flexure cracks. The tension zones are at mid-span and along the bottom of the girder for both simple and continuous span bridges. Additional tension zones are located at the top of the slab and over the piers in continuous spans. Cracks greater than 2 mm wide are considered wide cracks and indicate extreme bending and stress. Check for efflorescence from cracks and discolouration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity.

Figure 4-15: Longitudinal Crack at Girder Bulb

Figure 4-16: Bearing Crack

Areas exposed to drainage: Inspect areas exposed to carriageway drainage outlets for deteriorated concrete. This includes the entire riding surface of the slab, particularly around scuppers or drains. Spalling or scaling may also be found along the curb line and fascias.

One of the essential causes of deteriorating concrete spalling, rusting of bars, etc., at the cantilevered portion of the deck slabs, is the lack of a proper dripping course. In many cases the dripping course is not provided in older bridges. The presence and condition of the dripping course at both edges of the deck slab should be carefully inspected and reported.

How to quantify the defects:

Span, width, thickness

Centre to centre distance between expansion joints should be measured with a measuring tape to establish the span length. Width and thickness should also be measured with the measuring tape. The centre to centre measurement of the girders should also be taken.

Honeycombing and quality of concrete

Hit the slab and girder soffits and faces with a hammer at a rate of 10 blows per square metre of area, or chain drag. Listen to the sound carefully. A hollow sound indicates poor concrete and a metallic sound is an indication of good quality concrete.

Spalls in slab and Girders

Number of spalls	Can be counted
Area of spalls	Can be measured with a measuring tape
Depth of spall	Can be measured
Number of bars exposed	Can be counted
% of corrosion	Simple arithmetic calculation

Efflorescence, Dampness and Leakage

The number of affected locations in girders and slab, at each span, can be inspected visually and recorded.

Cracking in Span

Nature of crack	Inspect to ascertain if the cracks are horizontal, inclined, mesh or diagonal
Length of crack	Use a measuring tape
Width of crack	Use a crack gauge
Total area	Simple arithmetic calculation
Section of Super-structure	Locate visually

Corrosion of exposed reinforcement

Number of locations	Can be counted
Locations	Can be seen with respect to span length and width
% with respect to bar diameter	Simple arithmetic calculation
Pit corrosion	Visual inspection

Vertical deflection

No deflection	By observation
Moderate deflection	By using a string line
Excessive deflection	By using a string line

Water ponding

The number of locations where ponding of water occurs can be identified visually. If the ponding occurs at mid span it is an indication of span deflection.

Concrete Discolouration

The number and location of areas where the concrete has discoloured can be identified visually.

Table 4-3: Details of Defects for RCC T-girder

Types / Defects	Heavy	Moderate	Low
Spalling	More than 50% of total area spalled	Between 25% to 50% of total Area spalled	Less than 25% of total area spalled
Deflection	Greater than 20mm	10 to 15mm	Less than 10mm
Corrosion	Diameter of the bar reduced more than 20% of original diameter	Diameter of the bars reduced to 10% to 20% of original bar diameter.	Diameter of the bars reduced to less than 10% at the original bar diameter.

Condition rating of RCC T-beam and deck slab

Table 4-4: Guidelines for Condition Rating of RCC T-girder

Sl. No.	Defects	Condition rating	BCI Values
1	Excessive vertical deflection of a girder	Re-Construction / New Construction	<30
2	Shear crack in any T-Girder of a width more than 2mm	Requires Strengthening / Rehabilitation	45 - 30
3	Bearing crack in any T-Girder of width of more than 2mm		
4	Excessive spalling of concrete with heavily corroded reinforcement in any girder.		
5	Moderate deflection in T-Girder or shear crack of width less than 2mm	Moderate Repairs Required	65 - 45
6	Bending cracks in any T-Girder.		
7	Moderate spalling cavities in any T-Girder.		
8	Low deflection	Minor Repairs Required	80 - 65
9	Low spalling		
10	Pot corrosion of reinforcement		
11	Efflorescence, dampness, honeycombing, discolouration of concrete.		

Table 4-5: Guidelines for Condition Rating of Deck Slab

Sl. No.	Defects	Condition rating	BCI Values
1	Heavy spalling in deck slab	Strengthening / Rehabilitation	45 – 30
2	Low spalling in deck slab	Moderate Repairs Required	65 – 45
3	Cracks of width of more than2mm		
4	Cracks of width less than 2mm	Minor Repairs Required	80 - 65
5	Efflorescence, dampness, discoloration of concrete		

4.3 RCC Box Girder

Definition

A box girder bridge is the current 'state-of-the-art' type concrete bridge. Using a trapezoidal box shape with cantilevered top flange extensions, a single box (or multi-cell box, depending on the required width and available box depth clearance) girder combines mild steel reinforcement and concrete into a cross section capable of accommodating the entire roadway width. Designs are common for both segmental and monolithic box girder construction, although not yet standardised. In addition, reinforced concrete (mild steel reinforcement) box girder bridges were once commonly constructed for short spans and many of these type of bridges still exist today.

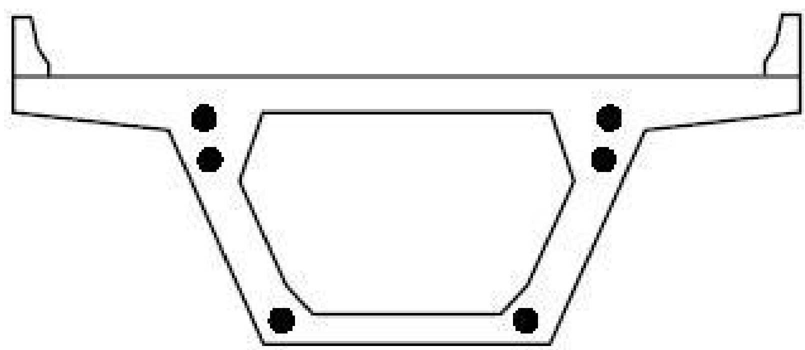


Figure 4-17: Typical Cast-in-place Box Girder Cross Section.

Depending on the configuration of the super-structure, the overall box height may stay constant or vary along the bridge spans. The bridge of a balanced cantilever type (common in Karnataka between 15 and 40 years ago) normally covers more than one span continuously without a joint. In such cases the box has a variable height, is deeper at pier locations and, becomes shallower the nearer to mid-span or abutments.

At least one hatch in each span must be provided in the bottom flange of boxes to allow for access inside the box. In the case of multi-cell box girders, either each cell should have a separate hatch or, openings in the internal wells should be provided at suitable locations.

Basic concepts of a concrete box girder

In the case of a carriageway with more than two traffic lanes, the box portion generally has internal webs and is referred to as a multi-cell box girder. Concrete box girder bridges are typically either single span or continuous multi-span structures. Spans can have a straight or curved alignment and are generally in excess of 45 m.

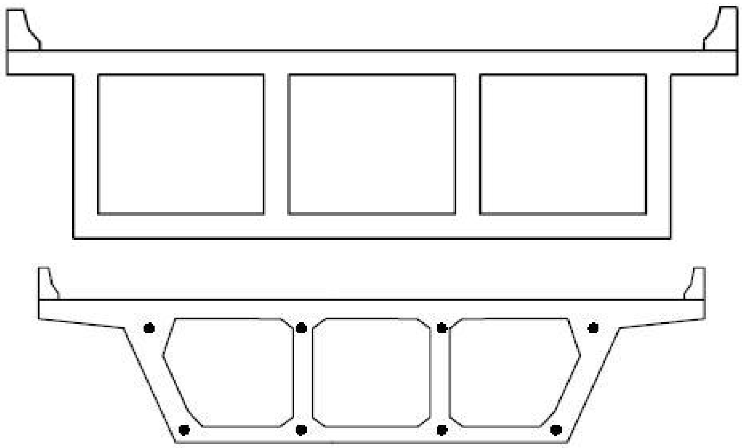


Figure 4-18: Multi-cell Girder

Figure 4-19: Typical Cast-in-place Concrete Box Girder Bridges

Primary members

For a box girder structures, the primary member is the box girder. When a single-cell box pattern design is used, the top flange or deck slab, the bottom flange and, both side walls, are all primary elements of the box girder. The top flange is considered an integral deck component.

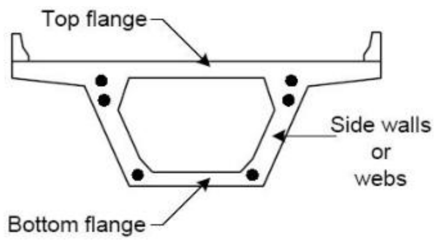


Figure 4-20: Basic Elements of a Cast-in-place Box Girder

In some multi-cell box girder bridges, the top flange or deck slab must be removable for future replacement. In such cases, the top flange functions similar to that of a composite deck slab and is in fact considered a separate deck component. Most exterior webs have higher stress levels than interior webs, but the interior webs of the box also play a significant role in the girder.

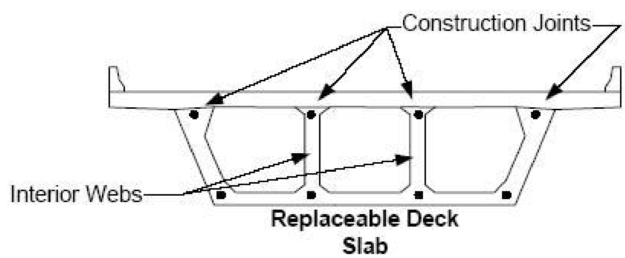


Figure 4-21: Replaceable Deck Slab on a Multiple Cell Cast-in-place Box Girder

Common defects

Common defects that occur in the super-structure of a concrete box girder bridge are similar to other RCC bridge components and include:

- Honeycombing
- Concrete spalling and cavities
- Efflorescence, dampness, leakage
- Corrosion of steel
- Cracking
- Vertical deflection

Inspection procedure

The inspection of concrete box girders for cracks, spalls, and other defects is primarily a visual activity. However, hammers are also used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Assessment Techniques:

- Each span of the bridge should be inspected.
- The general inspection should be carried out at the top and the soffit of the box girder, as well as inside.

Physical examination:

The physical examination of box girders requires a hammer. Many of the problems associated with concrete box girders are caused by corrosion of the rebar. When the deterioration of a concrete box girder progresses to the point where rehabilitation is required, an in-depth inspection of the box girder is necessary, in order to determine the extent, cause, and possible solution to the problem.

Concrete box girder specific issues

The inspection of a box girder bridge requires a clear understanding of the functions of the girders. This requires a thorough review of the design, or as-built drawings, prior to the inspection and a full understanding of the high stress regions that are specific to this particular structure. Due to the complexities of box girder bridges, many agencies develop a special inspection and maintenance manual for this structural type.

Arguably, the most important inspection a box girder will receive is its first. This inspection will serve as a benchmark for all future inspections. Since it is so important, the initial inspection should be scheduled as early as possible after the construction of the bridge. Due to the complex nature of the box girder, all interior and exterior surfaces of the girder will require visual examination.

Inspecting a concrete box girder bridge is similar to the procedure discussed earlier for a T-beam bridge, and includes the following specific procedures:

Bearing areas

The effects of temperature, creep and, concrete shrinkage on the super-structure with the consequent effects on the box, may produce undesirable conditions for the bearings. It is therefore necessary to check the bearing areas, as well as the bearings themselves, for proper movement and overall extent of movement.

Figure 4-22: Bearing Area of a cast-in-place Box Girder Bridge

Structural cracks

Shear: The shear forces acting on the super-structure are sustained by shear capacity of webs, concrete and reinforcement. Therefore, if there is any problem in handling the shear then cracks will occur in the webs of the girder and will be pronounced adjacent to abutments and piers. They will be at an approximate 45 degree angle when compared to the longitudinal axis of the girder, and will extend from the support towards the mid-span.

Figure 4-23: Shear Crack Location near an Abutment

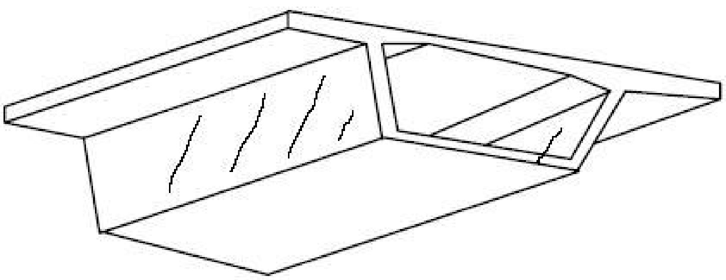


Figure 4-24: Box Girder Cracks Induced by Shear

Direct tension: Tension cracks will appear as a series of parallel cracks running perpendicular to the longitudinal axis of the bridge. The cracks can possibly pass through the entire depth of the box girder section. Cracks will usually be spaced at approximately 1 to 2 times the minimum thickness of the girder element.

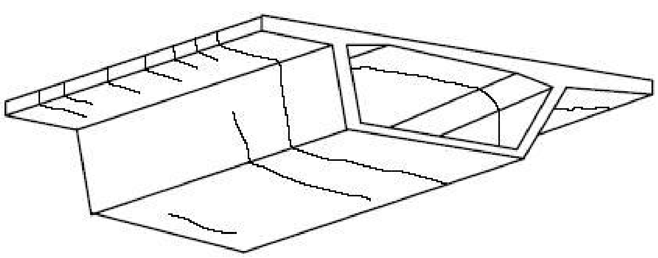


Figure 4-25: Box Girder Cracks Induced by Direct Tension

Flexure: These cracks will appear at piers at the top and bottom of the flange at mid-span. The extent of cracking will depend on the intensity of the bending moment being induced. Flexure cracks will normally propagate to an area around half the depth of the section. It is important that the location, the dimensions, and the severity of the crack be accurately identified.

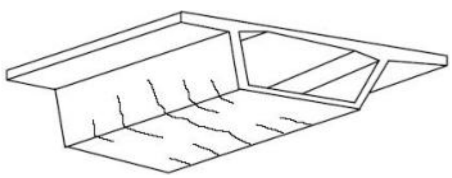


Figure 4-26: Box Girder Cracks Induced by Flexure (Positive Moment)

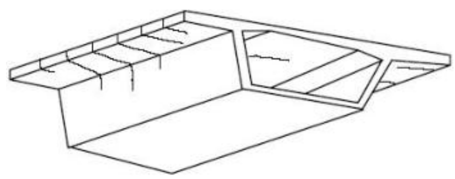


Figure 4-27: Box Girder Cracks Induced by Flexure (Negative Moment)

Flexure-shear: These cracks will appear close to pier support locations. They will begin on the bottom flange and be orientated perpendicular to the longitudinal axis of the bridge. The cracking will extend up the webs at approximately 45 degrees to the horizontal and toward the mid-span.

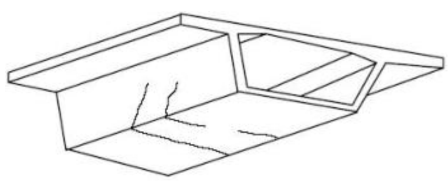


Figure 4-28: Box Girder Cracks Induced by Flexure-shear

It is necessary to inspect the upper side of the top flange for longitudinal flexure cracking directly over the interior and exterior girder walls. Inside the box, examine the bottom of the top flange for longitudinal flexure cracking between the girder walls. Any efflorescence or leakage through the top flange should be documented.

Other cracks

Cracks caused by torsion: This type of cracking will occur in both the slabs and webs of the box girder due to the twisting motion induced into the section. This cracking is very similar to shear cracking and will produce a helical configuration if torsion alone is present. Straight bridge structures often will not experience torsion alone but rather bending, shear and torsion will occur simultaneously. In this event, cracking will be more pronounced on one side of the box due to the additive effects of all forces.

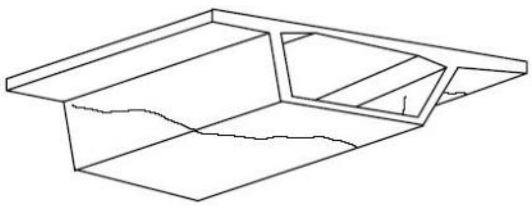


Figure 4-29: Box Girder Cracks Induced by Torsion and Shear

Thermal effects: Such cracks are caused by temperature differences between the inside and outside atmosphere of the box girder. Cracking will typically be transverse in the thinner slabs of the box and longitudinal near changes in cross section thickness.

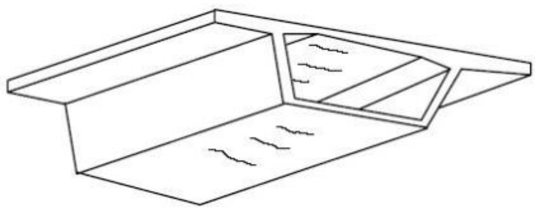


Figure 4-30: Temperature Cracks Thermally Induced Cracks in Box Girder

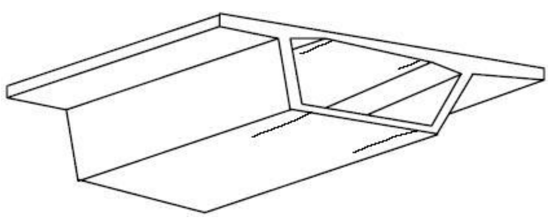


Figure 4-31: Temperature Cracks Thermally Induced Cracks at Box Girder Cross Section

Overstress: Older, 'cast-in-place' box girder interiors should be inspected to verify that inside forms left in place do not provide unintentional load paths which may result in overloading of the box components.

Structure Alignment: An engineering survey needs to be performed at the completion of construction and a schedule for future surveys established. The results of these surveys will aid the bridge engineer in assessing the behaviour and performance of the bridge. Permanent survey points at each sub-structure and at each mid-span should be established. Likewise, several points need to be set at each of these locations in the transverse direction across the top slab. During the inspection, the inspector should:

- Inspect the girder for the proper camber by sighting along the fascia of the top flange.

- On curved box girders, check for irregularities in the super-elevation of the top flange, which could indicate torsional distress.
- Inspect the road surface for cracking, spalling, twisting, and deformation. The presence of these defects can increase with the impact effect of traffic and may also be of great significance since, in many segmental bridges, the top of the structural member is the riding surface.
- Investigate any unusual noises, such as banging and screeching, as this may be the result of structural distress.
- Observe and record data from any monitoring instrumentation (e.g., strain gauges, displacement meters, or transducers) that have been installed on or within the bridge.

Diaphragms

The box girder cross section at the abutments and piers is different from that of any other typical section due to presence of the internal diaphragms. These diaphragms serve to stiffen the box section at these locations and to distribute the large bearing section loads. Like any other concrete element, the diaphragms are prone to different types of defects and must be inspected thoroughly from inside and outside the box. Structurally, they are deep beams sustaining heavy shear loads.

Areas close to drainage spouts

Examine the box girder for any delamination, scaling, spalling, or other defects, which may lead to exposure and further rusting of the box reinforcement. Areas exposed to drainage assemblies should receive special attention and care.

How to quantify the defects

Span and deck width

- Centre to centre distance between piers and pier-abutments, as well as the entire deck width, should be measured using a measuring tape to measure span length.
- The total number of cells at a box with, centre to centre distance of webs and, the total box depth and deck thickness, should be measured with a tape and recorded. Most of a box-girder super-structure has variable box depth. The deepest point at piers, and the shallowest at mid-spans and abutments, must also be measured at a sufficient number of points to be able to establish the longitudinal vertical curvature of box (es). If there is any articulation joint along the bridge, the location should be identified in relation to piers.

Honeycombing and quality of concrete

- Hit the deck slab, box soffit and the webs (from inside and outside) with a hammer at a rate of 10 blows per area of one square metre. Listen to the sound carefully. A hollow sound indicates poor concrete and a metallic sound indicates good quality concrete.

Spalls in deck slab, box soffit and webs

Number of spalls	Can be counted
Area of spalls	Can be measured with measuring tape
Depth of spall	Can be measured
Number of bars exposed	Can be counted
% of corrosion	Simple arithmetic calculation

Efflorescence, dampness and leakage

- Visually inspect for the number of affected locations on girders and the slab, for each span, and record the information.

Cracking in span

Nature of crack	Look at the cracks to determine whether they are horizontal, vertical inclined, mesh or diagonal
Length of crack	Use a measuring tape
Width of crack	Use a crack gauge
Total area	Simple arithmetic calculation
Section of Super-structure	Visual

Corrosion of exposed reinforcement

Number of location	Can be counted
Location	Identify with respect to span length and width
% with respect to bar diameter	Simple arithmetic calculation
Pit corrosion	Visual

Vertical deflection

No deflection	Visual
Moderate deflection	Use a string line
Excessive deflection	Use a string line

Water Ponding – The number of locations where the ponding of water occurs can be visually inspected. If ponding occurs at mid span it this is an indication of span deflection.

Concrete Discolouration – The number and location of the areas where concrete has become discoloured can be visually inspected.

Observation of excessive vibration

If an inspector can feel excessive vibration, then it should be considered critical and rated accordingly. This is subjective and should be based upon engineering knowledge, judgement and experience.

Table 4-6: Details of Defects for RCC Box Girder

Types / Defects	Heavy	Moderate	Low
Spalling	More than 50% of total area spalled	Between 25% to 50% of total area spalled	Less than 25% of total area spalled
Deflection	Greater than 20mm	10 to 20mm	Less than 10mm
Corrosion	Diameter of the bar reduced more than 20% of original diameter	Diameter of the bars reduced to 10% to 20% of original bar diameter.	Diameter of the bars reduced to less than 10% at the original bar diameter.

How to rate items

Table 4-7: Guidelines for Condition Rating of RCC Box Girder

Sl. No.	Defects	Condition rating	BCI Values
1	Excessive vertical deflection of girder	Re-construction / New Construction	< 30
2	Shear crack in any part of a box girder with a width of more than 2mm	Requires Strengthening / Rehabilitation	45 - 30
3	Bearing crack in any box girder with a width of more than 2mm		
4	Excessive spalling of concrete with heavily corroded reinforcement		
5	Moderate deflection in box girder or shear crack width of less than 2mm	Moderate Repairs Required	65 - 45
6	Bending cracks in any box girder.		
7	Moderate spalling/cracking in box girder		
8	Low deflection	Minor Repairs Required	80 - 65
9	Low spalling		
10	Pit corrosion of reinforcement		
11	Efflorescence, dampness, honeycombing, discolouration of concrete		

Table 4-8: Guidelines for Condition Rating of Deck Slab

S. No.	Defects	Condition rating	BCI Values
1	High spalling/cracking in deck slab	Requires Strengthening / Rehabilitation	45 - 30
2	Low spalling/cracking in deck slab	Moderate Repairs Required	65 - 45
3	Cracks of a width of more than 2mm.		
4	Cracks of a width of less than 2mm	Minor Repairs Required	80 - 65
5	Efflorescence, dampness, discolouration of concrete		

4.4 Pre-Stressed Concrete Super-Structure

The common types of PSC super-structure are:

- PSC-T girder with RCC/PSC deck composite super-structure.
- PSC box girder
- PSC voided slab

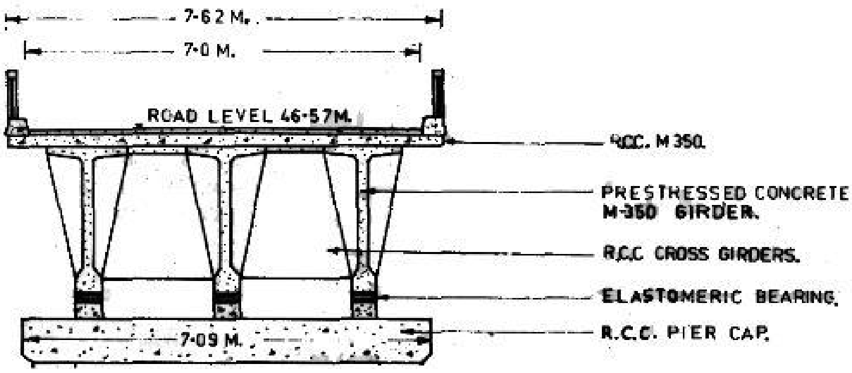


Figure 4-32: PSC T Girder

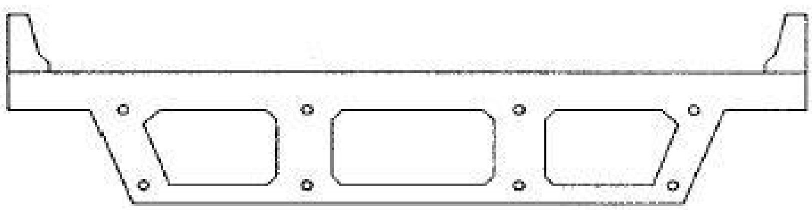


Figure 4-33: PSC Box Girder

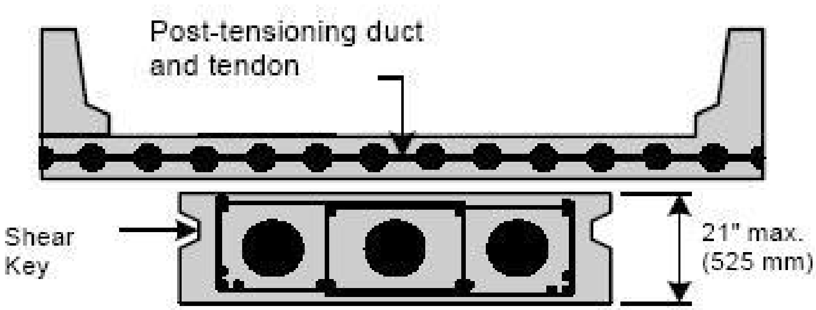


Figure 4-34: Typical PSC Voided Slab

Basic concepts of PSC super-structure

The principle of pre-stressed concrete has been widely applied for the design of bridges. The inherent advantages of pre-stressed concrete bridges are the higher load carrying capacity and the fewer piers and expansion joints. In the past, bridges with long spans had been considered practicable only when steel super-structure was employed. Using PSC is not only due to the high strength of the materials used but also to reduce the tensile stress in the concrete by applying initial compressive stress. The pre-stressed members are light and best suited for artistic and architectural aspects. Pre-stressing techniques eliminate the cracking of concrete. Cracks are harmful as they lower the life of the structure due to the atmosphere permeating into the material through the cracks and thus causing the steel to rust and the concrete to deteriorate, also the presence of cracks lowers the capacity of the structure to bear any reversal of stress, impact, vibration and shock. Thus elimination of cracks by pre-stressing reduces the maintenance cost and provides a smoother riding surface for vehicles. Pre-stressing techniques increases the shear capacity of concrete and therefore allows the use of thinner webs thereby resulting in a saving in the dead weight, which is of particular significance for long span bridges. The elimination of cracking in pre-stressed bridges under service loads also leads to better resistance to fatigue.

Pre-stressed concrete members require steel that has a high tensile strength, which is generally more expensive than ordinary mild steel. The concrete members also require to be constructed of high quality concrete which will require careful supervision. Special equipment like anchorages, jacks, etc. for pre-stressing are also required. The pre-stressing procedure can be summarised as follows:

Galvanized metal or polyethylene ducts are placed in the forms at the desired location of the tendons. When the concrete has cured to an acceptable level of strength, the tendons are installed in the ducts, tensioned, and then grouted.

Special “confinement” reinforcement is also required at the anchorage locations to prevent cracking due to the large transfer of force to the surrounding concrete.

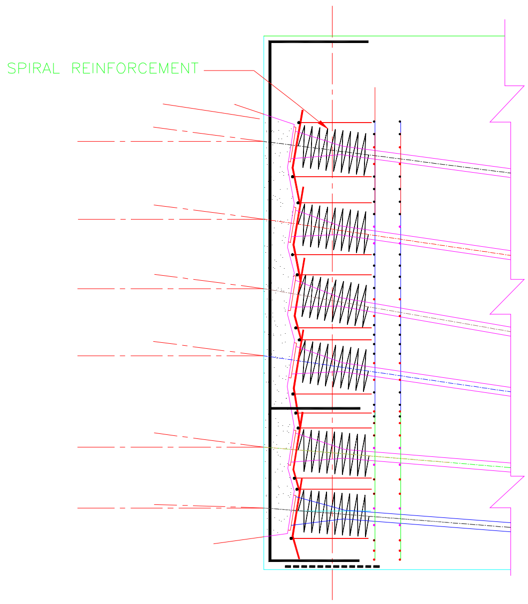


Figure 4-35: Schematic Illustrates of Pre-stressing end Anchorage System

Pre-stressed concrete bridges of medium or long span are generally of three basic types:

- PSC-T girder with RCC / PSC deck
- PSC box girder
- PSC voided slab


Figure 4-36: Typical Pre-stressed T-beam Slab Bridge

PSC T-girder

Pre-stressed T-girders have been in use for the last 50 years. They have proven to be successful because of their material saving shapes and their light weight. The T-shape allows a designer to have enough space to place the correct amount of reinforcement while reducing the amount of concrete needed.

A pre-stressed T-girder with bulb makes economic use of material since most of the concrete mass is located away from the neutral axis of the beam. Pre-stressed girders are shaped to provide minimum dead load with ample space for tendons and reinforcing bar. They are generally most economic for spans between 24 to 40 metres.

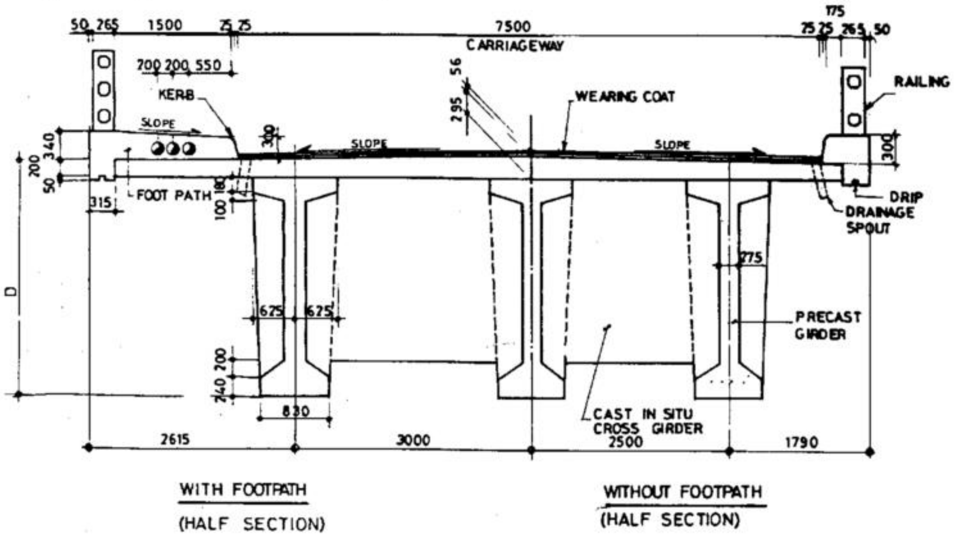


Figure 4-37: Typical Cross Section of PSC Girder and RC Slab widely used in India

Materials-strength and durability

- In a simply supported single span super-structure, steel tendons with high tensile strengths are located in the bottom bulb. These tendons are used to induce compression across the entire section of the beam prior to and during the application of live loads. This results in a crack free beam.
- The concrete used should also be of a higher strength ranging from M35 to M55.
- The deck is secured to, and can be made composite with, the T-girder through the use of extended stirrups cast in to the girder.

PSC box-girder

General

Pre-stressed box girders are constructed having an almost rectangular cross section with one or more rectangular/quadrilateral cells inside. The top and bottom slabs act as flanges, whilst the side walls act as webs. The pre-stressing reinforcement is placed in the bottom flange and in to the webs.

Box girders are advantageous in the way that they allow for reduced deck slab thickness and consequently reduce the dead load.

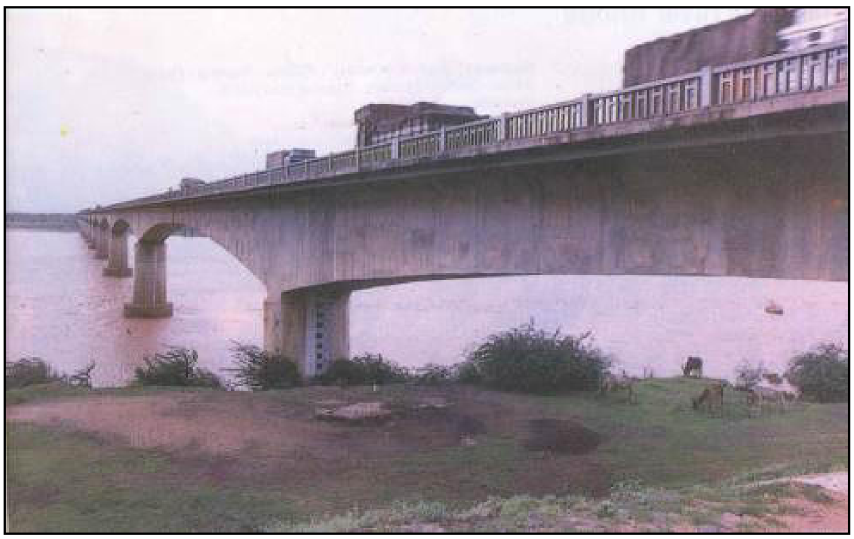


Figure 4-38: Segmental Concrete Bridge

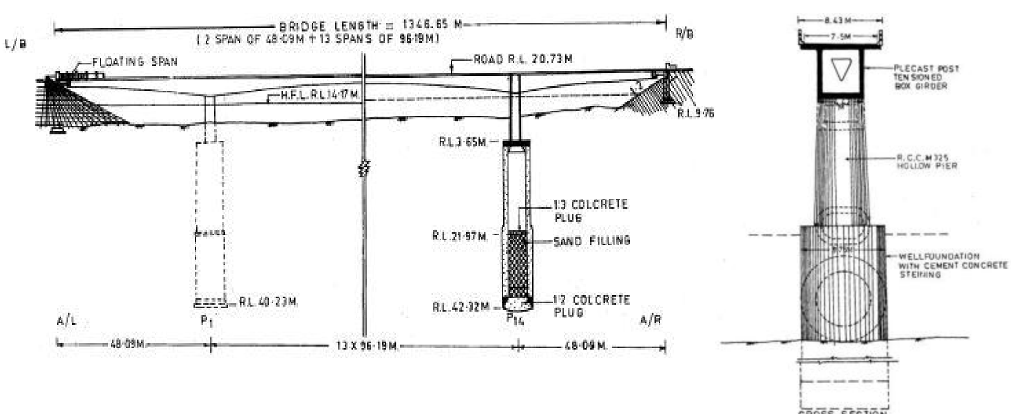


Figure 4-39: Longitudinal Schematic Section / Elevation of a Segmental Box Girder Bridge

A box girder is preferred for the following reasons:

- The top slab can be used as the road traffic surface
- The wide top and bottom slabs provide large compression areas
- The box shape provides excellent torsional rigidity
- The box shape lends itself well to horizontally curved alignments

A typical box girder section will have the following elements:

- Top slab
- Bottom slab
- Web walls
- Interior web walls (multi-cell)

Single box girder segments are usually used, although spread multiple boxes can also be used, if they are connected by external diaphragms.

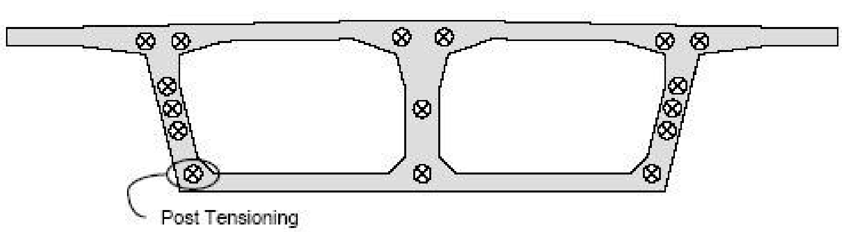


Figure 4-40: Box Girder (Concentric Post Tensioning)

'Cast-in-place' construction frequently does not enjoy the efficiencies of pre-cast construction but does have the advantage of relatively easy field adjustments for controlling line and grade of alignment.

PSC voided slab

The voided slab bridge is the modern replacement of the 'cast-in-place' slab. This type of bridge super-structure is similar to the 'cast-in-place' slab in appearance. The voids afford economy of material and reduce dead loads.

Inspection and defects of PSC super-structure

In the following paragraphs the methodology for the inspection and rating of different types of super-structure (PSC T-girders, boxes and voided slabs) are elaborated and discussed in detail.

PSC T-Girders

General

The basic concepts and configurations of PSC T-Girder bridges are elaborated in previous paragraphs. The common defects, inspection and rating procedures are discussed hereinafter.

Components of PSC T-girder with RCC / PSC deck

The main components of PSC T-Girder deck slab type bridges are:

- PSC girder (main)
- Stiffeners
- Diaphragms
- Deck slab (RCC/PSC)

Common defects

All the defects associated with RCC T-Girder bridges and PSC T-Girder bridges are the same, the inspection and rating guidelines as specified for RC Girder shall be followed for PSC I girder. In addition, the following defects may also occur in the pre-stressing elements of a pre-stressed girder. These do not occur in RCC girders

Anchor: In pre-stressed concrete girders, anchorages are very important and the main concern. They are located at the end blocks with the latter being designed to distribute the concentrated pre-stressing force to the anchorage locations. They should be inspected for damage and corrosion. A report should be prepared for any cracks in end anchorage zones. Due to these areas being exposed to high compression stresses this makes them prone to cracking.

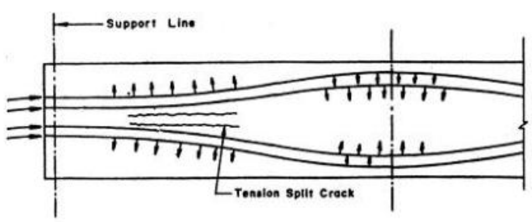


Figure 4-41: Plan sketch of tension split cracks in PSC super-structure

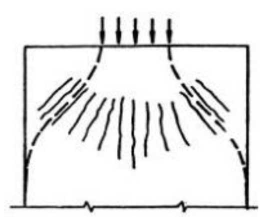


Figure 4-42: Planar Sketch of Cracks in the Anchorage Zone of a PSC Structure due to Inadequate/Bursting Reinforcement

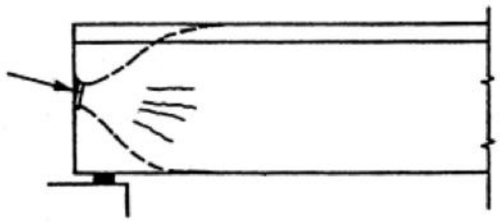


Figure 4-43: Elevation Sketch of Cracks in the Anchorage Zone

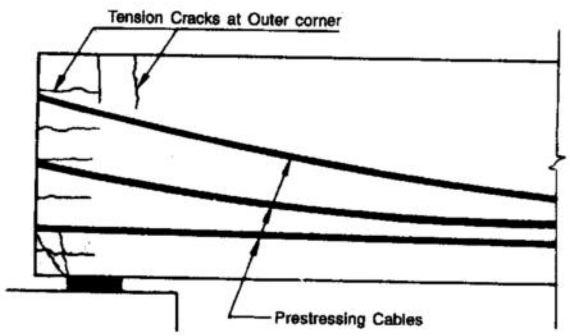


Figure 4-44: Defects in Anchorage Zone

Figure 4-45: Light Cracking

Figure 4-46: Horizontal and Vertical Crack

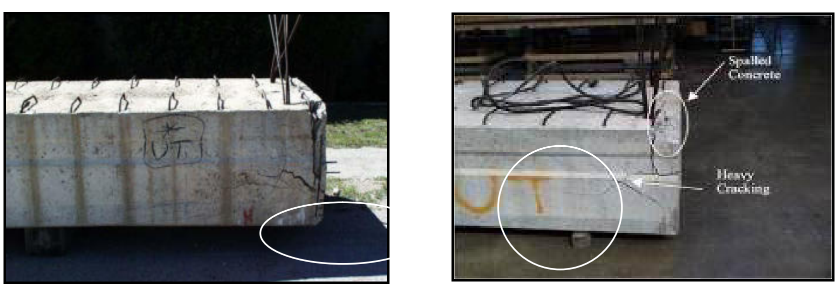


Figure 4-47: Spalled Concrete and Heavy Cracking

Figure 4-48: Spalled Concrete and Heavy Cracking

Figure 4-49: Efflorescence

Inspection procedure

The procedure is more or less similar to that of RCC T-Girder super-structure. Incorrectly designed, poorly constructed or badly maintained pre-stressed concrete structures have defects of a different nature.

