INSPECTION MANUAL FOR BRIDGES

PRINCIPAL

EDITION 1

The Project for Strengthening of Capacity Development on Bridge Management System in the Republic of Kenya

INSPECTION MANUAL FOR BRIDGES
— PRINCIPAL —
Edition 1

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FOREWORD

Bridges are integral elements of our road network. They perform effective linkage between two destinations thus they are critical for the economy. Despite their importance, maintenance of bridges has often not been prioritised in road network maintenance planning. This could be attributed to limited resources as well as other competing road network priorities. As a consequence, the deterioration rate of most bridges is not matched with maintenance interventions thus shortening their service life. Global warming and change in land use have made things worse as there has been a remarkable increase in surface run-off, resulting in overtopping and damage of bridges during the wet seasons. Therefore, without adequate attention, most bridges will be unsafe for use and will hinder the movement of people, goods, and services.

It is in view of the above, that there is need to put in place a framework to promote the inspection and maintenance of bridges in the road sector. This will ensure that our road assets are fit for purpose and safely provides connectivity at all times. This inspection manual is a product of a stakeholder-driven process which is intended to be a reference document to guide engineers and inspectors in carrying out bridge inspections and maintenance. The manual will be available for use for both the national government and county governments.

The objectives of this manual include assessing the current condition of the bridges and facilitating timely implementation of remedial measures, updating inventory data and carrying out performance evaluation of bridges. This will help to establish structural soundness, condition index and serviceability of the bridges to inform maintenance, improvements, design, and construction and to enable adequate planning and provision of resources essential to achieving efficient and effective bridge maintenance.

The manual addresses the most common bridge defects by outlining practical procedures for inspection and recommending appropriate tools and equipment to carry out the exercise. Defects have been discussed in detail with the help of pictures and sketches for ease of understanding. It is a comprehensive document and its implementation will be regularly monitored and reviewed to ensure it responds to emerging issues and meets desired performance.

To this end, the National Working Group (NWG) and the Sub-Working Group (SWG) have realized this important milestone for the road sector under *The Project for Strengthening of Capacity Development on Bridge Management System in the Republic of Kenya,* JICA. The implementation stage of this manual requires provision of adequate resources for the inspection and repair program and active participation by the stakeholders.

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JICA Bridge Management System Project Team
Kenya Roads Board (KRB)
Kenya National Highways Authority (KeNHA)
Kenya Rural Roads Authority (KeRRA)
Kenya Urban Roads Authority (KURA)
Kenya Wildlife Services (KWS)
Kenya Institute of Highways and Building Technology (KIHBT)
National Construction Authority (NCA)
Materials Testing and Research Department (MTRD)

Additionally, this Manual benefited greatly from the dedication of various individuals who were part of the Bridge Inspection and Database Sub-Working Groups (BI-SWG) that reviewed several literatures, best practices and held workshops to develop a well-benchmarked document for posterity. In line with this, special recognition goes to the below-named individuals for their immense contributions to the process.

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ABBREVIATIONS AND ACRONYMS

AC	Asphalt Concrete
ARBICS	Annual Road and Bridge Inventory and Condition Survey
ASR	Alkali Silica Reaction
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BI	Bridge Inspection
BMS	Bridge management System
BRM	Bridge Repair Manual
BS-EN ISO	British Standard European Norm
BSI	British Standard Institution
DOSH	Directorate of Occupation Safety and Health
DT	Destructive Test
EDM	Electronic Distance Meter
HGV	Heavy Goods Vehicle
HWL	High Water Level
JICA	Japan International Cooperation Agency
KeNHA	Kenya National Highways Authority
KeRRA	Kenya Rural Roads Authority
KIHBT	Kenya Institute of Highway and Building Technology
KRB	Kenya Roads Board
KURA	Kenya Urban Roads Authority
KWS	Kenya Wildlife Services
LCD	Liquid Crystal Display
MHWL	Mean of High Water Level
MoRT	Ministry of Roads and Transport
MT	Magnetic Particle Testing
MTRD	Material Testing and Research Division
NCA	National Construction Authority
NDT	Non-Destructive Test
NDT	Non-Destructive Test
NSE	Non-Structural Elements

NWG	National Working Group
OSHA	Occupational Safety and Health Act
PBC	Performance Based Contracts
PC	Pre-stressed Concrete
PLT	Point Load Test
RAs	Road Agencies
RC	Reinforced Concrete
SWG	Sub-Working Group

DEFINITION OF TERMS

Abutment	Vertical structural member located at the end of a bridge that connects the embankment portion of the approach road to the bridge. It supports the load from the superstructure and counters the earth pressure from the backfill.
Approach Slab	It is a concrete slab installed behind the abutment that acts as an intermediate bridge to avoid abrupt changes in elevation or alignment.
Back wall	The vertical wall at the ends of abutments that extends up from the bearing seat and supports the approach slabs, expansion joints and the embankment under the approach slabs.
Baseline inspection	An initial inspection conducted on a new bridge or an existing bridge to determine the primary condition in order to obtain information for BMS database and for future maintenance.
Bearing	Bearings are devices which transmit the vertical and horizontal actions from the superstructure to the substructure, and allow for movements between the superstructure and the substructure. Bearings allowing both rotation and longitudinal translation are called expansion/movable bearings, and those, which allow rotation, only are called fixed bearings
Bridge	A structure, that can be accessed by any traffic, with the function of aiding crossing over a waterway, road or any other obstacle. In the context of this manual, it also includes box culverts, viaducts and tunnels. *NOTE: The terms bridge and structure can be used interchangeably.*
Carriageway	The part of the bridge surface which carries vehicular traffic.
Complex bridge	A complicated structure by design and construction that requires specialized maintenance intervention.
Condition Rating	This is a status indicator for bridge elements based on location, severity and element importance assigned after detailed inspection.
Contractor	An entity engaged by the Employer for the implementation of supply, maintenance and/or repair assignment.
Corrosion	The gradual deterioration of material (usually metals) by oxidation reaction forming a more stable oxide.
Damage	Defect due to external forces e.g., Flood, Vehicular load, Vehicular collision, Earth pressure, Vandalism.
Deck slab	A structural member that directly supports vehicles, pedestrians, etc. passing through a bridge and transmits loading to the main girder (main structure).
Defect	Collective term for initial flaw, damage and deterioration
Deterioration	Defects caused by changes in condition with age eg Carbonation, Alkali-silica reaction, Salt damage

Diaphragm	It is a bracing that connects main girders at the supports, to resist lateral actions and transfer loads to the supports. It locks the girders in place and also provides support to the deck slab.
Drainage facility	A system that channels water away from the bridge deck, abutments and wing walls.
Emergency inspection	Inspection carried out after detection of abnormalities on the bridge. This may be after a natural disaster or accident to confirm safety of the bridge for use
Employer	The procuring entity responsible for the road network in Kenya and who enters into a road/bridge maintenance contract with a contractor on a certain section of the road.
Engineer	The representative of the Employer with responsibilities and obligations under the maintenance contract
Expansion gap	A gap provided to allow for expansion and contraction due to temperature changes. It can be between a bridge girder and abutment or between girders that are not continuous.
Expansion joint	It is a device installed at the expansion gap to ensure smooth expansion and contraction and to allow automobiles and other vehicles to run smoothly on the bridge. It is mainly made of steel or rubber.
Foundation	The part of the substructure that is in contact with the ground. Depending on the form, there are different types of foundations such as spread footing, pile foundations, and caisson foundations, etc. It transmits the loading from the substructure to the ground.
Implementers	The entity or persons directly involved in the inspections, maintenance/ repair of bridges. In maintenance of bridges, the implementers are the road agencies, engineering consultants and contractors engaged in the construction, repair and maintenance of structures/roads.
Initial Defect	Anomalies which are caused by design or occur during construction (poor workmanship) e.g Honeycomb, Cold joint.
Inspection	Diagnostic examinations on a bridge to discover any anomalies on the structural members.
Main girder/ Main structure	The main part of a superstructure that supports all the loads acting on the bridge. In general, it is called main girder in the case of girder structure, and main structure in the case of truss or arch structure.
Maintenance	The actions taken to keep the condition of a structural element to perform its level of service satisfactorily during its service life.
Obstructions	Accumulation of debris, driftwoods and stamps, rocks, silt, animals or anything that may impede free flow of water through a structure.
Ordinary bridges	Simply supported bridges with span lengths less than or equal to 30m.
Performance	It is the level of achievement or compliance with the specified service levels.

Performance Based Contracting	A series of works and services required for routine maintenance to bring up and sustain the bridge/road condition to the specified service levels.
Periodic inspection	Inspection carried out after every five years to check soundness of bridges.
Pier	A substructure member which supports the superstructure at intermediate points, and transmits the load to the foundation.
Repair	This is the reinstatement of a damaged member or structure to its designed or as-built condition.
Road Agencies	The Agencies dealing with structures that are part of the road network which include: Kenya National Highways Authority (KeNHA), Kenya Rural Roads Authority (KeRRA), Kenya Urban Roads Authority (KURA), Kenya Wildlife Services (KWS), County Governments and any other stakeholders.
Routine inspection for ARBICS	This inspection is carried out *annually* to obtain bridge condition information for maintenance planning purposes.
Routine inspection for PBC	Inspection to confirm the serviceability of a bridge conducted *at least once a month* to check for defects with an aim of ensuring smooth traffic flow and preventing damage/hazards to third parties.
Service Level	Service level is the minimum performance standards for the level of quality for each service criteria set under various service scope of the road as defined in the specifications.
Special inspection	Inspection for diagnostic study to examine the cause and extent of the damage based on findings from other inspections.
Stakeholders	Person(s) with interest in the use and operationalization of Inspection manual for bridges. They include the road agencies, engineering consultants, contractors, road users and the communities affected by the presence and usage of the bridge.
Substructure	The bridge structure that supports the superstructure and transfers loads from it to the ground or bedrock. The main components are abutments, piers, footings, and pilings.
Superstructure	The bridge structure that receives and supports traffic loads and in turn, transfers those loads to the substructure. It includes the main girder, deck slab, cross beam, lateral bracing, diaphragms. It comprises all the structural components of a bridge above the supports.
Wing wall	It is a wall adjacent to the abutment designed to retain-backfill material behind the abutment. The wing wall can be monolithic with the abutment or disjoint.

1 INTRODUCTION

1.1 Introduction of the manual

Bridges are a critical component of every road network that facilitate movement of goods, services and people. When a bridge is not functional, economic activities slow down or completely stop. Inspection is an essential part of the bridge maintenance management strategy which must be undertaken systematically and periodically to ensure that the bridges and by extension, road networks are safe for use and fit for purpose.

Bridge inspection enables prioritization of their maintenance and provides valuable data for assessment of their load carrying capacity. This information is an important baseline in design, construction and maintenance of the bridges.

The value of regular inspections lies in early detection of defects and timely intervention. Early detection helps in minimising potential risks to users and reduction of repair costs. Hence, although bridge inspection tasks may be mundane to some extent, utmost care must be taken to ensure that every defect, no matter the size is documented.

This Inspection Manual for bridges has been prepared to guide and establish a uniform and formal procedure for inspection of all bridges regardless of intended detail levels of data. It provides the official requirements for the visual assessment of bridges on Kenya's road network, provides requirements and supporting information for capturing inventory data, explains the inspection methodology and defines the technical expertise required for the visual assessment of the structures.

It is considered that the Manual can be used as a standalone reference book or it may be used in conjunction with other manuals herein referenced.

1.2 Contents of the manual

The Manual is divided into seven complementary chapters that provide guidance on a wide range of issues as listed in Table 1-1

Table 1-1 Contents of the manual

Chapter	Topic	Description
1	Introduction to the Manual:	The Chapter outlines the objectives of the manual, scope of coverage and target user group. The section further provides a snapshot of types of inspections and expected outcomes and impacts.
2	Bridge Terminologies and Classification:	Defines terminologies used in the manual, provides a detailed description of different types of bridges & their components and basic knowledge for bridge design.
3	Defects in Bridges:	Details different categories of bridge defects.
4	Bridge Inspection Process/Procedure:	A comprehensive description of the formal process to be followed when inspecting different types of bridges for different purposes.

Chapter	Topic	Description
5	Preparation for Inspection:	Provides details on personnel, tools, equipment and safety requirements to be availed before beginning inspection.
6	Bridge Condition: Assessment	A description of condition rating for principal and routine inspection.
7	Test Methods: for Bridges	Describes destructive and non- destructive tests.

1.3 Objective of the manual

The purpose of this manual is to guide and establish a uniform and formal procedure for inspection of all bridges. It provides guidelines for regular and systematic inspection of bridges on, under or over public highways and streets in the interest of public safety and protection of the public investments in such structures.

1.4 Scope of the Manual

This manual shall apply to the *Baseline inspection, Routine (PBC & ARBICS) inspection, Periodic inspection, Special inspection and Emergency inspection* of all bridges in the Republic of Kenya. It can be used for detailed investigations and evaluations of damage and/or material properties of specified elements and rating according to the bridge rating scale.

1.5 Expected outcomes and impacts.

This section defines the likely measurable short-term and broader long-term effects of the Inspection Manual for bridges in Kenya.

Table 1-2 Expected outcomes and impacts of the bridge inspection manual

	OUTCOME	IMPACT
1	Knowledgeable workforce (Bridge engineers and inspectors)	Enhanced workforce capacity on bridge inspection and condition assessment.
2	Availability of accurate and reliable data for design, construction and maintenance of bridges.	Data-based decision making in the sector for optimal asset management.
3	Well maintained bridges and road network	Reduction in maintenance cost of bridges and road network
4	Standardized data collection process across the sector for interoperability of the data	Enhanced policy formulation framework in the sector

1.6 Types of Inspections

There are different types of bridge inspection depending on the type of bridge and purpose for which the data is required. The categories are defined based on inspection frequency and methodology as shown in Table 1-3

Table 1-3 Objectives and Methodology of each inspection type

Inspection Type	Objective and description of inspection	Methodology
Baseline Inspection	An initial inspection conducted once on a new bridge or an existing bridge to determine the primary condition in order to obtain information for BMS database and for future maintenance.	Detailed visual inspection, measurement, and data from As-Built drawings
Routine inspection for PBC	Inspection to confirm the serviceability of a bridge conducted *at least once a month* to check for defects with an aim of ensuring smooth traffic flow and preventing damage/hazards to third parties.	Visual Inspection of the bridge to check for defects, damages and deteriorations.
Routine inspection for ARBICS	This inspection is carried out *annually* to obtain bridge condition information for maintenance planning purposes.	Visual inspection together with annual road inventory condition inspection
Periodic inspection	The inspection is for checking the soundness of the structure and shall be conducted at *intervals of 5 years.* It should be conducted to ascertain the sustainability of the performance of bridges. During the inspection, it is necessary to check for any defects.	Detailed visual inspection and measurement, conduct integrity tests and use of equipment /technical gear
Special Inspection	The inspection is conducted for diagnostic study to examine the cause and extent of damage based on the findings from previous inspections. Special inspection results are used to prepare a detailed plan of action. The diagnosis may involve field tests, laboratory tests, Non-Destructive Test or Destructive Tests and structural performance monitoring.	Detailed investigation using equipment /technical gear
Emergency Inspection	Emergency inspection is carried out after detection of severe defects and abnormalities on a bridge after a natural disaster or accident, to ascertain safety of the bridge for users and recommend appropriate remedial measures. It is important to compare the inspection results with past inspection data if available, so as to assess the extent of damage due to accident or natural disaster. The diagnosis may involve integrity tests and structural performance monitoring.	Detailed visual inspection and measurement, conduct integrity tests and use of equipment /technical gear

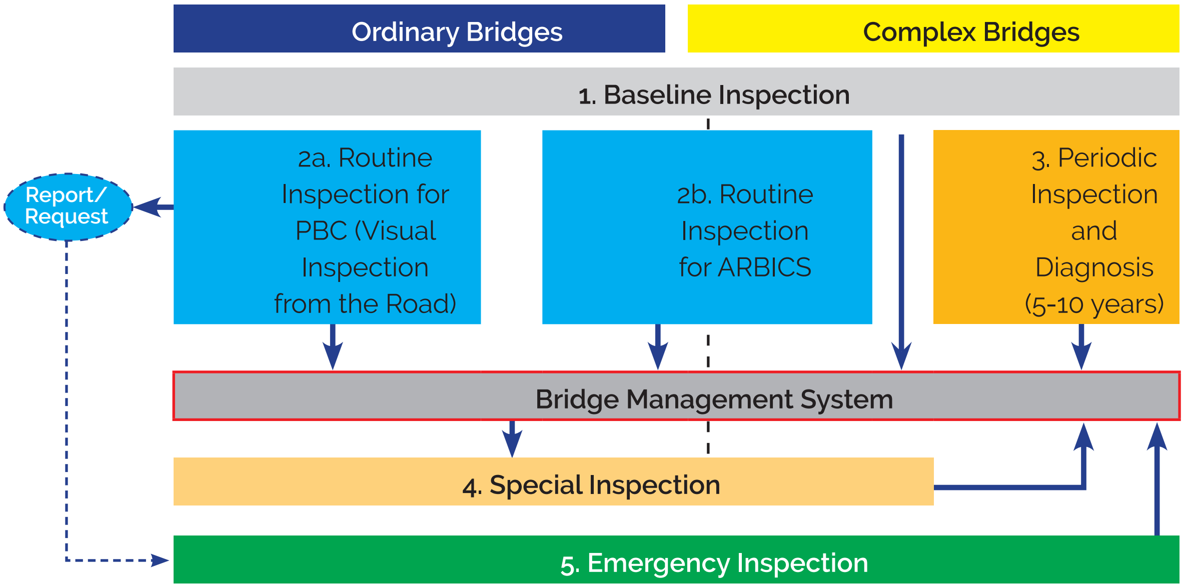


Figure 1-1 Inspection structure for ordinary and complex bridges

1.7 Safety and Health

The safety of the public and the inspectors is of major concern during inspection. The employer is responsible for providing a safe working environment, including: clear safety regulations and guidelines, safety training and proper tools and equipment.

1.8 Bridge Management System (BMS)

Bridge Management System is an online database for storage and management of bridge data to facilitate design, construction, operation, maintenance, monitoring and resource planning for structures.

The database function of storing all collected data from an inspection will support the bridge asset management. The damage score of the bridge is automatically calculated and thus inform maintenance option.

1.9 Stakeholders

Key Stakeholders as regards to bridge management in the republic of Kenya are listed in Table 1-4

Table 1-4 Stakeholders and their respective responsibilities

Stakeholder	Responsibility
Parent Ministry	- Develops policies and also mandates government departments and agencies to plan, construct, manage and maintain bridges.
Government departments and agencies	- To plan, construct, manage and maintain bridges. - To operationalize, review and revise this manual as needed in liaison with the ministry

Stakeholder	Responsibility
Implementers (Consultants, Contractors, Suppliers, Bridge Inspectors etc.)	- To inspect and repair bridges - To outline best practices, materials and methods for bridge inspection, recording and repair. - Information and awareness on availability of bridge maintenance standards. - To provide materials required for bridge construction, inspection and maintenance.
Trainers	- To impart knowledge, skills and attitude on inspection and repair of structures.
Development Partners	- To partner with Government of Kenya in development of Bridge Management System.

2 BRIDGE TERMINOLOGIES AND CLASSIFICATION

2.1 Introduction

A bridge is a structure, that can be accessed by any traffic, with the function of aiding crossing over a waterway, road or any other obstacle. In the context of this manual, it also includes box culverts, viaducts and tunnels. Bridges and other highway structures are fundamental to the transport infrastructure because they form essential links in the highway network. They are relied upon to remain in service year after year to carry designed traffic flow.

Bridges should be well maintained to minimize disruption, risk and consequential costs to road users and make economic and efficient use of resources. They should always be safe and fit for use.

2.2 Bridge components and terminologies

Bridge elements can be categorized under superstructure, substructure or ancillary elements that act to provide functionality, durability and safety requirements of a bridge. Every bridge member is designed to withstand a unique combination of tensile, compressive, torsional and shear forces. These are considered the four basic kinds of member stresses caused by the supported loads.

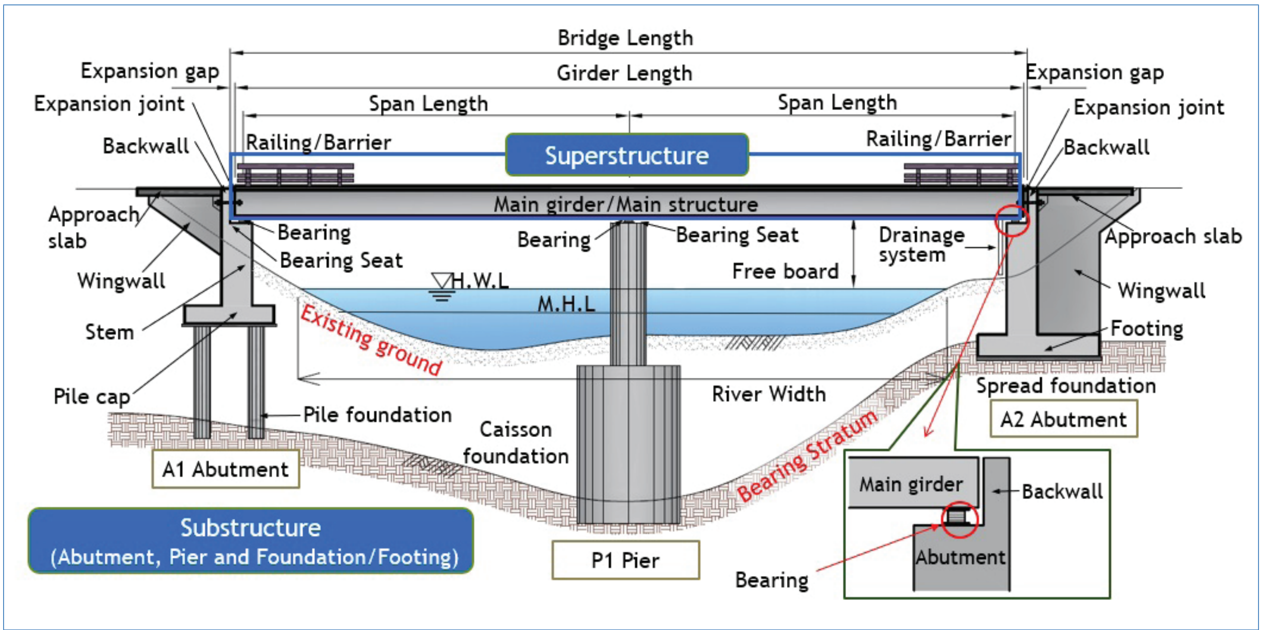
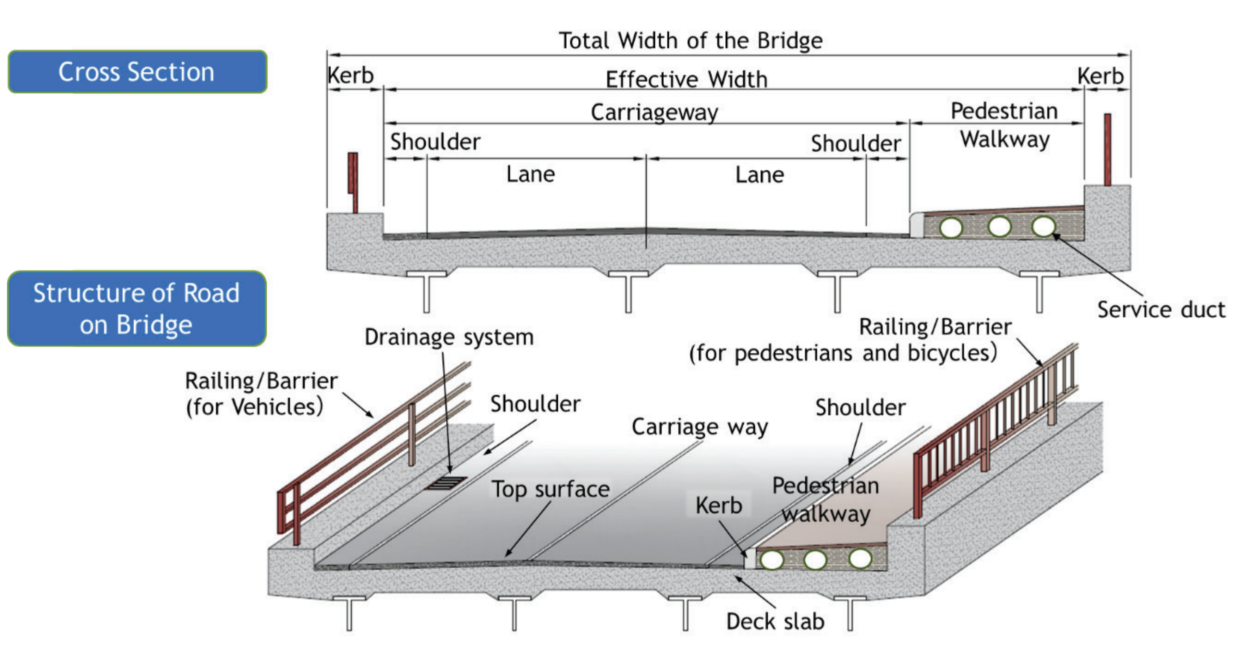


Figure 2-1 Bridge Components



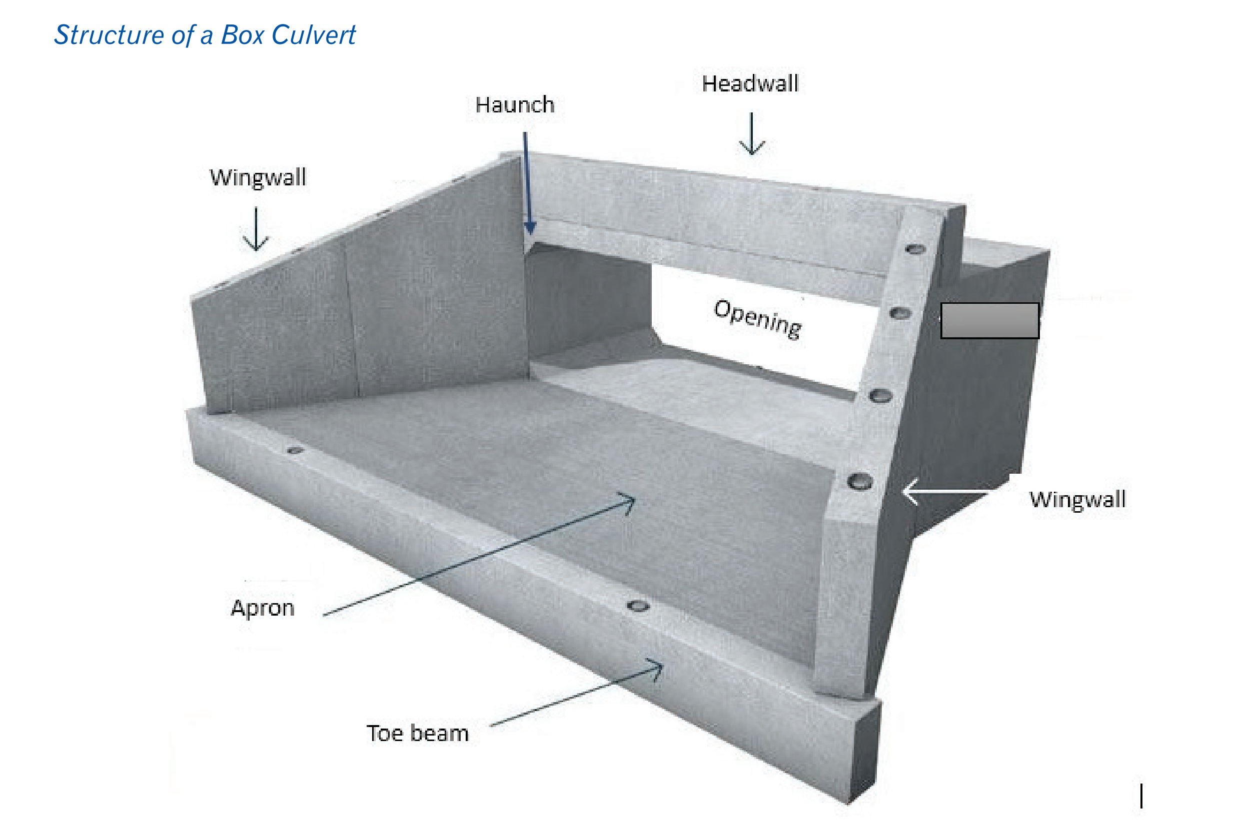


Figure 2-2 Structure of road on bridges and box culvert

Definition of bridge terminologies

Table 2-1 Definition of terminologies

Term	Components	Explanation
Superstructure	The bridge structure that receives and supports traffic loads and in turn, transfers those loads to the substructure. It includes the main girder, deck slab, cross beam, lateral bracing, diaphragms. It comprises all the structural components of a bridge above the supports.	
	Main girder/ Main structure	The main part of a superstructure that supports all the loads acting on the bridge. In general, it is called main girder in the case of girder structure, and main structure in the case of truss or arch structure.
	Diaphragm	It is a bracing that connects the main girders of a bridge in a transverse direction and assists in the distribution of loads.
	Deck slab	A structural member that directly supports vehicles, pedestrians, etc. passing on a bridge and transmits loading to the main girder (main structure).
	Expansion joint	Bridges expand and contract due to temperature changes and other factors. An expansion joint is a device installed at the end of a girder or at the gap between girders to ensure unhindered expansion and contraction and to allow automobiles and other vehicles to run smoothly on the bridge. It is mainly made of steel or rubber.
Bearings	Bearings are devices, which transmit the vertical and horizontal actions from the superstructure to the substructure, and allow for movements between the superstructure and the substructure. Bearings allowing both rotation and longitudinal translation are called expansion/movable bearings, and those, which allow rotation only are called fixed bearings.	
Substructure	The bridge structure that supports the superstructure and transfers loads from it to the ground or bedrock. The main components are abutments, piers, footings, and pilings.	
	Bearing seat	It is a vertical projection on an abutment or pier onto which a bearing is placed
	Beam seat	The area on top of an abutment or pier under the bearing seat, which directly supports the main girder
	Abutments	Abutments are earth-retaining structures, which support the superstructure and roadway at the beginning and end of a bridge. The abutments resist the longitudinal forces of the earth and vehicle surcharge.
	Backwall	The vertical wall at the ends of abutments that extends up from the bearing seat and supports the approach slabs, expansion joints and the embankment under the approach slabs.
	Stem	A stem is the primary component of the abutment acting as a retaining structure at each approach. It forms the abutment's front face to the river or to an underpass.

Term	Components	Explanation
	Wing wall	It is a wall adjacent to the abutment designed to retain-backfill material behind the abutment. The wing wall can be monolithic with the abutment or disjoint.
	Pier	A substructure member which supports the superstructure at intermediate points, and transmits the load to the foundation.
	Foundation	The part of the substructure that is in contact with the ground. Footings transfer loads from the substructure to the subsoil or piles.
	Piles	When the soil under a footing cannot provide adequate support for the substructure (in terms of bearing capacity, overall stability, or settlement), support is obtained through the use of columns which extend down from the pile cap to a stronger soil layer or to the bedrock.
Ancillaries	**Approach slab**	It is a concrete slab installed behind the abutment that acts as an intermediate bridge to avoid abrupt changes in elevation or alignment.
	Railing/ Barrier/ Guardrail	A structure designed to prevent vehicles and pedestrians falling off a bridge deck.
	Drainage facility	A system that channels water from the bridge deck, abutments and wing walls.
	Carriageway	The part of the bridge surface which carries vehicular traffic.
	Walkway	The pedestrian pathway on the sides of a bridge deck

Table 2-2 Other bridge terminologies

Other terminologies	
Term	**Explanation**
Span Length	The longitudinal distance between two supports of a bridge
Bridge length	The total length of the bridge i.e. the distance between the abutments
Girder length	Length of the main girder.
H.W.L	The measured High Water Level used in the design.
M.H.W.L	The arithmetic mean of the high water levels observed
Free board	Height between the soffit of the superstructure and the H.W.L.
Connections	A location where different structural elements, such as girders, beams, trusses, and columns are joined using bolts, welds, pins and plates to form a cohesive structure.
Parapet wall	A safety barrier installed at the edge of bridges or retaining walls to provide protection for vehicles and pedestrians.
Apron	A form of scour protection made of timber, concrete, riprap, paving, or other construction material placed adjacent to abutments and piers to prevent undermining of the structure.

Other terminologies	
Term	**Explanation**
Toe beam	It is an anchorage beam constructed at the end of an apron slab of a box culvert to protect the structure from sliding and undermining.
Haunch	Haunch is fillet or thickening of concrete at the joint of top slab and vertical walls of box culvert to provide support for top slab and additional resistance against lateral earth pressure. This allows even distribution of loads from backfill and traffic thus reducing stress concentration
Head wall	A concrete structure at the ends of a culvert to protect the embankment slopes and protect road users.
Limit state	State beyond which the structure no longer fulfills the relevant design criteria.
Ultimate limit state	Maximum loading condition which a structural element can withstand without failure (does not collapse, overturn or buckle)
Serviceability limit state	Loading condition range within which the structure does not exhibit excessive deflection, cracking or vibration to render it unfit for use.

2.3 Classification of bridges

Bridges are classified considering various aspects:

1. Classification by use
2. Classification by the material used
3. Classification by the support member
4. Classification by deck position
5. Classification by bridge plan shape
6. Classification by structure type
7. Classification by bridge location

1. Classification by use

Road bridge	Forming a section of the road, it is used for vehicular traffic.
Railway bridge	A structure constructed for the exclusive purpose of carrying railroad traffic across an obstruction.
Pedestrian bridge	For pedestrians only, also known as footbridge
Aqueduct bridge	Used as a waterway for water supply, hydropower generation, irrigation, etc.
Combined bridge	A bridge that combines the functions of a road and a railway, a road and a waterway, etc.

Road bridge

Railway bridge

Pedestrian bridge

Aqueduct bridge-

Figure 2-3 Classification by use

2. Classification by construction material

Timber bridge	Bridges made of wood
Masonry bridge	Bridges made of masonry blocks and bricks
Concrete bridge	A bridge principally made of reinforced concrete or pre-stressed concrete.
Steel bridge	Bridges whose superstructure is made of steel
Composite material bridge	A bridge whose superstructure is made of steel and concrete.

Timber bridge

Masonry bridge

Concrete bridge

Concrete bridge

Steel bridge

Steel bridge

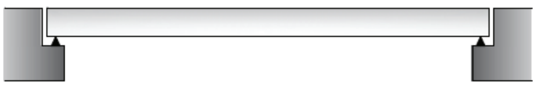
Composite material bridge

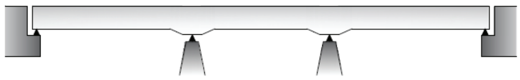
Composite material bridge

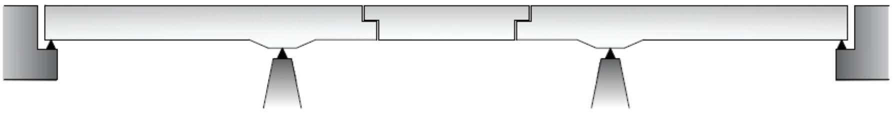
Figure 2-4 Classification by material type

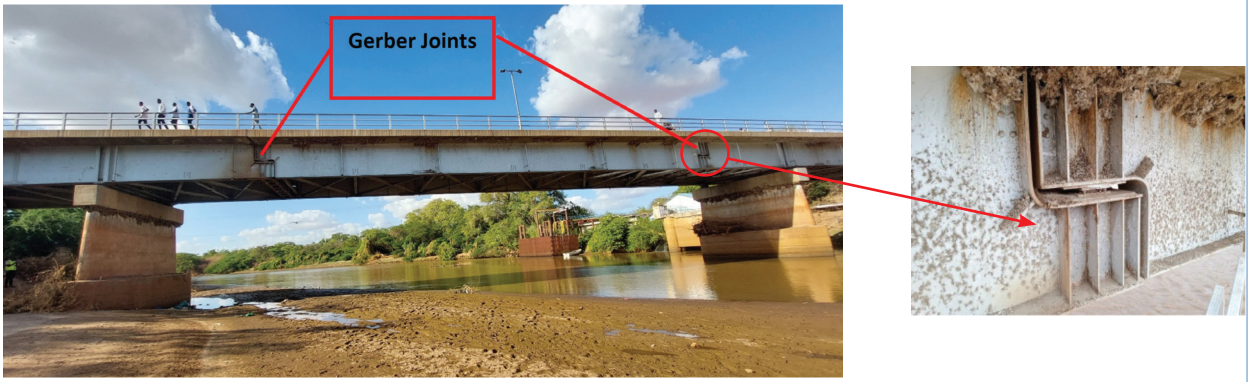
3. Classification by the support member

Simple girder bridge	It's a bridge whose girders (main trusses) are simply supported across each of the spans.
Continuous girder	It's a bridge whose girders (main trusses) extend over two or more spans.
Cantilever bridge (Gerber Girder Bridge):	It's a bridge whose continuous girders are provided with hinges at appropriate intervals.


Simple girder bridge


Continuous girder


Gerber Girder Bridge



Gerber girder bridge


Simple girder bridge


Continuous girder

Figure 2-5 Classification by Support method

4. Classification by deck position

Deck bridge	A bridge with a road on top of the superstructure. Girder bridge in general is classified as deck bridge
Half-through bridge	A bridge with a road in the middle of the superstructure
Through bridge	A bridge whose road surface is positioned on the lower part of the bridge structure
Double deck	Bridge with two decks of either a road or railway.

Deck bridge

Half-through bridge

Through bridge

Double deck

Figure 2-6 Classification by deck position

5. Classification by bridge plan shape

Straight bridge	It is a bridge with a straight axis
Squared bridge	It is a straight bridge, and the bearing line of the bridge girder is at right angle to the bridge longitudinal axis
Skew bridge	It is a straight bridge, and the bearing line of the bridge girder is oblique to the bridge longitudinal axis.
Curved bridge	It is a bridge with a curved bridge longitudinal axis.

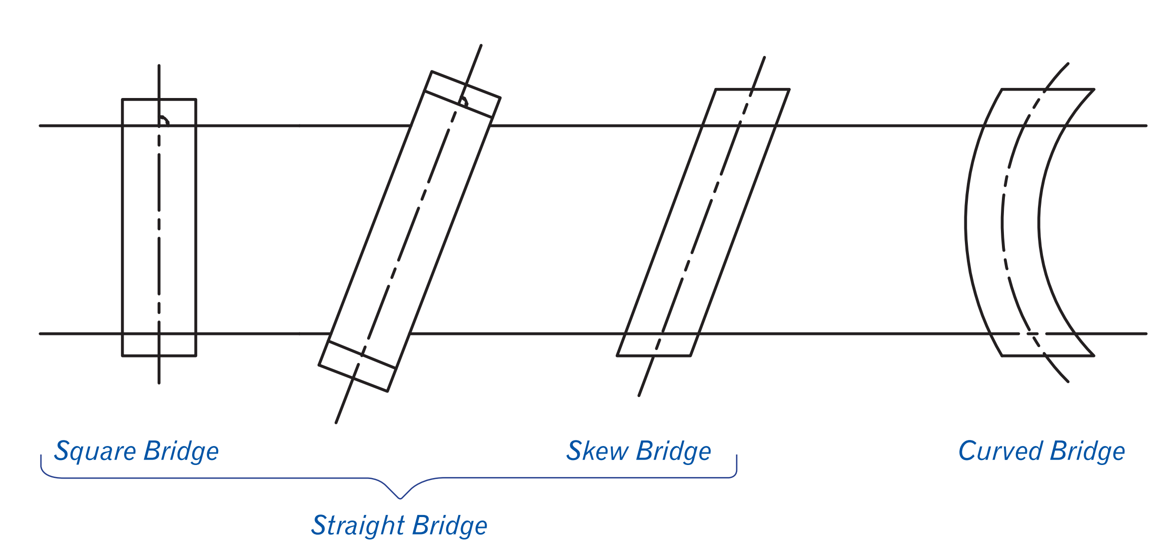


Figure 2-7 Classification by bridge plan shape

6. Classification by structure type

Girder bridge	A bridge composed of beam structure known as girder.
Truss bridge	A bridge composed of truss structure
Arch bridge	A bridge composed of arch structure comprising arch ribs
Rigid frame bridge	A bridge in which the superstructure and substructure are rigidly connected to act as a continuous unit. Typically, the structure is cast monolithically, making the structure continuous from deck to foundation.
Cable stayed bridge	A bridge configured with cables stretched aslant between the tower and the girder.
Suspension bridge	A bridge configured with cables stretched in-between towers to suspend stiffening girders

Girder bridge

Girder bridge

	
Truss bridge	Truss bridge
	
Arch bridge	Rigid frame
	
Cable stayed bridge	Suspension bridge

Figure 2-8 Classification by structure type

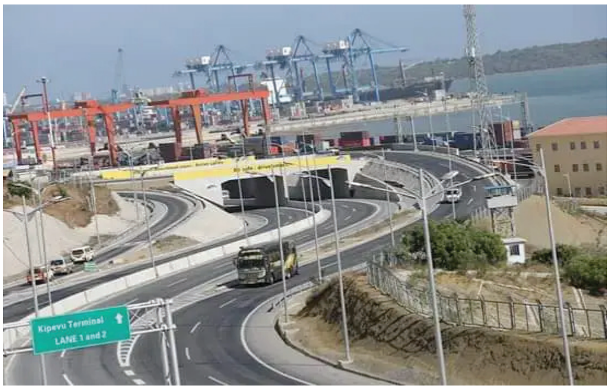
7. Classification by bridge location

Overpass	Bridges over a multi-level intersection.
Viaduct	Bridges that cross urban area or mountainous areas.
Underpass	Bridge/Road under a multi-level intersection.

Overpass

Viaduct

Underpass



Underpass

Figure 2-9 Classification by location

2.4 Overview of Bridge Design

2.4.1 Design load

Bridges are designed to carry vehicles, pedestrians, environmental and other transient loads (such as those due to temperature and wind effects); all collectively known as 'live loads'. In addition, bridges have to withstand their own weight and the weight of any permanent fixtures, such as parapets, surfacing and finishes, which constitute 'dead load'. Although dead loads on a structure usually remain constant over time in some cases these may change during the life of a bridge due to work such as installation of thicker surfacing, upgraded restraint systems and safety fencing or additional utilities. Bridge design loadings are loads that a bridge is designed to carry or resist and which determine the size and configuration of its members. Bridge members are designed to withstand the loads acting on them in a safe and economical manner.

In some bridges, such as arch bridges, the dead load greatly exceeds the live load with the result that the bridge is primarily required to sustain its self-weight, i.e. the effects of traffic being small compared to its self-weight.

Bridge design loadings can be divided into three principal categories:

- Dead loads
- Primary live loads
- Secondary loads

2.4.1.1 Dead load.

Dead loads do not change as a function of time and are considered full-time, permanent loads acting on the structure. Dead load includes both the self-weight of the structural members and other permanent external loads. They can be further broken down into two groups, initial and superimposed.

Initial dead loads are the weights of the materials and parts of the structure that are structural elements, while superimposed dead loads are loads which are applied after the deck is placed these include the parapets and pavement.

2.4.1.2 Primary live loads

These are live loads considered as temporary loads, mostly of a short-term duration, acting on the structure.

2.4.1.3 Secondary loads

In addition to dead loads and primary live loads, bridge components are designed to resist secondary loads, which include:

- **Earth pressure** - a horizontal force acting on abutments and retaining walls
- **Buoyancy** - the force created due to the tendency of an object to rise when submerged in water
- **Wind load on structure** - wind pressure on the exposed area of a bridge
- **Wind load on live load** - wind effects transferred through the live load vehicles crossing the bridge
- **Longitudinal load** - a load in the direction of the bridge caused by braking and accelerating of live load vehicles

- **Centrifugal load** - an outward force that a live load vehicle exerts on a curved bridge
- **Shrinkage** - applied primarily to concrete structures, this is a multidirectional force due to dimensional changes resulting from the curing process
- **Temperature** - since materials expand as temperature increases and contract as temperature decreases, the force caused by these dimensional changes must be considered
- **Earthquake** - bridge structures must be built so that motion during an earthquake will not cause a collapse
- **Impact loading** - the dynamic effect of suddenly receiving a live load; this additional force can be up to 30% of the applied primary live load force
- **Sidewalk loading** - sidewalk floors and their immediate supports are designed for a pedestrian live load.
- **Kerb loading** - kerbs are designed to resist a lateral force.
- **Railing loading** - railings are provided along the edges of structures for protection of traffic and pedestrians.
- **Dynamic loading** - Vibration induced loading caused by wind, vehicular traffic or pedestrians in footbridges
- **Fatigue loading**- changes observed in a material under the influence of stress generated during cyclic loading

Loads may be concentrated or distributed depending on the way in which they are applied to the structure. A concentrated or point load, is applied at a single location or over a very small area. Vehicle loads are considered to be concentrated loads. A distributed load on the other hand is applied to all or part of the member, and the amount of load per unit of length is usually constant. The weight of superstructures, bridge decks, carriageway surfacing, and bridge parapets produce distributed loads also the transient loads, such as wind, snow and ice, are distributed loads.

Bridges are designed to comply with the requirement to carry vehicles of up to 50 tonnes with adequate margins of safety against collapse for a design life of about 100-120 years with continued maintenance. However, a bridge may show signs of distress such as cracking, under successive smaller loads over the years due to changes in loading, fatigue, lack of preventive maintenance among others leading to a reduction in durability and carrying capacity of the structure or its individual components. Such deterioration affects the service levels of the structure and current design codes require adequate safeguards to ensure serviceability of all components for specified loading and life span.

2.4.2 Effect of loading on structural members

The following figure outlines the response of a bridge material to loads.

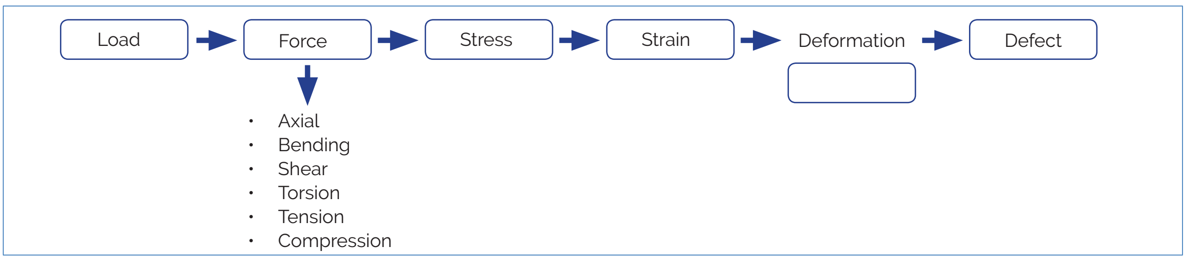


Figure 2-10 Effect of loading on structural members

Inspectors in the field should have basic knowledge of terms that relate to the above process:

i. *Force*

A force is the action that a body exerts on another body. A force can occur in any direction, for example, vehicular live load acts vertically on the deck of a bridge, whilst traction forces apply horizontally in the direction of movement. For engineering analysis the resultant force is translated into component forces in the x, y and z coordinate system. In most cases, the resultant force is known only by its magnitude, position and direction rather than its individual components.

ii. *Stress*

Stress is defined as the force per unit area within a body that balances and reacts to the loads applied to it. This is expressed in the formula below and the unit of stress is normally N/mm^2 or kN/m^2. When a force is applied to a material, an internal stress is developed.

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

iii. *Strain*

Strain is the basic unit of measure used to describe the amount of deformation. For example, strain in a longitudinal direction is computed by dividing the change in length by the original length.

$$\text{Strain} = \frac{\text{Change in length}}{\text{Original length}}$$

iv. *Deformation*

When a force is applied to a structural member, its shape changes or undergoes local distortion due to stress. This phenomenon is known as deformation.

Example: When force is applied to a cylindrical member it causes deformation to the member so that the original shape is changed (deformed) into one with bulging sides. The sides bulge because the material, although strong enough not to crack or otherwise fail, it is still not strong enough to support the load without change, thus the material is forced out laterally.

Deformation can be defined as;

a. Elastic deformation/ Elasticity

Elastic deformation is the reversible distortion of a material. A member is elastically deformed if it returns to its original shape upon removal of a force. Bridges are designed to deform elastically and return to their original shape after the live loads are remove.

b. Plastic deformation/ Plasticity

Plastic deformation is the irreversible or permanent distortion of a material. A material is plastically deformed if it retains a deformed shape even after removal of a force. Plastic strain is sometimes referred to as irreversible or permanent strain because it remains even after the stress is removed.

v. Creep

Creep is a form of plastic deformation that occurs gradually at stress levels and is normally associated with elastic deformation. Creep is defined as the gradual, continuing irreversible change in the dimensions of a member due to the sustained application of load. It is caused by the molecular readjustments in a material under constant load.

vi. Thermal Effects

Thermal effects are most commonly experienced in the longitudinal expansion and contraction of the superstructure. Thermal changes in bridge members can cause significant frictional stresses and must be considered during design

vii. Stress-Strain Relationship

For most structural materials, the values of stress and strain are directly proportional only up to a particular value called the elastic limit.

When applying stress up to the elastic limit, a material deforms elastically. Beyond the elastic limit, deformation is plastic and strain is not directly proportional to a given applied stress. The material property, which defines its stress-strain relationship, is called the modulus of elasticity.

viii. Modulus of Elasticity

Each material has a unique modulus of elasticity, which defines the ratio of a given stress to its corresponding strain. It is the slope of the elastic portion of the stress strain curve. It applies only as long as the elastic limit of the material has not been reached.

ix. Ductility and Brittleness

Ductility is the measure of plastic (permanent) strain that a material can endure. A ductile material will undergo a large amount of plastic deformation before breaking. It will also have a greatly reduced cross-sectional area before breaking. Structural materials that are generally ductile include steel and aluminium.

Brittle, or non-ductile, materials will not undergo significant plastic deformation before breaking. Failure of a brittle material occurs suddenly, with little or no warning. Structural materials that are generally brittle include concrete, cast iron, stone and timber.

x. Fatigue

Fatigue is a material response that describes the tendency of a material to break when subjected to repeated loading. Fatigue failure occurs within the elastic range of a material after a certain number and magnitude of stress cycles have been applied.

Each type of material has a hypothetical maximum stress value to which it can be loaded and unloaded a finite number of times. This stress value is referred to as the fatigue limit and is usually lower than the breaking strength for infrequently applied loads.

Ductile materials such as steel and aluminum have high fatigue limits, while brittle materials such as concrete have low fatigue limits.

xi. Yield strength

Yield is the change from an elastic state to a plastic state due to an increase in external force. The ability of a material to resist plastic (permanent) deformation is called the yield strength. Yield strength corresponds to stress level defined by a material's yield point. Knowledge of the yield point is vital when designing a component since it generally represents an upper limit to the load that can be applied without causing catastrophic failure of the structure.

xii. *Toughness*

Toughness is the energy required to break a material and this is not necessarily related to strength. A material might have high strength but little toughness. A ductile material with the same strength as a non-ductile material will require more energy to break and thus exhibit more toughness. A material is said to have high toughness if its fracture is accompanied by sufficient deformation.

xiii. *Axial Forces*

An axial force is a push or pull type of force which acts along the longitudinal axis of a member. An axial force causes compression if it is pushing and tension if it is pulling. Axial forces act uniformly over a cross-sectional area and the axial stress can be calculated by dividing the force by the area on which it acts.

When bridge members are designed to resist axial forces, the cross-sectional area will vary depending on the magnitude of the force, whether the force is tensile or compressive, and the type of material used.

The acceptable axial compressive stress is generally lower than that for tension because of a phenomenon called buckling.

xiv. *Bending forces*

Bending forces in bridge members are caused by moment. The force that causes the member to bend and the cross-section to rotate is called Bending Moment. This moment is commonly developed by a transverse loading which causes a member to bend.

The size and material of the member is determined by the greatest bending moment that a beam can resist.

Bending moments produce both compression and tension forces at different locations in the member and can be positive or negative.

When a member is bent, the member flexes and each cross section rotates. As the cross section rotates and flexes, compressive stress along the axial direction is generated on the shrinking side, and tensile stress along the axial direction is generated on the extending side. This bending moment produces the sagging deformation characteristic of a member.

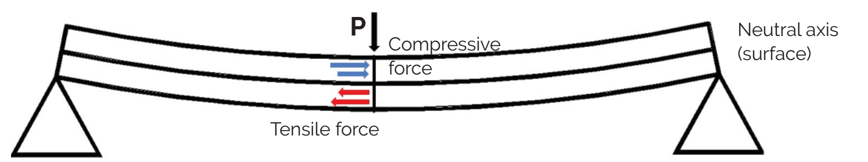


Figure 2-11 Behaviour of a member due to bending forces

Beams and girders are the most common bridge elements used to resist bending moments. The flanges are most critical because they provide the greatest resistance to the compressive and tensile forces developed by the moment.

Crack directions under bending moment occur in the direction perpendicular to the direction of the tensile force

xv. *Shear force*

Shear is a force, which results from equal but opposite transverse forces, which tend to slide one section of a member past an adjacent section causing slippage deformation.

The vertical shear force produces vertical shear stresses and complimentary equal horizontal shear stresses that cause a slicing or scissors action. Shear forces normally occur in conjunction with other forces (e.g. bending forces) and may result in the development of tension cracks, e.g. in concrete these appear as diagonal cracks.

Beams and girders are common shear resisting members. In an I or T-beam, most of the shear is resisted by the web. Bending moment and shear force calculations are essential while designing any structural members.

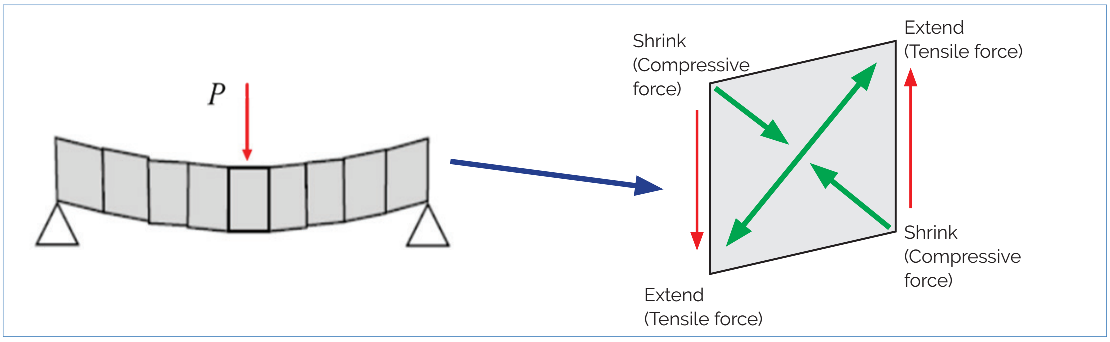


Figure 2-12 Member under shear force

Crack directions under shear force occur in the direction perpendicular to the direction of the tensile force.

xvi. *Torsion force*

Torsion is a force resulting from externally applied moments which tend to rotate or twist a member about its longitudinal axis. Torsional force is commonly referred to as torque.

Torsional forces develop in bridge members, which are interconnected and experience unbalanced loadings. Bridge elements are generally not designed as torsional members. However, in some bridge superstructures where elements are framed together, torsional forces can occur in longitudinal members. When these members experience differential deflection, adjoining transverse members apply twisting moments resulting in torsion. In addition, curved bridges are generally subject to torsion.

Note

The structural effects of loads and moments are assessed in terms of axial forces (tension and compression), bending forces, shear forces and torsion forces. These forces may act individually or in combination. In calculating these forces, the analysis is governed by equations of equilibrium. Equilibrium equations represent a balanced force system where the sum of all forces and the sum of all moments acting on a body in any direction must be zero.

2.4.3 Characteristics of Concrete Members

2.4.3.1 Introduction

Concrete is a composite building material made from a combination of a graded range of stone aggregate particles, a cement binder and water. During hydration and hardening, concrete develops certain physical and chemical properties including mechanical strength, low permeability to moisture, and chemical stability. The paste, which is a binder material, gradually develops strength through the hydration of the cement. The quality of concrete depends not only on the properties of individual constituent materials such as cement paste and aggregate, but also on the composite properties of these materials and mix proportion. The composite properties are influenced by the conditions of construction and curing, as well as by the age of the materials.

Concrete has relatively high compressive strength, but significantly lower tensile strength. The practical implication of this is that concrete elements subjected to tensile stresses must be reinforced or pre-stressed with steel.

Hydration and hardening of concrete during the first three days after casting is critical. Abnormally fast drying and shrinkage of concrete (due to factors such as evaporation during placement) may lead to increased tensile stresses before gaining significant strength, resulting in shrinkage cracks. The early strength of the concrete can be increased by keeping the concrete damp for a longer period during the curing process.

Plastic-shrinkage cracks are normally visible within the first 2 days of placement, while drying-shrinkage cracks develop over time.

The compressive strength is significantly greater than other strengths, and this is used effectively in the design of reinforced concrete members.