Visual inspection

Visual inspection is the most essential and least expensive method to detect any deterioration of the structure. Identification of any serious damage by visual inspection must be prompt followed by a detailed engineering inspection.

Where to look

Bearing areas: Examine the bearing areas for spalling, areas where there is a restriction of thermal movement and, where the high edge or bearing pressure could cause the concrete to spall.

Shear zones: Investigate areas near supports for shear cracking. The presence of transverse cracks on the underside, near supports, or diagonal cracks on the sides of the slab, indicate the onset of shear failure. These cracks represent loss in shear capacity and should be carefully measured.

Tension zones: Tension zones should be examined for flexure cracks, which will be vertical on the sides and transverse across the slab. The tension zones are at mid-span along the bottom of the slab for both simple and continuous span bridges. Additional tension zones are located on top of the slab and over the piers for continuous spans. Cracks that are greater than 2 mm wide can be considered wide cracks and indicate extreme bending stresses. Check for efflorescence from cracks and discolouration of the concrete caused by rust from the reinforcing steel. In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since cross section loss will decrease live load capacity.

Areas exposed to drainage: Inspect the areas exposed to road drainage for concrete deterioration. This includes the entire riding surface of the slab, particularly around scuppers or drains. Spalling or scaling may also be found along the line of the kerbs and fascias.

Anchor zone: Inspect the area for damage to the anchor and ducts, loose strands and corrosion.

Diaphragm: Inspect the diaphragms for all types of defect associated with concrete beams.

Previous repairs: Examine thoroughly any repairs that have been made previous to the inspection. Determine if patched areas are sound and functioning correctly. Effective repairs and patching are usually limited to protection of exposed tendons and reinforcement.

What to look for

Examine the alignment, profile, and look for impact damage with other structural members. Inspect and document any cracks in structural members. As pre-stressed members are under high compressive forces, cracking may frequently occur. Vertical or diagonal tension cracks in pre-stressed members are signs that the pre-stressing steel has failed or is failing, and the loads are therefore being carried by adjoining beams. This is a serious condition and steps should be taken to ensure the stability of the bridge as soon as possible.

The two most common causes of loss in pre-stress forces are, impact and corrosion. Generally, deterioration occurring in pre-stressed concrete members is self-evident but, in some cases, serious but latent corrosion of the pre-stressing strands may exist without many outward signs of the problem. It is therefore essential to check for concrete delamination, hairline cracks, efflorescence or rust stains at the pre-stressed strand level which can indicate strand corrosion. Longitudinal cracks may be the result of expansion forces caused by pre-stressed steel corrosion.

Recent research has suggested that once outward signs of pre-stressed steel corrosion are visible, deterioration occurs extremely rapidly. The inspector should therefore pay particular attention to areas where the concrete is patched. Another recently observed problem is the cracking at the ends of pre-stressed concrete elements. This can be so serious as to warrant complete bridge replacement.

Additional possible problems include:

- Any sagging of individual members could indicate overloading or loss of pre-stress.
- Horizontal deflections (sweep) may indicate asymmetric loading from either non-uniform pre-stressing forces or tendon failure.
- Efflorescence, leakage, and staining indicate the likelihood of pre-stressed steel corrosion and a diminished load carrying capacity.
- Concrete delamination or spalling is definitive signs of pre-stressed steel corrosion and diminished capacity.
- Check for tendon damage if any of the beams have been impacted. Cracks spreading from the damaged area indicate the extent of pre-stress loss.
- Longitudinal cracks in the wearing surface may indicate that the shear keys of the primaries are not working as designed.
- Check drain holes for rust stains which could possibly indicate deterioration that is currently not visible until it becomes more serious.

How to quantify the defects

Span, width, thickness

Centre to centre distance between expansion joints should be measured with a measuring tape to establish span length. Width and thickness should also be measured as should the centre to centre distance of the girders.

Honeycombing and the quality of the concrete

Hit the slab, girder soffits and faces with a hammer at a rate of 10 blows per one square metre or chain drag. Listen for the resulting sound carefully. A hollow sound indicates poor concrete and a metallic sound that of good quality concrete.

Spalls in slab and girders

Number of spalls	Can be counted
Area of spalls	Can be measured with a measuring tape
Depth of spall	Can be measured
Number of bar exposed	Can be counted
% of corrosion	Simple arithmetic calculation

Efflorescence, dampness and leakage

The number of affected girder and slab locations, at each span should be inspected visually, counted and recorded.

Cracking in span

Nature of crack	Inspect the cracks to determine if they are horizontal, vertical, inclined, mesh or diagonal
Length of crack	With a measuring tape
Width of crack	With a crack gauge
Total area	Simple arithmetic calculation
Section of Super-structure	Visual

Corrosion of exposed reinforcement

Number of location	Can be counted
Location	Visual with respect to span length and width
% with respect to bar diameter	Simple arithmetic calculation
Pit corrosion	Visual

Vertical deflection

No deflection	Visual
Moderate deflection	Use a string line
Excessive deflection	Use a string line

Water ponding

The number of location where ponding of water occurs can be visually inspected. If the ponding occurs at mid span it is an indicator of span deflection.

Concrete discolouration

The number and location of areas where concrete has become discoloured can be visually inspected.

Pre-stressing anchors

Number of damaged anchorage pans	Can be counted
Description of damage	Based on visual inspection
Degree of corrosion of the anchorage end	Noted as serious or Minor
Number of loose strands	Can be counted
Total number of strands in each anchorage	Can be counted

Overall rating of PSC super-structure

Pre-stressed concrete main members are rated for both physical condition and structural capacity and compared with the original design capacity. These are the same criteria as used for reinforced concrete main members. However, physical deficiencies (cracks, spalls) are generally more serious in pre-stressed members. The members are rated as a system.

- No spalling, scaling, cracking, or efflorescence. No signs of vertical or horizontal misalignment. Members show no physical limitations to their performance at full-design capacity**. Sound condition**.
- Isolated scaling, minor vertical deviations, little or no leakage between adjoining members and, only a few reflective cracks in the wearing surface. **Minor damage**.
- Web shear, flexural shear, and flexural cracks on isolated members indicate loss of strength in those members and, that the other beams are carrying the loads for these members. Leakage between adjoining members and reflective longitudinal cracks in the wearing surface indicates that the members are not functioning as originally designed which could mean the loss of pre-stress or, an overload condition. Efflorescence, delamination, and moderate spalling may indicate corrosion of tensioning strands or concrete deterioration.
- Web shear, flexural shear and flexural cracks on many beams indicate that the prestressed members are not functioning as originally designed and may have lost much of their original capacity. Horizontal deflections, vertical deflections, and/or severe or extensive deterioration in members (such as excessive deflection, tendon failure or spalling), indicates that the system has lost much of its original capacity **Serious damage.**

How to rate items

Table 4-9: Guidelines for Condition Rating of PSC T Girder

Sl. No.	Defects	Condition Rating	BCI Values
1	Excessive vertical deflection	Re-construction / New Construction	< 30
2	Shear cracks of a width of more than 1mm.		
3	Exposure corrosion of PSC cables		
4	Moderate vertical deflection	Strengthening / Rehabilitation	45 – 30
5	Torsional cracks in girder.		
6	Spalling of concrete and corrosion of PSC cable ducts		
7	Bending cracks in girder		
8	Excessive spalling of Cantilever deck slab concrete.	Moderate Repairs Required	65 – 45
9	PSC anchors damaged/corroded		
10	Efflorescence, dampness, honeycombing, discolouration of concrete.	Minor Repairs Required	80 - 65

Table 4-10: Guidelines for Condition Rating of PSC Deck Slab

S. No.	Defects	Condition rating	BCI Values
1	Heavy spalling in deck slab	Strengthening / Rehabilitation	45 – 30
2	Low spalling in deck slab	Moderate Repairs Required	65 – 45
3	Cracks of a width of more than 2mm.		
4	Cracks of a width of less than 2mm	Minor Repairs Required	80 - 65
5	Efflorescence, dampness, discolouration of concrete		

Inspection procedures and location for PSC Box Girders

Special concern

Since pre-stressed box girders are designed to maintain the entire concrete section in compression, cracks are indications of serious problems. For this reason, any crack should be carefully measured with an optical crack gauge and then documented.

Visual

The inspection of concrete box girders for cracks, spalls, and other defects is primarily a visual activity. As stated for RCC box girders, the PSC boxes should also be inspected from both inside and outside the box. Access hatches are primarily provided at each span of the box soffits to provide future access to inside the box cells. In the case of multi-cell box super-structures, either one hatch is provided for each box or, openings in the internal webs are provided at suitable locations. Hammers are primarily used to detect areas of delamination where a delaminated area will have a distinctive hollow “clacking” sound when tapped. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Whatever their nature and purpose, all structures must be subject to periodic inspection visits in order to detect any possible disorders as soon as they occur. An immediate repair will prove far less costly than a tardy one on a highly deteriorated structure.

Essential and often sufficient, visual inspection is the least expensive and the most productive method. This method often draws attention to the occurrence of disorders and therefore prompts a more detailed inspection.

The two important factors of concern are concrete integrity and the deflection of structures.

The most obvious lack of integrity consists of the formation of a crack. As soon as cracks occur it is important to map them on a large scale, with the visually discernible indications of the extremity plus their widths. This map should be periodically updated to allow an exact appreciation of the phenomenon. It may be useful to record the temperature for a better understanding of the load capacity of the structure at the time of the inspection.

After the cracks have been reported, the frequency of subsequent records depends on the deemed gravity of the disorders. When there is no evident emergency, bi-annual monitoring may be sufficient.

Excessive strain is a frequent fault in pre-stressed structures built at a time when the long term behaviour of concrete was as yet not well known. The most common practice for the provision of an upward camber in a single span is to precast the beam. In fact, in this type of bridge, the beams lower flange is highly compressed when unloaded and tends to shorten under the action of creep.

The excessive deflection of girders is quite unusual. It may be found in beams with a mid-span hinge and in central spans of bridges built using the successive cantilever method.

Physical

The physical examination of box girders with a hammer is necessary. Many of the problems associated with concrete box girders are caused by corrosion of the rebar. When the deterioration of a concrete box girder progresses to the point of needing rehabilitation, an in-depth inspection of the box beam is required to determine the extent, cause, and possible solution to the problem.

What to Look at

Bearing areas

- The top of the girder-ends should be examined for horizontal or vertical cracks. These cracks indicate a deficiency of reinforcing steel and are caused by the stresses created at the transfer of the pre-stressing forces.
- Check bearing areas for spalls or vertical cracks. Spalls and cracks may be caused by corrosion of steel due to water leakage or restriction of thermal movement due to a faulty bearing mechanism.
- Check for rust stains, which indicate corrosion of steel reinforcement.
- Check the bottom of the girder for longitudinal cracks originating from the bearing location. These cracks are sometimes caused by the unbalanced transfer of pre-stress force to the concrete, or by the accumulation of water inside the box, freezing and thawing

Figure 4-50: Spalled Ends

Figure 4-51: Exposed Bars at End of Box

Figure 4-52: Longitudinal Cracks in Bottom Flange

Shear zone

- Check girder ends and sections over piers for diagonal shear cracks in webs. These cracks will project diagonally upward from the support toward mid-span.
- The girder should be inspected throughout for flexure and shear cracks as well as pre-stress-induced cracks. Some shrinkage cracks are to be expected. Likewise, although post-tensioned, some small working cracks will be present. As with all pre-stressed concrete members, any cracks should be carefully measured with an optical crack gauge and its location, length, and width documented. For field notes, the inspector may wish to substitute the following descriptions for the various crack widths:

Hairline =	0.1 mm
Narrow =	0.1 to 0.25 mm
Medium =	0.25 to 0.76 mm
Wide =	0.76 mm

Note: These crack widths are for pre-stressed members only

Tension zones

- Investigate the lower portion of the beam for flexure cracks, particularly at mid span. This indicates a very serious problem resulting from overloading or loss of pre-stress.
- Check for spalling, delamination and exposed reinforcing steel. Exposed strands fail prematurely due to stress corrosion.
- Check for deteriorated concrete, which could cause un-bonding of the tension reinforcement. This would include spalls, delamination, and cracks with efflorescence.
- Check bottom flange for longitudinal cracks which may indicate a deficiency of pre-stressing steel or possibly, an overloading of the concrete due to the use of pre-stressing forces that are too large.
- For continuous bridges, heck the deck area over the supports for flexure cracks due to negative moments.

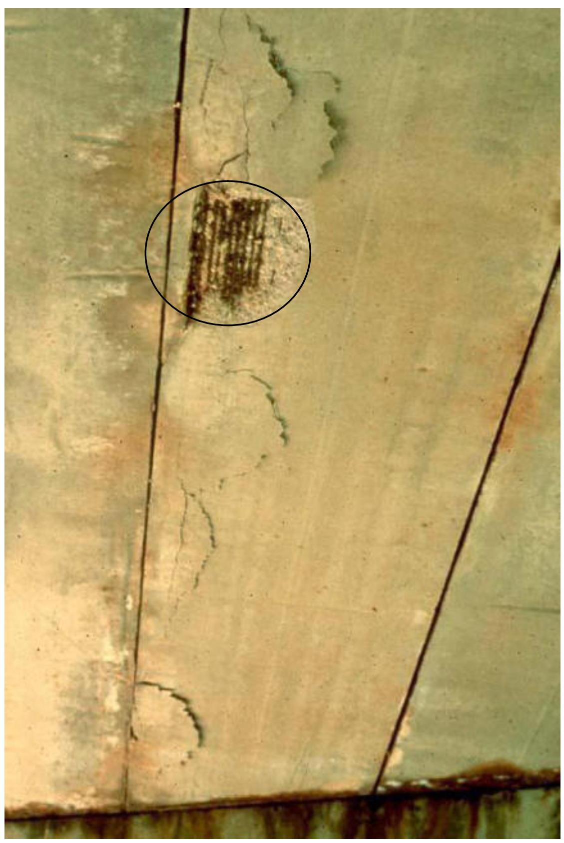


Figure 4-53: Spall and Exposed Reinforcement

Diaphragms

- Inspect the fixed diaphragms for spalling or diagonal cracking. This is a possible sign of shear failure caused by structural movement.
- Investigate the intermediate diaphragms for cracking and concrete spalling. Flexure and shear cracks may indicate excessive differential moments of the box beams.

Other areas to be looked at

- Areas Exposed to Drainage.
- Examine between boxes in a multi-spine box girder bridge for leakage and rust stains. Look for reflective cracking in the traffic surface and individual girder deflection under live loads. These problems indicate that the shear key between boxes has been broken and that the boxes are acting independently of each other. These problems could also indicate that the transverse post-tensioning is not acting as designed.

Figure 4-54: Post-tensioning Tendon Duct

Figure 4-55: Joint Leakage and Rust Stain

Cracking along the line of tendons: Cracking can occur along any of the lines of post-tensioning tendons. This is why it is important for the inspector to be aware of where the tendons are located within the box girder section. Hence, attempt must be made to collect the bridge 'as-built' drawings and make them available for the inspectors. This cracking may be the result of a bent tendon or a misaligned tendon with insufficient concrete cover. Shrinkage of the concrete adjacent to large tendons can also cause this type of cracking.

Radial cracking: Post-tensioning tendons can be curved in vertical, horizontal or both planes depending on the vertical and horizontal geometry of the finished structure. The tendons produce a component of force normal to the curvature of their alignment. The result of this force can be cracking or spalling of the concrete elements that contain these tendons. This type of distress is localised to the tendon in question, but can occur virtually anywhere along the length of the tendon. Joints of match for cast pre-cast segments are particularly sensitive to this type of cracking.

For externally post-tensioned box girders, deviation blocks and blister blocks should be carefully examined for spalling and / or cracking distress.

Thermally induced cracks in slab: Thermally induced cracks at a change in cross-section due to tendon sleeve misalignment. These are points of very high stress concentrations and their integrity is essential to the integrity of span continuity post-tensioning. Locating and mapping areas of spalling and delamination on the top slab is essential, because of the structural importance of this element.

Drain holes: Check drain holes for proper function as accumulated water can freeze and crack the webs of the beam.

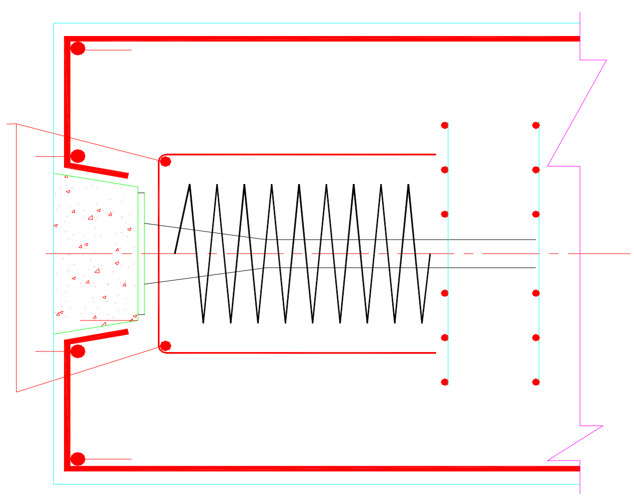


Figure 4-56: Detail of Blister Block in Plan

Examine the sides of the box girder for cracks. Adjacent box girder side surfaces are visible only on the fascias. For interior girders, inspect the bottom chamfers for cracks which may extend along the sides of the girders.

Using a string line, check for horizontal alignment and the camber of the pre-stressed beam. Signs of downward deflection usually indicate loss of pre-stress. Signs of excessive upward deflection usually indicate extreme creep and shrinkage.

Diagnosis

To provide a diagnosis one must find the answer to several questions:

- origin of the observed disorders,
- probable development in the absence of a remedy,
- possible consequences on the safety and durability of the structure,
- and, finally,,……… proposition of a repair solution.

This process is complex and requires, above all, vast experience and even intuition. This is the reason why the in depth inspection of bridges has often been compared to that of medical science, which is far from being an exact science and where the practitioner relies as much on his flair, intuition and experience as on the results of tests. In the following, therefore, the interpretation of cracks, the main symptom with regard to concrete, is dealt with exclusively.

Thermal effects, restrained shrinkage, excessive bending or tension, chemical swelling, etc..., the causes of cracking are numerous but rather than provide an extensive list of these, one can classify them into three main groups which are briefly described as follows:

Cracks due to the degradation of concrete

These may be due to physical phenomena (frost-defrosting) or, more often, chemical action, such as, for example, external sulphate aggression or indigenous degradation by alkali-reaction. The diagnosis is reached taking into account the arbitrary direction and the depth of the crack and can be probably confirmed following a chemical analysis of the salts formed at the bottom of the cracks. If the alkali-reaction is established, the prognosis is pessimistic since, despite several suggested remedies, none is really efficient. However, in the case of external aggression, the degradation is only superficial and the reconstitution of the damaged concrete can be considered, followed by the installation of a waterproofing membrane.

Cracks due to the corrosion of reinforcement

Corrosion results in the bursting of the concrete that surrounds the reinforcement which is then reflected by cracks along the outline of the bars, mainly along the edges of beams or columns. In a more advanced stage, these cracks generate scales resulting in falling concrete fragments and the exposure of reinforcement, thus accelerating the process of decay. The occurrence of cracks along the outline of the reinforcement, closest to the external concrete face, is the first symptom of corrosion. It demands an immediate and complete investigation of the structure since the occurrence of a crack is the indication that the concrete is 'bursting' due to the swelling of the steel already effected by rust and hence transformed into ferrous or ferric oxides. It is therefore highly probable that over a vast area the steel may not behave as designed. In order to determine the most suitable method for repair of cracking due to corrosion of reinforcement, an in depth and detailed assessment, of the steel in the structure that is not behaving as designed, is essential.

Quite often, the repair to cracking due to corrosion of steel reinforcement is carried out by removing the deteriorated concrete, cleaning the oxidised steel reinforcement, followed by the reconstruction of the affected component to its original geometrical shape using a concrete mix of the appropriate grade.

This approach to the repair is not satisfactory as beyond the limits of non-bonded concrete, steel is unlikely to be effective and will begin to oxidise. In order to determine the exact locations of the structure where repair is essential, mapping the equipotent areas may provide useful data. If the repair works are carried out without conducting a detailed investigation, as recommended, it is likely that new bursting cracks may develop in the vicinity of the area already repaired.

Cracks resulting from the mechanical behaviour of the structure

These are often transverse cracks due to bending or, slanted cracks due to the shear force.

In the case of reinforced concrete it should be noted that such cracks do not, in any way, constitute a defect resulting from a design or construction fault. Under high service stresses the reinforcement extends lengthwise, causing extra stress on the surrounding concrete. In time the actual stresses in the concrete will exceed the limit of allowable stresses and the phenomenon of the bursting of concrete is likely to take place. In order to prevent this bursting of concrete, it is essential to maintain the spacing of reinforcement in such a manner that it is capable of distributing the stresses uniformly, thereby controlling the crack width in concrete within the allowable limits. In other words the detailing of reinforcement and its placing should be planned carefully.

It might therefore be asked, what are the acceptable limits for cracks? For many years, it has been arbitrarily accepted that in an extremely aggressive environment (marine atmosphere) the values of 0.1 mm for a crack should be the maximum, 0.2 mm for normal external atmosphere and 0.3 mm for a sheltered structure. In fact, compliance with these values, especially the first, is in fact to limit the steel stress to an excessively low value of about 100 MPa, this figure being adjusted according to the diameter and the bond qualities of the reinforcement. However, numerous experiments have established that the corrosion risk is far more likely to be linked to the permeability of the concrete rather than to the cracks. Cracks of up to a few tenths of a millimetre do not, as was often believed, constitute a real hazard.

The case of pre-stressed concrete is not that different from that of reinforced concrete in the mind of its creators. Pre-stressing was intended to remove concrete tensile stresses, at least for those Class 1 verified structures, for which, under the most unfavourable actions, the normal bending stresses consist of compressive stresses in all sections. However this is not correct, except when extremely expensive biaxial pre-stressing is used. Concrete is not free from the main tensile stresses and the existence of such is linked to that of shear stresses. It is therefore incorrect to believe that all concrete cracks can be prevented by the implementation of pre-stressing. Here again, even under the strictest conditions the occurrence of a crack may result from the normal mechanical functioning of the structure. It is not necessarily detrimental and can be of no consequence to the structures durability if its opening is narrow and if the pre-stressing tendons are adequately protected by good quality grouting.

In the post-tensioning field during the last few decades, a constant increase in the unit force of a tendon has been achieved and currently this has reached the level of several mega-newtons. The splaying of the compressive stress from the anchorage to the whole section inevitably often results in the occurrence of considerable tensile stresses, as can be seen through the application of the finite elements method on such a diffusion area. Here also, fine and controlled cracking is perfectly permissible and it would be fruitless to try to prevent it by increasing the quantity of binding reinforcement since the risk is no longer the same. The reinforcement density becomes such that the pouring and vibration of concrete cannot be carried out correctly.

To summarise, a narrow crack, insofar as it results from the normal mechanical functioning of the structure, must not be considered as a disorder and under normal weather conditions does not necessitate any remedial action.

What to look for

Examine the alignment, profile, and impact damage of all members. Also inspect and document any cracks in the members. As pre-stressed members are under high compressive forces, cracking is significant. Vertical or diagonal tension cracks in pre-stressed members are signs that the pre-stressing steel has failed or is failing and that the loads are being carried by adjoining beams. This is a serious condition and steps should be taken to ensure the stability of the bridge as soon as possible.

The two most common causes of loss in pre-stressing forces are, impact and corrosion. Generally, deterioration occurring in pre-stressed concrete members is self-evident but, in some cases, serious and latent corrosion of pre-stressing strands may exist without many outward signs of a problem. It is therefore essential to check for concrete delamination, hairline cracks, and efflorescence or rust stains, at the level of the pre-stressed strands, which can provide an indication of strand corrosion. Longitudinal cracks may be the result of expansion forces caused by corrosion of the steel pre-stressing.

Recent research suggests that .once outward signs of corrosion in pre-stressing steel are visible, deterioration occurs very rapidly. The inspector should pay particular attention to areas where the concrete is patched. Another recently observed problem is cracking at the ends of pre-stressed concrete box girders. This can be serious enough to warrant complete bridge replacement.

Additional possible problems include:

- Any sagging by individual members could indicate overloading or loss of pre-stress.
- Horizontal deflections (sweep) may indicate asymmetric loading from either non-uniform pre-stressing forces or tendon failure.
- Efflorescence, leakage, and staining indicate the likelihood of pre-stressing steel corrosion and a diminished load carrying capacity.
- Concrete delamination or spalling is more definitive signs of pre-stressing steel corrosion and diminished capacity.
- Check for tendon damage if any of the beams have been impacted. Cracks spreading from the damaged area indicate the extent of pre-stress loss.
- Longitudinal cracks in the wearing surface may indicate that the shear keys of the primaries are not working as designed.
- Check drain holes for rust stains which would possibly indicate deterioration that is not visible until it becomes serious.

How to quantify the defects

Span, width, thickness

Centre to centre distance between expansion joints should be measured with a measuring tape. Width and thickness, and, centre to centre distance of girders should be measured with a measuring tape.

Honeycombing and quality of concrete

Hit the slab, girder soffits and faces with a hammer, at a rate of 10 blows per one square metre or, chain drag. Listen to the sound carefully. A hollow sound indicates poor concrete whilst a metallic sound indicates good quality concrete.

Spalls in slab and girders

Number of spalls	Can be counted
Area of spalls	Can be measured with a measuring tape
Depth of spall	Can be measured
Number of bar exposed	Can be counted
% of corrosion	Simple arithmetic calculation

Efflorescence, dampness and leakage

The number of affected girder and slab locations at each span, should be visually inspected and recorded.

Cracking in span

Nature of crack	Look to see whether the cracks are horizontal, vertical, inclined, mesh or diagonal
Length of crack	With a measuring tape
Width of crack	With a crack gauge
Total area	Simple arithmetic calculation
Section of super-structure	Visual

Corrosion of exposed reinforcement

Number of location	Can be counted
Location	Visual with respect to span length and width
% with respect to bar diameter	Simple arithmetic calculation
Pit corrosion	Visual

Vertical deflection

No deflection	Visual
Moderate deflection	With a string line
Excessive deflection	With a string line

Water ponding

The number and location of areas where ponding of water occurs can be visually inspected. If the ponding occurs at mid span it is an indicator of span deflection.

Concrete discolouration

The number and location of areas where concrete has discoloured can be visually inspected.

Overall rating of PSC super-structure

The main pre-stressed concrete members should be rated on both physical condition and structural capacity as compared to the original design capacity. These are the same criteria as for main reinforced concrete members. However, physical deficiencies are usually more serious in pre-stressed members. The members should be rated as a system.

- No spalling, scaling, cracking, or efflorescence. No signs of vertical or horizontal misalignment. Members show no physical limitations to performance at full-design capacity**. Sound condition**.
- Isolated scaling, Minor vertical deviations but little or no leakage between adjoining members and only a few reflective cracks in the wearing surface. **Minor Damage**.
- Web shear, flexural shear, and flexural cracks on isolated members indicate loss of strength in those members and, that the other beams are carrying the loads for these members. Leakage between adjoining members and, reflective longitudinal cracks in

the wearing surface indicate that the members are not functioning as originally designed which could mean a loss of pre-stress or an overload condition. Efflorescence, delamination, and moderate spalling may indicate corrosion of tensioning strands or concrete deterioration.

- Web shear, flexural shear and flexural cracks on many girders indicate that pre-stressed members are not functioning as originally designed and may have lost much of their original capacity. Horizontal deflections in members, vertical deflections, and/or, severe or extensive deterioration (such as excessive deflection, tendon failure or spalling) indicates that the system has lost much of its original capacity. **Serious damage**.

How to rate items

Table 4-11: Guidelines for Condition Rating of PSC Box Girder

S. No.	Defects	Condition rating	BCI Values
1	Excessive vertical deflection	Re-construction / New Construction	< 30
2	Shear crack of a width of more than 1mm.		
3	Exposure corrosion of PSC cables		
4	Moderate vertical deflection	Strengthening / Rehabilitation	45 – 30
5	Torsional cracks in girder.		
6	Spalling of concrete & corrosion of PSC cable ducts		
7	Bending cracks in girder		
8	Excessive spalling of cantilever deck slab concrete.	Moderate Repairs Required	65 – 45
9	PSC anchors damaged/corroded		
10	Efflorescence, dampness, honeycombing, discolouration of concrete.	Minor Repairs Required	80 - 65

Table 4-12: Guidelines for Condition Rating of PSC Deck Slab

Sl. No.	Defects	Condition rating	BCI Values
1	Heavy spalling in deck slab	Strengthening /	45 – 30
2	Low spalling in deck slab	Moderate Repairs Required	65 – 45
3	Cracks of a width of more than 2mm.		
4	Cracks of a width of less than 2mm	Minor Repairs Required	80 - 65
5	Efflorescence, dampness, discolouration of concrete		

4.5 Voided Slab (RCC / PSC)

Basic concepts of design

Slab bridges are frequently used for smaller spans. They require larger amounts of concrete and steel than girder bridges for the same span length, but construction cost in usually lower and their formwork is simpler and less expensive.

Slab bridges may be divided into three classes:

- Slabs ‘cast in situ’, solid or voided.
- Slabs built-up of pre-cast elements and,
- Composite slabs in which the pre-cast elements are used in combination with in-situ concrete filling

Figure 4-57: Voided Slab Super-Structure

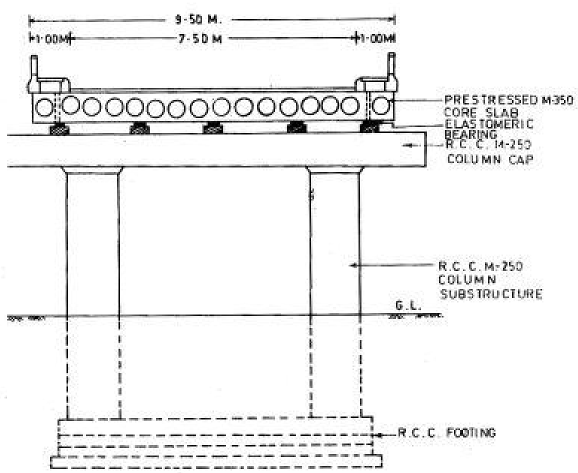


Figure 4-58: Schematic Section of a Voided Slab Bridge

Cast in situ’ slab bridges can be adopted for spans of between 6 to 30 metres. For spans up to some 8 metres, solid reinforced concrete slabs with depths up to 60 cm should be used.

Voided RCC slabs, with depths up to 80 cm, can be adopted for spans of about 8 to 15 metres. However, for spans of 15 to 30m, voided pre-stressed concrete slabs, of depths up to around 1.20 metres, are cheaper.

Solid composite slab decks, can be adopted for 8 to 15 metre spans and can consist of pre-cast units of various shapes. The units can be either an inverted 'T' or a symmetrical 'I' section, placed side by side and stressed together transversely, after the provision of in situ filling, or topping Shear connectors are used to achieve composite action between the pre-cast elements and the in-filling of the concrete or top slab, as required.

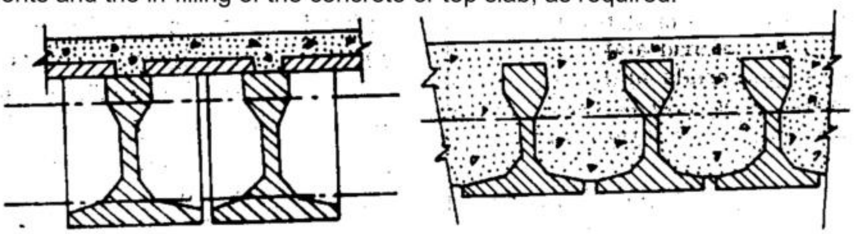


Figure 4-59: Schematic Cross Section of Composite Slab Decks

A slab system is usually adopted when the erection of formwork presents no great difficulty. Cables or reinforcements are then placed in position and after the concrete is set, cables are stressed and anchored. Some cables are usually bent up, to reduce shear stress and also to provide for a convenient distribution of end anchorages. The advantage of this is that the structure is monolithic and the stress distribution can be calculated. The disadvantages are, however, that the pre-stressing of the slab is generally uneconomic, the super structure is often heavy, and span lengths are limited.

The use of pre-cast elements is of advantage when there are difficulties in supporting the formwork. Fast construction is possible and it is economic if a large number of units are required.

Pre-cast and pre-stressed units (forming a part of the total deck) can be temporarily used as formwork for in situ concrete. Additional cables are then often used and, subsequently, stressed on the composite section. Transverse pre-stressing can then be employed to achieve transverse rigidity and integrity of the whole section.

The main problems in the design of a slab bridge are the choice of;

- maximum economic span length versus minimum depth,
- whether to precast or cast in situ,
- the type of cross-section to be used, transverse load distribution, deflection and vibration and, the method of erection.

Note: The Inspection procedure, Overall Observation and Condition rating of PSC / RC Box Girder as discussed in earlier paragraph shall be followed for PSC /RC Voided Slab.

4.6 Bow String Concrete Arch

Introduction

A Bow String arch is a type of concrete through arch that has been constructed having the crown of the arch above the deck and the arch bottom tension tie beams below the deck. Vertical columns, known as "suspenders", suspend the deck from the arch. Concrete through arches are, however, rare in Karnataka. These types of arches are sometimes also referred as "Rainbow Arches".

Figure 4-60: Close view of a Bow String Arch Span

Definition

A through arch has an elliptical shape and functions by pure axial compression and can be thought of as a long curved column. This makes the through arch ideal for the use of concrete.

Figure 4-61: Side Elevation of a Bow String Arch Bridge

Basic concept of design

Bow string arches are economic in design and satisfy the requirements for both long spans, ranging from 30m to 45m and, high clearance heights between the soffit of super-structure and the river bed.

In bow string arch bridges the horizontal thrust is resisted by horizontal ties at support locations, with the floor beams being suspended from the arches by means of vertical columns. The main support system, which is known as a "Bow String Girder" has been given this name due to its resemblance to a bow (the arch ring) and a string (the tie beams).

Bow string arches are structurally very stable and remain unaffected by small horizontal displacement of supports, namely piers or abutments, which can occur through movement caused by an earthquake or movement due to excessive earth pressure.

Components of the bow string girder

The following are the major components of an RCC Bow String Girder.

- Arch ring
- Suspender
- Beam
- Ribs
- Deck

The following are the major components of a PSC Bowstring Girder:

- Girder
- Top slab
- Bottom slab
- Web
- End diaphragms

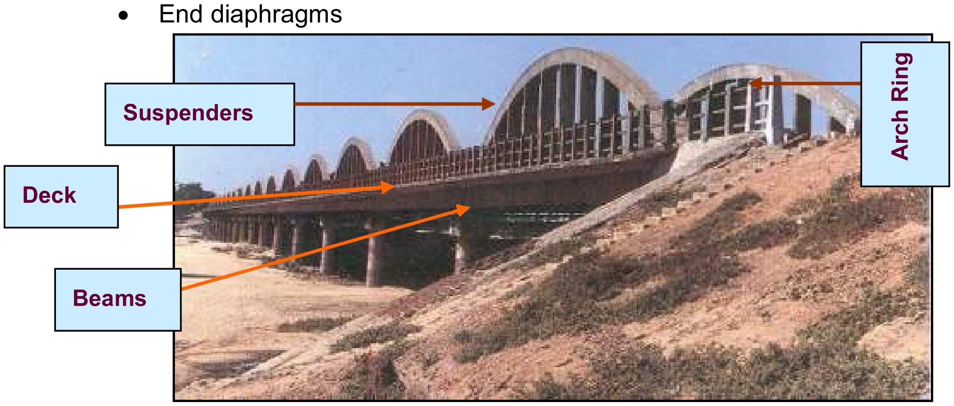


Figure 4-62: Components of Bow String Arch Superstructure

Common defects

For common concrete defects reference should be made similar to RCC Beam and Deck Slab.

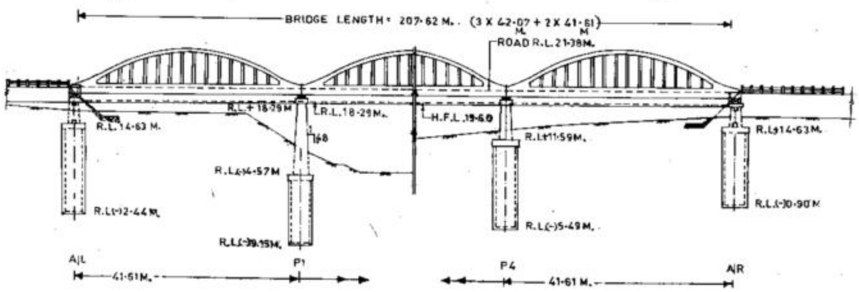


Figure 4-63: Schematic Elevation of a Bow String RCC Arch Bridge

Inspection

The following points are required to be inspected for a Bow String Concrete Arch.

- The opening and spans of the arch
- Cracks on all structural elements
- Segregation of concrete
- Concrete cover
- Corrosion of reinforcement
- Any damage to expansion joints
- Proper functioning of bearings
- Any longitudinal cracks on the suspenders
- Spalling of concrete
- Pot holes in the deck

Overall rating

In terms of rating this structure, reference should be made to RCC T beam and Deck Slab and, PSC T-beam and deck slab, contained within this chapter.

How to rate items

Table 4-13: Guidelines for Condition Rating of Bow String Arch

Sl. No.	Defects	Condition Rating	BCI Values
1	Excessive vertical deflection	Re-Construction / New Construction	<30
2	Shear crack in any girder of a width more than 2mm.	Requires Strengthening / Rehabilitation	45 - 30
3	Bearing crack in any girder of a width of more than 2 mm.		
4	Excessive spalling of concrete, with heavily corroded reinforcement, in any girder.		
5	Moderate deflection in girder or shear crack width less than 2mm.	Moderate Repairs Required	65 - 45
6	Bending cracks in any girder.		
7	Moderate spalling in any girder.		
8	Low deflection.	Minor Repairs Required	80 - 65
9	Low spalling.		
10	Pot corrosion of reinforcement.		
11	Efflorescence, dampness, honeycombing, discolouration of concrete.		

4.7 Composite Steel Structure

Introduction

Steel is a widely used construction material for bridges due to its strength, relative ductility, and reliability. It is found in a variety of members on a large number of bridges. Therefore, the bridge inspector needs to be familiar with the various properties and types of steel.

Common Methods of Steel Member Fabrication

Rolled Shapes

Rolled beams are manufactured in structural rolling mills. The flanges and web are one piece of steel. Rolled beams are generally “compact” sections which satisfy flange to web thickness ratios to prevent buckling.

Rolled beams generally will have bearing stiffeners but no intermediate stiffeners since they are compact. Although rolled beams may not incorporate intermediate stiffeners, they will have connection plates for diaphragms or cross-frames.

Built-Up Shapes

Plate girders are often specified when the design calls for members deeper depth.

Plate girders are built-up shapes composed of any combination of plates, bars, and rolled shapes. The term “built-up” describes the way the final shape is made.

Older fabricated multi-girders were constructed of riveted built-up members. Today’s fabricated multi-girders are constructed from welded members.

Figure 4-64: Schematic View of Steel I Girder

Anticipated Modes of Steel Deficiencies

Corrosion

To properly inspect a steel bridge, the inspector will have to be able to recognize the various types of steel deficiencies and deterioration. The inspector will also have to understand the causes of the deficiencies and how to examine them. The most recognizable type of steel deficiency is corrosion. Bridge inspectors will have to be familiar with corrosion since it can lead to a substantial section reduction resulting in decreased member capacity. Corrosion is the primary cause of section loss in steel members and is most commonly caused by the wet-dry cycles of exposed steel. When deicing chemicals are present, the effect of corrosion is accelerated.

Corrosion is the deterioration of steel by chemical or electro-chemical reaction resulting from exposure to air, moisture, deicing salts, industrial fumes and other chemicals and contaminants in the environment in which it is placed. The terms rust and corrosion are used inter-changeably in this sense. Corrosion, or rusting, will only occur if the steel is not protected or if the protective coating wears or breaks off.

Rust on carbon steel is initially fine grained, but as rusting progresses it becomes flaky and delaminates exposing a pitted surface. The process thus continues with progressive loss of section.

Figure 4-65: Schematic View of Corroded Steel Girder

Some of the common types of corrosion include:

Environmental corrosion - primarily affects metal in contact with soil or water and is caused by formation of a corrosion cell due to deicing chemical concentrations, moisture content, oxygen content, and accumulated foreign matter such as roadway debris and bird droppings

Bacteriological corrosion - organisms found in swamps, bogs, heavy clay, stagnant waters, and contaminated waters can contribute to corrosion of metals

Stress corrosion - occurs when tensile forces expose an increased portion of the metal at the grain boundaries, leading to corrosion and ultimately fracture

Permanent Deformations

Permanent deformation of steel members can take the form of bending, buckling, twisting or elongation, or any combination of these. Permanent deformations may be caused by overloading, vehicular collision, or inadequate or damaged intermediate lateral supports or bracing.

Permanent bending deformations occur in the direction of the applied loads and are usually associated with flexural members; however, vehicular impact may produce permanent deformations in bending in any other member.

Permanent buckling deformations normally occur in a direction perpendicular to the applied load and are usually associated with compression members. Buckling may also produce local permanent deformations of webs and flanges of beams, plate girders or box girders.

Permanent twisting deformations appear as a rotation of the member about its longitudinal axis and are usually the result of eccentric transverse loads on the member.

Permanent axial deformations occur along the length of the member and are normally associated with applied tension loads.

Cracking

CRACK is a linear fracture in the steel. Cracks are mainly produced due to fatigue and can, under certain conditions, lead to a brittle fracture.

Fatigue Cracking

Fatigue failure occurs at a stress level below the yield stress and is due to repeated loading. This type of cracking can lead to sudden and catastrophic failure on certain bridge types. Therefore, the bridge inspector needs to know where to look and how to recognize early stages of fatigue crack development.

Figure 4-66: View of Crack in Steel Girder

Some factors leading to the development of fatigue cracks are:

- Frequency of truck traffic
- Age or load history of the bridge
- Magnitude of stress range
- Type of detail
- Quality of the fabricated detail
- Material fracture toughness (base metal and weld metal)

- Weld quality
- Ambient temperature

Connection Deficiencies

Loose connections can occur in bolted, riveted or clamped connections. The loose condition may be caused by corrosion of the connector, gusset plates or fasteners, cracking or failure of the individual fasteners, excessive vibration, over stressing, or simply a lack of proper **tightening during construction.**

Heat Damage

Steel members undergo serious deformation when exposed to extreme heat. In addition to sagging, or elongation of the metal, intense heat often causes members to buckle and twist; rivets and bolts may fail at connection points. Buckling could be expected where the member is under compression, particularly in thin sections such as the web of a girder.

Figure 4-67: View of Bend due to severe heat Steel Girder

Coating Failures

Chalking, erosion, checking, cracking, and wrinkling caused by too much paint.

Blisters are caused by painting over surface contaminants such as: oil, grease, water, salt, or by solvent retention. Corrosion can occur under blisters.

What to look for

There are three basic methods used to inspect a steel member. Depending on the type of inspection, the inspector may be required to use only one individual method or all methods. They include:

- Visual
- Physical
- Advanced inspection methods

Visual Examination

Steel Members

- Inspect steel members for corrosion, section loss, buckling, and cracking.
- In the inspection records, identify the location of Fracture Critical Members

Some common steel bridge inspection locations and signs of distress include:

- **Bent or deficiency members -** determine the type of deficiency (e.g., collision, overload, or fire), inspect for proper alignment, and check for cracks, tears, and gouges near the deficiency location
- **Corrosion**, which could reduce structural capacity through a decrease in member section and make the member less resistant to both repetitive and static stress conditions; since rust continually flakes off of a member, the severity of corrosion cannot always be determined by the amount of rust; therefore, corroded members must be examined by physical as well as visual means
- **Fatigue prone details -** fatigue cracks may occur at certain locations on a bridge, and certain inspection procedures need to be followed when fatigue cracks are observed
- Other stress-related cracks - determine the length, size, and location of the crack
- Points on the structure where a discontinuity or restraint is introduced
- Loose members which could force the member or other members to carry unequal or excessive stress
- Damaged members, regardless of damage magnitude, which are misaligned, bent, or torn
- Problematic details: welded or mechanical connections; look for cracks in the paint, cracks in the steel
- Repairs that show indiscriminate welding or cutting procedures
- Areas of excessive vibrations or twisting

How to rate items

Table 4-14: Guidelines for Condition Rating of Steel Girder and Slab over Steel Girder

Sl. No.	Defects	Condition Rating	BCI Values
1	Excessive vertical deflection of a girder, Severe Corrosion, Wide Cracks of the Main Components of the Steel Structure	Re-Construction / New Construction	<30
2	Bends in webs, flanges, stiffeners or bracings, Excessive spalling of concrete with heavily corroded reinforcement in Slab.	Requires Strengthening / Rehabilitation	45 – 30
3	Moderate deflection in Steel Structure, Deterioration of Anti- corrosive paint or galvanizing, Loose bolts or rivets	Moderate Repairs	65 – 45
4	Low deflection, Small spalling of concrete, light patches of Deterioration of paint	Minor Repairs Required	80 - 65

4.8 Masonry Arch Bridges

Introduction

Masonry arches are closed spandrel arches. The spandrel area, the area between the arch and the roadway, contains 'fill' which is retained by vertical walls. The arch section is called a 'ring' or 'barrel' and is continuous member between the spandrel walls. Masonry arches disperse traffic loads through the fill material which is contained by the spandrel walls. This type of arch is efficient for short span applications.

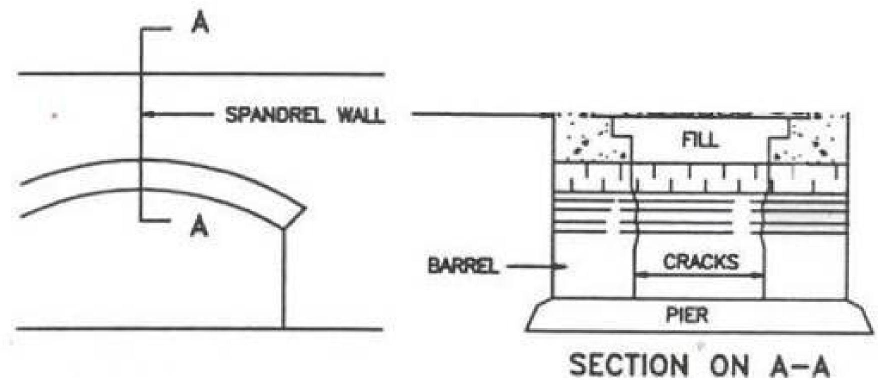


Figure 4-68: Arch Spandrel Wall

Definition

The arch form is generally used architecturally for its aesthetic qualities and, structurally, to generate compressive stress only, that is, for no tensile stress in the structure following the line of thrust of the resultant forces. Masonry construction is particularly well suited for small span openings in walls or over roads, rivers etc., with the arches being constructed in stone or brick masonry.

Arch basic concepts

The basic design concept and construction of a masonry arch uses a block building approach. Arch elements, although connected, are basically stacked one on top of another, with the elements at the bottom of the arch experiencing the largest compressive load due to the weight of the elements above. Arch spans are always considered as a 'simple span', during design, because of the basic function of the arch.

Figure 4-69: Elevation of a Stone Masonry Arch Bridge

Arch Components

The major components of an arch are listed and briefly explained in following Table and shown below figure.

Table 4-15: Arch Components - Definition

Abutments	Portions of a wall supporting the arch
Coursing joints	Joints between rings
Crown	Highest point of extrados
Depth	The normal distance between intrados and extrados
Extrados	The external curve of the arch, sometimes termed the back of the arch
Intrados	The inner curve of the arch
Keystone	The keystone is the top or central voussoir and is placed last in the construction of the arch.
Ring(s)	Course(s) comprising the arch.
Ring or bed joints	Joints between voussoirs
Rise	Vertical distance between the 'springing' line and highest point on the intrados
Skewbacks	Prepared or inclined surfaces of abutments from which the arch 'springs'
Soffit	The under surface of the arch. Both soffit and intrados are accepted as having the same meaning.

Span	Horizontal distance between 'springing' points
Springing line	Horizontal line between 'springing' points
Springing points	Points of intersection between skewbacks and the intrados
Voussoirs	The wedge-shaped units comprising the arch. Plain voussoirs are where rectangular units are used.

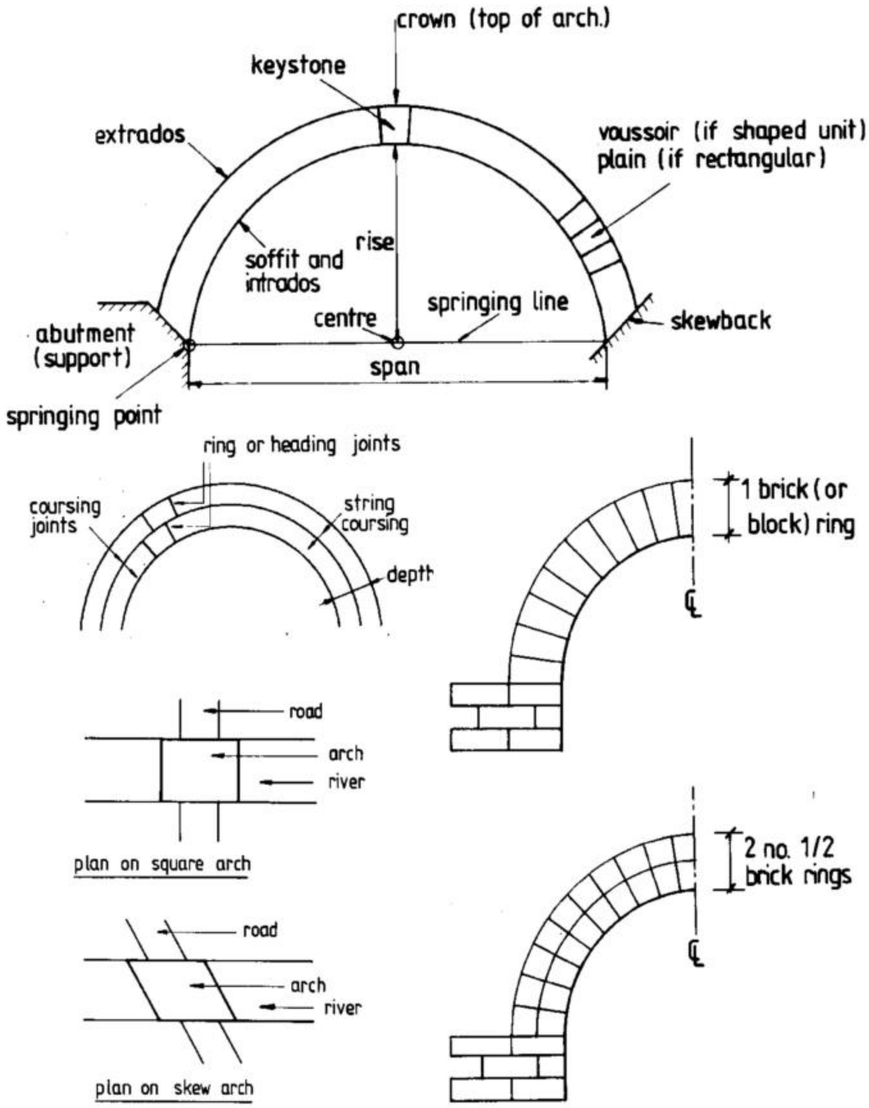


Figure 4-70: Component of Masonry Arches

Arches can be constructed from rectangular or shaped masonry units, depending on the type and dimensions of the arch.

Various forms and shapes of arches have been widely used. Their 'setting out' is based on basic geometrical methods relating to the size and shape of arch. Some common shapes are illustrated below.

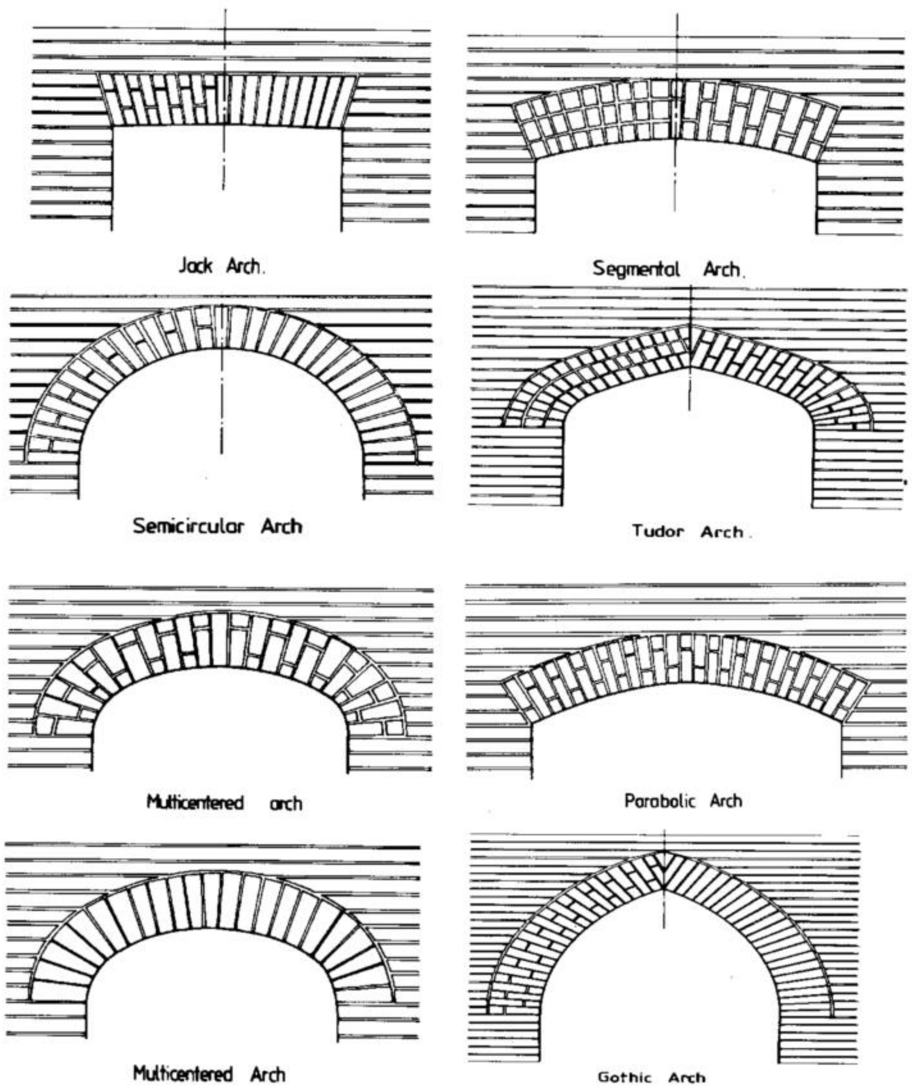


Figure 4-71: Common Shapes of Masonry Arch used in Bridge Construction

What to look for

- Stone masonry should be rated as a primary member only when it is structural masonry.
- Some of Karnataka's oldest bridges are masonry arches. In rating primary members, consideration should be given to the condition of: the brick/stone; the masonry work and, the overall behaviour of the arch and spandrel walls.
- In assessing stone/brick condition, it is necessary to look for weathering, splits, de-lamination or cracks in individual stones/bricks, spalling, and crumbling.
- The mortar should be examined for soundness, signs of leakage, and associated efflorescence, with the missing percentage of mortar being estimated.
- The masonry arch and spandrel walls should be examined as a part of main structural system for signs of distress, such as: moved or shifted stones, cracks, or splits through adjoining stones and, leakage that quickens deterioration. If movement has occurred, the extent of the movement, and whether it is progressive or has stabilised, should be ascertained by both measurement and comparison with its previous condition.
- If the masonry arch is partially or totally plastered then any cracks, and any other defects in the plaster should also be noted.

Structural defects

The following defects are generally associated with arch bridges.

Defects in arch barrel:

Due to both ageing and weathering, arch masonry or concrete may show signs of deterioration through leaching of joints, spalling of mortar and/or weathering of masonry. These signs of deterioration need to be attended to as soon as possible following detection. The following defects require special attention.

Extension of cracks from the sub-structure to the arch barrel: As the arch rests on the sub-structure, any cracks in the sub-structure, due to differential settlement etc., may extend through the arch barrel and may then also appear as longitudinal cracks (cracks parallel to the carriageway). These cracks require grouting with cement/epoxy mortar. The reasons for the unequal settlement should be identified and remedial measures should be undertaken.

Transverse or diagonal cracks in arch barrel (intrados): These cracks are serious in nature and indicate the presence of tensile stresses at the intrados. In their initial stages, these cracks are generally found in the vicinity of the crown of the arch. In stone masonry arches they have a tendency to progress in a diagonal/zigzag direction. Such cracks indicate a serious weakness in the arch and require proper investigation followed by the adoption of an appropriate strengthening measure including, in the worst case, reconstruction.

Crushing of masonry:

The probable causes of the crushing of the arch masonry are as follows;

- Leaching of mortar in the joints.
- Weathering of masonry
- Excessive loading
- Inadequate cushioning over the arch

Loose of keystone and voussoirs:

This can occur due to the settlement/titling of an abutment or pier, or, the hammering effect of dynamic loads due to inadequate cushioning and/or loss of joint material. The remedy lies in: the strengthening of the foundations; increasing of the cushioning; a reduction in the load transfer; modifications in the carriageway and, deep pointing of the joints, as the case may be.

Longitudinal cracks in arch away from spandrel wall: These cracks can occur due to differential stresses between the parts of arch barrel subjected to live loads. Such cracks may be seen between the carriageway and the spandrel walls. They may also occur due to differential settlement of foundations. The underlying cause should be identified and appropriate remedial action taken.

Defects associates with spandrel walls:

- Longitudinal cracks in the barrel.
- The sliding of spandrel walls over the arch barrel, bulging or poor fitting of the spandrel wall.

Plaster defects

Loose joints: Poor maintenance, poor quality of construction and, heavy rains/flooding, can all cause the loosening of joints.

Loss of joint material: Mortar or pointing is the joint material, between masonry layers, which is exposed. The flow of water usually loosens the mortar in joints, making them weaker. The alternating process of wetting and drying can also damage joint material.

Shifting of stones / bricks: Due to loose joints and loss of joint material, stones or bricks are disturbed from their original location.

Plaster condition covering masonry : Plaster can be damaged due to; the impact of floating objects/debris; eroded by rain water or changes in moisture content, or, cracked because of the poor quality of plaster used and/or a reflection of cracks in the masonry.

Damage to stone / brick: Many weaker types of brick or stone can have a short life. They can be damaged by

- Impact of floating objects/debris.
- Changes in moisture content.
- Alternating condition of wetting and drying.

Vegetation growth: It is not unusual for vegetation growth to be observed. If this is not removed, then it can damage the structure badly by causing extra pressure at joints.

Any sounds occurring during traffic movement over the arch.

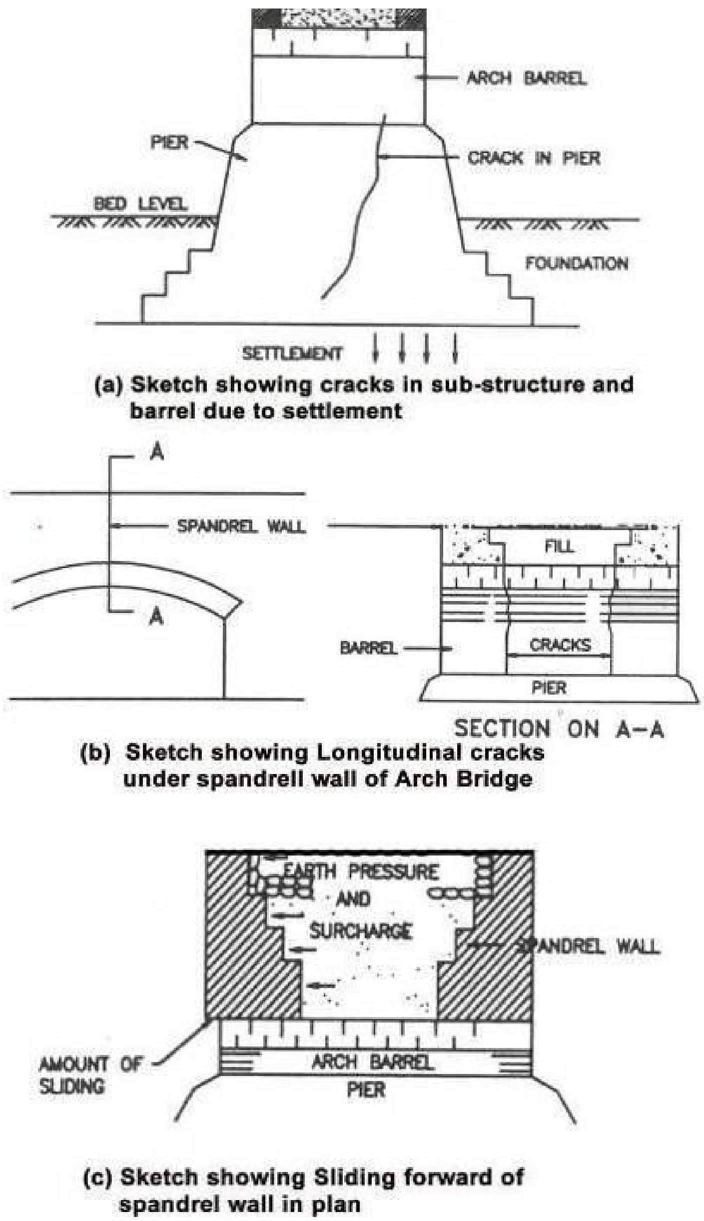


Figure 4-72: Some Types of Distress in Arch Bridges

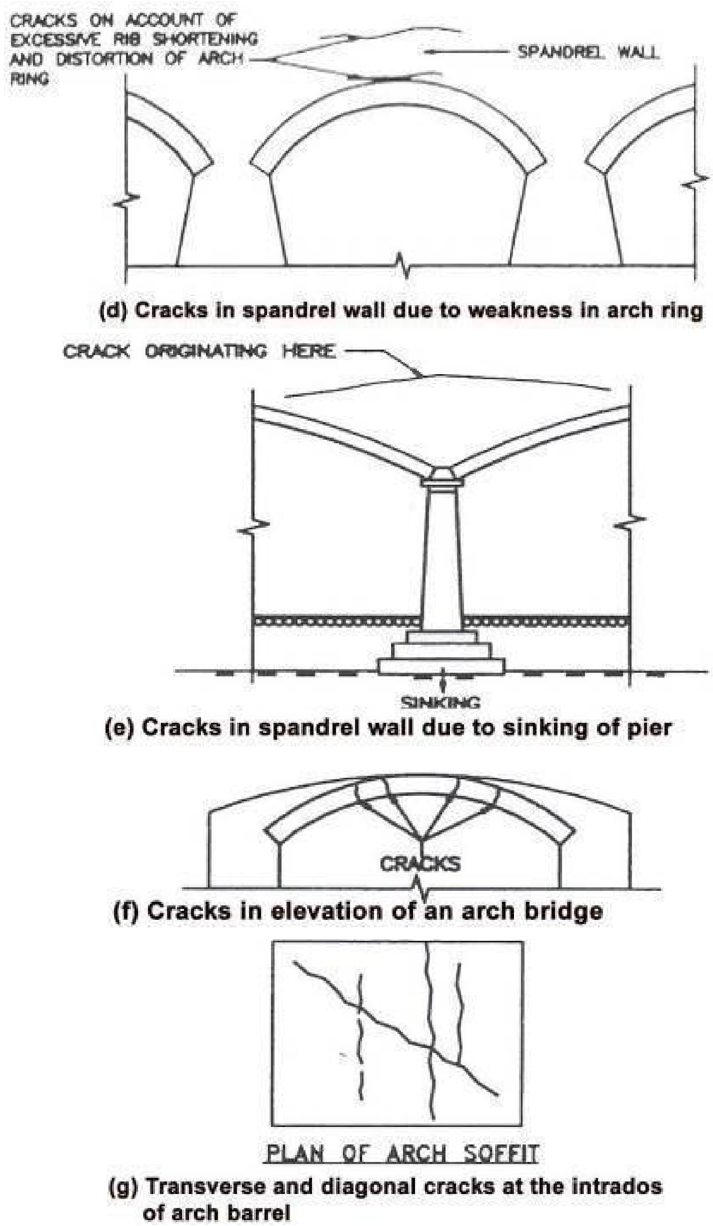


Figure 4-73: Other Types of Structural Distress in Arch Bridges

How to quantify the defects

Loose joints: Visual observation.

Loss of joint material: This can be assessed by hammering in a nail into the mortar. If the mortar falls out easily then this can be considered as a loss of joint material. The area affected should be measured using a measuring tape.

Shifted stone/brick: Visual observation.

Plaster condition over masonry: The condition of the plaster covering masonry can be tested by lightly hitting the surface with a hammer. If pieces of plaster fall off, then the indication is that the plaster is in poor condition. The area affected should be measured using a measuring tape

Damaged stone / brick masonry: If the light tapping of the stone or brick face with a hammer creates a hollow noise, it is an indication of deterioration.

Vegetation growth: Visual observation.

How to rate an item

Factors affecting condition rating

- Span
- Span/arch depth
- Profile
- Shape
- Material
- Ring
- Joint - Fill, Width, Depth, Condition
- Supports
- Cracks
- Deformation
- Abutment fault

Based on all these factors an arch can be rated using the following general guidelines:

- For any given load, a flat arch is generally weaker than that having a curved profile.
- A higher rating for sound condition should be given to arches built in granite as opposed to those built with random stone or brick masonry.
- Joints with a width of up to 6mm are considered good compared to those with a joint width of between 6mm to 12mm and over.
- Joints with pointing are generally better than those with plain joints.
- Mortar in good condition should be rated as sound in comparison to loose mortar.

Observations before rating

For masonry arches, the most important point to look for is any change in the shape of the arch. This can be observed in the following manner:

- Standing a long distance away, compare the shape on the left of the arch centre with that on the right. The observing of the shadows cast often reveals a lot of information.
- Look for any shifts in the key stone at the centre of the face walls.
- From under the arch looks for any change, local or otherwise, to the shape of barrel.
- The arch barrel should also be checked for any cracking. The crack details should be documented by means of sketches. Cracks across the road are usually a dangerous sign. There may also be bulging of face walls. Any bulge in the face walls should be documented.
- Any spalling of stones or bricks in the arch or spandrel walls should be documented.
- Quality and loss of pointing should be documented.
- Leakage through the arch: The effects of weather and water generally cause arch materials to deteriorate. With deterioration, water leakage becomes a common occurrence for most masonry arches. Small leakages do not cause problems but, if the leakage area is large, white stains will be observed near joints and clear wet areas may even be seen. If the leakage is excessive then the arch will become damaged by the loosening of mortar and the decay of masonry.


Loosening of Mortar Joints


Spandrel wall Damaged


Change in Arch Shape


Vegetative Growth in Spandrel wall


Severe loss of Bricks in Arch

Figure 4-74: Showing various condition of Arch Bridges

Overall rating of a Masonry Arch

Table 4-16: Guidelines for Rating of Arch Bridges

Sl. No	Defects	Condition rating	BCI Values
1	Significant movement of the key stone creating structural instability in the arch, Serious weathering of stones	Re-construction / New Construction	< 30
2	Signs of slight movement along arch or wall lines and/or, serious leakage causing deterioration of stones and mortar	Strengthening / Rehabilitation	45 – 30
3	Loss of a significant amount of mortar with around 40 percent of mortar missing	Moderate Repairs Required	65 – 45
4	With minor cracks being observed in the masonry, up to 15 percent of mortar maybe missing and leakage may be occurring but this is neither serious nor causing progressive deterioration. There may also be minor weathering of stones	Minor Repairs Required	80 - 65

CHAPTER – 5

Bearings

Chapter 5: Bearings

5.1 Bearings

Definition

A bridge bearing is an element of a bridge that provides an interface between the superstructure and substructure.

Basic Concept

The three primary functions of a bridge bearing are:

- To transmit horizontal and vertical loads from the superstructure to the substructure
- To permit longitudinal movement of the superstructure due to thermal expansion and contraction at designated support locations
- To allow rotation caused by dead and live load deflection.

Types of Bearing

Although there are many different types of bearings, bearing types can be broken into three major categories based upon the basic materials from which they are made:

- Metal bearings and PTFE Pot Bearings (Considered as all other types of bearing in the inventory form, except elastomeric bearings)
- Elastomeric bearings

Various metallic materials are used in bearings, including; steel, bronze, aluminium, lead, and cast iron. However, steel is by far the most prominent and the most susceptible to deterioration, whilst the others are either non-corrosive or corrosion-resistant. Consequently, the following discussion concentrates on the most common materials used, namely, steel bearings and elastomeric bearings.

Metal bearings

The materials commonly used for a metal bearing are;

- Mild and forged steel
- High tensile steel
- Stainless steel
- Cast steel / Grey iron / Welds

For the specifications and details on these materials reference should be made to IRC: 81 (Standard specifications and codes of practice for road bridges, Section-IX – Bearings, Part-I: Metallic bearing)

A Metal bridge bearing consists of four basic elements:

- Sole plate
- Bearing
- Masonry plate

- Anchorage

Sole plate - The sole plate is a steel plate that is attached to the bottom flange of girders or beams or to the bottom chord of trusses. A sole plate may also be embedded into the bottom flange of a pre-stressed girder. With concrete beams, girders, or slabs, the lower flange or bottom of the section may function as a sole plate.

Bearing - The bearing is secured to the sole plate and the masonry plate and provides for the transmission of the forces from the sole plate to the masonry plate.

Masonry plate - The masonry plate is a steel plate that is attached to the bearing seat of an abutment or pier. The masonry plate serves to distribute vertical forces from the bearing above to the substructure unit.

Anchorage - The anchor bolts connect the bearing to the substructure unit. Anchor bolts are designed to restrain the masonry plate from horizontal translation. The anchor bolts can, however, pass through or alongside the expansion bearing element to provide restraint against transverse movement.

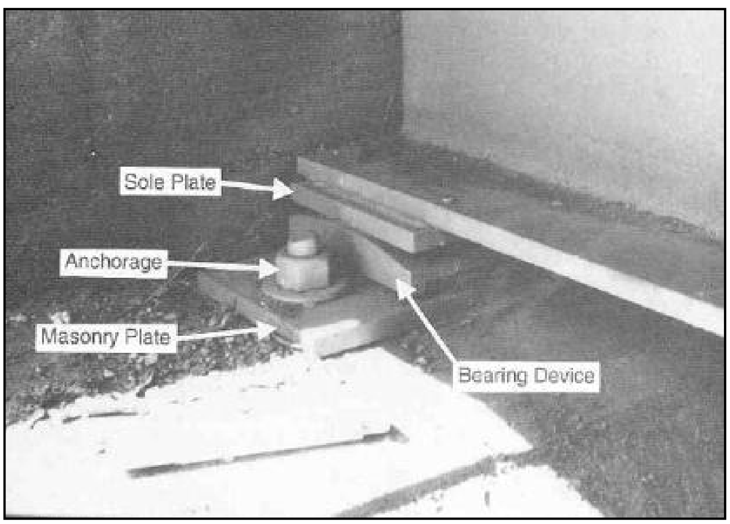


Figure 5-1: Elements of a Typical Metal Bridge Bearing

Common types of metal bearings

The common types of metallic bearings are

Roller bearings

A roller bearing consists of a cylinder which "rolls" between the sole and masonry plate as the superstructure expands and contracts. Roller bearings are used in a wide variety of forms, including single rollers and multiple rollers and are described as 'single roller bearings' and 'multiple roller bearings' respectively.

Figure 5-2: Single Roller Bearing

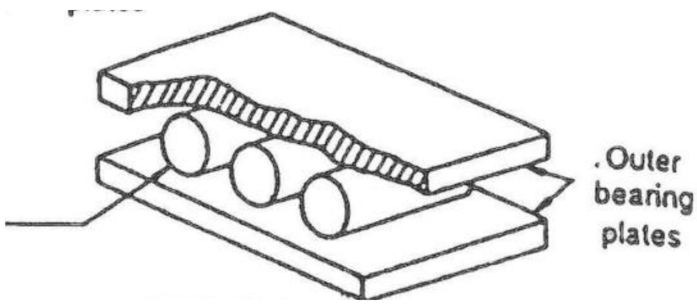


Figure 5-3: Sketch of a Multiple Roller Bearing

Rocker bearing

A bearing essentially consists of a curved surface in contact with a flat or curved surface and is constrained to prevent relative horizontal movement. The curved surface may be cylindrical or vertical. The rocker bearing functions in a similar manner to the roller bearing and is generally used where a substantial amount of movement is required. It permits rotation by the 'rolling' of one part or another.

As with roller bearings, rocker bearings come in different forms, such as segmental rockers, segmental rocker nests, point rockers, linear rockers and pinned rockers.

Figure 5-4: Segmental Rocker Bearing

Figure 5-5: Pinned Rocker Bearing

Figure 5-6: Segmental Rocker Nest Bearing

Knuckle bearing

A bearing essentially consisting of two or more members with mating curved surfaces. The curved surfaces may be spherical or cylindrical. Knuckle bearings permit rotation through the rolling of one part or another.

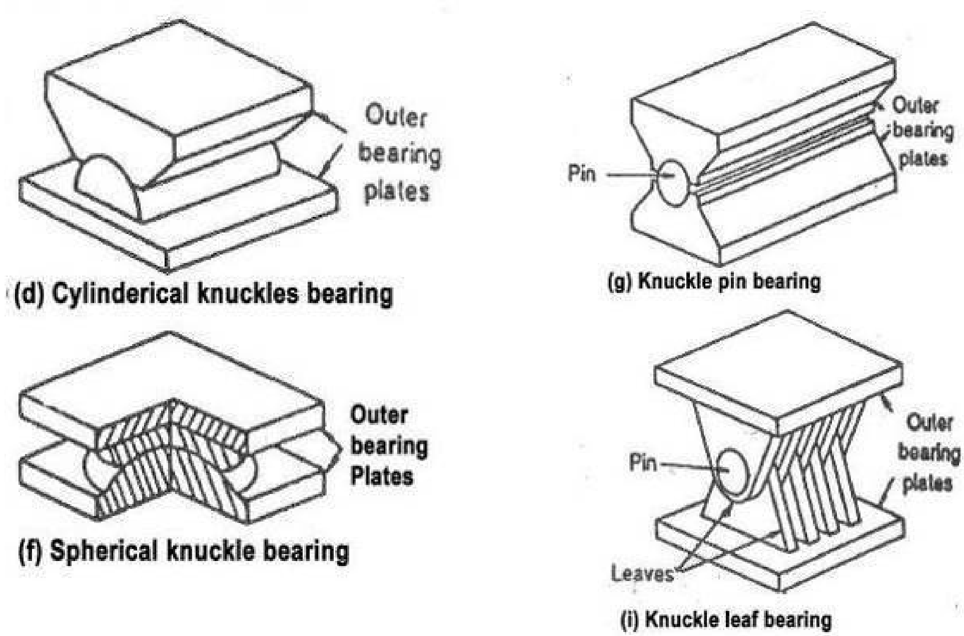


Figure 5-7: Sketches of Knuckle Bearings

Sliding bearing

A bearing consisting of two surfaces sliding one on the other.

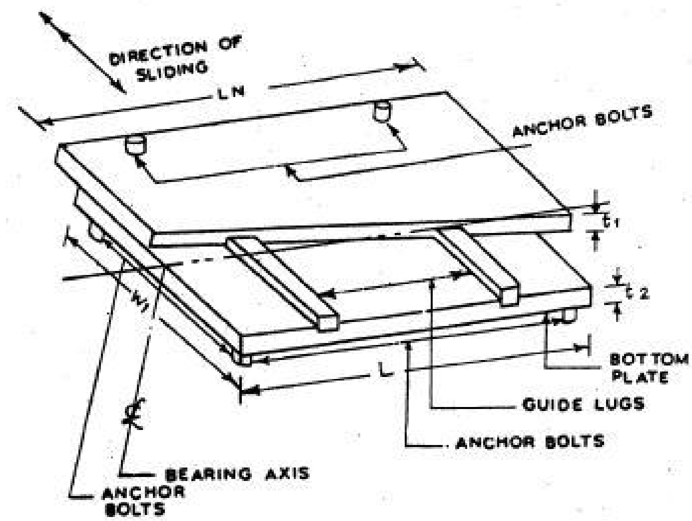


Figure 5-8: Sliding Bearing

Pot Bearing

A bearing consisting of a metal piston supported by a disc of un-reinforced elastomer that is confined within a metal cylinder or "Pot", allowing for the rotational movement about any axis in a horizontal plane in order to both bear and transmit vertical loads. A pot bearing may be provided with a sliding assembly comprising of a stainless steel plate attached to the metal backing plate, sliding in horizontal plane over the PTFE but confined in recesses on the piston and termed as a pot/PTFE bearing. Depending on the desired degree of freedom, a Pot bearing can be of three types, namely;

- Fixed type pot bearing
- Free sliding type pot/PTFE bearing
- Guided sliding type pot/PTFE bearing

Figure 5-9: Pot Bearing

Elastomeric bearing

An elastomeric bearing comprises a block of elastomer that may be reinforced internally with steel plates (i.e. steel laminates) which makes it a laminated or restrained elastomeric bearing. Various means are used to prevent the neoprene bearing from 'walking out' of position from under a beam. An epoxy compound can be used to bond the pad to the pedestal.

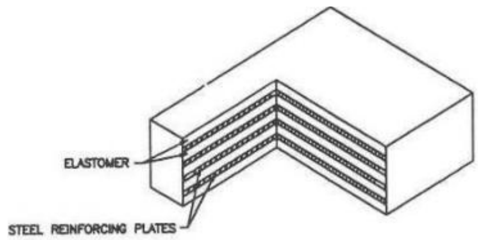


Figure 5-10: Elastomeric Bearing under a Girder and in Section

Bearing pedestals

The pedestals function is to support the bearings, transfer loads to the sub-structure and to make up any differences in elevation between the top of the cap or pier and the bottom of the bearing.

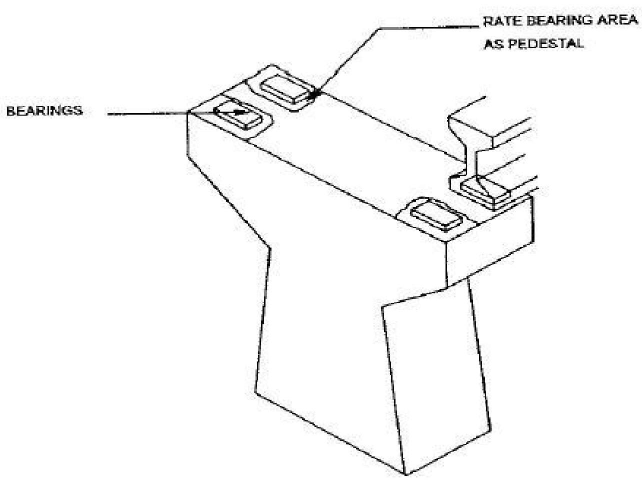


Figure 5-11: Bearing Pedestal

What to Look For

Elastomeric bearing

Compression bulging of sides: Neoprene bearing pads should be inspected for excessive bulging (approximately greater than 15% of thickness). This indicates that the bearing might be too 'tall' for the application and therefore improperly designed. Slight bulging in the sides of the pad can be expected. Whether or not it is excessive may be difficult to determine but, if it appears excessive for the height/thickness of the pad then it should be noted. As expansion and contraction of the structure takes place, the bulge will tend to roll on the beam or bridge 'seat'.