The other physical properties of concrete are:

- ***Thermal expansion*** – concrete expands as temperature increases and contracts as temperature decreases;
- ***Porosity*** – because of entrapped air, the cement paste never completely fills the spaces between the aggregate particles, permitting absorption of water and the passage of water under pressure;
- ***Volume changes due to moisture*** – concrete expands with an increase in moisture and contracts with a decrease in moisture;
- ***Fire resistance*** – quality concrete is highly resistant to the effects of heat;
- ***Formability*** – concrete can be cast to any shape prior to curing.

Elastic-plastic properties of Concrete (Stress-Strain Curve)- concrete not being completely elastic body, the relationship between stress and strain of concrete differs considerably from that of steel with the line starting to curve from low stress value in the case of concrete.

The stress-strain curve of cement paste and aggregate are almost completely linear over the entire range until the stress reaches maximum, but in the case of mortar and concrete the line starts curving from low stress levels. This is due to fine cracks inside the mortar and concrete particularly at the interface of the cement paste and aggregate.

Stress-strain curves from compressive strength tests of concrete are divided into the following three portions:

i. Portion that can be regarded as a straight line;

ii. Curved portion with increasing curvature until the maximum stress level is reached;

iii. The part of the curve where the stress level gradually decreases as the strain increases, and then rapidly reaches failure

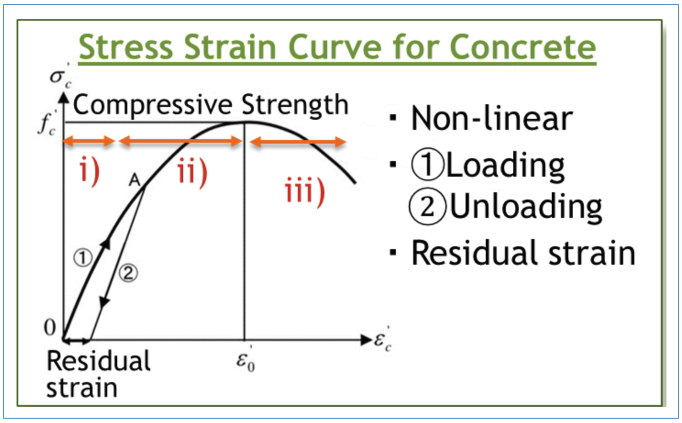


Figure 2-13 Stress-Strain curve for concrete

Concrete generates residual strain when the load is removed(creep). The ratio to the total strain is smaller at lower stress levels and is about 10% at stresses of about 50% of the breaking strength.

2.4.3.2 Reinforced concrete

Reinforced concrete is a composite material using concrete for compressive strength and steel reinforcing bars to accommodate the tensile forces. Concrete bend by receiving force from upwards. The upper side receives the compression force while the lower side receives the tensile force. Concrete is frangible when high tensile force is applied, the concrete may develop cracks and collapse due to high tensile force. Steel bars are therefore, placed at the lower part of the member to bear tensile force.

The concrete cast round the reinforcing bars or mesh slightly shrinks and hardens developing adhesion. The concrete provides good protection to the steel from corrosion provided the cover is adequate and the concrete is dense.

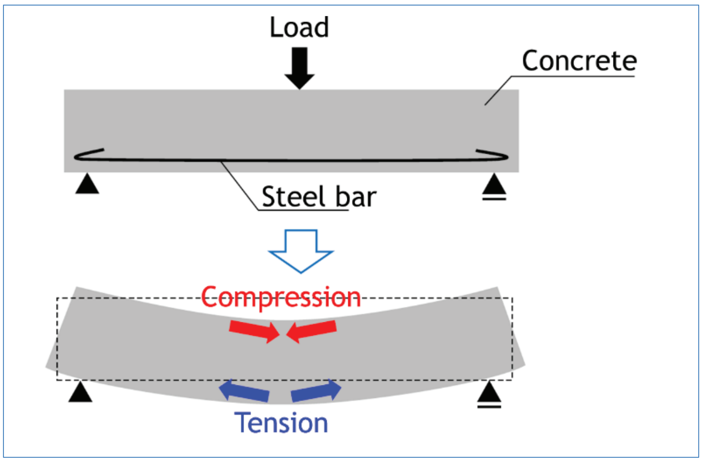


Figure 2-14 Reinforced concrete under load

Merits of reinforced concrete structures

- High fire resistance (Concrete is non-combustible)
- High durability (Lifespan is 50-100 years)
- Excellent in formability

Demerits:

- Large self-weight
- Poor workmanship affects the strength
- Formwork is required

2.4.3.3 Pre-stressed Concrete

Pre-stressed concrete, uses high tensile strength steel strands as reinforcement. Pre-stressed concrete is put into a state of compression by tension in steel tendons (either cables or wires), after casting. In this way the concrete in a beam is made to resist a bending moment because of the compression induced in the concrete due to the pre-stressing. Pre-stressing may be used to construct beams and bridges with longer spans than is possible with reinforced concrete. Steel for pre-stressing, which is named high tensile strength steel, comes in three basic forms as wires, strands and high tensile strength bars.

Pre-stressing may be classified by:

1) *Timing of pre-stressing: pre-tensioned or post tensioned.*

Pre-tensioning- The steel tendons are stressed before the concrete is cast around them and the concrete is allowed to harden and grip the steel before the initial tensile loads are released and transferred into the concrete as compression.

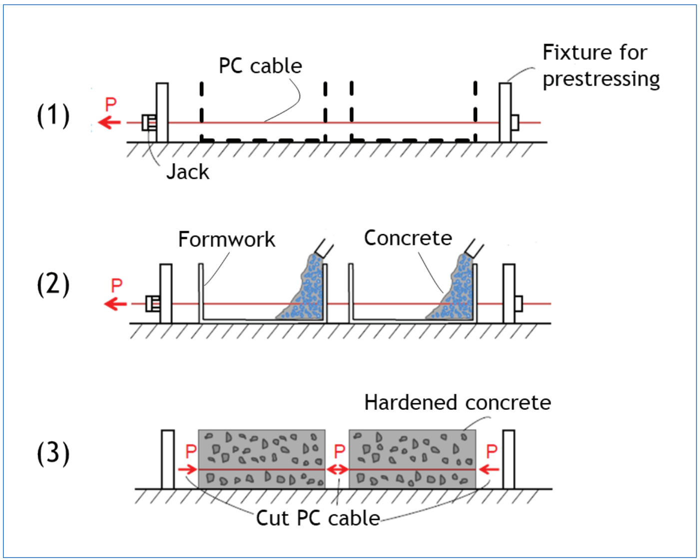


Figure 2-15 Pre-tensioning process

Post-tensioning -Ducts are formed in the concrete during casting and the tendons are placed in them and tensioned after the concrete has hardened. The tendons are protected from corrosion by cement grout injected into the duct to fill them completely, an objective which is not always achieved. In a few cases the tendons are external to the concrete and are protected by encasing in cementitious or other special materials.

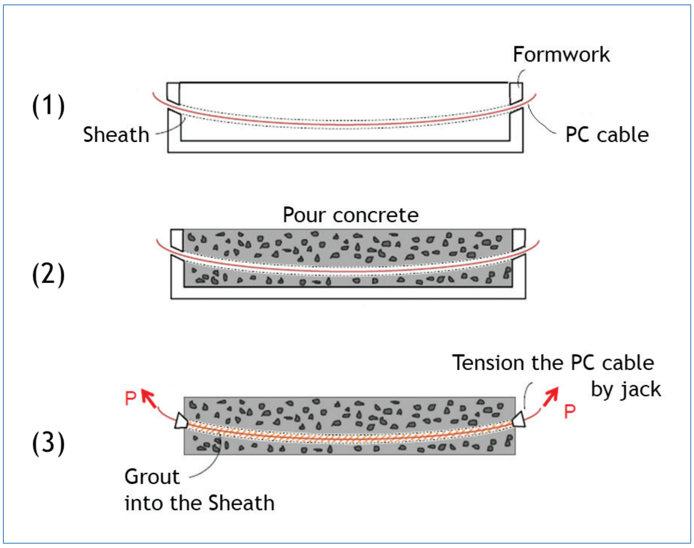


Figure 2-16 Post-tensioning process

2) *Structure type (amount of pre-stressing)*

Fully pre-stressing –Pre-stressing so that the combined stress on the tensile side is zero. (Effective for all cross sections)

Partial stressing-By adjustment of pre-stressing, tensile stress is allowable to occur to the extent that cracking does not occur, or cracking is allowed, but the crack width shall be kept below the tolerable limit.

3) *PC cable location*

Inner cable method-PC cable is placed inside the concrete member.

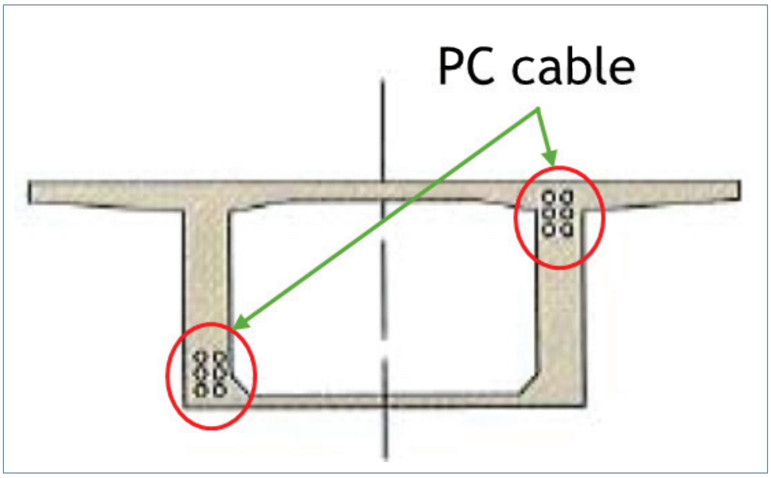


Figure 2-17 PC inner cable location

Outer cable method **-**PC cable is placed outside the concrete member

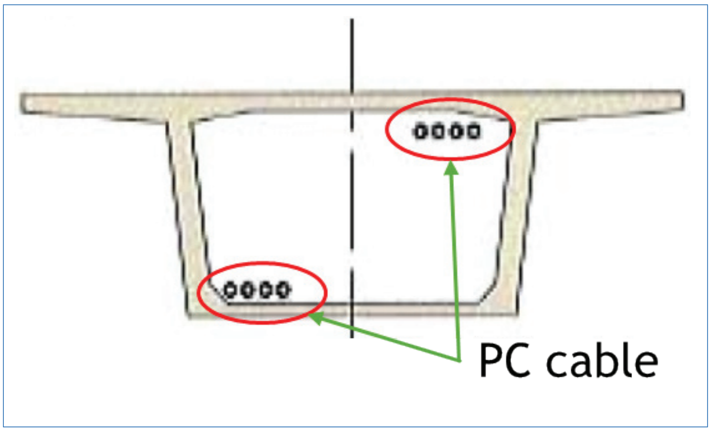


Figure 2-18 PC outer cable location

[Advantage on the maintenance aspect]

- The cross section can be thinner than inner cable method, then self-weight will be reduced.
- Maintenance work will be easier since the cable is accessible.
- Applicable to strengthen an existing reinforced concrete member.

2.4.4 Characteristics of Steel members

Steel is a metal alloy that can be plastically formed (pounded, rolled, etc.) and comprises of iron as its major component and carbon as the primary alloying material. Varying the amount of carbon and its distribution in the alloy controls qualities such as the hardness, elasticity, ductility, and tensile strength of the resulting steel material. It is used in a variety of members on a large number of bridges.

Steel is used for structural members, box girders, plate girders, rolled sections, tubes and plates and also as reinforcing bars and pre-stressing tendons in concrete.

Steel requires protection from the atmosphere to prevent rusting.

Weathering steel is used on some bridges which, under normal exposure to the atmosphere, corrodes and slowly produces an (oxide) patina or rust film that provides a measure of protection to the steel as it develops. Weathering steel does not require painting.

Steel as a bridge construction material is available as wire, cable, plates, bars, rolled shapes, and built-up shapes. Typical areas of application for the various types of steel shapes are:

- Wires are typically used as pre-stressing strands or tendons in beams and girders.
- Cable-stay and steel suspension bridges are primarily supported by steel cables.
- Steel plates have a wide variety of uses. They are primarily used to construct built-up shapes.
- Steel bars are generally placed in concrete to provide tensile reinforcement in the form of deformed round bars.
- Rolled shapes are used as structural beams and columns and are made by placing a block of steel through a series of rollers that transform the steel into the desired shape.
- Built-up shapes are also used as structural beams and columns but are composed

of any combination of plates, bars, and rolled shapes. Built-up shapes are riveted, bolted, or welded together.

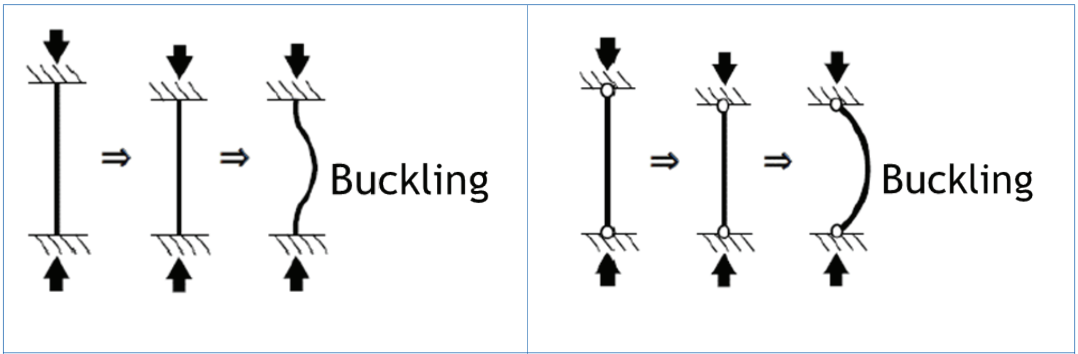
Some of the mechanical properties of steel include:

- Strength - steel is isotropic and possesses high compressive and tensile strength, which varies widely with type of steel.
- Elasticity - the modulus of elasticity is independent of steel type and is 200,000 MPa (29,000,000 psi).
- Ductility - both the low carbon and low alloy steels normally used in bridge construction are quite ductile; however, brittleness may occur because of heat treatment, welding, or metal fatigue.
- Fire resistance - steel is subject to a loss of strength when exposed to high temperatures such as those resulting from fire.
- Corrosion resistance - unprotected carbon steel corrodes (i.e., rusts) easily however, steel can be protected.
- Weldability - steel is weldable, but it is necessary to select a suitable welding procedure based on the chemistry of the steel.
- Fatigue - fatigue in steel members and connections can occur in bridges due to numerous live load stress cycles combined with poor welds or connection details.

2.4.4.1 *Buckling in steel*

Members of steel structures are more slender than those of concrete structures. Therefore, the design must consider that buckling does not occur. Buckling is the sudden change in shape (deformation) of a structural component under load, such as the bowing of a column under compression or the wrinkling of a plate under shear. The longer the member is, the more likely it is to buckle.

The buckling susceptibility also depends on the fixation conditions at the end of the element.



Case-A: Fixed both ends	Case-B: Pin connection both ends

Figure 2-19 Buckling in steel

Buckling is also more likely to occur when eccentric loading is applied.

Types of Buckling

There are two main types of buckling:

i. Global buckling — This is the type of buckling where the axis of the structural member changes, the strength of the whole member is reduced.

ii Local buckling — This is the type of buckling where the axis of the structural member does not change, because it happens on a specific part of column or web of beams, but the strength beam or column cross-section is reduced by the buckling of a component of that structural member.

Design for Prevention of Buckling

The formula derived by Euler for long slender columns is given below

$$F = \frac{\pi^2 EI}{(KL)^2}$$

Where

F: Maximum or critical force (axial load on member).

E: Modulus of elasticity.

I: Smallest area moment of inertia (second moment of area) of the cross section of the member.

L: Unsupported length of member.

K: Member effective length factor, whose value depends on the conditions of end support of the column, as follows:

KL: Effective length of the member.

K: Member effective length factor,

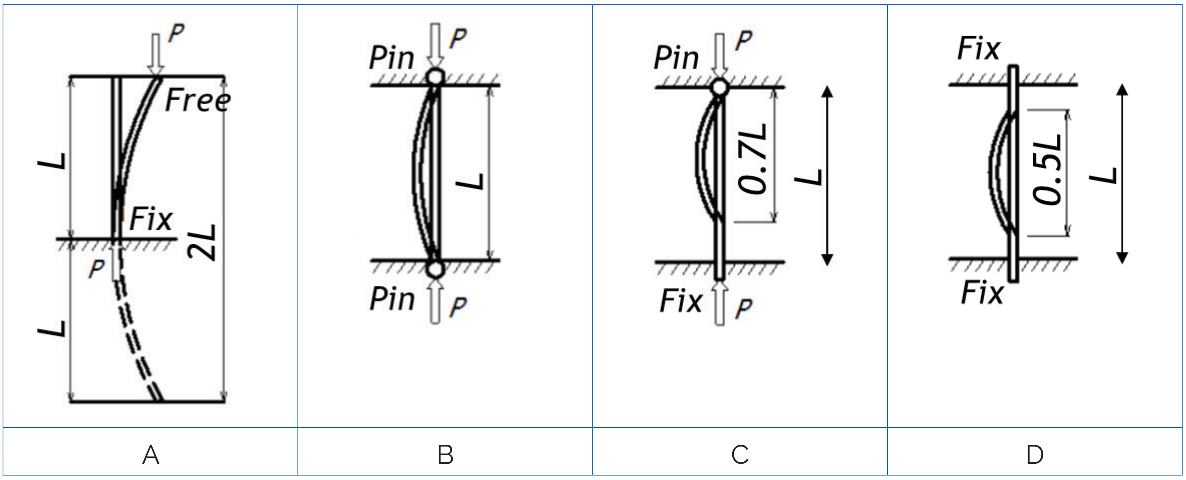


Figure 2-20 Design to prevent buckling

a) For one end fixed and the other end free to move laterally, K=2.0.

b) For both ends pinned (hinged, free to rotate), K=1.0.

c) For one end fixed and the other end pinned, K=0.7.

d) For both ends fixed, K=0.5.

$$\sigma = \frac{F}{A} = \frac{\pi^2 E}{\left(l/r \right)^2}$$

Where,

$\sigma = F/A$ is the stress that causes buckling of the member, and

l/r is the slenderness ratio.

r is the least radius of gyration and can be obtained by the following formula.

$$r = \sqrt{I/A}$$

In sections where bending moments predominate and compressive forces occur, the design should be such that buckling phenomena does not occur.

2.4.4.2 Connection between steel members

Normally, there are three joint methods between steel members namely:

i. Welded joint;

ii. High strength bolted connection;

iii. Riveted connection.

i) Welded joint

Conditions of stress concentration are often found in weldments, which are known to be prone to crack initiation. Welds are the connections of metal parts formed by heating the surfaces to a plastic (or fluid) state and allowing the parts to flow together and join with or without the addition of filler metal. The term base metal refers to the metal parts that are to be joined. Filler metal, or weld metal, is the additional molten metal generally used in the formation of welds. The complete assembly is referred to as a weldment.

The metal made by welding is called “bead”. Various defects are likely to occur around the bead.

The common types of welds found on bridges are, **fillet welds, full penetration weld** and **partial penetration weld.**

a) **Fillet welds** – Fillet welds connect members that either overlap each other or are joined edge to face of plate, as in plate girder assembly of web and flange plates. Fillet welds are the most common type of weld. It is a method in which triangular-shaped weld metal is applied to the corner angles formed by the pieces of material to be joined.

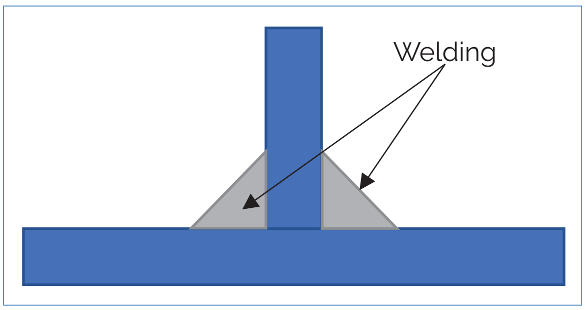


Figure 2-21 Fillet weld

b) **Full penetration weld** — Full penetration groove welds extend through the entire thickness of the piece being joined.

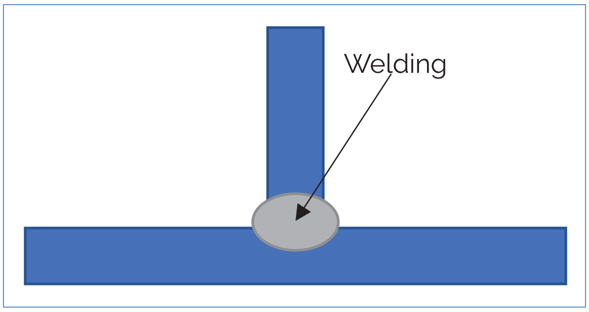


Figure 2-22 Full penetration weld

c) **Partial penetration weld** — A welding method in which the weld metal is partially integrated into the thickness of the joint.

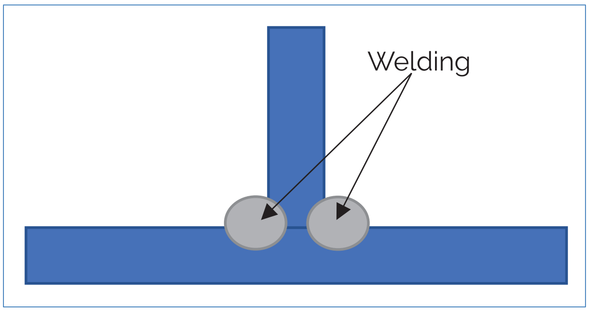


Figure 2-23 Partial penetration weld

ii) High strength bolted connection

A method of connecting between steel plates using high strength bolts. There are two types of connection methods using high-strength bolts: ***friction grip connection*** and ***bearing connection.***

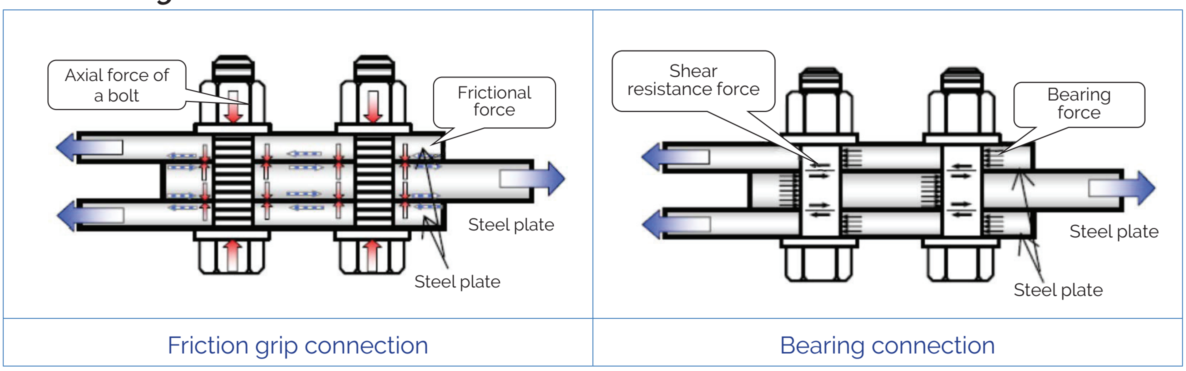
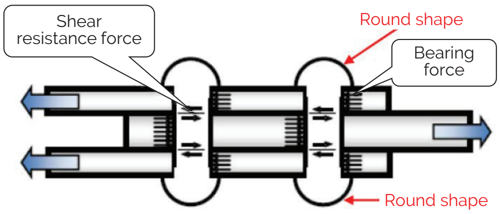


Figure 2-24 High tension bolt connection

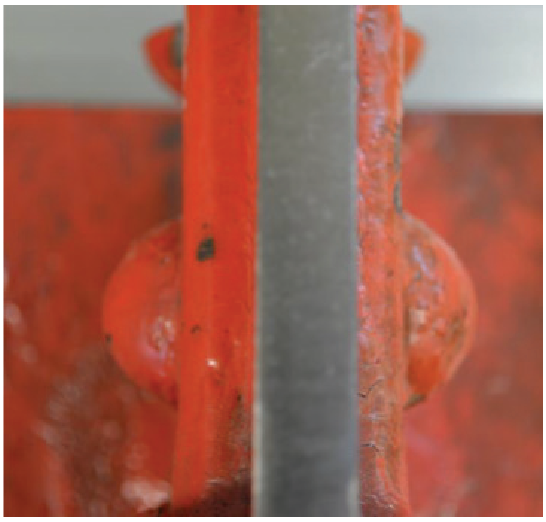
iii) Riveted connection

A method of connecting overlapping steel plates by drilling holes, and inserting rivets into them.
The principle is the same as that of a bearing connection with high-strength bolt.



Riveting connection

Riveting connection



Both sides of the shaft are round

Cut surface of rivet connection

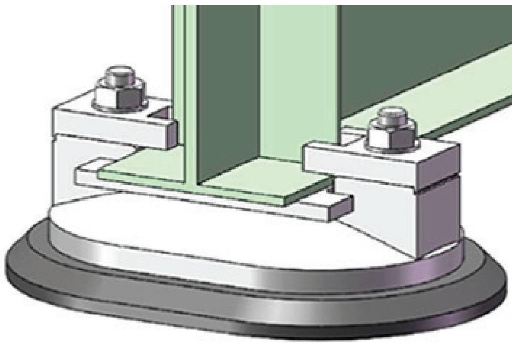
Figure 2-25 Riveting connection

2.4.5 Characteristics of Bearings

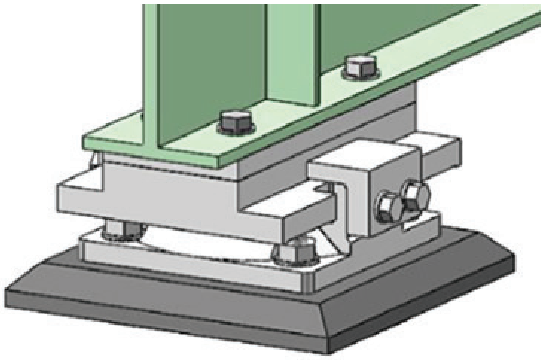
The condition of a bearing and its seat is an important indicator, not only on the condition of the bearing itself but sometimes on other elements in the structure. Bearings are located where movement is intended to take place such that if they do not function adequately the structure may suffer excessive stress. They are structural components that provide connections between the superstructure and substructure, the purpose of which includes the following:

- To transfer vertical/horizontal loads from the superstructure to the substructure.
- To allow longitudinal transverse movement of the superstructure.
- To allow rotation of girder/slab ends due to dead and live loading

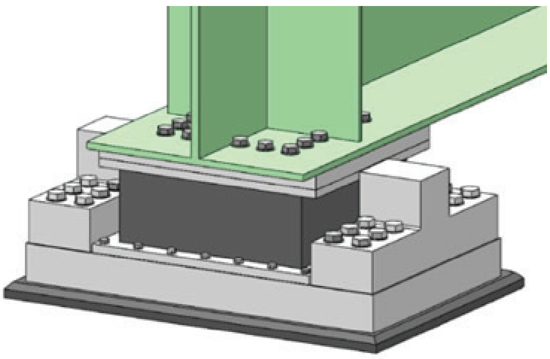
Bearings accommodate these movements by deforming (elastomeric), rotating, sliding and/or rolling.




Fixed bearing




Movable bearing




Horizontal bearing

Figure 2-26 Types of bearings

2.4.6 Characteristics of Timber members

2.4.6.1 Timber Bridge Overview

Wood is an organic material rather than a manufactured material such as concrete, steel, or masonry and it tends to be less homogeneous and more susceptible to various recurring random defects. Lumber is generally classified according to its species, size, and natural variations.

Timber bridge Super structure consist of beams, deck (slab), truss, arch and railings while substructure include abutment and bents. Abutments are supports to bridge ends while bents are intermediate support systems to multi-span timber crossings.

The application of preservative treatment by pressure methods enhances the durability of timber bridge components, but regular inspections are vital for the identification of damage and implementation of timely repairs and proactive maintenance programs. Mechanical damage might include damaged members or mechanical fasteners.

Deterioration of timber bridges can often be related to deficiencies in the bridge elements, connectors and/or because of exposure to aggressive environments. The maintenance cost of timber bridges is affected significantly by several deterioration mechanisms which require a systematic approach for diagnosis and treatment. Evaluating the risk of failure of these bridges is of importance in bridge performance assessment and decision making to optimize repair/ rehabilitation options.

2.4.6.2 Factors affecting Strength of Timber

The main factors affecting the strength of timber are:

- The density of the defect -free wood; This is governed by various growth and genetic factors and is closely related to the thickness of the cell walls. The density (and thus the strength) increases towards the outside of a tree and is lowest in the centre.
- The size, type and position of knots; the distortion of the grain around a knot which reduces the strength of a piece of timber.
- Slope of grain- Because of its microstructure wood is orthotropic, having much higher strength parallel to the grain than perpendicular to it. If the grain is not parallel to the axis of a board there will be components of stress perpendicular to the grain.
- Moisture content - The strength properties of wood decrease more or less linearly with increase in moisture content until the fibres are saturated.

Advantages of Timber as a structural material:

- Light weight, easy to work with (cut, drill and nail).
- Higher strength / weight ratio than steel
- Higher strength / weight ratio than reinforced concrete.
- High resistance to shock loading and a good capacity for resisting high incidental loads over short duration.
- Low thermal expansion and contraction.
- Better resistance to chemicals and fumes attack than concrete or metal.
- Low maintenance cost if properly treated.
- Aesthetically appealing.

Disadvantages of Structural Timber:

- Variability in mechanical properties.
- Wood is hygroscopic and susceptible to moisture which can produce warp and lead to decay. This problem can usually be avoided by careful detailing and treatment with suitable preservatives or sealers.
- Susceptibility to insect attack which can also be prevented by treatment with suitable preservatives.

- The size and length of a piece of timber is restricted by the dimensions of the log from which it is cut. This can be overcome by finger jointing boards into long lengths and laminating them to form structural members of required size or length.

2.4.7 Characteristics of Masonry bridges

2.4.7.1 Common Types of Masonry Bridges and Masonry Bridge Elements

Masonry bridges are an early bridge type, and many are still in service. Many of these bridges have historic and cultural significance to the community and are on, or eligible for, the National Register of Historic Places. The intent of this chapter is to offer guidance on maintaining and preserving masonry structures.

2.4.7.2 Arches

Masonry arches come in three main types (i.e., coursed ashlar, random ashlar, and rubble) and can be constructed of either brick or stone.

(a) Coursed Ashlar Masonry

Coursed Ashlar stones are most common with uniform sized, neatly dressed edges and consistent joint thickness over arch length, as shown in Figure 2-27 Coursed Ashlar Masonry To be considered ashlar masonry, the joints between the stones should be small and consistent and can either be mortared or dry-laid.

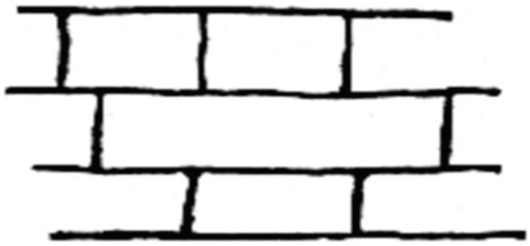
	
(a) Photo	(b) Schematic

Figure 2-27 Coursed Ashlar Masonry

(b) Random Ashlar Masonry

Random ashlar masonry is comprised of dressed stones or brick, where only the thickness of the masonry units and the longitudinal placement varies along the arch ring (arch stone) or wall face (spandrel), as shown in Figure 2-28 Random Ashlar Masonry This type of construction is more common in vertical walls (e.g., substructure units) than in arches.

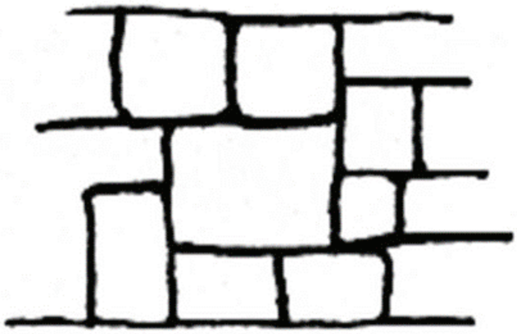
	
(a) Photo	(b) Schematic

Figure 2-28 Random Ashlar Masonry

(c) Rubble Masonry

Rubble masonry is comprised of undressed or roughly dressed stones. Figure 2-29 shows squared rubble masonry along the face stones (spandrel wall). The interior of the arch (intrados) in Figure 2-29 is constructed of stones that have not been squared and are placed in random coursing, grouted or dry-laid similar to ashlar masonry.

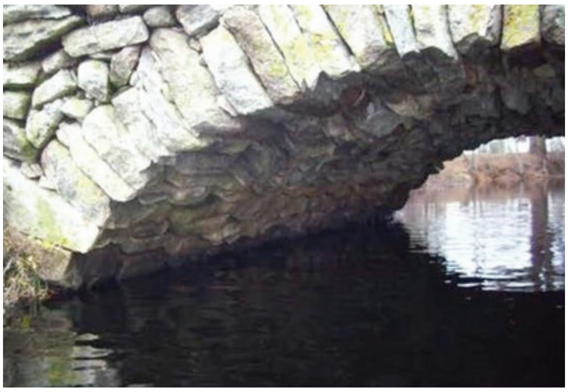
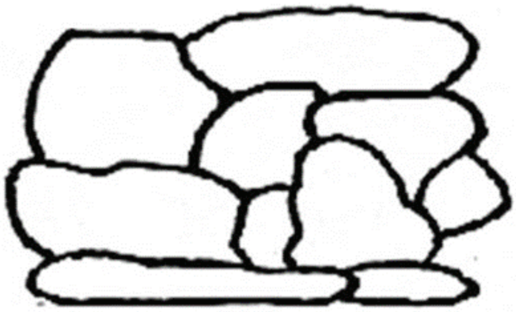
	
(a) Photo	(b) Schematic

Figure 2-29 Rubble Masonry

(d) Arch Elements

Arch elements are illustrated in Figure 2-30 Arch Elements

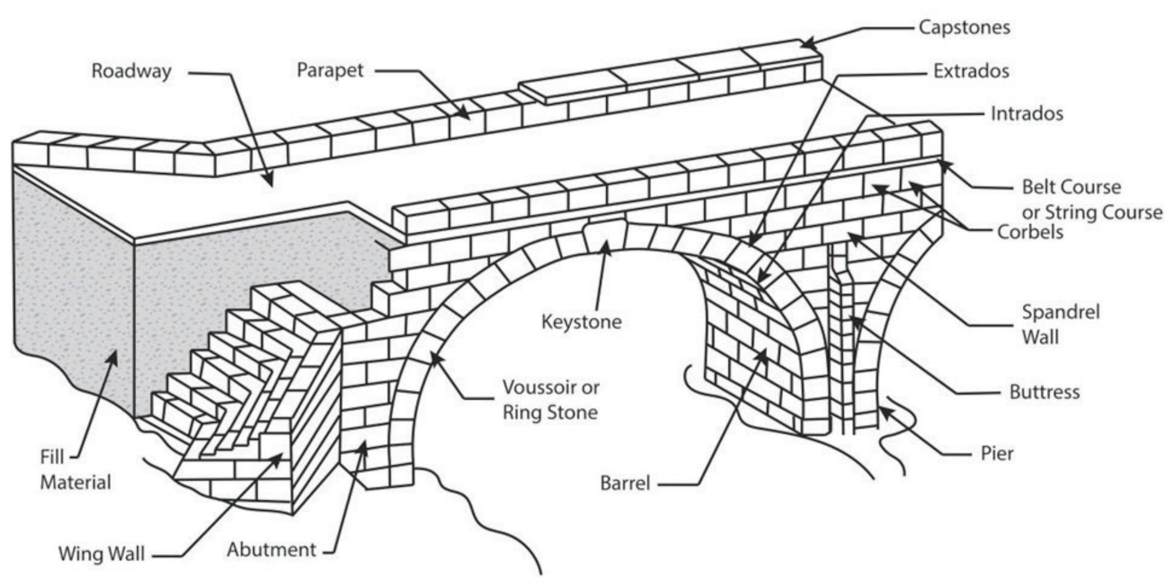


Figure 2-30 Arch Elements

Arches typically rely on the soil to provide lateral stability and to distribute the live load among the various elements.

2.4.7.3 Masonry Slab Bridges

Masonry slab bridges are typically small span structures, less than 3m. An example of a granite slab bridge is shown in Figure 2-31 These structures are comprised of butted individual slabs whose ends are resting on the substructure. The width of the slabs can vary over the width of the bridge. The thickness of the slabs is typically consistent over the entire structure, however, if for some reason the thickness varies, the least thickness should be used to analyze the bridge.

Figure 2-31 Granite Slab Bridge

2.4.7.4 Masonry substructure Elements

Abutment and piers can be constructed of masonry elements. The masonry units can be solid throughout the elements, or in areas where production concrete is not readily available, rubble abutments are a viable alternative. The rubble abutments are formed by dumping large quantities of masonry rubble (uncut stones, brick or even concrete rubble). The structure is then typically coated with concrete to form a cohesive structure. Another common use of masonry units in substructure is to use the masonry to form an aesthetic veneer over a reinforced concrete structure. It is common to find concrete caps and extensions on masonry substructure elements (as shown in Figure 2-32 Masonry Substructure). Sometimes rebar is drilled and grouted into the masonry to attach the concrete elements; however, the concrete can also be cast against the stone with no mechanical connection provided.

Figure 2-32 Masonry Substructure

2.4.7.5 Brick, Stone and Mortar Characteristics

(a) Brick

Brick is manufactured by forming clay or shale into blocks and hardening it by heating. Brick can be either molded or extruded and can vary greatly in appearance and composition. While there are standard brick sizes, bricks can also be manufactured in custom sizes and with custom finishes. Brick can be glazed to provide a different finish and to increase protection from the elements.

Figure 2-33 Brick Arch and Spandrel Walls

(b) Stone

Similar to brick, stone bridges can be constructed of Igneous stone (e.g., granite), sedimentary stone (e.g., limestone or sandstone) and metamorphic (e.g., marble) as the main types of stone. Sedimentary rock typically has little flexural strength and is therefore not used in slab bridges. All three stone categories are applicable for use in compression applications. Geological maps which show the typical bedrock profile for the area that the bridge is located are helpful in determining the type of stone used in a historic bridge. However, without testing or cleaning it is difficult to determine the stone type, as weathered stone typically has a gray appearance regardless of composition.

(c) Mortar

Mortar is used to joint/bond and separate masonry units, prevent water seepage and allows for a construction tolerance without sacrificing contact between the stones.

In addition to compressive and tensile strength, cohesion, bonding and porosity are important characteristics to consider in the choice of mortar for masonry bridge construction.

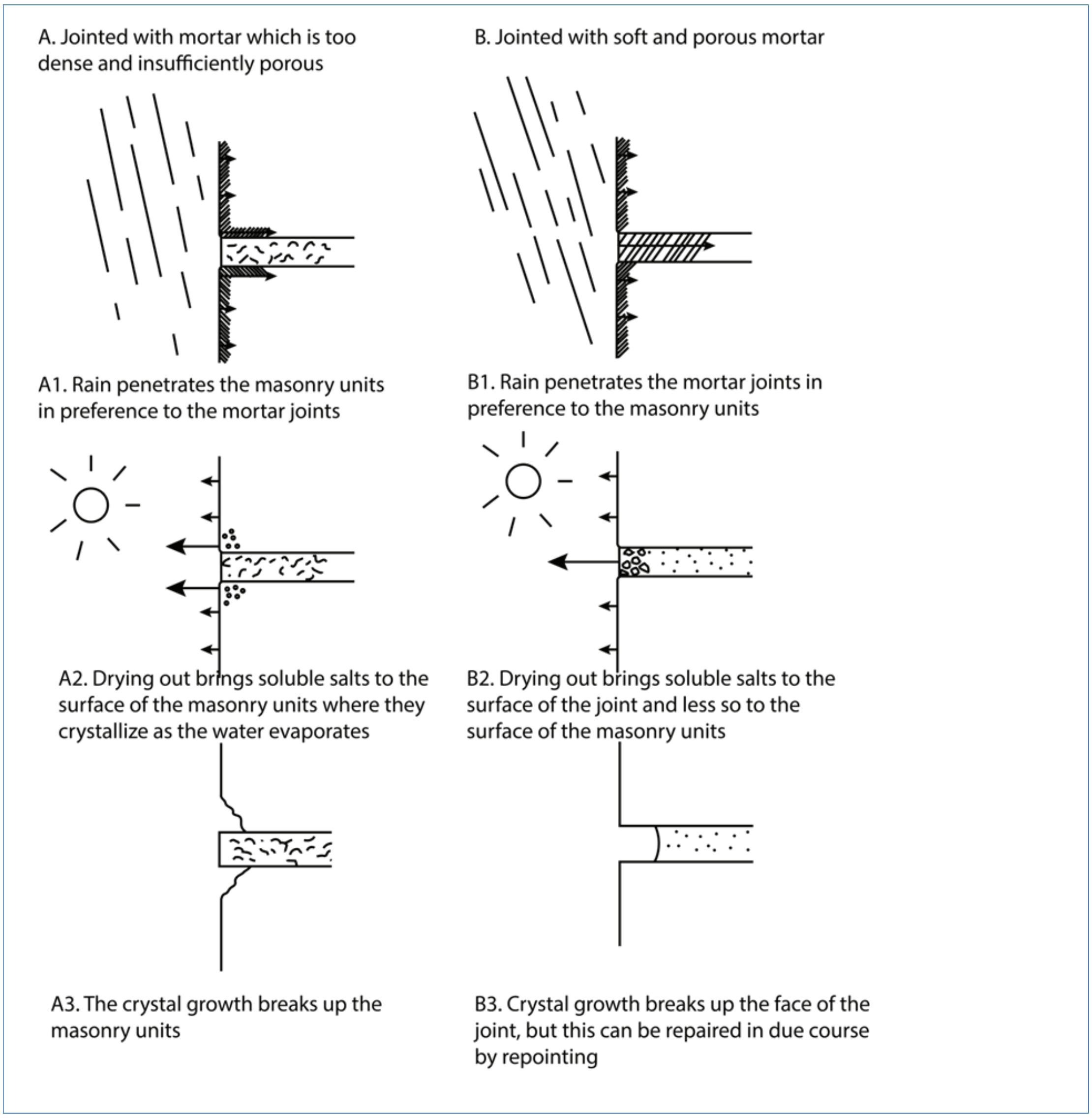


Figure 2-34 Benefits of Hard and Soft Mortar

(d) Architectural Veneer

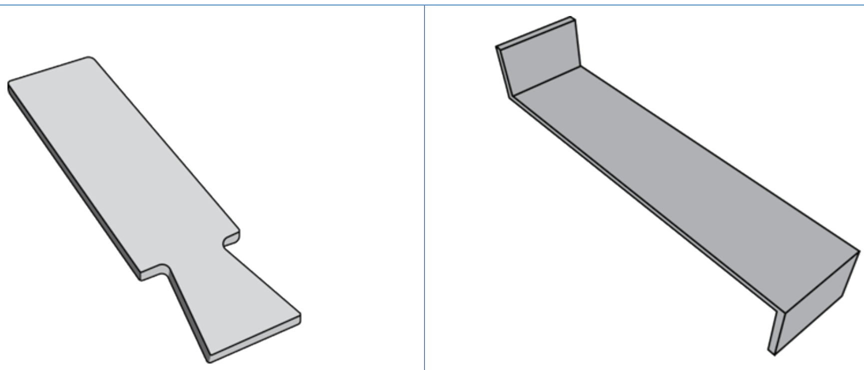
Architectural veneers are common in bridges. They are used for aesthetic purposes and are typically not structural elements. They are used to cover the structural element in order to form a more pleasing appearance.

Veneers can be mechanically attached by anchors or they can be cast into the supporting elements (see examples shown in Figure 2-35). When they are cast into the supporting element, the only element holding the masonry in place is the bond to the backing element. Therefore, use of mechanical anchors is the preferred method to attach masonry veneers.

Strap Anchors	Under Construction

Figure 2-35 Masonry Veneer

Masonry anchors are widely variable. Dovetail anchors and masonry strap anchors are both common types (see Figure 2-36). One side of the anchor is attached to the concrete typically by a mechanical connection. The other side of the anchor is placed into the mortar bed between stones. Once the mortar dries, the anchors provide a mechanical connection between the reinforced concrete structural wall and the masonry veneer. An air space can be left between the reinforced concrete wall and the veneer through the use of anchors. The void between the two layers can be used to provide drainage.



Dovetail Flat Anchor	Strap Anchor

Figure 2-36 Masonry Anchor Types.

2.4.7.6 Advantages of Masonry Construction

Masonry offers a high resistance against rotting, pests, weather, and natural disasters such as hurricanes and tornadoes. Masonry structures have an attractive rustic or elegant look depending on the workers' expertise.

3 DEFECTS IN BRIDGES

3.1 Introduction

Identification of structural defects and their causes require considerable care. Structural distress within an element may often have consequential effects in other elements and it may not be immediately apparent which element has caused the failure. While diagnosis of the causes of the defects is not necessarily a requirement of the inspection, it is of great value for the inspector to have an appreciation of structural behaviour and of the defects that might occur. Such an appreciation will guide the inspector to particular signs enabling attention to be focused where it is most needed. This would ensure that, when a defect is observed, the necessary data are collected on site so that a correct diagnosis can be made; especially when defects occur due to a combination of causes. Damages in structures can result from many factors among them poor design, poor detailing of drawings, construction deficiencies, structural failure, chemical attack, foundation settlement, changes to the support or loading due to traffic, scour or silting, failure of bearings or expansion joints and collision load.

Review of the structures' records prior to the inspection, careful recording and collation of the appropriate records after the inspection will usually allow identification of the failure mechanisms to enable further inspections and/or maintenance actions to be planned effectively.

A structure may exhibit signs of distress due to one or a combination of the following:

- *Inadequate structural capacity*– This includes inadequate design, construction or maintenance, excessive loading or overstress and substandard layout.
- *Naturally occurring damage* – This is contributed by unforeseen movement, water seepage, scour, erosion, vegetation, debris and marine fouling.
- *Accidental or deliberate damage* – Caused by fire or impact damage, graffiti, vandalism.
- *Structural material deterioration* – such as structural steel or concrete reinforcement corrosion.
- *Structural elements malfunction* – drainage, expansion joint, bearings, foundations not operating satisfactorily.
- *Safety elements* – vehicle and pedestrian restrain systems like parapets and safety fence are susceptible to damage due to traffic impacts.
- *Ancillary elements* - Such as approach slab, surfacing and kerbs, utilities, street lighting

It is often difficult to establish the actual cause of a defect on a bridge when the visible evidence obtained from any inspection is limited. Various causes may have contributed to the formation of a defect. Design and construction details will come in handy in determining the actual cause to facilitate the correct repair strategy.

Bridge engineers face serious challenges in inspection, repair, rehabilitation and maintenance of bridges. These challenges are:

1. *Design records* — lack of design records and a reliable bridge inventory database is a serious setback to meaningful intervention and remedial measures for bridges.
2. *Natural Phenomena* — Climatic and catchment characteristics changes pose a high risk of causing damage to bridges.
3. *Inadequate human resource capacity* — Maintenance of bridges requires well trained

human resource which is currently inadequate.

4. *Budget* — Budgetary constraints limits development of a well-planned maintenance program for bridges.
5. *Limited data* — Inadequate detailed inventory on monitoring and performance of existing structures limits the engineer to rate the performance of various bridge types.
6. *Hydrological data* — Lack of reliable hydrological data for various catchments make flood estimation for bridge design difficult.

3.2 Categorization of bridge defects

The bridge defects will be categorized as follows:

- Concrete defects
- Steel defects
- Bearing defects
- Timber defects
- Masonry defects
- Defects in bridge ancillary components
- Defects in other structural components
- Defects in unique/special bridges

3.2.1 Concrete Defects

This section describes typical defects that occur in concrete structures and in the concrete elements of structures. The different types of defects are described with particular emphasis on identification and likely causes.

Concrete defects are categorised as:

i. *Initial Defects* — Anomalies which are caused by design or occur during construction (poor workmanship) e.g Honeycomb, Cold joint.
ii. *Damages* — Defect due to external forces eg Flood, Vehicular load, Vehicular collision, Earth pressure, Vandalism.
iii. *Deteriorations* — Defects caused by changes in condition with age eg Carbonation, Alkali-silica reaction, Salt damage.
iv. Accumulation of debris, driftwoods and stamps, rocks, silt or anything that may impede free flow of water through a structure.

The inspector shall check for these types of defects and notify the Supervising Engineer.

3.2.1.1 Siltation and driftwood

Accumulation of silt, dirt, debris, driftwood and unwanted materials. This may cause growth of vegetation on the structures. Accumulation of silt and debris will affect the capacity of the structure leading to overtopping.

Dirt accumulation

Dirt accumulation

Debris accumulation on girders

Silt accumulation

Accumulation of debris at the pier

Accumulation of debris at the abutment

Figure 3-1 Sample photos of siltation on bridge components

3.2.1.2 *Corrosion*

It occurs due to chemical reaction leading to formation of iron oxides in the presence of moisture and oxygen. Formation of iron oxides around reinforcement bars leads to increase in volume of steel bars hence causing stresses in concrete. Corrosion can lead to loss of strength in concrete, fatigue and loss of bonding between steel and concrete. The early signs of reinforcement corrosion appear as cracking on the surface followed by spalling of the cover concrete.

	
Discoloration due to Corrosion	Corrosion of rebars leading to spalling
	
Exposed corroded rebars	Exposed corroded rebars

Figure 3-2 Sample photos of corroded rebars

3.2.1.3 *Cracks*

(1) *Introduction*

A crack is a linear fracture in concrete that extends partly or completely through the member.

Cracking may occur due to continuous loading, structural deficiency, vehicle impact, thermal variation at different concrete layers or unanticipated structural action. Vertically aligned crack patterns in the vicinity of the mid-span of a beam and diagonal cracking at the ends can be indicators that cracking is of a structural nature. However, the presence of very fine crack patterns may be due to normal loading experienced during construction, which has influenced the pattern of shrinkage cracks. Cracks in concrete also occur as a result of tensile stresses introduced in the concrete.

Cracking may occur at any time throughout the life of concrete both in its plastic, i.e. before hardening, and hardened state due to the nature of the material and its constituents.

Figure 3-3 Sample photos of concrete cracks

Cracks are the most typical defects in concrete structures, they can occur due to a wide range of causes as shown in *Table 3-1 Causes of cracks on concrete structures*

A. Cracks related to material properties of concrete.

B. Cracks related to construction.

C. Cracks related to use and environmental conditions.

D. Those related to structural and external forces.

Table 3-1 Causes of cracks on concrete structures

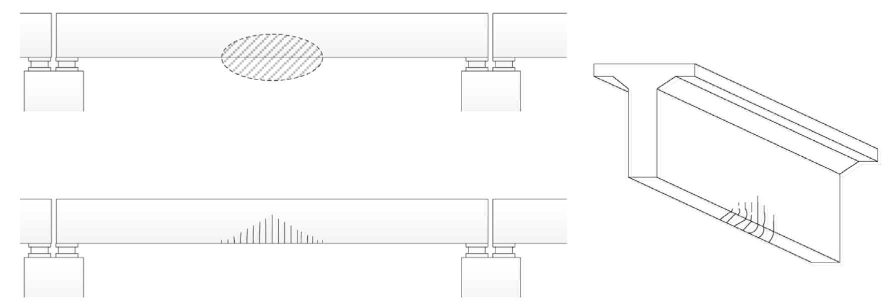
Classifications			Causes
A. Material	Before mixing	Cement	Abnormal cement condensation
			Heat of cement hydration
			Abnormal cement expansion
		Aggregate	Low quality aggregate
			Reactive aggregate (Alkaline Silica Reaction (ASR))
	Concrete		Chlorides in concrete
			Settlement and bleeding of concrete
			Drying shrinkage of concrete
			Self-shrinkage of concrete
B. Construction	Concrete	Mixing	Non-uniform dispersion of admixture materials
			Prolonged mixing
		Transport	Material separation
		Casting	Improper sequence of casting
			Rapid casting
		Compaction	Improper/insufficient compaction
		Curing	Vibration and loading before curing
			Rapid drying during initial curing
			Initial freezing
		Construction joint	Improper joint treatment
	Steel bar	Bar arrangement	Deviation of steel bar arrangement
			Insufficient cover thickness
	Formwork	Formwork	Formwork flap
			Water leakage from formwork gap
			Early removal of formwork
		Supporting	Settlement of supporting
	Other	Cold joint	Consolidated fresh concrete
		PC grout	Grout failure
C. Environment	Temperature and humidity		Changes in ambient temperature and humidity
			Difference in temperature and humidity
			Fire, surface heating
	Chemical action		Acids and salts
			Corrosion of rebar by carbonation
			Corrosion of rebar by salt damage
D. Structural and External Forces	Loading		Long-term load
			Exceeding design load
	Structural design calculation		Insufficient cross section and inadequate reinforcement
	Bearing stratum		Unequal settlement

(2) Structural Cracks

Structural cracks (load induced cracks) in concrete elements are recognized with specific crack patterns related to each type of internal forces (bending, shear). Structural cracking may occur due to overload, structural deficiency, vehicle impact or unanticipated structural action. The crack width and spacing will indicate the extent of the deterioration or damage.

Vertically aligned crack patterns in the vicinity of the mid-span of a beam and diagonal cracking at the ends can be indicators that cracking is of a structural nature. However, the presence of crack patterns with a width of below 0.4mm may be due to the normal loading experienced during construction, which has influenced the pattern of shrinkage cracks. Typical cracking patterns observed in reinforced concrete structures and the typical causes of each type of cracking are illustrated as follows.

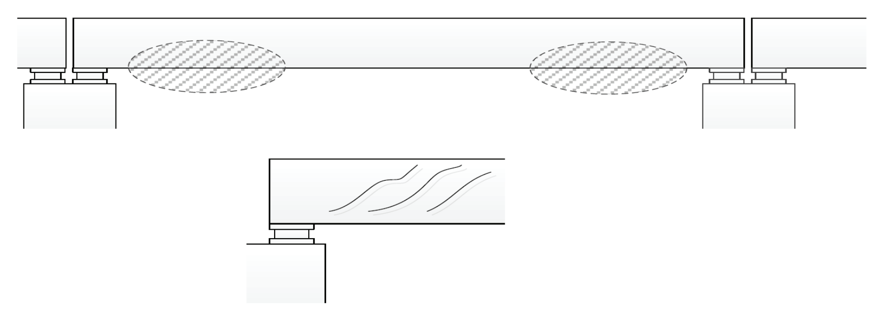
i. *Bending Cracks* - Evidence of flexural (bending) overstress is usually found within the middle of the span of a simply supported beam or slab.



(a) Bending Crack

Figure 3-4 Location of Crack

ii. *Shear Cracks* - Evidence of shear cracks are usually found within a quarter of the span from the edge supports.



(b) Shear Crack

Figure 3-5 Location of crack

Cracking for pre-stressed concrete is an indication of a potentially serious problem (overload, under-design, or design error). Normally no cracks should be visible in PC structures. It is important from a structural point of view, to distinguish structural cracks from the non-structural cracks caused by shrinkage, etc.

(3) Non-Structural Cracking.

Cracking may be non-structural or superficial and affect only the appearance of a structure or it may be indicative of a more serious underlying problem, e.g., formed due to structural loading.

Non-structural cracks before hardening can be due to plastic shrinkage, plastic settlement, and formwork movement during casting or poor workmanship (e.g., insufficient vibration leading to poor compaction and planes of weakness).

In hardened concrete, cracking can occur due to physical effects such as long-term drying shrinkage or crazing; chemical reactions such as, alkali-silica reaction (ASR), carbonation or due to thermal action such as freeze/thaw cycles or early thermal contraction.

Non-Structural cracks may be categorized as passive and active cracks. Passive cracks do not open or close in response to cyclic loads or temperature changes, e.g., plastic settlement cracks formed at the time of concrete casting. Active cracks on the other hand will either follow a hysteresis cycle as occurs with a normal structural crack or progressively widen and lengthen depending on the initial cause.

3.2.1.4 Spalling

Spalling is a phenomenon that occurs when a piece of concrete peels off from the main concrete member of a bridge and often leaves the reinforcement bars exposed. It may lead to corrosion of steel bars when exposed to adverse environmental conditions and degradation of structural members of the bridge hence affecting mechanical strength and durability. This can be caused by impact, vibrations and corrosion of rebar.

Spalling can be visually observed on the surface of concrete. Most of the factors that cause spalling in concrete are often as a result of impact/hit by external objects or deteriorating concrete.

Concrete surface spalling can also be caused by a series of cracks or defects in the concrete at the time of construction, and subsequent vibration or deformation forces.

Figure 3-6 Sample photos of spalling at the pier wall

Rebar exposure refers to a condition in which the concrete cover has spalled and the rebar inside is visible as shown in Figure 3-7. Rebar is easily corroded because it is exposed to the open air, water and oxygen, which are conditions for rebar corrosion. Therefore, cross-sectional repair and other measures are required as soon as possible.

Figure 3-7 Sample Photos of rebar exposure/corrosion

3.2.1.5 Scaling

Scaling is the loss of concrete from the outer surface of concrete members due to weather effects or low quality of concrete grade used on a structural member.