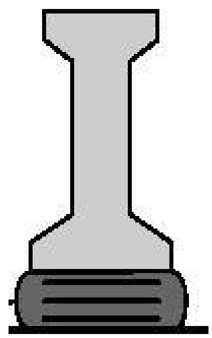


Figure 5-12: Compression Bulging of Elastomeric Bearing

Excessive longitudinal or transverse deformation marked as shear deformation in the inventory form: The longitudinal or transverse movement of a neoprene bearing pad is measured in nearly the same manner as that for a sliding plate bearing. The longitudinal movement (Δ) is the horizontal offset (in the longitudinal direction) between the top and the bottom edge of the pad. The temperature at the time of inspection should also be recorded.

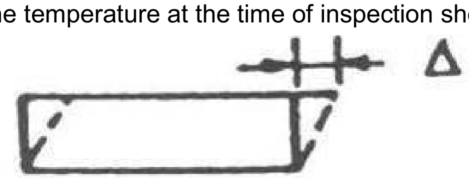


Figure 5-13: Horizontal Deformation

Radial cracking in the bulges: Excessive rotation in a neoprene bearing cause 'squeeze-out' effect in the bearing. Due to this 'squeeze-out' radial cracks can occur on the bearing surface. The rotation on a neoprene bearing is shown below in Figures 5-15 and 5-16. The top and bottom of the pad are normally parallel if no rotation has taken place. The inspector should measure the length and height of the pad at the front and rear of the bearing. If a bevelled pad is used to accommodate a bridge at grade, then the original dimensions of the pad must be known in order to determine the bearing rotation.

Figure 5-14: Rotation of Elastomeric Bearings and Squeeze-out Effect of Elastomeric Bearings

Surface cracking: Excessive horizontal movement, or bulging of the bearing surface, can cause cracking in the bearing surfaces which may lead to the splitting or tearing of the bearing surface, as shown.

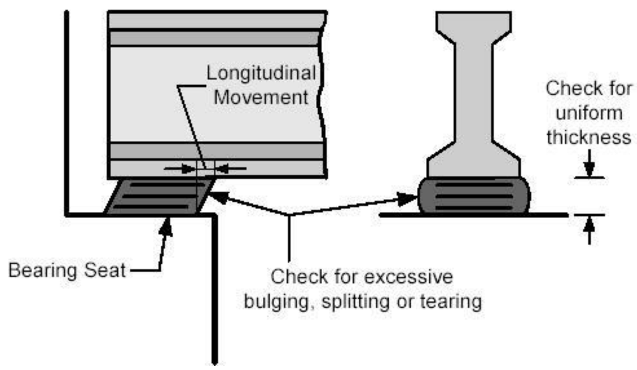


Figure 5-15: Surface Cracks in Elastomeric Bearings

Metallic and pot bearings

Deformity in the bearing: Deformity in the bearing may be caused by the excessive movement of the bearing. The inspector should check for any excessive movement or for a dislodged segment of the bearing, as shown.

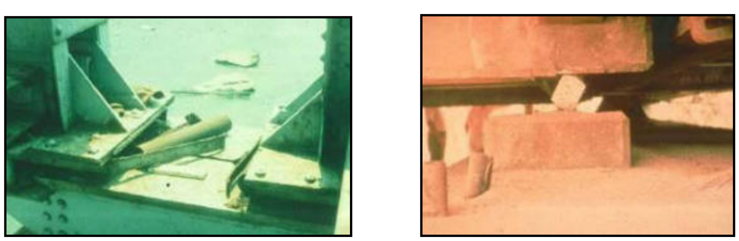


Figure 5-16: Dislodged Roller and Excessive Tilt in Rocker

Damaged anchor bolt: Check for any bend or deformity in the anchor bolt. Also check for any loose or missing nuts in the anchors.

Figure 5-17: Damaged Anchor Bolt

Free movement of the bearing: Frozen bearings can occur when the deterioration and build-up of debris causes the bearing to 'bind' up, thereby preventing free movement. Evidence of a frozen bearing includes bending, buckling, improper alignment of members, or, cracks in the bearing seat. The inspector should look for any build-up of dirt and debris in and around the bearing that could affect the smooth operation of the bearing. Since the pot bearing allows multidirectional rotation, the inspector should check rotation along both sides of the bearing.

Figure 5-18: Frozen Rocker Bearing

Figure 5-19: Movement of Sole Plate

Rusting of a metal bearing: Metal bearings should be checked for excessive rust or corrosion which results in a loss of material in the bearing itself.

Figure 5-20: Heavy Corrosion of Steel Rocker Bearing

Bearing seats/bearing pedestals

Disintegration of poorly prepared bearing seats (pedestals) is one of the main and most common causes of bearing failure. Uneven seating of bearing over the pedestal can cause localised overloading, resulting in failure of the bearing and damage to the pedestal. It can even damage the superstructure that is in contact with the bearing. The inspector should look for any water marks, accumulation of debris, localised damage, cracks, and, splitting of concrete in the pedestal.

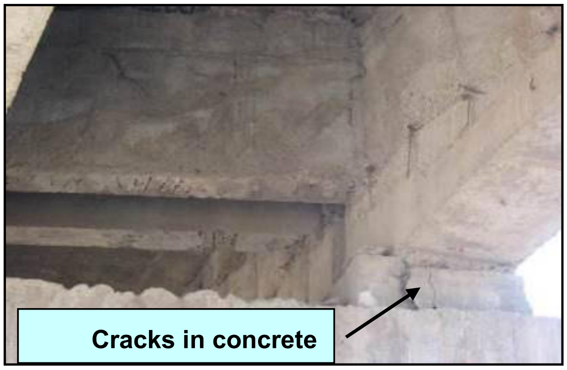


Figure 5-21: Cracks in Bearing Pedestal and Concrete Spalling in Pedestal

Figure 5-22: Accumulation of Debris at Bearing Pedestal Location

Condition Rating of a Bearing

The indicators given below are the key factors for condition rating. If any of these are seen to have occurred then the appropriate condition rating should be registered.

Table 5-1: Guidelines for Condition Rating of Elastomeric Bearings

Sl. No.	Defects	Condition rating	BCI Values
1	Surface cracking	Replace	< 30
2	Radial cracking	Replace	< 30
3	Excessive shear deformation	Replace	< 30
4	Spalling of concrete in pedestal	Rehabilitate	45 – 30
5	Compression bulging of sides	Rehabilitate	45 – 30
6	Splitting of concrete in pedestal	Rehabilitate	45 – 30
7	Cracks in pedestal	Moderate Repairs	65 - 45

Table 5-2: Guidelines for Condition Rating of Metallic and Pot Bearings

S. No.	Defects	Condition rating	BCI Values
1	Deformity or cracks in the bearing	Replace	< 30
2	Heavy rusting of bearing	Replace	< 30
3	Restricted free movement of bearing	Rehabilitate	45 – 30
4	Spalling of concrete in pedestal	Rehabilitate	45 – 30
5	Splitting of concrete in pedestal	Moderate Repairs	65 – 45
6	Bearing not sitting in full length	Moderate Repairs	65 – 45
7	Cracks in pedestal	Moderate Repairs	65 – 45
8	Damaged Anchor bolt	Minor Repairs	80 – 65
9	Missing or loose nuts for anchors	Minor Repairs	80 – 65
10	Nominal Rusting of bearing	Minor Repairs	80 – 65

“Heavy rusting of a bearing” means the thickness of the bearing components has reduced by 20% or more of its original thickness.

CHAPTER – 6

Sub-Structure

Chapter 6: Sub-Structure

6.1 Abutment

Definition

The super-structure transmits all loads and forces to a vertical supporting system which is called the sub-structure with this being composed of piers and abutments. The vertical support at each end of a bridge is called the abutment, whilst other intermediate supports are called piers.

This supporting system is also subjected to other forces such as wind, earthquakes, water current, impact from floating debris, earth pressure on abutments etc.

Abutments normally have a return wall at either end constructed at an angle parallel to the approach road and embankment. These are called wing walls and have separate foundations. In some bridges an RCC box is also provided behind the abutment.

RC Wall Abutment

Stone Masonry Abutment

Figure 6-1: Typical Elevation of Abutment

Type of abutment

Abutments are classified according to their location with respect to the approach embankment. The most common types are:

Spill through

An open type of abutment with RCC columns are preferred where the height of the formation is very high. In order to relieve abutments from excessive earth pressure, the earth is allowed to spill in front. A screen wall of about 1.5 to 2.5 metres deep is required to be provided which connects to the columns and hangs from the capping beam. The function of this screen wall is to prevent the top movement of earth.

Open, or spill-through, abutments are similar in construction to multi-column piers. Instead of being retained by a solid wall, the approach road embankment extends on a slope below the bridge seat and between ("through") the columns. Only the topmost few feet of the embankment are actually retained by the abutment cap.

The advantages of an open abutment are; lower cost, since most of the horizontal load is eliminated and the massive construction and heavy reinforcement, usually associated with retaining walls, is not needed, and, the ability to convert the abutment to a pier if additional spans are added in the future.

The disadvantages are a tendency for the fill to settle around the columns since good compaction is difficult to achieve in confined spaces, and, for excessive erosion to occur in the front slope. Rock fill is sometimes used to counter these problems.

This type of construction is not suitable where it is adjacent to streams, due to its susceptibility to scour.

Solid wall

These gravity, solid wall type, abutments are usually of shorter height and are founded on open foundation.

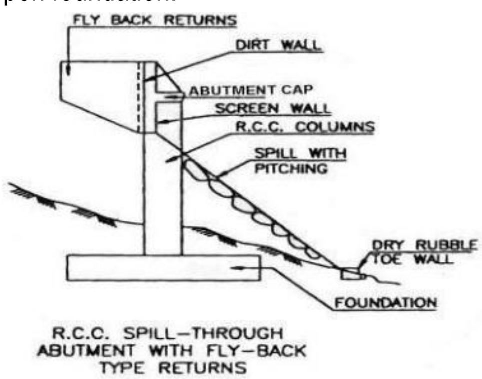


Figure 6-2: Spill through (Open) Abutment

Figure 6-3: Solid Abutment

Weep Holes

In closed type abutments, an adequate number of weep holes should be provided in order to drain the water that accumulates at the back of the abutment. If this is not provided then additional horizontal pressure on the abutment will be exerted by the accumulated water. The weep holes should be made at a slope on the outer side for the facilities of easy drainage. The back of the weep holes should be properly packed and protected with filter materials of varying sizes. The larger size should be in contact with the wall so that neither the back fill materials nor the filter materials can pass through the weep holes. The spacing should be about 1 meter from centre to centre in both the horizontal and vertical direction.

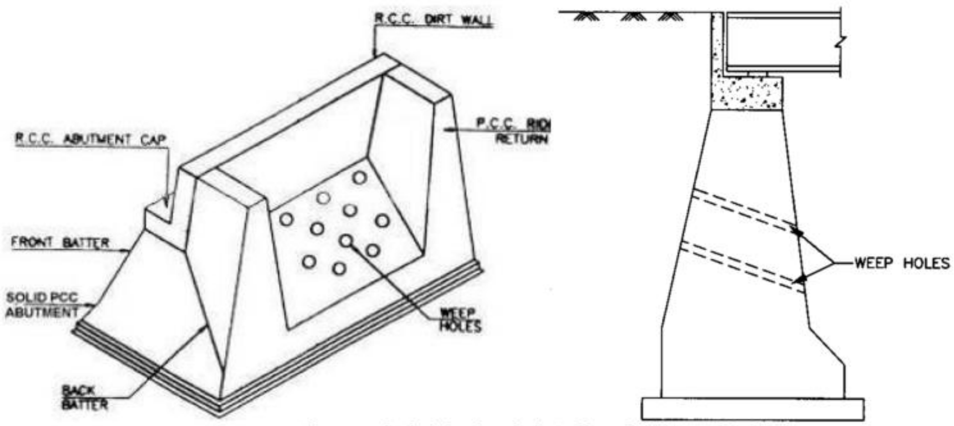


Figure 6-4: Typical details of Weep Holes

Abutment Cap and Dirt wall

A sub-structure supporting the end of a single span, or the extreme end of multi-span super-structure and in general and retaining and supporting the approach embankment. All abutments are capped with structure which is called abutment cap and dirt wall.

Types of material

Abutments, which are a crucial sub-structural element can be constructed in:

- Brick
- Stone
- Plain cement concrete
- Reinforced cement concrete

Basic concepts of Abutments

Design of Abutments: These are designed in a similar manner as piers with the exception that they act as a retaining structure and are therefore subjected to the additional force of earth pressure. The magnitude of the earth pressure depends upon the type and moisture content of the backfill material. It is therefore extremely difficult to correctly assess the magnitude of the pressure imposed by the earth. Hence the earth filling behind the abutment merits special attention. Normally a porous backfill, of a thickness of about 60cm, should be provided immediately behind the abutment, with 15cm diameter weep holes placed at suitable intervals. These should have a gentle slope in order that they are at least 15cm above normal water level on the vent side, thus ensuring the drainage of the fill material. The impact effect from moving loads is not usually taken into account since any vibration should be dissipated through the embankment. The stability condition of abutments is similar to that for piers.

Common defects

Material defects

Concrete (for defects of concrete refer to Chapter - 3):

- Cracking
- Delamination
- Spalling
- Scaling
- Crushing
- Exposure of reinforcement

Masonry (for defects of masonry refer to Chapter - 3):

- Weathering
- Spalling
- Cracking
- Splitting
- Mortar cracking and deterioration

Inspection procedures and locations for abutments

The inspection procedures for abutments are the same as detailed for super-structure, particularly when it involves material deterioration. However, because stability is of paramount concern, the checking for various forms of movement is also required.

The abutment location for which an inspection is to be carried out are not specific but be in relation to common abutment problems. The most common problems likely to be observed during an inspection of abutments are:

- Vertical movement
- Lateral movement
- Rotational movement
- Material defects
- Scour of the foundation
- Drainage system malfunction

Vertical movement: Vertical movement can occur in the form of uniform or differential settlement. A uniform settlement of all bridge substructure units, including abutments, will have little effect on the structure. Uniform settlements of 0.3 m have been detected on small bridges with no signs of distress.

However, differential settlement can produce serious distress in a bridge. Differential settlement can occur between different substructure units, causing damage of varying magnitude, depending on span length and bridge type. It may also occur under a single substructure unit. This may cause an opening of the expansion joint between the abutment and wing wall, or it may cause cracking or tipping of the abutment, pier, or wall.

The most common causes of vertical movement are soil bearing failure, consolidation of soil, scour, and deterioration of the abutment foundation material.

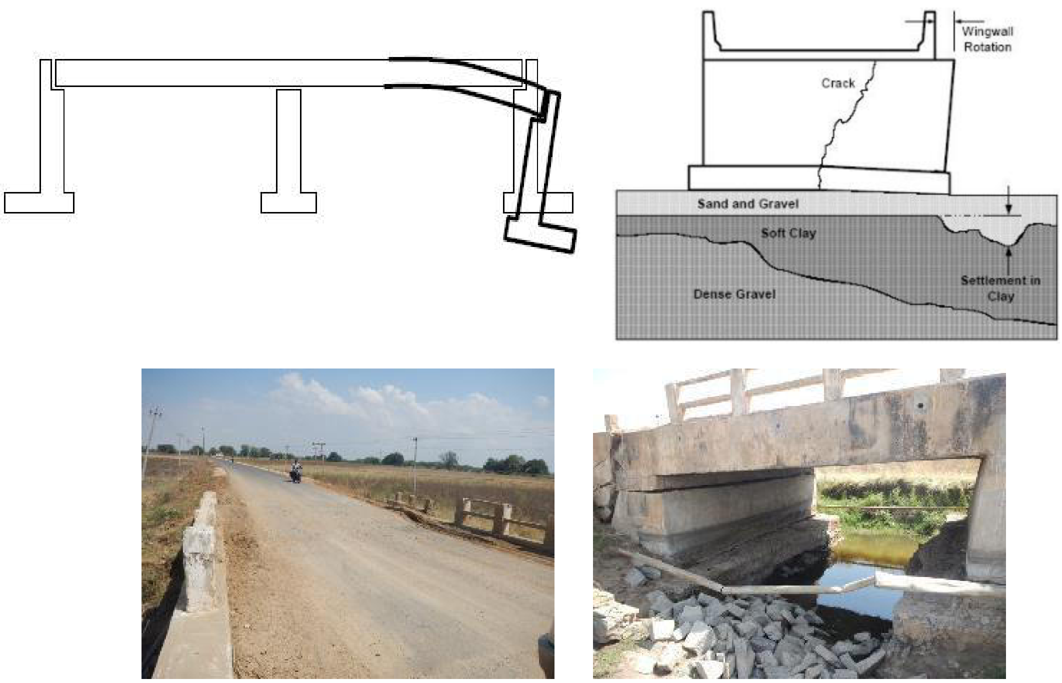


Figure 6-5: Differential Settlement under an Abutment

An inspection for vertical movement, or settlement, should include:

- Inspection of the joint opening between the end of the approach slab and the deck. In some cases, pavement expansion or approach fill expansion could conceivably cause vertical movement in the approach slab.
- Investigation of existing and new cracks for signs of settlement.

- Examination of the alignment of the super-structure for evidence of settlement (particularly the bridge railings).
- Checking for scour around the abutment footing or foundation.
- Inspection of the joint that separates the wing wall and abutment for proper alignment.

Lateral movement: Earth retaining structures, such as abutments and retaining walls, are susceptible to lateral movements, or sliding. Lateral movement occurs when the horizontal earth pressure acting on the wall exceeds the friction forces that hold the structure in place.

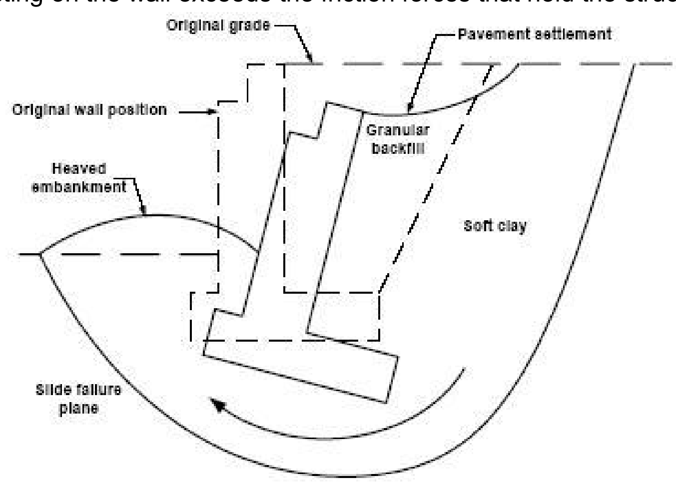


Figure 6-6: Lateral Movement and Settlement of an Abutment due to Slope Failure

The most common causes of lateral movement are slope failure, seepage, changes in soil characteristics (e.g., frost action and ice), and time consolidation of the original soil.

The inspection for lateral movement, or sliding, should include:

- Inspection of the general alignment of the abutment.
- Checking of the bearings for evidence of lateral displacement.
- Examination for the opening in the construction joint between the wing wall and the abutment.
- Investigation of the joint opening between the deck and the approach slab.
- Settled approach pavement
- Checking of the distance between the end of the super-structure and the back wall.
- Examination for clogged drains (approach road, weep holes, and sub-structure drainage).
- Checking for any erosion or scour of the embankment material in front of the abutment.

Rotational movement: Rotational movement, or tipping of sub-structure units, is generally the result of unsymmetrical settlement or lateral movement due to horizontal earth pressure. Abutments and walls are subject to this type of movement.

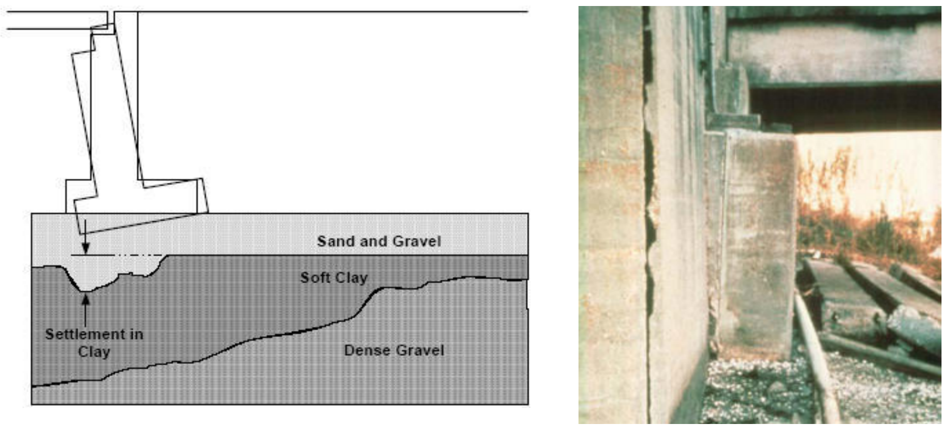


Figure 6-7: Rotational Movement of an Abutment

The most common causes of rotational movement are scour, saturation of backfill, soil bearing failure, erosion of backfill along the sides of the abutment and, improper design.

Inspection for rotational movement, or tipping, should include:

- Checking of the vertical alignment of the abutment using a plumb line; keeping in mind that some abutments are constructed with a battered or sloped front face.
- Examination of the clearance between the beams and the back wall.
- Inspection for clogged drains or weep holes.
- Investigation for cracks and, the recording of the width, length, and direction of such.

What defect to look out for

Abutment cap and earth wall

- Deformation in earth wall
- Movement from the original position and a disturbed shape indicates deformation in an earth wall.
- Cracks on the outside of an earth wall

Abutment foundation settlement

- Foundation scour

For safety of abutment sub-structure, it is necessary to check for scour. The water flowing in a river picks up material from the river bed and carries it away. This is called scour. In simple terms this is the lowering of the average bed level in a channel.

- Foundation settlement

It is necessary to inspect the settlement of a foundation as if there is any settlement in a foundation, there will normally be settlement in the abutment structure.

Masonry abutments

The following are the defects to be looked for with masonry abutments. Masonry piers are generally of the solid wall type.

- **Impact due to floating objects/debris:**

Heavy floating objects/debris can damage a masonry pier and can generally be noted visually.

- **Loss of pointing:**

Pointing is the mortar fill between bricks or stones

Flowing water usually loosens the mortar in joints thus making them weaker. Poor pointing can also lead to such a problem. The alternating between wet and dry can also impact damage on the pointing material.

- **Plaster deterioration and deterioration of brick and stones:**

The surface that is used to cover masonry is called plaster and can be damaged by the impact of floating objects/debris. Many weaker types of brick or stone are also susceptible to a shorter life due to erosion by weathering and frequent changes in moisture content.

- **Cracking:**

Cracking is an indication of distress in masonry. In a masonry abutment, it is necessary to map all cracks wider than 3mm, at the widest location, and also when there is a 'step across' crack.

Any cracks near bearings, especially if these go all round the bearing, and cracks which run underneath the bearing, are important and should be noted very carefully.

For abutments built in masonry, it is necessary to remember that cracks can be caused by a failure of the foundations. These cracks are usually long and go deep into the body of the pier. Overloading can also cause cracks around bearings.

- **Bulging:**

Bulging is a change in the shape or the curving of the face of a masonry wall. It is usually caused by excessive back pressure. This also occurs, if the fill drainage is inadequate where weep holes are provided in the abutments and returns.

Concrete abutments

Concrete is made from course aggregates, sand, cement and water. It is strong in compression and weak in tension. For piers built in concrete, it is necessary to inspect the following:

- **Cracking of concrete:**

Cracking should be checked for, especially around bearings given that these are an indication of distress. This can be caused by overloading, vibration due to traffic and, settlement of foundations.

- **Spalling of concrete:**

If some of the concrete in the structure falls away, it is termed as spalling of concrete. It is usually caused by corrosion of reinforcement. Spalling causes a loss in cross-section area. Spalled areas should be noted with the aid of sketches and/or photographs.

- **Corrosion of un-tensioned or tensioned reinforcement:**

Corrosion is caused by water and air permeating into the concrete and reaching the reinforcement and can be found in concrete spalled areas. It is necessary that the loss of bar diameters be measured. When steel becomes corroded its volume increases and the resulting pressure breaks away, or spalls, concrete.

The indicators of reinforcement corrosion are - Exposure of reinforcement, Spalling and Evidence of cracks, rust stains or leach marks

- **Bulging:**

Bulging is a change in the shape or the curving of the face of a masonry wall. It is usually caused by excessive back pressure. This also occurs, if the fill drainage is inadequate where weep holes are provided in the abutments and returns.

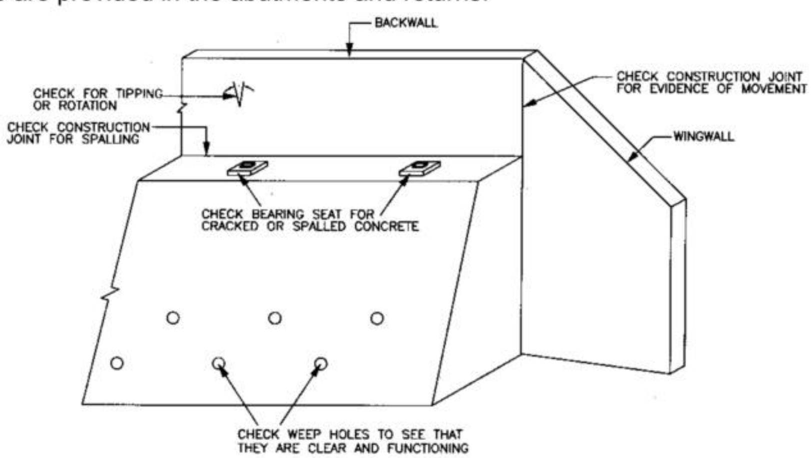


Figure 6-8: Abutment Inspection Checklist Items

How to quantify the defects

Abutment cap and dirt wall

- Deformation in an dirt wall can be inspected visually
- Cracks in a dirt wall can be measured with the help of a crack gauge and/or tape.

Abutment foundation settlement

- Foundation scour
- Compare the existing levels around the abutment with those shown in the drawings.
- Foundation Settlement
- Abutment settlement is same as foundation settlement.


Cracks due to Earth Pressure


Cracks due to Settlement


Deformation of Dirt Wall


Poor Quality of Stones and workmanship

Figure 6-9: Cracks in Abutments

Masonry abutments

- **Impacts from floating objects/debris:**

This can be seen visually.

- **Loss of pointing:**

With the help of nails this can be inspected. If the mortar falls out when a nail is inserted then it is an indication of poor joint condition. The area affected can be measured using a tape.

- **Plaster deterioration and deterioration of brick or stone:**

Deterioration of plaster should be tested by hitting the surface with hammer. If pieces fall off then this indicates that the plaster is in poor condition. The area affected can be measured using a tape.

When the light tapping of the stone or brick causes pieces to break off then this is an indication of deterioration.

- **Cracking:**

Cracks can be measured by using a crack-meter, crack gauge or a tape.

Concrete abutments

- **Cracking of concrete:**

The length of cracks can be measured using a crack gauge, crack films or a tape. Cracks of 1 mm or wider are important. A simple metal gauge or crack gauge film is all that is required to measure crack width.

- **Spalling of concrete:**

The area of spalling can be measured using a tape.

- **Corrosion of reinforcement:**

By inspection of the exposed reinforcement, the loss of bar diameter through corrosion can be measured using a gauge.

Checklist for concrete and stone masonry

Inspection for defects in concrete and stone abutments should include:

- Examination of the bearing seats for cracking and spalling, particularly near the edges. This is critical where concrete beams bear directly on the abutment seat.
- Inspection for the presence of debris and standing water on the bearing seats.
- Checking for deteriorated concrete in areas that are exposed to road drainage, particularly below the joint and between the back wall and the deck.
- Checking of the back wall for cracking and possible movement.
- Examination of the construction joint between the back wall and the abutment stem.
- Inspection of stone masonry for mortar cracks or loss of mortar in the joints.
- Examination of stone masonry for vegetation, water seepage through cracks, loose or missing stones, weathering, and spalled or loose blocks.

How to rate items

The rating is based on the physical condition and functional capability.

Table 6-1: Guidelines for Condition Rating of Concrete Abutment

Sl. No.	Defects	Condition rating	BCI Values
1	Observed settlement at abutment location	Re-construction	< 30
2	Crack width greater than 4mm along with excessive, spalling of concrete and highly corroded reinforcement, Loose / shifted masonry.	Rehabilitation	45 – 30
3	Deformation of earth wall, Cracks in earth wall	Rehabilitation	45 – 30
5	Width of cracks in abutments is between 2mm and 4mm, Spalling / cracking / damage to Masonry	Moderate Repairs	65 – 45
6	Spalling of concrete and exposed reinforcement, Loss of joint material	Moderate Repairs	65 – 45
7	No weep holes.	Moderate Repairs	80 – 65
8	Partly blocked weep holes, Vegetation growth.	Minor Repairs	80 - 65

6.2 Pier

Definition

The substructure is a component of a bridge that includes all elements supporting the super-structure. Piers are transverse intermediate supports (sub-structure) constructed of concrete or masonry. It should support the super-structure with minimum obstruction to the flow of traffic or water.

Basic concept

The function of piers is to support a bridge at intermediate intervals with minimal obstruction to the flow of traffic or water below the bridge. A pier should support its own weight and carry both the vertical and horizontal forces transmitted by the ends of bridge span, within the allowable ranges as specified by the applicable codes. A pier must also withstand impact from vehicular collision, water-borne traffic, impact of ice, water flow and objects carried by water.

What to rate

The physical condition and functional adequacy of a pier requires to be rated.

Type of piers

According to material type

- Reinforced cement concrete pier.
- Plain cement concrete pier.
- Brick masonry / Stone masonry pier.

According to structural arrangement - The most common pier types are:

- Solid shaft pier
- Column pier, Column pier with web wall
- Cantilever or hammerhead pier
- Frame pier.

Solid wall pier: - When the length of a solid pier is more than four times its thickness then it is called a wall pier.

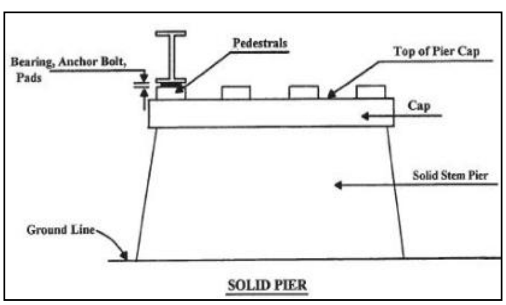


Figure 6-10: Typical Details of Solid Wall Pier



PCC Wall | Stone Masonry Wall | Brick Masonry Wall

Figure 6-11: Various types of Solid Wall Pier

Column pier: Column piers are used in following cases:

- Limited horizontal is available clearance under the bridge;
- Narrow superstructure widths; or
- Aesthetic purposes.

Figure 6-12: Circular Column Pier

Column pier with web wall: To add stability, when the column height is excessive the columns are combined with a web wall. Web walls also serve to strengthen the columns in the event of a vehicle collision.

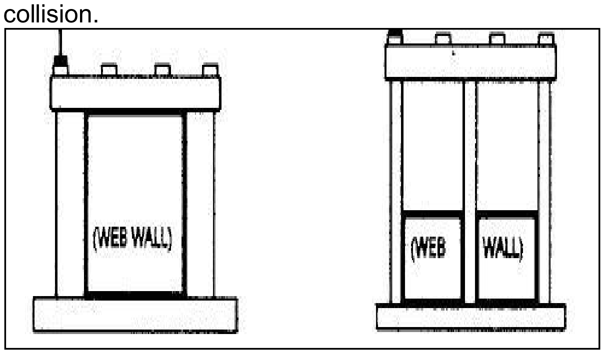


Figure 6-13: Column Pier with Web Wall.

Frame pier: Frame type piers have two or more columns inter-connected by beams/pier caps.

Figure 6-14: Frame Pier

Hollow piers: Hollow piers are usually tall shaft type piers built for high-level bridges.

Items to Check

- Material type and dimensions of the pier.
- Impact due to floating objects/debris.
- Evidence of tilt or settlement.
- Measure amount of pier movement (misalignment) using survey tools.
- Common concrete defects.
- Exposed and corroded reinforcement.
- Common masonry defects.
- Common defects of plaster over masonry.
- Any vegetation growth.

Check for damage due to floating objects / debris: Damage of a pier due to floating objects or debris can be identified visually. This defect is manifest by either a cracked pier or damaged concrete and, brick / stone damage if it is a masonry pier.

Check for loose joints: This defect occurs in brick/stone masonry piers. It is necessary to check the location and number of loose joints, the loss of joint materials and, the number of loose or shifted brick / stones. The bridge inspector should visually identify the location and number of loose joints, material loss at joints and loose or shifted brick/stones.

Check for plaster condition: Check the condition of the plaster on the masonry pier i.e. the plaster is crack and / or damaged.

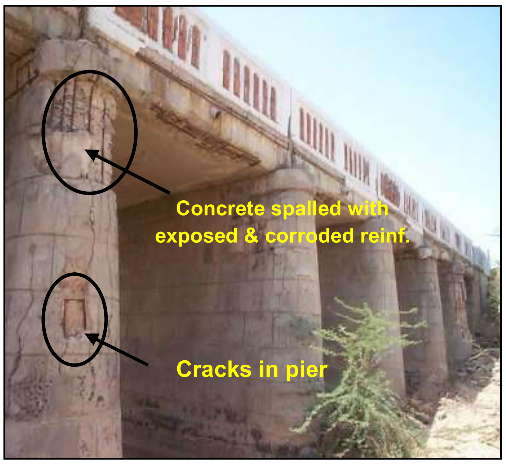
Check for vegetation growth: on pier and in masonry joints.

Check for cracks in pier: identify location and nature of cracks e.g. structural cracks are critical in comparison to shrinkage cracks.

Check for spalling of concrete: Spalling of concrete can be identified visually.

.**Check for corrosion of reinforcement:** Visually check for reinforcement corrosion in a pier.

Settlement of pier: Check for settlement at the pier foundation.



Cut Water / Pier Damaged due to Debris

Crack in pier due to Settlement

Damaged Stone Masonry due to Insufficient Mortar Joints

Road Surface settled due to settlement of Pier

Figure 6-15: Various Condition of Pier.

Table 6-2: Guidelines for Condition Rating of Concrete Pier

Sl. No.	Defects	Condition rating	BCI Values
1	Observed settlement at pier location	New Construction / Reconstruction	< 30
2	Crack width greater than 4mm along with excessive spalling of concrete and highly corroded reinforcement	Rehabilitation / Strengthening	45 – 30
3	Partial collapse of pier cur water portion, Loose/shifted masonry		
4	Crack width between 2mm to 4mm	Moderate Repairs	65 – 45
5	Spalling of concrete, cracking / damage to Masonry, Loss of joint material		
6	Crack width less than 2 mm, Vegetation growth.	Minor Repairs	80 - 65

6.3 Pier Cap

Definition

The Pier cap is a Sub-structure element located below the bearing pedestal. Bridges having monolithic piers have no pier cap.

Basic concept

The primary function of pier cap is:

- To transmit loads (Horizontal and Vertical) from the bridge bearing to the pier

Types of pier cap

Pier caps can be further split into three major categories based on the structural arrangements

- Pier cap over a solid shaft pier
- Cantilever pier cap or hammerhead pier cap
- Pier cap or pier beam for frame type pier

Pier cap over solid shaft pier

Solid shaft piers are common in Karnataka. A solid shaft pier is used when it is advantageous to use a large mass or, when a continuous support is required for the super-structure, such as a solid slab.

The pier cap over a pier with a solid slab is a reinforced concrete band supported by the masonry or concrete pier over its total length. Generally these pier caps are under direct compressive stress as the super-structure load, bending and shear stresses, are not generated in this type of pier cap.

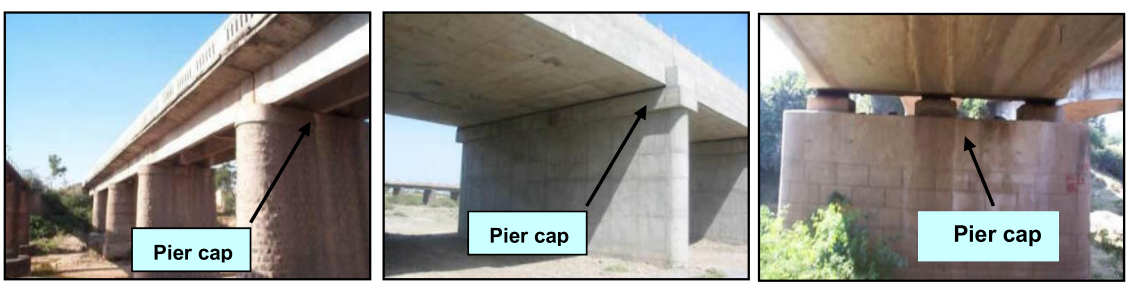


Figure 6-16: Typical details of Pier Cap

Hammerhead pier cap

Hammerhead pier caps a cantilever pier caps for a single stem pier, used to support a multi beam super-structure. The cantilever length of the pier cap is the distance between the edge of the pier cap and the face of the pier. The pier cap can be cantilevered in both the longitude (i.e. parallel to traffic direction) and transverse (i.e. perpendicular to traffic direction) direction or, in one direction only. The pier cap is named a “Hammer head” due to it’s shape.

The super-structure load is applied to the pier cap as a point load at bearing locations. Depending on the ratio of the distance between the face of the pier and the centre-point of the outer most bearing, and/or depth of pier cap at pier face, the pier cap is called a Long or Short cantilever pier cap. If the ratio is greater than 1 then the pier cap will be a long cantilever and if it is less than or equal to 1 a short cantilever pier cap. If the pier cap has a short cantilever in any direction it will behave as a short bracket in that direction. In the case of a long cantilever, the projected portion will behave as a cantilever beam. The behaviour and nature of failures are different for both long and short cantilevers.