Scaling is associated with a loss of surface concrete in the form of flakes. It is usually observed in the exposed faces of structures.

Scaling is only an aesthetic problem, affecting the first few millimetres of the concrete, but it can initiate other forms of deterioration.

Figure 3-8 Sample photos of scaling

3.2.1.6 Delamination

Delamination is the detachment or partial detachment of a section of concrete from the parent mass concrete. It occurs due to expansion in concrete resulting from corrosion in embedded reinforcement bars. Expansion in concrete may result into horizontal cracking or sub surface fracture in concrete at or just above the level of embedded reinforcement.

Figure 3-9 Sample photos of delamination

3.2.1.7 Honeycomb

Concrete is a mixture of cement, water, sand and aggregates each of which has a different density (specific gravity). Therefore, when concrete is subjected to vibration, heavy materials sink and light materials float. This movement causes separation of the materials, and only the coarse aggregate is concentrated in one area, resulting in honeycomb. Concrete honeycomb is a defective portion of a structure which is caused by poor workmanship and is usually found in construction with dense reinforcement or inaccessible corners of formwork. Inadequate compaction may also lead to honey combing and is recognized as open textured course aggregates without a dense matrix of cement mortar between them resulting in voids. (See Figure 3-10).

Figure 3-10 Sample photos of honeycomb

In extremely severe cases, voids are created and when the coarse aggregate is struck, it may crumble apart, exposing the reinforcing bars. Since the concrete cover to protect the reinforcing steel is insufficient, neutralization and salt damage tend to progress easily and corrosion of the reinforcing bars occurs.

Honeycomb is likely to occur in the following situations:

- Locations where rebar is densely arranged.
- Locations where it is difficult to apply a vibrator, such as where there is an upper formwork.
- When concrete is moved horizontally during compaction.
- When the speed of placing is too fast and compaction is insufficient.
- When the casting height of concrete is high (H > 2 m).

3.2.1.8 Efflorescence

Efflorescence in concrete is a white or cream-colored powdered deposition of salts on the concrete surface that is formed due to evaporation of water from the concrete. The water-soluble salts present in the concrete material, come to the surface when water penetrates through cracks or porous areas in the concrete.

Figure 3-11 Sample photos of efflorescence

3.2.1.9 Disintegration

Disintegration is the physical deterioration or breaking down of the concrete into small fragments or particles. The deterioration usually starts in the form of scaling and if allowed to progress beyond severe scaling is considered as disintegration.

Typical concrete deterioration factors and reasons for disintegration:

i. Carbonation

It occurs as a result of chemical reaction between Calcium Hydroxide, Calcium Carbonate and water due to insufficient cover on structural concrete or porosity/voids in concrete leading to breakage of the protective layer around steel reinforcement.

Normally, $Ca(OH)_2$ is present in large amounts in the concrete, maintaining a high alkalinity of pH 12 or higher. Thus, the rebar does not rust since it is protected by a passive film.

$Ca(OH)_2$ in the concrete reacts with CO_2 in the presence of water to form $CaCO_3$. This causes the pH to decrease destroying the passive state film in the reinforcing bars, thus the bars are oxidized or rusted.

The expansion caused by the corrosion of the reinforcing bar acts as a force that pushes out the concrete and cracks appear.

The rate at which concrete will carbonate depends on various factors including cement content, original water - cement ratio and ambient humidity. The adequacy of the concrete cover shall be inspected during construction to ensure that it is as designed.

Figure 3-12 Sample photos of carbonation

ii. Chemical attack

Inorganic acids (sulfuric acid, hydrochloric acid, nitric acid) and organic acids infiltrate into concrete, reacting with the hydrates inside the concrete, causing expansion and cracking, which in turn leads to spalling as deterioration progresses.

It also occurs when concrete is exposed to environmental conditions saturated with sulphur dioxide and nitrogen oxides. When precipitation occurs, acid rain is formed which could lead to chemical attack on bridge structures. This phenomenon is common in coastal environments and can lead to accelerated deterioration in concrete surfaces exposed to acids. Chemical attack may occur as a result of the following:

- Acids
- Salts and alkalis
- Sulphate attack

Figure 3-13 Sample photos of chemical attack

iii. Alkali Silica Reaction

The reactive aggregate reacts with the alkaline components in the concrete to generate a gel (a substance that absorbs water and expands). As the gel absorbs water and expands, cracks appear in the concrete.

As the alkali-silica reaction progresses, the cracks gradually spread to the surface of the concrete, causing alligator cracks, as shown in Figure 3-14 :

Figure 3-14 Sample photos of ASR

iv. Chloride Induced deterioration

If the concrete contains large amounts of chloride ions, the chloride ions will destroy the passive film around the reinforcing bar, and the reinforcing bar will corrode.

The expansion caused by the corrosion of the reinforcing bar by the chloride damage, is similar to that of carbonation, causing spalling on the concrete surface.

Figure 3-15 Sample photos of chloride attack

3.2.1.10 Abrasion

It occurs when concrete surfaces are unable to resist wear and tear caused by external forces exerted by traffic and hydraulic effects.

Figure 3-16 Sample photo of concrete abrasion erosion

3.2.1.11 Leakages

This is the presence of passage of liquids on concrete elements due to lack of proper waterproofing material, presence of cracks, poor drainage and failing joints.

Figure 3-17 Sample photos of leakage

3.2.1.12 Leaching and staining

Seepage of water through cracks and voids in hardened concrete which may dissolve Calcium Hydroxide and other constituent materials in concrete. It can be evident in the form of staining, efflorescence and encrustation at cracks.

The water will penetrate most readily where sections are thin with high porosity and at construction joints, particularly if the concrete is honeycombed. When alkali is being leached from the concrete, corrosion of the reinforcement may eventually occur. The most serious form of staining is the brown efflorescence of reinforcement corrosion.

Leaching, staining and algae growth are readily identifiable indications of either current or historic water leakage. The inspector should note the location of staining in order to determine the source of the water leak. Where secondary consequential defects have occurred, such as reinforcement corrosion, further testing may be appropriate.

Figure 3-18 Sample photos of leaching and staining

3.2.1.13 Excessive deformation, deflection/vibrations

Traffic loads are dynamic loads and cause a bridge to vibrate. Excessive loadings cause abnormal shaking of structures especially those with long spans. The vibrations contribute to the stresses and have a significant impact on structural and material fatigue.

Figure 3-19 Sample photo of excessive deformation

3.2.1.14 Fatigue

Repeated loading with relatively low load acting on concrete can cause cracks in the reinforcing bars and flexural cracks in the concrete, followed by progressive deterioration that can lead to spalling of concrete.

Deck slab is most frequently damaged by fatigue because it is directly exposed to the repeated loads.

Progress of deterioration by fatigue in RC Slabs of Road Bridges is as follows.

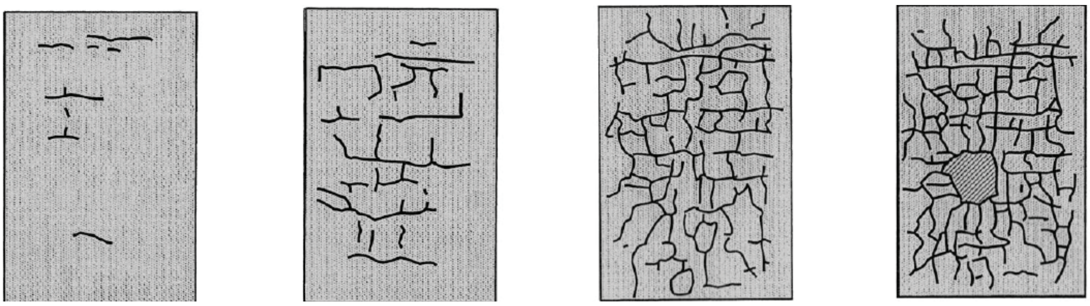


Figure 3-20 Progression of Fatigue

	
Fatigue cracks (stage 1)	Fatigue cracks (stage 2)

Fatigue cracks (stage 3)

Fatigue cracks (stage 4)

Figure 3-21 Sample photos of fatigue

3.2.1.15 Discoloration

This occurs when water penetrates through the deck surface onto the columns and beams below, causing a brown discoloration of the members. This is usually caused by poor drainage on the deck surface.

It also occurs due to smoke, graffiti and animal activity such as bird nest, waste.

Discoloration due to water leakage

Discoloration due to water leakage

Discoloration due to animal droppings

Discoloration due to smoke

Discoloration due to graffiti	Discoloration due to graffiti

Figure 3-22 Sample photos of discoloration

3.2.1.16 Buckling

In structural engineering, buckling is the sudden change in shape (deformation) of a structural component under load, such as the bowing of a column under compression.

Figure 3-23 Sample photos of buckling

3.2.1.17 Cold joint

A cold joint is an area where, during the placing of a concrete overlay, the previously placed concrete begins to set and harden and does not bond with the freshly placed concrete.

Unlike normal construction joints, the joints are not treated, which means that there are vulnerable areas in the concrete, thus exposing it to deterioration factors.

Figure 3-24 Sample photos of cold joint

3.2.1.18 Sand streak

This occurs when there is a large amount of water in the concrete and the water bleeds along the formwork face. As the bleed water moves upwards there's material separation that results in exposed fine aggregates on the surface of the formed concrete. It also occurs when cement paste leaks out of the formwork through the joints and gaps.

This causes aesthetic loss, reduction in strength and the concrete to be more susceptible to wear.

Sand streak due to water bleeding

Sand streak due to cement paste leak

Figure 3-25 Sample photos of sand streak

3.2.1.19 Surface bubbles

This is when the air bubbles trapped in the concrete appear on the surface. Thus, making the concrete surface less resistant to environmental conditions and more susceptible to wear.

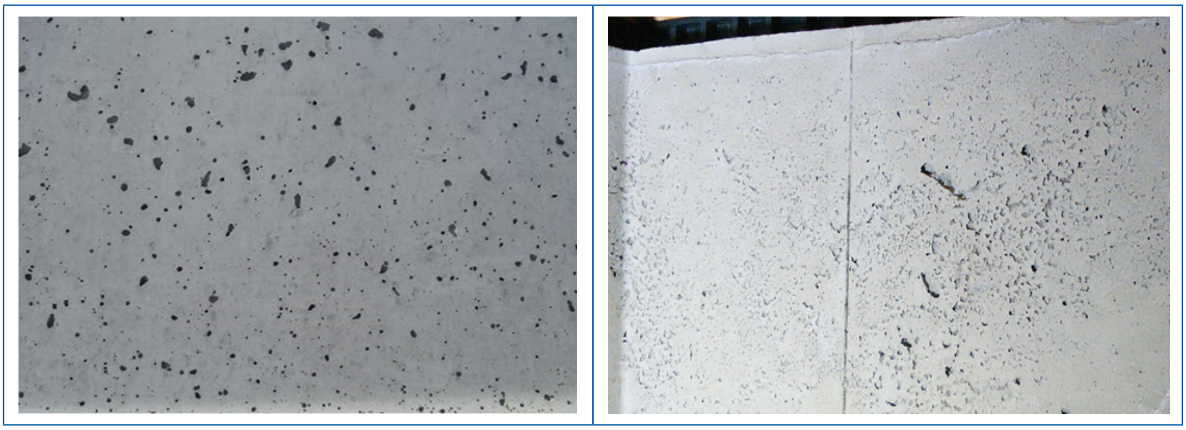


Figure 3-26 Sample photos of air bubbles

3.2.1.20 Cavity

Unfilled areas in the concrete due to dense reinforcement, complicated formwork shape or insufficient compaction of the concrete.

Grout failure in the sheath of pre-stressed concrete structures may also result in cavities.

It is caused by the separation of mortar and coarse aggregate during the placing of concrete. This defect leads to corrosion of the steel bars and leakage.

Cavity on finished concrete | Cavity leading to exposed Rebars

Figure 3-27 Sample photos of cavity

3.2.2 Steel Bridges defects

Steel is a metal alloy that can be plastically formed (pounded, rolled, etc.) and comprises of iron as its major component and carbon as the primary alloying material.

Steel is primarily used for its tensile characteristics, but it can be used in compression provided care has been taken to ensure that relatively slender plates or sections do not buckle. Steel is used as structural members, box girders, plate girders, rolled sections, tubes and plates and also as reinforcing bars and pre-stressing tendons in concrete. There are various grades of steel; mild steel is the most commonly used but high yield steels are used as structural members which have to carry higher stresses and for reinforcement and pre-stressing tendons.

Steel defects can be as a result of:

i. Initial Defects- Anomalies which are caused by design or occur during construction (poor workmanship) e.g., Welding defects, Insufficient paint thickness, Insufficient bolt tightening (torque), Poor fabrication.

ii. Damages- Defect due to external forces (Flood, Vehicle load, Vehicle collision, Vandalism, etc.) e.g., Deformation, Missing bolts/steel members

iii. Deteriorations- Defects caused by changes in condition with. E.g., Corrosion, Deterioration of corrosion protection, Abnormal deflection, Cracks, Fracture

iv. Accumulation of debris, driftwoods and stamps, rocks, silt or anything that may impede free flow of water through a structure

The items to be inspected in steel bridges are as shown below. The inspector shall check for these types of damages and shall notify the Supervising Engineer.

3.2.2.1 Siltation and driftwood

Accumulation of silt, dirt, debris, driftwood and unwanted materials around some of the steel bridge elements, hampering the proper functioning of those elements or other surrounding elements.

Accumulation of silt

Accumulation of silt and wasp nest

Accumulation of debris.

Accumulation of debris.

Figure 3-28 Sample photos of siltation

3.2.2.2 Corrosion

Corrosion, in the case of ordinary steel, refers to a state of intensive rusting, or a state in which rusting has progressed to such an extreme degree that a reduction in thickness has resulted in a section defect. In the case of weathering steel, it refers to a state in which abnormal rusting occurs without the formation of protective rust or in which the thickness of the plate is reduced due to extreme rusting progression.

The following locations are prone to corrosion:

- Girder ends, where leakage is frequent.
- Top surfaces of horizontal materials and other locations where water tends to stagnate.
- Around the bearings.
- Connections with poor ventilation and exhaust.
- Top surface of the lower flange, where mud and dust tend to accumulate.
- Welds and bolted joints where coating thickness tends to be thin.

In addition, when dissimilar metals such as stainless-steel and ordinary steel come in contact, the ordinary steel corrodes significantly. Such corrosion is called "galvanic corrosion". Galvanic corrosion refers to the formation of a corrosion cell between metals of different potentials when they come in contact in the presence of an electrolyte solution, causing the metal with the lower potential to oxidize and corrode.

Figure 3-29 Sample photos of galvanic corrosion

3.2.2.3 Paint deterioration

Paint deterioration on steel members results in loss of corrosion protection performance.

Painting shields steel from water and oxygen by covering it, thereby preventing corrosion.

However, the paint film deteriorates over time, and if the paint is not reapplied at the appropriate time, the corrosion protection function will deteriorate.

Causes of Deterioration

Deterioration causes can be attributed to *exposure to ultraviolet rays* and *faulty surface preparation.*

1. Ultraviolet deterioration

   Ultraviolet deterioration is a condition in which ultraviolet rays destroy the molecular structure of the paint.

It is characterized by the appearance of discoloration on the entire bridge, which progresses to chalking, peeling, and cracking.

The resin content of the painted surface decomposes due to ultraviolet rays, oxygen, and moisture, and the pigment content appears as a powder.

Epoxy resin-based paints are particularly vulnerable to ultraviolet rays, and care should be taken if they are used as the topcoat or if rust-preventive paints are used for exposure.

2. Deterioration due to poor surface preparation

Deterioration due to poor or inadequate surface preparation is characterized by localized deformation. Bubbles, encapsulated rust develop and progress to peeling. This deterioration can be caused by inadequate removal of rust and peeling paint from the steel member prior to painting.

There are several different types of surface preparation method, and the type used depends on the situation. If these are not performed properly and paint is applied while dirt remains, corrosion protection will be reduced and deterioration accelerates.

Figure 3-30 Sample photos of paint deterioration

Measures to prevent paint deterioration

It is better to repaint the entire bridge at the appropriate time, as the process rarely progresses uniformly over the entire bridge.

However, it is difficult to repaint the entire surface of a bridge due to budget constraints.

Since corrosion accompanied by a decrease in plate thickness often occurs at the ends of girders, it is necessary to give priority to painting the ends of girders.

In addition, touch-up painting should be applied to areas where significant deterioration has occurred due to leakage from expansion joints, drainage basins, and concrete slabs.

When repainting, it is difficult to completely remove rust and adhered chloride ions, and the durability of the paint film in the corroded areas is greatly inferior to that of the newly constructed areas.

Re-degradation of the painting film may begin at an early stage. In areas where corrosion has occurred in the past, the paint film has been re-coated many times at relatively short intervals due to the deterioration of the paint film and the progression of corrosion.

3.2.2.4 Heat Damage

Steel members undergo serious deformation upon exposure to fire or extreme heat. In addition to sagging, or elongation of steel, intense heat often causes members to buckle and twist. Therefore, it is necessary to check for the presence of any flammable materials or debris e.g., tree limbs under the girders during inspection.

Figure 3-31 Sample photo of heat damage

3.2.2.5 Section Loss

This is the reduction in mass of a steel structure due to corrosion. It is therefore important to assess the magnitude, location and form of corrosion and to identify its cause. Particularly vulnerable locations are areas that experience water leakage and those where water may stagnate, e.g., horizontal surfaces and joints. All loss of effective structural section should be assessed.

Figure 3-32 Sample photos of section loss caused by corrosion.

3.2.2.6 Missing parts/sections

Parts of the steel forming a structure may be missing due to excessive vibrations and vandalism.

Figure 3-33 Sample photos of missing parts

3.2.2.7 Cracks

Cracks are linear fractures in a steel member mainly produced due to defects, and can under certain conditions, lead to brittle fracture.

The primary factors leading to fatigue cracking are:

- The number of applied stress cycles, which is a function of the volume of traffic.
- The magnitude of stress range, which depends on the applied live load.
- The fatigue strength of the connection detail.

Cracks caused by fatigue usually occur at points of tensile stress concentration, at welded attachments or at termination points of welds. Cracks may also be caused or aggravated by overloading, vehicular collision or loss of section resistance due to corrosion. In addition, stress concentration due to poor quality of fabricated elements and the fracture toughness of materials used are contributing factors. Material fracture toughness will determine the size of crack that can be tolerated before fracture occurs.

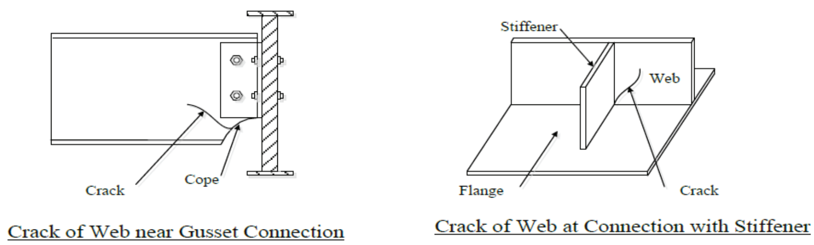


Figure 3-34 Common crack locations in steel members

Figure 3-35 Sample photos of cracks of steel members

3.2.2.8 Fracture

Fracture is the breaking of steel due to fatigue or impact. The fractured section may fall off completely or may remain attached but cannot carry any load.

Figure 3-36 Sample photos of fracture of steel members

3.2.2.9 Excessive vibrations and noise

This is the abnormal shaking of steel structures when subjected to live loads, as the structure shakes it produces a lot of noise.

3.2.2.10 Deformation/Deflection

Deflection is the displacement of a structural member under the influence of loads. Excessive deflection is a type of defect in steel structures.

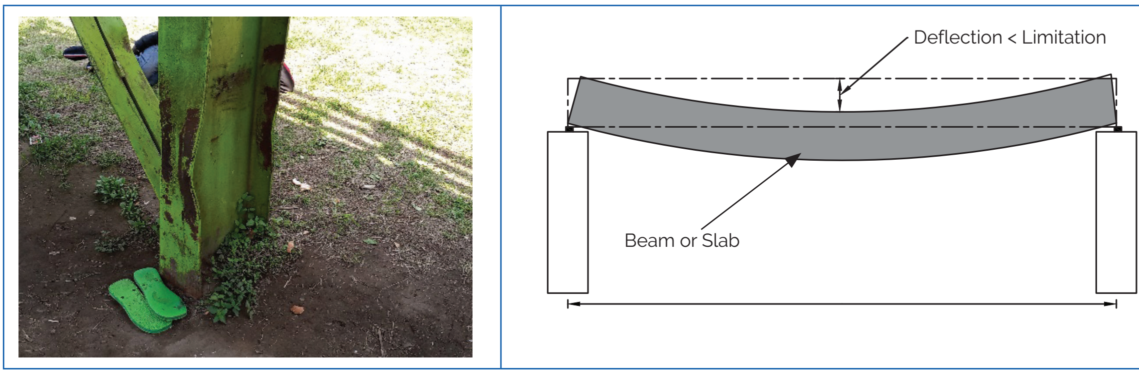


Figure 3-37 Sample photos of deformation

3.2.2.11 Buckling/Kinking/Warping.

Buckling is the sudden change in shape of a slender structural component under compressive force.

Kinking is the loss of shape or twisting of a bridge member as a result of prolonged loading.

Warping occurs when the twisting of a member results in the cross-sections distorting out-of-plane along the direction of the member's longitudinal axis. Most cold-formed members (i.e., all except closed hollow circular sections) have cross-sections which tend to warp when subjected to torsion.

	
Buckling	Twisting

Figure 3-38 Sample photos of buckling and twisting

3.2.2.12 Loose connection/Missing Bolts

A condition in which bolts and nuts connecting steel members are loose or have fallen off. It also includes the state in which bolts are broken. Even if the unit appears sound to the eye, it may be loose, so it is advisable to check for looseness by tapping it with an inspection hammer during inspection.

Figure 3-39 Sample photos of loose connection/missing bolts

3.2.2.13 Accumulation of water

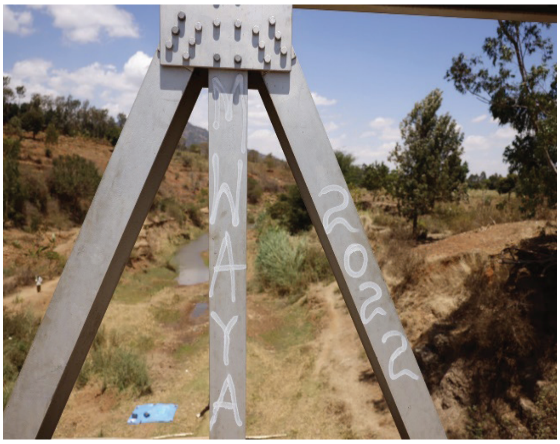
Water accumulation in steel structures contributes to oxidation of metal leading to corrosion

Figure 3-40 Sample photo of water accumulation

3.2.2.14 Discoloration

This occurs when water penetrates through the deck surface onto the columns and beams below, causing a brown discoloration of the members. This is usually caused by poor drainage on the deck surface.

Discoloration can occur due to graffiti



Graffiti will cause discoloration.

Discoloration due to rust.

Figure 3-41 Sample photos of discoloration

3.2.3 Defects in Bearings

Bearings are structural components that provide connections between the superstructure and substructure, the purpose of which includes the following:

- To transfer vertical/horizontal loads from the superstructure to the substructure.
- To allow longitudinal transverse movement of the superstructure.
- To allow rotation of girder/slab ends due to dead and live loading

Bearings accommodate these movements by deforming (elastomeric), rotating, sliding and/or rolling. Defective bearings will hinder the function of the structure to a large extent. Regular inspection is critical to be able to pick up any defects within the bearing and immediate repair action taken. The following defects are found in bearings and inspection should be geared towards identifying any of the listed defects.

Table 3-2 Common defects found on bearing

Defect	Description
Corrosion	Corrosion occurs on steel bearings; this is caused by water leakages from the expansion joints. This reduces the lifespan of the bearings.
Siltation	This is the accumulation of solid material on the bearings, this may provide conducive environment for corrosion. The debris deposited of the bearings can also hinder the movement of the bearings.
Loose bolts/ Missing bolts	Anchoring bolts may be loose or missing. This may cause excessive movements and vibrations at the joints.
Deformation in elastomeric bearings	Faults include splitting, tearing or cracking of the outer casing and even bulging and distortion. The first sign of distress usually shows non uniform ripping of the vertical surfaces followed by horizontal cracks near the junction of the rubber pad and steel laminate. Differences in thickness between the front and back of the bearing shows the amount of rotation which should not be in excess. The bearings may fail because of deterioration of materials, excessive crushing due to excessive shear force and separation of composite pad laminations. Uneven compression and twisting of the bearings can contribute to failure.
Position and alignment	The bearings must be set relative to the ambient temperature (air temperature of the local surroundings) at installation. Bearing usually are installed horizontally. A deviation from the horizontal X and Y axis should not exceed 3% and 5% for elastomeric bearings. For sloped bridges, the Structural Engineer may prefer the bearings to be aligned in parallel to the local gradient of the bridge. Movement/Rotation of the bearing will be restricted if, during installation, the bearing is set at a position where it has already reached its maximum limit of movement/ rotation, before the maximum or minimum local temperature is attained.
Bearing seat	This applies to the seating of superstructure on bearing and of bearings on substructure. The seating material may crack or disintegrate and gaps may occur between the bearings and seating. These are potential serious defects since they can reduce the support given to the superstructure
Sliding bearings faults	Excessive wear, dirt or corrosion of the sliding surfaces will increase the resistance to movement. Where a low friction sliding material such as PTFE (Polytetrafluoroethylene) sliding on stainless steel is used, it is important that no faults develop which could increase frictional resistance since this would transmit undesirable forces to the substructure. Any suspected malfunctioning of a PTFE bearing may require; detailed inspection.

Siltation on the bearings

Siltation on the bearings

Corrosion of the bearings

Corrosion of the bearings

Leaking bearings

Water stagnation at the bearings

	
Siltation at the bearings	Deformation of the bearings
	
Corrosion of the bearings and cracking of the bearing seat.	Bearing displacement

Figure 3-42 Sample photos of bearing deteriorations

3.2.4 Timber bridge defect

Timber is an organic material rather than a manufactured material such as concrete, steel, or masonry and it tends to be less homogeneous and more susceptible to various recurring random defects. Lumber is generally classified according to its species, size, and natural variations.

Timber is a natural engineering material that is prone to deterioration caused by decay fungi, insect attack, fire, and through mechanical damage. Typically, areas of high moisture content in decking, girders, abutment caps and pilings create conditions suitable for biological damage. Types of biological damage include decay and insect damage caused by a variety of species of fungi and insects such as ants or termites.

The application of preservative treatment by pressure methods enhances the durability of timber bridge components, but regular inspections are vital for the identification of damage and implementation of timely repairs and proactive maintenance programs. Mechanical damage might include damaged members or mechanical fasteners.

Defects in Timber:

Defects in timber are classified into:

i. Natural defects which occur during growth of the tree.
ii. Secondary or Artificial defects arising from handling of the timber.

The defects to be inspected on timber bridges are shown in Table 3-3. The inspector shall inspect the following defects and shall notify the Supervising Engineer.

Table 3-3 Inspection items for timber bridges

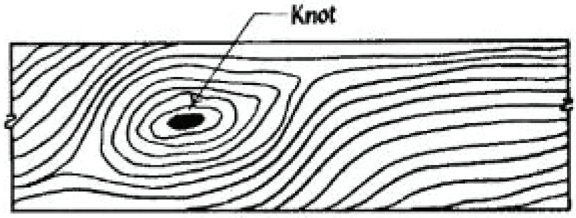
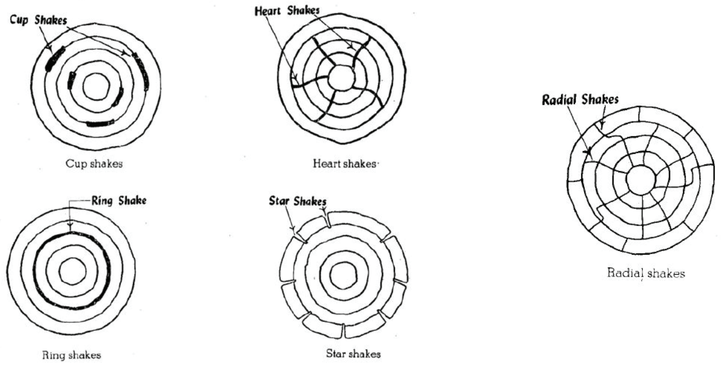
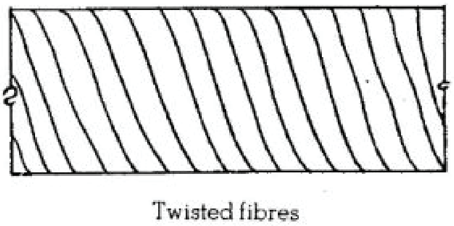
Part	Inspected defects
Timber member	Crack
	Rot
	Missing member
	Rattling of member
	Stain (Wood-destroying fungi)
Whole bridge	Abnormal deflection
	Abnormal alignment (Plan/Profile)
	Inclination
	Scouring
	Clogged drainage system
	Siltation

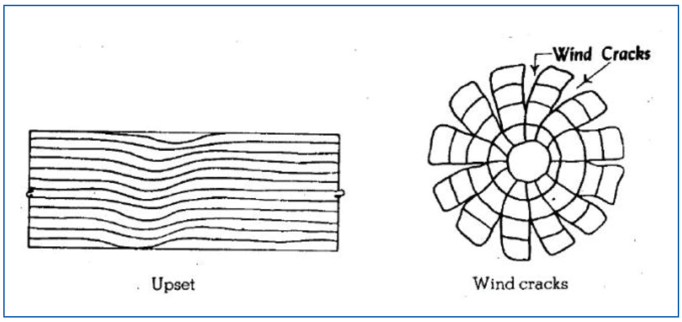
Table 3-4 Common defects found in timber bridges

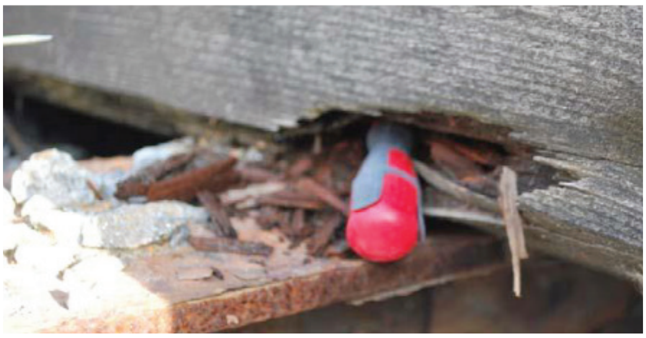
No.	Defect	Description
1.	Siltation	Any build-up of dirt, vegetation, or water has an influence on the drying and equilibrium moisture content of the timber and can hasten deterioration of timber.  **Figure 3-43 Accumulation of gravel, splits and advancement of decay at bearing area of timber beam**
2.	Defects due to conversion	During the process of converting timber to commercial form, the following defects may occur. ▪ *Chip mark:* mark or sign placed by chip on finished surface of timber. ▪ *Diagonal grain:* Due to improper sawing of timber. ▪ *Torn grain/form grain:* Usually caused by a small depression formed on the finished surface of the timber by accidental falling of the tool. ▪ *Wane:* Presence of original rounded surface on the manufactured piece of timber.

<table>
<tr><th>No.</th><th>Defect</th><th>Description</th></tr>
<tr><td>3.</td><td>Defects due to fungi</td><td>When moisture content of timber is above 20% and there is presence of air and warmth, growth of fungi is accelerated causing the following defects:
▪ Blue stain: It is when sap of the timber is stained to bluish colour.
▪ Brown rot: It is the decay of timber in which the cellulose compounds from wood are removed and the wood assumes the brown colour.
▪ Dry rot: This is when the wood is converted into dry powder form.
▪ Heart rot: Heart rot is generated in the trees when fungi attack the heartwood through its newly formed branch. This type of fungi makes the tree hollow by consuming heartwood. The tree becomes weak and gives out hollow sound when struck with a hammer
▪ Sap stain: When the moisture content in the timber is more than 25%, some types of fungi attack the sapwood and make it discoloured.
▪ Wet rot: Wet rot is caused by fungi that decompose the timber and convert it into a greyish-brown powder form. Wet rot cause fungi growths mainly when there are alternate dry and wet conditions of timber.
▪ White rot: Some types of fungi attack lignin of timber and leaves cellulose compounds; hence the wood turns into white colour, referred to as white rot.

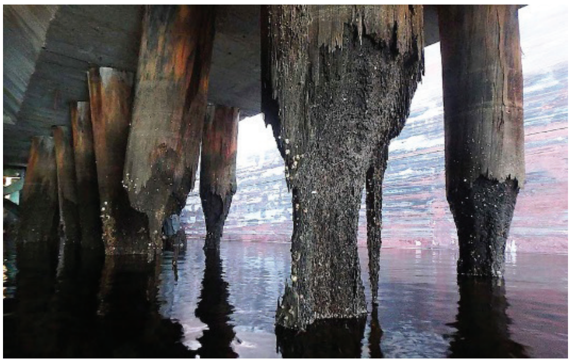
Figure 3-44 Girder decay in a timber bridge</td></tr>
<tr><td>4.</td><td>Defects due to natural forces</td><td>The main natural forces responsible for causing defects in timber are abnormal growth and rapture of tissues
▪ Burls: These are uneven projections on the body of the tree during its growth. These are mainly due to the effect of shocks and injuries received by the tree during its early age of growth.
▪ Callus: The damaged section is covered by a soft skin referred to as callus.
▪ Chemical stain: It is formed on the wood by the action of any external chemical agents like reaction by the gases present in the atmosphere etc. The stained area gets discoloured as a result of this defect.
▪ Coarse grain: The age of a tree can be determined by the number of annual rings. For fast-growing trees, the gap between the annual rings is very large. These types of trees are called a coarse-grained tree, and timber obtained from them is of less strength.</td></tr>
</table>

No.	Defect	Description
		▪ Dead wood: Timber obtained from dead standing tree is light in weight, reddish in colour and has less strength. ▪ Druxiness: White decayed spots by fungi ▪ Foxiness: Due to poor ventilation during storage or by commencement of decay due to over maturity is indicated by red or yellow tinge in timber ▪ Knots: Bases of branches or limbs which are broken or cut off from the tree as shown in Figure 3-45  **Figure 3-45 Knot** ▪ Rind galls: Rind means bark and gall indicates abnormal growth and peculiar curved swellings found on the body of a tree. ▪ Shakes: These are cracks which partly or completely separate the fibres of wood shown in Figure 3-46  **Figure 3-46 Different types of shakes** ▪ Twisted fibres/Wandering hearts: caused by twisting of young trees by fast blowing wind as shown in Figure 3-47  **Figure 3-47 Twisted Fibres**

No.	Defect	Description
		▪ Upsets or ruptures: Indicate wood fibres which are injured by crushing or compression as shown in Figure 3-48  **Figure 3-48 Upset**
5.	Defects due to environmental effects	**Aging** – Caused by exposure to the sun. Manifested by cracks on the surface. **Rotting** – Caused by high moisture content. Manifests in the form of aggressive wood destroying fungal growth. **Cracking** – Caused by highspeed winds and the sun causing cracks on the timber surface. Manifested by surface cracks on the timber member. **Deflection** – Caused by sustained loading. Manifested by a curve along its longitudinal length which may affect its serviceability or functionality. **Anchorage failure** – Caused by secondary loading. Occurs when the member dislodges from position due to deflection, shear or other catastrophic failures.
6.	Structural Damage and Defects	The structural defects and damages are caused by loading or collisions. These include: ▪ Fractures due to loading, particularly in flexural (bending) members. ▪ Local crushing at bearings, including the ends of truss members. ▪ Propagation (or extension) of the natural end splits in flexural members. ▪ Loose connections, including local crushing of timber and/or enlarged holes around bolts. ▪ Collision damage. Timber Kerbs and rails are subjected to vehicle impact. ▪ Misalignment. Sag in main beams or trusses, lateral bucking in truss compression chord, or abrupt misalignment of secondary members such as kerbs and rails resulting in failing capacity and performance. ▪ Abrasion. Mechanical wear and loss of section may result from traffic effects on deck timbers, which sometimes result in an undesirable slipperiness or from stream bed movement on piles.

No.	Defect	Description
		▪ Pile damage. Timber piles do suffer at bed level or water level from insect attack and decay.  **Figure 3-49 Fractures due to loading**
7.	Discoloration/ Deteriorations	Reduced service life may be due to various causes, inadequate scoping, poor workmanship, failure to repair damage and poor maintenance. The following are the findings according to the structural effect: ▪ Precipitation running off from one member to the one below it.  **Figure 3-50 Rainwater follows the steel parts to the timber parts** ▪ Stagnant water which is absorbed into the timber sections.  **Figure 3-51 Stagnant water on the steel beam has overtime caused the decay of the timber beam**

No.	Defect	Description
		▪ Dirt or debris on the construction section keeping the moisture content high. ▪ Horizontal member without structural protection.  **Figure 3-52 Horizontal members without any structural protection is prone to experience fungus attack** ▪ Dowels dislodging.  **Figure 3-53 Dowels dislodging from the structure – horizontal dowel with alternating load direction** ▪ Corrosion on the pre-stressing bars (tendons).



Sectional-loss of timber piles

Crack on coping beam

Wood-destroying Fungi

Wood-destroying Fungi

Figure 3-54 Sample photos of deterioration of timber bridge

3.2.5 Masonry Bridges

3.2.5.1 Introduction

The damage items to be inspected in masonry bridges shall be as shown in Table 3-5. The inspector shall check for these types of damages and shall notify the supervising engineer.

Table 3-5 Inspection items for masonry bridges

Part	Inspected Items
Stone	Crack
	Sectional loss
	Deformation/ Displacement of masonry blocks
	Loss of mortar
	Fall down
	Water leakage between stones
Whole bridge	Abnormal deflection
	Abnormal alignment (Plan/Profile)

Table 3-6 Common defects found in masonry bridges

S/No.	Defect	Description
1.	Siltation	This is the accumulation of dirt or debris on the components of the bridge.
2.	Efflorescence	This occurs when salt laden water typically seeps into the mortar joints first; therefore, water stain and efflorescence is most likely to be first visible in the mortar joints.
3.	Split and spall	This occurs when the porosity of the masonry unit exceeds that of the mortar, or if the mortar is harder than the adjacent masonry units.
4.	Mortar Deterioration	Mortar deterioration is expected to occur over the service life of the bridge. However, if the contact between the stones is significantly reduced, if water infiltration is occurring, or if other signs of distress are present, repair of the joint may be required.
5.	Cracking	Many cracks in the mortar and masonry occur either when the forms are removed or while the arch is being backfilled. Cracking in the mortar is common and is not necessarily a sign of distress for the masonry structure. Mortar will fail first to alleviate the pressure on the masonry itself.
6.	Slipped Masonry Units	A slipped masonry unit is a stone or brick that is lower than the adjacent stones and one that has displaced below the interior of the arch barrel (or the intrados). Many times, the stone slips during construction. This typically only occurs in un-mortared masonry arches.
7.	Missing Masonry Units	One modification historically made to masonry bridges is the removal of masonry units for the installation of utilities or drainage. Typically, the arch (or the soil in a slab bridge) is able to create an "arching effect" over the missing masonry units. The condition should be noted, but is not typically critical to the load carrying capacity of the bridge.
8.	Masonry Displacement	Masonry displacement, or arch deformation, is an indicator that failure of the masonry arch has occurred.
9.	Scour	Scour is the erosion of the channel bed. Scour is critical if it occurs adjacent to the footings. If the soil behind the arch is scoured away, the integrity of the arch is compromised.
10.	Vegetation growth	This occurs when the walling has fissured and silt settles in it. The growth of vegetation encourages expansion of fissures and can lead to damage of masonry walling.
11.	Water infiltration	Water gets into the structure through an opening on the wall. This is as a result of either cracks, missing mortar/loose mortar, porous brick/block.
12.	Impact damage	This occurs when masonry walling is subjected to impact like that of accidental loading.
13.	Discoloration/ Deteriorations	This is the change in color of the masonry material caused by dampness, chemical attack or even impurities in the environment like smoke from traffic.

Cracks

Deformation/Displacement

Fall down

Water leakage between stones

Missing bricks

Vegetation growth on masonry bridge

Figure 3-55 Sample photos of deterioration of masonry bridge

3.2.5.2 Spandrel walls failures

Spandrel wall is the part of the bridge constructed above the arch, made of masonry to provide lateral restraint/support to back fill material and pavement layers. It is mostly constructed with top and bottom sections thicker than the middle part to enhance stability in the top part of the structure.

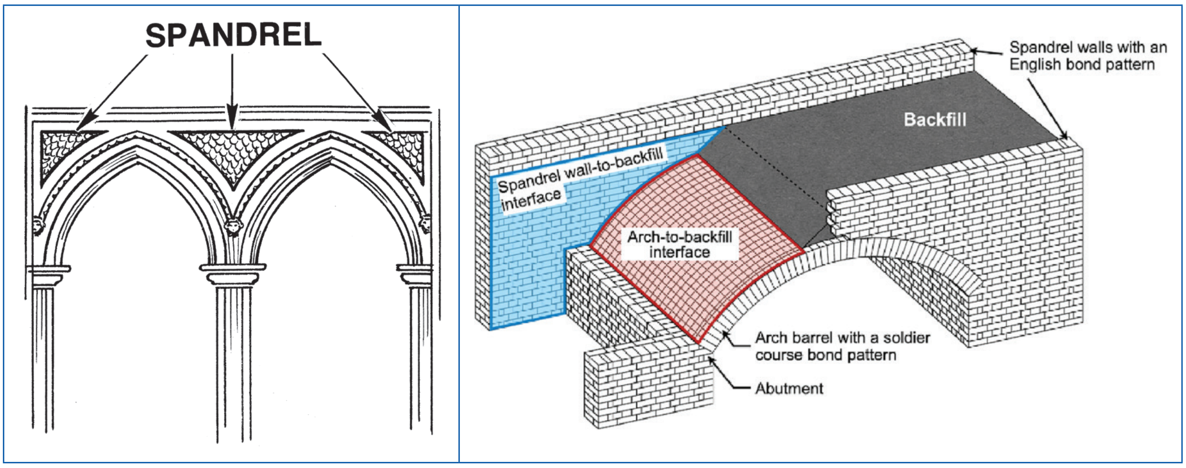
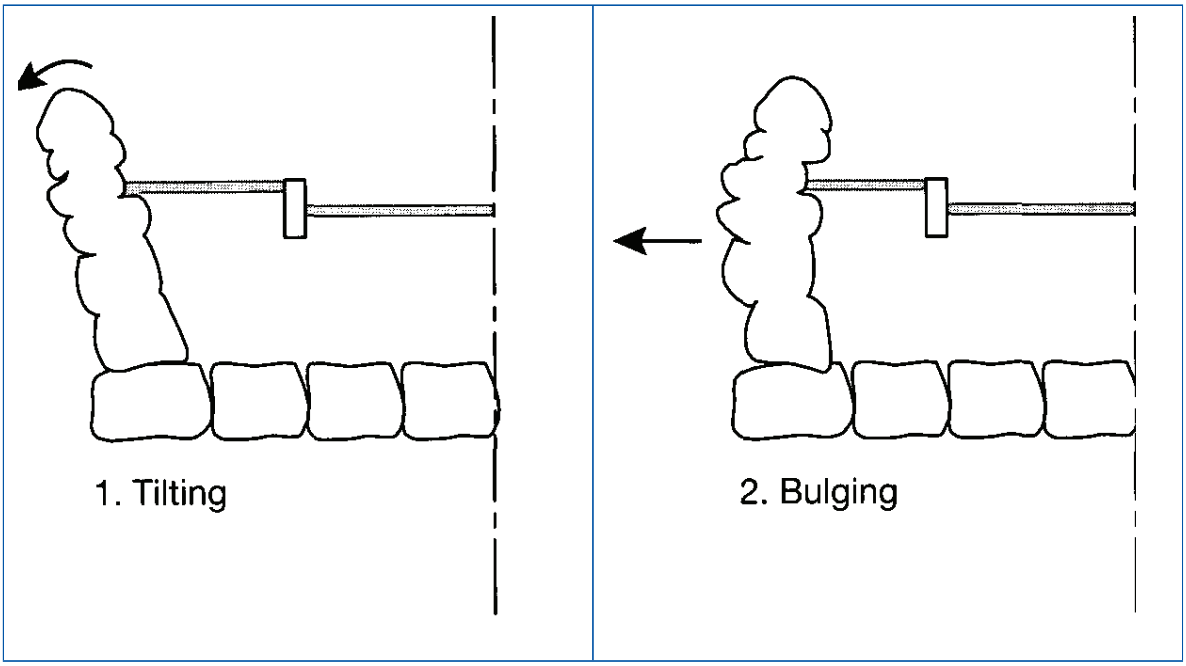


Figure 3-56 Cross section of arch bridge

Lateral forces or pressure in the fill material, especially if it becomes saturated, or those due to traffic loading may destabilize spandrel walls on arch bridges; vertical traffic loading increases lateral forces as it is distributed through the depth of fill.

Centrifugal forces can also be generated on curved bridges by turning and braking traffic, and these will be transmitted into the structure through the fill. Spandrel walls are more vulnerable to damage or displacement if no footway exists to prevent vehicles passing close to the side of the bridge. Without footpaths, vehicular impact is more likely and the effects of the lateral loading generated by the vehicle through the fill will be acute.

The consequence of this loading may lead the wall to tilt by rotating outward from the arch barrel, to deform by bulging, to slide on the arch barrel or to displace outwards detaching part of the arch ring, as indicated in Figure 3-57



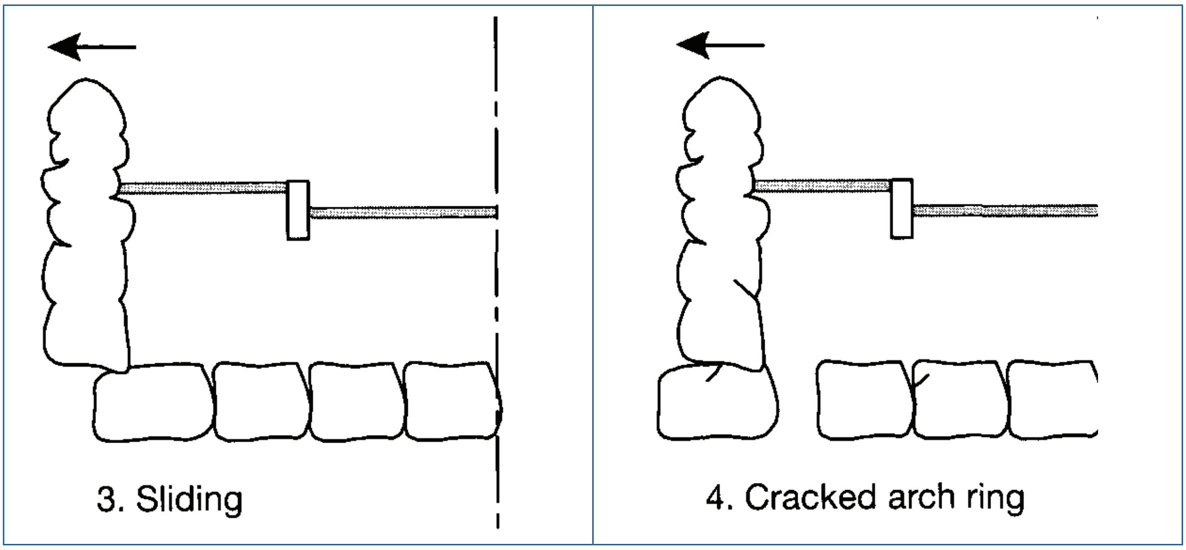


Figure 3-57 Sample photos of spandrel wall failures

3.2.6 Ancillary Elements

These are the component units of a structure that do not form the structural part i.e., they do not carry any load on the structure. They can be damaged and this can only affect the serviceability of the structure.

3.2.6.1 Railings/Parapets

These are rails or concrete barriers that are found at the edge of the deck to prevent road users from falling off.

Table 3-7 Common defects found on bridges railings

Defect	Description
Loss of parts	This is the loss of bolts, sections, rivets and anchorages, due to vandalism and accidental knocking by traffic or forces of nature.
Discoloration	This is the change in colour on surfaces of railings as a result of corrosion, aging on paint coating, defacing of members.
Bent members	This is the change in shape on members or parts of the bridge as a result of accidental knocking by traffic or forces of nature.
Loose connections/ missing bolts	This is weakening on steel connections after long term loading and exposure to environmental serviceability and vibrations.
Corrosion	Railings made of steel material are susceptible to corrosion when the antirust protective layer is worn out due to environmental changes and abrasion by the road users.
Crack in steel	Presence of cracks in a steel railing is a sign of failure and weakness.
Fracture	This is the breaking of steel members.
Spalling	Spalling occurs in concrete parapets due to impact or hit by the road users or even during construction.
Water leakage/ efflorescence	Due to the crystallization of soluble salts, as evidenced by white areas on the surface.

	
Missing members of the Railing	Deformed railing
	
Missing parts	Missing members of the Railing
	
Corroded railings	Missing members of the Railing

Figure 3-58 Sample photos of railing deteriorations

3.2.6.2 Drainage facility

Drainage system of a bridge comprises of drain pipes, weep holes and side drains which provide channel for flow of water from the structure. Drainage components are made up of various materials like PVC, Steel or even concrete.

A deck drainage system has the following components:

- Deck drains
- Outlet pipes - to lead water away from drain
- Downspouts pipes - to transport runoff to storm sewers
- Cleanout plugs - for maintenance

A joint drainage system is typically a separate gutter or trough used to collect water passing through a finger plate or sliding plate joint.

Substructure drainage allows the fill material behind an abutment or wing wall to drain any accumulated water. Substructure drainage is accomplished with weep holes or substructure drain pipes.

Table 3-8 Common defects found on drainage facilities

Defects	Description
Blockages	Blockage of bridge drainage systems occurs as a result of accumulation of debris in the conduits or at the inlet of drainage channels. **Causes:** ▪ accumulation of refuse, leaves and earth in the drain ▪ structures within the vicinity of the bridge can obstruct the flow of water ▪ excessive vegetation growing in drainage channels ▪ silt deposited in low sections owing to misalignment or where the slope is insufficient and cleaning is not regular enough.
Siltation	Long term accumulation of debris leads to siltation hence covering the drainage inlet and causing ponding.
Loss of cover	Cover on bridge drainage inlets occurs as a result of vandalism or accidental damage by traffic.
Broken or displaced joints	This is the loss of bolts, sections, rivets and anchorages due to vandalism and accidental knocking by traffic or other forces of nature such as wind, storm and earthquake.
Root intrusion	It occurs when roots initially find their way into the drainage lines through small crack, holes, or even the joints or gaps that are in between pipes if they are not secure. Roots from nearby trees will tend to grow into drains, especially if they contain stagnant water and the linings are permeable.
Collapsed pipe sections	This occurs when pipe sections fall off from hanging pipe conduits and collapses as sections, joints or as components. **Causes:** ▪ Erosion of the bottom and sides of the drain (scouring). ▪ Excessive pressure of water in the ground beneath and beside the drain lining. ▪ Vehicles passing over or too close beside the drains. ▪ Root growth, especially from nearby trees. ▪ Crown corrosion in closed drains containing sewage.

Defects	Description
Corrosion	Crown corrosion occurs in closed drains containing sewage, where gases from the sewage can attack and weaken cement, particularly over the crown or cover of the drain.
Outfall defects	All drainage outfalls should be free from damage and all joints or connections should be properly sealed. Adequate falls must be maintained. Outfalls should not discharge water where it may be detrimental to the bridge components, cause erosion of fill and embankment material or spill directly onto the road or railway below.
Drainage in box girders	In box girder bridges drains should be provided to remove water from the lowest point of the boxes, except for some steel box girders which are deliberately sealed to prevent ingress of air and water.
Short drain pipe	Drain pipes through deck slab should be extended beyond soffits of the slab and girders to avoid staining and subsequent damage of the surfaces of those elements.

Broken drainage system

Broken drainage system

Clogged drainage system

Missing manhole cover

	
Clogged drainage system	Clogged drainage system

Figure 3-59 Sample photos of drainage system deteriorations

3.2.6.3 Embankment Protection

Embankments around the abutments and wing walls should be protected against erosion. This is achieved by constructing gabions and stone pitching the surfaces. The gabion wire mesh can be torn or the material inside can be damaged thus reducing its ability to protect the surface. Stone pitching can be washed away by storm water or break when subjected to external loads.

Table 3-9 Common defects found in bridge embankments

Defect	Description
Embankment erosion	Erosion on bridge occurs as result of surface run off saturated with debris due to excessive precipitation. It can also occur due to wash out in case of heavy rainfall upstream leading to scouring on the side of the bridge embankment.
Damaged gabion protection	Gabion wire baskets can be worn out or torn due to wire abrasion by bedload movements in stream or can be vandalized. The permeable nature of gabions will usually arrest failures due to hydraulic pressure. However, this porosity can allow fines from the earth behind the wall to be leached out through the gabions. This may reduce porosity and increase the hydraulic pressure causing displacement of the gabions. Alternatively, voids may be formed behind the wall and settlement may occur.
Unwanted vegetation.	This is growth of unwanted vegetation near the bridge structure which could lead to damage on the bridge abutment and slope protection work.
Slope failure	Slope failure occurs when a slope collapses abruptly due to weakened stability of the earth under the influence of rainfall or earthquake.

Damaged protection works

Damaged gabion protection works

Damaged stone pitching

Damaged stone pitching

Figure 3-60 Sample photos of embankment deteriorations

3.2.6.4 Signage and lighting

Signs are provided to inform the road users about highway conditions and hazards and may include the following types: Regulatory signs, Warning signs, Direction signs, and Information signs.

When present, lighting on highway structures serves several purposes and consists of the following types:

- *Street or Highway Lighting* — lighting for illuminating carriageway, footpaths, cycle tracks and pedestrian subways open to public access.
- *Traffic Control Lights* — light signals used to control traffic.
- *Illuminated Traffic Signs* — internally or externally illuminated traffic signs, e.g., flashing school crossing warning signs, centre island beacons, and pedestrian crossing beacons.
- *Illuminated Traffic Bollards* — bollards lit by internal or base-mounted lighting units, irrespective of whether they carry a sign or not.

Lighting forms part of the traffic management, signalling equipment like lightings and road signs should be fully functional. Signage and lighting are prone to vandalism.

Table 3-10 Common defects found in bridges signage and lighting

Defect	Description
Defective Lighting	Bridge lighting systems should be effective, especially for underpass (tunnel) that are dark and need to be properly lit.
Missing Signage	Signage should be available to inform the road users about the safe use of the bridge/road.

Vandalized solar panel

Vandalized street light

Figure 3-61 Sample photos of signage deteriorations

3.2.7 Defects in other Structural Elements

They are component units of a structure that carry load and are common to all the bridge types.

3.2.7.1 Pavement/ Surface

Part of the bridge deck that provides a smooth-running surface for traffic and other road users. Can have potholes and ruts if made of Asphalt Concrete.

Table 3-11 Common defects found on pavement:

Defect	Description
Cracking	This refers to cracking on the pavement/surfacing on the deck slab due to excessive loading on the bridge structure. Cracking can take many forms depending on the nature of the failure and the characteristics of the particular surfacing materials. In some cases, the cracking is an indication of failure to the surfacing material, while in others it indicates excessive movement or deterioration of the underlying deck. With time, crumbling of the surface material along the edges of the cracks takes place and the ingress of water may lead to loss of adhesion between surfacing and deck. Check the positional relationship between the damaged position of the underside of the deck and the damaged part of the pavement.

Defect	Description
Excessive deformation	This defect results from excessive loading on a bridge member as a result of long-term loading.
Loss of skid resistance	This is loss of sufficient grip/friction needed for traffic movement on the bridge deck. It can be attributed to wear and tear due to traffic whip off and traction forces on tyres.
Siltation	Siltation occurs as result of water pollution caused by particulate terrestrial clastic material, with a particle size dominated by silt or clay. It refers both to the increased concentration of suspended sediments and to the increased accumulation (temporary or permanent) of fine sediments on underside where they are undesirable.
Potholes	These occur as a result of damage on pavement layers and surfacing as result of deterioration of materials due to traffic action and poor drainage.
Rutting	This deformation is caused by continues heavy wheel loads passing along the carriageway in the longitudinal direction. Wheel indentation may progress rapidly in warm weather. Whilst wheel indentation by itself may not indicate failure of the surfacing the main effects are to prevent water draining effectively from the carriageway surfacing.
Other pavement surface failure	These are other failures like, blisters may form in the surfacing in warm weather, uneven riding surface that may cause discomfort to the road users.

Siltation on the pavement

Siltation on the pavement

Cracks on the pavement

Potholes on the pavement

	
Cracks on the pavement	Potholes on the pavement

Figure 3-62 Sample photos of pavement deteriorations

3.2.7.2 Foundation

The foundations should be checked for any movements either settlement or lateral. Also, should be protected from sapping/scouring.

Table 3-12 Common defects found in foundations:

Defect	Description
Scouring	Scouring occurs when moving water erodes foundation material causing displacement/loss of material adjacent to the foundation.
Sapping	Sapping is the wearing off of material beneath the foundation of a structure leaving a space between the foundation and the ground.
Settlement	Differential settlement is the difference in vertical movement of a foundation. This can be determined by cracks formed on the structure components supported by the foundation.
Lateral Movement	Lateral movement is the horizontal movement of a foundation, this mostly happen when the abutment or pier is constructed on a slope or near river bed.

	
Scouring	Sapping

Scouring

Sapping

Figure 3-63 Sample photos of foundation deterioration

3.2.7.3 Expansion joints

Joints provide a running surface across the expansion gap. Joints allow movement and/or are a feature of the construction form. They may be open (allow water and debris to pass through) or closed (do not allow water and debris to pass through).

Expansion joints can be corroded if made of steel, can be clogged by silt material hence not allowing smooth movement of deck at the joints, expansion joint devices can be vandalized.

Types of expansion joint

1. **Buried joint:** formed from a flexible component such as an elastomeric pad installed beneath continuous surfacing. This type of joint is selected for smaller movement ranges (up to 20mm horizontally and 1.3mm vertically. The expected lifespan is 10-12 years and the recommended inspection interval is 6 years or 2 years after the end of the expected service life

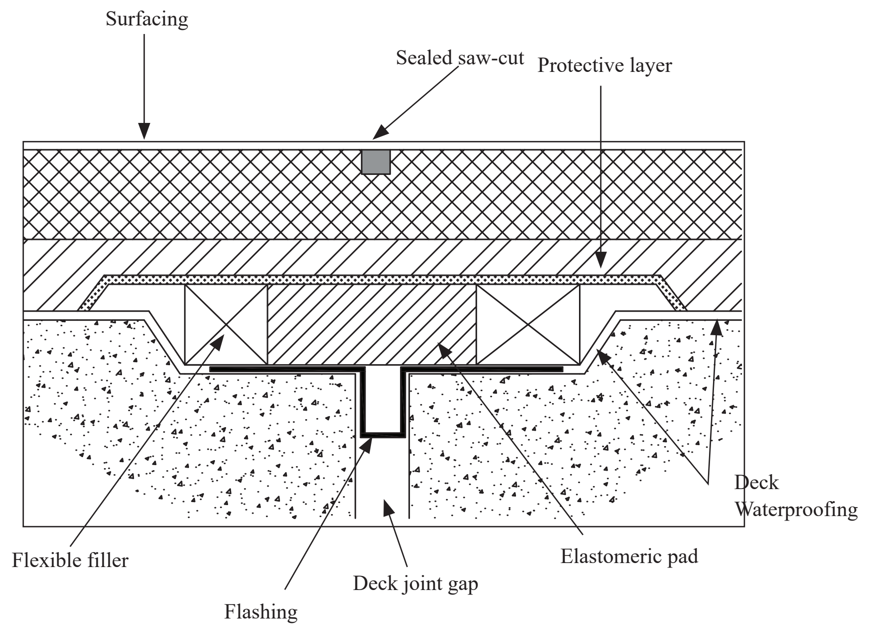


Figure 3-64 Buried joint

Table 3-13 Common defects found on buried joint

Type	Defect	Description
Buried joint	Surfacing cracking or breaking up	This is likely to be caused by deck movement, which the surfacing has been unable to accommodate (indicated by cracks across the carriageway). Once cracked, water and vehicle impact will lead to further damage. The top of a crack may close on a heavily trafficked route due to the flexible nature of the surfacing, but it will still allow water seepage and be liable to break up.
	Crack inducer defects	Cracking can be managed by a crack inducer, typically a saw-cut across the surfacing, filled with flexible sealant. This allows some movement without generating stresses in the surfacing. The sealant in the crack can be pushed out, as the saw-cut will tend to close under traffic loading. The sealant will also deteriorate with time, cracking by itself. A lack of sealant in the saw-cut will allow the surfacing to break up as it will be unsupported.
	Leakage	Leakage is less likely in buried joints than most other joint types because the waterproofing is continuous. One possible cause of leakage is a discontinuous flashing across the deck.

2. **Asphaltic plug joint:** formed from a flexible material, which also forms the road surface over the expansion joint gap. Typically, a metal plate, or other similar component, spans the gap to support the plug. This joint is for smaller movement ranges, though greater than the buried joint (typically up to 40mm horizontally and 3mm vertically). The expected lifespan is 5 years and the recommended inspection interval is 2 years.

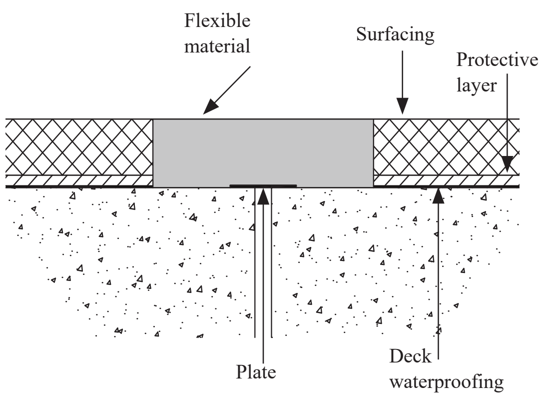


Figure 3-65 Asphaltic plug joint

Table 3-14 Common defects found on Asphaltic plug joint

Type	Defect	Description
Asphaltic plug joint	Tracking and flow of binder over adjacent road surface	If the plug material is too soft, it will become depressed under tyre loading, and will also flow out of the joint and onto the adjacent surfacing forming mounds at the edges. This is most likely under slow moving traffic or at higher temperatures. Tracking leads to breaking up of the plug and loss of support to the adjacent surfacing.

Type	Defect	Description
	Debonding between joint and road surfacing	The watertight ability of the joint is dependent on a good bond between the plug and the deck and surfacing. Debonding allows water into the joint. A lack of bond will also lead to damage to the top edges of the plug and adjacent surfacing leading to break up of both plug and surfacing. Debonding is most likely to occur where the plug material is stiff coupled with relative movement.
	Breaking up of road surface adjacent to joint	When the joint becomes de-bonded, the edge of the surfacing becomes unsupported, which leads to break-up. It could also be caused by water underneath the surfacing being unable to dissipate due to blocked or lack of sub-surface drainage. It is most likely to occur on the upper side of the joint, where the water has drained to and then stopped as the joint forms a dam across the road. Break up of surfacing will expose the plug, leading to its break up, deteriorated ride quality and seepage of water to the joint.
	Cracking	Cracks are most likely to occur at a position coinciding with the plate and in this case are probably caused by an uneven joint base causing the plate to bend. Cracks also occur when the movement range is large.
	Breaking up of plug material	In addition to the causes above, break up can be caused by water saturating the plug, usually after debonding from the surfacing. Hydraulic forces then lead to break up. Poor workmanship at installation may cause break-up of the plug, due to a lack of binder in lower levels or the binder and aggregate becoming detached. Break up leads to deterioration of ride quality, damage to surfacing and water access.
	Leakage	Leakage caused by the defects described above will affect the durability of the structure.

3. **Nosing joint:** The nosing materials protect the adjacent edges of the road surfacing, and may be pre-fabricated or cast in-situ. The two nosings support a seal. The joint relies on the adhesion of the seal on the vertical interfaces with the nosing material. The seal can be replaced, without interfering with the nosings. Type 3 joint has a poured sealant (maximum movement of 12mm), type 4 joint has a pre-formed compression seal (as shown in the diagram, maximum movement 40mm). The expected lifespan is 5 years and the recommended inspection interval is 2 years.

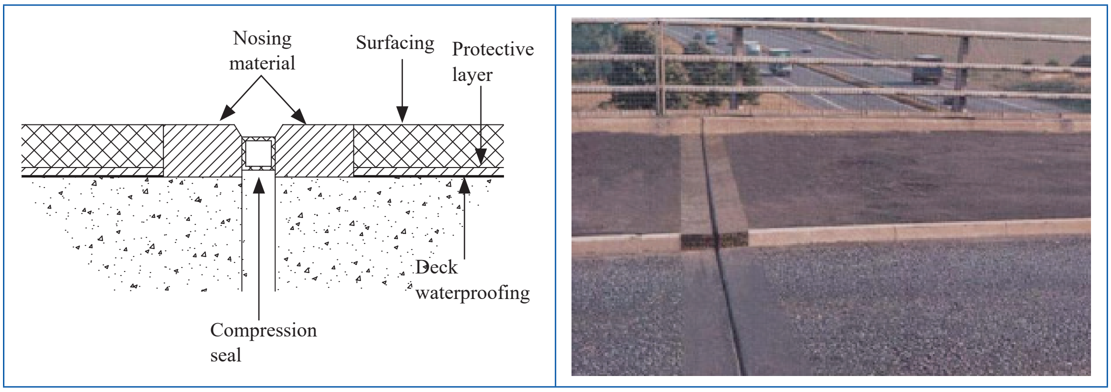
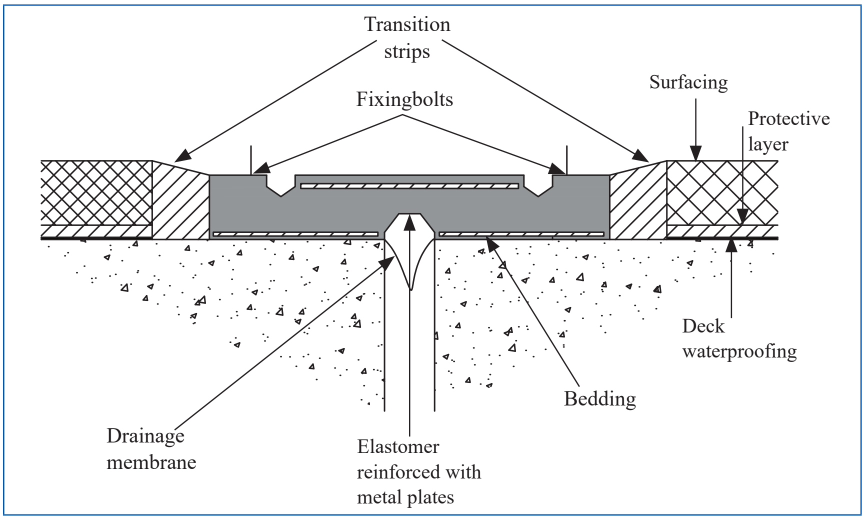


Figure 3-66 Nosing joint

Table 3-15 Common defects found on Nosing joint:

Type	Defect	Description
Nosing joint	Seal can slacken under temperature extremes	Temperature extremes will compromise the resistance of the adhesive holding the seal leading to ingress of water into the joint.
	Seal displacement	Debris build up on the seal will allow greater forces to be transmitted from vehicles to the seal, leading to debonding from the nosing material.
	Ponding at back of nosing	The nosing material forms a barrier across the permeable surfacing material. Blocked, non-existent or otherwise failed drainage will not allow this water to dissipate, and so subject the surfacing to internal hydraulic pressures as traffic crosses. This will cause the surfacing to break up, leaving the nosing material exposed. An exposed nosing will be subject to horizontal forces and start to break up or detach from the concrete deck.
	Nosing break up and de-bonding from adjacent surfacing	Breakup of the nosing usually follows debonding or deterioration of the adjacent surfacing. Break up then happens as the edge is unsupported and so subject to increased traffic forces and is not restrained.
	Concrete break up	Impact from Heavy Goods Vehicles (HGV) causes underlying concrete to break. HGV loading may be transferred through the nosing material and impact on the structure below the joint.
	Leakage	Once the seal is displaced, water will leak through into the structure below affecting its durability.

4. **Reinforced elastomeric joint:** The major component comprises of an elastomeric unit, reinforced by metal plates. It is secured to the deck concrete with fixing bolts, which are sealed with resin plugs. Transition strips provide a continuous running surface between the road surface and joint unit. They come in a variety of shapes and sizes, with varying movement ranges up to approximately 330mm. The expected lifespan is 6 years and the recommended inspection interval is 2 years or annually after the end of expected service life. A disadvantage of this joint is that "failure is likely to cause a hazard to traffic and for this reason frequent inspection is necessary".



	
Wide joint, in fair condition. Note debris in grooves.	Narrower version, but in poor condition. Note missing resin plugs, top plate and rubber. Also note depression in carriageway to left of joint, and cracks to the surfacing adjacent to transition strip, which is beginning to break up.

Figure 3-67 Reinforced elastomeric joint

Table 3-16 Common Defects in reinforced elastomeric joints

Type	Defect	Description
Reinforced elastomeric joint	Breaking up or cracking of transition strips	This is generally caused by the transition strip becoming debonded, either from the surfacing or from the deck or abutment. Once debonded, the edge will be unsupported, and start to break up. This can happen to the transition strip and adjacent surfacing. Tracking of the adjacent surface can lead to the transition strip becoming exposed, and therefore subject to much greater forces from traffic loading, causing break up.
	Bolt cover pads missing	The cover pads can be flicked out by traffic, leaving the bolts underneath exposed. Corrosion of the bolts will lead to premature bolt failures
	Loose bolts	This will lead to movement of the joints, detected either through noise or visual observation under traffic loads. This leads to further loosening of bolts.
	Lifting of the joint	Severe bolt failures will cause the joint to move under traffic. This will lead to impact damage to the deck below the joint.
	Debris in grooves	Debris in grooves will restrict movement of the joint and cause wearing of rubber under traffic loading.
	Wear of rubber ribs on top of joint.	Wear will reduce the skid resistance. Significant wear will expose the steel plates beneath the rubber, leading to delamination.
	Delamination of elastomer/ metal plate interface	Progressive wear and tears in the elastomer will result in delamination, exposing the steel plate over significant areas of the joint. The metal is smooth, and so skid resistance will be limited. The exposed metal plate may also lift up, causing an obstruction in the carriageway.

Type	Defect	Description
	Leakage	This could be caused by any of the defects above, or failure of the drainage membrane. The effects could be damage to the carriageway on either side of the joint, or early deterioration of the bridge structure.

5. **Elastomeric in metal runners (cast-in and resin encapsulated):** The expected lifespan is 20 years (cast-in) and 10 years (resin encapsulated) The recommended inspection interval is 6 years or 2 years after the end of the expected service life

a) Cast-in (single element):

In this joint the outer rails are secured into the deck and abutment with reinforcement as shown in the drawing. On the deck, there is no transition strip; the surfacing is separated from the rails only by sealant. Movement ranges are typically up to 80mm, although it also restricts the width of an open gap to 65mm.

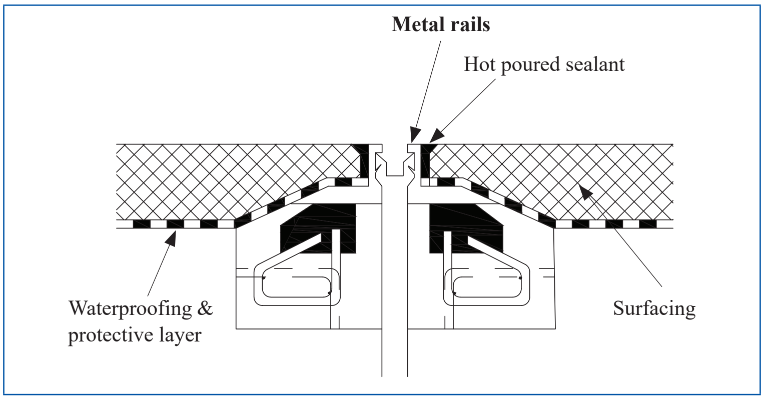


Figure 3-68 Cast-in (single element)

b) Cast-in (multiple element):

To accommodate greater movement, this type of joint can feature several rails in the configuration shown. The bearing components of the joint permit movement, while the elastomeric elements keep the surface continuous and seal the joint. The securing framework is cast into the deck and abutment. The joint can be made from multiple rails depending on the movement range required, up to around 640mm.

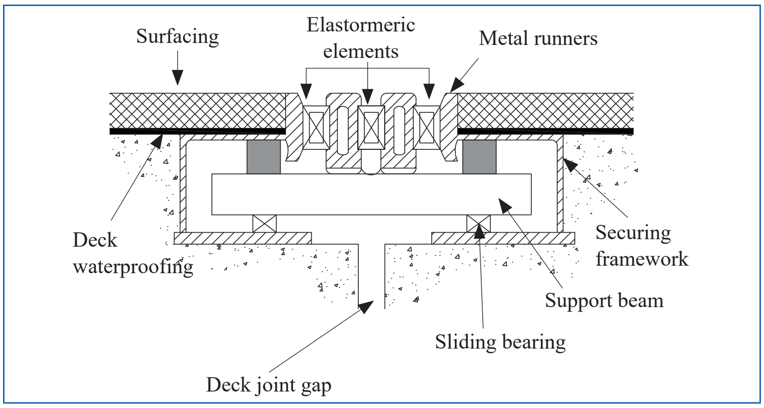


Figure 3-69 Cast-in (multiple element)

c) Resin Encapsulated Joint

This joint type functions on a similar principle to the top joint, above. The elastomeric seal is attached to the metal rails. The rails are held in place by reinforcement, which is encapsulated in a resin which is bonded to the deck/abutment. The movement range will depend on manufacturer/model, but is typically up to 150mm, although it restricts the width of an open gap to 65mm.

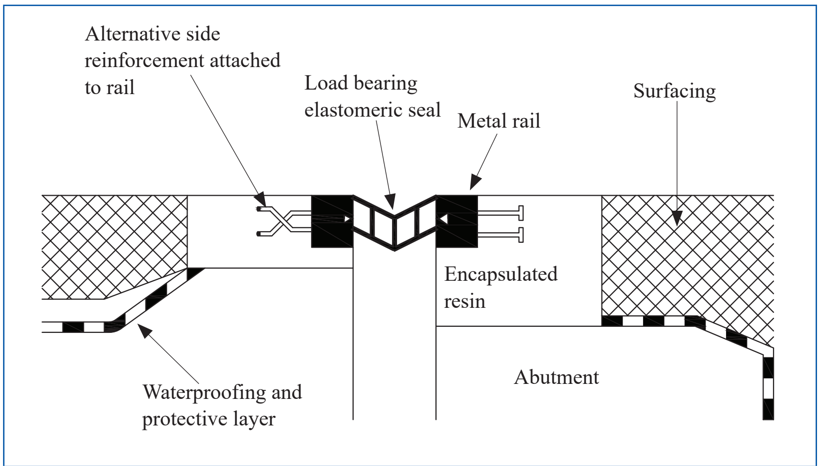


Figure 3-70 Resin Encapsulated Joint

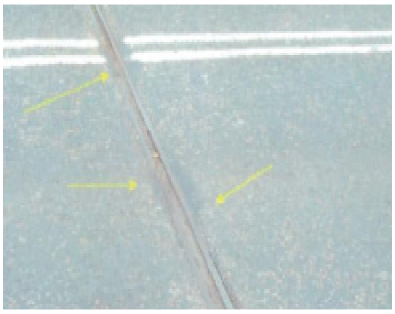
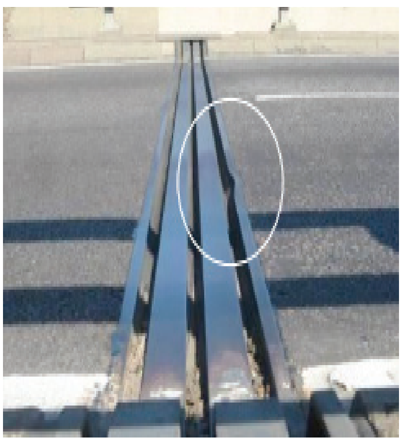
		
No central rail configuration, cast-in type.	Several central rails configuration	Resin encapsulated (resin visible either side of rails).
		
Deformed metal rail	Resin has broken down, exposing reinforcement	Rail has dropped, visible from underneath

Figure 3-71 Sample photos of deteriorations in Resin Encapsulated Joint

Table 3-17 Common defects found on Elastomeric in metal runners cast-in and resin encapsulated

Type	Defect	Description
Elastomeric in metal runners (cast-in and resin encapsulated):	Elastomeric seal breaks up or pulls out	Siltation and debris will enable forces from passing vehicles to exert forces on the seal, leading to failure. This will then cause leakage. Debris can be left following resurfacing works. The seals on resin encapsulated joints are wider, and so larger and more debris can collect, leaving this seal more vulnerable. Excessive movement may cause the seal to pull out.
	Seal puncture	Stones or other sharp object may be pushed through the seal by traffic. The breach may be difficult to identify without close inspection, or inspection from underneath.
	Surfacing or resin breaks up or cracks adjacent to metal rails	This is usually caused by water ingress and aided by vehicle loading. Wet weather, followed by freezing conditions will accelerate deterioration of adjacent surfacing. This will at first leave the resin exposed, which is often relatively brittle and will deteriorate quickly. The metal rails then become exposed and so will be subject to lateral vehicle loading, causing distortion. Breakup of the resin can also leave the reinforcement exposed.
	Worn out metal rails	Worn out runners will be polished and are a hazard to vehicles, particularly motorcyclists and particularly if located on a skew or at a curve in the road.
	Distorted metal rails	Tracking of the adjacent surfacing, or of the resin, will leave the leading rail exposed to lateral traffic forces. This will cause that rail to twist or rotate. This can also be caused by resurfacing works not being completed to the correct level. Distorted runners can be caught by trailing elements of vehicles pulling them out.
	Fatigue of metal component	Fatigue damage is caused by cyclic loading of a component. This is exactly what happens as traffic crosses the joint. Eventually the component will fracture. Welded joints are prone to fatigue failure. Fatigue is difficult to detect prior to fracture, but age of component and expected lifespan can provide an estimate to residual life. A heavily trafficked route or a route with a high number of HGVs will increase cycle frequency and increase loading range, both of which reduce component service life.
	Snapping of top plate	The top plate which secures the seal can snap due to fatigue dislodging the seal. When the seal breaks free there will be ingress of water into the joint, causing damage to the joint components, as well as to the bridge structure.
	Leakage	Research has shown that the cast-in type joints are the least likely to leak. However, leakage is still a possibility, and will have an impact on the durability of the structure.
	Sub-surface components	The multi-element joints have a support mechanism below the surface level rails. This supports the rails and keeps them evenly spaced and parallel as the bridge deck moves. Leakage into the joint could cause corrosion of these parts, ultimately leading to failure of the joint.

Type	Defect	Description
	Vegetation	Vegetation can grow where debris builds up in the void underneath the joint, allowing accumulation of water inside the joint and interference with the smooth operation of the mechanical parts.
	Debris in seal	Debris in the seal can restrict movement of the joint, as well as leading to increased forces on the seal.

6. **Cantilever comb or tooth:** These joints can be purpose made for a particular installation and can accommodate large movement ranges, up to approximately 1000mm. The gaps between the teeth open and close as the bridge contracts and expands. The expected lifespan is 25 years and the recommended inspection interval is 6 years or 2 years after end of expected service life.

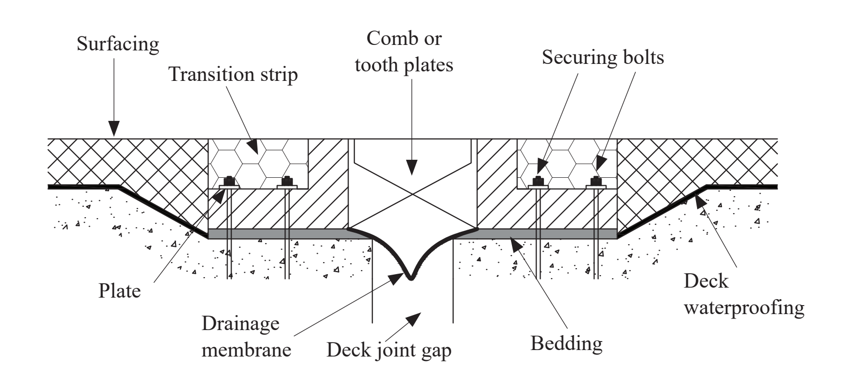


Figure 3-72 Cantilever comb or tooth

		
Gaps in teeth need cleaning and metal surface appears polished.	Plate missing in centre of photograph	Teeth, broken from the main component.

Table 3-18 Common defects found on cantilever comb or tooth

Type	Defect	Description
Cantilever comb or tooth:	Wear of metal surfaces	Friction from vehicles will smooth and polish the metal, reducing the skid resistance, increasing the potential for accidents, especially on skewed joints, curved roads or at junction approaches.

	Loosening of bolts/failure of concrete anchorage	Initially this will cause movement of the plates, causing noise and increasing the probability of further bolt failures. This could lead to misaligned teeth or damage to adjacent surfacing or bedding material through impact.
	Misaligned teeth	Lateral displacement of one set of teeth means the teeth are no longer aligned. This is more likely to happen on skewed joints, or where vehicles are turning, which produces lateral forces. The result will be a restricted movement range.
	Drainage membrane splits	Permits water to enter the expansion gap, leading to reduced durability for the structural elements of the bridge.
	Debris / Corrosion	A build-up of debris will block the joint, restricting movement and imposing undesired forces on the bridge structure. The debris will also hold water, and the combined effect of wear caused by the debris and the moisture will lead to corrosion of the components. Corrosion will lead to loss of section of the teeth, reduced load capacity, loss of ductility and eventual breakage of the teeth.
	Hairline cracks	Hairline cracks are an early sign of eventual tooth failure. Where discovered, the supervising engineer should be notified.
	Breakage of teeth	Missing teeth can be a hazard to pedestrians, animals, cyclists and motorcyclists, as wheels can slip or become trapped.
	Abnormal gap	Damage to the expansion joint may occur due to damage of the bearing or bearing seat and movement of the substructure.

	
Siltation of the expansion joint	Water ponding at the expansion joint

	
Pavement failure on expansion joint	Cracks on post cast concrete
	
Abnormal gap	Corroded expansion joint

Figure 3-73 Sample photos of expansion joint deteriorations

3.2.7.4 Approach slab

The approach slab, is a slab positioned below the road surface on the approach to a bridge, the end of which normally rests on the back of the abutment which shows the typical location of the approach slab in relation to the bridge abutment. The purpose of the approach slab is to provide a smooth transition for traffic from the road to the bridge and vice versa. Approach slabs are normally made of reinforced concrete.

Table 3-19 Common defects on the approach slab

Defects	Description
Settlement of approach slab	This occurs due to inadequate compaction of pavement layers below the approach slab or due to inadequate provision of dowel bars connecting the abutment wall to the approach slab.
Cracks	This could be caused by consolidation of backfill material over time or due to poor quality or workmanship of concrete works.
Scour or erosion of back fill	This occurs due to inadequate protection of backfill material which is susceptible to erosion by storm water.

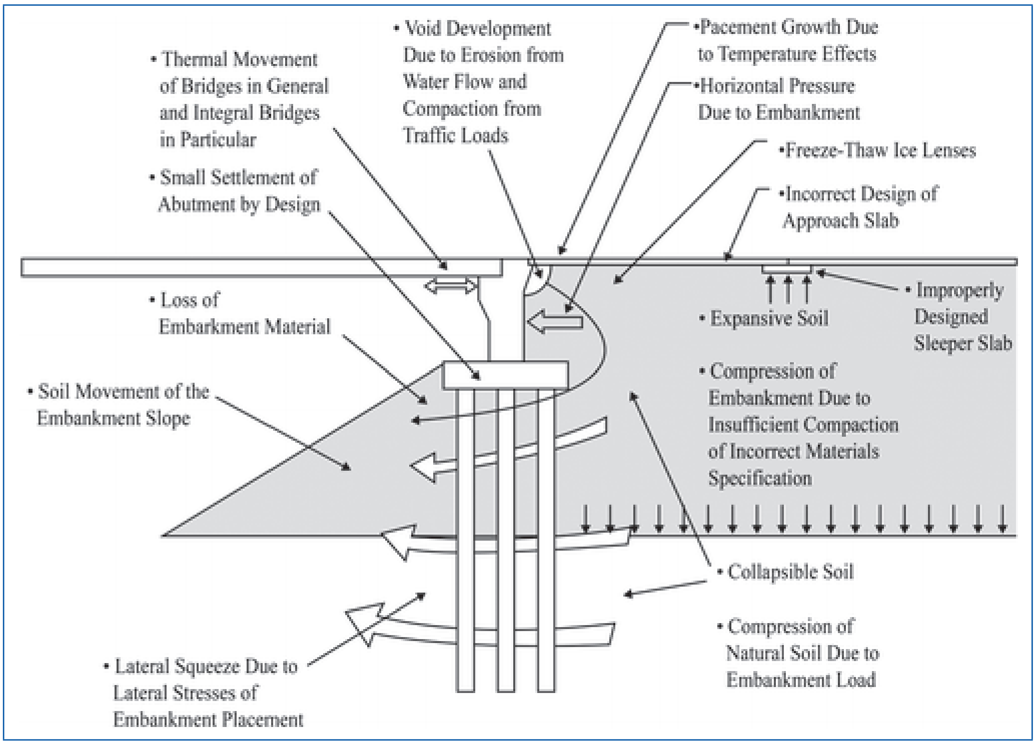


Figure 3-74 Sample diagram showing the causes of settlement of an approach slab.

Settlement of approach slab

Gap at barrier end

Figure 3-75 Sample photos of approach slab deteriorations

3.2.7.5 Damage on reinforcing members

Reinforcing members can be corroded which may lead to section loss if not protected, bolts and nuts can be loose or even missing. They should also be inspected if there are cracks present.

Vandalism of bracings, beams, bolts, nuts and gusset plates has been experienced in steel truss bridges and can cause collapse of such structures.

Dislodging of steel members on steel bridges by debris (rocks, logs etc.) carried by floods waters during the rainy season.

Damage of steel reinforcement bars in concrete girders by trucks carrying loads exceeding the legal clearance of the bridge.

Figure 3-76 Sample photos of reinforcing members deteriorations

3.2.7.6 Gap error of girder end

Abnormal gap between the girder end and the abutment back wall/pier. This can be caused by foundation failures due to lateral movements, exposure to thermal movement, constant vibrations, extreme weathering, mechanical impact from the traffic and chemical impact from spillage.

The gap can be sealed with sealants e.g., polyethylene which is elastic and non-biodegradable. The sealants must prevent ingress of water and dirt from accessing the gap and protect the structure from damage of bridge bearings and girder elements through corrosion. Durable waterproofing has a significant impact on the life expectancy of the bridge.

Figure 3-77 Sample photos of gap error of girder end

3.2.8 Defects in complex bridges

Even for large scale bridges, the items that must be inspected are the same, unless the structural type is unique. This section discusses cable-stayed bridges as special bridges and introduces inspection items that arise for cable-stayed bridges.

3.2.8.1 Damage on Cable

Cable-stayed bridge cables are important structural members suspending the superstructure. Since the strand inside the cable is normally covered and not visible, it is necessary to check the surface for damage to the cable. If internal deterioration is suspected by inspection of the cable surface, remove the cover and inspect the strands directly.

Figure 3-78 Sample photos of Damage on the Cable

3.2.8.2 Anchorage

Anchorage is the part where the cable is anchored to both sides of the superstructure and the pylon, and must be carefully inspected because it is the area where the force borne by the cable is concentrated. In addition, water entering the anchorage from the boundary between the cable and the anchorage will cause deterioration, so the anchorage must be designed to prevent water ingress.

Figure 3-79 Anchorage

3.2.8.3 Inclination of pylon

The cable-stayed bridge is designed to balance on both sides of the main pylons. Therefore, it is necessary to inspect the main pylons to ensure that they are not tilted as compared to the design. Since some designs may intentionally incline the main pylon, the original angle of the pylon must be ascertained in advance from the design drawings or as-built drawings, before the inspection.

4 BRIDGE INSPECTION PROCESS

4.1 Introduction

An initial inspection is a detailed observation of all visible elements of the bridge, it shall be systematically conducted so as to avoid any errors and omissions. In order to achieve this, a rational approach is required for the development and delivery of a robust inspection regime. This chapter introduces a six-step process to be adopted by implementers to develop and execute an effective inspection.

The Inspection process involves the following steps:

1) Planning and scheduling the inspection
2) Preparing for the inspection
3) Performing the inspection
4) Analysis and assessment
5) Record and report
6) Input to maintenance planning process

Figure 4-1 The inspection process

Specific details of each section have been outlined in table 4.1. The topics covered herein apply to all inspection types, however, the amount of time and effort required should be commensurate with the specific circumstances and inspection type.

Table 4-1 Summary of purpose and content of each section

Section	Summary of purpose and content of each section
Planning and scheduling the inspection	This section provides guidelines for scheduling inspections and outlines the factors that should be considered when organizing different types of inspection.
Preparing for the inspection	This section provides guidance on adequately planning for inspections and outlines the factors that should be considered. It provides advice on the preparation of method statements, risk assessments, guidance on the selection of appropriate access and other equipment. This section also outlines Health and Safety considerations and potential environmental impacts.
Performing Inspections	This section provides details relating to performing inspections on structures constructed of different materials and certain special structures.
Analysis and assessment	The aim of analysis and assessment is to establish the safe load carrying capacity of the bridges.

Section	Summary of purpose and content of each section
Record and report	This section provides recommendations on the adoption of a generic process that would facilitate the recording, rating and reporting of defects and inspection results.
Input to maintenance planning process	This section provides brief guidance and appropriate references that should be utilized for the input of the inspection findings into the maintenance planning process.

4.1.1 Planning and scheduling the Inspection

This section provides guidance on scheduling inspections and outlines the factors that should be considered when programming different types of inspections. Table 4.2 below outlines the different types of inspection, objectives of the inspection, methodology to be adopted, frequency of the inspections and tolerance.

4.1.1.1 Objectives of the inspection

All structural maintenance and management activities have the ultimate aim of ensuring the continued safety and functionality of the structure. However, the work may be subdivided into two phases, each with different objectives:

i. *Phase 1: Condition Monitoring* - the process of inspecting, testing and recording the condition of the structure.

ii. *Phase 2: Diagnosis* - the process of determining the causes of any defects that are observed.

Inspections may be required during each phase. Most inspections fall clearly into Phase 1, e.g., safety, general and initial inspections, others may have objectives that cover two phases, e.g., special inspections fall into Phases 1 and 2.

4.1.1.2 Planning for inspection

There are a wide range of criteria that can potentially influence the date of an inspection. Common issues that should be taken into account during the scheduling of inspections include:

- Inspection requirements
- Availability of resources
- Traffic management
- Stakeholder engagement
- Weather conditions
- Tidal locations
- Environmental issues
- Scheduling tolerances

4.1.1.3 Inspection Requirements

The inspection schedule should align with Table 4-1. Where the implementing entity deviate from these requirements, it is important that they fully document their reasons for the departure and the supporting rationale for the alternative timings. Careful consideration should be given to increased inspection intervals, failure of which could lead to defects becoming more severe before they are detected. This could lead to possible danger to the public and may leave the implementing entity exposed to liability claims.

4.1.1.4 Availability of Resources

The inspection schedule should be commensurate with the available resources. Consideration should also be given to the availability of inspection equipment, personnel and funds. The schedule should optimize the use of available resources.

4.1.1.5 Traffic Management

The schedule should put into consideration the traffic management measures that are applicable to the type of inspection, location and time.

4.1.1.6 Stakeholder engagement

The supervising engineer/inspector should adhere to statutory requirements and seek approval from the concerned stakeholders in regards to working on the structure which might be in proximity to an area under their management.

4.1.1.7 Weather Conditions

When programming inspections, due regard should be given to prevailing weather conditions. Some defects, such as leaking joints, blocked drainage or cracks in concrete elements, are more prominent during or just after rainfall. While it is difficult to program work to coincide with wet weather, the opportunity should not be overlooked. Bridges inspected during dry weather could be revisited (as part of a Safety Inspection) during the next spell of rain to check whether expansion joints or drainage are leaking/blocked and adequate.

4.1.1.8 Tidal location

Inspection of structures at tidal locations should be planned to coincide with advantageous tidal conditions. For instance, high tides may prevent access to more parts of the structure whereas low tides may afford slower tidal flow and less change in water level or vice versa depending on the specific inspection point.

4.1.1.9 Environmental Issues

When scheduling inspections, due consideration should be given to environmental issues that may influence the timing of inspections, such as nesting birds, hibernating bats, etc. If access is required over agricultural land, the timing of the inspection could be affected by growing crops or other farming activities.

4.1.2 Preparation of Inspection

This section provides guidance on adequately planning and preparing for inspections and outlines the factors that should be considered. Appropriate planning should consider the factors as described below:

- *Method statement* - The method statement summarizes all relevant information that should be prepared and agreed before undertaking an inspection. It should include information such as details and programme of activities, resources allocated, health and safety, environmental and traffic management considerations, temporary works provided, necessary approvals and need for coordination required among others.
- *Resource Allocation:* Selection of the inspection team and the necessary equipment required for the inspection needs to be determined. Consideration for the competency of the inspection staff should be reviewed and the availability and serviceability of the equipment should be checked.

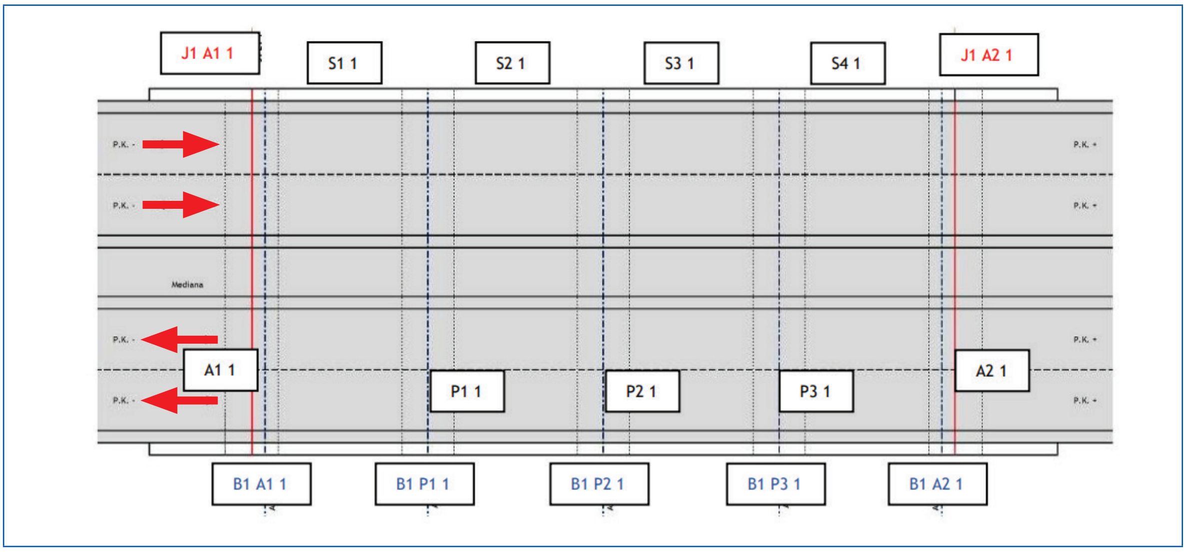
- *Reviewing the bridge structure file* - Ensuring the review and consideration of various structural records available e.g. As-built bridge plans, previous inspection reports.
- *Health and Safety* - The appropriate health and safety considerations should be taken into account as highlighted in *Chapter 5* of this manual. However, in addition to this the considerations should be managed to comply with the requirements of the Occupational Safety and Health Act (OSHA) 2007 as well.
- *Methods of access* - This would generally require consideration of the types of access equipment to be used, the restrictions or obstructions caused by the equipment, traffic management requirements, and the routes to be used to and from the highway structure site.
- *Type and extent of testing* - Reviewing and confirming the types of tests, their location, extent and intensity.
- *Notification of the work* - Ensuring that all the necessary notifications and approvals have been done or obtained from other relevant parties identified during the planning phase.
- *Other special consideration:* Environmental impacts and risk assessment should also be reviewed and necessary mitigation measures for dealing with hazards should be undertaken before work starts.

4.1.3 Performing the Inspection

This is an on-site activity to access and examine all relevant bridge attributes including measurements and entails the following basic activities;

- Identification of the correct location of the itinerary bridges.
- Setting up of respective traffic management and safety measures.
- Do reconnaissance of the site and establish any requirements for any deviations in the planned method statement initially envisioned for implementation if any.
- Systematic identification of elements
- Visual examination of bridge components
- Physical examination of bridge components using equipment
- Evaluation of bridge components
- Examination and evaluation beneath the structure, and approach slab.

Upon arriving at site and performing the necessary traffic and safety checks, it is prudent for an inspector to establish the orientation of the site and bridge elements, ensuring adherence to identification criteria of bridge parts as sampled in Figure 4-2 The inspection process_before embarking on the on-site inspection. This enables the ease of performing the inspection and recording the identified defects.



Key	
A1	Abutment 1,2
B1	Bearing 1,2,3...
J1	Joint 1,2,3...
P1	Pier 1,2,3...
S1	Span 1,2,3...

Figure 4-2 Sketch for identification of bridge elements

The inspections should be done sequentially from the top of the bridge to the underside covering all elements of the bridge and ensuring that the team in-charge has captured each defect for each identification, the team shall collect the following data:

i. Inspection general data

ii. Observed deterioration and its location

iii. Comments

iv. Photographs

An inspector also needs to be knowledgeable about the general procedures and areas that may require special attention when inspecting various bridges which can depend on the bridge type, the materials used, and the general condition of the bridge.

Table 4-2 Example of bridges that require special attention when inspecting

No	Name of bridges	Type of Bridge
1	Masalani bridge	Suspension bridge
2	Bura bridge	Cable Stayed bridge
3	Nyali bridge	Box Girder bridge
4	Mtwapa bridge	
5	Sabaki bridge	
6	Kilifi bridge	
7	Baricho bridge	

No	Name of bridges	Type of Bridge
8	Marigat bridge	Steel Truss bridge
9	Galana Kulalu bridge	
10	Endau bridge	
11	Nginyang bridge	
12	Wei Wei bridge	
13	Lomut bridge	
14	Mbita Causeway bridge	
15	Kalobeyei River bridge	
16	Lugards bridge	Bailey bridge
17	Thua bridge	Steel box girder/modular
18	Likoni floating footbridge	Steel truss/floating truss
19	Makupa Bridge,	Pre-Stressed Conc. girder bridge
20	Mteza Bridge	
21	Tsunza bridge	
22	Mwache bridge	

(1) Cable stayed and suspension bridges

These bridges primarily rely on the action of cables to support the structure. The major comparison is that Cable Stayed Bridge require less cable, constructed at a shorter time and cost-effective than suspension bridges.

During the inspection of such bridges, inspectors walk through upper part of the bridge on pavement and also on the ground level around piers and abutments. Inspectors should find common defects and also any severe damage. Inspectors can also use specialized safety equipment to manually inspect the cables or devices such as drones.

One of the special check points is the abnormal condition of the cable and anchorage. It should be investigated carefully with more emphasis on the shape, alignment, proportion and color because they are the most important attributes for the stability of the structure.

In case of abnormal vibration of the stay cable, the extent of vibration should be measured using video and other amplitude measuring instruments. Aside from the vibration amplitude, the tensile strength of the cables should also be determined. Further when water leakage and discoloration of cable element is observed, there is a possibility that the inside of the cable is already corroded and should be thoroughly inspected.

Safety of workmen, public and environment, safe work practices are essential on every work site. All statutory rules and regulations and recommended safety practices given in this manual are for general guidance in planning for safety at all site inspections *(Refer Chapter 5).*

(2) PC Box girder bridge

The inspection of concrete box girders for cracks, spalls, and other defects is primarily a visual activity. However, hammers are primarily 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. Several advanced techniques are available for concrete inspection for example Non-Destructive Tests. *(Refer Chapter 7).*

The inspection of a box girder bridge requires a clear understanding of its function. This requires a thorough review of design and as-built drawings prior to the inspection and identify high stress regions peculiar to a particular structure.

In order to perform proper and efficient inspection, appropriate equipment and manpower should be readily available. However, the following factors should also be considered:

- Traffic restrictions,
- Access difficulties (e.g., waterways, terrain, buildings, built-up areas, combined bridges)
- Safety of personnel undertaking the inspection,
- Specialized equipment or personnel such as divers that may be needed
- Water level restrictions (i.e., tide level)

Safety of workmen, public and environment, safe work practices are essential on every work site. All statutory rules and regulations and recommended safety practices given in this manual are for general guidance in planning for safety at all site inspections *(Refer Chapter 5).*

In conducting inspection of this structure, give priority to the following:

- Bearing area
- Shear (near supports) and tension (mid-span) zones
- Areas close to drainage systems
- Areas exposed to traffic
- Areas previously repaired
- Areas with visible defects cracks, efflorescence etc.

(3) Truss bridge

Trusses form the primary (main) longitudinal members in a truss bridge. The members that make up a truss are normally straight metal sections (steel in modern constructions), although timber and occasionally reinforced concrete are used.

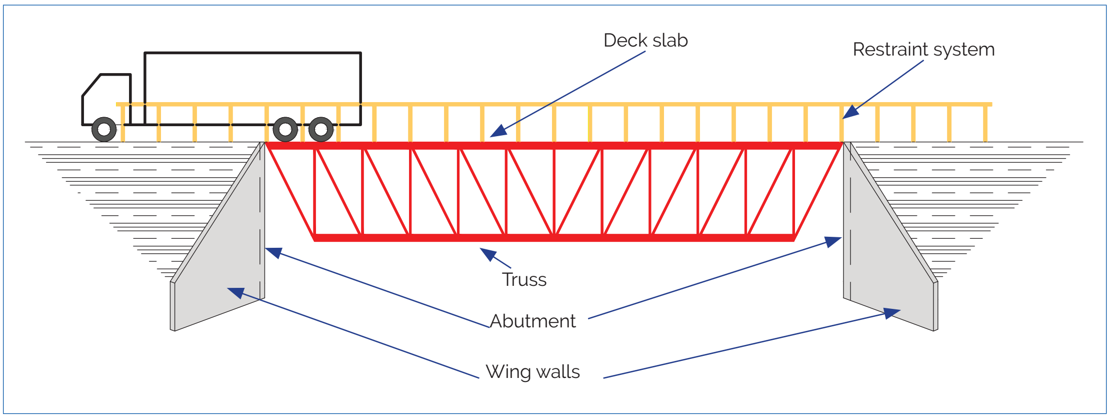


Figure 4-3 Cross-section of an underslung truss bridge

During the inspection of steel trusses check the following areas:

- Bearing areas
- Connections
- Tension members
- Compression members
- Deck slab
- Areas likely to trap water and debris
- Noncritical element for corrosion, examining horizontal surfaces where moisture can collect

Common defects that occur on steel truss bridges are:

- Failure of the paint system
- Pitting
- Surface rust
- Section loss
- Tack welds in tension zones
- Fatigue cracking
- Collision damage
- Overload damage
- Heat damage

In line with the aforementioned defects, visual inspections can only point out the ones that present themselves on the surface. Therefore, advanced inspection techniques may be employed to achieve a more rigorous and thorough inspection of the steel truss members. Some of these methods include:

- Magnetic induction
- Electrical resistivity
- Dye penetrant
- Ultrasonic testing
- Radiographic testing
- Accelerometers
- Strain measurements
- Vibration measurements
- Magnetic flux leakage
- Measurement of loads
- Measurement of stress ranges

Safety of workmen, public and environment, safe work practices are essential on every work site. All statutory rules and regulations and recommended safety practices given in this manual are for general guidance in planning for safety at all site inspections *(Refer Chapter 5)*.

4.1.3.1 Material type

For successful inspection of bridge elements, the inspector must be familiar with bridge defects that are visibly identifiable depending on the type of material. Familiarity of common defects exhibited by a material can enable the effective, speedy and comprehensive inspection of a bridge. Some easily identifiable defects are;

Table 4-3 Material types, common defects and inspection methods

Material	Common defects	Inspection methods
Concrete	Spalling, corrosion of rebar, cracking in element	Visual, hammer test, DT test and NDT tests *(Refer Chapter 7)*
Steel	Corrosion of member, fatigue cracks, Member distortion, loose connections and parts	Visual and other NDT Tests *(Refer Chapter 7)*
Timber	Splitting of member, decay, damaged joints, warping	Visual, sounding and probing techniques, drilling and coring techniques among other NDT tests *(Refer Chapter 7)*
Masonry	Cracking, separation of section, loss of parts/section, bulging.	Visual and other NDT Tests *(Refer Chapter 7)*

4.1.4 Analysis and Assessment

In bridge maintenance and management, the most important activity is to identify the damage, determine the cause, assess/analyze and take appropriate countermeasures.

The aim of analysis and assessment is to establish the safe load carrying capacity of the bridges. This is confined to the bridge superstructure which is regarded as the weakest element of most bridges, and then extended to bridge support and foundations. It involves the following;

1. Establish causes of damage based on results of condition inspection *(Refer to chapter 3)*
2. Identify severity (Low, Moderate, High & Very high - Refer to damage catalogue) and defect rating based on results of Non-Destructive Test (NDT) for each defect (N, DLI DLII & DLIII). *(Refer to chapter 6)*
3. *Evaluate the overall assessment of bridges based on soundness of the bridge.* The Inspection Team shall determine soundness of bridge by overall bridge rating. *(Refer to chapter 6)*
4. *Determine appropriate repair methods for damages*; the Inspectorate Team shall identify the repair method and estimate cost in accordance with the latest edition of the *Bridge Repair Manual (BRM)*

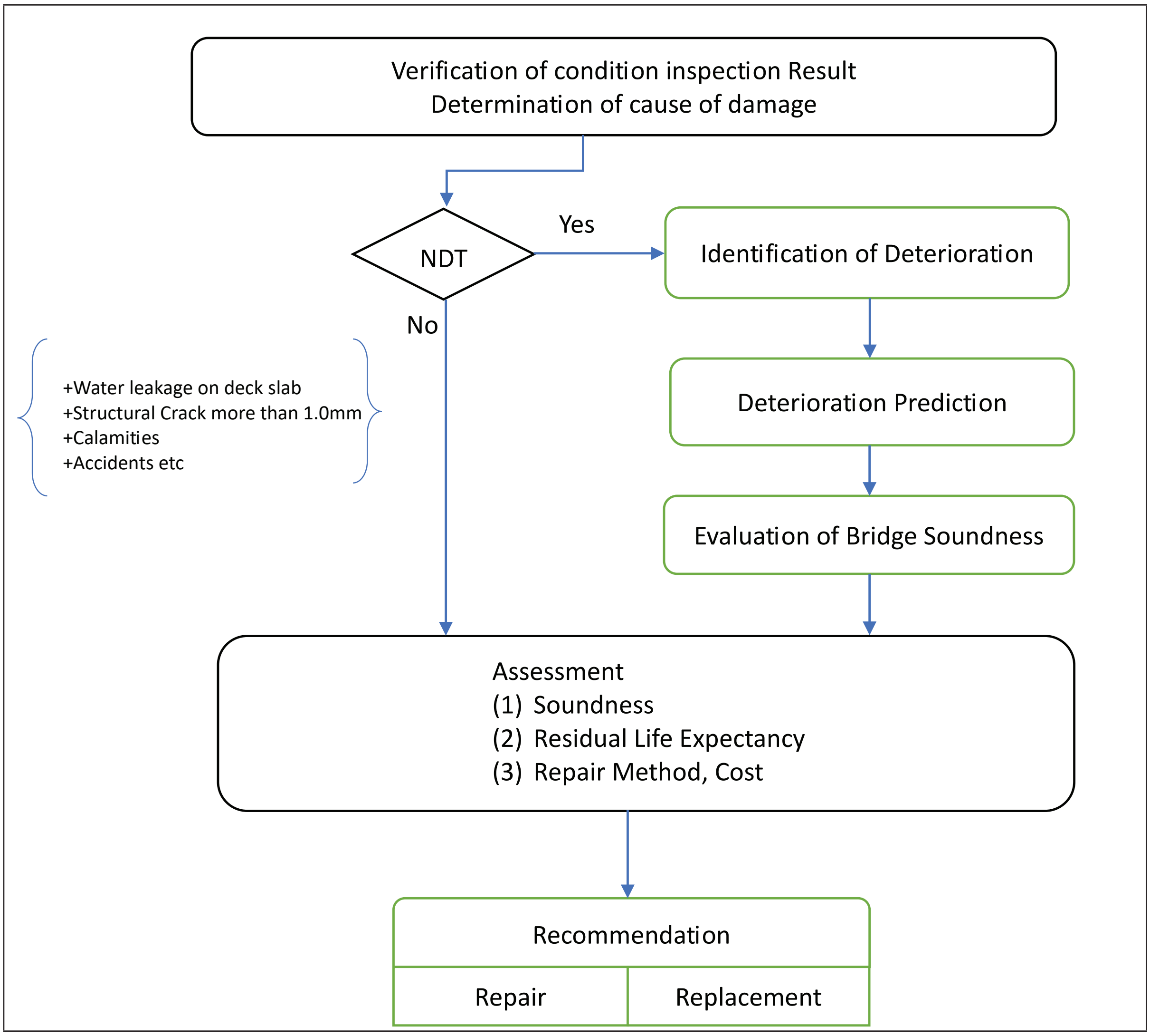


Figure 4-4 Flow chart of assessment for bridge engineering inspection

4.1.5 Recording inspection findings

4.1.5.1 Introduction

Initial inspection work entails collecting relevant data and identifying defects based on their type, location, extent, severity, and the cause. These data should include appropriate photographs for both individual defects and the general condition of the structure. The records will both help to decide on and prioritize any maintenance actions needed and to monitor the development of the defects in the subsequent inspection cycle. It is therefore important to accurately report to enable the supervising engineer to make appropriate decisions concerning the safety and maintenance of the structure.

4.1.5.2 Data capture

Generally, the inspection form should be designed to record a defect in terms of its influence on the condition of the element in which it is located. It should capture data in a format that gives a clear and accurate description of the condition of a structure. Specifically, the form should capture a reference number, date of inspection, material, span, elements of the bridge, location of any defects, the damage extent and severity, possible causes, photographs and inspector's comments. This information should be recorded in the initial inspection form (Refer to Appendix 3) as guided by the damage catalogue.

The inspection team should ensure all inspection forms are dully filled on site before submission to the office.

When bridge inspection is carried out using the BMS tool, the following responsibilities shall be assigned accordingly:

a) Data Input of Inspection Results (Inspectors/Engineers)

b) Confirmation of the Data Input (Supervising Engineer)

c) Database Management (Parent Ministry)

(a) Data Input of Inspection Results

Inspectors/Engineers in each Governmental Department/Agency charged with the mandate to maintain Kenyan Road networks, shall be responsible for inputting the inspection result data for roads under their jurisdiction, in the BMS Database. It is preferable that the inspection data is uploaded electronically while the inspector is still at the bridge site, unless the site conditions do not allow.

(b) Confirmation of the Data Input

The supervising Engineer is responsible for input confirmation.

(c) Database Management

The parent ministry will host and will be responsible for the Bridge Management System. The server shall remain activated always so that authorized persons can access and use the system at any time.

4.1.5.3 Inspection records

All inspections result should be recorded in a format appropriate to the inspection type. The format should be clear, logical, and complete. In addition, all inspection records should also contain the date of the inspection, those responsible for undertaking the inspection, general information about the structure, details of the prevailing weather conditions at the time of the inspection and where appropriate the weather during the previous few days.

The following provides a checklist of records that should be considered during initial inspection;

- Designs
- As-built drawings
- Bridge Inventory form
- Initial Inspection form

The following provides a checklist of factors to be considered during initial inspection:

i. The location, severity, extent, and type of all defects on the structure, including, where appropriate, detailed descriptions and/or photographs (or sketches) of the defects that identify their location and illustrate the severity/extent of damage.

ii. Headroom information on bridges over roads and railway lines based on measurements taken during the inspection.

iii. Any significant change/improvement (e.g., works carried out or deterioration) since the last Initial Inspection.

iv. The scope and timing of any actions required before the next inspection.

v. The need for additional investigations, Detailed Inspection and/or monitoring.

vi. A description of any testing that was undertaken, details of the information collected, and an interpretation of the information.

vii. Any other information relevant to the integrity and stability of the structure.

4.1.5.4 Data storage

The principal information obtained from all inspections should be entered into the database, thus providing an up-to-date record of the condition of each bridge structure. The retained information from the previous inspections would provide a build-up of a profile of the change of condition over time. To improve working efficiency, electronic data storage, browsing, and retrieval methods should be employed.

4.1.5.5 Evaluation of inspection results

The inspection results should be adequate to determine the structural integrity of a bridge. Additionally, the inspection results should provide a condition rating that will enable the identification of current and future maintenance and prioritization of work. The condition rating scores are to be monitored over time to assess whether the condition is declining, improving, or remaining constant as maintenance is carried out. In this connection, the engineer should maintain documented information as regards the evaluation of inspection results.

4.1.6 Reporting inspection findings

The recorded inspection results are the essential source of information for keeping all bridges in healthy condition with the sustainable maintenance activities including damage diagnosis, repair work planning and the budget preparation. The results which are input in the Bridge Management System (BMS) database include not only the level of damage if any, but also the no-damage status. The data on the condition of the structure is necessary for prediction of occurrence period when the damage is identified.

Once inspection data for bridges within a road network are captured in the BMS database, the system can be utilized to generate various reports, depending on the output required, for purposes of reporting and planning.