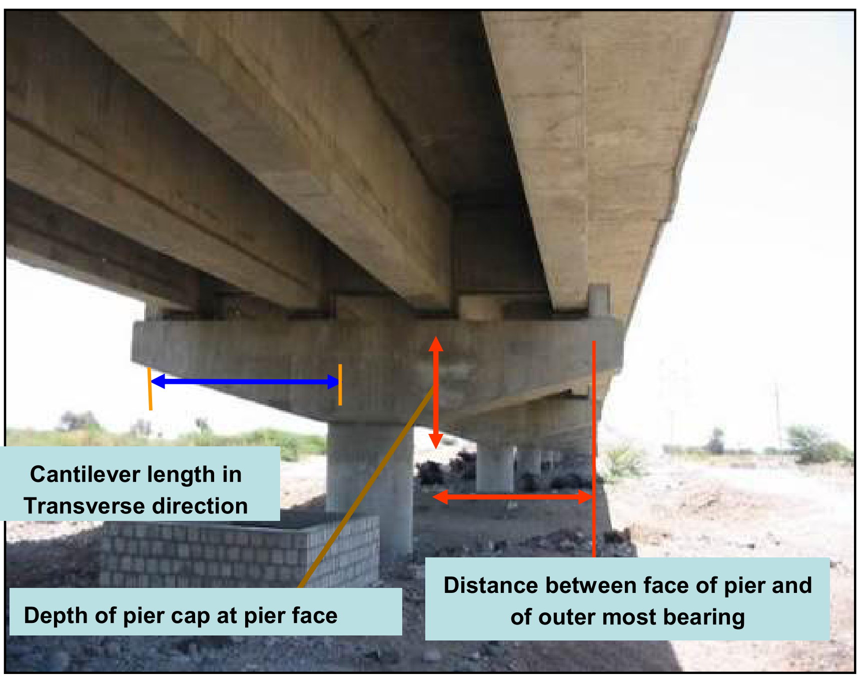


Figure 6-17: Long Cantilever Hammerhead Pier Cap

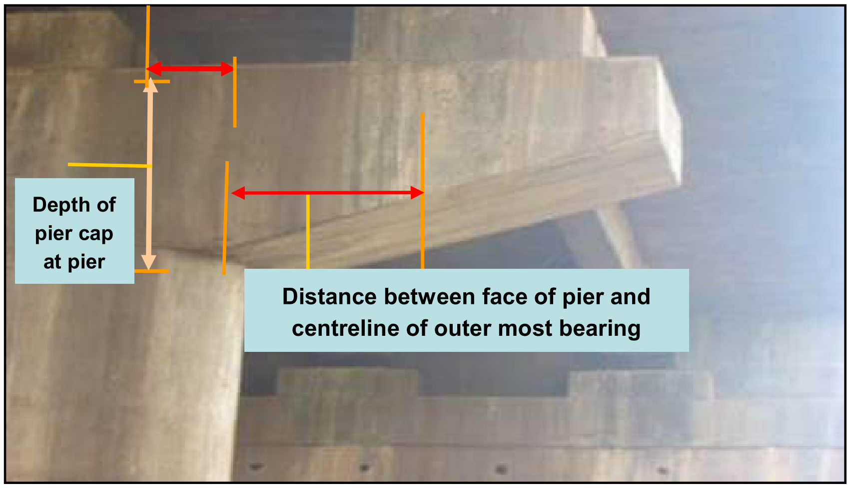


Figure 6-18: Short Cantilever Hammerhead Pier Cap
(Short Cantilever along both Longitudinal and Transverse Direction)

Figure 6-19: Pier Cap in Longitudinal Direction

Pier cap or pier beam over a frame type pier

A frame type pier consists of two or more columns. Here the pier cap is similar to a beam spanning the columns.

Figure 6-20: Frame Type Pier Cap

What to look for

Water marks on the pier cap: Water marks on the pier cap are a sign of inadequate drainage, absence of a proper drip course in the super-structure and, leaking expansion joints. The water marks are not an indicator of pier cap deterioration but indicate the insufficiency of other structural components. The constant flow of water over a pier cap expedites any existing deterioration of the pier cap, concrete and reinforcement. To identify the water marks it is necessary to look for discoloured concrete or the accumulation of salts over the pier cap.

Figure 6-21: Water Marks on Pier Cap

Cracks in Pier cap: Cracks are an indication of deterioration of a failed concrete section or, high corrosion of the reinforcement in the pier cap. The type of crack and it's effect are different for different type of pier caps. The inspector needs to note down the location, width and length of the cracks in order to determine the type and severity. Examples of some typical types of cracks are shown in Figure below

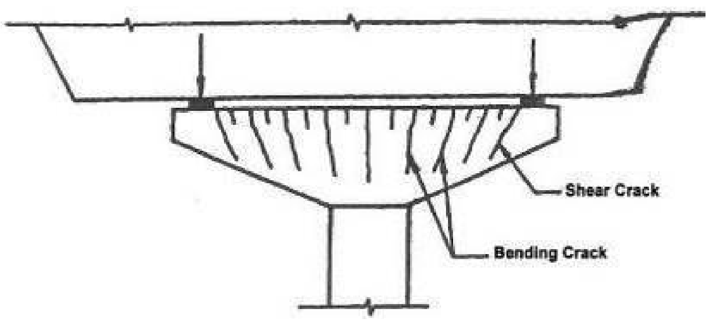


Figure 6-22: Nature of Structural Cracks in a Long Cantilever Hammer head Pier Cap

A long cantilever pier cap behaves similar to that of a cantilever beam undergoing bending and shear stresses. The typical arrangements for primary bending reinforcement, and stirrups for shear reinforcement, are shown below with location of cracking may occur in the section due to inadequate or lack of proper reinforcement in the section.

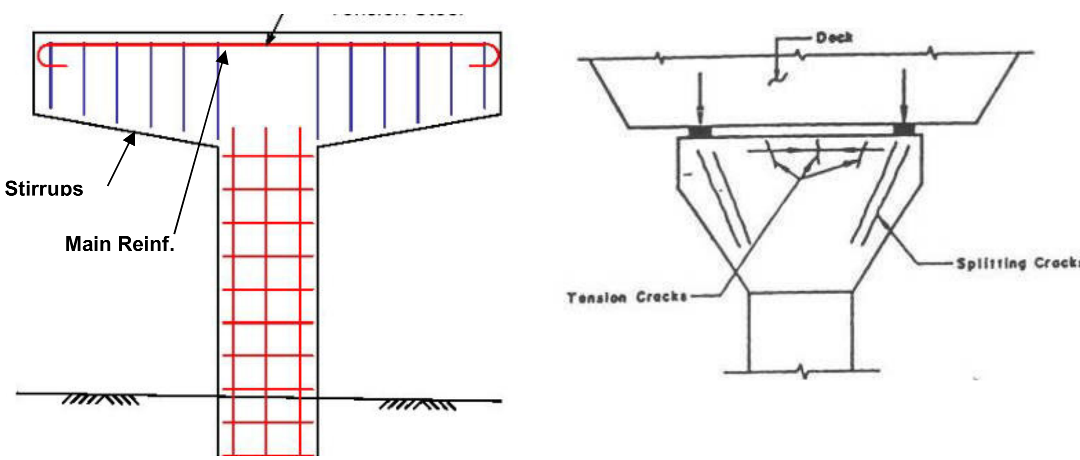


Figure 6-23: Primary Reinf. and Nature of Cracks in Pier Cap

The short cantilever pier cap behaves as a bracket and undergoes direct tension and compression forces. Tension cracks appear in a pier cap due to the failure of the concrete in tension and the splitting cracks due to failure of the concrete under compression.

Spalling of concrete and corroded reinforcement in Pier a cap: Spalling of concrete and the exposure of reinforcement is a major factor in the deterioration in a pier caps over solid shaft, cantilever and frame type pier caps as these reduce the effective depth of the pier cap and the structural capacity of the section.

Figure 6-24: Cracks in Pier Cap

Condition rating of pier cap

The table for the condition rating of a Pier cap is as follows;

Table 6-3: Guidelines for Condition Rating of a Pier Cap

Sl. No.	Defects	Condition rating	BCI Values
1	Crack width greater than 4mm in a pier cap along with excessive spalling of concrete and highly corroded reinforcement.	Reconstruction	< 30
2	Crack width between 2mm and 4mm in pier cap.	Rehabilitation / Strengthening	45 – 30
3	Spalling of concrete.		
4	Exposed reinforcement	Moderate Repairs	65 – 45
5	Crack width less than 2mm in pier cap.		
6	Accumulation of debris and water marks on pier cap.	Minor Repairs	80 - 65

Note: “Highly corroded reinforcement” means the diameter of the bar has been reduced to 80% or less than 80% of it’s original diameter.

6.4 Wing Walls

Definition

The super-structure transmits all its loads and forces to a vertical supporting system which is called the sub-structure. The sub-structure is composed of piers, abutments and, wing-walls/returns. The vertical support at each end of the bridge is called an abutment, whilst other such intermediate supports are called piers.

Abutments normally have a return wall at either end, constructed at some angle parallel to the approach road and embankment. These are called wing walls and they have separate foundations. For some bridges, RCC boxes are also provided behind the abutment. For a bridge provided with closed type abutments, the sides are also to be protected by walls in order to prevent earth spills. These walls, when placed at an angle to the road or embankment, form wings and are therefore known as wing walls whereas they are termed return walls when placed parallel to the embankment.

Return walls are generally of four types:

- Gravity wall (solid type)
- Cantilever wall
- Box returns
- Butterfly wing wall

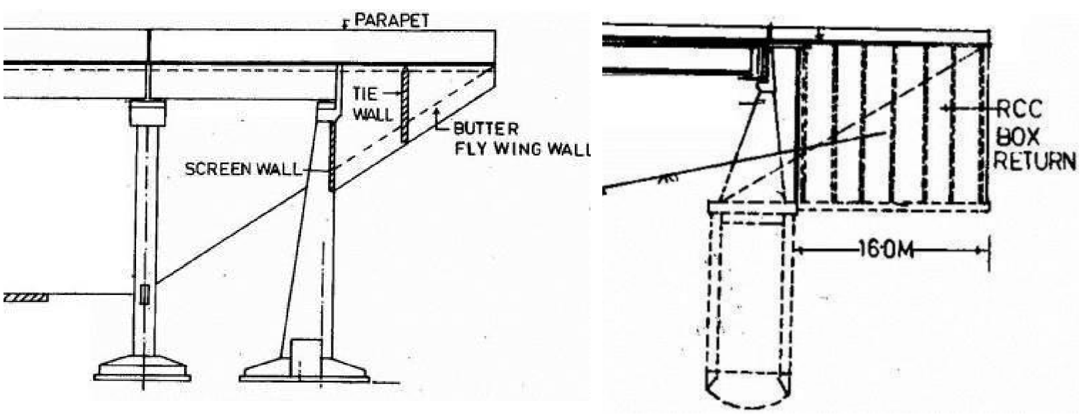


Figure 6-25: Butterfly Wing Wall and RC Box Return wall details

Gravity wall (solid type): solid gravity wall abutments are usually of shorter heights and are founded on open foundations Suitable for heights of up to 6 metres.

Cantilever, counter fort and box returns: Reinforced cement concrete sections are used in the construction of these, when the nominal height exceeds 6 meters.

Geometrical classifications

There are several geometrical classifications of wing walls, with their use being dependent on the design requirements of the structure:

- **Straight -** extensions of the abutment wall
- **Flared -** forms an acute angle with the bridge and road
- **U-wings / Return Walls -** parallel to the road

Figure 6-26: Straight Wing wall

Figure 6-27: Flared Wing wall

Figure 6-28: U-Wing wall

Figure 6-29: Masonry Wing Wall / Return Wall

There are also several types of construction for wing walls:

- **Integral -** constructed monolithically with the abutment, normally with cast-in-place concrete.
- **Independent -** constructed separately from the abutment where expansion or mortar joint separates these from the abutment breast wall.

Figure 6-30: Integral Wing wall and MSE Wing wall

Weep holes

All wing and return walls should be provided with an adequate number of weep holes, in the same manner as an abutment.

For the closed type of abutment, an adequate number of weep holes should be provided to drain the water that accumulates at the rear of the abutment. If this is not done then additional horizontal pressure will be exerted by the accumulated water. Weep holes should be located on the outer side to facilitate drainage. The back of the weep holes should be properly packed and protected with filter materials of varying sizes, the larger size being in contact with the wall so that neither the back fill materials nor the filter materials can pass through these. The spacing should be about 1 meter from centre to centre in both the horizontal and vertical direction.

Types of material

Wing walls/return walls can be constructed of:

- Brick masonry
- Stone masonry
- Plain cement concrete
- Reinforced cement concrete

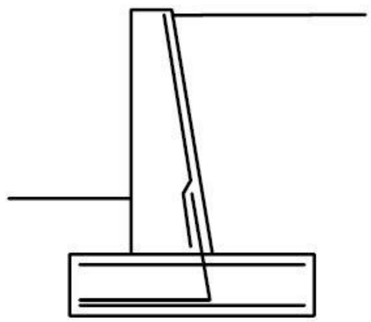


Figure 6-31: Main Reinforcement in RCC Cantilever Wing Wall

Basic concept

Wing walls are located on the sides of an abutment and enclose the approach fill. These are generally considered to be retaining walls since they are designed to maintain a difference ground surface elevation on both sides of the wall.

A wing wall is similar to an abutment except that it is not required to carry any vertical loads. The absence of a vertical super-structure load usually necessitates a wider footing to resist an overturning moment

Defects to look for

Concrete wing / return walls:

Concrete is made from course aggregates sand, cement and water. It is strong in compression and weak in tension. For wing/return walls built in concrete, it is necessary to inspect the following:

Cracking of concrete: An inspection should be made for cracking especially as this is an indication of distress. This can be caused by overloading, vibration due to traffic and, settlement of the foundations.

Spalling of concrete: (a) If some of the concrete in the structure falls away, it is termed as spalling. It is usually caused by corrosion of reinforcement and results in a loss in cross-section.

Corrosion of exposed reinforcement: Corrosion is caused by water and air permeating into the concrete and reaching the reinforcement. The corrosion of reinforcement can be inspected on spalled areas. It is necessary that the loss of bar diameter should be measured. Basically when steel gets corroded its volumes increases and the resulting pressure breaks away, or spalls, pieces of concrete.

Indications that corrosion of reinforcement is or has taken place are: Exposure of reinforcement, Spalling, Cracks, rust stains or leaching marks

Masonry wing / return walls:

These are generally of the solid wall type the following are the defects to be looked for in masonry wing walls. .

Loose joints: Pointing is the mortar placed between bricks or stones, Flowing water usually loosens the mortar in joints rendering them loose or weak. Poor pointing can lead to such problems. Alternate wetting and drying can also damage the wing/return walls joints.

Plaster deterioration and deterioration of brick and stones: The surface covering masonry is called plaster. This can be damaged due to impact of floating objects or debris. Many weaker types of brick or stone can have a short life expectancy and can be eroded by weathering or changes in moisture content.

Splitting, cracking: Cracking is an indication of distress in masonry. In a masonry wing/return wall, it is necessary to map all cracks wider than 3mm at the widest point and also where there is a ‘step across’ crack.

For wing / return walls built of masonry, it is necessary to remember that cracks can be caused by a failure of the foundations. These cracks are usually long and go deep into the body of the wall.

Vegetation and growth in joints: A joint can fill with material and house vegetation.

Dislodgement: In many instances earthquakes can damage wing walls badly and at worst, dislodge the wing wall.

Figure 6-32: Dislodged Wing Wall

How to quantify the defects

Masonry wing / return walls

Loose joints: Using a nail these can be inspected. If mortar fall out when a nail is driven into the mortar this is an indication of poor joint condition and the number of such joints should be counted.

Plaster deterioration and deterioration of brick or stone: Deterioration of plaster should be tested by hitting the surface with hammer. If pieces fall off, the indication is that the plaster is in poor condition. The area affected should be measured with a tape.

When the light tapping of the stone or brick face with hammer causes pieces to break off, this is an indication of deterioration.

Splitting, cracking: Cracks can be measured using a crack-meter, crack gauge or tape with splitting being identified visually.

Concrete wing / return walls

Cracking of concrete: This can be measured with the help of crack gauge, glass tell-tale, crack films and a tape measure for the length of cracks. Cracks that are 1 mm, or wider, are important. A simple metal gauge or crack gauge film is all that is needed to measure crack width.

Spalling of concrete: This can be measured a tape.

Corrosion of exposed reinforcement: Given any exposed reinforcement, the loss of bar diameter can be measured with the help of gauge and the corrosion can then be estimated.

How to rate items

The items can be rated based on physical condition and functional capability.

Table 6-4: Guidelines for Condition Rating of a Return / Wing Wall

Sl. No.	Defects	Condition rating	BCI Values
1	Crack width greater than 4mm along with excessive spalling of concrete and highly corroded reinforcement. Loose / shifted masonry causing partial collapse of wall	Reconstruction	< 30
2	Partial collapse or settlement or movement of wing wall		
3	Crack width between 2mm and 4mm. Splitting /cracking /damaged masonry	Rehabilitation / Strengthening	45 – 30
4	Spalling of concrete, Exposed reinforcement, Loss of joint material	Moderate Repairs	65 – 45
5	Crack width less than 2mm, Vegetation growth	Minor Repairs	80 - 65

CHAPTER – 7

Foundation

Chapter 7: Foundation

Foundations are critical to the stability of a bridge since this ultimately supports the entire structure. All loads and forces coming from the Super/Sub-structure will ultimately need to be transferred safely to the earth below the riverbed or below any other natural soil formations. The load transfer should take place in such a manner that there is no unexpected total or differential settlement of piers and abutments or result in any damage due to scour during the design life of the bridge. The structural system, which enables the safe load-force transfer to the sub-strata, from the sub structural components, is called the “Foundation”.

Two major types of foundation are used for bridges, namely:

- Shallow (open) foundations
- Deep foundations:
    - Well foundations
    - Pile foundations

Although for economic reasons, and reasons of construction, it is desirable to transfer foundation loads to the earth at shallow depths, wherever the strata of the soil close to ground level is not capable of carrying the design load safely. ”Deep Foundations” are required to be adopted.

Deep foundations of either the well or pile type, transfer foundation loads to suitable soil or rock layers through “skin friction” and/or “end bearings”. In open foundations, however, load transfer is achieved through “contact pressure” between the footings and the soil/rock strata.

In the following pages the methodology for the inspection and reporting of different types of foundations are discussed and cover;

- Open foundations
- Well foundations
- Pile foundations

7.1 Scour

Channel scour

Scour is defined as the removal and transport of material from the bed and banks of rivers and streams as a result of the erosive properties of running water. Nevertheless, some general scouring continually takes place in all stream/river beds, particularly during periods of flood.

Basic concepts

Scour is the result of the erosive properties of flowing water. Water flowing at high speed tends to be more erosive than low-velocity flows. However, different materials scour at different rates. For example, loose granular soils are rapidly eroded by underwater action while cohesive or cemented soils are more scour resistant. Scour will reach its maximum depth in sand and gravel beds in hours, cohesive materials in days, glacial tills, sandstones and shales in months, limestones in years, and dense granites in centuries. Inspectors need to carefully study the site-specific information when evaluating scour potential at bridges.

A factor for the determination of scour at highway crossings or encroachments is whether the scour is 'clear-water' or 'live-bed' scour. Clear-water scour occurs where there is no transport of suspended bed material upstream of the crossing or encroachment. Live-bed scour occurs, however, where there is transport of suspended bed material from the upstream reaches of the stream or river into the crossing or encroachment.

This chapter discusses scour in both riverine (those relating to, formed by, or resembling a river; including tributaries, streams, brooks, etc) and coastal areas. In riverine environments, scour results from the flow in one direction (downstream). In coastal areas, highways that cross streams/rivers, and/or encroach longitudinally on such, are subject to tidal fluctuation and scour results from the bi-directional flow. In waterways influenced by tidal fluctuations, flow velocities do not necessarily decrease as scour occurs and the area of the waterway increases. This is in sharp contrast to riverine waterways where the principle of flow continuity requires that velocity be inversely proportional to the waterway area.

What to rate

The rate the erosion and scour of channel banks and the 'bed' or channel of the stream/river is discussed herein. The rating should cover as far upstream and downstream from the structure as is necessary in order to observe the changes that will affect the integrity of the structure or its approaches. <u>This is not a rating of the scour of the material at the substructure and footings</u>.

What to look for

Check for the erosion of stream/river banks and increasing channel depths.

High water velocities indicate a potential for scour. Check for situations that increase stream velocity, such as siltation in any part of the channel, deflection of the stream/river by protruding substructures or, inadequate openings. Compare new scour documentation and required profiles with previous readings.

Reasons for Scour

S. No.	Details
1	Channel migration
2	Stream flow velocity
3	Channel opening
4	Streambed material
5	Substructure shape and orientation
6	Skew angle
7	Orientation of piers for parallel bridges

8	Protruding abutments
9	Foundation type
10	Local scour at piers and abutment locations

Channel migration

A change in the channel is generally due to artificial or natural alteration in the width, alignment, or profile of the channel. These alterations, which may take place at the bridge site or some distance upstream or downstream, upset the equilibrium of the channel. A channel is said to be in equilibrium if the rate of flow is such that it neither picks up material from the river bed nor deposits it. Channel degradation and scour seriously endanger bridges whose foundations are located in river bed where the natural deposits are considered to have high erosion properties. The problem is further compounded if the foundation does not extend to a depth below that of the anticipated scour. In channels susceptible to degradation and scour, a channel profile requires to be taken periodically.

Stream flow velocity

Stream / river flow velocity is a major factor in the rate and depth of scour. During flood events the stream / river flow velocity increases significantly and produces accelerated scour rates and depths. At high stream/river flow velocities, bridge foundations are highly susceptible to becoming undermined.

Figure 7-1: Flood Flow around a Pier Showing Stream Flow Velocity

Channel opening

It is necessary to consider the adequacy of the hydraulic opening (the cross sectional area under bridge) to convey anticipated flows, including the design flood, without damage to the bridge.

Contraction scour occurs when the flow area of a stream/river in flood is reduced either by natural contraction or by the bridge and/or its approach embankments. A decrease in the flow area, contraction, results in an increase in average velocity and bed shear stress. The result of such is an increase in the erosive forces at the point of contraction resulting in increased 'bed' material being removed from the area of contraction into the 'reaches' of the stream/river. This increase in elevation is lowered, the flow area increases and, in the riverine situation, the velocity and shear stress decrease until relative equilibrium is reached; i.e., the quantity of bed material that is transported into the reach is equal to that removed from the reach.

Contraction scour is typically cyclical. That is, the bed is scoured during the rising stage of a run-off event and is filled during the 'falling' stage. The contraction of the flow due to the bridge can be caused by either a natural decrease in the area of flow of the stream/river channel or by abutments projecting into the channel, and/or, the piers may block a large portion of the flow area. Contraction can also be caused if the approaches to a bridge cut off the flow from the floodplain. This can cause clear water scour on a setback portion of a bridge section, and/or a relief bridge, as the floodplain flow does not normally transport significant concentrations of bed material and sediment. Clear-water therefore picks up additional sediment from the bed before reaching the bridge opening. In addition, local scour at abutments may well be greater as a result of the clear-water floodplain flow returning to the main channel at the end of the abutment.

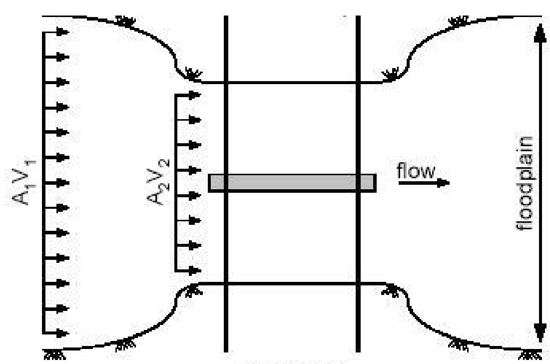


Figure 7-2: Scour due to inadequate waterway

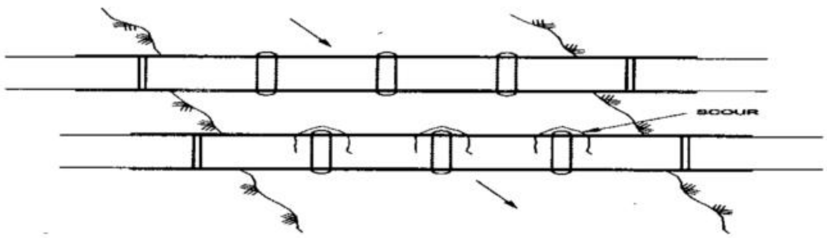


Figure 7-3: Scour due to Different Alignments of Piers for Two Adjacent Bridges

Stream / river bed material

The size, gradation, cohesion, and configuration of the stream/river bed material can affect scour rates, depths, and significance of scour. The size of the stream/river bed material has little effect on the depth of scour but can affect the amount of time needed for this depth to be attained. Cohesive stream/river bed materials that are 'fine' usually have the same ultimate depth of scour as sandy stream/river beds. The difference is, however, that cohesive stream/river beds take a longer period to reach the ultimate scour depth. For these reasons, the stream/river bed material type is important and should be correctly evaluated by the bridge inspector. Stream/river bed rates of scour for different types of material are described later.

Substructure shape and orientation

Substructure members on old bridges have not necessarily been designed to withstand the effects of scour. Wide piers and piers skewed to the flow of the stream are examples of waterway substructure deficiencies. These deficiencies have the potential to increase the depth of scour. Due to increased awareness of bridge waterway scour, substructure members have recently been designed to allow the stream/river to pass under a bridge with as little resistance as possible. Many newer piers have rounded or pointed 'noses' which can decrease scour depth by up to 20%.

Skew angle

Orientation of abutments and piers can be a major reason for local scour. Abutments and piers that are orientated at a high skew angle with respect to the flow direction, provide a greater obstruction to stream/river flow. As such these are therefore prone to high scour in comparison to bridges where the abutments and piers are orientated parallel to the stream/river flow.

Orientation of piers for parallel bridges

The non-alignment of piers for parallel bridges (piers not aligned in the same line with respect to the stream flow) can be a major cause for local scour.

Protruding abutments

Protruding abutments where the abutments project inside the channel, attract more local scour at the location of the abutment location.

Foundation type

The foundation type for the substructure members should also be determined. If these are undermined but are founded on piles, this is not as critical as the undermining of spread footings. The inspector should be aware of the substructure foundation type in order to properly evaluate the substructure and the waterway. The foundation type may often be determined from the design and/or construction drawings. In some older bridges, the foundation type is not known. In such a case, advanced inspection techniques may be required, by a trained professional, in order to verify the foundation type.

Local scour at pier and abutment locations

Local scour occurs around an obstruction that has been placed within a stream/river, such as a pier or an abutment.

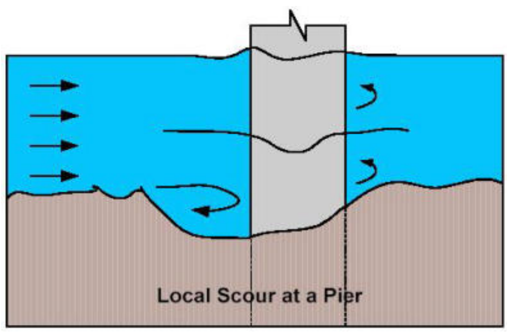


Figure 7-4: Horseshoe and Wake Vortices Causing Scour

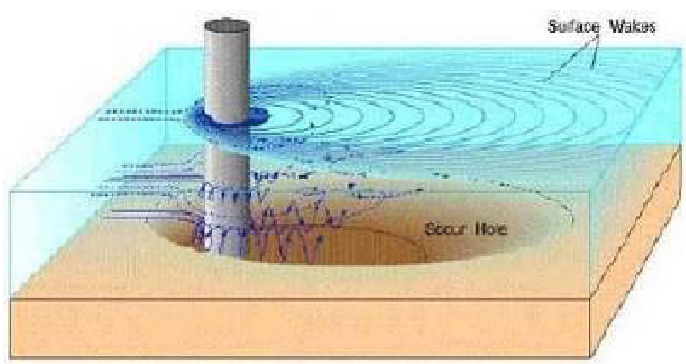


Figure 7-5: Local Scour Due to Stream flow Behaviour in Deep Water

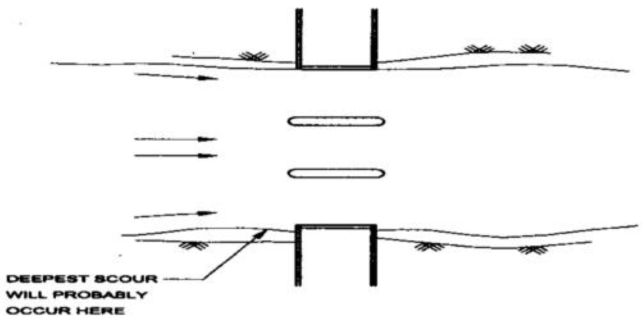


Figure 7-6: Scouring due to Protruding Abutments (Protruding Abutments may Produce Local Scour)

Figure 7-7: Local Scour at an Abutment

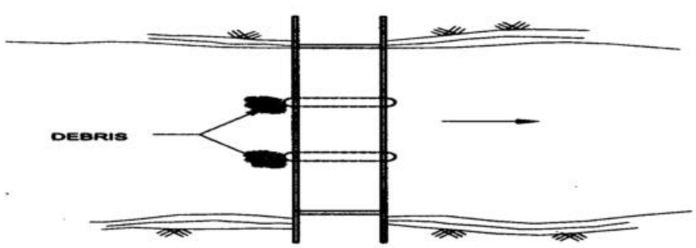


Figure 7-8: Extra Scouring due to Debris: (Collection of Debris around Piers, enlarges the effective size of the Piers and Causes increased area and depth of Scour)

Figure 7-9: Increase in Scour due to Accumulation of Debris at Pier Location

Undermining

Undermining is the impact of the scouring of a stream/river bed and the supporting foundation material from beneath the substructure (see Figure 7.5 and Figure 7.10). Local scour often produces undermining of both piers and abutments. Such undermining is an extremely serious condition which requires immediate correction to assure the stability of the substructure. The undermining of structural elements is basically an advanced form of scour. It is essential to determine whether or not undermining has already occurred or has the potential to develop. Undermining can pose an immediate threat to safety and must be dealt with immediately.

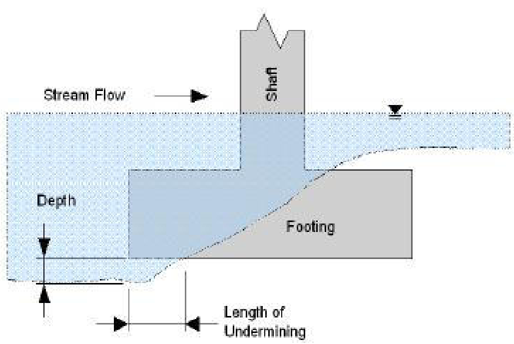


Figure 7-10: Longitudinal Cross Section Illustrating Undermining

The evaluation process

The major objectives of scour evaluation are to:

- identify and review all bridges susceptible to scour within the bridge inventory
- determine those foundations which are stable for estimated scour conditions and those which are not

- provide for frequent inspection of scour critical bridges during and after flood events until adequate scour counter measures are implemented
- install scour counter measures in a timely manner.

Items to be checked at site for assessing the scour potential at a bridge location.

Upstream and downstream conditions

Banks

- Bank sloughing, undermining, evidence of lateral movement, damage to stream stabilisation measures, etc.
- Natural vegetation, trees, bank stabilisation measures (such as 'riprap'), paving,
- gabions, channel stabilisation measures (such as dykes and jetties).

Main channel

- Clear and open with the good approach flow conditions or meandering or braided with the main channel at an angle to the orientation of the bridge.
- Existence of islands, sand bars, debris, cattle guards, fences etc that may affect flow.
- Evidence of the movement of the channel with respect to the bridge (make sketches, take photographs).

Floodplain

- Evidence of significant flow on the floodplain.
- Floodplain flow patterns - does the flow 'overtop' the road/bridge and, does it return to the main channel?
- Existence of floodplain development and any obstructions to the flows approaching the bridge and its approaches.
- Evidence of overtopping of approach roads (debris, erosion of embankment slopes, damage to riprap or pavement, etc.).

Debris

- Extent of debris in the upstream channel.

Other features

- Existence of upstream tributaries, bridges, dams, or other features, that may affect flow conditions at a bridge.

Condition of existing channel protection and counter-scour counter measures at site

- **Floor protection** adequately 'toed' into the streambed or is it being undermined and washed away
- **Guide banks** (Spur dikes) Check for damage by scour and erosion
- **Stream / river and the stream / river bed Check** for evidence of scour and erosion of stream/river bed and banks, especially adjacent to piers and abutments. Check for any stream/river cross section change since the last measurement.

Figure 7-11: Failed Bed Protection Riprap due to Scour

Figure 7-12: Excessive Scour in the Down Stream of a Slab Culvert (Bed Protection Entirely Washed Away and Embankment Damaged)

Waterway area

- Does the waterway area appear small in relation to the stream/river and floodplain?
- Is there evidence of scour across a large portion of the streambed at the bridge?
- Are sand bars, islands, vegetation and debris constricting the flow and concentrating this into one section of the bridge or is it causing the flow to attack the piers and abutments?

- Does the superstructure, or do the piers, abutments, and fences, etc., collect debris and constrict the flow?
- Are the approach roads regularly overtopped?
- If the waterway opening is inadequate, does this increase the scour potential at the bridge foundation?

Figure 7-13: Local Scour at Pier Location

Foundation scour inspection: It is necessary to identify and assemble the following documentation and equipment in order to conduct a waterway inspection. The equipment required will depend upon the characteristics of the river, the characteristics of the bridge and, the accessibility of the site.

Inspection requirements: Prior to beginning the inspection, the inspector should understand the type and extent of the inspection required. Waterway inspections are typically undertaken by one of two methods:

Surface or "wading" inspection: A submerged substructure, stream/river bed and embankments are often accessible using hip boots or chest- waders and probing. Often boats are used as a surface platform for gathering data.

Underwater diving inspection: Site conditions often require the waterway and submerged substructure units to be evaluated using divers in order to obtain complete and accurate data. This is the case when water depths are too great for wading inspection and/or, undermining of substructure elements are suspected.

Equipment: The type of equipment needed for a waterway inspection is dependent on the type of inspection. The following list represents the most common waterway inspection equipment required.

- Probing rods
- Waders (Waterproof hip boots)

- Sounding line (lead line to measure depths of scour)
- Fathometer
- Boat and anchor
- Survey tapes and chains
- Level rod
- Digital camera or camera and film (underwater or conventional)
- Video equipment and tapes (underwater or conventional)
- Stopwatch (To calculate the stream flow velocity)

Figure 7-14: Probing Rod and Waders

Movement of Foundations (Settlement)

Basic concepts

The movement of a foundation, and the subsequent movement of the structure, is the results of the deformation of the supporting subsoil under total stresses induced in soil/rock allude to structural loads. The most common foundation movements can be categorised as:

- Vertical movement (normally called "settlement" if movement downwards),
- Lateral movement and,
- Rotational movement (normally called "tilt" if rotation is vertical).

The elements of a foundation (either open or deep) are always buried or under water. In order to determine if a foundation has moved, a reference level pertaining to the original level, and the location of foundation, is required. It is therefore almost impossible to check the movement of such just by inspecting the foundation. Care should therefore be taken when inspecting a foundation to identify any movement by looking for certain common signs and defects in sub/super-structure. Some of these signs and the evidence associated with such foundation movement are briefly discussed in the following paragraphs.

Vertical movement

Vertical movement can occur in the form of uniform or differential settlement. A uniform settlement of all bridge foundation /substructure units will have little effect on the entire structure, whereas differential settlement can produce serious distress in a bridge.

Differential settlement is the uneven settlement of individual or independent elements of a substructure; tilting in the longitudinal or transverse direction due to deformation or loss of foundation material.

Differential settlement can occur between different substructure units which can cause damage of varying magnitude depending on the span length and bridge type. It can also occur under a single substructure unit. This can cause an opening of the expansion joint between the abutment and wing wall or, it may cause cracking or tipping of the abutment, pier, or wall.

The most common causes of vertical movement are; soil bearing failure, consolidation of soil, scour and, deterioration of the foundation material.

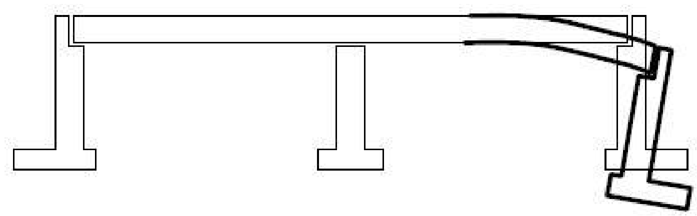


Figure 7-15: Differential Settlement between Different Substructure Units

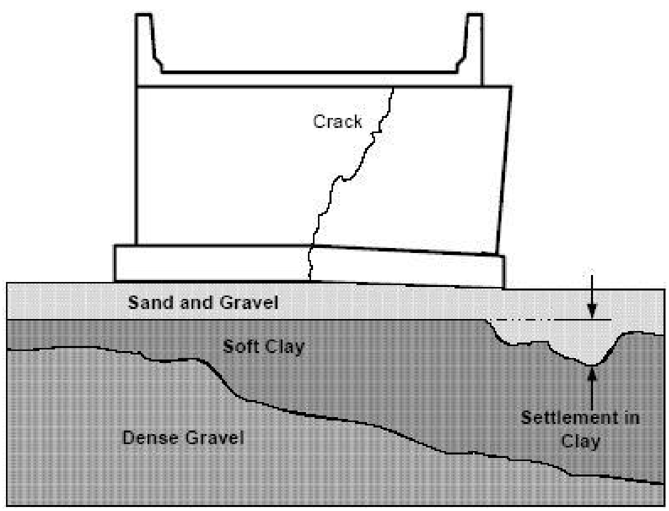


Figure 7-16: Differential Settlement under an Abutment / Pier

- Inspection of the joint opening between the end of the approach slab and the deck. In some cases, pavement expansion or approach fill expansion could conceivably cause vertical movement in the approach slab.
- Investigate existing and new cracks for signs of settlement.
- Examine the alignment of the superstructure for evidence of settlement (particularly the bridge railing).
- Check for scour around abutment foundations.
- Inspect the joint that separates the wing wall and abutment for proper alignment.

Figure 7-17: Cracks in Abutment due to Settlement

Differential settlement at piers can cause serious problems for a bridge. Deck joints can open excessively or close up completely. Local deterioration, such as spalling, cracking, and buckling, can also occur.

Similar to abutments, the most common causes of vertical movement are; soil bearing failure, soil consolidation, scour, and subsidence from mining or solution cavities.

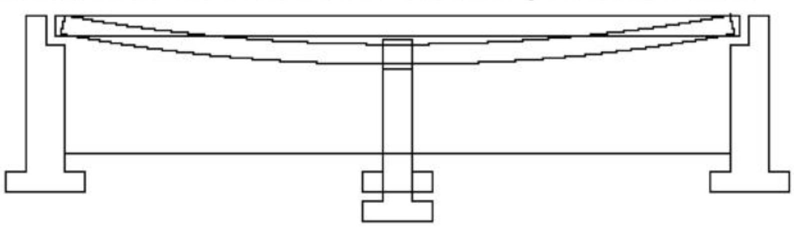


Figure 7-18: Differential Settlement between Different Substructure Units

At piers, inspection for vertical movement, or settlement, should include:

- For bridges with multiple simple spans, (the most prevalent case in Karnataka) examine the joint in the deck above the pier as well as at adjacent piers and at abutments.
- Check for any new or unusual cracking in the pier.
- Investigate for 'buckling' in pier columns.
- Check the superstructure for evidence of settlement by 'sighting' along parapets, railings, etc.
- Investigate for scour and undermining around the pier footing.
- In some cases, the check of a bearing seat or the top of pier elevations, using survey equipment, may be necessary.

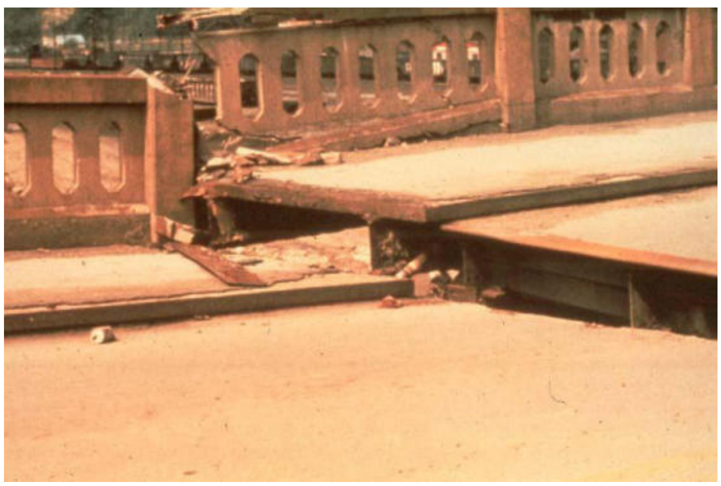


Figure 7-19: Evidence of Pier Settlement at Superstructure

The phenomenon of differential settlement may also occur in a single footing. Figure below shows an affected footing as a result of differential settlement. This can occur in both plain concrete and/or masonry open foundations.