4.1.7 Input to maintenance planning process

The aim of the inspections is to generally provide the most up-to-date and comprehensive data on the condition of the structure and as such through assigning damage ratings which should be used to inform the maintenance planning process. Maintenance planning and management is an on-going activity and as such requires up-to-date and relevant information on structural condition and performance to ensure the correct work is being planned and to assess the effectiveness of previous work.

The inspector must be able to diagnose the causes of damage and deterioration and determine the consequences of not making repairs. In making the diagnosis, the recommendations of the previous inspection reports should be reviewed and priorities for measures should be determined based on what repairs and maintenance had been made. The scores from the inspection are the basis of determining the priority of measures of bridges and therefore a key input for maintenance planning

4.2 Types of inspections

Table 4-4 Scheduling for different types of inspections

Types of bridge inspection	Objectives of the inspection	Methodology	Frequency	Tolerance to inspection schedule
Baseline inspection	To assess soundness of the bridges	Up – close visual inspection and measurement.	Once	1 month
Routine inspection for PBC	To keep smooth traffic flow, avoid third party disaster	Visually inspecting the structure for failure, damage, debris etc.	Monthly	1 week
Routine inspection for ARBICS	To obtain bridge condition information for maintenance planning purposes.	Visual inspection together with annual road inventory condition inspection.	Annually	1 month
Periodic Inspection	To assess soundness of the bridges	Up – close visual inspection and measurement.	Every 5th to 10th year	1 month
Special Inspection	To design for repair and strengthening	Investigation using equipment/ technical gear	Whenever necessary	1 month
Emergency Inspection	To study incidents and immediate action	Investigation using equipment/ technical gear	Whenever necessary	Immediate

NB: The routine bridge inspection scheduling requirements are outlined in the Bridge Inspection Manual for PBC & ARBICS.

4.2.1 Special Inspection

4.2.1.1 Definition

The inspection is conducted for diagnostic study to examine the cause and extent of damage based on the findings from previous inspections. Special inspection results are used to prepare a detailed plan of action. The diagnosis may involve field survey, Non-Destructive Tests or Destructive Tests and structural performance monitoring.

i. Preparation and planning
ii. Field Survey
iii. Necessity of a detailed investigation
iv. Execution of the detailed investigation
v. Analysis and reporting

4.2.1.2 Preparation and planning

The bridge inspector collects the past data, documents and ascertains the inventory and history of the bridge in advance including the previous inspection results, as-built bridge plans, repair history, and repair work reports.

Some of the tools and equipment required for surveys of bridges are:

Table 4-6 Equipment required for emergency surveys

Equipment	
PPEs	Helmet/safety belt/safety vest/ boots/work gloves
Inspection and investigation	Writing implements, drawings, camera, scale, rangefinder, inclinometer, inspection hammer
Tools	Cutter, knife, portable saw, wire brush, vinyl tape, marking spray
Safety measures	Materials and equipment for traffic control, ladders, stepladder, rope
Other materials	Battery, chargers, power cable, media (flash drive), etc.
Other equipment	Bridge Inspection Vehicle, boat, drones

4.2.1.3 Field survey

Field survey is an important activity to be conducted following the review of existing data and documentation.

It is necessary to check the location of the defects, condition of the defect and its adjacent members, vibration of bridge, surrounding conditions such as road surface and drainage.

It is also necessary to check traffic condition on the bridge, material, geographic location, ventilation and profile of road.

Hands-on inspection should be carried out as possible in order to accurately understand the damage condition.

4.2.1.4 Necessity of a detailed investigation

Case 1

When the cause of the damage is identified during the field survey and data collected, detailed investigation is not required.

Case 2

When the cause of the defect cannot be identified from the field survey, a detailed investigation shall be carried out as described in the "TEST METHODS" in this manual.

4.2.1.5 Necessity of detailed investigation for concrete members

There are multiple causes of damages in concrete members, and it is difficult to identify the cause of a damage.

- As the cause of damage is difficult to identify because of multiple reasons, we compare the bridge conditions confirmed by field surveys with the inspection results of a bridge with similar materials and damage in past to determine the possible cause.
- If aforementioned procedure is not adequate then a detailed investigation will be conducted to make a comprehensive decision based on the investigation results.

The relationship between damage to concrete members and typical causes of damage is shown in Table 4-5 .

Table 4-5 Relationship between damage to concrete members and typical causes of damage

		Typical causes of damage						
		Carbonation	Chloride induced deterioration	Alkali Silica Reaction	Chemical attack	Fatigue of Slab and Girder	Insufficient covering depth	Water leakage
Crack situation	Occurs in the cover part parallel to the Rebar	✓✓	✓✓	✓✓			✓✓	✓
	Alligator			✓✓				
	Grid/mesh					✓✓		
	Bending cracks/shear cracks					✓✓		
Flaking concrete		✓✓	✓✓	✓	✓✓		✓✓	✓
Rebar exposure		✓✓	✓✓	✓	✓		✓✓	✓
Rust		✓✓	✓✓	✓	✓✓			✓
Free Lime		✓	✓	✓		✓✓		✓✓

✓✓: closely related

✓: related

4.2.1.6 Necessity of detailed investigation for steel members

There are two types of detailed investigations for steel members.

- Detailed investigation on corrosion; corroded area and thickness, number of loose and missing bolts.
- Detailed investigation on crack; paint film cracks (width and length).

4.2.1.7 Necessity of detailed investigation for other elements

As for the following cases the detailed investigation of other bridge elements are required;

- To determine the damage situation especially scouring, subsidence, movement and inclination of the foundation.
- To investigate the relationship among the damages observed i.e. (Relationship between potholes on the bridge pavement and cracks on deck slab, excessive vibrations and missing cross members, leaking expansion joint and corroded girder ends, etc.)

4.2.1.8 Execution of detailed investigation

Detailed investigations are to be carried out according to the methods described in the "TEST METHODS" in this manual *(Refer to Chapter 7).*

4.2.1.9 Analysis and reporting

The inspector must be able to diagnose the causes of damage and deterioration and determine the consequences of not making repairs. He/she is also responsible for inputting the inspection result data in the Bridge Inspection Database System. The scores from the inspections are the basis of determining the priority of measures of bridges and therefore a key input for maintenance planning.

4.2.2 Emergency Inspection

4.2.2.1 Definition

Emergency inspection is carried out after detection of severe defects and abnormalities on a bridge after a natural disaster or accident, to ascertain safety of the bridge for users and recommend appropriate remedial measures.

4.2.2.2 Preparation and equipment

The bridge inspector should check the past data and documents to ascertain the inventory and history of the bridge in advance including the previous inspection results, as-built bridge plans, repair history, and repair work documents as possible.

It is important to always have the equipment ready and to check their functional status periodically.

For materials and equipment required during emergency surveys after a disaster or an accident, refer to Table 4-6.

4.2.2.3 Emergency inspection method

During emergency inspections, check the whole bridge for any abnormalities by visual inspection in principle. Special methods should be considered for *scouring, flaking and delamination of concrete members, rapture and loosening of bolts*, etc.

i. Conduct detailed visual inspections of the girder ends, bearings, abutments and bridge foundations.

ii. Check bolts of bearings by test hammering.

iii. If access to abutments and piers is not possible, the condition of girder ends, bearings, piers and abutments should be investigated in as much detail as possible.

iv. In addition to localized damages, check for any abnormalities such as inclination and irregular shape of a whole bridge.

4.2.2.4 Priority bridges for emergency inspection

The following bridges should be considered as priority during emergency inspections;

i. Bridges where considerable deformation has been confirmed in a previous inspection.

ii. Bridges with a high risk of collapse due to the destruction of some members. Examples: Cantilever bridges, truss bridges, arch bridges, rigid frame bridges.

iii. Bridges with substructures (abutments and piers) located in the river channel.

iv. Bridges that have experienced disaster in the past.

v. Bridges whose bearings and superstructures may have been affected by flooding.

vi. Bridges within the seismic line of action.

4.2.2.5 Inspection items of emergency inspection

The main parts/materials and damage subject to emergency inspections/emergency investigations are as shown in Table 4-7.

Table 4-7 Check elements for emergency inspection

Members	Defects to check	Check elements	Evaluation	
			Load Capacity	Passability
Steel members	Corrosion	Girder End	✓	
	Crack	Girder End	✓	
	Missing Bolts		✓	
	Rupture		✓	
	Deformation/Section loss		✓	
Concrete members	Crack		✓	
	Spalling		✓	
	Abnormalities at the post-tensioned anchorage		✓	
	Deformation/Section loss		✓	
Other members	Abnormal expansion gap		✓	✓
	Unevenness of the road surface			✓
	Dysfunction of the bearing		✓	
	Deformation of substructure (settlement, movement, inclination, scouring)	Substructure	✓	

4.2.2.6 Check points for emergency inspections

The main points to consider for emergency inspections are as follows;

a) Bearings

Bearings are one of the most susceptible components to the disasters e.g earthquakes, floods etc, so it is necessary to carefully inspect the following items;

- Deformation of the bearings
- Damage of bearing seat
- Breaking or falling out of bearing mounting bolts, etc.
- Detachment of girders from bearings

b) Superstructure

It is necessary to accurately inspect the defect that may lead the damaged bridge to collapse.

- Local buckling of the fulcrum (girder end) web and vertical stiffeners due to corrosion which lead to collapse and large deformation of the main girder.
- Rapture of girders due to damaged welds of the gussets and stiffeners at the locations adjacent to the bearings (sole plates, etc.)
- Collapse of the entire girder due to movement of the substructure, etc.

c) Substructure

The substructure is prone to damage during earthquakes and floods. The effects on load capacity and stability of the bridge greatly depends on the nature and extent of the damage. The following need to be assessed;

- Cracks leading into the vicinity of the bearing.
- Cracks that may continue deep into the ground (footing/foundation)
- Condition of the foundation

d) *Other elements*

In addition, the following points should be considered.

- Discontinuity of railings and curbs can be an indication of *substructure subsidence or inclination*, girder buckling or bearing failure.
- The distortion of the camber and expansion gap may be an indication of an anomaly of the whole bridge.
- Check for abnormality of expansion joint which may occur due to abnormality of the bearings or substructure.
- The damages with risk to third parties including; deterioration of the inspection path, spalling slab, flaking concrete, abnormalities in attachments should be inspected.

4.2.2.7 Result sheet for emergency inspections

Result sheet for Emergency Inspection (SAMPLE)

Name		**Inspection Date**	
Code		**Abnormal event type**	
Road		**Degree of anomalous event**	
Location		**Technical Investigator**	

Elements	**Members**	**Damage Condition**	**Flag Indicator**		**Photo File**
			existence	**nonexistence**	
A whole bridge		The bridge is collapsing		☑	
Superstructure	Main Girder/Slab	The bridge is damaged.(deformationn, crack)		☑	
Substructure	Wall/Foundation	The bridge is damaged.(settlement, movement, inclination, scouring, crack)		☑	
Bearings	Body/Bridge Seat	The bridge is damaged.(falling, destruction)		☑	
Road condition	Road surface	There are significant bumps on the road.		☑	
		Abnormal sound or vibration is occurring.		☑	
	Curb/Pavement	Significantly damaged.		☑	
	Expansion Joint	Gap is wide open.	☑		001.jpg
		Expansion Joint is badly damaged.	☑		002.jpg
	Railing/Barrier	Dangerous damage or deformation to road traffice users.		☑	
Other elements	Drainage	Badly damaged. Or water is accumulated on the bridge surface and overflows.		☑	
	Inspection facilities, Attachments, Retaining walls	Badly damaged.	☑		003.jpg
	others	Considered dangerous damage for traffice users.		☑	
Comprehensive evaluation		Neccesity for urgent measures	☑		

Points to note

Figure 4-5 Sample emergency inspection form

5 PREPARATION FOR INSPECTION

5.1 Preparations before Inspection

Prior to the inspection, any available information on the existing bridge for example, maintenance history and previous inspection reports, if any, shall be reviewed by the inspecting officer who will undertake the inspection. It is necessary to search for bridge drawings, maintenance histories, consultant's reports, etc.

The points of preparations before inspection are as follows.

- Inspector shall collect the inspection report and all available documents (plans, drawing and reports) of the bridge to be inspected;
- Inspector shall check equipment (including all non-destructive testing apparatus) and/or vehicles required for inspection.
- Inspector shall check and confirm that all necessary materials and safety gadgets are prepared and functional (for instance all battery powered tools & equipment are properly charged and have adequate portable power back-up.)
- Inspector shall fill in the *Inspection Form.*
- Inspector shall make sure that safety measures are in-place prior to inspection.
- Clear vegetation and other obstacles around the bridge site that may hamper the inspection activity.
- Take note of bridge site terrain to establish whether specialized equipment are required to undertake the inspection e.g., drones, specialized bridge inspection vehicle, pole cameras etc.
- Ascertain prevailing/ forecasted weather conditions at site to determine appropriate time for inspection.

5.2 Competence of inspection staff

All inspections should be undertaken by personnel that have been evaluated by the Supervising Engineer to satisfy the minimum professional qualification, health and where appropriate, experience for the particular inspection type.

5.2.1 Supervising Engineer

Inspections of highway structures should be carried out under the direction of the Supervising Engineer. The Supervising Engineer should be a Registered Civil or Structural Engineer with appropriate experience in design, construction and maintenance of structures. The responsibilities of the Supervising Engineer shall include checking and countersigning all Inspection data and reports, including those prepared by other consultants, for concurrence.

The Supervising Engineer should give due consideration to the inspection requirements set out by the highways authority and ensure that all inspections are undertaken by personnel that satisfy the minimum experience and, where appropriate, qualification requirements for the particular inspection types.

Tasks/Activities of Supervising Engineer

- Appointment of bridge Inspectorate Team;
- Supervision/monitoring of the activities of the bridge Inspectorate Team;
- Provision of the requirements (i.e. expertise, skilled personnel, equipment, etc.) to the Bridge Inspectorate Team;
- Review, analyze and assess the Inspection Report submitted by the Bridge Inspectorate Team; and,
- Submit findings and/or recommendations to the respective authority for appropriate action for the success of the operations of the BMS.

5.2.2 Bridge Inspector

The most important member of any inspection regime is the Bridge Inspector, who is relied upon to perform their duties accurately, consistently, thoroughly and safely. The Bridge Inspector works under the Supervising Engineer and should have at least a diploma in Civil Engineering with a minimum of 3 years' experience working on highway bridges. The inspector should have attended, and be accredited in the *Bridge Inspection and Repair Course* by a qualified institution such as, Kenya Institute of Highways and Building Technology (KIHBT) or equivalent. The experienced bridge inspector, should always be present on site during an inspection exercise. The qualities of this experienced inspector should include, but should not be limited to the following:

i. Knowledge of the safe working practices and methods of access required for inspection;

ii. Ability to recognize and evaluate defects on bridges; an understanding of the behavior of highway structures;

iii. Knowledge of the construction methods and materials used in the construction of highway structures;

iv. Knowledge of the causes of defects and suitable testing methods to identify, confirm or investigate them;

v. Ability to record defects accurately, clearly and consistently.

vi. All the inspectors in a team should be in sound health and have a realistic appreciation of their own limits of experience and ability. Inspectors with limited experience should work under the supervision of experienced staff.

vii. Particular training in safe working practices is essential for all those required to work in hazardous situations such as in confined spaces or at elevated areas. All members of the inspection team must be made aware of the particular risks associated with an inspection before starting work. This will normally take the form of a site-specific briefing by the team leader before starting work. Such a briefing is in addition to training in safe working practices and is intended to highlight particular features of the site.

viii. In addition to civil engineering qualifications, Bridge Inspectors should undertake appropriate training in inspection procedures and techniques, including any necessary formal training and accreditation *by a qualified institution such as,* Kenya Institute of Highways and Building Technology (KIHBT) or equivalent. Inspectors should be encouraged to obtain other qualifications which could be useful during inspection work, e.g. training and qualifications in first aid, qualifications and experience in specialized forms of access, notably diving and abseiling, training on use of specialized equipment such as drones and bridge inspection vehicle.

5.3 Safety and health consideration

For the protection and safety of inspectors, general public and the surrounding environment, safety practices are essential on every work site. Health and safety have a high priority at all times during field operations.

The safety of the public and the inspectors is of major concern during inspection. Having the proper equipment can play a key role in maintaining the safety of both.

When inspectors do not have the right equipment, they may attempt to use an alternative type of equipment that is not really designed for the job. This cannot only prove dangerous for the inspector, but for the public as well. Inspectors should never try to replace equipment in the interest of saving time. The best way to avoid these circumstances is to ensure the inspectors have the proper equipment for the job. This responsibility lies not only with the inspector but also their employer. It is important that the employer make every effort to properly equip all the inspectors. Also, the inspector should be familiar with every piece of equipment and how to use and operate it properly.

The employer is responsible for providing a safe working environment, including:

- Clear safety regulations and guidelines
- Safety training
- Proper tools and equipment

The supervisor is responsible for maintaining a safe working environment, including:

- Supervision of established job procedures
- Guidance in application of safety procedures
- Guidance in proper use of equipment
- Enforcement of safety regulations

Bridge inspectors are ultimately responsible for their own safety. The bridge inspector's responsibilities include:

- Recognition of individual limitations – Only the individual inspector knows what they are capable of doing. If uncomfortable at doing something, let it be known.
- Knowledge of rules and procedures of a task - If you do not understand something or are not qualified to perform a particular task safely, it is your responsibility to stop and seek guidance. If a procedure is unsafe, review it and constructively develop a better way.
- Safety of coworkers - Do not endanger coworkers by your actions. Warn them if you see them doing something unsafe.
- Reporting an accident - If there is an accident, it is essential to report it to a designated individual in your agency or company within the prescribed time frame, usually within 24 hours. Any injury must be promptly reported in order to assure coverage, if necessary, under workmen's compensation or other insurance.

It is important to dress properly for the job. Field clothes should be properly sized for the individual, and they should be appropriate for the climate. For general inspection activities, the inspector should wear safety boots with traction soles. For climbing of bridge components, the inspector should wear boots with a steel shank (with non-slip soles), as well as leather gloves. Wearing a tool pouch enables the inspector to carry tools and notes with hands free for climbing and other inspection activities.

Safety equipment is designed to prevent injury. However, the inspector must use the equipment in order for it to provide protection. The following are some common types of safety equipment:

1) Helmet- to prevent head injuries.

2) High visibility clothing/Reflective jacket - High visibility outer clothing of approved type should be worn at all times, except while in a vehicle, when working within the highway boundary or on railway property.

3) Safety googles- necessary when the inspector is exposed to flying particles and high intensity glare.

4) Buoyancy aid/Life jackets - Inspection staff should wear a buoyancy aid when working in or over water or in danger of falling into water.

5) Dust mask-protect the inspector from harmful airborne contaminants and pollutant.

6) Full body safety harness with lanyard and shock absorber - A full body safety harness fitted with an energy absorber, lanyard and connectors should be worn at all times when working where there is a significant risk of falling. All mobile elevating work platforms should be equipped with safety harness attachment points.

7) Gloves- Wearing gloves will protect the inspector's hands from harmful effects of deteriorated members.

8) Safety footwear - Safety boots or shoes with steel toe caps and steel mid-soles should be worn. For working in shallow water or corrosive materials, Wellington boots with steel toe caps and steel mid-soles should be worn.

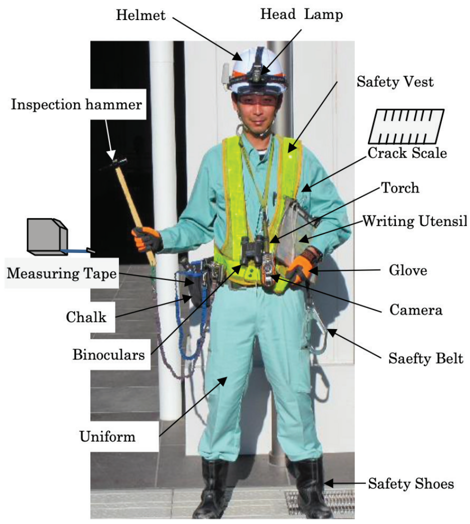
9) Waders should be used with caution; in the event of falling over in water, the waders may float, inverting the wearer and making it difficult to regain an up-right posture.

Other specialized equipment will be required in certain situations; for example, breathing apparatus for use in confined spaces. The actual requirements should be specified after the risk assessment.

All PPEs should be handled, stored and used carefully. They should be protected and maintained as recommended by the manufacturers. All PPEs should be fitted correctly and securely, badly fitted equipment may not perform as anticipated and could even be a hazard in itself.

Basic safety gears required in the inspection are shown in *Figure 5-1 Basic safety gears required in the inspection*.

Inspection Gear



Gear and Protective Clothes

Figure 5-1 Basic safety gears required in the inspection

5.3.1 Safe Inspection Guidelines

Some general guidelines for safe inspections are as follows:

- Keeping well rested and alert - Working conditions encountered during an inspection are varied and can change rapidly requiring the inspector to be fit and attentive.
- Maintaining proper mental and physical condition - Inspection tasks require a multitude of motor skills. To perform at acceptable levels, the inspector must be physically fit and free from mental distractions.
- Using proper tools - Do not try to use tools and equipment not suited for the job.
- Keeping work areas neat and uncluttered – Tools and equipment scattered carelessly about the work area present hazards that can result in injury.
- Establishing systematic procedures - Establish procedures early in the job utilizing them so that everyone knows what to expect of one another.
- Follow safety rules and regulations - Adhere to the safety rules and regulations established by the Occupational Safety and Health Administration (OSHA), the agency, and your employer.
- Use common sense and good judgment - Do not engage in horseplay, and do not take short cuts or make risky decisions.
- Avoid use of intoxicants or drugs - Intoxicants impair judgement, reflexes, and coordination.
- Medication - Prescription and over-the-counter medications can cause drowsiness or other unwanted and potentially dangerous side effects.
- Electricity - This is a potential killer. All cables and wires should be assumed to be live, even if they appear to be telephone cables. The conditions encountered on many bridges are conducive for electric shock. These conditions include steel members, humidity, perspiration, and damp clothing. Transmission lines on a structure should be identified prior to the inspection. All power lines should be shut down. In rural areas, electric fences can be a hazard and should be avoided.
- Assistance - Always work in pairs. An inspector should not take any action without someone else available to help in case of an accident. Always make sure someone else knows where you are. If someone seems to be missing, locate that person immediately.
- Inspection over water - A safety boat must be provided when working over bodies of water. It should be equipped with a life ring and have radio communication with the inspection crew.
- Waders (waterproof overall) - Caution should be used when wearing waders. If the inspector falls into a scour hole, the waders can fill with water, making swimming impossible.
- Inspection over traffic - It is best to avoid working above traffic. If it cannot be avoided, equipment, such as tools and notebooks, should be secured.
- Entering dark areas - Use a flashlight to illuminate dark areas prior to entering as a precaution against falls, snakebites, and stinging insects.

When planning and carrying out inspections at any location, the safety of the public and other third parties must be considered. Traffic management will normally be used to provide safe conditions for motorists, but the needs of pedestrians, cyclists, equestrians and occupiers of adjacent land or property must also be catered for.

5.3.2 Work Safety

Work safety measures must be planned ahead.

The points of work safety are as follows:

1) Ensure that all tools, equipment and apparatus are available and in good working condition;
2) Inspector shall prepare helmets, masks, safety harnesses, footwear, gloves, and any other necessary safety gears
3) Plan and arrange road closures and suitable traffic management procedures if necessary;
4) Identify and locate all the utilities existing at site such as electricity, water, sewerage, communications, and gas lines. If any risk is foreseen, inspector shall inform the relevant authorities to stand by for any emergencies;
5) All inspections should be carried out in well-ventilated and well-lit areas. If necessary, make prior arrangements for exhaust fans and artificial lighting; and
6) Do not allow personnel under the influence of alcohol (or any medication which impairs alertness or causes drowsiness) to work at site or to operate any mechanical equipment.

5.4 Bridge Records

When preparing for inspections, a review of the structure records should be undertaken, to obtain a thorough understanding of the characteristics of the structure and of any features or defects which may require special attention, such as the condition of the structure at the time of the last inspection and any significant maintenance or modifications since the last inspection.

The number and type of records to be reviewed would depend on availability and the nature of the inspection.

This should contain relevant database associated with the design, construction and maintenance of the highway structure which include records under the following headings:

- Inventory Data
- Drawings
- Design Data
- Construction and Demolition Methods,
- Material Components
- Treatments Certification
- Test Results
- Operation Requirements
- Inspection Schedules and Records
- Maintenance Records
- Structural Assessment
- Load Management Data
- Legal Documentation
- Environmental Information
- Supplementary records

It is desirable that the records listed above are held for all existing structures as these are extremely useful and may contribute to reducing the work of preparing for inspections. For example, records of the methods of access and traffic management used for previous inspections, together with notes on any challenges encountered, will eliminate the need to plan the work from scratch.

For some existing structures there may be gaps between the records listed above and those currently held. The Supervising Engineer should seek to identify these gaps and close them in a cost effective and efficient manner by combining record reviews, data collection and record creation with on-going management activities. For example, these activities may be combined with Baseline Inspections and/or routine maintenance activities, where records are verified by inspectors whilst on site.

Where the structure is old it may be helpful to obtain information concerning the construction materials and methods in use at the time of construction. Several publications provide useful background information on historical construction procedures for concrete, steel, timber and masonry structures.

5.5 Type and extent of testing

Testing of structures is normally identified during or following a Baseline, Routine, Special or Emergency inspection or it may be required to obtain additional data to support a structural assessment. It is therefore essential to plan testing operations, i.e., the range of tests and their location, extent and intensity, to suit the specific objectives for which testing may be required.

5.6 Environmental and Social Consideration

5.6.1 Stakeholders and third parties engagement

Highway authorities do not necessarily own all the land under or near a highway structure and may only retain a right to access. Where inspections require access to land under different ownership, either at the highway structure or adjacent to it, the records should be checked and any landowners and/or tenants consulted to approve access.

For bridges over/under railways, canals and navigable waterways, it is essential to consult with the relevant authorities in advance and agree on details of access and safe working practices.

The presence of services in or near the highway structure should be considered and the service providers consulted for details. Underground services or drains may restrict the placing of access equipment or the location of trial excavations. Overhead lines may also restrict the types of access equipment to be used.

Consultation with environmental or conservation bodies may be necessary where the inspection work is liable to have a significant environmental impact.

In some circumstances, it may be necessary or advisable to notify the general public of the proposed inspection work. Appropriate situations that should be considered include:

- Where severe delays to road users are unavoidable;
- Where the inspection work would result in the temporary closure of vehicular or pedestrian routes; or
- When noisy or night-time working is required in residential areas. In such cases the Environmental Health Department of the local authority should be consulted and prior consent obtained.

Prior notification and advance publicity could help reduce distress that may be caused by the work, by informing people of the need and duration of the work and demonstrating that their concerns have been considered.

5.6.2 Environmental considerations

Due consideration should be given to the environment when inspections are planned and undertaken at highway structures, including access and working operations at adjacent areas. The Supervising Engineer should ascertain whether any significant environmental impacts are likely to occur and, if so, seek expert advice to identify and implement the appropriate working practices and/or mitigation measures. Effort should be made on conserving the population of the country's characteristics of fauna and flora and the existing economic and socio-cultural practices of the local communities.

Highway structures, although man made, are part of the landscape and quickly become habitats used by wildlife. Also, some structures are situated in areas of special environmental interest or designated areas protected by legal statutes, which could be interfered with by inspection activities.

The recommendations in the Table 5-1 should be considered for planning and carrying out inspections.

Table 5-1 Environmental Considerations for planning and carrying out inspections.

Environmental considerations		
Impacts on	**Aspects to be considered**	**Action**
Motorists	Safety and disruption of traffic	Provide traffic management plan
Pedestrians	Safety and convenience	Possible alternative routes Cordoning off works
Adjacent residences and businesses	Noise pollution Night time working	Adopt quiet working methods Avoid working at night unless where unavoidable. Obtain consent from relevant authorities Advance public notification
Landowners and tenants	Convenience and access	Check records for right of access and agree on access arrangements
Farmland and Livestock	Access, Timing	Consult with farmers Hoard off working space Close gates etc. Adopt necessary safety procedures
Crops	Crop damage, Disease	Consider timing of inspection Keep to planned locations Adopt necessary safety procedures
Habitats	Ecological or landscape Significance of adjacent land	Obtain advice/consent from relevant body. Keep to planned locations
Watercourses	Pollution	Adopt best practices Avoid spillage of fuel or other pollutants

Environmental considerations		
Impacts on	**Aspects to be considered**	**Action**
Plants	Destruction of rare or protected species	Adopt necessary procedures Keep to planned locations
Bats Nesting birds and Other wildlife	Disturbance of bats or roost sites. Disturbance of birds when nesting Disturbance of protected wild-life	Consult KWS and arrange bat survey where required Time inspection to avoid disturbance. Obtain general licence to remove pest species Consult relevant organizations
Bird droppings	Accumulations can be a health hazard	Use respirators and other PPEs

5.6.3 Social Consideration

Some highway structures are sited in sensitive areas, such as residential areas or adjacent to hospitals, where inspection work or noise from plant may cause inconvenience or nuisance to the public. The adoption of good working practices and sensible timing may help to reduce the effects of noise. Nevertheless, the Directorate of Occupational Safety and Health (DOSH) of the local county should be consulted if there are likely to be challenges. The Environmental Health Officer may set limits to the noise which will be permitted.

Night-time working can be particularly disruptive. If work at night is planned near residential properties or other sensitive areas, the DOSH must be consulted and prior consent obtained. This consent will stipulate noise limits.

5.7 Bridge access Requirements

5.7.1 Pre-Inspection

As part of the pre-inspection process the bridge inspector should visit bridge site to decide how the inspection can be carried out in a safe manner and what level of access equipment is appropriate for the type of inspection to be carried out. Access to many bridges can be obtained using simple equipment such as ladders, vertical portable platforms or small lorry mounted hoists (such as lamp cranes). Where access is more difficult, alternatives have to be considered taking into account the type and thoroughness of the inspection (whether Routine, Baseline, Periodic, Emergency or Special) and the nature of the different tasks that need to be carried out.

All transportation and access equipment including power units should be inspected and maintained regularly. The safe working load of any access equipment must never be exceeded. Advantage should be taken for occupations arranged for other purposes (such as a railway possession), making liaison with other maintenance authorities is important.

5.7.2 Scaffolding

The provision of scaffolding for the inspection can be expensive and time-consuming procedure. The use of scaffolding should only be considered for inspection purpose if no other cost-effective access method is available.

Scaffolding has the advantage that it can provide access for several tasks to be carried out at the same time, or successively. Such tasks may include repair and maintenance work such as weld examination, concrete repairs, painting and drainage maintenance. However, these different works must be coordinated.

Scaffolding has the disadvantage of being fairly expensive, time consuming to erect and dismantle. If erected from the ground a pre-inspection of the site should confirm the adequacy of founding strata and the suitability of this type of access. Difficult access erection would include bridges over river or railways. Extreme caution must be taken in the vicinity of overhead electric cables with firm assurances that the electric power has been switched off when erecting and dismantling scaffolding. No metal scaffold tube must be within 3 meters of a live electric overhead cable.

Scaffold staging may also be suspended from the bridge but care must be taken not to infringe the minimum headroom (when erected over a highway) and the scaffolding should also be protected from accidental impact from vehicles.

5.7.3 Fixed Ladders and Walkways

Means of access to bearings, drainage items and parts of the bridge soffit is by the use of fixed ladders and walkways. Steel ladders can be permanently fixed to abutments and Piers and suspended walkways can be supplemented by staging, cradles and scaffolding to give access to any part to the bridges. In view of the substantial cost and time of erecting scaffolding from the ground, permanent walkways maybe a quicker and cost-effective long-term solution in some situations, yet still preserve the flexibility of scaffolding in providing safe access for a variety of concurrent or successive tasks.

Before using any permanently installed access equipment the inspector should ensure that the equipment has been maintained and is safe to use: it should be clear who is responsible for regular inspection and maintenance. Where appropriate, the equipment should be examined and tested before use.

The provision of permanent access ladders and walkways should encompass any security requirements e.g., non-motorized traffic management and related security operations. Special precautions should be taken to avoid unauthorized access onto the ladders and walkways (such as a lockable gate).

5.7.4 Travelling Gantries

Some long span structures have been equipped with purpose built permanent travelling gantries suspended from the structure. Such gantries provide the means for effective and safe access for the inspection team whilst being secure to prevent unauthorized use. It should be noted that the travelling gantry must be inspected annually and this includes the runway beams on which the gantry is likely to be mounted.

5.7.5 Mobile Equipment (Hydraulic Platforms and Lifts)

There is a large range of hydraulic platforms and lifts available in the market which can provide access for bridge inspection. The following includes details of equipment currently available to the parent Ministry and equipment types that can be hired or purchased in the future:

- For points that are not so high, platforms extending in the vertical direction only can be used. These machines should be located immediately adjacent to or below the area to be inspected. These types of platforms are generally not self-propelling and need a firm level surface under the bridge to be inspected. For detailed inspection of localized areas scissors lofts are available with large platform areas which are capable of reaching 12m. Additionally, small extending boom hoists having a reach up to 10m can be towed to site and are useful for the inspection of small structures.

- Extending and telescopic hoists mounted on trucks have the adaptability to reach low, medium and large heights. These are the commonly available types of access equipment available at parent ministry as they are normally used to maintain lamp column lighting. The larger truck mounted hoists tend to have telescopic arms and are capable of reaching in excess of 40m. They are heavy vehicles and require a firm base on which to stand but they can inspect a large area from one position.

Also self-propelled hoists, controlled from the inspection cage are available for inspection of heights of up to 15m. These are often available with 4-wheel drive for areas of rough uneven ground. The most critical disadvantage is that a separate vehicle is required to transport the inspection vehicle to site adding to the inspection cost.

Small self-propelled all-terrain vehicles with telescopic hoists are also useful on rough ground sites. The reach is generally limited to 10m and the machines rely on outriggers for stability. They also require frequent changes of position to cover a large inspection area.

When it is difficult or impossible to provide access from below, proprietary under bridge platforms, or a Specialized Bridge Inspection Vehicle equipped with a boom arm and access platform can be used.

These are either lorry or trailer mounted platforms and the larger platforms can be used up to 20m under the bridge soffit. For these types of inspection vehicles, care must be taken to ensure that the bridge structure including the verges is capable of withstanding vehicle wheel and outrigger loads which can be considerable. Attention has to be given to the amount of space needed to mobilize the vehicle and it is necessary to check for any obstructions such as high kerbs or parapet which may hinder the use of this type of platforms.

For all types of hydraulic access equipment, the load carrying capacity of the structure shall not be exceeded and in such cases, it may be necessary to restrict live loading of the deck by coning off one carriageway. Again, sufficient carriageway must be coned off when the inspection vehicles are in use. Often it is advisable to park another vehicle in a position that protects the inspection vehicle and inspection personnel.

Figure 5-2 Types of hydraulic access equipment

5.7.6 Confined Spaces

As part of a detailed inspection structural members such as steel and concrete box girders, hollow abutments and towers require to be internally inspected. Access to such confined spaces should be strictly controlled and the following guidelines on Hazards associated with confined spaces include oxygen deficiency, flammable gases or liquids, toxic fumes, fungal or bacterial organisms and dust.

These confined spaces can be accessed through manholes/inspection chamber without much disruption to traffic flow. When working the manhole cover should be secured to prevent closure during inspection and all openings adequately protected to prevent anyone from falling off.

The following guidelines are recommended for inspection in confined spaces:

The inspection team members should be physically fit and should not have psychological problems such as *vertigo* (fear of heights) or *claustrophobia* (fear of enclosed spaces).

There should be sufficient light for visually inspecting the whole member, seeing any potentially dangerous insects or small animals within the vicinity, and for preventing accidents such as running/tripping over obstacles.

Detailed briefing by the inspection Team Leader shall be carried out prior to entering the confined space.

The biological hazards from items such as *mold growth* and *bird droppings* shall be assessed. If it is detected that mold is growing on the structural member, the Public Health officer of the county should be urgently informed and the effect on health checked. Entry to the confined space should be avoided until samples of the mold have been analyzed. If it is very urgent to access a structural member, it can only be done through the use of recommended breathing apparatus.

The ventilation within the confined space should be checked before accessing. If the ventilation is not adequate, more ventilation shall be ensured by opening additional manhole covers and pumping in fresh air.

5.7.7 Abseiling/Roped Access

The use of abseiling, or roped access, allows inspections to be carried out where the provision of more conventional means of access would be difficult or prohibitively expensive. Access is gained from above by means of suspended ropes, which provide means of support and positioning. In addition to inspecting vertical faces of a bridge it is also possible to inspect the soffit using ropes or light weight metal structures slung under the bridge.

Abseiling is a specialized task and must only be undertaken by trained and experienced firms. An inspector using this method must have a support team at all times and sufficient, well-maintained equipment.

Due to the nature of the equipment, it may not always be possible to inspect all parts of the structure at touching distance. It may be necessary to attach eye bolts and other fixing points on the structure to anchor or support ropes.

5.7.8 Underwater Access

The method to be applied for underwater inspection of bridge elements partially or wholly submerged water is different from that of bridge elements on land. Underwater inspection shall only be undertaken by qualified persons specializing in this type of work. Access to site can be done by means of either diving from shoreline or diving from a standby boat in the case of strong currents. Appropriate safety lines need to be established.

In extreme cases where the inspection results cannot be confirmed or extensive repair works are required to be carried out, a caisson should be constructed and water pumped out. This will then provide the appropriate conditions to allow access for inspection.

5.8 Tools & equipment

Several factors play a role in determining the type of equipment needed for an inspection. Bridge location and type are two of the main factors in determining equipment needs. If the bridge is located over water, certain types of equipment such as life jackets and boats are important to have. Also, if the bridge is made of timber, then special equipment like increment borers and ice picks are needed, whereas they would not be necessary on a steel or concrete bridge. Another factor influencing equipment needs is the type of inspection. It is therefore important to review every facet about the bridge before heading out on an inspection. A few minutes spent reviewing the bridge files and making a checklist of the necessary equipment can save hours of wasted inspection time in the field if the inspectors do not have the required equipment.

In order for the inspector to perform an accurate and comprehensive inspection, the proper tools must be used. Standard tools that an inspector should have available at the bridge site can be grouped into seven basic categories:

- Tools for cleaning
- Tools for inspection
- Tools for visual aid
- Tools for measuring
- Tools for documentation/Data recording
- Tools for access
- Miscellaneous equipment

Table 5-2 Tools & equipment

EQUIPMENT /TOOL	USE
Tools for Cleaning	
Whisk broom	For removing loose dirt and debris
Wire brush	For removing loose paint and corrosion from steel elements
Scrapers (2 inch or 50 mm)	For removing corrosion or growth from element surfaces
Flat bladed screwdriver	For general cleaning and probing
Shovel	For removing dirt and debris from bearing areas
Dust Blower	To remove/blow away dust and loose debri so that one can inspect flat surfaces
Tools for Inspection	
Pocket knife	For general duty
Ice pick	For surface examination of timber elements
Hand brace and bits	For boring suspect areas of timber elements
Increment borer	For internal examination of timber elements

EQUIPMENT / TOOL	USE
Chipping hammer with leather holder	For loosening dirt and rust scale, sounding concrete, and checking for sheared or loose fasteners
Plumb bob	To measure vertical alignment of a superstructure or substructure element
Tool belt with tool pouch	For convenient holding and access of small tools
Chain drag	To identify areas of delamination on concrete decks
Range pole / probe	For probing for scour holes
Tools for Visual Aid	
Binoculars	To preview areas prior to inspection activity and for examination at distances
Flashlight	For illuminating dark areas
Lighted magnifying glass (e.g., 5power and 10power)	For close examination of cracks and areas prone to cracking
Inspection mirrors	For inspection of inaccessible areas (e.g., underside of deck joints)
Dye penetrant	For identifying cracks and their lengths
Tools for Measuring	
Pocket tape (6-foot rule)	To measure defects, element and joint dimensions
25 foot and 100-foot tape	For measuring component dimensions
Callipers	For measuring the thickness of an element beyond an exposed edge
Optical crack gauge	For precise measurements of crack widths
Paint film gauge	For checking paint thickness
Tiltmeter and protractor	For determining tilting substructures and for measuring the angle of bearing tilt
Thermometer	For measuring ambient air temperature and superstructure temperature
4-foot carpenter's level	For measuring deck cross-slopes and approach pavement settlement
D-Meter (ultrasonic thickness gauge)	For accurate measurements of steel thickness
Electronic Distance Meter (EDM)	For accurate measurements of span lengths and clearances when access is a challenge
Line (spirit) level and string line	To check if a surface is horizontal/vertical
Tools for Documentation	
Digital Bridge Inspection form, phone/tablet	Digital tool (phone/tablet application) for data collection during site inspection that uploads/downloads data from BMS
Inspection forms, clipboard, and pencil	For record keeping for most bridges
Field books	For additional record keeping for complex structures
Straight edge	For drawing concise sketches
35 mm camera	For visual documentation of the bridge site and conditions
Polaroid camera	To provide instant documentation for serious conditions which require immediate review by office personnel

EQUIPMENT /TOOL	USE
Digital camera	To provide digital images of defects which can be downloaded and e-mailed for instant assessment
Chalk, keel, paint sticks, or markers	For element and defect identification for improved organization and photo documentation
Center punch	For applying reference marks to steel elements for movement documentation (e.g., bearing tilt and joint openings)
"P-K" nails/Parker Kalon masonry survey nails	For establishing a reference point necessary for movement documentation of substructures and large cracks
Equipment for Access	
Ladders	For substructures and various areas of the superstructure
Scaffolds	To provide an efficient access alternative for structures that are high.
Rigging	To gain access to floor systems and the bottom of main load carrying members in areas where access by other means is not feasible or where detailed inspection procedures are required
Boat	For soundings and inspection; safety for over water works
Rope	To aid in climbing
Waders	For shallow streams
Miscellaneous equipment	
"C"-clamps	To provide a "third hand" when taking difficult measurements
Penetrating oil	Aids removal of fasteners, lock nuts, and pin caps when necessary
Insect repellent	Reduces attack by mosquitoes, ticks, and jiggers
Wasp and hornet killer	To eliminate nests to permit inspection
First-aid kit	For small cuts, snake bites, and bee stings
Dust masks or respirators	To protect against inhalation in dusty condition or work around pigeon droppings
Coveralls	To protect clothing and skin against sharp edges while inspecting
Life jacket	For safety over water
Cell phone/tablet	To communicate/call in emergencies
Toilet paper/sanitary wipes	For cleaning and other emergencies
Special equipment to prepare the bridge prior to the inspection	
Air-water jet equipment	To clean surfaces of dirt and debris
Sand or shot blasting equipment	To clean steel surfaces to bare metal
Burning, drilling, and grinding equipment	To clear unwanted material
Drone / Unmanned Aerial Vehicle (UAV)	For inspection of inaccessible parts of a bridge by digitally recording sections to be reviewed later.
Specialized Bridge Inspection Vehicle	Equipped with a boom arm and inspection platform (Bridge Checker) to allow inspection/access below bridge deck and other inaccessible parts of a bridge.

Inspection using a Bridge Inspection Vehicle

Inspection using a pole camera

Inspection using a ladder

Inspection using a drone

Figure 5-3 Tools and equipment for inspection

5.9 Desktop study

This Bridge Inspection Manual is written to establish a uniform and formal procedure for the bridge inspection. These requirements provide for regular and systematic inspection of bridges on, under or over public highways and streets in the interest of public safety and protection of the public investments in such bridges.

The Bridge Inspection Manual is a combination of guidelines, example forms, charts, policies and procedures designed as an aid to all who are concerned with bridge inspections. This manual will be used in conjunction with the following documents:

i. Bridge Inspection Handbook
ii. Bridge Inspection Manual for ARBICS and PBC
iii. Inspection Manual for bridges

5.10 Traffic Control

Bridge inspection and maintenance activities on bridges, often presents motorists with unexpected and unusual situations. When working in an area exposed to traffic, the bridge inspector should ensure traffic is controlled.

The objective of a traffic control plan is to ensure smooth, safe vehicular movement past the work area and at the same time provide safety for the equipment and the workers on the job.

Motorists should be well guided while approaching and traversing work areas.

Adequate signage, delineation, and channelization should be provided to ensure the motorist advance through the work area safely. Proper signage and other devices which are effective under varying conditions of light and weather must be used.

Individuals in a work zone must wear approved safety vests and helmet for visibility and identification.

Requirements of Traffic Control Devices

1. They must be visible.

    Bright colors make devices easier to see.

    All signs must be legible and color distinguishable at night as well as during the day. Nighttime sign visibility is provided through retro reflectivity, which is accomplished by spherical glass beads or prismatic reflectors in the sign material. The headlights reflect off the sign and back to the driver, making the sign visible at night.

    New sign messages such as *"Slow Down. My Daddy Works Here"* and *"Give Us A Brake. Slow Down"* cause the driver to think on a more personal level.

2. They must give clear direction.
3. They must command respect. They should be official.
4. They must elicit the proper response at the appropriate time.

    The decision process includes the classical chain of sensing, perceiving, analyzing, deciding, and responding.

Types of Traffic Control Measures

1. Signage
2. Channelizing devices
    - Cones
    - Drums
    - Wands
    - Portable Cement barrier
3. Lighting
4. Traffic marshals

5.11 Bridge Management System (BMS)

5.11.1 Introduction

The BMS was developed with a mobile inspection software that is used to record bridge inspection data at site and electronically update onto the BMS automatically.

The ultimate objectives of the BMS are to facilitate safe usage of bridges and optimal use of financial resources. Bridge Inspection data is the foundation for the entire bridge management system. Information obtained during the inspection will be used for determining required maintenance and repairs, identifying preservation needs, prioritizing rehabilitations and replacements, allocating resources, evaluating and improving design for new bridges. The accuracy and consistency of the inspection and documentation is vital because it not only impacts programming and management of the bridge inventory but also affects public safety.

A uniform reporting system is essential to evaluate the condition of a bridge correctly and efficiently. Consequently, the bridge inspection data should be clear, accurate and complete, since it is an integral part of the lifelong record file of the bridge.

5.11.2 The BMS Cycle

The BMS cycle outlines the major stages for bridge management. The stages include collection of inventory data, regular inspection, assessment of condition and strength, countermeasure (repair, strengthening or replacement) and recording.

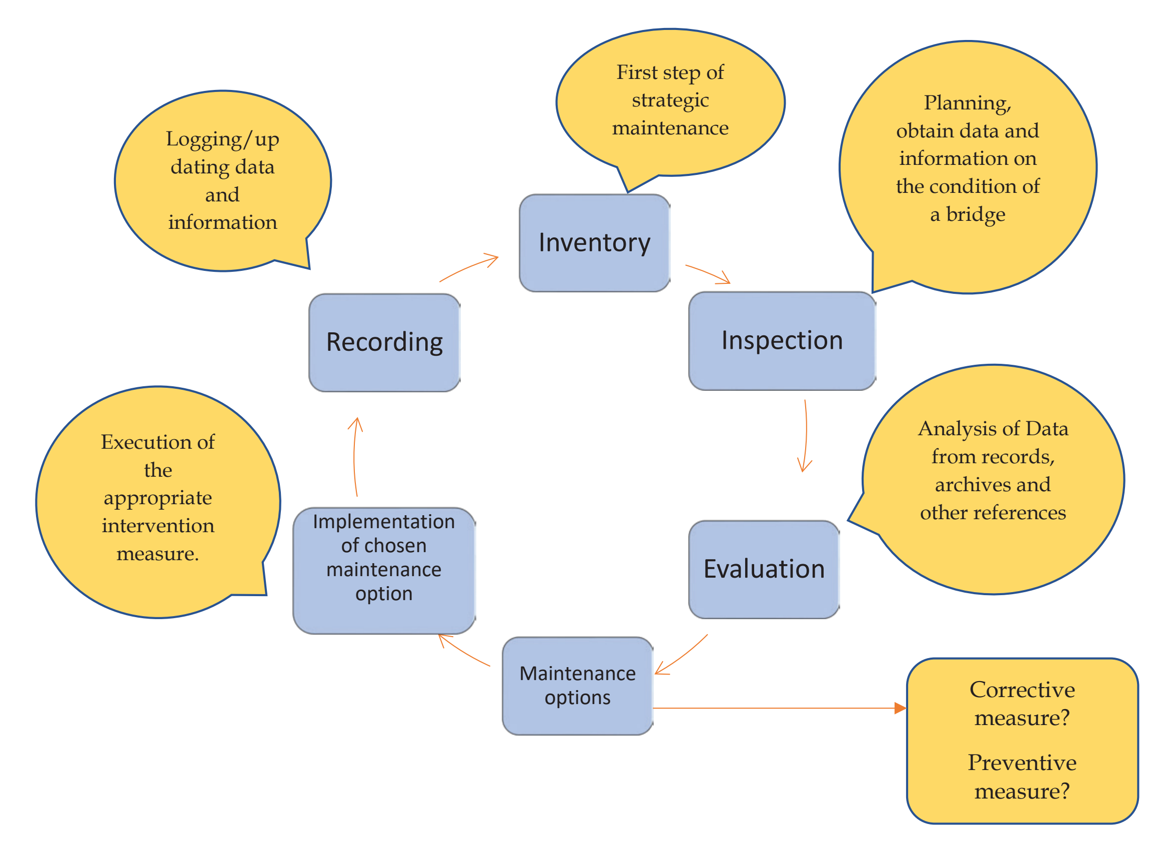


Figure 5-4 Summary of a BMS cycle

- ***Inventory*** – This captures the information regarding the structure after construction or as existing. The inventory may contain administrative data (road register, bridge identification etc.), Technical data (Bridge types, dimensions, materials etc.) Passage data (Data on roads, waterways etc. including clearances and load carrying capacity classes for the bridges), Archive references (Information on the contents of the archives), Chronological overview (A list of important events in the life of each bridge)
- ***Inspection*** – Helps with obtaining data and information on the bridge condition. The main activities leading to the choice of appropriate measures for a damaged bridge is initiated at the inspection stage. The purpose is to obtain an overview of the general condition of bridges and to detect significant damage at an early stage so that correction works can be undertaken optimally. Therefore, it is critical that the inspector is qualified and capable to identify and examine defects.
- ***Evaluation***– Helps in determining the condition and soundness of a bridge and it's appropriate condition rating based on inspection data.
- ***Maintenance*** – Based on the evaluation results a decision is made on the best intervention. Action is taken to address defect or damage identified in the bridge. The specific action is based on the score obtained after rating.
- ***Recording*** – This involves storing information regarding the structure for the entire management system.

6 BRIDGE CONDITION ASSESSMENT

6.1 Introduction

The condition assessment of an existing bridge aims at determining functionality and serviceability of a bridge. This could be achieved through inspection of a bridge component, elements within a span or the entire bridge. The inspection is aimed at identifying and quantifying deterioration, which may be caused by applied loads and influences exerted by the environment. In this case, bridge inspections should aim at providing information that will assist in decisions as follows;

a) A reliable record of the structure's condition that makes it possible to assess the significance of any changes (accidents, overloading, or deterioration of the environment);

b) The data upon which the safety, functionality and serviceability of the bridge can be assessed;

c) Details on any potential hazards;

d) Data from which a reliable maintenance plan and strategy can be developed;

e) Data to track the impact of any alterations on traffic loads;

f) The utilization of new structural designs and materials, if any; and

g) The efficiency of new strengthening methods.

The inspection information should be recorded as clearly as possible so that aquick and appropriate evaluation can be made as to the action necessary. In addition, the initial recording of the basic bridge data and regular reporting of a bridge's conditions provides a way of updating on the status of deterioration of the bridge thus enabling assessment of maintenance requirement.

6.2 Bridge Condition Rating

The condition of an element or component of a bridge is an evaluation of its current physical state compared to what it was after completion and opening to traffic. The condition rating is not influenced by the ability of the element or component to carry design loads. Accuracy in assigning of the condition ratings is dependent on the bridge inspector's ability to identify defects in the bridge components and their elements. Bridge condition assessment levels include components (superstructure, bearing and substructure) and elements (girder, deck slab, abutment, column among others).

The overall condition rating of bridge components is directly related to the physical deteriorations of the bridge elements and by extension, the bridge components.

In determining bridge condition, an inspector must be familiar with common damages associated with various construction materials *(Refer to Chapter 3).* The table below shows some of the damages affecting steel, concrete and other materials.

Table 6-1 Some of the damages affecting steel, concrete and other material

Material	Type of damage
Steel	Corrosion
	Cracking
	Loose bolts, Missing parts
	Fracture
	Degradation of anti-corrosion function
Concrete	Crack
	Peeling, Exposure of re-bar
	Leaching, Free lime
	Fall off
	Cracks on slab
	Spalling, Delamination
Other materials	Unusual or Abnormal Space
	Rough surface
	Abnormal surface (Pavement)
	Lack of bearing function
	Deterioration on repairing/strengthening
	Abnormal anchorage
	Discoloration and degradation
	Leaking, surface ponding
	Abnormal Sound and Vibration
	Abnormal deflection
	Deformation, fracture
	Drainage problem
	Subsidence, displacement, inclination
	Scouring

The overall condition of a bridge is numerically expressed as Bridge Condition Rating (BCR) calculated according to the following formula:

$$\text{Bridge Condition Rating} = \frac{\sum(\text{Rating} \times \text{Weighting})}{\sum(\text{Weightings})}$$

The details of the weightings of bridge components and elements are provided in the BMS Manual. The referred weights take into consideration degree of damage, extent of damage, importance of the structure and urgency required to make or correct the observed deterioration.

6.2.1 Routine inspection condition rating

Routine inspection is a visual inspection conducted to provide information that helps in planning for the necessary bridge repairs, to inform the necessity of urgent action and to inform change of maintenance plan of a structure.

The check elements for this inspection are:

1. Road surface
2. Superstructure
3. Substructure
4. Bearings
5. Embankments

The inspector goes to site to observe the severity and the extent of the defects on the bridge, then determine the Defect Condition Level of individual defects on elements according to the BMS App.

The defects can be rated under 4 levels as shown in Table 6-2 Defects levels:

Table 6-2 Defects levels

Defect Level	Description	Recommended action
N	No defect found or defect is minor	• No action nor no monitoring required
DL I	Defects to observe. Defects do not compromise the structural integrity of the structure.	• Monitoring of defects under ARBICS and Periodic inspection • Preventive measures
DL II	Defects need action. Clear defects may compromise the structural integrity of the structure if no action in few years is taken.	• Detailed inspection • Remedial measures/ preventive measures
DL III	Defects need urgent action Clear defect that has significantly compromised the structural integrity of the structure/high risk.	• Emergency inspection • Immediate action (including control of traffic)

Routine inspection calculation approach

A tree diagram is used to allocate points to various bridge components that are used to calculate the routine inspection rating. The tree diagram has the bridge at the top having 100% of the components donated point (DP) which is a summation of the distributed points of the elements making up the bridge.

The bridge is then subdivided into three major components i.e. Principal Structure, Non- structural elements (NSE) and Road restrain systems.

The three major components are then divided into sub-components and allocated donated points as shown in *Figure 6-1.*

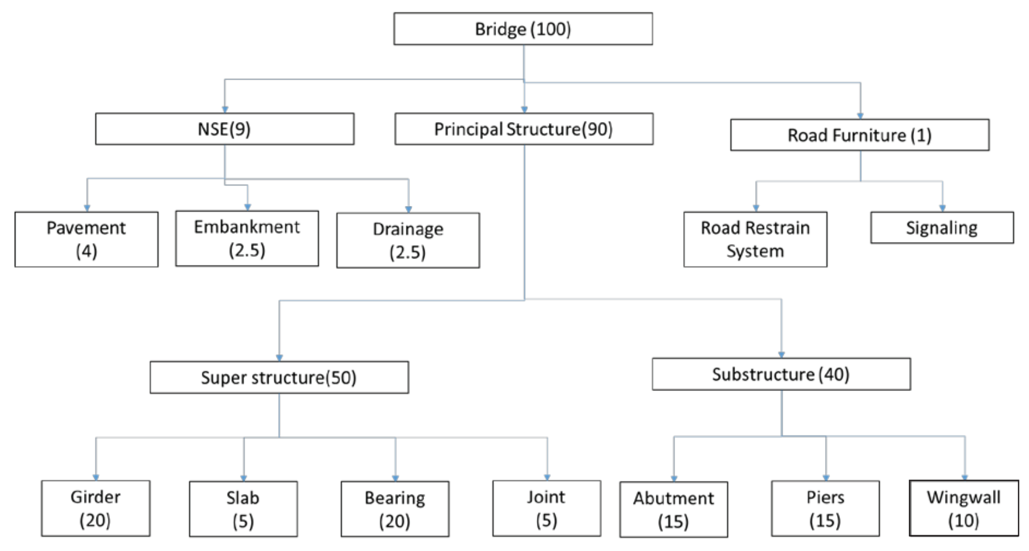


Figure 6-1 Bridge distribution of donated points

Using a formula, the member donated points (MDP) are calculated to get the member soundness. From this data collected, and by means of different algorithms, the bridge rating is obtained. This bridge rating enables to categorize the bridge state based on five defined ranges. From N-blue, O-green, D-yellow, SD1-orange to SD2-red.

The different colour ranges from blue to red enables to prioritize the maintenance of bridges as well as to determine the need for action for each bridge. The manual adopts a five-point condition rating as shown in Table 6-3 Routine Inspection Condition Rating

Table 6-3 Routine Inspection Condition Rating

Routine Inspection			
Defects Level on Structure elements	Action/ Response time		Overall Condition Category
N	80-100	Long – term action	N
N, DL I	60-79	Mid-long-term action	O
DL I, DL II	40-59	Mid-term action Require preventive measures	D
DL II, DL III	20-39	Short –term action (Requires prompt action)	SD1
DL III	0-19	Bridge collapsed/ Immediate urgent action (Require emergency measures)	SD2

6.2.2 Categories of Soundness Evaluation for Initial inspection

An algorithm to obtain the overall bridge rating upon completion of initial inspection has been developed where the dependency relation between constituent parts of the bridge causes the rating to be transferred from different parts of the structure in ascending order to give the final overall bridge rating.

Condition rating evaluates each element separately; however, other deficiencies may affect the condition if they are directly related e.g. instability of an approach embankment will affect the condition of the abutment but not of the superstructure

Indicators such as extension and severity, enabling the damage assessment, are collected for each of the damages existing in a certain member of the structure. From this data, and by means of different algorithms, the bridge rating is obtained. The bridge rating enables to categorize the bridge state of conservation based on five defined ranges. This numerical value enables to prioritize the state of maintenance of a set of bridges at a specific moment as well as to determine the need for action in each bridge.

This evaluation (both from the bridge and from each of the subcomponents in which it is divided) ranges from 0, 'collapsed bridge', to 100, 'bridge in perfect condition'.

Table 6-4 Baseline Inspection Bridge Condition Rating

Score/Rating	Damage description	Action/Response time
80-100:	Bridge with minor durability or functional damages.	Long-term action
60-79:	Bridge with moderate durability or functional damages.	Mid / long-term action
40-59:	Bridge with minor structural damages or extended durability or functional damages.	Mid-term action Requires preventive measures
20-39:	Bridge with moderate structural damages. Serious durability or functional damages.	Short-term action (Requires prompt action)
0-19:	Collapsed bridge or bridge with high-severity structural damages.	Immediate urgent action (Require emergency measures)

An evaluation between 80 and 100 means that the bridge deteriorations do not affect the structural capacity of any of its elements but only minor durability or functional deteriorations are observed, requiring a long-term repair or not requiring any action.

An evaluation between 60 and 79 means that the bridge deteriorations do not affect the structural capacity of some of its elements and only moderate durability or functional deteriorations are observed, requiring a mid-term or long-term repair.

An evaluation between 40 and 59 means that the bridge deteriorations have minor effects on the structural capacity of some of its elements and extended durability or functional damages requiring a Mid-term action and preventive measures.

An evaluation between 20 and 39 means that the bridge deteriorations have moderate structural damages of some of its elements and serious durability or functional damages requiring short-term and prompt action.

An evaluation between 0 and 19 means that the bridge deteriorations seriously affect the structural capacity of some of its elements, requiring urgent action.

Summary of bridge condition ratings for both the Routine Inspection and Baseline Inspection is given in Figure 6-2 Overall Bridge Condition Rating.

Principal Inspection				Overall Condition Category		Routine Inspection	
Stage	Score/ Rating	Damage Description	Action/ Response time			Defects Level on Structure elements	
1	80-100	Bridge with minor durability or functional damages	• Long – term action	Observe or monitor	• N (No Damage, Observe)	80-100	N
2	60-79	Bridge with moderate durability or functional damages	• Mid-long term action	Low priority for repair	• O (Observe, Minor Repair)	60-79	N,DL I
3	40-59	Bridge with monitor structural damages or extended durability or functional damages	• Mid-term action • Require preventive measures	Repair before next inspection	• D (Damage, Repair before next Inspection)	40-59	DL I, DL II
4	20-39	Bridge with moderate structural damages. Serious durability or functional damages.	• Short –term action • (Requires prompt action)	High priority Reduce inspection frequency time	• SD1 (Severe Damage Level 1, Prioritize Repair)	20-39	DL II , DL III
5	0-19	Collapsed bridge or bridge with high-severity structural damages	• Immediate urgent action (Require emergency measures)	Immediate action/ replacement required	• SD2 (Severe Damage Level 2, Immediate Repair or Replacement)	0-19	Bridge collapsed/ DL III

Figure 6-2 Overall bridge condition rating.

6.3 Deterioration model and Repair Timing

In order to draw a preventive maintenance plan for taking measures to address bridge defects, it is necessary to predict future state of deterioration of bridges (what state of damage is reached, and when). Progress of deterioration can be modelled by deterioration curve as explained by Bridge Condition Rating (BCR) formula below;

$$\mathbf{BCR_T} = 100 - aT^2$$

Whereby:

a is the gradient factor *(to be established based on past inspection results)*, and

T is time in years elapsed from the base year.

Consequently, repairing of relevant parts of a bridge shall be carried out in the year following the year when BCR_T falls below the set criterion in the relevant policy. Therefore, the deterioration curve is critical in the development of a bridge maintenance plan and improvement requirements that may include preventive maintenance, rehabilitation and replacement.

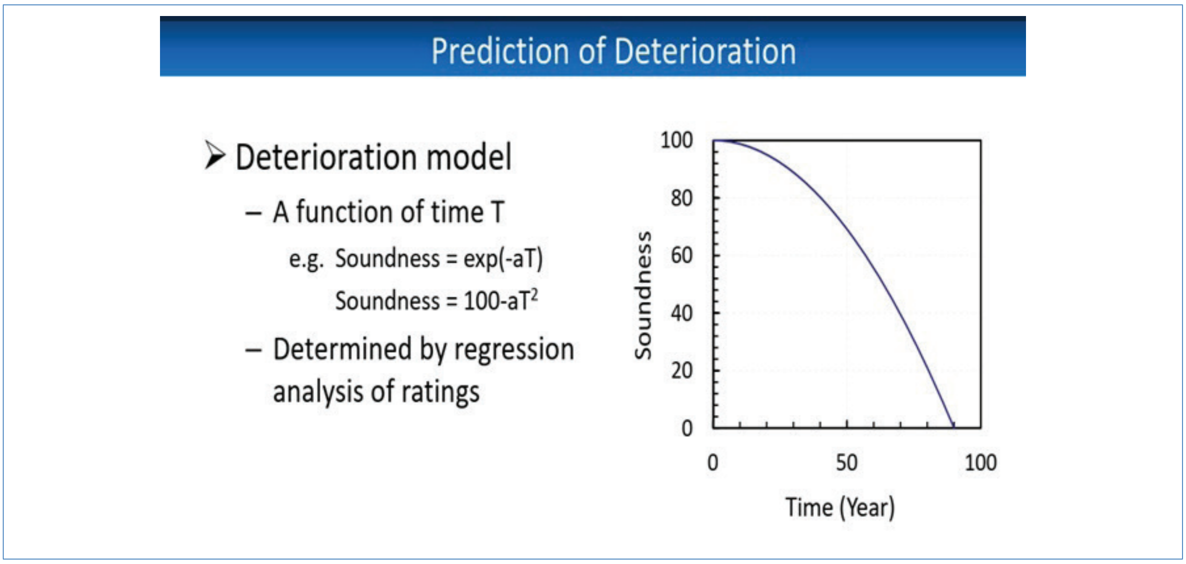


Figure 6-3 Soundness Evaluation & Deterioration prediction curve

7. TEST METHODS FOR BRIDGES

7.1 Introduction

Once a bridge has been inspected and analysis done for its overall condition, it is necessary to carry out tests for further diagnostic process.

Generally, there are two types of bridge test methods;

i. Non-destructive tests (NDT).
ii. Destructive tests (DT).

7.2 Non-Destructive Tests

Non-destructive testing involves carrying out tests without destroying any part of the structure.

NDTs are normally conducted to determine:

- The physical quality of the materials; and
- The position and extent of hidden defects, elements and material boundaries.

NDTs are carried out in-situ to provide further information from which an improved diagnosis can be made to enable the bridge engineer to make decisions on the necessary remedial work.

Reliability of Non-Destructive Tests

Concrete strength, rebar status, painting conditions, etc. on existing bridges and other structures can be checked by NDT.

NDT result may not always be accurate. There is a possibility that the accuracy of NDT outcome could differ depending on the degree of compliance of the prescribed preparatory works and the technical operation of the NDT apparatus. NDT operator has to undergo proper training.

The result therefore of NDT has to be sufficiently evaluated by the Engineer from the objective and technical point of view.

The following are some of the typical NDT methods for concrete and steel structures described in this manual and are classified according to the type of material as shown in Table 7-1

Table 7-1 Types of Non-Destructive Tests

For Concrete Structures	i. Rebound Hammer Test
	ii. Ultrasonic Pulse Velocity Test
	iii. Rebar Detection Test
	iv. Infrared Thermal Image Test
	v. Resistivity Test
	vi. Half-Cell Electrical Potential
For Steel Structures	i. Paint Thickness Test
	ii. Metal Thickness Test
	iii. Ultrasonic Flaw Detection Test
	iv. Magnetic Particle Testing (MT)

7.3 Non -destructive tests for concrete structures

7.3.1 Rebound Hammer Test / Schmidt Hammer

A rebound hammer also known as Schmidt hammer, Swiss hammer or concrete hammer, is a device used to measure the elastic properties or strength of concrete or rock, mainly surface hardness and penetration resistance.

7.3.1.1 Fundamental Principles

The test method is based on the principle that the rebound of an elastic mass (the hammer piston or impact plunger) depends on the hardness of the material it strikes, and the assumptions are that;-

(a) The hardness is proportional to the materials strength and

(b) The material is homogenous.

Rebound hammer test can only assess the compressive strength of the near surface layer of concrete in the zone of influence of hammer impact. It is useful in detecting weak areas in a concrete structure.

7.3.1.2 Apparatus

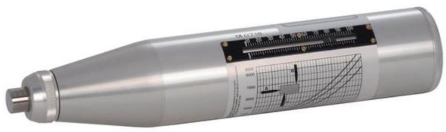
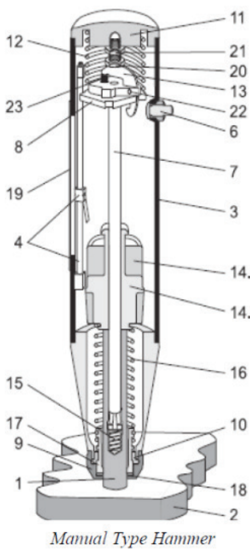
<table>
<tr><th>Concrete Manual Test Hammer</th><th>Concrete Digital Test Hammer</th></tr>
<tr><td></td><td></td></tr>
<tr><th colspan="2">Mechanical Parts of a Concrete Test Hammer</th></tr>
<tr><td>
</td><td>1. Impact Plunger
2. Test Surface
3. Housing
4. Rider with guide rod
5. Not used
6. Push-button, complete
7. Hammer guide bar
8. Guide disk
9. Cap
10. Two-part ring
11. Rear Cover
12. Compression spring
13. Pawl
14. Hammer Mass
15. Retaining spring
16. Impact spring
17. Guide sleeve
18. Felt washer
19. Plexiglas window
20. Trip screw
21. Lock nut
22. Pin
23. Pawl spring</td></tr>
</table>

Figure 7-1 Rebound hammer

7.3.1.3 Procedures

a. Use of the Rebound Hammer

General procedures when using rebound hammer;

i. Gather Reference Information on bridge/structure

Determine the following information on the bridge before testing

- Design compressive strength
- Age of concrete (reckoned from date of construction)
- Concrete mix proportions

ii. *Set-up of Apparatus:* Take out the test hammer from the carrying case, press the plunger head until it is released, check surface of plunger and remove any dust or oil with cotton cloth to avoid scratching the surface.

Confirm calibration status of the equipment before use.

> Calibration of the rebound hammer is necessary for proper operation. A steel anvil is used for verification. Refer to the manufacturer's instruction manual.

iii. Preparation of Test Surface

a. If necessary, grout or plaster that covers the concrete surface should be ground smooth with abrasive stone *(The surface to be tested MUST be smooth).*

b. Avoid testing near joints and areas exhibiting honeycomb, scaling and high porosity. In cases where carbonation is present or suspected, the surface layer should be removed using power grinder to obtain rebound numbers representative of the interior concrete.

c. Avoid tests directly on top of bars. Where possible, use a cover meter to locate bars close to the surface before taking a test or setting out a grid for a number of tests.

d. Where tests are required on concrete members less than 100mm thick, members should be rigidly supported.

e. The number of test points shall be determined in the field. Minimum spacing between test points shall be 150 mm.

iv. Testing procedure

a. Draw Grid on Concrete Surface to be Tested. Mark test points (20 points) using a marking sheet as shown in Figure 7-2. The distance between each point should be 25 mm to 50mm.

Figure 7-2 Marking test points

b. Press release button to release the plunger head.

c. Rest the plunger head at right angles to the concrete surface.

d. Press the hammer until it strikes the surface.

(Note: Do not press push-button under any circumstances when taking readings)

e. The hammer rebounds moving a reference pointer with it.

f. Hold the hammer at its maximum position and record the reading.

g. Repeat procedures for next measurements until a total of 20 readings (Cells A1 to D5) are taken.

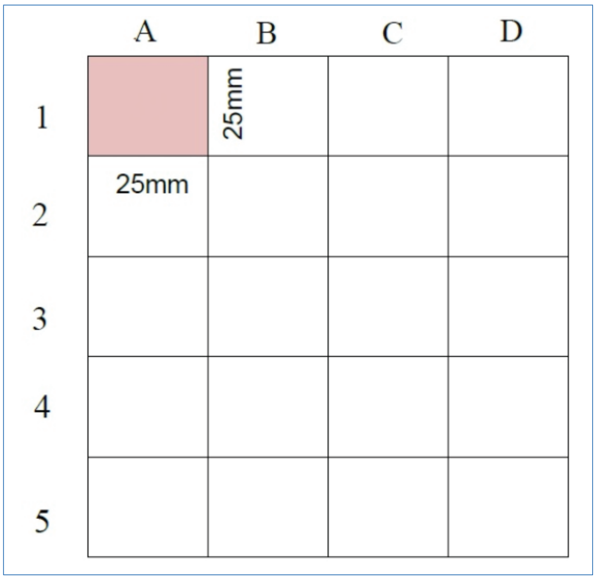


Figure 7-3 Test points with distance between each point is 25 mm

> *The hammer can be used to test surfaces at any inclination but readings at the same inclination (horizontal, up, down, etc.) shall be compared. Test inclination shall be recorded on the test sheet.*

7.3.1.4 Analysis

The reading on the rebound hammer does not directly indicate the compressive strength of concrete. The estimated concrete strength is then calculated using either of the following equations as illustrated below.

$$\mathrm{fc} = (\mathrm{R} + \Delta) \text{..................................Equation 1}$$

Where,

fc — *Estimated concrete strength (N/mm²)*

R — *Mean value for rebound values excluding singular values*

Δ — *mean error*

> Note: Several strength estimation equations have been proposed, but the strength estimated by rebound hammer is only an estimate.

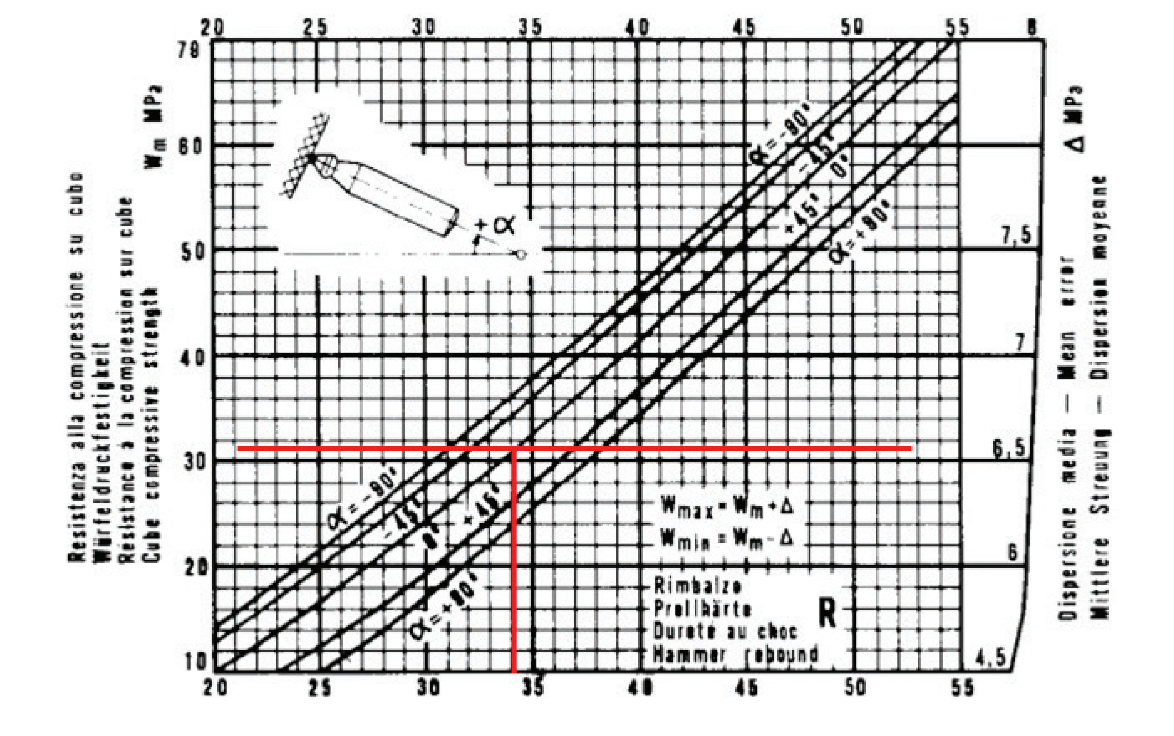


Figure 7-4 Rebound Value and Cube Compressive Strength Chart

In the example above, R = 34 is the mean or average of 20 readings taken from the test of a horizontal wall (angle of inclination θ = 0°). Projecting a vertical line at R = 34 until it intersects the graph of θ=0° inclination, the resulting mean compressive strength, fc mean (Wm) and Δ (mean error) are obtained. R = 34,fc_{mean} (Wm) = 31 MPa and Δ = 6.55MPa

fc_{max} =31+6.55 = 37.55MPa

fc_{mean} = 31 MPa

fc_{min} =31−6.55 =24.45 MPa

Alternatively:

$fc = (-18 + 1.27R_o) \times \alpha$..............................Equation 2

Where,

fc *Estimated concrete strength (N/mm²)*

R_o *– Hardness (R + ΔR)*

R *– Mean value excluding singular values*

ΔR *– Angle correction*

α *– Age correction coefficient*

Table 7-2 Age coefficient and Hardness values

Age(days)	28	50	100	150	200	300	1000	3000	10000	20000
α	1.00	0.87	0.78	0.74	0.72	0.70	0.65	0.63	0.57	0.41

Table 7-3 Concrete strength conversion table

ΔR \ θ	+90°	+45°	-45°	-90°
10	-	-	2.4	3.2
11	-	-	2.4	3.2
12	-	-	2.4	3.2
13	-	-	2.4	3.2
14	-	-	2.4	3.2
15	-	-	2.5	3.3
16	-	-	2.5	3.3
17	-	-	2.5	3.3
18	-	-	2.5	3.4
19	-	-	2.5	3.4
20	-5.4	-3.5	2.5	3.4
21	-5.3	-3.5	2.5	3.4
22	-5.3	-3.4	2.5	3.3
23	-5.2	-3.4	2.4	3.3
24	-5.1	-3.3	2.4	3.3
25	-5.1	-3.3	2.4	3.3
26	-5.0	-3.3	2.4	3.2
27	-4.9	-3.2	2.4	3.2
28	-4.8	-3.2	2.3	3.2
29	-4.8	-3.1	2.3	3.1
30	-4.7	-3.1	2.3	3.1
31	-4.6	-3.1	2.3	3.1
32	-4.5	-3.0	2.2	3.0
33	-4.5	-3.0	2.2	3.0
34	-4.4	-2.9	2.2	2.9
35	-4.3	-2.9	2.2	2.9
36	-4.2	-2.8	2.1	2.9
37	-4.1	-2.8	2.1	2.8
38	-4.1	-2.7	2.1	2.8
39	-4.0	-2.7	2.0	2.7
40	-3.9	-2.6	2.0	2.7
41	-3.8	-2.6	2.0	2.7
42	-3.7	-2.5	1.9	2.6
43	-3.7	-2.5	1.9	2.6
44	-3.6	-2.4	1.8	2.5

θ / ΔR	+90°	+45°	-45°	-90°
45	-3.5	-2.4	1.8	2.5
46	-3.4	-2.3	1.7	2.4
47	-3.3	-2.3	1.7	2.4
48	-3.3	-2.2	1.6	2.3
49	-3.2	-2.2	1.6	2.3
50	-3.1	-2.1	1.5	2.2
51	-3.0	-2.1	1.5	2.2
52	-2.9	-2.0	1.5	2.1
53	-2.9	-2.0	1.5	2.1
54	-2.8	-1.9	1.4	2.0
55	-2.7	-1.9	1.4	2.0
56	-2.6	-1.8	1.4	1.9
57	-2.5	-1.8	1.4	1.9
58	-2.5	-1.7	1.3	1.8
59	-2.4	-1.7	1.3	1.8
60	-2.3	-1.6	1.3	1.7

7.3.1.5 Evaluation and Recommendations

The following points should be considered when analyzing test values from the rebound hammer test:

a. Rebound hammer test is useful in identifying weak areas in concrete structures.

b. Test results depend on angle of inclination of hammer to the horizontal plane, because of the influence of gravity on the amount of energy imparted.

c. The test only gives indication of surface strength of concrete.

> The test is the first step in the investigation. If the results are unreliable or less than the design compressive strength, detailed investigations including microcore test should be carried out. If the results show abnormal data between three (3) test points, lowest data is indicative of suspected defects in the concrete.

7.3.2 Ultrasonic pulse velocity test

The ultrasonic pulse velocity tester is used to measure the velocity of propagation of ultrasonic pulses through concrete for determination of the following:

a. Uniformity and homogeneity of concrete;

b. Presence of cracks or voids;

c. Spalling, delamination, deterioration due to fire, frost or chemical attack;

d. Determination of dynamic elastic constants (E and v); and

e. Estimating time for formwork striking

7.3.2.1 Fundamental Principles

A pulse of longitudinal vibrations is produced by an electro–acoustical transducer, which is held in contact with one surface of the concrete under test. When the pulse generated is transmitted into the concrete using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves develops, which include both longitudinal and shear waves, and propagates through the concrete. The first waves to reach the receiving transducer are the longitudinal waves, which are converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time 'T' of the pulse to be measured.

7.3.2.2 Apparatus

Figure 7-5 Apparatus

The use of ultrasonic pulse velocity technique to define the extent of internal defects should be restricted to well–skilled personnel. When an ultrasonic pulse travelling through concrete meets a concrete–air interface, there is negligible transmission of energy across this interface. Thus any air-filled void lying immediately between transducers will obstruct the direct ultrasonic beam when the projected length of void is greater than the width of transducers and the wavelength of sound used. Thus the pulse is diffracted around the periphery of the void and transit time will be longer than in similar concrete with no void. Test procedure for inspection of delamination, spalling and cracks are described in this section.

7.3.2.3 Procedure of using Ultrasonic Pulse Velocity Tester

a. Arrangements of Transducers

The receiving transducer detects the arrival of that component of the pulse, which arrives earliest. This is generally the leading edge of the longitudinal vibration. Although the direction in which the maximum energy propagated is at right angles to the face of the transmitting transducer, it is possible to detect pulses, which have travelled through the concrete in some other direction. It is possible therefore to make measurements of pulse velocity by placing the two transducers on either:

- Opposite faces (direct transmission),
- Adjacent faces (semi-direct transmission); or
- The same face (indirect or surface transmission).

These three arrangements are shown in Figure 7-6

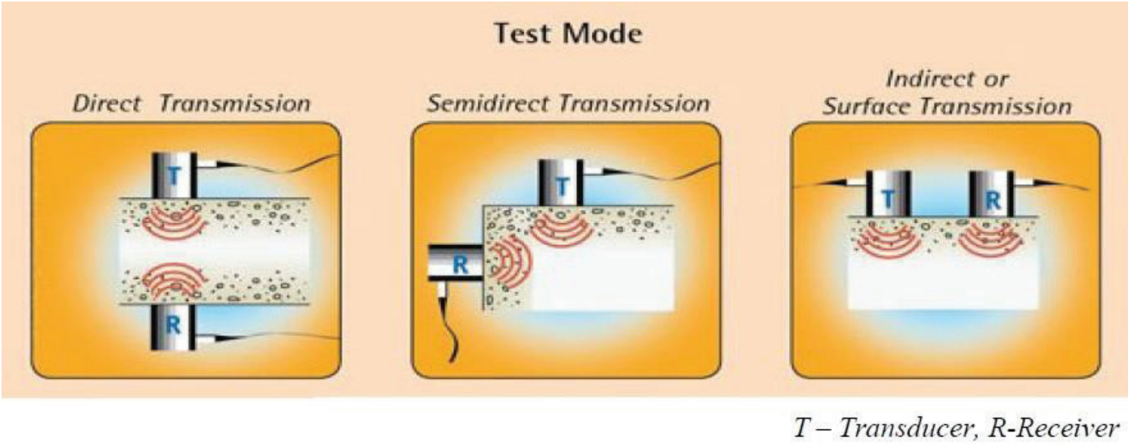


Figure 7-6 Placing of the two transducers

b. Determination of Pulse Velocity by Direct Transmission

Where possible, direct transmission arrangement should be used since the transfer of energy between transducers is at its maximum and the accuracy of velocity determination is therefore governed principally by the accuracy of path length measurement. The couplant to be used should be spread as thinly as possible to avoid any end effects resulting from the different velocities in couplant and concrete.

Longitudinal pulse velocity is given by:

$$V = \frac{L}{T} \quad \text{.. Equation 3}$$

Where:

V is the longitudinal pulse velocity in km/s or m/s

L is the path length, in mm

T is the time taken by the pulse to traverse that length, in μ(s)

c. Determination of Pulse Velocity by Semi-Direct Transmission

The semi-direct transmission arrangement has a sensitivity intermediate between those of the other two arrangements, and, although there may be some reduction in the accuracy of measurement of the path length, it is generally found to be sufficiently accurate to take this as the distance measured from center to center of the transducer faces. This arrangement is otherwise similar to direct transmission. The formula for direct transmission is also used for determining pulse velocity for semi-direct transmission.

d. Determination of Pulse Velocity by Indirect (Surface) Transmission

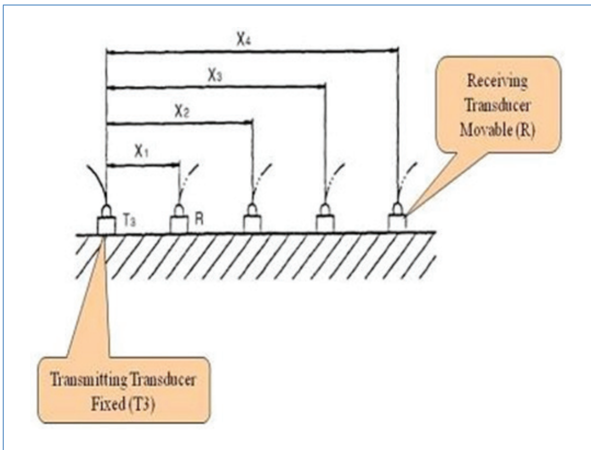
Indirect transmission is used only when one face of concrete is accessible, when depth of surface crack is to be determined or when the quality (uniformity & homogeneity) of the surface concrete relative to the overall quality is of interest. It is the least sensitive of the arrangements and, for a given path length, produces at the receiving transducer a signal which has an amplitude of only about 2% or 3% of that produced by direct transmission.

Furthermore, this arrangement gives pulse velocity measurements which are usually influenced by the concrete near the surface. This region is often of different composition from that of the concrete within the body of a unit and test results may be unrepresentative of that concrete. The indirect velocity is invariably lower than the direct velocity on the same concrete element. This difference may vary from 5% to 20% depending largely on the quality of concrete under test.

Where practicable, site measurements should be made to determine this difference. With indirect transmission, there is some uncertainty regarding the exact length of the transmission path because of the significant size of areas of contact between transducers and the concrete. It is preferable to make a series of measurements with the transducers at different distances apart to eliminate this uncertainty.

To do this, the transmitting transducer is placed in contact with concrete surface at a fixed point "P" and the receiving transducer shall be placed at fixed increments "x" along a chosen line on the surface. The transmission times recorded should be plotted as points on a graph showing their relation to distance separating the transducers. An example of such plot is shown in Figure 7-7

The line of the bestfit drawn through the points (tanθ) is measured and recorded as the mean pulse velocity along the chosen line on the concrete surface.



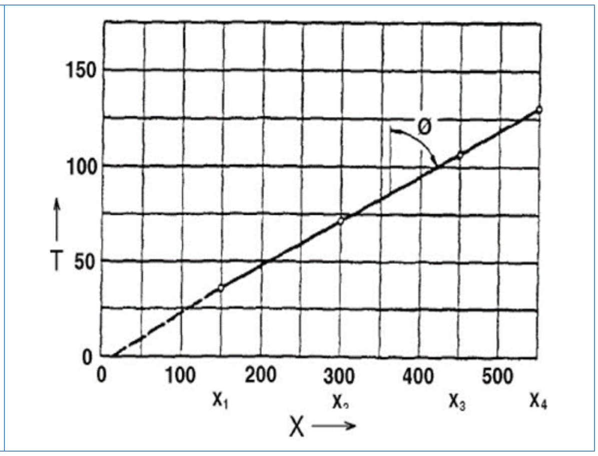


Figure 7-7 Indirect (Surface) Transmission

e. *Investigation of Depth of Cracks*

Depth of cracks that are ≥ 0.20 mm wide should be inspected. When the depth of a crack has to be measured, perform two pulse transit time readings as indicated in Figure 7-8

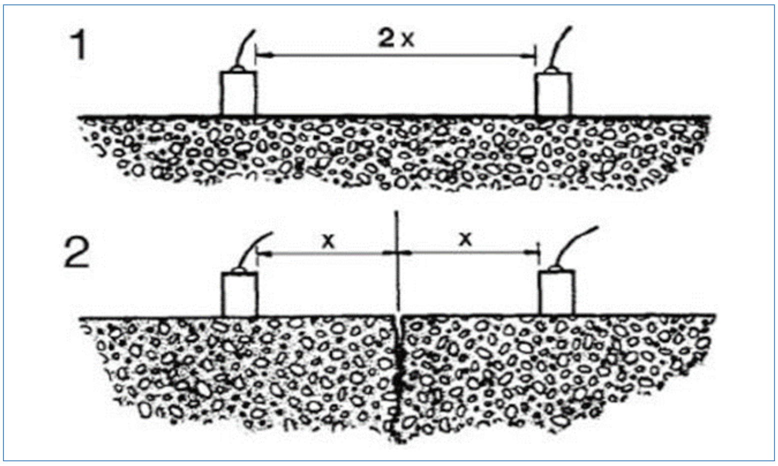


Figure 7-8 Transducers positioning for Estimation of Crack Depth

Testing procedure

1. Set up apparatus.
2. Readings are taken with the transducers placed in several symmetrical positions with respect to the crack (diagram 2 above), another reading is with the same distance between the transducers but without any crack between them (diagram 1) along the same structural member (for example girder).
3. Record the transit times for both cases. Make sure that the crack spaces are not filled with water during the testing since transit time will be affected.

> NOTE: Test Points
>
> Along the line of crack, determine readings at every 100mm or shorter interval depending on the length of crack. Record maximum crack depth in the engineering inspection form (EIF).

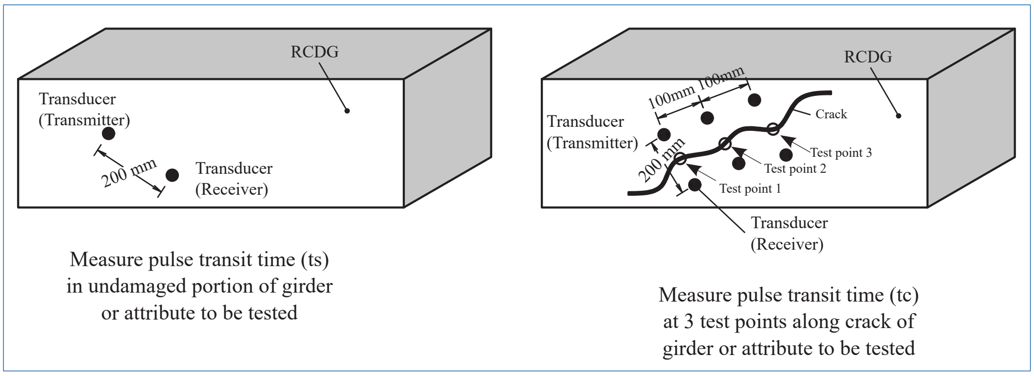


Figure 7-9 Measuring pulse transit time

f. Investigation of Scaling, Delamination and other Flaws

The depth of observed delamination and extent of scaling can be determined by this test. This test is suitable considering that pulse velocity in defective concrete layer (V1) is less than in the sound concrete layer (V2). Perform readings as shown in (Figure 7-10 Sampling Pattern for Investigation of Scaling, Delamination,,)

1. Set up apparatus. (Refer to Operation Manual)

2. Check rebar locations and mark area/locations for the test.
3. Place the transmitting transducer Tx as shown, then place receiving transducer Rx at distances x, 2x, 3xand 4x from Tx.
4. Distance "x" should be less than t/2 where "t" is the thickness of suspected damaged layer.
5. For each location of Rx make sure that couplant is applied. Record measured values of Transit Time (T) and Path Length (L) at each location.

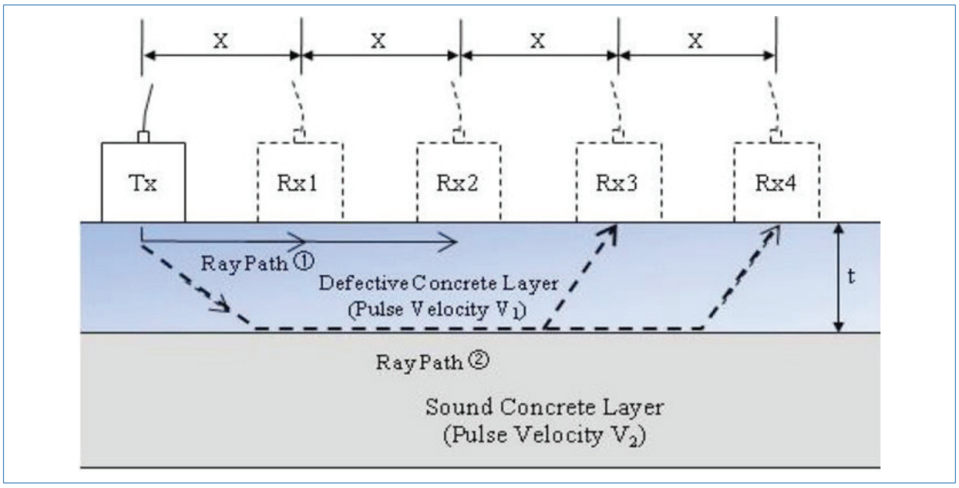


Figure 7-10 Sampling Pattern for Investigation of Scaling, Delamination,

7.3.2.4 Analysis

a) Investigation of Quality (uniformity and homogeneity) of concrete

The following table is used to evaluate the quality of the concrete using the ultrasonic pulse velocities.

Table 7-4 Classification of the Quality of Concrete on the Basis of Pulse Velocity

Ultrasonic Pulse Velocity (km/s)	Inference
> 4.5	Excellent Quality Concrete
3.5-4.5	Good Quality Concrete
3.0- 3.5	Satisfactory
2.0-3.0	Poor Quality Concrete
< 2.0km/s	Very Poor Quality Concrete

b) Investigation of Scaling, Delamination and other Flaws

i. Plot results of test graphically as shown in Figure 7-11 Plot of Transit Time versus Distance

ii. Ray path ① (Figure 7-10 Sampling Pattern for Investigation of Scaling, Delamination,) in surface layer of defective concrete is fastest/shortest path for test at Rx1 (x) and Rx2 (2x).

Ray path ②in surface layer of sound concrete is fastest /shortest path for Rx3 (3x) and Rx4 (4x).

iii. The velocity, $V_d = X_1/T_1$ in the defective concrete is less than $V_s = X_2/T_2$.

Point A is the location of the boundary between defective and sound concrete.

iv. The thickness of the defective layer, "t" in mm, is estimated from the following relation:

$$t = \frac{X_1}{2}\left(\frac{V_s - V_d}{V_s + V_d}\right) \text{..............................Equation 4}$$

Where:

Vd = *pulse velocity in defective concrete (km/s)* = $V_d = X_1/T_1$

Vs = *pulse velocity in sound concrete (km/s)* = $V_s = \frac{(X_2 - X_1)}{(T_2 - T_1)}$

X_1 = *distance at which the change of slope occurs*

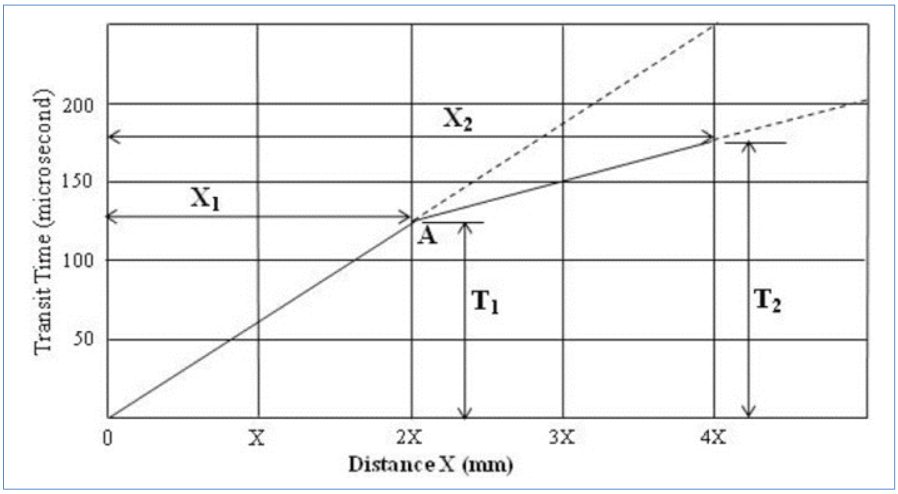


Figure 7-11 Plot of Transit Time versus Distance

The first set of tests should be on trial-and-error basis, to confirm the approximate thickness of the defective layer. To investigate the maximum thickness "t" of the defective layer, the value of "x" may be measured in increments of 10 or 20% until maximum is found. This new value of "x" should then be used in further tests on grid basis to define the area affected.

c) *Depth of Cracks*

The following formula is used to calculate the depth "h" of the crack, provided that the crack space is not filled with water:

$$h = x\sqrt{\left(\frac{t_c}{t_s}\right)^2 - 1} \text{.....................................Equation 5}$$

where:

x = *half distance between the transducers (mm)*

h = *crack depth (mm)*

t_c = *transit times across the crack of concrete structure (microsecond)*

t_s = *transit time along the surface of portion of same concrete structure without defects (microsecond)*

7.3.2.5 Evaluation and Recommendations

a) Scaling, Delamination and Other Flaws

i. Confirm depth of suspected defective layer thickness and area affected by core test. Subject core sample to carbonation test to determine if rebars are likely to be corroded.

ii. The procedure can also be used to investigate concrete damaged by fire, chemical attack, etc. where a surface or upper layer has less strength than the layer below.

Table 7-5 Degree of Damage

Degree of Damage	Crack Depth (D in mm)	Status	Countermeasure
I	C/2 > D	Rebar will be corroded in the future.	Monitor
II	C > D ≧ C/2 (C≧40mm)	Rebar may be corroded	Conduct periodic inspection
III	C > D ≧ C/2 (C<40mm)	Rebar may be corroded.	Conduct Carbonation Test Conduct Half –Cell Test.
IV	D ≧ C	Rebar must be corroded.	Repair Damage

C: concrete cover

7.3.3 Rebar detection test

7.3.3.1 Fundamental Principles

Electromagnetic waves are transmitted from the antenna toward the concrete as shown in diagram below. The electromagnetic waves are reflected by an interface with the reflecting objects (e.g., reinforcing steel bars or cavities) whose electrical property is different from that of concrete.

The waves are reflected back into the surface of concrete and received by the receiving antenna placed near the concrete surface. The distance to the reflecting objects can be calculated from the time the reflected waves need to reach the receiving antenna. The horizontal locations of the objects can be detected by moving the main unit on the surface of concrete.

Since this radar is designed to probe objects with high resolution that are close to the surface of concrete, it transmits pulse waves having a width of only about one nanosecond (one-billionth of a second) or less.

The velocity V of electromagnetic waves in concrete is obtained from the following formula:

$$V = \left(\frac{C}{\sqrt{\varepsilon_r}}\right) \text{m/s} \quad \text{.......................Equation 6}$$

where:

C: *Velocity of electromagnetic waves in vacuum (in air) (3 × 108 m/s)*

ε_r : *Relative dielectric constant of concrete (6 to 11)*

The distance D to the reflecting object is obtained from the following formula:

$$D = \frac{1}{2} VT \ (\text{m}) \quad \text{.......................Equation 7}$$

Where:

***T**: Time taken by the wave to reach receiving antenna*

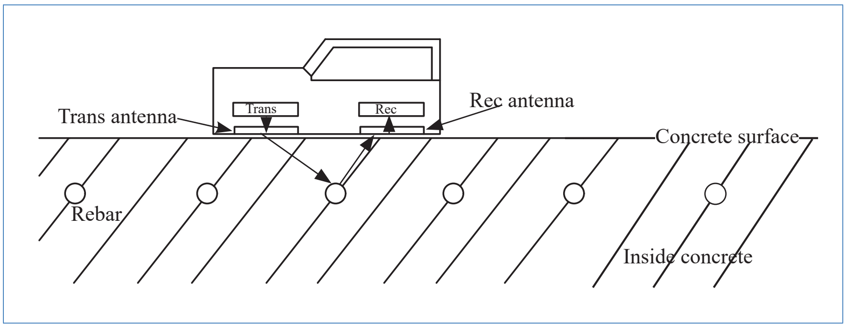


Figure 7-12 Diagram of Principle

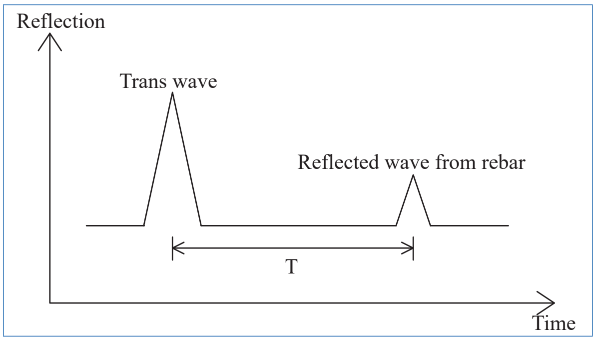


Figure 7-13 Diagram of Reflected Wave Form

7.3.3.2 Apparatus

Figure 7-14 Rebar Detector (Radar Type)

A. Applicable measuring conditions are:

- Scan test depth (covering depth) within 0.5 ~ 30 cm (case where relative permittivity of concrete is 6.2 and the diameter of the rebar is at least 6mm)
- Objects to be probed that are at a depth of less than 75 mm have an interval spacing of at least 75 mm and where the depth of the object to be probed is greater than 75 mm, the interval spacing of the objects is more than the depth.
- Quality of concrete should be uniform.
- Direction of reinforcing steel: Orthogonal to the Handy Search's traveling direction.

B. Inapplicable measuring conditions are:

- Scanning of reinforcing steel bars or the like in concrete whose surface contains objects such as metal that reflect radio waves
- Presence of reinforcing steel bars that are parallel to the Handy Search's traveling direction
- Concrete that has a narrow (pitch) arrangement for the interval of rebar in the horizontal direction. E.g., depth less than 75 mm with spacing between rebar less than 75 mm, and depth greater than 75 mm with spacing between rebar less than depth.

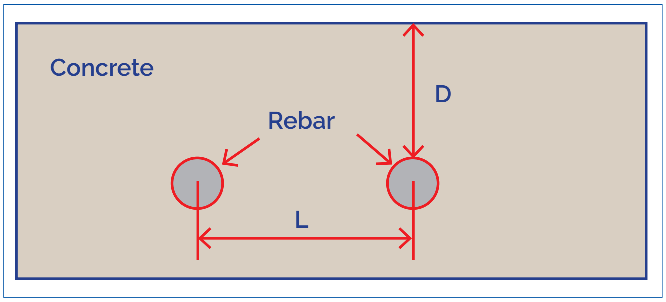


Figure 7-15 Measuring Conditions related Concrete Depth and Spacing

7.3.3.3 Procedures

C-1. Preparation for Scanning

1) Using chalk (or similar tool) make markings on the concrete surface to indicate where to start testing (starting line) and where to scan (scan test line).

2) Make sure the start line and the scan test line are orthogonal (perpendicular to each other). (As necessary, in order to perform a retest, use an endpoint of the wall as a reference standard for the start line and scan test line).

3) A scan test applicable set up example is shown in Figure 7-16 Example of Scan Test Set-up

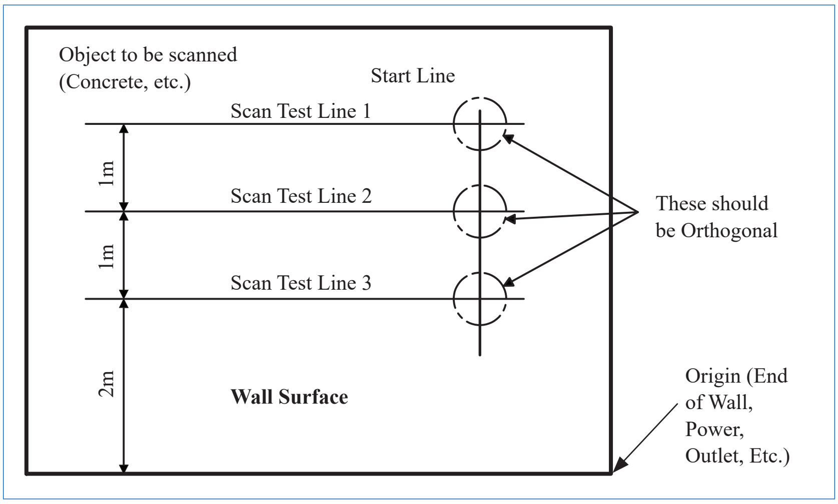


Figure 7-16 Example of Scan Test Set-up

C-2. Scanning

(1) Power-on

1) The liquid crystal display lights up roughly 5 seconds after the power is turned on by turning on the power switch, and the initialization screen is displayed.
2) After the initialization screen completes, the scan test screen is displayed.
3) After confirming that the scan test screen is displayed on the liquid crystal display, start the scan test.

(2) Scan test

1) Place the unit over the intersection of start line and the scan test line.
2) After about one second after pressing START, a short single buzzer sound is generated, the fixed cursor is displayed at a position of about 10cm of the movement distance scale on the screen, and then scan test preparation is complete.
3) Move the unit on top of the scan test line at a speed of less than 40 cm/s by rotating the wheels.
4) Press START again to finish. A double buzzer sound is generated and the scan test is stopped.
5) However, if the scan distance reaches 15 m, the buzzer sounds twice and the scan test automatically finishes.

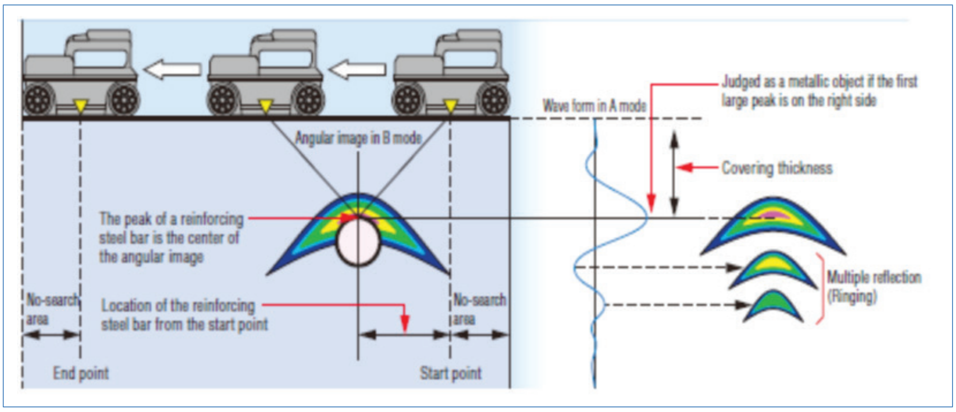


Figure 7-17 Scanning Diagram

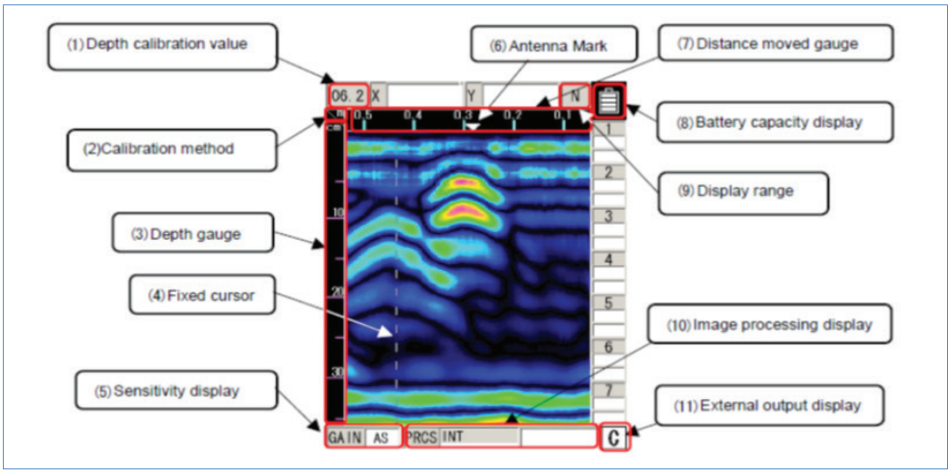


Figure 7-18 Example of a Test Scan

7.3.3.4 Analysis (Interpretation of Data)

- The reflected waves shown in the scan test example in Figure 7-18 are reflections of rebar.
- The position of the object to be probed (e.g., reinforcing steel bar) in the traveling direction is determined as the peak of the reflected wave.
- An approximate depth (covering depth) of the object to be probed (e.g., reinforcing steel bar) is determined as the center of the reflected wave.
- Perform depth calibration to reduce the error in the depth (covering depth) of the object being probed (such as rebar). The position of the object to be probed (such as rebar) is shown by the peak on the right side of the A mode waveform.
- Match the cursor to the peak position to determine the depth.
- Refer to Figure 7-19 sample data analysis

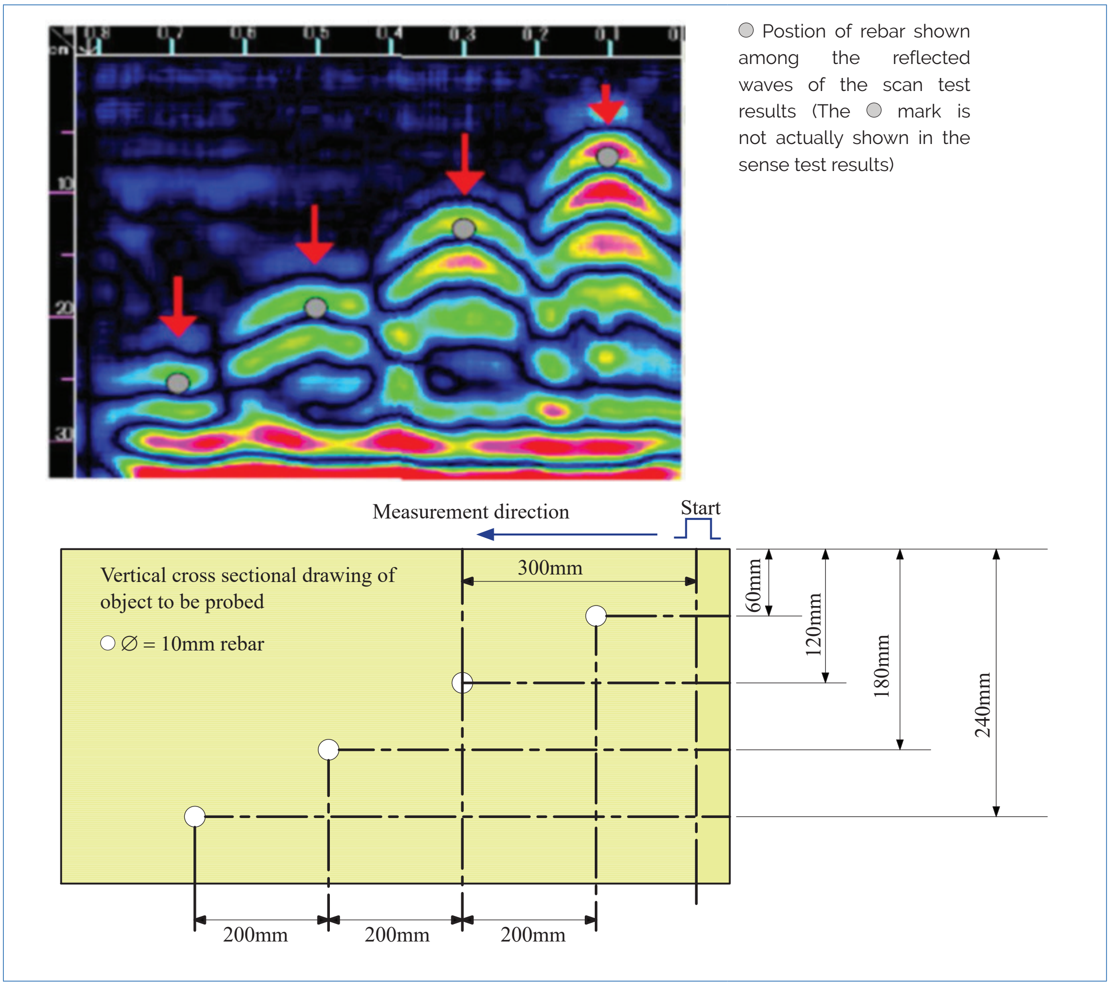


Figure 7-19 Sample Data Analysis

7.3.3.5 Evaluation and Recommendations

The test is useful in the:

- Verification of reinforcement: locate rebar when plans are missing, for acceptance inspections, before structural repair or change of loads on a structure.

- Verification of concrete cover over reinforcement: obtain concrete cover information over large areas for acceptance inspections, before renovation or for quality control.
- Avoidance of hitting rebars: avoid cutting through critical reinforcement or costly rebar hits.
- Determination of bar depth and determination of average concrete cover over large areas.
- Investigation of concrete members of which records are not available or need to be checked.

7.3.4 Infrared thermal image test

7.3.4.1 Fundamental Principles

Infrared Thermography is the process of using an instrument and a method to detect infrared energies emitted from an object, convert these emitted energies to temperature values, and display an image of the object showing the temperature distribution.

Infrared is an electromagnetic wave. Infrared wavelength is 0.7μm or longer. For a wavelength of 1mm (1000μm) or less the frequency is 300GHz or greater.

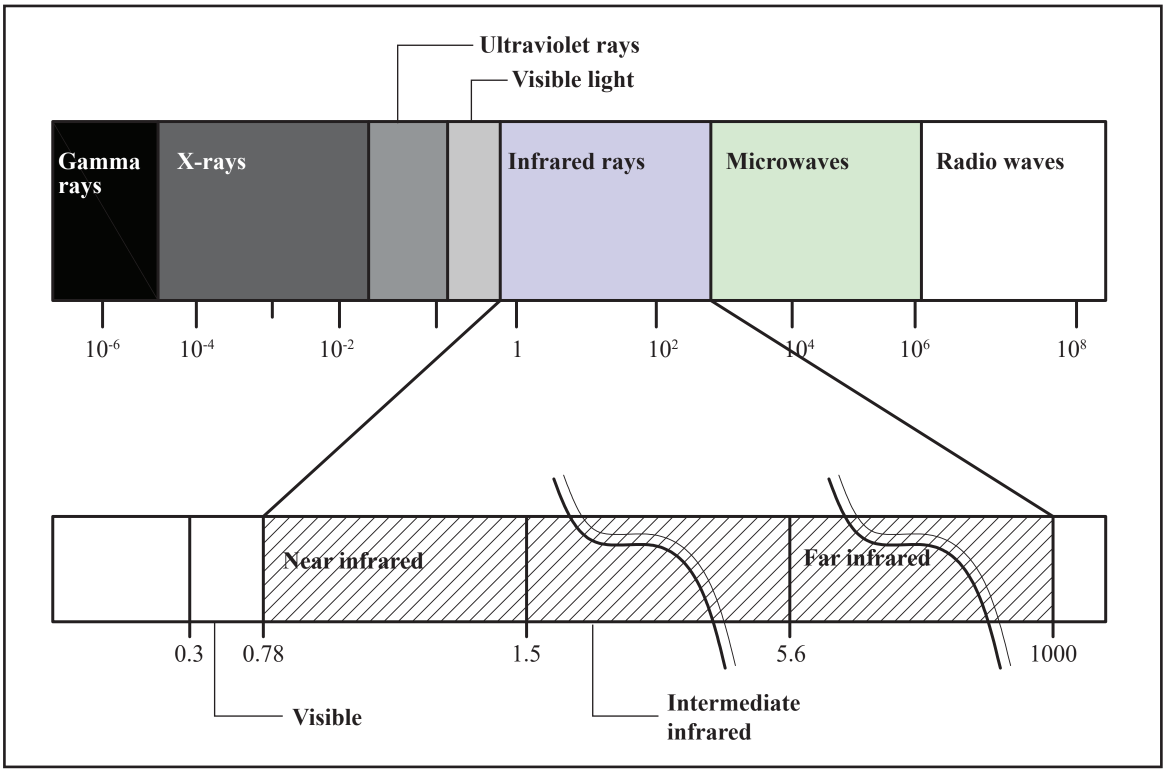


Figure 7-20 Spectrum of Electromagnetic Radiation

Characteristics of Infrared:

- It is invisible since its wavelength is longer than visible light. It has nothing to do with brightness or darkness of visible light.
- It has a characteristic of heating an object. Therefore, it is sometimes called heat wave.
- Because it is a kind of light (electromagnetic wave) is transmitted through a vacuum.