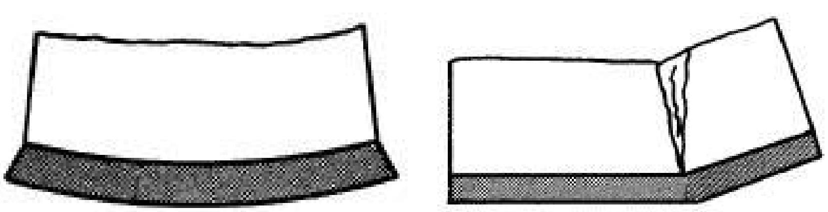


Figure 7-20: Differential Foundation Settlement

The inspection of footings should include a check for differential settlement along the length of a footing. This might be evidenced by severe cracking, spalling, or crushing across the footing at the critical location.

Lateral / rotational movement

Earth retaining structures, such as abutments and retaining walls, are susceptible to lateral movements, or sliding. Lateral movement occurs when the horizontal earth pressure acting on the wall exceeds the friction forces that hold the structure in place.

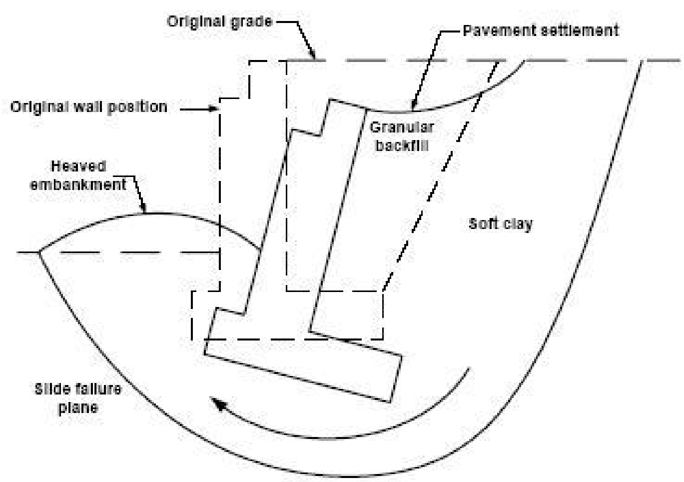


Figure 7-21: Lateral Movement of an Abutment due to Slope Failure

The most common causes of lateral movement are slope failure, seepage, changes in soil characteristics and, time consolidation of the original soil.

Inspection for lateral movement, or sliding, should include:

- Inspection of the general alignment of the abutment.
- Checking of the bearings for evidence of lateral displacement.
- Examination of the opening in the construction joint between the wing wall and the abutment.
- Investigation of the joint opening between the deck and the approach slab.
- Settled approach pavement
- Checking of the distance between the end of the superstructure and the earth wall.
- Examine for clogged drains (approach roadway, weep holes, and substructure drainage).
- Inspect for erosion or scour of the embankment material in front of the abutment.

Figure 7-22: Erosion at Abutment Exposing Footing

Rotational movement, or tipping, of the substructure units is generally the result of unsymmetrical settlement or lateral movements due to horizontal earth pressure. Abutments and walls are subject to this type of movement.

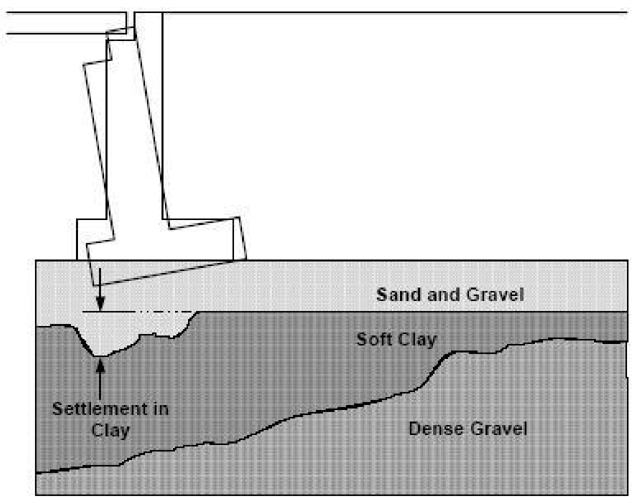


Figure 7-23: Rotational Movement of an Abutment

The most common causes of rotational movement are; scour, saturation of backfill, soil bearing failure, erosion of backfill along the sides of the abutment and, improper design.

Inspection for rotational movement, or tipping, should include:

- Checking of the vertical alignment of the abutment using a plumb line; it should be remembered that some abutments are constructed with a battered or sloped front face.

- Examination of the clearance between the beams and the earth wall.
- Inspection for clogged drains or weep holes.
- Investigation for cracks, whose width, length, and direction should be recorded.

Figure 7-24: Rotational Movement at Abutment

Differential settlement or excessive longitudinal or transverse forces, such as those experienced during an earthquake, may cause rotational movement (tipping) and lateral (horizontal) movement of piers.

Inspection for rotational movement, or tipping, at piers should include:

- Checking of the vertical alignment of the pier using a plumb line or level.
- Investigation of the clearance between the ends of beams at piers and between beams and earth walls.
- Inspection for cracking or spalling that may otherwise be unexplained; in the case of an inspection following an earthquake, such damage will be readily apparent.

Inspection for lateral movement should also include the checking of the linear alignment of the bridge railing or barrier.

Measuring the settlement

At the stage of routine bridge inspection, the only feasible way to measure differential settlement could be the checking of the levels of:

- FRL,
- Top of bridge railing/barrier wall,
- Finished level of kerb or,
- Finished level of footpath,

at each pier / abutment location and comparing them. Given that most bridge decks in Karnataka are constructed with a level deck, then by using common measuring devices any drop at finished levels over each pier or abutment can be deemed as a sign of settlement at that location.

In case of sloped decks, special care should be taken to establish the original FRL of the entire bridge by referring to the original design/construction and or "as-built" drawings. By then checking the existing finished road levels and comparing these to the as per drawing levels, the amount of settlement at each pier/abutment location can be measured. Care should be taken to consider any changes in FRL due to a change in the thickness of wearing course in longitudinally sloped bridges.

River Bed Protection

Definition and basic concepts

To provide bridge protection against lateral migration of the channel and high velocity flows and scour, structural methods are often used. River bed protection or hydraulic control structures are man-made and/or placed devices, designed to direct the stream / river flow and protect against undermining or lateral migration. These flow control structures may be used either at the bridge site or, upstream or downstream from the bridge.

River bed protection devices

Hydraulic control structures, installed to control stream flow and flood flows within the watercourse and through the bridge waterway opening, can comprise; riprap, spurs, training walls, gabions, slope stabilisation, channel linings, footing aprons, or other flow-control structures. River bed structures can either be man-made or comprise natural materials placed by man. Some of the more common hydraulic control structures include:

Riprap consists of properly sized and graded rock, either natural or manmade, placed adjacent to abutments, piers, or along embankments. Riprap should be protected against subsurface erosion by filters formed either of properly graded sand/gravel or of synthetic fabrics developed and used to replace the natural sand/gravel filter system. Such riprap must be of suitable dimensions and of a proper grade. It must be placed on an adequately flat slope to be able to resist the forces of the flowing water and of gravity.

- Spurs are devices designed to protect as well as redirect stream flow. Common applications occur on meandering rivers. The spurs are placed at the outside of the meandering bends to redirect the flow and minimize lateral migration.
- Training walls are constructed in order to redirect flood flows smoothly through the bridge waterway opening without endangering the end substructure units from scour. Scour hole formation occurs at the end of training walls rather than along the structure.
- Gabions consist of rectangular rock-filled wire mesh baskets anchored together and, generally, anchored to the surface which they are designed to protect, such as embankments and substructure footings. Gabions may be placed on steeper slopes

than riprap or may even be stacked vertically, depending upon the design procedure and the objective for the placement of the gabions.

- Slope stabilisation is the placement of geo-textiles, wire mesh or, the planting of plants, on the existing channel embankments.
- Channel lining is a concrete or other pavement material lining, placed on the channel embankment, which sometimes extends across the stream/river bed. Channel linings can also be revetment mats or some other form of stream/river bed armouring.
- Footing aprons are protective layers of material surrounding the footing of a sub structural unit. Footing aprons usually comprise ‘cast-in-place’ concrete formations, and protect footings from undermining. The aprons are not a structural element of the abutment or pier footings.

Crushed Stone Riprap

Spurs Constructed on River Meandering

Guidebanks Close to Bridge Location.

Gabion Basket Serving as Slope Protection

Wire Mesh and Grass Slope Stabilization

Concrete Revetment Mat

Figure 7-25: Showing Various types of Protection works

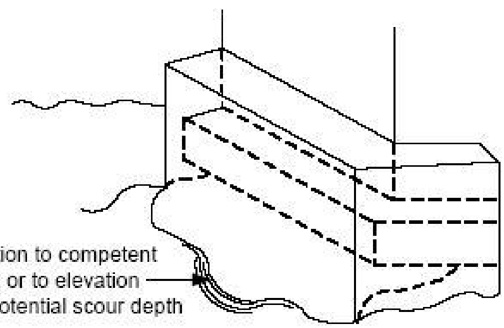


Figure 7-26: Concrete Footing Apron on a Masonry Arch Bridge

Inspection of river channel

The physical conditions associated with the flow of water through the bridge such as stream/river stability and, the condition of the channel, riprap, slope protection, or stream protection devices, including spur dykes, should be assessed and defective elements reported in the inspection forms. The inspection should also be particularly concerned with any visible signs of excessive water velocity which may cause the undermining of slope protection, erosion of banks, and realignment of the stream. Material defects that can be caused by waterway deficiencies, including the deterioration and damage to channel protection elements (i.e. abrasion, corrosion, scaling, cracking spalling, and decay) should also be identified.. As an integral part of the waterway inspection, therefore, careful consideration should also be given to the identification and reporting of material defects in stream/river bed protection works.

The following features require to be visually inspected by the inspector and, based on the overall condition at each foundation location, evaluated as “Good”, “Fair”, “Poor” or “Bad” and noted in the Foundation Inspection Forms.

- Examine any river training and bank protection elements to determine their stability and condition.
- Check for any gaps or spreading that may have occurred in the protective elements.
- Check for separation of slope pavement joints.
- Check for exposure of underlying erosion sensitive material.
- Inspect for ‘steepening’ of the protective material and the surface upon which these materials are placed.
- Check for evidence of slippage of protection work.
- Check the condition and function of riprap as well as any changes in the size of riprap.
- Check for evidence of failed riprap in the stream/river.
- Check for the proper placement, condition, and function of training walls, or spurs.
- Check the stream/river bed in the vicinity of the channel protection work for evidence of scour under the element.
- Check to see if the stream/river flow is impinging behind protective elements.

It is essential to identify any change that is observable, including changes in the grading of riprap. It is also essential to carefully inspect the integrity of the wire basket where gabions have been used. Disturbance or loss of embankment and embankment protection material is usually obvious from close scrutiny of the embankment. Unevenness of the surface protection is often an indicator of the loss of embankment material from beneath the protective works. However, loss of embankment material may not be obvious in the early stages of failure. The inspector should also look for irregularities in the embankment slope.

It is even more difficult to determine the condition of the protective works beneath the surface of the water. In shallow water, evidence of failure or partial failure of protective works can usually be observed. However, with deeper flows, and sediment-laden flows, it will be necessary for the inspector to probe or sound for physical evidence to identify whether failure or partial failure exists.

7.2 Open Foundation

Definitions

A shallow foundation (also called “open foundation”) generally derives its support from the soil or rock close to the lowest part of the structure that it supports. Shallow foundations include such common footing types as slabs, spread footings, strip footings, rafts, and mats.

Basic concepts

A spread footing is used when the bedrock layers are close to the ground surface or when the soil is capable of supporting the bridge loads close to the ground surface. A spread footing is typically a rectangular slab made of reinforced concrete. However, in old bridges spread footings made of plain concrete or stone/brick masonry are often widely used. This type of foundation "spreads out" the load from the bridge to the underlying rock or well compacted soil. While a spread footing is usually buried, it is generally covered with a minimum amount of soil. Visual inspection of spread footings is normally not possible unless the surrounding soil is heavily scoured.

Figure 7-27: Masonry Open Foundation Partly Exposed

The foundation should withstand the most critical load combination geo-technically - the maximum contact pressure at the interface of footing and soil/rock should not exceed the minimum bearing capacity of the foundation layer - and structurally - the footing structure should be capable of carrying all the induced forces/moments, within the acceptable structural code limits, that result from the most critical load combinations.

The other major concern is settlement of the foundations. The total settlement of the foundation (short-term plus long-term settlement) must not exceed the maximum allowable limits of the applicable codes. If this is exceeded then the entire bridge structure would be vulnerable to collapse.

Components of open foundations

As mentioned earlier, an open foundation (spread footing) is typically a rectangular reinforced concrete slab. In some cases, due to design considerations or other constraints, different shapes such as hexagonal or octagonal plates may be also used. The thickness of the slab (plate) may vary in terms of a minimum thickness at the edge, becoming thicker at column/pier/wall locations.

In the past, plain concrete and stone or brick masonry footings were also used. In the case of masonry footings, instead of sloping the top surface of the open foundation to achieve the required thickness at the wall/column location, a stepped top surface was previously adopted.

The foundation strata is normally covered with a thin layer of plain concrete to create a levelled working surface for the foundation, as well as to prevent the direct contact between the soil/rock and main body of the footing.

Figure 7-28: Reinforced Concrete Open Foundation

Common defects

The common defects of open foundations can be categorised under two major group headings, i.e. General Defects and Structural Defects.

In the following, first the issues dealing with the measurement of the actual dimensions of a spread footing (open foundation) are discussed, followed by the identification of the two major defect categories together with methodology for both inspection and recording.

Dimension details

Open foundations are normally constructed below the natural ground level of stream/river bed or bank. They will not therefore be visible unless the river bed is scoured around them. Due to these being below ground level, the actual dimensions of spread footings cannot be completely measured on site, and the construction/as-built drawings, if available, cannot be verified by measurement on site.

However, if the footings are visible/accessible, then by using a measuring tape, the planar dimensions should be checked and noted on the “Bridge Foundation Inspection Forms”.

General defects

The term “General Defects”, pertains to the physical and geotechnical environment that surrounds the foundation being considered given that this may cause scour, damage to bed protection, settlement etc. This therefore requires to be inspected and reported as follows:

Scour: The phenomenon of scour at an upstream or downstream location of each pier/abutment should be examined and the possible reasons for the scour, as mentioned in para 7.1, require to be noted in the "Bridge Foundation Inspection Form". The inspector should identify all possible causes for such.

Moreover, the scour depth at upstream and downstream of each open foundation to be measured as per the guidelines explained in above chapters.

Damaged stream / river bed protection: Conditions of the riverbed protection elements should be inspected and reported on following the procedure as outlined in above chapters of this Inspection Manual. If any damage has occurred, "Yes" is to be noted for the footing, and where no damage has occurred the answer is "No".

Settlement: As explained in Chapter on Settlement, the differential or overall settlement of bridge foundations can be measured by checking the levels of FRL and then comparing these with each other and/or with the original design / construction levels. The measured settlement values must be reported in the "Bridge Foundation Inspection Form".

Damage due to floating debris: Since open foundations are generally buried in soil or rock, floating debris is unlikely to damage spread footings. However, if in an exceptional case any damage has occurred to an exposed open foundation, the condition of the open foundation must be reported on the "Bridge Foundation Inspection Form".

Structural defects: The Inspector should examine all visible parts of the open foundations of a pier / abutment and, record all defects on the "Bridge Foundation Inspection Form" for each individual pier/abutment and footing. For buried footings, these should be reported as "Not Inspected".

Figure 7-29: Damaged Masonry Open Foundation

How to quantify defects

Masonry defects:

If open masonry foundations of a bridge are visible, then they should be inspected thoroughly. The three main problems associated with masonry foundations are:

Cracking: Cracking is an indication of distress in masonry and may be caused by over-loading or settlement of foundations. Cracking is considered 'serious' when – cracks are 5mm or wider.

Loss of pointing: Pointing is the mortar that is exposed between bricks or stones. It is usually weaker than stones or bricks it surrounds but it does deteriorate with age and may also be eroded by the flow of water.

Deterioration: Weak types of stone or brick tend to have a short life and may be eroded by heavy rains and the general flow of water. Other potential problems comprise bulging, plaster defects, cavities, etc.

Concrete defects

If the open concrete foundations are visible then the following potential defects should be checked for and, where necessary, quantified based on the guidelines as explained in above chapters for concrete structures. The results for each pier / abutment foundation should be reported on the relevant inspection form and can cover.

- Cracking, Spalling
- Scaling, Erosion of the concrete surface
- Honeycombing, Porosity
- Hollow sound
- Exposed reinforcement, Corrosion of bars.

Defect to component of bridge:

General Defects

The defects for Scour, Stream / river bed protection and Settlement shall be noted as explained in earlier chapters

Condition Rating of Open Foundations

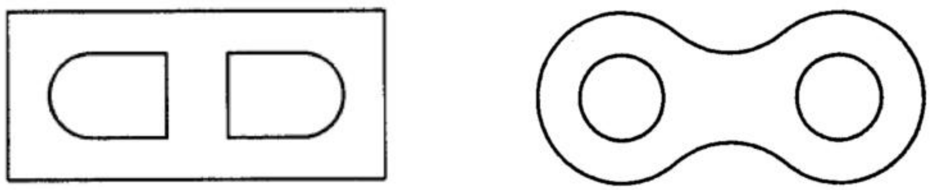
Table 7-1: Guidelines for Condition Rating of Open Foundations

Sl. No.	Defects	Condition rating	BCI Values
1	Observed settlement at foundation.	Re-construction / New Construction	< 30
2	Stream/river bed protection completely washed away.		
3	Scour Criticality ‘High Risk”	Strengthening / Rehabilitation	45 - 30
4	Scour criticality “Medium Risk”	Moderate Repairs Required	65 - 45
5	River bed protection partially washed away		
6	Observe cracks, spalling of Concrete, exposed reinforcement in the exposed portion of the footing		
7	Scour criticality “Low Risk”.	Minor Repairs Required	80 - 65
8	Minor damage to stream/river bed protection.		

7.3 Well Foundation

Definition

The most common type of deep foundation in India, and specifically in Karnataka, is "Well Foundation". Generally, well foundations can be categorised as "Caissons". The wells are normally of hollow circular section, or attached twin wells ("00" shape in plan). Typical Planner sections of combined / attached wells are shown below.



Double-D Well **Twin Well**

Figure 7-30: Plainer Sections of Combined/Attached Wells.

Basic concepts

A deep foundation is a foundation unit that provides support for a structure by 'toe' resistance, in the competent of soil or rock, at some depth below ground level and/or, by shaft resistance in the soil in which it is placed. Although capacity aspects may be emphasised in design, the foremost reason for using wells (as well as piles) is to reduce displacement, normally referred to as settlement. In other words a well foundation tends to be advantageous when some of the following conditions exist:

- A massive substructure is required to extend well below the river bed in order to attract the necessary net soil resistance and/or to withstand overturning, heavy scour, rolling boulders and floating debris. Under such conditions piles are unlikely to be suitable.
- The substrata contain large boulders which obstruct the penetration of a driven pile or boring holes for piles cast-in-situ.
- The foundation is subject to large lateral forces.

Components of well foundations

Wells of various shapes are used, depending on the type of soil through which they will be 'sunk', the type of pier/abutment to be supported and, the magnitude of applicable loads and moments.

Different components of a circular well foundation are shown schematically in below Figure. Combined wells also have similar components. The components are briefly explained below:

Cutting Edge: At the bottom and lowest part of the curb, wells are provided with a cutting edge, made of steel plates and angled, which are welded to each other and anchored into the curb by means of steel anchor bars.

The steel cutting edge should be strong enough to allow the sinking of the well through the forecast strata without suffering damage. The detail for the cutting edge will vary for soil and rocky strata, as well as for circular and combined wells.

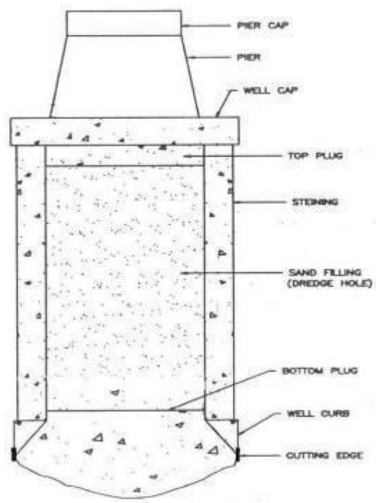


Figure 7-31: Typical Vertical Cross Section of a Circular Well Foundation

Well curb: Concrete well curbs are triangular in section in order to assist in the removing the earth by grabbing and to help easy sinking of the wells. Well curbs are reinforced to be strong enough to resist stress during the sinking of a well.

Steining: Steining is the playing the role of "vertical shaft" for well (caisson) foundations. Due to codal requirements, the steining is normally designed to act as a compression member. Well curb is constructed of plain concrete with nominal skin reinforcement. Being a compression member, in old bridges, brick/stone masonry steinings were also used.

In end bearing wells, the steining transfers the sub/super structure loads to the bottom plug. Where the friction resistance of the soil needs to be utilized (depending on the type of strata), the shaft has to transfer it, too.

Bottom plug: The function of the bottom plug is to transmit the load from the steining to the base of well and, ultimately, in to the founding strata. The bottom plug is normally of plain concrete with a thickness not less than half the diameter of the dredge hole measured from the bevel point of the well curb to the bottom of sump.

It should be noted that the cutting edge, well comb, bottom plug, and most of the steining, are always sunk deep into the ground and may not therefore be inspected.

Sand filling: The well pocket(s) are usually filled with sand or sandy clay but sometimes the pockets are kept empty to reduce the dead load of the well on the founding strata. It is desirable that at minimum the pockets below maximum scour level should be filled with sand to enhance the stability of the well. In each case a top plug, called an 'intermediate plug', should be provided over the sand filling.

Well cap: Loads from the piers and abutments are transferred to the well-steining through the well-caps which should, therefore, be reinforced adequately to withstand the resulting stress caused by the applied loads and moments.

Common defects

Distress or defects in bridge foundations, caused by various factors either individually or in combination, are discussed hereinafter. The defects pertaining to concrete, e.g. spalling, cracking, surface erosion, reinforcement corrosion, etc. are as per details for concrete structures.

Scour: Scour is defined as the removal and transportation of material from the bed and banks of stream and river as a direct result of the erosive action of flowing water. General scouring takes place in all stream and river beds, particularly during period of floods.

Excessive Scour Around Well Foundation

Exposed Bars of Well Cap

Figure 7-32: Scour Around Well Foundation

Damage to stream/river bed protection: If a river is causing scour, the abutment and piers require protection, e.g. 'bed protection'.

Settlement: The movement of foundations due to the deformation of the founding strata under applied loads are generally named as "Settlement". Defects due to settlement, their measurement and rating, are discussed in detail in above chapters.

Cracking: Cracks are defined as the separation of media in concrete. They may be an indication of distress in concrete.

Spalling: If some of the concrete in the structure falls away, it is termed as spalling of concrete.

Exposed reinforcement: Due to spalling of the concrete the reinforcement becomes exposed to the atmosphere.

Corrosion of reinforcement: This is a serious problem and can cause a bridge to fail if neglected. Corrosion is caused by water and air infiltrating into the concrete and reaching the reinforcement.

Damage due to floating debris: During heavy flooding, some floating debris may strike the foundations with the heavy impact causing structural damage.

Inspection procedure

Where to look at

Normally bridge foundations are below ground level or average bed level. Only after excessive scour takes place, therefore, may some parts of the foundation become visible.

Close inspection of important well foundation components is therefore not possible, other than the well cap and the top most portion of steining. When the stream/river is flowing, the site and well cap should be inspected with the aid of a boat. The well cap should be inspected as closely as possible, with care being taken to monitor all defects.

What to look for

Foundations are usually visible only after erosion or scour has removed significant embankment material. When exposed, check for signs of deterioration, such as cracking, leaching, spalling, and hollow-sounding concrete. (Refer paragraph 4.1 for details of concrete defects). Also check for signs of distress in the form of large cracks or splits, which should be documented for future reference. Check for evidence of settlement or other movement, following the guidelines as given in paragraph 8.2 of this chapter. For unpaved areas, lines in the soil could suggest the same.

Vertical movement can occur in the form of uniform or differential settlement. Uniform settlement of all bridge substructure units has little effect on the structure. Differential settlement, however, is the more common form and may produce serious distress. The most common causes of vertical movement are soil bearing failure, soil consolidation, scour, or deterioration of footing material.

How to quantify

Scour: For quantification of scour refer para 7.1.

River Bed Protection: Damage to the stream / river bed protection can be identified visually.

Settlement: Refer earlier chapters.

Cracking: The width of the crack should be measured using: Crack film, Crack gauge, Crack comparator card.

The length of the crack should be measured using a Scale, Foot-rule and Tape

Cracks can be inspected visually but, if necessary, binoculars can be used.

Spalling: This defect can be identified visually. A spalled area can be measured with the help of measuring tape.

Exposed reinforcement: This defect is identified visually.

Corrosion of reinforcement: This defect is identified visually. Reduction in bar diameter should be measured using Varnier Callipers.

Damage due to floating Debris: The sign of such damage can be identified visually.

Condition rating for well foundation

Table 7-2: Guidelines for Condition Rating of Well Foundation

S. No.	Defects	Condition rating	BCI Values
1	Differential settlement of foundation	Re-construction / New Construction	< 30
2	Bed protection completely washed out	Requires Strengthening / Rehabilitation	45 - 30
3	Scour criticality “High Risk”..		
4	Crack width more than 4mm along with spalling of concrete and corroded reinforcement in well cap or top portion of steining.		
5	Scour criticality “Medium Risk”.	Moderate Repairs Required	65 - 45
6	Bed protection partly washed out		
7	Crack width 2 to 4mm in well cap or Steining.		
8	Spalling of concrete and exposed reinforcement		
9	Scour criticality “Low Risk”.	Minor Repairs Required	80 - 65
10	Damaged bed protection.		
11	Crack width less than 2mm.		

7.4 Pile Foundation

Definition

Piles are the second type of deep foundation used in Karnataka. A pile is a long slender support (vertical or inclined) that is typically made of cast-in-situ concrete, constructed inside the bored holes. The terms “Caisson”, “drilled caisson”, “drilled shaft” and “bored piles” are frequently used by engineers to denote the drilled pile construction. In Karnataka, the holes are normally bored by the percussion method. However, use of the drilling system is growing fast. As yet, driven piles are not used in bridge construction in the state. Driven piles can be of steel, timber or pre-cast concrete.

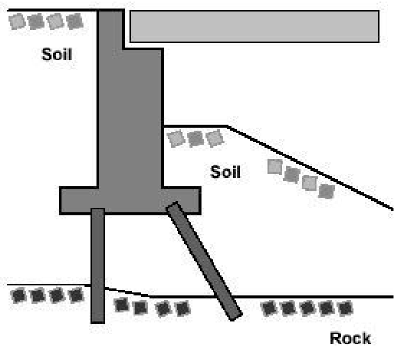


Figure 7-33: Schematic Elevation of a Pile Foundation

Basic concepts of pile foundations

Piles carry structural loads through the soil to the underlying rock (bearing piles) or dissipate the loads into the surrounding soil (friction piles).

Pile foundations are generally suited for use in the following situations:

- Availability of good founding strata below a thick layer of soft soil.
- There is a need to have a very deep foundation beyond the limit of pneumatic operations (usually a depth beyond around 35 m).
- The Founding strata underlying deep 'standing' water, the strata being very hard not permitting easy sinking of wells.
- Economic factors determine the use of piles as compared to wells.

Various numbers and configurations of piles can be used to support a bridge foundation. Piles may be partially exposed, and their upper ends can be embedded in the abutment stem, or more likely in a concrete pile cap which is similar to a footing.

In many cases, the piles are continued up to the pier cap level to form a frame type pier where the exposed parts of the piles are deemed to be columns.

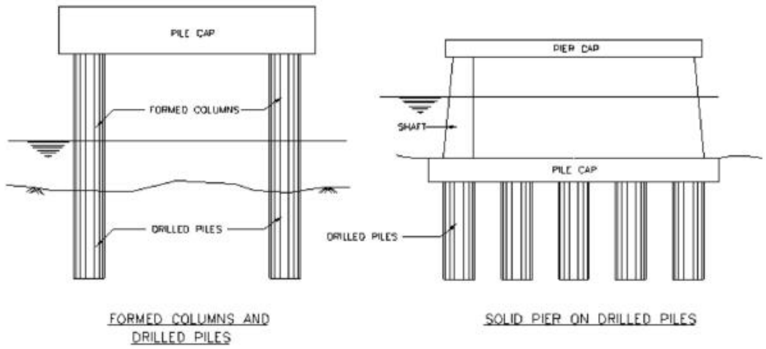


Figure 7-34: Representative Pile Configurations

Piles can be made of steel, timber or reinforced concrete. The popular type of piles in Karnataka are cast-in-situ concrete. Some types of concrete piles are described briefly below.

Pre-cast driven piles

Pre-cast concrete piles may be square, hexagonal or octagonal in shape, the former being commonly used because of the advantage of easy molding and drilling. In addition, square piles also provide more frictional surfaces which assists in taking more load. For ensured quality of concrete, correct disposition of reinforcement, least deviations in structural dimensions and, the fast pace of construction, pre-cast piles are generally used.

Driven cast in situ piles

Driven cast in situ piles are suitable for greater depths, of the order of 50m or so, and can penetrate a harder strata by virtue of the steel shoe at the end of the pile.

Bored cast in situ piles

The bored cast-in-situ piles are used for moderate depths of penetration in soil or rocky strata. The percussion system is the dominant technique for pile boring in Karnataka, however, in many cases rotary hydraulic or mechanical drills are also used. The stability of the bore hole is maintained by means of bentonite (drilling mud) or temporary/permanent casings.

Components of pile foundation

The major components of pile foundations are:

- Piles
- Pile cap

Piles

Piles may be of various forms and of different material. Most common types of piles used in construction of Karnataka bridges are reinforced concrete piles. The number and arrangement of piles varies depending on the magnitude of load, shape and dimension of piers/abutments, and, the characteristics of the strata.

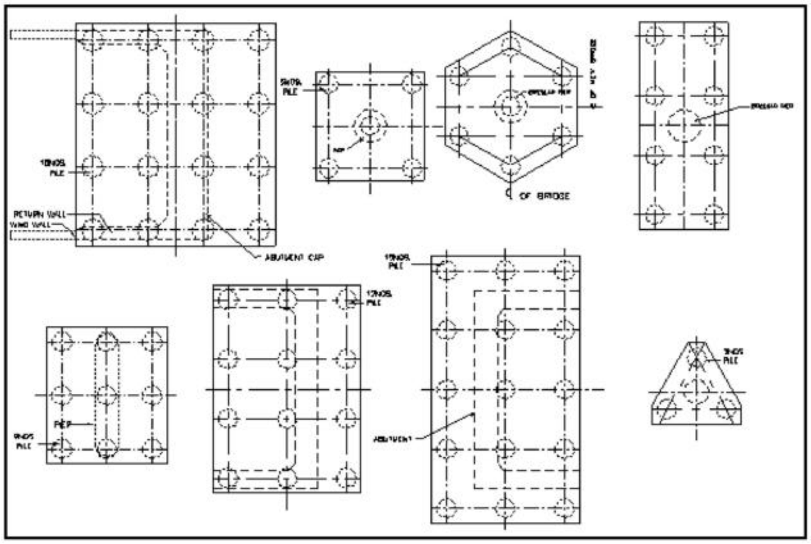


Figure 7-35: Typical Pile Group Layouts

Pile cap

The load from piers and abutments is transferred to the pile group through the pile cap, which is a reinforced concrete slab, thick enough to distribute all the bending and shear forces amongst the piers. Pile caps are normally constructed below natural ground level to minimise the obstruction against the water flow. However, some pile caps are constructed well above ground level due to construction constraints.

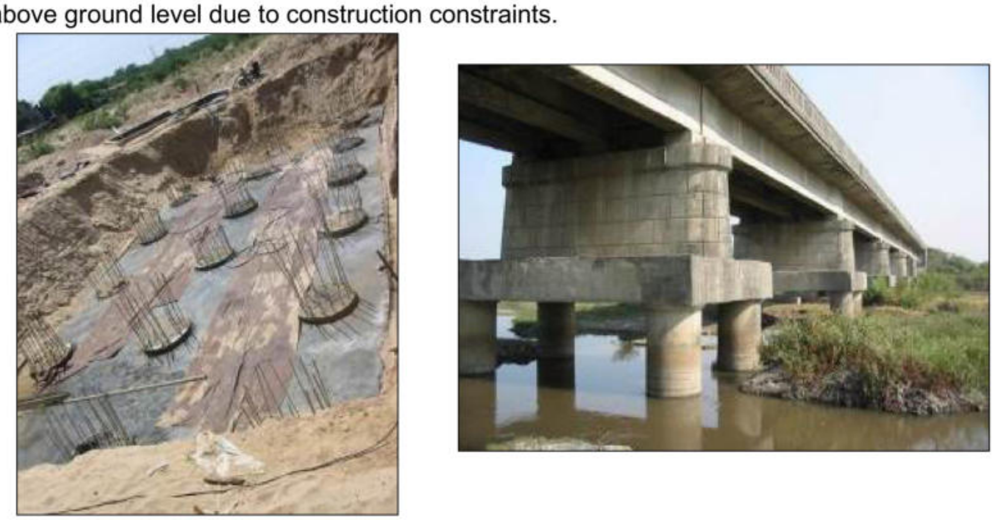


Figure 7-36: Pile Cap below GL and Pile Cap above Natural Ground Level

Common defects

The common defects found in pile foundations can be categorised under two major groupings, i.e. General Defects and Structural Defects.

In the following paragraphs, first the issues dealing with the measurement of the actual dimensions of the pile cap is discussed, followed by a discussion of the two major defect categories together with the methodology for the inspection and reporting of defects.

Dimension details

If the pile cap is constructed below the natural ground level of the stream/river bed or banks, it will not be visible, unless the stream/river bed has been scoured around the pile. As this is generally below ground, the actual dimensions of the pile cap cannot be completely measured on site or, if the construction/as-built drawings are available, the actual constructed dimensions cannot be verified by measurement on site.

However, if the pile caps are visible/accessible or it has been constructed above ground level then by using a measuring tape, the planar dimensions and thickness should be checked and noted in the "Bridge Foundation Inspection Form".

General Defects:

"General Defects", refer to issues pertaining to the physical and/or geo-technical environment surrounding the foundation which may cause scour, damage to bed protection, settlement, impact of floating objects, etc. The general defects should be inspected and reported as follows:

Scour: The phenomenon of scour at an upstream or downstream location of each pier/abutment should be examined and the possible reasons for the scouring, should be mentioned in the "Bridge Foundation Inspection Form". The inspector should note all possible reasons.

Furthermore, the scour depth at the upstream and downstream locations each open foundation should be measured as per the guidelines given and noted on the requisite form.

Damaged stream/river bed protection: The condition of the stream / river bed protection should be inspected and reported on, following the procedure outlined of this Inspection Manual. If any damage has occurred this should be recorded as "Yes" for each affected footing, otherwise the answer will be "No".

Settlement: As explained, the differential or overall settlement of bridge foundations may be measured by checking the levels of FRL and, comparing these with each other and/or the original design/construction levels. The measured settlement values must be reported in the "Bridge Foundation Inspection Form".

Damages due to floating debris: If the pile cap is buried in the strata, floating objects are unlikely to damage the foundation. However, in case of exposed cap / piles, if any damage due to such impacts has occurred to the exposed part of the pile or pile cap, the general deficiency condition of open foundation on the "Bridge Foundation Inspection Forms".

Structural defects: The Inspector should examine all the visible elements of the pier and abutment pile foundations, and note all the defects on the “Bridge Foundation Inspection Form” for each foundation. For non-visible or buried pile caps and piles, they should be reported as “Not inspected”.

How to quantify the defects

As discussed in earlier chapters

Figure 7-37: Erosion of Concrete Surface at Exposed Portion of Piles and Concrete Surface Defects at the Soffit of an Exposed Pile Cap

Pile foundation condition rating

Table 7-3: Guidelines for Condition Rating of Pile Foundation

Sl. No.	Defects	Condition rating	BCI Values
1	Observed settlement at foundation location.	Re-construction / New Construction	< 30
2	Bed protection completely washed out	Requires Strengthening / Rehabilitation	45 - 30
3	Scour criticality "High Risk".		
4	Crack width more than 4mm along with spalling of concrete and corroded reinforcement in pile cap or top portion of pile.		
5	Scour criticality "Medium Risk".	Moderate Repairs Required	65 - 45
6	Bed protection partly washed out		
7	Crack width 2 to 4mm in pile cap or pile.		
8	Spalling of concrete.		
9	Scour criticality "Low Risk".	Minor Repairs Required	80 - 65
10	Damaged bed protection.		
11	Crack width less than 2mmin pile cap or pile.		

CHAPTER – 8

Miscellaneous – Bridge Elements

Chapter 8: Miscellaneous – Bridge Elements

8.1 Expansion Joint

Definition

An expansion joint is a gap between the end of edges of two adjacent superstructure spans, or between the end edge of a superstructure span and dirt wall at abutment (or any fixed structural element; which accommodates the expansion or contraction of deck spans

Basic concept

In bridges, the transverse deck joints (i.e. expansion joint) must accommodate the longitudinal movement due to expansion and contraction. The close type expansion joint also prevents runoff from reaching bridge elements below the surface of the deck. In addition, the expansion joint provides a smooth transition from the approach road to the bridge deck and between the different spans of the superstructure. The expansion joint must be able to withstand all possible weather extremes in the local area of the bridge.

What to rate

Rate the condition of all transverse deck joints. In determining the rating this should also include the condition of the adjacent concrete and the smoothness of the transition to the deck.

Type of expansion joints

The two major categories of deck joints commonly used in Karnataka are open joints and closed joints.

Open joints

Open joints allow water and debris to pass through the joint.

Types of open joints

Finger plate joints

A fingerplate joint, also known as a tooth plate joint or a tooth dam, consists of two steel plates with interlocking fingers. These joints are usually found on longer span bridges where greater expansion is expected and also in balance cantilever types of bridge. The two types of fingerplate joints are cantilever fingerplate joints and supported fingerplate joints. The cantilever fingerplate joint is used when relatively small movement is required. The fingers on this joint are cantilevered out from the deck side plate and the abutment side plate. The supported fingerplate joint is used on longer spans. The fingers on this joint have their own support system in the form of transverse beams under the joint. Some types of fingerplate joints are segmental allowing for maintenance and replacement, if necessary. Fingerplate joints are used to accommodate movement from 100 to over 600 mm.

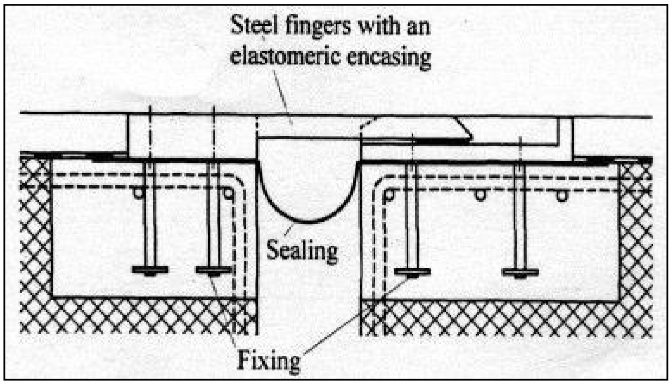


Figure 8-1: Cross Section of a Cantilever Finger Plate Joint

Closed joints

Closed joints are designed so that water and debris do not pass through them. This protects the superstructure and substructure members directly below the joint from the effects of water and debris build-up. There are many types of closed joints, including the following:

- Strip Seal joint.
- Modular type joint
- Asphaltic plug expansion joint.
- Filler joint.

Strip seal joint

A strip seal consists of two slotted steel anchorages cast into the deck and back wall. A neoprene seal fits into the grooves to span the joint. This joint can accommodate a maximum movement of approximately 100 mm.