- There is a correlation between infrared energy and temperature of an object. Therefore, it can be used to measure the temperature of an object.

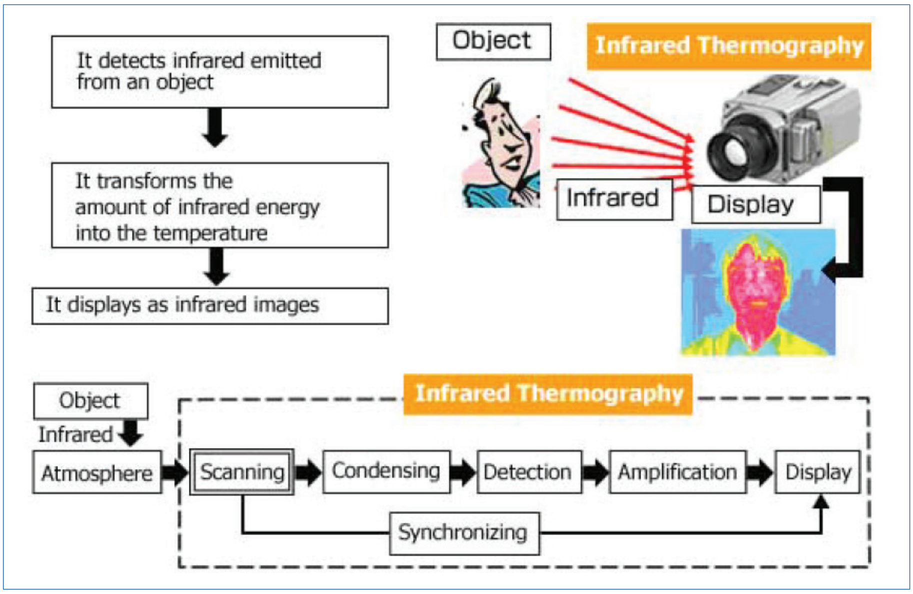


Figure 7-21 Process of Thermal Imaging

Characteristics of Infrared Thermography Instrumentation:

- Captures a surface temperature distribution and displays it as visible information.
- Temperature is measured from a distance without coming into contact with the measured object.
- Temperature is measured in real time.

Used for detection of defects of concrete structures such as:

- Spalling
- Voids
- Delamination

The detectability of any internal flaw such as voids, delamination or layer thickness depends on the physical properties (heat capacity, heat conductivity, density, emissivity) of the materials of the test object. The internal flaw has an effect on temperature distribution on the surface. If temperature changes occur on the surface, there will be a delay before the effect of this change is relayed to the location of the defect, such as voids. The longer the time delay before the temperature changes, the greater the depth of a defect below the surface. Generally anything deeper than 10 cm will only show after a long period of time (>1 hr) after the temperature change has occurred.

Since infrared system measures surface temperatures only, the temperature measured are influenced by three factors:

(1) Subsurface configuration,

(2) Surface condition; and

(3) Environment.

As an NDT technique for inspecting concrete, the effect of subsurface configuration is usually the most interesting. All the information revealed by the infrared system relies on the principle that heat cannot be stopped from flowing from warmer to cooler areas; it can only be slowed down by the insulating effect of materials through which it is flowing. Various types of construction materials have different insulating abilities or thermal conductivity values. For example, air voids have a lower thermal conductivity compared with surrounding concrete. Hence, the surface of a section of concrete containing air voids could be expected to have a slightly different temperature from a section of concrete without air voids.

When tests are performed during daylight hours, the defective concrete areas will appear warmer, while tests performed after dark, defective areas will appear cooler.

7.3.4.2 Apparatus

Infrared cameras are not only used for inspection of civil engineering structures, but also for many other purposes, and can be procured from the market. The measurement range may vary depending on the application, so equipment that covers the temperature (air temperature range) that civil engineering structures have should be selected appropriately.

Figure 7-22 Sample of Infrared Camera and Accessories

7.3.4.3 Procedure

Refer to the Operation Manual on how to set-up, operate controls and commands on using the camera. The engineer should be trained on using these sophisticated apparatus.

A typical image produced by the camera is shown on Figure 7-23 Sample Image from Infrared Camera.

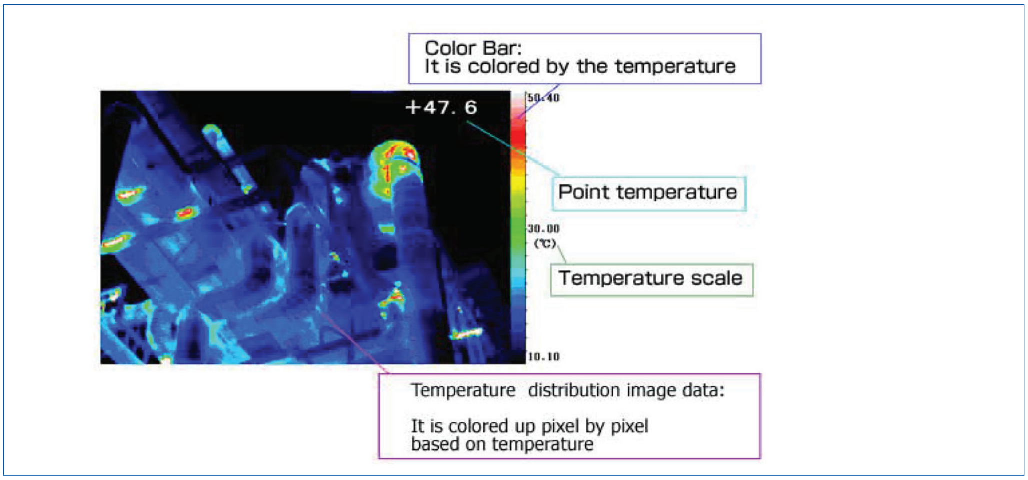


Figure 7-23 Sample Image from Infrared Camera

Infrared Thermography instruments display temperature distribution image data using a matrix of pixels (each pixel being a miniature infrared energy detector).

7.3.4.4 Analysis (Interpretation of Data)

Images are uploaded to a computer for detailed analysis with the use of software that interprets infrared images. The location and extent of voids, delamination and spalling of concrete structures are determined.

The following examples show results of infrared thermal imaging of defects in a structure.

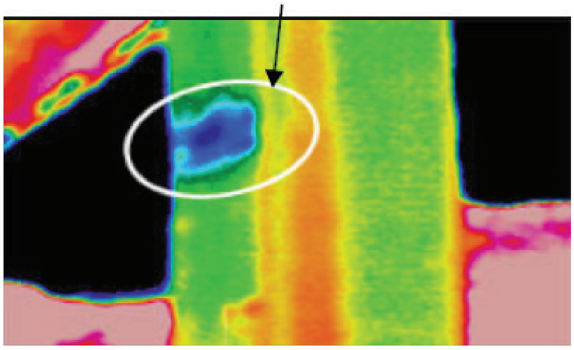
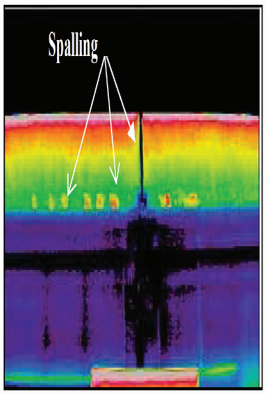
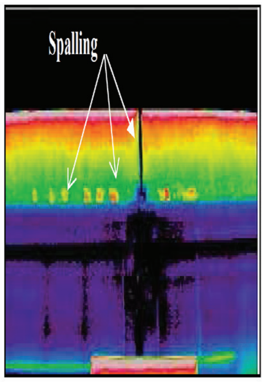
	
Visual Image	Thermal Image
Pier Defect	
 	 
Visual Image	Thermal Image
Concrete Barrier Defect	

Figure 7-24 Examples of Defects Detection using Infrared Thermal Imaging

7.3.4.5 Evaluation and Recommendations

Infrared thermographic analysis of large concrete areas does not require destruction of concrete structures during testing. Only small calibration cores are used. This results in major savings on time, labor, equipment, traffic control, and scheduling.

Infrared thermographic equipment is safe as it emits no radiation. It only records thermal radiation, which is naturally emitted from the concrete, as well as from all other objects. It is similar in function to an ordinary thermometer, only much more efficient.

Infrared thermography is an area testing technique, while the other NDT methods are mostly either point or line testing methods. Infrared thermography can form a two-dimensional image of the large test surfaces showing the extent of subsurface anomalies.

It is recommended that infrared thermography be used to survey large areas for defects. Once specific defects locations are established, radar can be used to spot check the anomaly for its depth and thickness. This combined technique would give the best combination of accuracy, efficiency, economy and safety.

Temperature and weather are very sensitive. Therefore, it is recommended that infrared thermography be used at nighttime (around 6p.m. to 7a.m) due to the accuracy factor of temperature being ±2˚C or ±2% of absolute temp. in ˚C.

The test locations must be subjected to solar radiation for temperature variation of the sound and damaged point to be detected by infrared thermography.

The use of infrared thermography should be avoided:

- During rainy and cloudy weather,
- When there are slight changes in temperature,
- After a few hours at the time of highest and lowest temperature (approximately 3 hours).

7.3.5 Resistivity test

7.3.5.1 Fundamental principles

There are many techniques used to assess the corrosion risk or activity of steel in concrete. The most commonly used is the half cell potential measurement that determines the risk of corrosion activity. Whilst the half cell potential measurement is effective in locating regions of corrosion activity, it provides no indication of the rate of corrosion. However, a low resistance path between anodic and cathodic sites would normally be associated with a high rate of corrosion than a high resistance path. Such resistivity measurements determine the current levels flowing between anodic and cathodic portions, or the concrete conductivity over the test area, and are usually used in conjunction with the half-cell potential technique. This is an electrolytic process as a consequence of ionic movement in the aqueous pore solution of the concrete matrix. An alternative technique to estimate the rate of corrosion, which is becoming increasingly popular, is the linear polarization resistance.

7.3.5.2 Equipment

Two probe	Four probe

Figure 7-29 Two and four probe Resistivity meter

Although other commercial devices like the less accurate two probe system are also available, the Wenner four probe technique is generally adopted for resistivity measurement of *in situ* concrete.

The technique was first used by geologists to investigate soil strata. The technique can be used to determine resistivities quickly and with little or no damage to the concrete structures under study, Figure 7-30 Schematic of Wenner 4 probe resistivity meter.

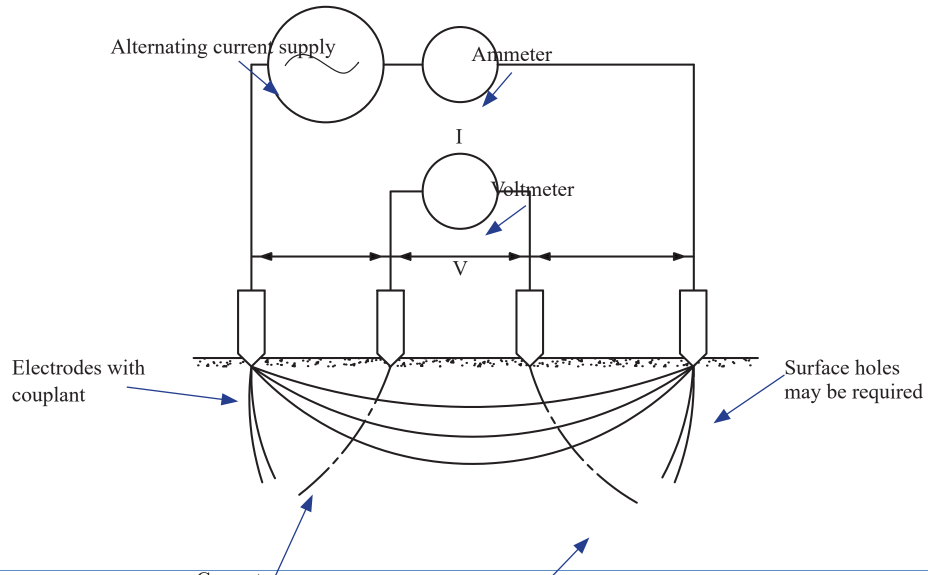


Figure 7-30 Schematic of Wenner 4 probe resistivity meter

The equipment consists of four electrodes (two outer current probes and two inner voltage probes) which are placed in a straight line on or just below the concrete surface at equal spacings. A low frequency alternating electrical current is passed between the two outer electrodes whilst the voltage drop between the inner electrodes is measured. The apparent resistivity (ρ) in *ohm-cm* may be expressed as:

$$\rho = \frac{2\pi aV}{I} \quad \text{.......................................Equation 8}$$

where

V *- is voltage drop,*

I *- is applied current,*

a *– electrode spacing.*

The calculation assumes the concrete to be homogeneous and the inhomogeneity caused by the reinforcement network must be allowed for by properly placing the probes to minimize its effect.

7.3.5.3 General procedure

Resistivity measurement is a fast, simple and cheap *in situ* non-destructive method to obtain information related to the corrosion hazard of embedded reinforcement.

To measure the resistivity, metallic probes are placed over the concrete surface. A known current is passed on the outer probes and resulting potential drop between inner probes is measured.

The resistance is computed by dividing the potential drop by the current (refer equation 8 above)

A conductive gel is used between probe and concrete surface to make effective contact. The probable rate of corrosion with respect to the value of resistivity of concrete is normally considered as given in Table 7-5 Guide for the Interpretation of the Measurements During Corrosion Assessment

7.3.5.4 Applications

The ability of corrosion currents to flow through the concrete can be assessed in terms of the electrolytic resistivity of the material. This resistivity can determine the rate of corrosion once reinforcement is no longer passive. The presence of ions such as chloride will also have an effect. At high resistivity, the rate of corrosion can be very low even if the steel is not passive. For example, reinforcement in carbonated concrete in an internal environment may not cause cracking or spalling due to the very low corrosion currents flowing.

The electrical resistivity of concrete is known to be influenced by many factors including moisture, salt content, temperature, water/cement ratio and mix proportions. In particular, the variations of moisture condition have a major influence on *in situ* test readings. Fortunately, in practice, the moisture content of external concrete does not vary sufficiently to significantly affect the results. Nevertheless, precautions need to be taken when comparing results of saturated concrete, e.g. those exposed to sea water or measurements taken after rain showers, with those obtained on protected concrete surfaces. Another important influence is the ambient temperature. Concrete has electrolytic properties; hence, resistivity will increase as temperature decreases. This is particularly critical when measurements are taken during the different seasons, with markedly higher readings during the winter period than the summer period.

The principle application of this measurement is for the assessment of the corrosion rate and it is used in conjunction with other corrosion tests such as the half-cell potential measurement or linear polarization measurement methods.

7.3.5.5 Analysis

The readings are read directly from the equipment and compared against the table.

Table 7-6 Guide for the interpretation of the measurements during corrosion assessment

Resistivity (ohm cm)	Likely Corrosion Rate	Degree of Damage
Greater than 20,000	Negligible	I
10,000 – 20,000	Low / Moderate	II
5,000 – 10,000	High	III
Less than 5,000	Very high	I V

7.3.6 Half-cell electrical potential

7.3.6.1 Test Fundamental Principles

a) General

The corrosion (rusting) of steel rebar is an electro-chemical process, involving anodic (corroding) and cathodic (passive) areas of the metal. By measuring concrete-surface electrical potentials relative to a standard reference electrode on a pre-defined grid, the presence and location of corrosion and its probable future performance may be assessed.

To use this technique, it is necessary that a continuous electrical current is present in the reinforcing bars (this is normally achieved with a metal wire connecting the various reinforcing element, for example horizontal and vertical bars). A multimeter can be used to check that this electric current exists.

b) Applications

This technique is used to assess the durability of reinforced concrete members where reinforcement corrosion is suspected. The method has the advantage of being simple and it allows an almost non-destructive survey to produce equi-potential contour maps of surface of concrete member. Reported uses include the location of areas of high reinforcement corrosion risk in bridge decks and abutments.

The technique may be used to identify areas of reinforced concrete in need of repair or protective treatment and, by regular measurements, monitor the behavior of new and relatively new structures and thus minimize maintenance costs.

7.3.6.2 Apparatus

Figure 7-31 Half-Cell Digital Corrosion Meter

7.3.6.3 Procedures

a) Test Surface Preparation

1. Mark out the desired grid on the surface to be surveyed. Grid spacing should be 100mm to 300mm. Use narrow spacing if the test will be carried out around surface crack.
2. Locate and expose a rebar approximately at the center of the area to be surveyed.
3. Clean the exposed rebar to bright metal to ensure good electrical contact and attach the reference cable using the crocodile clip. If the rebar is corroded, drill a small diameter hole into the steel and screw into it a T-bar Gimlet onto which to attach the cable.

b) Equipment Set-up

The Set-up equipment as shown in Figure 7-32 and Figure 7-33 as appropriate. Apparatus must be calibrated before use. Refer to instruction manual on how to calibrate.

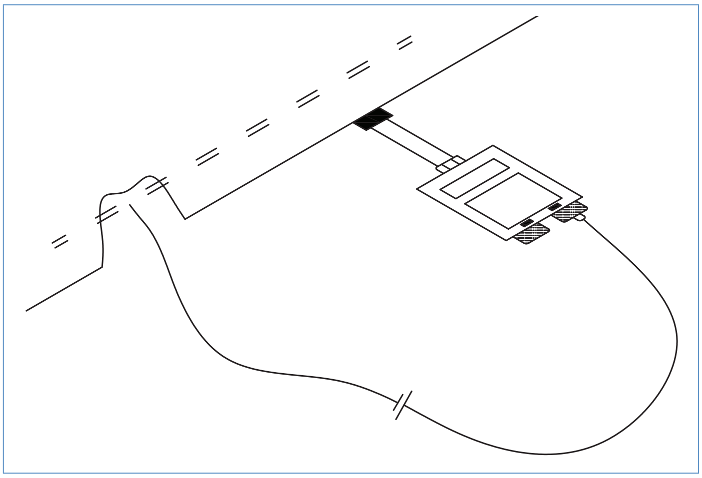


Figure 7-32 Set–up for Surveys on Vertical Surfaces and Soffits

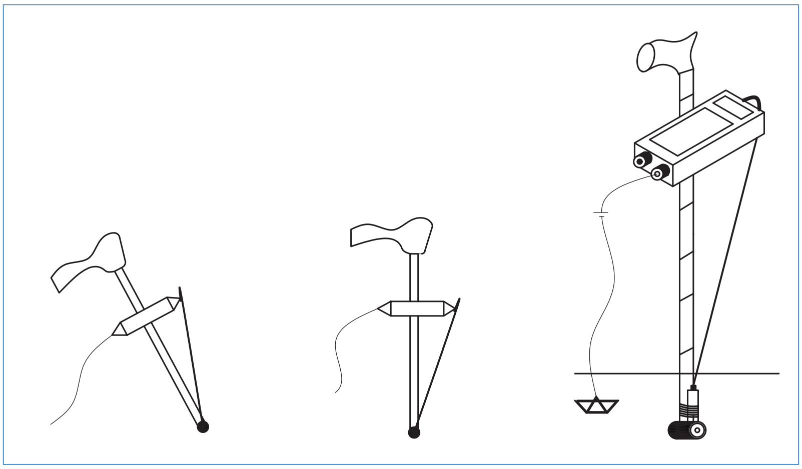


Figure 7-33 Set–up for Surveys on Horizontal Surfaces such as Bridge Decks/Slabs etc.

c) *Testing*

1. Replace the solid cap on the cell electrode with one of the sponge heads and moisten it with clean, slightly soapy water.
2. Dampen the concrete surface over its entire surface or grid points.
3. Place cell electrode probe on first test position. Position should be just above the rebar. Refer to diagram in Figure 7-34 Only light contact pressure of the sponge head is necessary.
4. The probe is precision equipment and should be treated accordingly. Inspector should follow manufacturer's recommendation in the instruction manual.
5. Allow reading to settle within 10mV (second least significant digit) and record reading.
6. Proceed to second test position and repeat testing procedure steps 3 and 4.

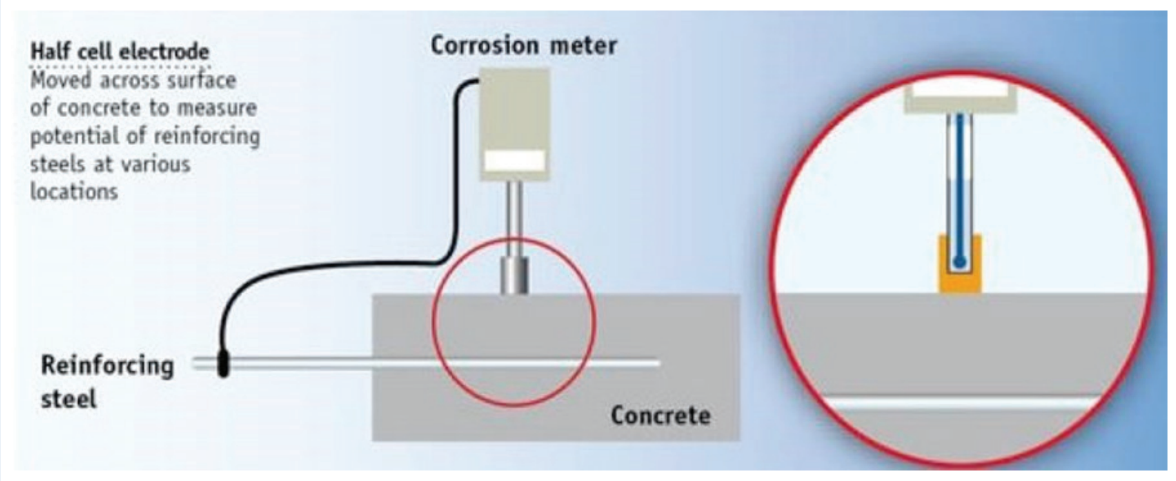


Figure 7-34 Testing Diagram

d) Test Points

Perform tests near areas where there is corrosion potential of rebar. If the corrosion potential is higher or extensive, suggest further testing within its surroundings.

7.3.6.4 Analysis

Measurements are to be presented with an equipotential contour map which will provide a graphical delineation of areas in the member where corrosion activity may be occurring. The contour map provides a graphical delineation of areas in the member where corrosion activity may be occurring.

The risks of corrosion based on potential difference reading are shown in Table 7-6. The data are based on the principle of Copper/Copper Sulphate electrode measurement technique as described in ASTM C876–80, in BS1881:201, in ASTM C876–80 and in a number of technical articles.

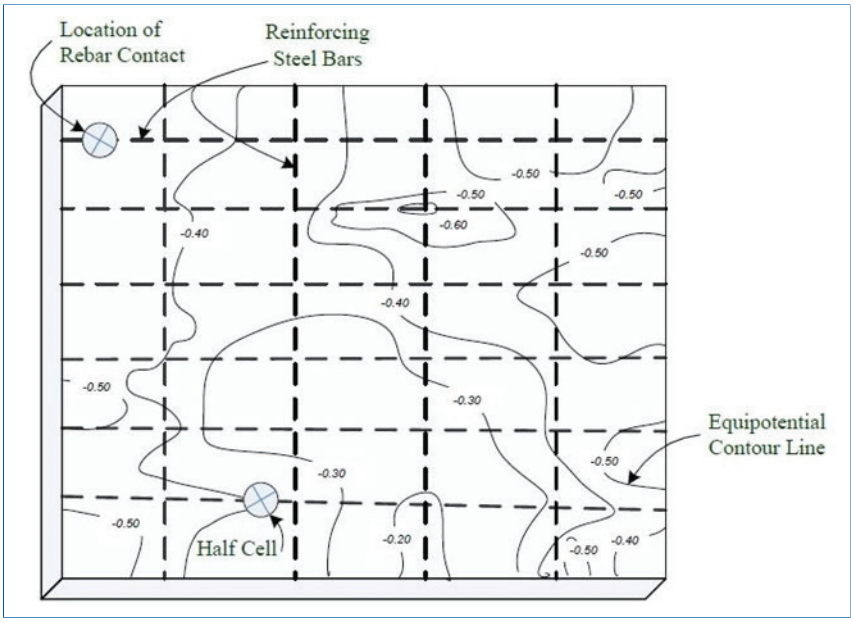


Figure 7-35 Example of Equi-potential Contour Map

Table 7-7 Risk of Corrosion Against the Potential Difference Readings

Potential Difference Levels (mV)<E>	Chance of Rebar Being Corroded
Less than -500 (E ≦-500)	Visible evidence of corrosion
-350 to -500 (-350 < E < -500)	95% probability of corrosion
-200 to -350 (-200 ≦ E ≦-350)	50% probability of corrosion
More than -200 (–200 < E)	5% probability of corrosion

7.3.6.5 Evaluation and Recommendations

Depending on the analysis of results, the following degrees of damage are established:

Table 7-8 Degree of Damage

Degree of Damage	Potential Difference Levels (mV) <E>	State
I	–200 < E	Rebars will be corroded in the future
II	–200 < E≦–350	Rebars may be partly corroded
III	–350 < E≦–500	Rebars are be corroded
IV	E ≦–500	Rebar are seriously corroded

NB: *Half cell electrical potential test should be carried out together with rebar detection test investigation and carbonation test at the same time.*

A more detailed investigation is required especially around cracks.

It is generally accepted that corrosion potential measurements must be complemented by other methods, because although reliable relationships between potential and corrosion rate can be found in the laboratory for well–established conditions, these can in no way be generalized, since wide variations in the corrosion rate are possibly in very narrow range of potentials. Values obtained can only provide information for corrosion probability and cannot indicate the rate of corrosion.

7.4 Non-destructive tests for steel structures

7.4.1 Paint Thickness Test

Coating thickness measurements are based on the fact that the inductance between an electromagnet and a metallic surface varies with the thickness of a nonmagnetic interface coating. Changes in the inductance are electronically transmitted to a digital measurement of the coating thickness.

7.4.1.1 Fundamental Principles

When iron is moved toward or away from a steel core coil which carries electric current, self-inductance increases or decreases in accordance with distance. This change in inductance can be read as a deflection of needle of an ammeter, or a digital indicating signal connected as shown in Figure 7-36. This principle is utilized to measure the thickness of non-magnetic surface treated film (D) on steel plate.

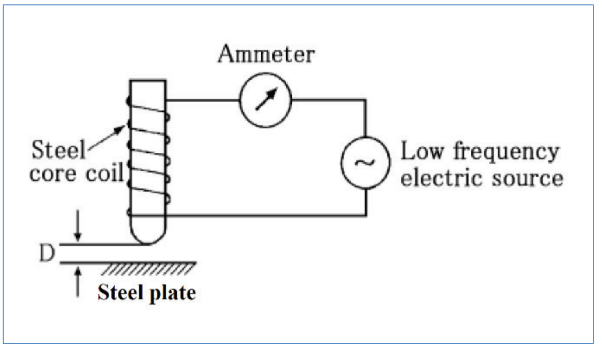


Figure 7-36 Principle of Coating Thickness Measurement on Surface of Steel Plate

7.4.1.2 Apparatus

Figure 7-37 Film Thickness Meter

7.4.1.3 Procedure for Paint Thickness Test

Detailed measurement procedures must be referred to the instruction manual of each equipment. General procedure is as follows.

I. Preparation equipment

Connect the main unit display to the measurement terminal.

II. Calibration

Calibration is performed using a calibration steel plate. The calibration steel plate must be the same type of metal as the structure to be measured, without coating.

Next, a plate of known thickness (standard plate) is put on the calibration steel plate and its thickness measured. Adjust the measurement to that thickness on the main unit, and calibration is finished.

III. Measurement

Measure the film thickness at the point to be measured.

7.4.1.4 Analysis

Compare the design film thickness with the measured value to confirm the amount of painting remaining. If the amount of remaining paint is a few millimeters, countermeasure work (re-painting, etc.) should be considered.

7.4.1.5 Evaluation and Recommendations

Control of the paint film thickness is important for steel structures. Condition of paint influences the service life of the structure. Therefore, paint film thickness should be inspected at fabrication shop before shipping.

Paint film thickness should be inspected periodically. To avoid paint damage, the surface should be cleaned regularly.

If the existing film thickness is found to be less than the designed thickness but there is no damage, condition should be monitored. Additional painting will be required in case of new fabrication.

If damaged, the repair method should be planned based on the degree of damage.

The coatings must be non-magnetic with a thickness preferably less than 1 mm. The method can be used on paint, plastic, vitreous, enamel, galvanized and hard chrome, to name examples of non-magnetic coatings

The reliability of the readings depends on the calibration, the test item and the geometry of the item.

7.4.2 Metal Thickness Test

The thickness gauge is used to determine the remaining thickness of corroded metallic items.

7.4.2.1 Fundamental Principles

This ultrasonic non-destructive testing is used in characterizing material thickness, integrity, or other physical properties by means of high-frequency sound waves. It has become a widely used technique for quality control. In thickness gauging, ultrasonic techniques permit quick and reliable measurement of thickness without requiring access to both sides of a part. Accuracies as high as ±1 micron or ±0.0001 inch are achievable in some applications.

Precision ultrasonic thickness gauges usually operate at frequencies between 500 KHz and 100 MHZ, using piezoelectric transducers to generate bursts of sound waves when triggered by electrical pulses. Typically, lower frequencies will be used to optimize penetration when measuring thick, highly attenuating, or highly scattering materials, while higher frequencies will be recommended to optimize resolution in thinner, non-attenuating, non-scattering materials.

A pulse-echo ultrasonic thickness gauge determines the thickness of a part or structure by accurately measuring the time required for a short ultrasonic pulse generated by a transducer to travel through the thickness of the material, reflect from the back or inside surface, and be returned to the transducer. In most applications this time interval is only a few microseconds or less. The measured two-way transit time is divided by two to account for the down-and-back travel path, and then multiplied by the velocity of sound in the test material. The result is expressed in the well-known relationship:

$$d = \frac{Vt}{2} \quad \text{..........................Equation 9}$$

Where:

> ***d:** the thickness of the test piece*
> ***V**: the velocity of sound waves in the material*
> ***t:** the measured round-trip transit time*

Thickness of most engineering materials can be measured ultrasonically, including metals, plastic, ceramics, composites, epoxies and glass. In the field, it is used to determine remaining plate thickness of corroded steel bridge structures. In the fabrication shop, it is used to test uniformity of thickness of steel plates used in various structures.

7.4.2.2 Apparatus

Figure 7-38 Ultrasonic Thickness Gauge (Sample)

7.4.2.3 Procedure for Operation

Refer to the Operation Manual for adjustments, calibration and proper usage.

I. Investigation

Before testing, the following items should be investigated:

- Design steel thickness
- Repair work records
- The latest thickness test results

II. Measurement

1) Press the probe against an object to be measured and the measured value is indicated on the LCD.
2) Record measured steel plate thickness and its location on the plan.
3) Repeat measurements at other locations as necessary
4) Measure thickness of both corroded and un-corroded steel for comparison. Be sure to remove rust on corroded surface by sanding before measuring

III. Test Guidelines

The transducer should be placed on the surface of the test item. The ultrasonic waves will then be reflected by the opposite surface. The thickness is shown digitally. For uneven or corroded surfaces, it may be necessary to grind the surface at the test positions to make proper contact. Possible rust on the opposite surface does not disturb the reflections.

Note: If steel plates are laminated, the measured thickness will only be the depth of the first layer.

Before starting the measurements, a contact liquid is applied to the test locations. Further, the equipment must be calibrated. For common steel alloys, the calibration is performed by means of test blocks. For unknown alloys (or if one is not sure), the calibration is performed by adjusting the sound velocity setting of the equipment until the equipment shows the same thickness as can be measured by a slide caliper at a free edge.

IV. Test Points

- Measure thickness of good condition metal for reference.
- Measure thickness of deteriorated metal and analyze deterioration area.

7.4.2.4 Analysis

Compare the design thickness with the measured value to confirm the amount of steel plate reduction. The design calculation sheet should be checked, and if the thickness reduction is at a level where there is no stress margin, countermeasure method should be considered as soon as possible.

7.4.2.5 Evaluation and Recommendations

Steel structures should be inspected regularly. To avoid damage, surfaces should be applied with appropriate paints.

If the existing plate thickness is found to be less than the designed thickness due to corrosion, repair method should be planned based on the degree of damage.

The method is generally applicable and is particularly efficient for measuring possible corrosion of structural elements with access only possible from one side. The gauge uses dual transducers to measure the thickness of corroded, pitted, scaled, granular materials from one side only.

Thicknesses of between 0.50 mm and 200 mm can usually be determined within ± 2%.

The degree of deterioration can be estimated using Table 7-8 Degree of Damage

Table 7-9 Degree of Damage

Degree of Damage	Steel plate thickness, t	Degree of Deterioration
I	$1/4t_o < t$	None
II	$1/4t_o \leq t < 1/2t_o$	Low
III	$1/2t_o \leq t < 3/4t_o$	Medium
IV	t≥3/4to	Large

Where;

t_o = *design strength or the thickness of healthy section of the same member.*

7.4.3 Ultrasonic Flaw Detection Test

7.4.3.1 Fundamental Principles

Ultrasonic flaw detection test can detect surface and intentional defects using high frequency elastic pulse wave.

The ultrasonic flaw detection test is that a transmitter transducer introduces acoustic energy of high frequency inside the specimen which propagates in the form of waves. When there is a discontinuity (such as a crack) in the wave path, a part of the energy will be reflected back from the flaw surface. This reflected energy is picked up by a receiver transducer and is an indication of the size of the defect.

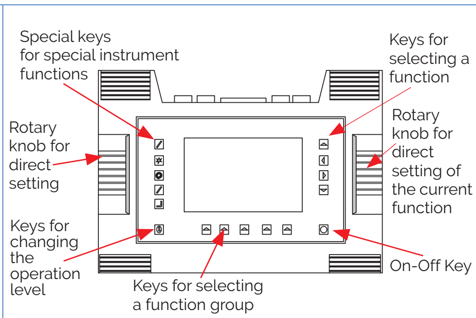
Ultrasonic flaw detection test is used to assess the quality of the steel structure in relation to:

- Locating and evaluating defects of welds
- Locating and evaluating other flaws such as crack and void
- Measuring thicknesses

7.4.3.2 Apparatus

This ultrasonic flaw detector has a frequency range from 0.5 to 20 MHz and a maximum calibration range of 10 m (steel). Probes connected by cables to the sockets at top right portion of the apparatus are used to send and receive ultrasonic pulses from test material which are then analyzed and displayed on the screen.

Main Unit



Controls

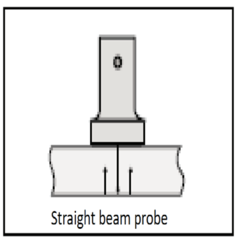
Probes

Figure 7-39 Ultrasonic Flaw Detector

7.4.3.3 Procedures

Before testing, the type of welding (full-penetrated or partial-penetrated groove weld, fillet weld, etc.) should be determined. Ultrasonic test can only assess the full-penetrated weld.

Use Straight Beam Probe which has a single transducer to transmit the ultrasonic pulses vertically into the test object and receive the returning reflections. They are suitable for detection and evaluation of flaws which reflect parts of the pulse back to the probe, e.g. shrinkage cavities, gas bubbles, inclusions or flat reflectors which are located vertically to the beam direction (cracks or bonding defects).



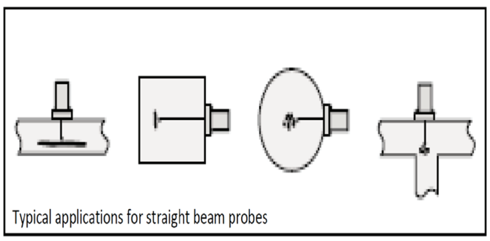


Figure 7-40 Types of Defects

In testing of the weld, the presence of defect (Flaw or "F") is indicated by the spike in the graph. This is illustrated in Figure 7-41.

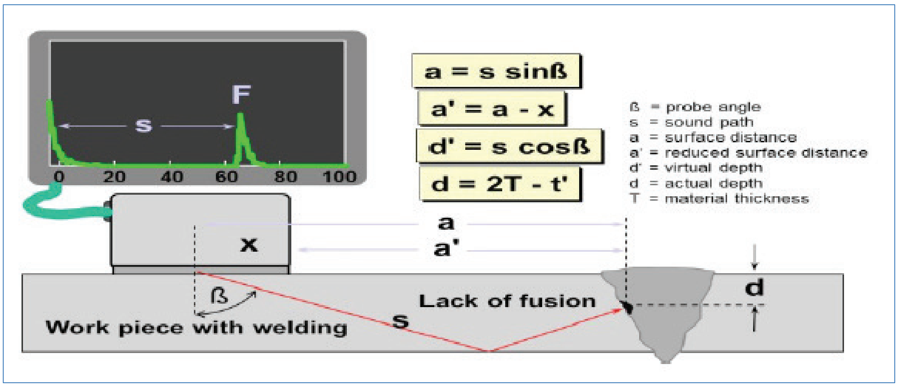


Figure 7-41 Testing of Flaws

In the detection of flaws, the presence of damage is explained by diagrams in Figure 7-42

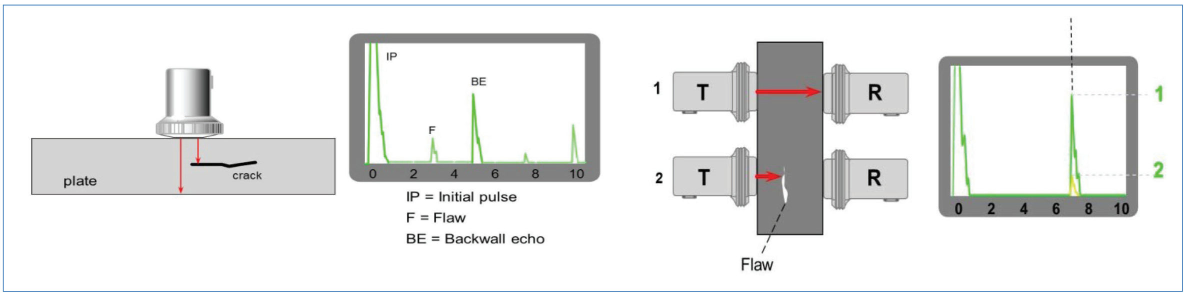


Figure 7-42 Detection of Flaws

7.4.3.4 Evaluation and Recommendations

This test method can assess the defect occurring only in the "Full-penetrated" weld. Ultrasonic test should be carried out during steel structure fabrication at the shop for the quality control.

The inspector should be trained on proper use of the apparatus.

Advantages

- Thickness and lengths up to 30 ft can be tested.
- Position, size and type of defect can be determined.
- Instant test results.
- Portable
- Extremely sensitive if required.
- Capable of being fully automated.
- Access to only one side necessary.
- No consumables required.

Countermeasures

If there is defect on welding, the welding should be repaired in accordance with AWSD1.1. Basically, the defect should be removed and re-welded.

After repair, ultrasonic test should be carried out again.

7.4.4 Magnetic Particle Testing (MT)

7.4.4.1 Fundamental Principles

Magnetic Particle Testing (MT) is NDT process for detecting surface and slightly subsurface discontinuities in ferromagnetic materials such as iron, nickel, cobalt, and some of their alloys. The process injects a magnetic field into the part. The piece can be magnetized by direct or indirect magnetization. Direct magnetization occurs when the electric current is passed through the test object and a magnetic field is formed in the material. Indirect magnetization occurs when no electric current is passed through the test object, but a magnetic field is applied from an external source.

MT involves visual testing of the crack length on the surface Figure 7-43 Magentic Particle Testing.

There are 'wet method' and 'dry method' in MT but generally, 'wet method' is adopted.

Magenitizing equipment

Ultraviolet light

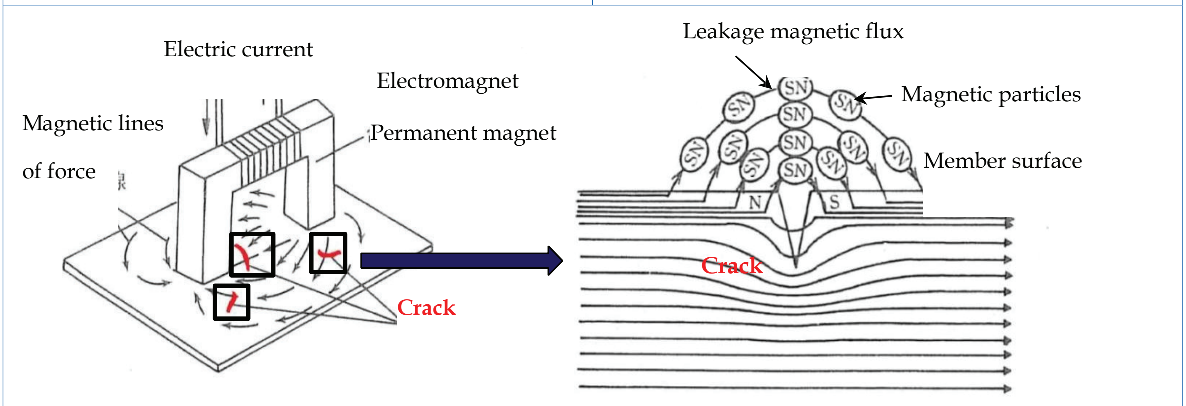


Figure 7-43 Magnetic Particle Testing

Wet method' involves magnetic particles dispersed in a liquid, and the magnetic particles are deposited to the magnetic flux leakage near the crack using liquid flow.

Fluorescent magnetic particles are detected by applying ultraviolet light to the surface Figure 7-44 Detection of crack by Magnetic Particle Testing

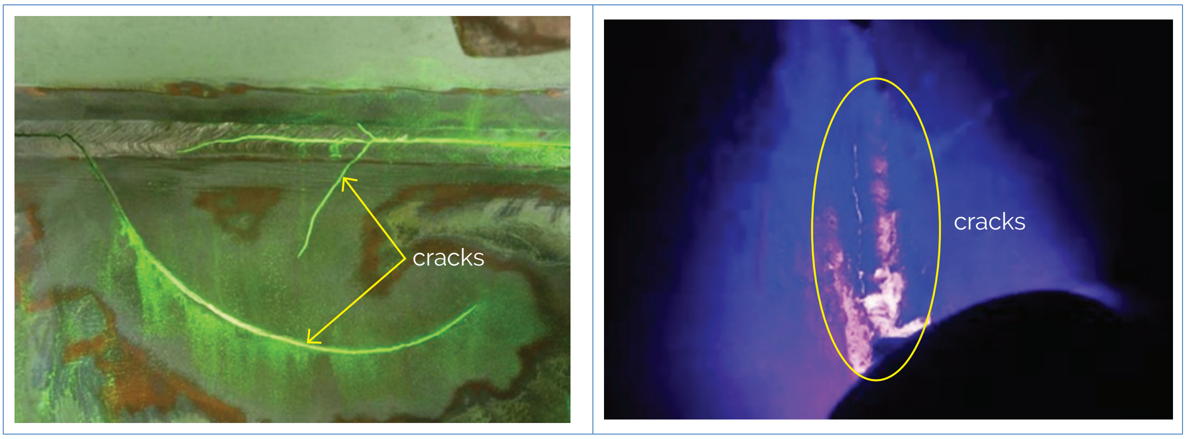


Figure 7-44 Detection of crack by Magnetic Particle Testing

7.4.4.2 Procedures

(a) Pre-processing

Remove oils, paints, rust and other foreign material from the test member by mechanical or chemical treatment before magnetization.

(b) Magnetization

The test member is magnetized in a direction perpendicular to the direction of the crack and the direction of the magnetic flux.

(c) Application of magnetic particles

There are two methods used in application of the magnetic particles;

1. Continuous method: Applying the magnetic particles directly from the supplied current.
2. Residual method: Using the residual magnetism of the test member.

(d) Crack confirmation

In case of use of fluorescent magnetic particles, the darkness of the peripheral part of the image under ultraviolet light makes detection of the crack easier.

(e) Post-processing

It is necessary to carry out the post-processing, such as removal of magnetic particles and anti-rust treatment.

Advantages and disadvantages

Advantage of Magnetic particle Testing is as follows;

- It can accurately measure the shape and dimensions of surface-crack as compared to other methods.

Disadvantage;

- Power requirement.
- It cannot detect internal defects.
- It requires coating to be removed.

7.4.5 Eddy current testing

7.4.5.1 Fundamental Principles

When an alternating current is supplied to a coil of winding wire, the magnetic flux is generated. When the magnetic flux is absorbed to conductor, a current is generated on surface. If there is crack on the surface and electromagnetic on the surface changes, the current which is generated on the surface changes. Eddy current testing is non-destructive inspection method about surface cracks by utilizing this phenomenon.

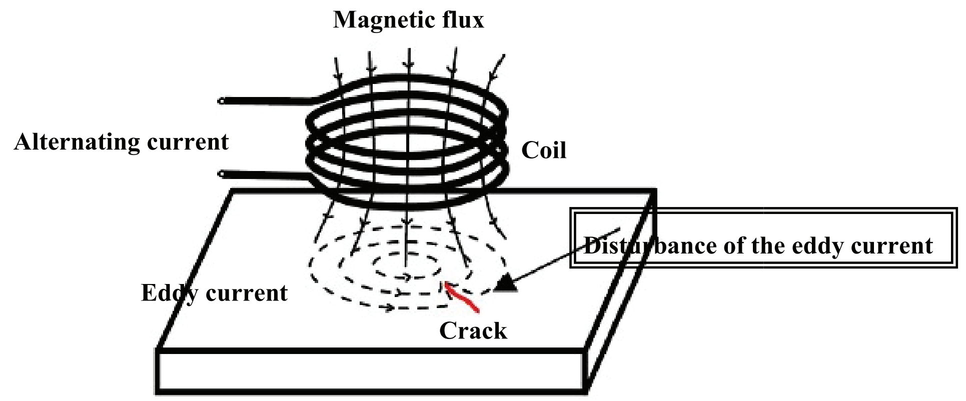


Figure 7-45 Eddy current Testing

Figure 7-46 Equipment for Eddy current testing

Advantages and disadvantages

Advantage of eddy current testing is as following;

- It can be used in testing large areas/sections in a short period.
- It can be used without peeling the paint.
- It is simple and inexpensive testing method.

But the disadvantage is as following;

- It can't be used to detect internal defects.
- It is difficult to know the accurate crack shape and dimension

7.4.6 Dye Penetration Test

7.4.6.1 Fundamental Principle

Liquid penetrant processes are non-destructive testing methods for detecting discontinuities that are open to surface. They may be effectively used in the inspection of both ferrous and non-ferrous metals and on non-porous, non-metallic materials, such as ceramics, plastics and glass. Surface discontinuities, such as cracks, cold shuts and laminations, are indicated by this method.

A suitable liquid penetrant is applied to the surface of the component under examination and is permitted to remain there for sufficient time to allow the liquid to penetrant into any defects open at the surface. After the penetrant time, the excess penetrant, which remains on the surface, is removed. Then a light coloured, powder absorbent called a developer is applied to the surface. This developer acts as a blotter and draws out a portion of the penetrant which had previously seeped into the surface openings. As the penetrant is drawn out, it diffuses into the coating of the developer, forming indications of the surface discontinuities or flaws as shown in the figure below.

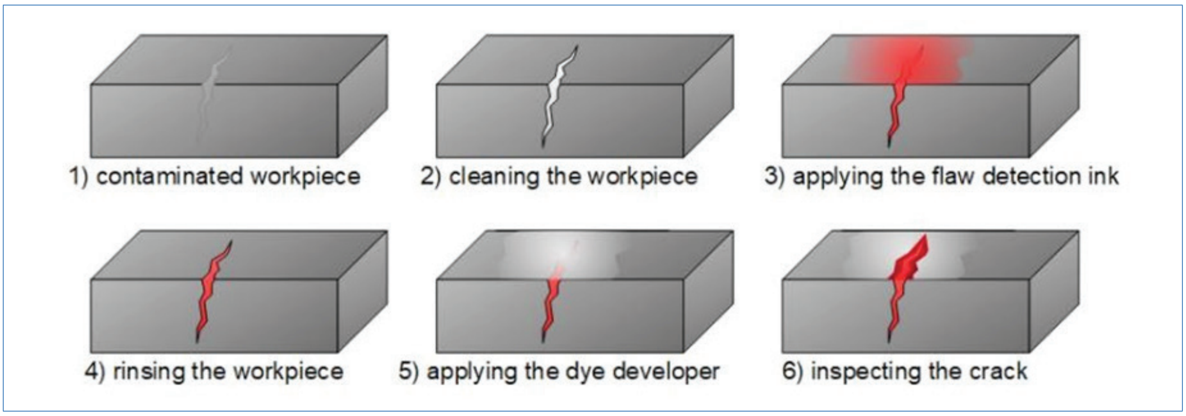


Figure 7-47 Indications of the surface discontinuities or flaws

7.4.6.2 Apparatus

Figure 7-48 Surface Cleanser, Developer and Penetrant

7.4.6.3 Test Procedure

(a) Surface Preparation

- The surface to be examined and all adjacent areas within at least 25 mm should be dry, free from any dirt, lint, grease, welding flux, weld spatter, oil, or other extraneous matter that could obscure surface openings or otherwise interfere with the examination. The method of cleaning depends on the nature of the material of the part and contaminants. Typical cleaning facilities make use of detergents, organic solvents, descaling solutions, alkali solutions, paints removers, vapour degreasing, ultrasonic cleaning, abrasive blasting, etc.
- The parts are thoroughly dried after cleaning so that no water or solvent remains in or over the discontinuities, as this will hinder entrance of the penetrant. Drying may be accomplished by warming the parts with infrared lamps, drying ovens, forced air circulation, etc.

(b) Penetrant

- After the part has been thoroughly cleaned, the penetrant is applied to the surface to be inspected. In case of small components, they may be dipped in a tank of penetrant. Where only a local area of a component is to be tested, the penetrant may be applied by a brush or spray. Regardless of how it is applied, it is important that all surfaces are wet by the penetrant.
- In the standard testing temperature range of 15-60°C, and using post emulsified/ solvent removable penetrants, a minimum of 10 minutes shall be allowed as standard penetration time; and for cracks with specially narrow widths, twice the time given above should be allowed.
- If water washable penetrants are used, the penetration time shall be about 1.5 to 2.0 times of that stated above.
- When a high viscosity fluorescent penetrant is used, the penetration time may be longer than the normal penetration time. In such a case, time shall he subject to agreement between the manufacturer and the purchaser.
- An extremely, long penetration time does not affect the results except to increase the brilliance of indications slightly and make removal of the excess penetrant more difficult.

(c) Rinsing

- After allowing for necessary penetrant time, the surface film of penetrant on the part is removed by rinsing. The rinsing must be through and complete so that the penetrant within the discontinuities of the part alone is intact. Special attention
- should be given to drilled holes and threads, which are highly prone to retain penetrant.
- When using water washable penetrant, rinsing should be done with water spray nozzle. The water droplet from the nozzle should be spray type rather than pointed.
- Also, when using post emulsifying penetrants, an additional step is required. This is the application of a liquid emulsifier prior to rinsing operation. The emulsifier may be applied by spraying or dipping.

- While using solvent removable penetrants, care should be taken not to use while excess of the solvent to avoid removal of penetrants from defects.
- On smooth surfaces, it may be possible sometimes to remove excess penetrant merely by wiping the surface with clean dry lint free rags.
- Using fluorescent type of penetrant, it is helpful to use portable black light source, while rinsing, so as to ensure that rinsing operation is complete. Rest of the procedure is same as outlined for dye penetrants.
- The piece after removal of excess penetrant should be dried with the help of dry lint free cloth, by normal evaporation method at ambient temperature and/or by application of low pressure compressed air at a temperature not exceeding by 50°C.

(d) Developing

- After washing off the surface penetrant in the rinsing operation, developeris applied to the part to blot back to the surface any penetrant that may have penetrated into discontinuities. Developers are either of dry type or wet type.
- Dry developer is a powder and can be applied by dipping the part in powder chamber, a hand powder bulb, a tower gun or in a dust storm chamber after drying the part by warm air or hot air circulation oven. Oven temperature should not exceed 1 10°C and the part surface temperature should not exceed 55°C.
- Wet developer is a suspension of powder in water or a volatile solvent. It is applied by dipping or spraying and should be agitated before use to ensure uniform dispersal of solid particles in the carrier fluid. When the developer dries, a film of powder is left on the surface. Where a water suspension developer is used, drying time may be decreased by the use of warm air, or by keeping in hot air oven as per procedure mentioned above. Thick coatings and pools of wet developer may result in marking of indications. and shall be avoided.
- Developer, whether dry or wet, shall be applied as soon as possible after removal of the excess penetrant and start observing.

(e) Inspection

- With visible dye penetrants, surface defects are indicated by bleeding out of penetrant, which is normally of deep red colour, against white background.
- With fluorescent penetrants, inspection is carried out in a darkened area using high intensity black light, whereby indications fluorescence brilliantly. A portable hand lamp should be used over the surface of large parts. Small parts are conveniently viewed under a fixed light. Adequate black light for inspection is obtained by using a 100 watt mercury vapour bulb of the sealed reflector type and a special filter which filters out most of visible light.
- Usually a crack or similar opening will show a line and tight crack or a partially welded lap will show a broken line. Gross porosity may produce large indications covering an entire area. Very fine porosity will be indicated by random dots.
- When an indicated pattern has appeared, the evaluation must be made to ascertain if the pattern is attributed to the actual flaw or an apparent one.
- Depth of surface discontinuities may be correlated with the richness of colour and speed of bleeding. Wiping the first layer of developer and immediately spraying the

second coat may help in judging the depth of flaw by observing speed and intensity of second bleeding.

- The nature, size, type and location of defects shall be recorded.
- Thorough cleaning of test pieces shall be carried out after inspection to ensure that no corrosive action takes place, on the same due to penetrant chemicals.

Advantages and Disadvantages of Dye Penetration Test

Advantages

- Easy to perform, even with complicated surfaces/shapes
- Inexpensive—no expensive cameras or equipment are required to perform the test.
- Can be used to inspect large areas quickly.
- Findings (i.e., defects identified by this method) can be seen visually on the surface of the materials and can show the dimensions of the defect.
- Material flexibility—can be used on a variety of materials, including ferrous/non-ferrous, conductive/non-conductive, and magnetic/non-magnetic

Disadvantages

- Limited findings—only detects cracks on the surface (or "open" to the surface)
- Porous materials can't be inspected with dye penetrant
- Dirty surfaces can't be inspected with dye penetrant—DP won't work on surfaces that contain paint, oil, dirt, rust, or any other similar kind of obstruction
- Direct access to the material is required
- There are several steps in the inspection process, each of which could impact the quality of the findings
- Cleaning is required both before and after the inspection (before to prepare the surface for the penetrant and after to clean the penetrant off the surface)
- Chemicals are involved—inspectors must follow protocol to handle and get rid of them, and these chemicals could produce hazardous or flammable fumes

7.5 Destructive Tests (DT)

Destructive test is a way of testing by destroying a small portion of the structure to investigate the physical properties and deterioration of the material.

Destructive tests are performed when visual observation and non-destructive testing does not provide sufficient information, or when more accurate information is needed. Destruction of the structure should be kept to the minimum necessary, and the destroyed areas should be treated with appropriate methods, such as repair by non-shrink mortar.

Table 7-9 shows some of the destructive tests based on the type of the material.

Table 7-10 Types of Destructive Tests

Concrete Structures	(1) Carbonation Depth Measurement Test (2) Compressive Strength Test using Micro-core Specimen (3) Test for ASR
Metallic Structures	1) Breakout and Coring 2) Plate thickness measurement 3) Paint film thickness 4) Chemical analysis 5) Adhesion

7.6 Destructive tests for concrete structures

7.6.1 Carbonation Depth Measurement Test

7.6.1.1 Fundamental Principles

Carbonation of concrete occurs when carbon dioxide, in the atmosphere, in the presence of moisture, reacts with hydrated cement minerals to produce carbonates, e.g., calcium carbonate. The carbonation process is also called de-passivation. Carbonation penetrates below exposed surface of concrete extremely slowly.