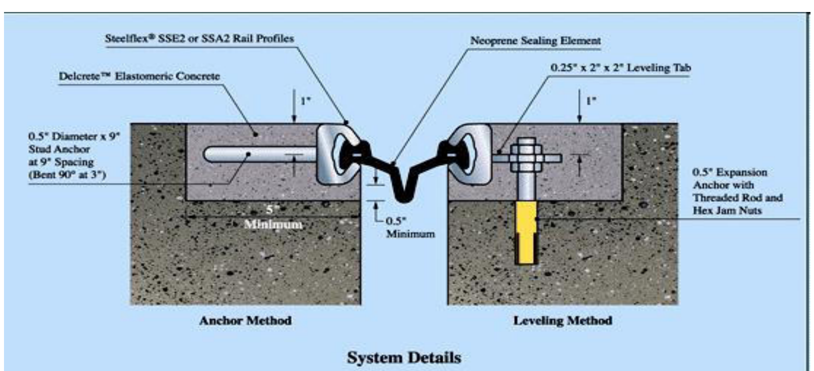


Figure 8-2: Cross Section of Strip Seal Type Expansion Joint

Modular type joint

The modular elastomeric seal is another neoprene type seal, which can support vehicle wheel loads. It consists of hollow, rectangular neoprene block seals, interconnected with steel and supported by its own stringer system. The normal range of operational movement is between 100 and 600 mm. It can, however, be fabricated to accommodate movements up to 1200 mm.

Asphaltic plug expansion joint.

An asphaltic plug expansion joint is typically used on short bridges that are to be overlaid with asphalt. The joint expansion must be 50 mm (2 inches) or less. A backer rod is then placed in the open joint and a sealant material is placed in the joint. An aluminium or steel plate is then centred over the joint to bridge the opening with pins being put through the plate, into the joint, to hold it in place. A heated binder material is then poured on the plate to create a watertight seal. Layers of aggregate saturated with hot binder are then placed to the depth needed. The filled joint is then compacted. This type of joint is gaining popularity as it allows bridge decks to be overlaid without damaging existing expansion joints.

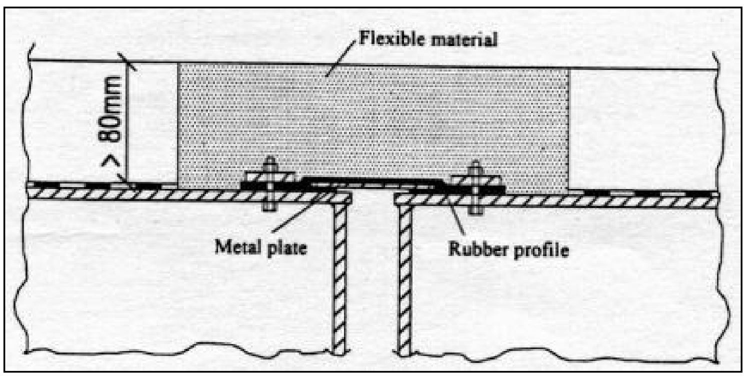


Figure 8-3: Asphaltic Plug Joint Additional Sealed by a Rubber Profile

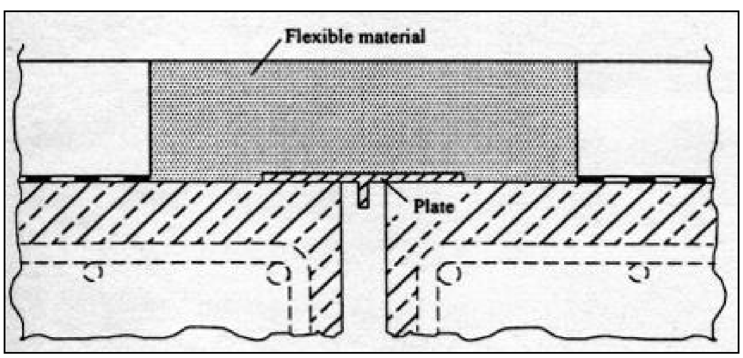


Figure 8-4: Asphaltic Plug Joint

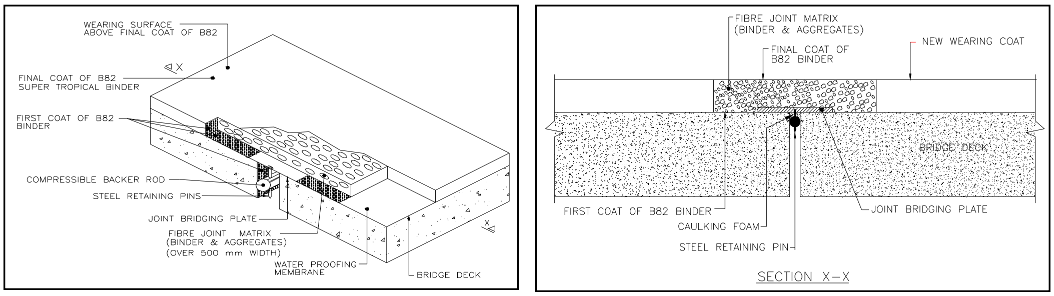


Figure 8-5: Schematic View of Asphaltic Plug Expansion Joint

Filler joint

The components of this type of joint are:

- 2 mm thick corrugated copper plate placed slightly below the wearing coat,
- 20 mm thick compressible fibre board to protect the edges,
- 20 mm thick pre-moulded joint filler which fills the gap to the top level of the wearing coat, sealed with a joint sealing compound.

The material used for filling the expansion joint should be bitumen impregnated felt. The joint filler should consist of large pieces with the use of small pieces to make up the required size being avoided.

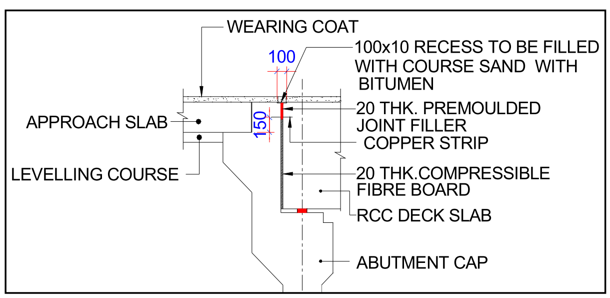


Figure 8-6: Schematic Diagram of Filler type Expansion Joint

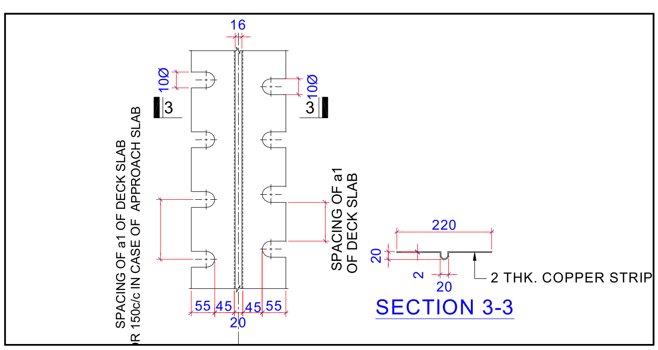


Figure 8-7: Sketch of Copper Strip Used in Filler Type Expansion Joint

What to check for

- Proper vertical alignment.
- Accumulation of debris.
- Water tightness (Deterioration of seal or sealant).
- Cracking and spalling of concrete at expansion joint location.
- Rust in the steel plates.
- Loose anchorages and missing end plates or angles.
- Broken components, bolts and welds.
- Any sound at the expansion joint with traffic movement.

Identification of defects

Check for vertical alignment: The expansion joint must have proper vertical alignment in order that vehicle riding quality is not affected. If the joint is not properly aligned then it creates noise when vehicle passes over it and also damages the adjacent concrete and joint anchorages. Cracking takes place in the concrete at the location of joints, if the joints are not properly vertically aligned.

Proper levelling: Both edges of the joint should be at the same level with no vertical difference between the two. The joint opening should be constant along the length of the joint, i.e. the joint edges should be parallel. For a fingerplate joint, the individual fingers should mesh together properly and, they should have the same horizontal plane as the deck surface. Fingers should be parallel to the deck centreline.

Proper levelling can be identified with the use of a level, a measuring tape and, visually.

Check for freedom of movement: The deck joints must accommodate the expansion and contraction of the deck slab. To identify this defect, check for any debris in the joint. The joint must be properly cleaned otherwise the expansion and contraction movement will not take place properly and will result in the cracking and damage of adjacent concrete.

Dirt and debris accumulation: Dirt and debris lodged in the joint may prevent normal expansion and contraction, causing cracking in the deck and back wall, and overstress in the bearings. In addition, as dirt and debris is continually driven into a joint, the joint material can eventually deteriorate leading to the failure of the joint.

Debris and dirt can be visually identified. A wire brush may be applied to check the extent of accumulation of debris or dirt.

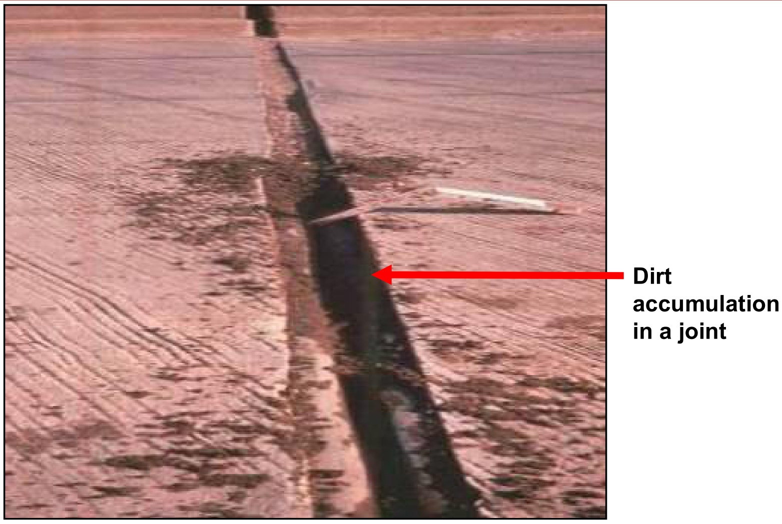


Figure 8-8: Dirt in a Seal Joint

Figure 8-9: Damaged expansion joints

Check the joint water tightness and general condition: Joint seal is a component of closed type expansion joints. It prevents runoff from reaching bridge elements below the surface of the deck. If the joint is not watertight it means either the seal or sealant has pulled away or physical deterioration of the components has taken place. This can be identified if watermarks are visible over the pier or abutment cap, or on the super structure at the joint location. Due to the leakage of water and leaching, concrete deterioration may have taken place at the joint locations.

Damage of seals and anchor plates: Heavy traffic movement, accumulation of debris, faulty installation could all be a major cause for the damage of a seal. The anchorage plate may also become damaged due to the pulling out or removal of the seal. The inspector should note any of these conditions and should also look for any evidence of leakage through closed joints.

Stains and signs of leakage beneath the deck, i.e. at pedestal, pier cap, pier, abutment, indicates that the seal is not water tight. This defect can be identified visually.

Check for rust in steel plates: Check for the visible rusting that takes place in steel plates, angle and bolts. This is a visual identification, with a change in the colour of the steel plate indicating rusting.

Check for spalling of concrete: A visual check for deteriorated concrete, spalling of concrete and, exposed reinforcement at expansion joint location should be undertaken.

Check for loose anchorages and missing end plates or angles: A visual check for loose anchorages and missing end plates or angles should be made. Some sound with the movement of vehicles will indicate the loosening of an anchorage.

Check for broken components, bolts and welds: A visual check for broken components, bolts and welds should be made.

Table 8-1: Guidelines for the Condition Rating of Expansion Joints

Sl. No	Defects	Condition Rating	BCI Values
1	Sealant pulled away	Replace	< 30
2	Seal physically deteriorated	Strengthening / Rehabilitation	45 - 30
3	Stains or other signs of leakage underneath the deck		
4	No freedom of movement (Not cleaned)	Moderate Repairs Required	65 - 45
5	Loose anchorages and missing end plates or angles		
6	Joint not properly vertically aligned		
7	Cracking and spalling at joint location	Minor Repairs Required	80 - 65
8	Broken components, bolts and welds		
9	Any sound at the joint under traffic movement		
10	Rusting of the steel plates		

The indicators given above are the key factors for condition rating. If any of these are seen to have occurred then the appropriate condition rating should be registered.

8.2 Drainage

Definition

The purpose of providing a drainage system is to remove water, and all the hazards that are associated with it, from the structure. The drainage system should require as little maintenance as possible and be located such that it does not cause damage and/or any improper functioning of the structure.

Basic concept

Runoff is the water, and any content therein, that may run off the surface of the bridge deck. The drainage system is provided to discharge the runoff from the bridge super structure without causing any damage to the system.

What to rate

It is necessary to rate the effectiveness of the drainage system in preventing water from running onto the bridge.

Deck drainage system

In order to perform an inspection of a bridge deck drainage system, it is necessary to become familiar with its various elements:

- Bridge deck cross slope and profile
- Deck drains
- Outlet pipes
- Downspout pipes

Bridge deck cross slope and profile

The cross slope of a bridge deck is the first component of the drainage system that is encountered by runoff. A proper cross slope and profile will direct the runoff to the deck drains and will eliminate or reduce ponding. Cross slope may be in one or both directions.

Deck drains (grill and the box)

Deck drains are the second component of the drainage system that runoff encounters. A deck drain is a receptacle to receive water. Deck drains may be nothing more than openings in a filled grid deck, or holes in the concrete deck.

Outlet pipes

An outlet pipe directs water away from the drain. The outlet pipe projects downwards from the deck in order that the water does not affect the super structure.

Down spout pipes

When a bridge is located over a road, the deck drainage must be directed from the outlet pipe to a nearby storm sewer system or any other appropriate release point. This is achieved using a downspout pipe network.

Check for:

- Improper cross fall.
- Proper orientation of the piping.
- Material in the drainage pipe.
- The existence of a collection pit at the drainage location.
- Grills over the drainage spout.
- The projection of the drainage pipe below the soffit of the deck slab.
- Any missing drainage pipes.
- Any broken pipes.
- Any watermarks, delamination or spalling of concrete at the drainage locations.
- Clogging by debris at drainage locations.
- Corrosion of grills.

Identification of defects

A properly functioning drainage system removes water, and all hazards associated with such, from the structure. However, it is important for the inspector to note the condition since drainage system problems can eventually lead to structural problems. The following should be inspected properly:

- Bridge deck cross slope and profile
- Grills
- Deck drains and inlets
- Deterioration of concrete at drainage location
- Outlet pipes
- Collection pits.
- Orientation of drainage pipes.

Bridge deck cross slope and profile: Adequate cross slope should be provided so that water runs off the bridge deck at a sufficient rate. If water accumulates on the deck then it will damage the wearing coat and deck concrete. Existing cross fall shall be approximated visually and its adequacy shall be noted.

Grills: Grills should be clear of debris (e.g., plants and grass) and free to allow deck runoff to pass. Grills that are deteriorated, broken, or missing should be reported. Grills condition is identified visually.

Deck drains and inlets: Deck drains and inlets must be of a proper size, location and spacing to carry the runoff away from the structure effectively. The existence of inlets should be noted carefully with the drainage elements being carefully examined during each bridge inspection. Clogged deck drains can lead to accelerated deck deterioration.

- The existence of inlets and corrosion can be identified visually. The spacing and size of drains should be measured using a measuring tape.

- Deterioration of concrete at a drainage location: Watermarks and the spalling of concrete at a drainage location is due to an improper drainage system. This can be identified visually.
- Outlet pipes: Outlet pipes carry runoff away from the structure. The outlet pipe can be a straight extension of the deck drain but it should be of sufficient length that runoff is not discharged onto the structure. The outlet pipe can be of either PVC or cast Iron. It is recommended that cast iron pipes be changed to PVC. The outlet pipe may also be a series of pipes called down spouting. This type of outlet pipe should be examined for splits or signs of disconnection or leaching which can accelerate deterioration of the structure.
- The working of the outlet pipe and its condition can be identified visually. Damaged lengths of pipe and length of pipe projection can be measured using a tape.

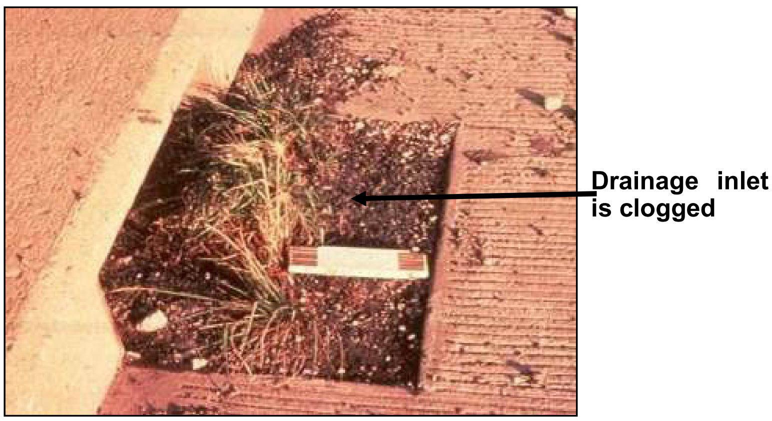


Figure 8-10: Clogged Drainage Inlet

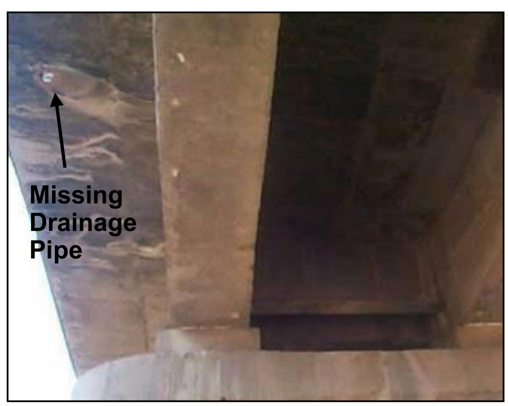


Figure 8-11: Proper Projected Length of Drainage Pipe and Missing Drainage Pipe

Orientation of drainage pipes: Drainage pipes must be properly orientated in order that water drains off properly and does not contaminate the substructure/superstructure. The proper orientation of pipes can be identified visually.

Figure 8-12: Proper Orientation of Drainage Pipe

Table 8-2: Guidelines for the Condition Rating of Drainage Systems

Sl. No	Defects	Condition Rating	BCI Values
1	Drainage pipes are missing	Re-construction	< 30
2	No grills over drainage spouts	Strengthening / Rehabilitation	45 - 30
3	No collection pits at drainage locations	Moderate Repairs Required	65 - 45
4	Drainage pipes are broken		
5	Orientation of pipes are not correct		
6	Projection of the pipe below the soffit of a deck slab is not as designed		
7	Water marks, delamination, spalling of concrete at drainage locations	Minor Repairs Required	80 - 65
8	Clogging by debris at drainage locations		
9	Corrosion of grills		

The indicators given above are the key factors for condition rating. If any of these are seen to have occurred then the appropriate condition rating should be registered.

8.3 Footpath

Definition

A separate space provided for pedestrians confined within the total width of the bridge. A footpath can be either both sides of the carriageway or on one side and will run parallel to the centreline of the carriageway.

Basic concept

The basic concept of providing a footpath on bridge is to provide safe passage for pedestrian movement over the structure.

What to rate

The footpath should be rated for its provision of a safe walking area. Inspect the footpath and rate the elements which are in the poorest condition.

Types of footpaths

- Solid type footpath.
- Hollow type footpath providing ducts for service lines.
- Separated or guarded footpath.

Solid type: - This type of footpath has no ducts for service lines and is either of plain cement concrete or has a kerb on both sides, running parallel to the carriageway, with the central portion being filled with sand and covered with tiles.

Figure 8-13: Solid Type Footpath

Hollow type: - This type of footpath has ducts provided below the footpath for service lines.

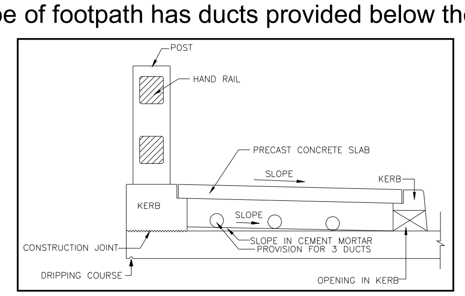


Figure 8-14: Hollow Type Footpath

Separated or guarded footpath: This type of footpath is generally provided where pedestrian traffic is heavy and provides a large and safe/protected space for pedestrians.

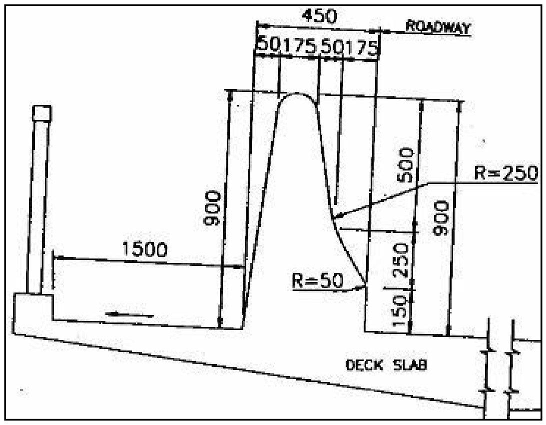


Figure 8-15: Separated or Guarded Footpath

Check for: -

- Type of footpath.
- Number of service ducts in footpath.
- Damaged length of footpath, Nature of damage to footpath.
- Number of blocked ducts.

Identification of defects

Walking surface: The damage to the footpath and the nature of the damage (cracking / spalling / damaged tiles) should be identified by the bridge inspector. The damaged length should be measured using a measuring tape.

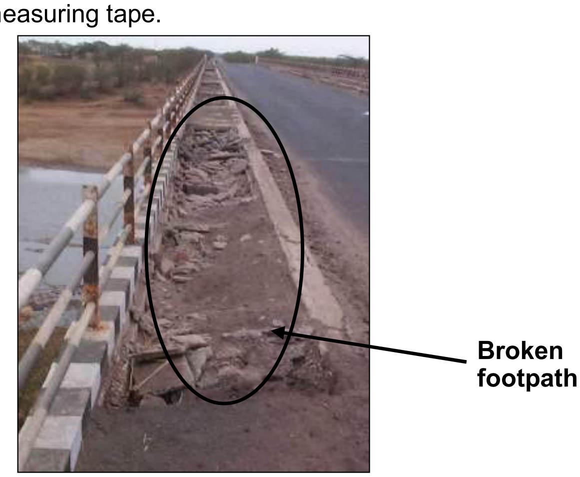


Figure 8-16: Broken Footpath

Figure 8-17: Footpath Tiles Damaged

Ducts: The ducts should be checked whether or not they are blocked. The bridge inspector can visually check the openings of the ducts.

Crash barrier and kerbs: - Check visually for any damage to the concrete kerb and any other damage.

Table 8-3: Guidelines for Condition Rating of a Footpath

Sl. No	Defects	Condition Rating	BCI Values
1	Footpath damaged over more than 50% of total length	Reconstruction	< 30
2	Footpath damaged over 50% to 75% of total length	Rehabilitation	45 – 30
3	Damaged kerbs	Moderate Repairs	65 – 45
4	Blocked ducts	Minor Repairs	80 - 65

The indicators given above are the key factors for condition rating. If any of these are seen to have occurred then the appropriate condition rating should be registered.

8.4 Railings and Crash Barriers

Definition

Railings or crash barriers protections at the edge of the superstructure or carriageway, parallel to the carriageway, provided for the safety of vehicles and pedestrians.

Basic concept

The primary function of any railing or crash barrier is to protect pedestrians and vehicles. The objectives of such are; hazard elimination, vehicle retention and vehicle redirection.

What to rate

Inspect the railings and/or the crash barriers attached to both sides of the bridge superstructure or deck. Rate the structural condition of these to function as originally designed.

Types of railing and crash barrier

There are two main types of railing and crash barriers used on bridges

Reinforced concrete railing/crash barrier

Reinforced concrete railing: RCC railings have vertical posts cantilevering from the kerb / deck with horizontal rails.

Figure 8-18: Reinforced Concrete Railing.

Reinforced concrete crash barrier: Reinforced concrete crash barriers are solid sections designed to withstand the impact of vehicle of a certain weight at a certain angle whilst travelling at a specified speed. Crash barriers, when provided, should essentially be one of the following types:

- Vehicle crash barrier: Provided for bridges without footpaths incorporated to contain errant vehicles.
- Combination pedestrian railing/vehicle crash barrier: Provided for bridges with footpaths to contain vehicles and safeguard pedestrians.
- High containment barriers: Provided mainly on bridges over busy railway lines and/or complex interchanges.

Figure 8-19: Reinforced Concrete New Jersey Type Crash Barrier

Steel railing / crash barrier

Steel pipe railing: In general, steel pipe railing is used for submersible bridges in India. Steel railings should be either collapsible or removable. Collapsible railing should be used where it is necessary to have railings removed immediately when a submerging flood has been observed. Removable Railings Bridge is opened to traffic immediately after a submerging flood has been recorded. Removable railings may be adopted when there is no danger to traffic using the bridge for short period without railings. Steel railings have two vertical post members and horizontal rails. The vertical post may be inserted in concrete pedestals or over the bridge deck.

Figure 8-20: Steel Railing

Galvanized steel crash barriers: Steel crash barriers can be of different types, namely, single head, double head, double head double side. (For details refer IRC-5: 2001)

Figure 8-21: Steel Crash Barrier

Check for

- Railing with or without kerb.

Concrete railing/concrete crash barrier:

- Common concrete defects.
- Damage to railing/crash barrier.

Steel railing/steel crash barrier:

- Shape of railing.
- Number of pipes missing.
- Number of posts missing.
- Damage to the crash barrier.

Identification and quantification of defects

- **Check for cracking:** Reinforced concrete railings /crash barriers should be checked for cracks. If the visible cracks are in a vertical post then it can be considered more critical than in a horizontal member. The pattern of cracks in concrete crash barriers should be identified carefully.
- **Check for spalling of concrete:** Spalling of concrete, and exposed reinforcement in a vertical member of an RCC railing, is more critical than in a horizontal railing member.
- **Detail of damaged railing / crash barrier:** The details of the damage to railings/crash barriers can be identified visually.
- **Missing pipes / posts:** Missing pipes/posts of steel railings can be identified visually the lengths of such being measured using a measuring tape.

Figure 8-22: Broken Railing

Figure 8-23: Broken and Damaged Railing

Figure 8-24: Damaged RCC Railing

Figure 8-25: Missing Steel Pipe at top of Railing

Figure 8-26: Pipe is missing from Steel Railing

Figure 8-27: Steel Railings Pipe Missing

Table 8-4: Guidelines for Condition Rating of Railings/Crash Barriers

S. No	Defects	Condition Rating	
1	Heavily damaged railing/crash barrier	Reconstruction	< 30
2	Moderately damaged railing/crash barrier	Rehabilitation	45 – 30
3	Minor damage to railing/crash barrier	Moderate Repairs	65 – 45
4	Pipes and posts missing		
5	Cracks in RCC railing/crash barrier	Minor Repairs	80 - 65
6	Spalling in RCC railing/crash barrier		

The indicators given above are the key factors for condition rating. If any of these are seen to have occurred then the appropriate condition rating should be registered.

8.5 Wearing Coat

Definition

The layer provided on the top of the deck, comprising either a bituminous or concrete layer.

Basic concept

The wearing coat provides for a better riding quality for traffic. It also protects the bridge deck from contamination and deterioration resulting from the effects of traffic and weather.

What to rate

The riding quality should be rated for the effectiveness of wearing coat in protecting the superstructure, i.e. the stopping of water permeation.

Types of wearing coat

The surface materials most commonly used as a wearing coat on concrete decks are generally either special concrete mixes or asphalt concrete. Two types of wearing coat are generally used on bridge decks:

Concrete wearing coat:

There are two categories of concrete wearing surfaces: integral and overlays. An integral concrete wearing surface is cast with the deck slab, typically adding an extra thickness to the slab. When the wearing surface has deteriorated to the extent that ride quality is affected, it is milled, levelled and replaced with an overlay. A concrete overlay wearing surface is cast separately over the previously cast concrete deck. Concrete wearing surfaces are normally roughened/patterned to prevent the skidding of vehicles.

Asphalt concrete wearing coat:

Asphalt (Bituminous) wearing surfaces over deck slabs should be provided with a waterproof membrane between the asphalt course and the concrete deck. The membrane assists in the prevention of water permeating through to the deck and super structure.

Figure 8-28: Bituminous and Concrete Wearing Coat

General definition of defects:

Ravelling: This is the progressive separation of aggregate particles in a wearing coat either downward from the surface or from the edges inward. Ravelling is usually a symptom of poor mix, design and defective construction methods.

Rutting: This is the displacement of material resulting in the creation of channels in wheel paths caused by traffic compaction or displacement of unstable material. They result from the consolidation of the asphalt under the pressure of wheel loads or from the lateral movement of the surface material, again due to wheel loads.

Cracking: The cracked surface is not watertight and therefore permits water to percolate.

Cracks in concrete wearing coat: A crack is a linear fracture in the concrete wearing surface that may only extend partway through the deck or it may occur as a failure plane running completely through the concrete structural element. The five types of cracks are: longitudinal, transverse, diagonal, pattern or map, and random.

Longitudinal cracks are reasonably straight cracks running parallel to the centreline of the roadway. These cracks are usually caused by shrinkage, settlement, differential deflection of adjacent beams or girders, voids in the slab, or corrosion of reinforcing steel.

Transverse cracks will appear in patterns roughly perpendicular to the centreline of the roadway. These cracks are usually caused by shrinkage, settlement, corrosion of the reinforcing steel, or by deflection of the superstructure.

Diagonal cracks are similar to longitudinal and transverse cracks, but they tend to run at an angle to the centreline of the roadway. Frequently a bridge constructed on a skew angle to the centreline will exhibit diagonal cracks.

When an interconnected network of cracks appears, similar to the cracks that occur in dried mud flats, it is classified as pattern or map cracking. This normally results from improper curing of the concrete or a weakness in the concrete mix design.

If cracks are meandering, irregular, and have no particular form or direction, they are classified as random.

Cracks in the bituminous wearing coat: Cracks in an asphalt wearing surface may take different forms from those appearing in concrete wearing surfaces. They include alligator or map cracks, edge cracks, lane joint cracks, reflection cracks, shrinkage cracks, and slippage cracks.

Alligator or map cracking is defined as interconnected cracks forming a series of small blocks resembling an alligator skin or chicken wire. This type of cracking is generally caused by the asphalt material drying out, but could also be caused by excessive deck deflection.

Edge cracks are longitudinal cracks near the edge of the deck. These are usually caused by the asphalt drying out, or by deterioration of the underlying concrete deck.

Lane joint cracks can develop along the seam between two paving lanes in a longitudinal pattern. A weak seam between two adjacent passes of the asphalt-paving machine usually causes this type of cracking.

Reflection cracks can develop in the asphalt-wearing course that result from a crack pattern in the underlying concrete deck.

Shrinkage cracks are interconnected cracks forming a series of large blocks in the surface. It may be difficult to determine if the cracks are caused by a volume change in the asphalt.

Slippage cracks are crescent-shaped cracks caused by a lack of bond between the asphalt surface course and the concrete deck beneath it.

Corrugation: Corrugations result from the plastic movement of surface materials that lack internal friction and stability, producing ripples across the asphalt surface. Corrugations may also appear in a crescent shape with the curved part pointing in the direction of traffic movement or, they can develop into a noticeable 'bump' in the direction of traffic flow.

Depression: Depressions are characterised as localised low areas of relatively small size that may or may not display cracking around the slightly sunken area. Due to the depression traffic movement is impaired

Potholes: A damaged portion of the surface displayed in the form holes in which water can stagnate. Potholes slow down traffic movement and create water ponding.

Potholes in wearing coat

Figure 8-29: Pot Holes in Wearing Coat

Check for:

- Type of wearing coat.
- Fine and wide cracks.
- Any depressions.
- Potholes.
- Ravelling.
- Any marks of corrugation or rippling.

Identification and quantification of defects

The following defects can be identified visually and measured using a measuring tape.

- Cracking
- Depressions
- Potholes
- Ravelling
- Corrugation marks

Figure 8-30: Damaged Wearing Coat

Table 8-5: Guidelines for Condition Rating of Wearing Coat

Sl. No	Defects	Condition Rating	BCI Values
1	Potholes over more than 50% of deck length (Depth > 25 mm)	Reconstruction	< 30
2	Ravelling over more than 50% of deck length	Strengthening / Rehabilitation	45 - 30
3	Cracking over more than 50% of deck length		
4	Frequent deep potholes over 10% to 30% of deck length (Depth < 25 mm)	Moderate Repairs Required	65 - 45
5	Ravelling over 10% to 30% of deck length		
6	Marks of corrugation over more than 50% of deck length		
7	Depression over more than 50% of deck length	Minor Repairs Required	80 - 65
8	Cracking over 10% to 30% of deck length		

The indicators given above are the key factors for condition rating. If any of these are seen to have occurred then the appropriate condition rating should be registered.

8.6 Service Line

Definition

Service lines are utilities on or carried by the bridge. Typical utilities are water, electricity, Optical fibre cable, cable TV, telephone, and sewage lines.

Basic concept

The basic concept of providing for service lines on or attached to a bridge is in order to prevent the changing of the alignment or grade if water/sewer line, of such services. If the service lines were to be carried by a separate bridge, it would require land acquisition and incur additional costs.

What to rate

Rate the condition of the utilities on the structure on a per span basis. This includes the pipes, ducts, conduits, wires and junction boxes.

Types of service lines

- Water pipe line.
- Sewer pipeline.
- Electrical wire line.
- Fibre optical cables / Cable TV line / Telephone line.


Figure 8-31: Service Lines outside the Deck Area

Figure 8-32: Service Line over the Footpath


Figure 8-33: Service Line Over Bridge Deck inside the Carriageway

Check for

- Number, size, type and location of service lines.
- Any leakage from service lines.
- Any damage in service lines.
- Any damage of concrete due to leakage from service lines.

Identification of defects

Check for Leakage: Visually check for water or sewage leaking onto decks, or members, causing a corrosion problem and damage to concrete.

Check for damaged or collapsed service lines: Visually check for damaged or collapsed service lines. If water/sewerage lines are encroaching on the carriageway, it will have the effect of slowing down the traffic movement.

Figure 8-34: Partially Collapsed Service Lines

Check for concrete damaged due to leakage: The deterioration of concrete due to the leakage of pipes can be identified visually. The subsequent deterioration of concrete can also be identified visually.

Table 8-6: Guidelines for Condition Rating of Service Lines

S. No.	Defects	Condition Rating
1	Dislodged service lines	Re-construction
2	Damaged service lines	Strengthening / Rehabilitation
3	Leakage from service lines	Moderate Repairs Required
4	Damage of concrete due to leakage from service lines	Minor Repairs Required

The indicators given above are the key factors for condition rating. If any of these are seen to have occurred then the appropriate condition rating should be registered.

8.7 Seismic Restrainer

Definition

A seismic restrainer is a structural attachment provided on a pier/abutment cap to prevent the transverse movement of superstructure during an earthquake.

Basic concept

The basic concept of providing a seismic restrainer is to prevent the transverse movement of superstructure keeping order to retain its position during an earthquake. Due to horizontal seismic forces the superstructure moves. Seismic restrainer therefore prevent horizontal movement of the superstructure in the transverse direction.

What to rate

The structural condition/integrity of the seismic restrainer requires to be rated.

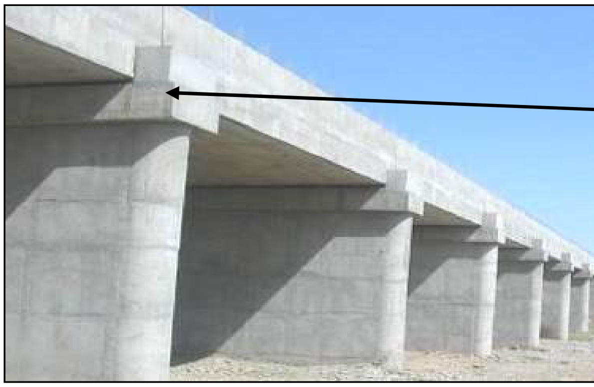
Type of seismic restrainer

Seismic restrainer are normally provided on the top of pier/abutment caps at a nominal distance from the outer face of girders (In line with a cross girder) or, on the exterior faces of a slab (at the bridge slab). A neoprene pad is used to fill the gap between the restrainer and the superstructure.

Seismic restrainer are normally made of reinforced concrete. However, in exceptional cases steel restrainer may also be present, mainly on bridges in seismic prone zones that have been strengthened/repaired.

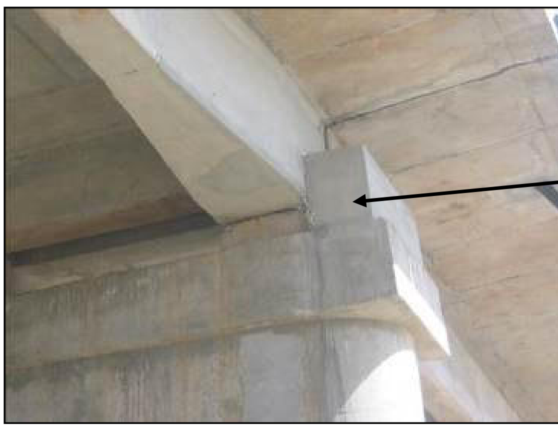
Reinforced concrete seismic restrainer: An RCC seismic restrainer are provided at the ends of longitudinal girders/solid slabs, on the pier/abutment caps.

Figure 8-35: RCC Seismic Reistrainer



RCC Seismic restrainer (Solid slab type super structure)

Figure 8-36: RCC Seismic Attachment on Pier Cap



RCC Seismic restrainer (Slab and girder type superstructure)

Figure 8-37: RCC Seismic Attachment on Pier Cap

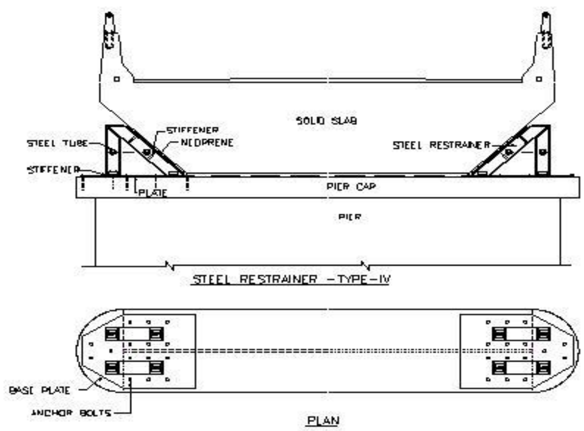


Figure 8-38: Typical Details of Steel Seismic Restrainer

Check For:

- Presence of a seismic restrainer.
- Type of restrainer.
- Common concrete defects.
- Any damaged or broken part of the concrete restrainer.
- Any sign of dislodgement, movement and local buckling of steel restrainer.
- Corrosion of steel.
- Loose / missing nuts, bolts and/or cracked welds.

Table 8-7: Guidelines for Condition Rating of Seismic Restrainer

Sl. No	Defects	Condition Rating	BCI Values
1	Broken restrainer	Re-construction	< 30
2	Sign of dislodgement, movement, local buckling	Strengthening / Rehabilitation	45 - 30
3	Cracks in restrainer	Moderate Repairs Required	65 - 45
4	Spalling, delamination of concrete		
5	Exposed or corroded reinforcement		
6	Loose nuts, bolts, cracked welds	Minor Repairs Required	80 - 65
7	Paint damage		

The indicators given above are the key factors for condition rating. If any of these are seen to have occurred then the appropriate condition rating should be registered.

CHAPTER – 9

Overall Condition Rating, Other Inspection and Photographs

Chapter 9: Overall Condition Rating, Other Inspection and Photographs

9.1 Overall Condition Rating

Definition

The numeric scale used to rate the condition of a bridge and its components, compares the present condition of the bridge/component, with the original design capacity and functioning but, disregards any non-compliance to current standards and codes. In other words, items should not be 'down-rated' if their condition is good but, the design and configuration does not comply with the latest version of applicable codes and standards.

Works Categories Proposed	BCI Valves	Priority for Bridges
Bridge Proposed for **Re-construction / New Construction**	< 30	**1**
Bridge **Retained with Strengthening / Rehabilitation**	30 – 45	**2**
Bridge **Retained with Moderate Repairs**	45 - 65	**3**
Bridge **Retained with Minor Repairs**	65 – 80	**4**
Bridge **Retained with Routine Maintenance**	80 - 100	**5**
Bridge **Retained with Repairs** and **Proposed for Widening :** Lane width required as per the AADT requirement OR If Overall Width < 8.0m for Minor Bridges and < 7.0m for Major Bridges		
Bridge Proposed for **Replacement of Super Structure:** If Super-structure BECI is less than 30%.		

The following rating scale has been adopted in the manual:

Condition Rating of Elements

It is essential that the Inspector use the rating scale in a manner consistent with the criteria established in this manual. Meaningful state wide assessment of bridge condition is possible only through consistent use of the rating system.

Rating of Multiple Elements

The following bridge elements are rated on the basis of the condition of the worst component. The condition of the components must not be averaged:

- Abutment bearings (Adopt the worst rating)
- Abutment pedestals (Adopt the worst rating)
- Wing walls/ Return Walls

- Footpaths (Adopt the worst rating)
- Railings and Crash Barriers (Adopt the worst rating)
- Pier bearings (Adopt the worst rating)
- Pier pedestals (Adopt the worst rating)
- Pier columns (Adopt the worst rating)
- Utilities and utilities supports
- Drainage Spouts, Wearing Coat
- Seismic Restrainer (Adopt the worst rating)

Overall Rating of the Bridge

The overall rating for bridge condition will be given as the worst condition rating of its constituent essential elements, i.e. Superstructure, Bearings, Sub-structure and Foundations.

9.2 Other Inspection

In the following the different types of inspection, together with their relevance to this manual, is briefly explained.

- Inventory
- Regular
- Detailed
- Emergency

Inventory Inspection

An inventory inspection is the first inspection for a bridge as the information thus obtained becomes the State Bridge Inventory. Therefore, all bridges in Karnataka and under CRN should be inspected as a first step for the setting up of BMS. Thereafter an inventory inspection will only apply when a new bridge has been constructed or, a change is made to the configuration of the structure, such as, widening, lengthening, to replacement, Major River training works, etc.

The guidelines and instructions given in the manual should be followed implicitly at the stage of Inventory Inspection in order to establish the BMS database. The importance of the Inventory Inspection is that this determines the baseline structural conditions and also identifies any existing problems in the Structure that may cause further problems in the future.

Regular / Routine Inspection

A Regular Inspection is a scheduled inspection consisting of sufficient observations and measurements to determine the physical and functional condition of the bridge, to identify any change from ”Inventory” or previously recorded conditions and, to ensure that the structure continues to satisfy present service requirements

This are carried out periodically. The purpose is to report the fairly obvious deficiencies which might lead to traffic accidents or cause high maintenance and repair costs, if not attended to promptly. The routine inspection will have to rely mainly on visual assessment. The frequency of inspection shall be at least once a year, bur preferably twice a year, before monsoon and after monsoon. However bridges located in hilly terrain prone to effects of landslides and bridges in severe exposure conditions shall be inspected twice a year before and after the monsoon.

Principal / Detailed Inspection

When a Regular Inspection or an Inventory Inspection reveals serious damage of any element, a Detailed Inspection of the Structure is required. In other words, when the condition rating is Re-Construction / Rehabilitation / Moderate repairs then a Detailed, or In-depths inspection is required.

For a Detailed Inspection the inspection should be carried out under the supervision and guidance of a qualified and experienced Bridge Engineer. At his discretion, other means of evaluation and examination of structural components, such as NDT (Non-Destructive Test), may also be utilised.

This is a more intensive and detailed inspection and will involve close examination of elements of the structure. It will be primarily a close visual assessment supplemented by standard instrumental aids. This inspection shall be carried out against the items related to the material, condition and situation of the structure. This principal inspection shall be followed by subsequent inspections at intervals of maximum three years. The observations made in the first principal inspection shall serve as a benchmark for subsequent inspection observations. More frequent inspections will be essential if the routine inspection reveals any distress in the bridge structure.

Emergency Inspection

These may also be specific events and conditions that affect a bridge and therefore require that non-scheduled inspections of a bridge be made. These include, but may not be limited to, the following:

- Unusual floods
- Earthquakes
- Traffic accidents
- Floating object impact
- Unusual build-up of debris at piers or abutments
- Evidence of rapid deterioration or movement
- Adverse environmental conditions
- Critical location in highway network: Where a structure, whose loss may have significant economic / social / political impact to the state.

This shall be undertaken in the event of unusual occurrences such as strong earthquake, accidents, passage of unusual loads or floods, major weaknesses noticed during routine and principal inspection, unusual settlement of foundations, and subsequent changes of traffic pattern. When any bridges of similar design and constructed almost at the same time are showing similar distress, all such bridges may be subjected to special inspections. Such inspections require a good deal of supplementary testing and structural analysis and will invariably require detailed involvement of design organisations and experts in the relevant fields.

In all cases, the appropriate sections contained within this manual must be used, under the direct guidance of an experienced bridge engineer.

9.3 Photographs:

Bridge Inspection must always include the following photos, which are noted under the relevant elements. These photos must be properly numbered in order to ensure the correct number of photo pages appear in the report:

In identifying the photos from a specific structure it may be useful to start with a photo of the structure identification which has been placed on the structure as part of the inventory activity.

Approach (showing surface, parapets, footways and medians, seen from one end of the bridge). If there is a signpost with the name of the bridge, this should be included in the photo.

Elevation (showing the whole structure (if possible) from both u/s and d/s side). If the elevations are different, i.e extensions to original structure, then two elevation photographs shall be taken.

Abutment (showing the general arrangement of the abutment, including the underside of the superstructure). If the abutments are of different types, photographs of both should be taken. Photos highlighting the condition of the abutment shall be taken.

Pier (showing a pier and the underside of the superstructure). If the bridge has different types of piers, photos of all types should be taken. Photos highlighting the condition of the Pier shall be taken.

Bearings: If the structure has different types of bearings, photos should be taken of all types, if accessible.

Expansion Joints on the structure should be photographed

Scour / Protection works Details: The photos of the Scour and the condition of the existing Protection work details shall be taken in detail.

When photographing various structural elements it is advisable to include items such a pencil or ruler which help the viewer to gain an appreciation of scale from the photograph.

ANNEXURE

Format for Inventory and Condition Survey of Bridges

Format for Inventory and Condition Survey of Bridges

GENERAL INFORMATION		**SUPER STRUCTURE DETAILS**	
Road Number		No. of Longitudinal Girders / Box Girders / Vents (Nos)	
Name of the Road		Centre to center Spacing (m)	
Bridge No / Bridge ID / LRP ID		Girder Depth (m) / Slab Thickness (m)	
From Chainage		No. of Cross Girders (Nos)	
To Chainage		Cross Girder Depth (m)	
Date of Inventory		Cross Girder Thick (m)	
Link ID		**SUB STRUCTURE : ABUTMENT - TYPE AND DIMENSION**	
PWD Km Stone		Main Type of Abutment	
PWD Str Number		Type of Abutment	
Road Category (NE / NH / SH / MDR / ODR / VR)		No. of Columns (Nos)	
Zone		Thickness / Diameter @ Top (m)	
Circle		Thickness / Diameter @ Bottom (m)	
Division		Height (m)	
District		Dirt Wall Thickness (m)	
Taluk		Dirt Wall Height (m)	
Sub division		Width of Abutment Cap (m)	
GENERAL INFORMATION		Height of Abutment Cap (m)	
Latitude		**SUB STR : WING WALL / RETURN WALL - TYPE & DIMENSION**	
Longitude		Main Type of Wing wall / Return wall	
Type of the Bridge		Type of Wing wall / Return wall	
Name of River / Nala / Stream		Length (m)	
Year of Construction		Length of Straight Return (m)	
Name of Nearby Place		Railing / Parapet over Return wall (Concrete / Steel / Masonry)	
Repairs done Prior to Inventory		Length (m)	
Direction of Flow		**SUB STRUCTURE : PIER - TYPE AND DIMENSION**	
Whether Bridge is Square or Skew? Skew Angle		Main Type of Pier	
Whether the Bridge is High level / Submersible?		Type of Pier	
Altitude		No. of Columns (Nos)	
SPAN DETAILS		Thickness @ Top / Dia of Column (m)	
Main Type of Superstructure		Thickness @ Bottom / Dia of Column (m)	
Type of Superstructure		Length at Top (m)	
Total No.of Spans (No)		Length at Bottom (m)	

No. of Span (Type-1)		Height (m)	
Length of each Span (Cen to cen of exp. Joints) (m)		Cut / Ease water (Semi-circular / Triangular)	
No. of Span (Type-2)		Thickness / Radius of Cut /Ease Water (m)	
Length of each Span (Cen to cen of exp. Joints) (m)		Width of Pier Cap (m)	
No. of Span (Type-3)		Uniform height of cap (m)	
Length of each Span (Cen to cen of exp. Joints) (m)		Tapered height of cap (m)	
Overall length of Bridge from Inner Face to Inner Face of Dirt Wall (m)		Length of Pier Cap (m)	
TOP DECK DETAILS		**BEARINGS - TYPE AND DIMENSION**	
Overall Deck Width (m)		Type of Bearings:	
Footpath / Kerb Width - Left (m)		No. of Bearings on Abutment Cap (Nos)	
Footpath / Kerb Width - Right (m)		No. of Bearings on Pier Cap (Nos)	
Footpath Height from Deck (m)		Earthquake Restrainer (Nos)	
Carriageway Width (m)		**FOUNDATIONS, WATERWAY, BED DETAILS**	
Median Opening (m)		Type of Foundation & Dimension (if visible)	
Deck Slab / Arch / Top slab (Concrete / Masonry)		Hydraulic details - Any Visible Scour? (Yes / No)	
Type of Wearing Coat		Type of Bed Material : Soil / Boulders / Rock	
Expansion Joints Details		a) Alluvial / Quasi Alluvial / Rigid	
Type of Railing / Parapet / Crash Barrier : Concrete / Steel / Masonry		Top level of Deck RL (m)	
Width (m)		Soffit RL of Deck (m)	
Height (m)		HFL RL (m)	
Centre to Centre of Railing / Parapet		Vertical Clearance above Lowest Bed Level (m)	
Whether Approach Slab is provided?		Whether Bridge is in Gradient? (Yes / No)	
If Yes, Length of App Slab (m)		Whether Stream is Perennial / Seasonal/ Navigable?	
Whether Drainage Spouts are provided? (Yes / No)		Bank Protection - Height (m)	
If Yes, No. of Drainage Spout per Span (Nos)		Bank Protection - Length (m)	
Design Loading:		Floor Protection - Width (m)	
		Floor Protection - Length (m)	
		Is there any Service Crossing the river through the Bridge (Electrical / Telephone / Water / Sewage / Gas)	
		Is there any Signboard over the Bridge (Yes / No)	

CONDITION - DECK SURFACE	
Wearing Coat - Cracking (sqm)	
Wearing Coat : Spalling (sqm)	
Wearing Coat : Pot Holes (sqm)	
Approach Slab- Condn- Cracked (Yes / No)	
Approach Slab- Condn : Settled (Yes / No)	
Footpath : Length of Damaged Portion (m)	
Railing : Length Damaged (m)	
Crash Barrier : Length Damaged (m)	
Concrete Parapet- Length Damaged (m)	
Masonry Parapet- Length Damaged (m)	
Expansion Joint- Length Damaged (m)	
Damage to deck near Expansion Joint (m)	
Drainage Spouts- No.of Pipes to be Repaired (Nos)	

CONDITION - RCC / PSC SUPER STR	DECK SLAB	LONG. GIRDER
Severe Cracks Visible (Yes / No)		
Length of Cracks (mm)		
Width of Cracks (mm)		
Nature and Location of crack		
Spalling (sqm)		
Number of Bars Exposed (nos)		
Corrosion of Reinforcement (Sqm)		
Poor Concrete, Honey Combing (Sqm)		
Deflection Visible (Yes / No)		
Whether any Vibrations are observed? (Yes / No)		
Anchorage Portion Damage (PSC Structure) (Yes / No)		
Water Leakage (Sqm)		

CONDITION - BEARINGS	ELASTOMERIC	METALLIC / OTHERS
Compression Bulging of Sides / Deformation (Yes / No)		
Excessive Shear Deformation / Steel Damage (Yes / No)		
Anchor Bolt Damage / Corrosion (Yes / No)		
Cracks in Bearing Pedestal (Yes / No)		
Debris or Vegetation around Bearings (Yes / No)		
Seismic Restrainer :Damaged or Loose Restrainer/ Dampeners (Yes / No)		

CONDITION - SUB-STR	ABUTMENT	CAP & PEDESTALS
Severe Cracks Visible (Yes / No)		
Length of Cracks (mm)		
Width of Cracks (mm)		
Nature and Location of crack		
Spalling / Bulging (Sqm)		
Bars Exposed / Corroded / Brick / Stone Loss (sqm)		
Poor Concrete / Poor Pointing (Sqm)		
Debris/ Vegetation (Sqm)		
Any Scour Observed? (Yes / No)		
Any Settlement Observed? (Yes / No)		

CONDITION - SUB-STRUCTURE	WING WALL / RETAINING WALL
Deformation (m)	
Honey Combing (m)	

CONDITION - SUB-STRUCTURE	PIER	CAP & PEDESTALS
Severe Cracks Visible (Yes / No)		
Length of Cracks (mm)		
Width of Cracks (mm)		
Nature and Location of crack		
Spalling / Bulging (Sqm)		

Others:			Bars Exposed / Corroded / Brick / Stone Loss (sqm)		
CONDITION - SUPER-STR	**MID DIAPH**	**END DIAPH**	Poor Concrete / Poor Pointing (Sqm)		
Severe Cracks Visible (Yes / No)			Debris/ Vegetation (Sqm)		
Length of Cracks (mm)			Any Scour Observed? (Yes / No)		
Width of Cracks (mm)			Any Settlement Observed? (Yes / No)		
Nature and Location of crack			**CONDITION - FDN**	**OPEN**	**PILE / WELL**
Spalling (sqm)			Any Visible Damage / Cracks		
Number of Bars Exposed (nos)			**CONDITION - MISC. ITEMS**	**U/S**	**D/S**
Corrosion of Reinforcement (Sqm)			Approaches- Damaged (Yes / No)		
Poor Concrete, Honey Combing (Sqm)			Bank Protection- Stone Pitching Damaged (Yes / No)		
CONDITION	**STEEL GIRDERS**	**BRACINGS**	Floor Protection- Damaged (Yes / No)		
Cracking (Yes / No)			Blockages in Waterway (Yes / No)		
Deterioration of Paint or Galvanising (Y / N)			**CONDITION - PIPE STRUCTURE, STONE SLAB**		
Bends in Webs, Flanges, Stiffeners or Bracings (Yes / No)			Condition of Pipes - (Good / Fair / Poor)		
Corrosion (Yes / No)			Type of Headwall		
Loose Bolts or Rivets (Yes / No)			Length of Headwall		
Deflection Visible (Yes / No)			Condition of Headwall - Spalling / Bulging		
CONDITION	**MASONRY ARCH**		Condn of HW - Bars Exp / Corroded / Brick / Stone loss (sqm)		
Change of Shape of Arch (Yes / No)			Condition of Headwall - Poor Concrete / Poor Pointing (Sqm)		
Cracking of Arch Barrel (Yes / No)			Stone slab Condition - (Good / Cracked)		
Cracking or Bulging of Spandrel Walls (Yes / No)			Cushion above Slab / Box / Pipe (m)		
Spalling of Stones or Bricks (Sqm)			NDT Tests Conducted		
Poor Pointing (Sqm)			Values of NDT		
Water Leaking through Arch (Sqm)			Whether BIV required for further Inspection (Yes / No)		
OVERALL REMARKS					
Remarks / Observations:					

Sample Data filled in for Inventory and Condition Survey of Bridges

INFORMATION DETAILS	Data_Type	Example	Remarks
GENERAL INFORMATION - BRIDGES-01			
Road Number	Text	SH5	
Name of the Road	Text	Highway Connecting Bangalore to Mysore	
Bridge No / Bridge ID / LRP ID	Text	BR:SH5:KOL2:010.000	
From Chainage	whole Number	9975	
To Chainage	whole Number	10025	
Date of Inventory	Date format	6/20/2014	
Link ID	Text	KOL2	
PWD Km Stone	Number with Decimal	10.50	
PWD Str Number	Text	11/2	
Road Category (NE / NH / SH / MDR / ODR / VR)	Text	SH	
Zone	Text	Z3	
Circle	Text	C1	
Division	Text	22	
District	Text	19	
Taluk	Text	19/8	
Sub division	Text	Kolar	
GENERAL INFORMATION - BRIDGES-02			
Latitude	Number with Decimal	13.089	
Longitude	Number with Decimal	78.149	
Type of the Bridge	Text	Minor Bridge	As per Lookup Table
Name of River / Nala / Stream	Text	Pennar River	
Year of Construction	whole Number	1985	
Name of Nearby Place	Text	Kolar	
Repairs done Prior to Inventory	Text	Plastering in deck slab carried out	
Direction of Flow (L to R / R to L)	Text	L to R	
Whether Bridge is Square or Skew? Skew Angle	whole Number	30	
Whether the Bridge is High level / Submersible?	Text	High Level	
Altitude	Number with Decimal	860.00	

INFORMATION DETAILS	Data_Type	Example	Remarks
SPAN DETAILS			
Main Type of Superstructure	Text	Slab	As per Lookup Table
Type of Superstructure	Text	RC Slab	As per Lookup Table
Total No.of Spans (No)	whole Number	5	
No. of Span (Type-1)	whole Number	1	
Length of each Span (Center to center of exp. Joints) (m)	Number with Decimal	12.50	
No. of Span (Type-2)	whole Number	2	
Length of each Span (Center to center of exp. Joints) (m)	Number with Decimal	8.50	
No. of Span (Type-3)	whole Number	2	
Length of each Span (Center to center of exp. Joints) (m)	Number with Decimal	10.25	
Overall length of Bridge from Inner Face to Inner Face of Dirt Wall (m)	Number with Decimal	50.00	
TOP DECK DETAILS			
Overall Deck Width (m)	Number with Decimal	12	
Footpath / Kerb Width - Left (m)	Number with Decimal	2.25	
Footpath / Kerb Width - Right (m)	Number with Decimal	2.25	
Footpath Height from Deck (m)	Number with Decimal	0.3	
Carriageway Width (m)	Number with Decimal	7.5	
Median Opening (m)	Number with Decimal	0	
Deck Slab / Arch / Top slab (Concrete / Masonry)	Text	Concrete	
Type of Wearing Coat	Text	Bitumen	
Expansion Joints Details	Text	Strip Seal	
Type of Railing / Parapet / Crash Barrier : Concrete / Steel / Masonry	Text	RC Railing	As per Lookup Table
Width (m)	Number with Decimal	0.5	
Height (m)	Number with Decimal	1.1	
Centre to Centre of Railing / Parapet	Number with Decimal	1.75	
Whether Approach Slab is provided?	(TRUE for Yes / FLASE for No)	TRUE	
If Yes, Length of App Slab (m)	Number with Decimal	3.5	
Whether Drainage Spouts are provided? (Yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
If Yes, No. of Drainage Spout per Span (Nos)	whole Number	2	
Design Loading:	Text	Cl 70R	

INFORMATION DETAILS	Data_Type	Example	Remarks
SUPER STRUCTURE DETAILS			
No. of Longitudinal Girders / Box Girders / Vents (Nos)	whole Number	5	
Centre to center Spacing (m)	Number with Decimal	0.00	
Girder Depth (m) / Slab Thickness (m)	Number with Decimal	0.90	
No. of Cross Girders (Nos)	whole Number	0	
Cross Girder Depth (m)	Number with Decimal	0.00	
Cross Girder Thick (m)	Number with Decimal	0.00	
SUB STRUCTURE : ABUTMENT - TYPE AND DIMENSION			
Main Type of Abutment	Text	Stone Masonry	As per Lookup Table
Type of Abutment	Text	Stone Masonry Wall Abutment	As per Lookup Table
No. of Columns (Nos)	whole Number	1	
Thickness / Diameter @ Top (m)	Number with Decimal	1.00	
Thickness / Diameter @ Bottom (m)	Number with Decimal	1.50	
Height (m)	Number with Decimal	3.50	
Dirt Wall Thickness (m)	Number with Decimal	0.30	
Dirt Wall Height (m)	Number with Decimal	1.10	
Width of Abutment Cap (m)	Number with Decimal	0.80	
Height of Abutment Cap (m)	Number with Decimal	0.30	
SUB STRUCTURE : WING WALL/ RETURN WALL - TYPE AND DIMENSION			
Main Type of Wing wall / Return wall	Text	Stone Masonry	As per Lookup Table
Type of Wing wall / Return wall	Text	Stone Masonry Return wall	As per Lookup Table
Length (m)	Number with Decimal	5.00	
Length of Straight Return (m)	Number with Decimal	0.00	
Railing / Parapet over Return wall (Concrete / Steel / Masonry)	Text	Stone Masonry Parapet	
Length (m)	Number with Decimal	5.00	
SUB STRUCTURE : PIER - TYPE AND DIMENSION			
Main Type of Pier	Text	Stone Masonry	As per Lookup Table
Type of Pier	Text	Stone Masonry Wall Pier	As per Lookup Table
No. of Columns (Nos)	whole Number	1	
Thickness @ Top / Dia of Column (m)	Number with Decimal	0.80	

INFORMATION DETAILS	Data_Type	Example	Remarks
Thickness @ Bottom / Dia of Column (m)	Number with Decimal	0.90	
Length at Top (m)	Number with Decimal	12.00	
Length at Bottom (m)	Number with Decimal	12.50	
Height (m)	Number with Decimal	3.50	
Cut / Ease water (Semicircular / Triangular)	Text	Semicircular	
Thickness / Radius of Cut /Ease Water (m)	Number with Decimal	0.40	
Width of Pier Cap (m)	Number with Decimal	1.10	
Uniform height of cap (m)	Number with Decimal	0.60	
Tapered height of cap (m)	Number with Decimal	0.00	
Length of Pier Cap (m)	Number with Decimal	12.00	
BEARINGS - TYPE AND DIMENSION			
Type of Bearings:	Text	Elastomeric	As per Lookup Table
No. of Bearings on Abutment Cap (Nos)	whole Number	4	
No. of Bearings on Pier Cap (Nos)	whole Number	8	
Earthquake Restrainer (Nos)	whole Number	0	
FOUNDATIONS, WATERWAY, BED DETAILS			
Type of Foundation & Dimension (if visible)	Text	Open	As per Lookup Table
Hydraulic details - Any Visible Scour? (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Type of Bed Material : Soil / Boulders / Rock	Text	Soil	
a) Alluvial / Quasi Alluvial / Rigid	Text	Alluvial	
Top level of Deck RL (m)	Number with Decimal	3.50	
Soffit RL of Deck (m)	Number with Decimal	2.60	
HFL RL (m)	Number with Decimal	1.50	
Vertical Clearance above Lowest Bed Level (m)	Number with Decimal	3.50	
Whether Bridge is in Gradient? (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Whether Stream is Perennial / Seasonal/ Navigable?	Text	Seasonal	
Bank Protection - Height (m)	Number with Decimal	3.00	
Bank Protection - Length (m)	Number with Decimal	6.00	
Floor Protection - Width (m)	Number with Decimal	15.00	
Floor Protection - Length (m)	Number with Decimal	50.00	

INFORMATION DETAILS	Data_Type	Example	Remarks
Is there any Service Crossing the river through the Bridge (Electrical / Telephone / Water / Sewage / Gas)	Text	Yes, OFC Cables on LHS	
Is there any Signboard over the Bridge (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
CONDITION - DECK SURFACE			
Wearing Coat - Cracking (sqm)	Number with Decimal	10.00	
Wearing Coat : Spalling (sqm)	Number with Decimal	0.00	
Wearing Coat : Pot Holes (sqm)	Number with Decimal	2.00	
Approach Slab- Condition-Cracked (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Approach Slab- Condition : Settled (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Footpath : Length of Damaged Portion (m)	Number with Decimal	10.00	
Railing : Length Damaged (m)	Number with Decimal	5.00	
Crash Barrier : Length Damaged (m)	Number with Decimal	0.00	
Concrete Parapet- Length Damaged (m)	Number with Decimal	0.00	
Masonry Parapet- Length Damaged (m)	Number with Decimal	3.00	
Expansion Joint- Length Damaged (m)	Number with Decimal	0.00	
Damage to deck near Expansion Joint (m)	Number with Decimal	0.00	
Drainage Spouts- No.of Pipes to be Repaired (Nos)	whole Number	2	
CONDITION - RCC / PSC SUPERSTRUCTURE (DECK SLAB)			
Severe Cracks Visible (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Length of Cracks (mm)	Number with Decimal	0.00	
Width of Cracks (mm)	Number with Decimal	0.00	
Nature and Location of crack	Text		
Spalling (sqm)	Number with Decimal	3.00	
Number of Bars Exposed (nos)	whole Number	0	
Corrosion of Reinforcement (Sqm)	Number with Decimal	0.00	
Poor Concrete, Honey Combing (Sqm)	Number with Decimal	10.00	
Deflection Visible (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Whether any Vibrations are observed? (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Anchorage Portion Damage (PSC Structure) (Yes / No)	(TRUE for Yes / FLASE for No)		

INFORMATION DETAILS	Data_Type	Example	Remarks
Water Leakage (Sqm)	Number with Decimal	0.00	
Others:	Text		
CONDITION - RCC / PSC SUPERSTRUCTURE (LONGITUDINAL GIRDER)			
Severe Cracks Visible (Yes / No)	(TRUE for Yes / FLASE for No)		
Length of Cracks (mm)	Number with Decimal		
Width of Cracks (mm)	Number with Decimal		
Nature and Location of crack	Text		
Spalling (sqm)	Number with Decimal		
Number of Bars Exposed (nos)	whole Number		
Corrosion of Reinforcement (Sqm)	Number with Decimal		
Poor Concrete, Honey Combing (Sqm)	Number with Decimal		
Deflection Visible (Yes / No)	(TRUE for Yes / FLASE for No)		
Whether any Vibrations are observed? (Yes / No)	(TRUE for Yes / FLASE for No)		
Anchorage Portion Damage (PSC Structure) (Yes / No)	(TRUE for Yes / FLASE for No)		
Water Leakage (Sqm)	Number with Decimal		
Others:	Text		
CONDITION - CONCRETE SUPERSTRUCTURE (MID DIAPHGRAM)			
Severe Cracks Visible (Yes / No)	(TRUE for Yes / FLASE for No)		
Length of Cracks (mm)	Number with Decimal		
Width of Cracks (mm)	Number with Decimal		
Nature and Location of crack	Text		
Spalling (sqm)	Number with Decimal		
Number of Bars Exposed (nos)	whole Number		
Corrosion of Reinforcement (Sqm)	Number with Decimal		
Poor Concrete, Honey Combing (Sqm)	Number with Decimal		
CONDITION - CONCRETE SUPERSTRUCTURE (END DIAPHGRAM)			
Severe Cracks Visible (Yes / No)	(TRUE for Yes / FLASE for No)		
Length of Cracks (mm)	Number with Decimal		
Width of Cracks (mm)	Number with Decimal		

INFORMATION DETAILS	Data_Type	Example	Remarks
Nature and Location of crack	Text		
Spalling (sqm)	Number with Decimal		
Number of Bars Exposed (nos)	whole Number		
Corrosion of Reinforcement (Sqm)	Number with Decimal		
Poor Concrete, Honey Combing (Sqm)	Number with Decimal		
CONDITION - STEEL GIRDERS			
Cracking (Yes / No)	(TRUE for Yes / FLASE for No)		
Deterioration of Paint or Galvanising (Yes / No)	(TRUE for Yes / FLASE for No)		
Bends in Webs, Flanges, Stiffeners or Bracings (Yes / No)	(TRUE for Yes / FLASE for No)		
Corrosion (Yes / No)	(TRUE for Yes / FLASE for No)		
Loose Bolts or Rivets (Yes / No)	(TRUE for Yes / FLASE for No)		
Deflection Visible (Yes / No)	(TRUE for Yes / FLASE for No)		
CONDITION - BRACINGS			
Cracking (Yes / No)	(TRUE for Yes / FLASE for No)		
Deterioration of Paint or Galvanising (Yes / No)	(TRUE for Yes / FLASE for No)		
Bends in Webs, Flanges, Stiffeners or Bracings (Yes / No)	(TRUE for Yes / FLASE for No)		
Corrosion (Yes / No)	(TRUE for Yes / FLASE for No)		
Loose Bolts or Rivets (Yes / No)	(TRUE for Yes / FLASE for No)		
Deflection Visible (Yes / No)	(TRUE for Yes / FLASE for No)		
CONDITION - MASONRY ARCH			
Change of Shape of Arch (Yes / No)	(TRUE for Yes / FLASE for No)		
Cracking of Arch Barrel (Yes / No)	(TRUE for Yes / FLASE for No)		
Cracking or Bulging of Spandrel Walls (Yes / No)	(TRUE for Yes / FLASE for No)		
Spalling of Stones or Bricks (Sqm)	Number with Decimal		
Poor Pointing (Sqm)	Number with Decimal		
Water Leaking through Arch (Sqm)	Number with Decimal		

INFORMATION DETAILS	Data_Type	Example	Remarks
CONDITION - BEARINGS (ELASTOMERIC)			
Compression Bulging of Sides / Deformation (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Excessive Shear Deformation / Steel Damage (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Anchor Bolt Damage / Corrosion (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Cracks in Bearing Pedestal (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Debris or Vegetation around Bearings (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Seismic Restrainer :Damaged or Loose Restrainers/ Dampeners (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
CONDITION - BEARINGS (METALLIC / OTHERS)			
Compression Bulging of Sides / Deformation (Yes / No)	(TRUE for Yes / FLASE for No)		
Excessive Shear Deformation / Steel Damage (Yes / No)	(TRUE for Yes / FLASE for No)		
Anchor Bolt Damage / Corrosion (Yes / No)	(TRUE for Yes / FLASE for No)		
Cracks in Bearing Pedestal (Yes / No)	(TRUE for Yes / FLASE for No)		
Debris or Vegetation around Bearings (Yes / No)	(TRUE for Yes / FLASE for No)		
Seismic Restrainer :Damaged or Loose Restrainers/ Dampeners (Yes / No)	(TRUE for Yes / FLASE for No)		
CONDITION - SUB-STRUCTURE (ABUTMENT)			
Severe Cracks Visible (Yes / No)	Text	FALSE	
Length of Cracks (mm)	Number with Decimal	0	
Width of Cracks (mm)	Number with Decimal	0	
Nature and Location of crack	Text	0	
Spalling / Bulging (Sqm)	Number with Decimal	5	
Bars Exposed / Corroded / Brick / Stone Loss (sqm)	Number with Decimal	2	
Poor Concrete / Poor Pointing (Sqm)	Number with Decimal	5	
Debris/ Vegetation (Sqm)	Number with Decimal	15	
Any Scour Observed? (Yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
Any Settlement Observed? (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	

INFORMATION DETAILS	Data_Type	Example	Remarks
CONDITION - SUB-STRUCTURE (ABUTMENT CAP AND PEDESTALS)			
Severe Cracks Visible (Yes / No)	Text	FALSE	
Length of Cracks (mm)	Number with Decimal	0	
Width of Cracks (mm)	Number with Decimal	0	
Nature and Location of crack	Text	0	
Spalling / Bulging (Sqm)	Number with Decimal	0	
Bars Exposed / Corroded / Brick / Stone Loss (sqm)	Number with Decimal	0	
Poor Concrete / Poor Pointing (Sqm)	Number with Decimal	0	
Debris/ Vegetation (Sqm)	Number with Decimal	0	
Any Settlement Observed? (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
CONDITION - SUB-STRUCTURE (WINGWALL / RETAININGWALL)			
Deformation (m)	Number with Decimal	0	
Honey Combing (m)	Number with Decimal	2	
CONDITION - SUB-STRUCTURE (PIER)			
Severe Cracks Visible (Yes / No)	Text	FALSE	
Length of Cracks (mm)	Number with Decimal	0	
Width of Cracks (mm)	Number with Decimal	0	
Nature and Location of crack	Text	0	
Spalling / Bulging (Sqm)	Number with Decimal	5	
Bars Exposed / Corroded / Brick / Stone Loss (sqm)	Number with Decimal	2	
Poor Concrete / Poor Pointing (Sqm)	Number with Decimal	5	
Debris/ Vegetation (Sqm)	Number with Decimal	15	
Any Scour Observed? (Yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
Any Settlement Observed? (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
CONDITION - SUB-STRUCTURE (PIER CAP AND PEDESTALS)			
Severe Cracks Visible (Yes / No)	Text	FALSE	
Length of Cracks (mm)	Number with Decimal	0	
Width of Cracks (mm)	Number with Decimal	0	

INFORMATION DETAILS	Data_Type	Example	Remarks
Nature and Location of crack	Text	0	
Spalling / Bulging (Sqm)	Number with Decimal	0	
Bars Exposed / Corroded / Brick / Stone Loss (sqm)	Number with Decimal	0	
Poor Concrete / Poor Pointing (Sqm)	Number with Decimal	0	
Debris/ Vegetation (Sqm)	Number with Decimal	0	
Any Settlement Observed? (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
CONDITION - FOUNDATION			
Any Visible Damage / Cracks - Open Foundation	Text	Not visible	
Any Visible Damage / Cracks - Pile / Well Foundation	Text		
CONDITION - MISCELLANEOUS ITEMS			
U/S Approaches- Intact (yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
U/S Bank Protection- Stone Pitching Damaged (Yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
U/S Floor Protection- Damaged (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
U/S Blockages in Waterway (Yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
D/S Approaches- Intact (yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
D/S Bank Protection- Stone Pitching Damaged (Yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
D/S Floor Protection- Damaged (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
D/S Blockages in Waterway (Yes / No)	(TRUE for Yes / FLASE for No)	TRUE	
CONDITION - PIPE STRUCTURE, STONE SLAB			
Condition of Pipes - (Good / Cracked / Cracked at Edges)	Text		As per Lookup Table
Type of Headwall	Text		As per Lookup Table
Length of Headwall	Number with Decimal		
Condition of Headwall - Spalling / Bulging	Text		
Condition of Headwall - Bars exposed / Corroded / Brick / Stone loss (sqm)	Number with Decimal		
Condition of Headwall - Poor Concrete / Poor Pointing (Sqm)	Number with Decimal		
Stone slab Condition - (Good / Cracked)	Text		

INFORMATION DETAILS	Data_Type	Example	Remarks
Cushion above Slab / Box / Pipe (m)	Number with Decimal		
OVERALL REMARKS			
Remarks / Observations	Text	Structure in good condition, Plastering to be carried out in slab soffit at edges, railings to be repaired, Vegetative growth to be cleared, side slope pitching to be provided.	
NDT Tests Conducted	Text	Rebound Hammer	
Values of NDT	Text	35	
Whether Bridge Inspection Vehicle required for further Inspection (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	
Whether Bridge is in Critical condition / requires immediate attention (Yes / No)	(TRUE for Yes / FLASE for No)	FALSE	

Reference / Lookup Tables

Look Up Tables for Bridges

For Type of Bridge

Type of the Bridge	Description
Major Bridge	Major Bridge
Minor Bridge	Minor Bridge
Submersible Bridge	Submersible Bridge / Irish Causeway / Vented Causeway
ROB	Road Over Railway Line
RUB	Road Under Railway Line
Underpass	Vehicular / Pedestrian / Flyover

For Type of Super structure

Main Type of Superstructure	Type of Superstructure	Description
Pipe	HP	Hume Pipe
Pipe	MCPC	Mass Concrete Pipe Culvert
Stone Slab	Stone Slab	Stone Slab
Arch	Brick Masonry Arch	Brick Masonry Arch
Arch	Stone Masonry Arch	Stone Masonry Arch
Arch	RC Arch	Reinforced Concrete Arch
Slab	RC Box	Reinforced Concrete Box
Slab	RC Slab	Reinforced Concrete Slab
Girder	RC Girder	Reinforced Concrete Girder
Girder	RC Box Girder	Reinforced Concrete Box Girder
Slab	RC Voided Slab	Reinforced Concrete Voided Slab
Girder	Balanced Cantilever	Balanced Cantilever
Girder	PSC I Girder	Pre Stressed Concrete I Girder
Girder	PSC Box Girder	Pre Stressed Concrete Box Girder
Slab	PSC Voided Slab	Pre Stressed Concrete Voided Slab
Girder	Bow String Arch	Bow String Arch
Steel Structure	Steel I Girder	Steel I Girder
Steel Structure	Steel Truss	Steel Truss
Steel Structure	Cable Stayed	Cable Stayed
Others	Brick Arch Widened / RC Slab, Stone Slab widened / RC Slab etc…	Brick Arch Widened / RC Slab, Stone Slab widened / RC Slab etc…

For Type of Railings

Type of Railing / Parapet / Crash barrier	Description
RCC Railing	Reinforced Cement Concrete Railing
MS Railing	Mild Steel Railing
Stone Masonry Parapet	Stone Masonry Parapet
Brick Masonry Parapet	Brick Masonry Parapet
RCC Parapet	Reinforced Cement Concrete Parapet
RCC Crash Barrier	Reinforced Cement Concrete Crash Barrier
Guard Posts	Guard Posts
MS Railing with RCC Posts	Mild Steel Railing with Reinforced Cement Concrete Posts

For Type of Abutment

Main Type of Abutment	Type of Abutment
Stone Masonry	Stone Masonry Wall Abutment
Brick Masonry	Brick Masonry Wall Abutment
Plain Cement Concrete	PCC Wall Abutment
Reinforced Cement Concrete	RCC Wall Abutment
Reinforced Cement Concrete	RCC Counterfort Abutment
Reinforced Cement Concrete	RCC Spill Through Abutment
Reinforced Cement Concrete	RCC Box Type Abutment
Others	Combination of Above

For Type of Pier

Main Type of Pier	Type of Pier
Stone Masonry	Stone Masonry Wall Pier
Brick Masonry	Brick Masonry Wall Pier
Plain Cement Concrete	Plain Cement Concrete Wall Pier
Reinforced Cement Concrete	Reinforced Cement Concrete Wall Pier
Reinforced Cement Concrete	Reinforced Cement Concrete Column Pier
Reinforced Cement Concrete	Reinforced Cement Concrete Frame Pier
Others	Combination of Above

For Type of Wing wall / Return wall

Main Type of Wing wall / Return wall	Type of Wing wall / Return wall
Stone Masonry	Stone Masonry Return wall
Stone Masonry	Stone Masonry Wing wall
Brick Masonry	Brick Masonry Return wall
Brick Masonry	Brick Masonry Wing wall
Plain Cement Concrete	PCC Return wall
Plain Cement Concrete	PCC Wing wall
Reinforced Cement Concrete	RC Return wall
Reinforced Cement Concrete	RC Wing wall

For Type of Bearing

Type of Bearing	Description
Tar Paper	Tar Paper
Elastomeric	Elastomeric
POT-PTFE	POT-PTFE
Metallic	Metallic

For Type of Foundation

Type of Foundation	Description
Raft	Raft
Open	Open
Pile	Pile
Well	Well

For Type of Headwall

Type of Headwall	Description
Stone Masonry	Stone Masonry Headwall
Brick Masonry	Brick Masonry Headwall
Plain Cement Concrete	PCC Headwall
Reinforced Cement Concrete	RC Headwall

For Condition of Pipe

Pipe Condition	Description
Good	Good
Cracked	Cracked
Cracked at Edges	Cracked at Edges