The significance of carbonation is that the usual protection of reinforcing steel generally present in concrete due to the alkaline conditions caused by hydrated cement paste is neutralized by carbonation. Thus, if the entire concrete cover over the reinforcing steel is carbonated, corrosion of steel would occur if moisture and oxygen could reach the steel.

7.6.1.2 Apparatus

The 1% Phenolphthalein Solution is made by dissolving 1gm of Phenolphthalein in 90 cc of ethanol. The solution is made up to 100 cc by adding distilled water. The pH value indicates if a solution is acid or alkaline, and therefore corrosion of reinforcing steel bars is determined if possible or not.

- pH < 7: acid
- pH = 7: neutral
- pH > 7 up to 14: alkaline

7.6.1.3 Procedure

The freshly extracted core is sprayed with Phenolphthalein solution, and the depth of uncolored layer (the carbonated layer) from the external surface is measured to nearest mm at 4 or 8 positions, and the average is taken. If the concrete still retains its alkaline characteristic, the color will change to red violet. If carbonation has taken place pH will have changed to 7 (i. e. neutral condition) and there will be no color change.

If test sample is cored by coring apparatus:

- Phenolphthalein shall be sprayed on the concrete surface after cleaning.
- The phenolphthalein becomes red-violet when it meets normally alkaline concrete.
- If phenolphthalein does not discolor, the concrete is carbonated.
- The depth of carbonated concrete shall be measured Figure 7-45 Measurement of Carbonation Depth on chipped off concrete surface

Figure 7-49 Measurement of Carbonation Depth on Concrete Core Sample

> ***Note:*** *When cored sample is used, point load test should also be carried out on the sample. After coring, the hole shall be sealed by mortar.*

If test is to be done in a chipped hole, the dust is first removed from the hole using an air brush and again the depth of uncolored layer is measured at 4 to 8 positions and the average taken. If the concrete still retains its alkaline characteristic, the color will change to red violet. If carbonation has taken place pH will have changed to 7 (i. e. neutral condition) and there will be no color change. See *Figure 7-50 Measurement of Carbonation Depth on chipped off concrete surface*.

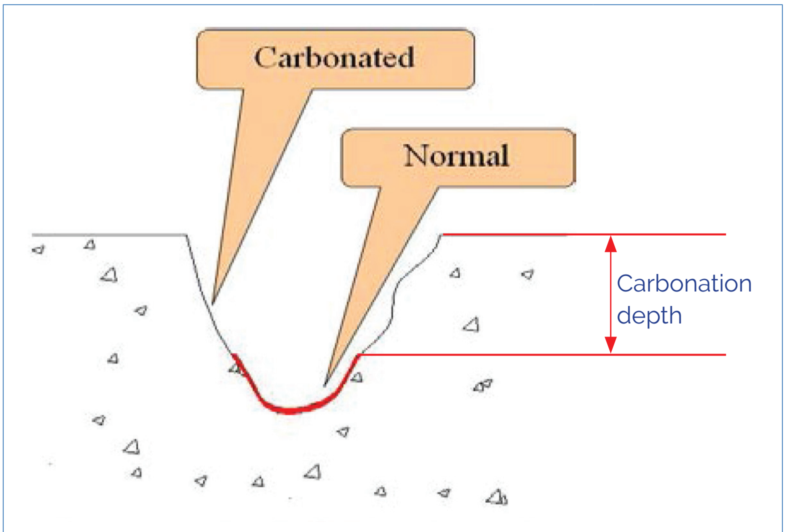


Figure 7-50 Measurement of Carbonation Depth on chipped off concrete surface

i. If concrete surface is chipped off by hammer, breaker or other apparatus:

ii. Spray Phenolphthalein Solution on the chipped surface after cleaning.

iii. If not discolored, the concrete is carbonated.

iv. The depth of carbonated concrete shall be measured.

> ***Note:*** *Chipped concrete shall be sealed with mortar after testing*

7.6.1.4 Analysis

Carbonation rate coefficient (b) can be computed by the formula below. It is advisable to determine the carbonation rate coefficient from the carbonation depth measurements, utilizing the fact that the carbonation depth is proportional to the square root of the carbonation period.

$y = b\sqrt{t}$ ....Equation 10

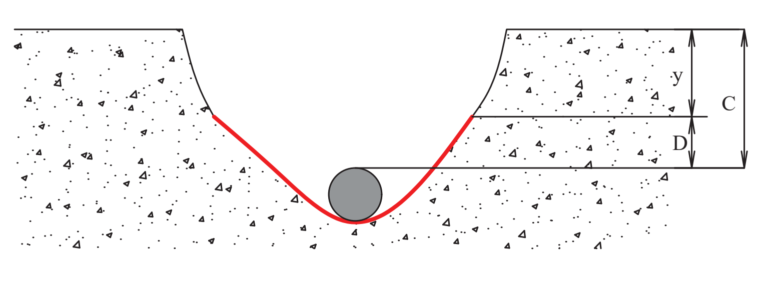


Figure 7-51 Un-carbonated Depth

Where:

y: *carbonated depth (mm)*

b: *carbonation rate coefficient (mm/√year)*

t: *carbonation period (year)*

D: *Un-carbonated depth (mm) = C-y*

C: *Concrete cover thickness (mm)*

7.6.1.5 Evaluation and Recommendations

The result of test is evaluated based on un-carbonated depth as in *Table 7-10 Evaluation of Carbonation Depth according to the degree of damage*

Table 7-11 Evaluation of Carbonation Depth according to the degree of damage

Degree of Damage	Un-carbonated depth (D)	Degree of reinforcement corrosion	State
I	30 mm≤ D	None	Rebars will be corroded in the future
II	10 mm≤ D< 30 mm	Low	Rebars may be partly corroded
III	0 mm ≤ D< 10 mm	Medium	Rebars are corroded
IV	D= 0 mm	Large	Rebar are seriously corroded

Note: Un-carbonated depth (D) = Cover – Carbonation depth

7.6.2 Compressive Strength Test using Micro-Core Specimen

7.6.2.1 Fundamental Principles

Micro-coring is the method chosen to obtain samples of existing concrete structures that are used to determine in-situ compressive strength of concrete. In heavily reinforced concrete structures, it may be impossible to obtain a large core specimen from which compressive strength may be taken since reinforcing steel may be so prevalent in the concrete. Therefore, small cores extracte by micro-core apparatus are used as substitutes for large cores to test concrete strength.

Compressive Strength Test in the form of The Point Load Test (PLT) is intended as an inde test for the strength classification of rock materials and concrete core samples, but it may als be widely used to predict other material strength parameters with which it is correlated. It ca provide similar data at a lower cost due to its ease of testing and simplicity of sample preparatio

7.6.2.2 Apparatus

Micro-core Apparatus: It is used for drilling holes (diamond core drilling) of 8–35 mm Ø reinforced concrete, masonry and natural stone. It drills up to 300 mm depth with little vibratic and low noise and can cut through reinforcing steel bars. Its water pump and extraction functic are activated/deactivated automatically by the drilling machine.

Figure 7-52 Micro-Core Apparatus

Point Load Test Apparatus: is used for compression test on small cylinder specimens and co samples. The load is applied by a hand pump and is measured by a precision digital display rang 0-56kN, with an accuracy of ± 1%, resolution of 65000 points. The compression platens have Ø 6 mm, the upper one has a spherical seat and vertical height of 110 mm. It comes with a set of tw hardened conical points for point load testing.

Figure 7-53 Point Load Test Apparatus

7.6.2.3 Procedure for Compressive Strength Test using Micro-Core Specimen

i. Coring

a. Assemble the apparatus in accordance with instructions in the Operation Manual.

b. Drilling

- To begin drilling, press the control switch before the core bit has been brought into contact with the base material. Begin drilling the hole only when the water flow indicator shows that water is flowing through the core bit.
- Press the core bit gently against the base material. Ensure that the core bit is perpendicular to the base material. The pressure applied to the core bit should be regulated so that the tool continues to run at its highest speed. Application of higher pressure does not increase the rate of drilling progress.
- Hold the tool straight. Do not tilt it at angle as this may result in reduced drilling performance. Always ensure that the tool continues to run at a high speed.
- Immediately after beginning drilling, check the water flow rate indicator to ensure that water is flowing.

c. Removing the core from the hole

- Take the core removal tool out of the toolbox. Ensure that the diameter of the core removal tool corresponds to the diameter of the core bit used.
- Push the core removal tool into the hole as far as it will go while rotating it slightly.
- Break the core by applying slight lateral pressure to the core removal tool.
- Use the core removal tool to pull the broken core out of the hole. Turn the core removal tool through 180˚ and re-insert it in the hole.
- Use a ruler to measure the effective hole depth reached.
- Repeat this procedure, if necessary, several times until the entire core has been removed.

Figure 7-54 Core Removal Tool and Core Sample

Point Load Test (Reference standard ASTM D5731)

Diametrical Test

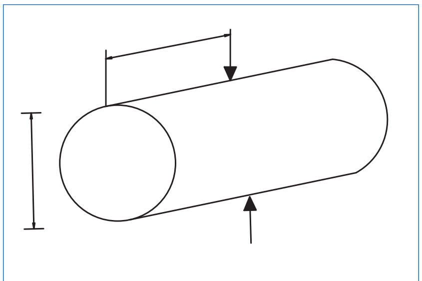


Figure 7-55 Core Configuration for Diametrical Test

- Mark the desired test orientation on the sample with lines along the surface. These lines are used for centering the sample before the test and checking the proper stress orientation along the compression to failure.
- Close the valve of the hydraulic circuit of the hand pump. Insert the extension rod into the jack lever and set to zero the readout unit (make reference to the Instruction Manual for the use of the manometer).
- Insert the sample between the conical points along a direction perpendicular to the end faces of the core and jack to close the platens to the core. The core surfaces generally consist of failure planes.
- Before starting compression, check that the conical points are in contact with the core sample along the diameter D and that the distance L between the contact points and the nearest free end of the core is as follows:
  - ✓ Use the graduated scale inserted on the frame of the machine to record the distance D of the points to the nearest ± 2%.
  - ✓ Check that the manometer records a small load and operate with the pump to increase the load steadily such that the failure occurs within 10 to 60 sec.
  - ✓ Record the maximum force displayed by the manometer (the peak load value is frozen on the display) and measure again the distance D' of the points. If a partial failure occurs, the test result is not considered.
  - ✓ Open the hydraulic circuit of the pump and push down manually the loading piston, to start again with a new test of core samples. Where possible, the test is repeated with at least 10 core samples.

Axial Test

- Measure first the size of the core sample, in order to check that the length/diameter ratio is between 1/3 and 1. Mark the desired test orientation on the sample with lines along the surface. These lines are used for centering the sample before the test and checking the proper stress orientation along the compression to failure.
- Close the valve of the hydraulic circuit of the hand pump. Insert the extension rod into the jack lever and set to zero the readout unit.

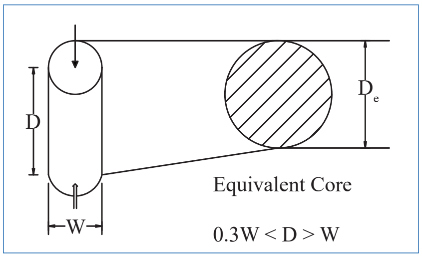


Figure 7-56 Core Configuration for Axial Test

- Insert the sample between the conical points along a direction perpendicular to the end faces of the core and jack to close the platens to the core. The core surfaces generally consist of failure planes.
- Use the graduated scale inserted on the frame of the machine to record the distance D of the points to the nearest ± 2%.
- Check that the manometer records a small load and operate with the pump to increase the load steadily such that the failure occurs within 10 to 60 sec.
- Record the maximum force displayed by the manometer (the peak load value is frozen on the display) and measure again the distance.

NOTE: Test Points

- One test result needed for superstructure and one for substructure.
- One coring piece can be divided into two or three test pieces.
- Be careful so that coring does not affect structure.
- If test results are less than design compressive strength, then take another core and test again.

7.6.2.4 Analysis (Interpretation of Data)

Calculate Point Load Strength Index in (MPa) as follows:

$$I_S = \frac{P \times 1000}{De^2}$$ ....Equation 11

where:

***P:** Peak resistance expressed in kN*

***De**: Equivalent diameter of the core expressed in mm*

For diametrical test: *De* = diameter

For axial test: $D_e = \sqrt{\frac{4 \times A}{\pi}}$

where: A= W x D; (W= width of the sample)

Apply size correction factor if core sample diameter is other than 50mm, as follows:

$$Is_{(50)} = F \times I$$ ....Equation 12

Where: $F = \left(\frac{De}{50}\right)^{0.45}$

Calculate Mean Value

To calculate the average point load index $Is_{(50)}$, at least 10 point load tests are required. From these tests eliminate the highest and the lowest readings and calculate the mean of the remaining values.

Compressive Strength can be estimated as follows:

$$\delta uc = C \times Is_{(50)} \qquad \text{...Equation 13}$$

where:

δuc: *Uniaxial Compressive Strength*

C: *Factor that depends on site-specific correlation between δuc and* $Is_{(50)}$

$Is_{(50)}$: *Corrected Point Load Strength Index*

Table 7-2 Values of "C"

Core Diameter (mm)	Value of "C"
20	17.5
30	19
40	21
50	23
54	24
60	24.5

7.6.2.5 Evaluation and Recommendations

- Micro-coring has the advantages of cores being easily drilled and cut with minimum damage to structures and requires use of a portable lower-capacity machine.
- Cores can also be used for carbonation test.
- PLT is used as an index test for strength classification of materials such as existing concrete
- PLT requires smaller breaking force so that a small and portable testing machine may be used.

7.6.3 Tests for Alkali-Silica Reaction (ASR)

7.6.3.1 Fundamental Principles

This section describes a test that uses concrete cores taken from a structure to investigate whether there is an ASR.

Diagnosis of ASR is performed using stereomicroscopy and polarized light microscopy to identify reactive aggregates and minerals. The degree of ASR deterioration progression is also determined, as well as analysis of the amount of alkali contained in the concrete and accelerated expansion testing.

7.6.3.2 Apparatus

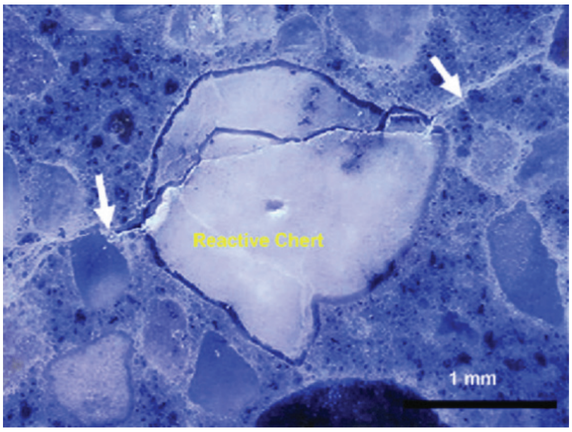
	
Stereomicroscope	Polarized Light Microscope

Figure 7-57 Stereomicroscope and Polarized Light Microscope

7.6.3.3 Procedures/Analysis

The sides and cross sections of concrete cores are visually observed or by use of stereomicroscope/ polarized light microscope to identify the presence or absence of ASR occurrence and the aggregate rock and reactive minerals that cause the ASR.

Using stereomicroscope /polarized light microscope, one can observe the progression of cracks within the aggregate and cracks that have propagated from the aggregate into the paste due to ASR.



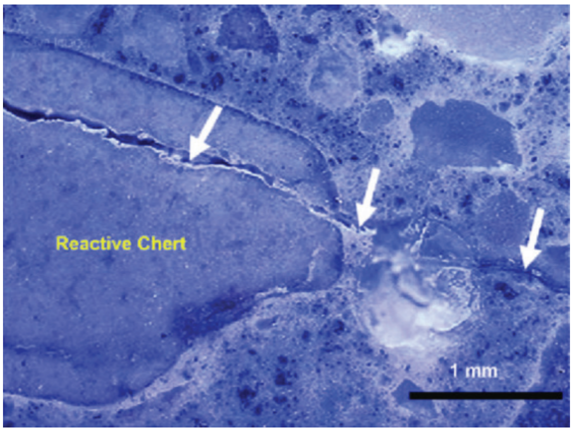


Figure 7-58 Cracks from Reactive Chert fine aggregate particles into paste

7.7 Destructive tests for Steel structures

7.7.1 Breakout and coring

Break out and coring physically removes material and exposes inner and/or hidden parts of the structure. This technique damages the structure but enables direct inspection and measurement of features exposed by the holes and also provides samples for further testing.

This technique can provide valuable information on structural arrangement and assist in the detection of suspected/hidden features. The holes drilled in metal elements can be used to determine thickness, e.g. sheet pile walls and hollow cast iron members.

To avoid unnecessary damage, exploratory holes may be drilled during an initial investigation, e.g. of geometrical details. Damage can be restricted in certain circumstances by taking the necessary measurements via these holes, for example, insertion of poker type covermeters for locating internal prestressing tendons. In some cases, it may be prudent to check thickness at several points, for example, around the perimeter of a hollow core cast iron column as parts may have moved during casting.

Break out is most commonly carried out using small hand-held or machine mounted impact breakers. Break out is usually confined to a small area, sufficient to locate and inspect the desired feature, but occasionally may be used to expose relatively large areas.

7.7.2 Plate thickness measurement

7.7.2.1 Fundamental Principles

The normal approach for measuring the corrosion rate of metal structures includes: measurement of plate thickness (e.g. flange/web) and/or corrosion/pit depth, and comparison with the original design or manufactured thickness.

This can give an indication of the rate of thickness loss if the original construction date is known. However, this rate can be misleading if the corrosion initiated after the date of construction; if this is the case then a suspected date of corrosion initiation can be used.

Drilling of elements, can be used to measure the thickness of elements where only one side is accessible. A series of measurements of plate thickness (e.g. flange/web) and/or corrosion/pit depth over a period of time, thereby enabling the corrosion rate to be directly calculated (without the need to refer to the construction date or a known/suspected corrosion initiation date).

The frequency of the measurements will depend on the suspected rate of corrosion, in some case they may need to be spread over a period of years. Formal long term programmes of thickness measurements on a selected number of structures or elements, say as part of the baseline Inspection, can provide highly beneficial information for Whole Life Cost analysis and determination of service life.

7.7.2.2 Procedure

- Locate and mark the area or section for extracting the sample. Make sure that it is easily accessible.
- Drill a section of the steel on the marked area.
- Remove the rust if any from surface of the steel using the applicable solvent or chemical.
- Using a micrometer screw gauge or a metal thickness gauge, measure and record the thickness of the extracted steel sample (procedure for using metal thickness gauge discussed in NDT 's).

7.7.2.3 *Equipment*

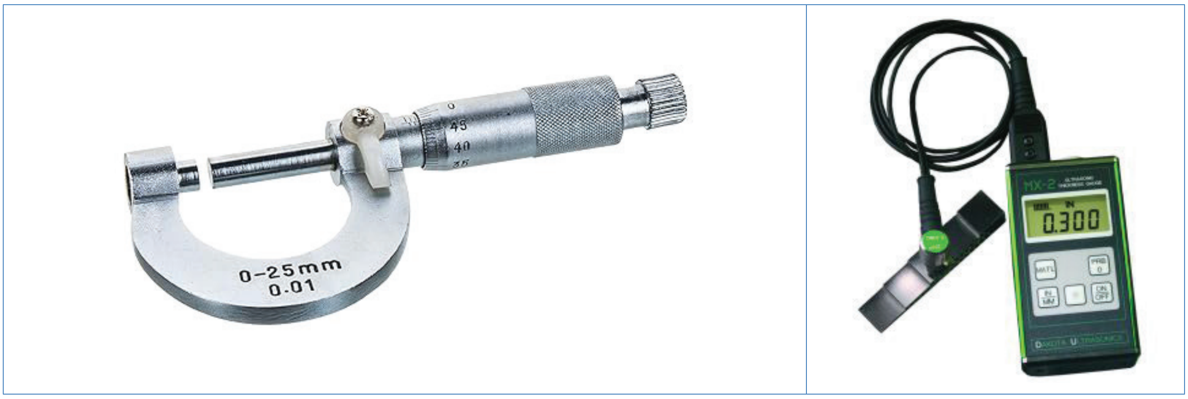


Figure 7-59 Micrometer screw gauge and metal thickness gauge

7.7.2.4 *Analysis*

Compare the design thickness with the measured value to confirm the amount of steel plate reduction. The design calculation sheet should be checked, and if the thickness reduction is at a level where there is no stress margin, countermeasure method should be considered as soon as possible.

If the design thickness is not present, extract another sample from a sound/undisturbed location on the same structural member and compare their thickness.

7.7.2.5 *Evaluation and Recommendations*

- Steel structures should be inspected regularly. To avoid damage, surfaces should be applied with appropriate paints.
- If the existing plate thickness is found to be less than the designed thickness due to corrosion, repair method should be planned based on the degree of deterioration.

Table 7-13 Degree of damage

Degree of Damage	Steel plate thickness, t	Degree of Deterioration
I	$1/4t_o < t$	None
II	$1/4t_o \leq t < 1/2t_o$	Low
III	$1/2t_o \leq t < 3/4t_o$	Medium
IV	$t \geq 3/4\, t_o$	Large

Where $\boldsymbol{t_o}$ = design thickness or the thickness of healthy section of the same member.

7.7.3 Paint film thickness

7.7.3.1 *Fundamental Principles*

Good practice suggests that measurements should initially be taken at the rate of one per square metre. If the results of testing 10m² indicate that the coating is reasonably uniform and no measurement is below the specified minimum, then the rate of measurement can be continued. If wide variations exist in the first group of readings the number of measurements should be increased. If the uniformity of the coating persists over a large number of the 10 m² areas, then the number of measurements may be reduced.

A range of instruments are available for the measurement of dry paint film thickness and, if used properly and correctly calibrated, they provide reasonably accurate measurements. The difficulty is in deciding the number of measurements, which should be taken to indicate the true average thickness.

Where the specification calls for measurements to be taken over specific areas this must be carried out, alternatively, the judgement of an experienced inspector should be relied upon. Further examination of the paint film may be carried out using a paint inspection gauge.

The gauge cuts a V-shape in the paint film through to the steel. The cut is inclined on one side to enable individual coats of paint to be identified and if there is sufficient contrast between the coats, the thickness of each coat can be determined. The gauge can also be used to examine any irregularities such as under or interface corrosion creep. Paint flakes may be removed to confirm with the aid of a **stereo microscope** the total or individual paint film thickness.

7.7.3.2 Procedure

i. Select a test panel or choose a site for the thickness measurement.

ii. Using an appropriate surface marker of contrasting colour, mark a line on the surface approximately 2 inches long (51mm) where the thickness measurement will be made.

iii. Select a cutting tip based on estimated film thickness as follows:

Tip	Thickness Range, mils (µm)	Conversion Factor
1x	20 to 50 (500 to 1250)	1.0
2x	2 to 20 (50 to 500)	0.5
10x	0 to 3 (0 to 75)	0.1

iv. Cut a groove, grasp the gauge with the studs and cutting tip firmly forming a tripod on the painted surface. Place the gauge at right angles to and about 2 inches (51 mm) perpendicularly from a marked line.

v. Draw the gauge across the paint film toward the body, with guide of studs leading the cutting tip, and increase pressure on the cutting tip until it barely cuts into the substrate before it crosses the marked line.

vi. Take readings at the intersection of the marked line and incision. Read by measuring on the reticle the distance from the substrate/coating demarcation up to the longer machined slope of the incision to the upper cut edge of each respective coating layer of the coating system. Make sure that the smooth cut face of the groove is measured. (The machined upper edge of the cutting tip usually leaves a less jagged cut). If multiple coats are observed, individual thicknesses of each coat may be read.

7.7.3.3 Equipment

Figure 7-60 Elcometer

7.7.3.4 Analysis

The actual coating thickness is derived by multiplying the rectile reading by the conversion factor for the respective cutting tip.

Results of a thickness are recorded, and if more than one measurement is made and specific results for each location are not needed, record the minimum, the maximum, and the average thickness.

7.7.4 Adhesion

7.7.4.1 Fundamental Principles

The adhesion of paint coatings both to the substrate and interstitially should be checked when chemically cured paints are used. Spot checks can be made by the cross-hatch adhesion test or the cross cut adhesion test, both of which attempt to lift the film from an incision made into the paint film.

The technique often used is that which measures the perpendicular force required to remove a 'dolly' adhered to the surface by using a quick curing resin.

This pull-off test can be performed using the Elcometer or HATE apparatus, test details are described in BS EN IS0 4624 [61]. Generally, these tests only provide an indication of the potential defects and further investigations are often required to substantiate the results.

The adhesion of a coating or several coated samples of any paint product is measured by assessing the minimum tensile stress needed to detach or rupture the coating perpendicular to the substrate. Unlike the other methods, this method maximizes the tensile stress, therefore, results may not be comparable. The test is done by securing loading fixtures (dollies) perpendicular to the surface of a coating with an adhesive. Then the testing apparatus is attached to the loading fixture and aligned to apply tension perpendicular to the test surface. The force that is applied gradually increases and is monitored until a plug of coating is detached or a previously specified value is reached.

7.7.4.2 Procedure

i. Apply the adhesive evenly to the uncoated, freshly-cleaned surface of a dolly.

ii. Place the adhesive-coated face of the dolly in contact with the coating, for a period equal to the curing time of the adhesive.

iii. Carefully use the cutting device to cut around the circumference of the dolly through to the substrate, unless otherwise specified or agreed.

iv. Place the outer ring in position and test as indicated in Figure 7-57

The adhesion is measured by the tensile pull on a Dolly glued to the coating surface. The force is applied through the centre of the Dolly by a hydraulically loaded pin. This ensures an exactly central point-loading of the force.

The maximum value achieved at pull-off is recorded by a reset needle that is easily read on the large scale of the pressure gauge.

7.7.4.3 Equipment for Pull-off test

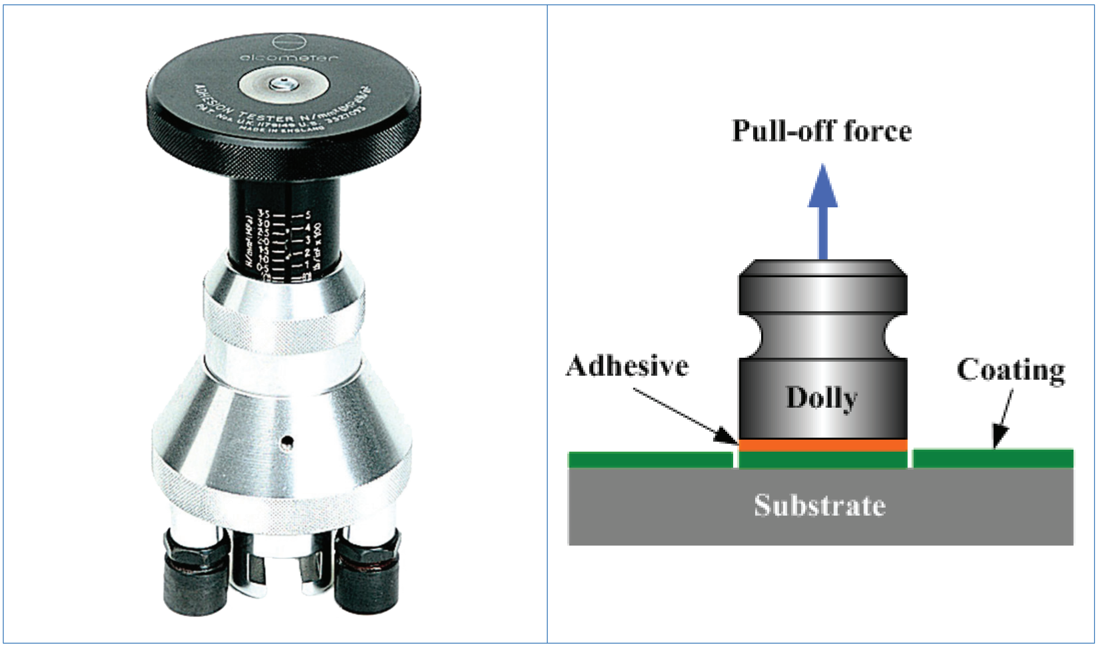


Figure 7-61 Equipment for Pull-off test

7.7.4.4 Analysis

Breaking strength

The breaking strength , in MPa, for each test assembly is given by the equation;

$$\sigma = \frac{F}{A} \quad \text{.. Equation 14}$$

where

F *is the breaking force, in newtons;*
A *is the area of the dolly, in square millimetres.*

7.7.5 Chemical analysis

7.7.5.1 Fundamental Principles

Chemical analysis techniques include ;optical emission spectrometer for bulk elemental analysis of steel, stainless steel,cast iron,copper,aluminium, cobalt, nickel, tin and zinc alloys.

Diagnosis is performed using a spectroscopic machine and polarized light microscopy to identify reactive chemicals. The degree of chemical deterioration progression is also determined.

Spectroscopy is used in physical and analytical chemistry to detect, determine or quantify the molecular and/or structural composition of a sample. Each type of molecule and atom will reflect, absorb or emit electromagnetic radiation in its own characteristic way.

7.7.5.2 Apparatus

Spectroscope

Figure 7-62 Spectroscope

7.7.5.3 Procedures/Analysis

Refer to the user manual of a spectroscope

The cross sections of steel samples are observed with the spectroscopic machine to identify the presence or absence of chemicals such as chlorides, sulphites, carbonites etc

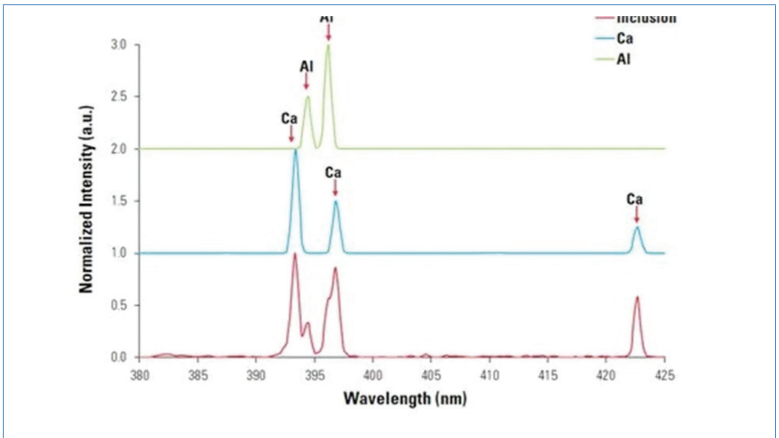


Figure 7-63 A spectrograph showing the intensity of chemicals present in a steel sample.

APPENDIX 1: MASTER BRIDGE DAMAGE CATALOGUE

BI manual with defect codes linked to the Centunion Inspection Manual

Concrete Structures (A)	**Steel Structures** (B)	**Wooden Structures** (C)	**Masonry Structures** (D)	**Non-Structural Elements** (E)	**Other Structural Components** (F)
Siltation (A1) 25 30	Siltation (B1) 25 30	Siltation (C1) 25 30	Siltation (D1) 25 30	Railings/ Parapets (E1) 01 05 06 07 17 18 19 21 26 27	Pavement/ surface (F1) 06 07 11 17 22 25 30
Corrosion (A2) 05	Corrosion (B2) 05	Processing defects (C2)	Loss of bricks (D2) 18	Drainage (E2) 01 03 05 18 25 30	Foundations (F2) (Scouring/ Sapping/ Settlement/Lateral movement) 02 10 23
Cracking (A3) 01 06	Paint peel-off (B3) 24	Fungal attack (C3)	Effervescence (D3) 20	Embankment protection (E3) 11 15 30	Bearings/ Bearing devices. (F3) 01 05 06 07 17 18 19 29
Spalling (sectional loss) (A4) 26 27	Heat damage (B4) 01 07	Natural defects (C4) 07	Opening of arch joints (D4) 07	Signalling (E4) (Faulty Lightings/ Road signs) 01 05 13	Bridge expansion joint /irregularities of road surface(F4) 01 05 06 07 18 19 20 25 30

Concrete Structures (A)	**Steel Structures** (B)	**Wooden Structures** (C)	**Masonry Structures** (D)	**Non-Structural Elements** (E)	**Other Structural Components** (F)
Scaling (A5) 24	Sectional loss (B5) 11	Environmental defects (C5) 01 06 07 17 28	Longitudinal cracking (D5) 01 06		Approach slab (F5) 06 11 22
Delamination/ horizontal cracking (A6) 08	Missing parts (B6) 18 19 28 29	Discoloration/ Deteriorations (C6) 14 21	Penetration by vegetation (D6) 30		Damage of reinforced members (F6) 01 05 06 07 19
Honeycomb-ing (A7) 16	Cracking (B7) 06		Discoloration/ Deteriorations (D7) 14 21		Gap error of girder end (F7)
Efflorescence (A8) 12	Fracture (B8) 01				Anchorage (F8) 01 05 28
Carbonation (A9) (Detailed inspection)	Excessive vibration and noise (B9) 09				
Chemical Attack (A10) (Detailed inspection)	Deformation and deflection (B10) 07				
Alkali-aggregate reactivity (A11) (Detailed inspection)	Buckling, kinking and warping (B11) 11 17				
Abrasion erosion (A12) 02 11 15 23	Loose bolts (B12) 09 19				

Concrete Structures (A)	Steel Structures (B)	Wooden Structures (C)	Masonry Structures (D)	Non-Structural Elements (E)	Other Structural Components (F)
Leakage (A13) 20 31	Accumulation of water (B13) 20 31				
Leaching (A14) 12	Discoloration/ Deteriorations (B14) 14 21				
Excessive deformation, deflection/ vibration (A15) 09 10					

Damage catalogue damage list

01 Broken
02 Burrows
03 Clogging/Obstruction
04 Construction remnants
05 Corrosion
06 Cracking
07 Deformation
08 Delamination
09 Disintegration
10 Displacement/Settlement
11 Distortion / Surface deterioration
12 Efflorescence
13 Faulty lighting
14 Graffiti
15 Gullies
16 Honeycombs
17 Misalignment
18 Missing parts
19 Missing screws, rivets, anchors
20 Moisture, leaks

21 Patina, rust stain
22 Potholes, ruts
23 Sapping
24 Scaling
25 Siltation
26 Spalling concrete not showing reinforcing rods
27 Spalling concrete showing reinforcing rods
28 Unfixed anchors
29 Unfixed parts
30 Vegetation
31 Water runoff

APPENDIX 2: BRIDGE INVENTORY FORM

i) General Data

Name	Nyakoye River Bridge	Code	R01-00A1-00200-B-02
Ownership	KeNHA	Region	Nyanza
Township	Kisii	Inventory Date	10.8.2022
Road	A	Road Category	A1
Initial Chainage	0+200	Final Chainage	0+240
Location point	+37.345668, -0.3456767		

ii) Geometric Information

Total length (m)	38.0	Overall Width (m)	10.0
Alignment	Straight	No. of Components	1
No. of spans	3	No. of Abutments	2
No. of Piers	2	No. of Lateral walls	4
No. of expansion joint lines	4	No. of bearing lines.	4

iii) Structural Information

General typology	Major Bridge	Structural typology	Girder
Presence of other structures	No.	Main material	Composite
Structure description	The bridge has 3 spans which are simply supported		

iv) Safety features

Accident type	Normal	Carriageway Narrowing	No.

v) Functionality (Bridge Users)

Vehicles	Yes	Railway	
Pedestrian	Yes	Bicycles	Yes
Animals	Yes		

vi) Obstacle under the structure

Riverbed	Yes	Road	
Railway		Rugged terrain/ Obstacle.	

vii) Road supported

Traffic direction	Both	No. of carriageways	1
Paved	Yes	No. of lanes	2
Lane width (m)	3.5	Shoulder width (m)	1.5
Horizontal Clearance (m)	10.0	Pavement material	Asphalt

viii) Parameters

a. Principal structure

i. Abutment

Abutment Code	Dimension		Material	Type of Foundation
	Width (m)	Onsite Height (m)		
A1	10.0	3.5	R.C.C	Footing
A2				

ii. Pier

Pier Code	No. of Columns	Section type	Dimension			Material	Type of Foundation
			Length/ Diameter (m)	Width (m)	Onsite Height (m)		
P1	1	Rectangular	1.2	10.0	4.6	R.C.C	Pile
P2							
P3							
P4							
P5							
P6							
P7							
P8							
P9							
P10							
P11							
P12							

iii. Lateral wall

Lateral Wall Code	Dimension		Material	Type of Foundation
	Length	Onsite Height		
LLWA1	3.5	3.0	R.C.C	Footing
RLWA1				
LLWA2				
RLWA2				

b. Span

i. Slab/Deck

Span Code	Deck Typology	Dimension			Material
		Length	Width	Max. slab thickness (mm)	
S1	Slab	12.5	10.0	400	R.C.C
S2					
S3					
S4					
S5					
S6					
S7					
S8					
S9					
S10					

ii. Beams

Span code (Where the beams are)	Beam type	No. of Beams	Dimensions				Material
			Height (m)	Width/ Flange width (m)	Web thickness (mm)	Interaxis (m)	
S1	I-type	5	1.0	0.4	15	1.5	Steel

iii. Bearings

Bearing line	No. of Bearings	Dimension		Material	Movement
		Width (mm)	Thickness (mm)		
B1A1	5	300	60	Elastomeric	x, y. z

iv. Expansion Joints

Joint line	Type of expansion joint	Material	Joint direction

c. *For Truss/ Bailey structures*

Typology	Member	Dimension		Section Type	Material
		Length (m)	Thickness (mm)		
	Top chord				
	Bottom chord				
	Diagonal				
	Top bracing				
	Bottom bracing				
	Platform / slab				

d. *Non-structural elements (NSE)*

i. Drainage

Element	Quantity	Location	Material
Weepholes	30	Abutments and lateral walls	PVC
Drain pipes	20	Slab	PVC

ii. Embarkment protection

Element	Quantity	Material
Stone pitching		
Gabions		

iii. Road restrains systems

Barrier Line	Dimension		Material	Protection
	Length (m)	Height (m)		
RRS1				
RRS2 (outer)				
RRS2 (inner)				
RRS3				
RRS4				
RRS5 (outer)				
RRS5 (inner)				
RRS6				

General Comments: ....

....

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....

....

Inspector Name .... Supervisor Name ....

Signature .... Signature ....

Date .... Date ....

APPENDIX 3: INITIAL/DETAILED INSPECTION FORM

i. Bridge Information

Name		Ownership	
Code		Region	
Township		Road	
Location Point		Road Category	
Initial chainage		Final Chainage	
General typology		Structural typology	

ii. Deteriorations

a) Principal Structure Components

i. Abutment

Frontload Bearing Wall			Material:	
Defect	**Unit**	**Measurement**	**Severity**	**Remarks**
Cracking				
Corrosion				
Honeycomb				
Spalling/ Sectional Loss				
Efflorescence				
Water Leaks				
Graffiti				
Construction Remnants				
Patina/Rust/ Discoloration				
Vegetation				
Missing Parts				

ii. Pier

Column			Material:	
Defect	**Unit**	**Measurement**	**Severity**	**Remarks**
Cracking	P1	0.2mm	Low	The crack might be due to concrete shrinkage. See photos attached.
Corrosion				
Honeycomb				
Spalling/ Sectional Loss				
Efflorescence				
Clogging/ Obstruction				

Column			Material:	
Defect	**Unit**	**Measurement**	**Severity**	**Remarks**
Graffiti				
Construction Remnants				
Patina/Rust/ Discoloration				
Vegetation				
Missing Parts				
Delamination				

iii. Pier cap/ Bearing shelf

Defect	Unit	Measurement	Severity	Remarks
Siltation				
Cracking				
Corrosion				
Honeycomb				
Spalling/ Sectional Loss				
Efflorescence				
Graffiti				
Construction Remnants				
Patina/Rust/ Discoloration				
Vegetation				
Missing Parts				
Delamination				

iv. Lateral Wall (Wing Wall)

Soil Retaining Wall			Material:	
Defect	**Unit**	**Measurement**	**Severity**	**Remarks**
Cracking				
Corrosion				
Honeycomb				
Spalling/ Sectional Loss/ Loss of bricks				
Efflorescence				
Water Leaks				
Graffiti				
Construction Remnants				
Patina/Rust/ Discoloration				
Vegetation				
Delamination				

b) Span

i. Deck/Girder/Lintel

Defect	Unit	Measurement	Severity	Remarks
Cracking				
Corrosion				
Honeycomb				
Spalling/ Sectional Loss				
Efflorescence				
Water Leaks				
Graffiti				
Construction Remnants				
Patina/Rust/ Discoloration				
Vegetation				
Missing Parts				
Delamination				

ii. Lower slab (For Box Culverts only)

Defect	Unit	Measurement	Severity	Remarks
Siltation				
Cracking				
Clogging/ Obstruction				
Scouring/ Abrasion erosion				
Vegetation growth				

c) Non-Structural Elements (NSE)

i. Railings/ Parapet walls

Material				
Defect	**Unit**	**Measurement**	**Severity**	**Remarks**
Broken				
Corrosion				
Cracking				
Deformation				
Misalignment				
Missing Parts				
Missing Screws/ Bolts/ Nuts				
Patina/Rust stain				
Spalling				
Unfixed parts				

ii. Drainage.

Weep holes/ Drain pipes.				
Defect	**Unit**	**Measurement**	**Severity**	**Remarks**
Broken				
Clogging/ Obstruction				
Corrosion				
Missing parts				
Siltation				
Vegetation				

iii. Embarkment Protection

Gabions/ Stone pitching				
Defect	**Unit**	**Measurement**	**Severity**	**Remarks**
Distortion/ Surface deterioration				
Gullies				
Vegetation				

iv. Signalling

Road signs/ Lightings.				
Defects	**Unit**	**Measurement**	**Severity**	**Remarks**
Broken				
Corrosion				
Faulty Lightings				
Missing parts				

d) Other Structural Components

i. Road Surface/ Pavement/ Approach slab.

Defect	Unit	Measurement	Severity	Remarks
Cracking				
Surface deterioration				
Misalignment				
Potholes, Ruts				
Siltation				
Vegetation				

ii. Foundation

Defects	Unit	Measurement	Severity	Remarks
Sapping				
Scouring				
Burrowing				

iii. Bearing/Bearing devices

Defect	Unit	Measurement	Severity	Remarks
Siltation				
Broken				
Corrosion				
Cracking				
Deformation				
Misalignment				
Missing parts				
Unfixed parts				

iv. Expansion joint

Defect	Unit	Measurement	Severity	Remarks
Siltation				
Broken				
Corrosion				
Cracking				
Deformation				
Misalignment				
Missing parts				
Unfixed parts				
Moisture leaks				
Vegetation				

General Comments: ....

....

....

....

....

Inspector Name .... Supervisor Name ....

Signature .... Signature ....

Date .... Date ....

How to use the form.

For example, if a bridge has 2 piers and there are cracks on the column of pier P1. This defect is indicated in the table under principal structure-pier-column, choose the defect crack then specify the code provided below by ticking either **(A3)** or **(B7)** referring to Master damage catalogue. The Unit column in the table is where the inspector specifies the pier where the defect is as P1. After measuring the crack width, the inspector should put it in the Measurement column in the table. Severity of the damage to be captured in the severity column the remarks to be put in the remarks column. As inserted in red font.

A3- The defect code of cracking in concrete structures
P1- The pier affected by the defect
0.2mm- The width of the crack
Low- The severity of the defect is low

The remarks in red describe the nature of the defect further indicating the possible cause of the defect.

APPENDIX 4: PBC INSPECTION FORM

Basic Information

Structure Name		Inspection Date	
Road Name	123 Road	Chainage	00+100
Road Agency	KeNHA/KeRRA/KURA/KWS	Regional office	
Contractor	ABC		
Project Name	Performance Based Maintenance Contract for the Maintenance of 123 Road		
Structure Type	Bridge/Box Culvert/Footbridge	Superstructure Material	Concrete/Steel/Masonry/ Wooden
Structure Length	100 m	Structure Width	15 m

Inspection items

Inspection Item	Inspection Sub -Item	Time		Remarks	Photo
		Detection	Removal/ Notification		
Cleanliness	Pavement				
	Slab				
	Bridge Seat				
	Sidewalk				
	Beams				
	Drainage				
	Railings / Guardrails				
Vegetation overgrowth/control	Pavement				
	Bridge Seat				
	Sidewalk				
	Beams				
	Drainage				
Encroachment	Birds				
	Animals				
	Humans				
Vandalism	Railings/Guardrails				
	Signs				
	Lane Markers				
	Graffiti				
	Joints				
	Slope Protection				
	Structural Members				

Inspection Item	Inspection Sub -Item	Time		Remarks	Photo
		Detection	Removal/ Notification		
Damage to Members	Railings/Guardrails				
	Signs				
	Pavement			ex. Rutting, Cracks, Pothole, Damage on Expansion Joint and Kerb	
	Slab			ex. Cracks, Spalling, Rebar Exposure, Rusting, Honeycombs, Delamination	
	Superstructure			ex. Cracks, Spalling, Rebar Exposure, Corrosion, Honeycombs, Delamination, Paint Peel-off, Loose Bolts	
	Abutment			ex. Cracks, Spalling, Rebar Exposure, Corrosion, Honeycombs, Deformation, Settlement	
	Piers			ex. Cracks, Spalling, Rebar Exposure, Rusting, Honeycombs, Deformation, Settlement	
	Bearings			ex. Sedimentation, Corrosion, Functional Impairment, Slipping Out	
	Slope protection				
	Lighting				
	Expansion Joint				
	Foundations			ex. Scouring, Settlement, Exposure	

APPENDIX 5: ROUTINE INSPECTION FORM

Road Authority					
Project/Road					
Bridge Name		Chainage			
Road Class		Standard Service Level			
Bridge Classification		Bridge Type			
From		To			
Inspected By		Sign:		Date:	

Category	Element	Material	Deterioration	Severity	Indicator
Road surface	Pavement		Siltation	N	Not observed or very limited
				III	Special case
				II	Above 50 mm thickness, narrow carriageway and drainage facilities clogging
				I	Less 50mm thickness,partial loss of function of carriageway
			Crack	N	Not observed or very limited
				III	Arrigator cracks (partial with depression) reflectction from bridge slab deformation
				II	Arrigator cracks (local, without depression)
				I	Only partial linier cracks
			Potholes	N	Not observed or very limited
				III	Above 50% of pavement
				II	25-50% of pavement
				I	Below 25% of pavement

Category	Element	Material	Deterioration	Severity	Indicator
Road surface	Pavement		Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
	Bridge Railing/ Guardrail/Curb		Deformation	N	Not observed or very limited
				III	Completely deformed or removed and lost function completely
				II	Deformed and lost function partialy
				I	Partialy deformed but maintain function
			Faulty lighting	N	Not observed or very limited
				III	>50 % - if there is Accident Risk
				II	10-50%-if no accident Risk resulting from loss of Visibility
				I	< 10% -No accident Risk
			Missing parts	N	Not observed or very limited
				III	The part loss has a serious impact on the element's structural behavior.
				II	The missing has a moderate impact on the element's structural behavior.
				I	The missing part has a minor impact on the element's structural behavior.
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
	Expansion joints		Deformation	N	Not observed or very limited
				III	above 2cm and presence of structural instability
				II	displacement 1cm to 2cm
				I	displacement less 1cm
			Misalignment	N	Not observed or very limited
				III	Element has completely lost its functional properties
				II	Element loses part of its functional properties
				I	Element preserves its functional properties

Category	Element	Material	Deterioration	Severity	Indicator
Road surface	Expansion joints		Abnormal Spacing	N	Not observed or very limited
				III	Completely No space and unbalanced(too wide space on the other end)
				II	Spacing is maintained but abnormaly small or large
				I	Silted but spacing is properly maintained at both ends
			Abnormal Sound	N	Not observed or very limited
				III	Abnormal sound when vehicles pass on joints and effects to other elements
				II	Abnormal sound when vehicles pass on joints
				I	Small abnormal sound when vehicles pass on joints
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
	Drainage system		Clogging	N	Not observed or very limited
				III	Over 75% of structure's free section is blocked
				II	50% - 75% of structure's free section is blocked
				I	25% - 50% of structure's free section is blocked
			Broken	N	Not observed or very limited
				III	Few drinage systems are broken and necessary to exchange new drinage
				II	Few drinage systems are broken
				I	A drinage system is broken and easy repair
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function

Category	Element	Material	Deterioration	Severity	Indicator
Superstructure	Superstructure	Steel	Surface alteration	N	Not observed or very limited
				III	Abnormal alteration observed (special investigation proposed)
				II	The alteration has a functional impact and could cause an accident
				I	The alteration has only an esthetic impact
			Corrosion	N	Below 10% of the element's surface is affected
				III	The element's surface is entirely affected. There is section loss (over 20% of the thickness)
				II	Over 50% of the element surface is affected, with section loss (less than 20% of the thickness)
				I	Between 10% and 50% of the element's surface is affected
			Deformation	N	Not observed or very limited
				III	Clear deformation of entire components and hampers the proper functional or a serious accident.
				II	The deformation is noticeable at entire components of the structure and affecting other components.
				I	The partial deformation, sectional loss, lateral buckling observed.
			Crack	N	Not observed or very limited
				III	Identified cracks have extended to main components and may lead to breakage or collapse.
				II	Identified cracks have extended to main components further propagation leads to depression and pavement damage.
				I	Cracks are identified in elements but are unlikely to reach the main components immediately.
			Missing parts	N	Not observed or very limited
				III	The part loss has a serious impact on the element's structural behavior.
				II	The missing has a moderate impact on the element's structural behavior.
				I	The missing part has a minor impact on the element's structural behavior.
			Missing screws, rivets, anchors	N	Not observed or very limited
				III	The bolts are missing/broken or the support function is deteriorated
				II	The bolts are missing/broken
				I	Bolts are loosening

Category	Element	Material	Deterioration	Severity	Indicator
Superstructure	Superstructure	Steel	Rupture	N	Not observed or very limited
				III	Rupture has occurred in critical components which may impair the function of the bridge.
				II	The rupture has occourred in components with significant effect on the load bearing capacity of the structure.
				I	The rupture has occurred in components that have little effect on the load bearing capacity of the structure.
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
Superstructure	Superstructure	Concrete	Honeycomb	N	Not observed or very limited
				III	<25mm deep without Reinf. Expossure (>50% surface)
				II	0-5mm deep (<50% of surface)
				I	Partially observed
			Spalling	N	Not observed or very limited
				III	The spalling depth is over 100mm and wide area
				II	Partially depth is over 100 mm.
				I	Partially depth is between 10 and 100 mm.
			Spalling concrete showing reinforcing bars	N	Not observed or very limited
				III	The spalling observed of components and corrosion/rupture of reinforcing bars widely.
				II	The spalling observed of components and corrosion of reinforcing bars limited.
				I	The spalling observed partially and limited to find no corrosion of reinforcing bars.
			Crack	N	Not observed or very limited and crack width less than 0.4 mm
				III	Serious impact on the structural behavior or cracks with a width more than 2.0mm
				II	Fissures with structural impact and crack width less than 0.4mm, or cracks with a width more than 1.0mm
				I	Fissures with structural impact and crack width less than 0.4mm, or cracks with a width between 0.4-1.0mm

Category	Element	Material	Deterioration	Severity	Indicator
Superstructure	Superstructure	Concrete	Precipitate (Freelime, Rust fluid)	N	Not observed or very limited
				III	The deterioration extent is over 50% of the element surface or there are other associated moderate or high severity deteriorations
				II	The deterioration extent is below 50% of the element surface or there are not any associated moderate or high severity deteriorations
				I	Partially observed.
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
		Other (masonry, Wooden)	Corrosion	N	Below 10% of the element's surface is affected
				III	The element's surface is entirely affected. There is section loss (over 20% of the thickness)
				II	Over 50% of the element surface is affected, with section loss (less than 20% of the thickness)
				I	Between 10% and 50% of the element's surface is affected
			Deformation	N	Not observed or very limited
				III	Clear deformation of entire components and hampers the proper functional or a serious accident.
				II	The deformation is noticeable at entire components of the structure and affecting to other components.
				I	The partial deformation, sectional loss, lateral buckling observed.
			Misalignment	N	Not observed or very limited
				III	Element has completely lost its functional properties
				II	Element loses part of its functional properties. Found abnormal behavior.
				I	Element loses part of its functional properties. Not found abnormal behavior.

Category	Element	Material	Deterioration	Severity	Indicator
Superstructure	Superstructure	Other (masonry, Wooden)	Crack	N	Not observed or very limited and crack width less than 0.4mm
				III	Serious impact on the structural behavior or cracks with a width more than 2.0mm
				II	Fissures with structural impact and crack width less than 0.4mm, or cracks with a width more than 1.0mm
				I	Fissures with structural impact and crack width less than 0.4mm, or cracks with a width between 0.4-1.0mm
			Missing parts	N	Not observed or very limited
				III	Relative movements between parts have been detected and there are loose parts with a falling risk.
				II	All mortar joint is missing
				I	Partial loss of the mortar joint
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
	Slab	Steel	Corrosion	N	Below 10% of the element's surface is affected
				III	The element's surface is entirely affected. There is section loss (over 20% of the thickness)
				II	Over 50% of the element surface is affected, with section loss (less than 20% of the thickness)
				I	Between 10% and 50% of the element's surface is affected
			Deformation	N	Not observed or very limited
				III	Deformation very noticeable and severe consequences on structural/ functional behavior.
				II	Deformation noticeable and consequences on structural/functional behavior.
				I	Deformation noticeable (above 1mm)

Category	Element	Material	Deterioration	Severity	Indicator
Superstructure	Slab	Steel	Crack	N	Not observed or very limited
				III	Identified cracks have extended to main components and may lead to breakage or collapse.
				II	Identified cracks have extended to main components further propagation leads to depression and pavement damage.
				I	Cracks are identified in elements but are unlikely to reach the main components immediately.
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
	Slab	Concrete	Honeycomb	N	Not observed or very limited
				III	<25mm deep without Reinf. Expossure (>50% surface)
				II	0-5mm deep (<50% of surface)
				I	Partially observed
			Deformation (leaning)	N	Not observed or very limited
				III	Deformation of slab is observed clearly
				II	Suspected deformation of slab is observed
				I	Non-active process without consequence on structural and functional properties, deformation of slab is hardly detectable visually < 10 mm
			Spalling	N	Not observed or very limited
				III	The spalling depth is over 100 mm and wide area
				II	Partially depth is over 100 mm.
				I	Partially depth is between 10 and 100 mm.
			Spalling concrete showing reinforcing bars	N	Not observed or very limited
				III	The spalling observed of components and corrosion/rupture of reinforcing bars widely.
				II	The spalling observed of components and corrosion of reinforcing bars limited.
				I	The spalling observed partially and limited to find no corrosion of reinforcing bars.

Category	Element	Material	Deterioration	Severity	Indicator
Superstructure	Slab	Concrete	Crack	N	Not observed or very limited and crack width less than 0.2mm
				III	Cracks more than 0.3 mm wide with intervals of less than 30cm in biaxial direction togher with water leakage, free lime
				II	Cracks within 0.2-0.3 mm width in a uniaxial direction with water leakage
				I	Cracks are within 0.2 mm with no indication of water leakage.
			Precipitate (Freelime, Rust fluid)	N	Not observed or very limited
				III	The deterioration extent is over 50% of the element surface or there are other associated moderate or high severity deteriorations
				II	The deterioration extent is below 50% of the element surface or there are not any associated moderate or high severity deteriorations
				I	Partially observed.
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
		Slab (Wooden)	Corrosion-Rotting	N	Below 10% of the element's surface is affected
				III	The element's surface is entirely affected. There is section loss (over 20% of the thickness)
				II	Over 50% of the element surface is affected, with section loss (less than 20% of the thickness)
				I	Between 10% and 50% of the element's surface is affected
			Deformation	N	Not observed or very limited
				III	Relative movements between parts have been detected and there are loose parts with a falling risk that may cause a serious accident.
				II	All mortar joint is missing
				I	Partial mortar joint is missing

Category	Element	Material	Deterioration	Severity	Indicator
Superstructure	Slab	Others	Crack	N	Not observed or very limited
				III	Serious crack and water leakage, concrete falls off due to the action of wheel load
				II	Latticed crack and water leakage
				I	Crack limited of the part or water leakage from penetrated crack
			Missing parts	N	Not observed or very limited
				III	The part loss has a serious impact on the element's structural behavior.
				II	The missing has a moderate impact on the element's structural behavior.
				I	The missing part has a minor impact on the element's structural behavior.
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
Sub-structure	Abutment	Concrete	Honeycomb	N	Not observed or very limited
				III	<25mm deep without Reinf. Expossure (>50% surface)
				II	0-5mm deep (<50% of surface)
				I	Partially observed
			Deformation (Leaning)	N	Not observed or very limited
				III	Leaning of abutment is observed clearly
				II	Suspected leaning of abutment observed.
				I	Non-active process without consequence on structural & functional properties. Leaning of abutment is hardly detectable visually <10mm
			Spalling	N	Not observed or very limited
				III	The spalling depth is over 100mm and wide area
				II	Spalling depth is over 100 mm.
				I	Spalling depth is between 10 and 100 mm.

Category	Element	Material	Deterioration	Severity	Indicator
Sub-structure	Abutment	Concrete	Spalling concrete showing reinforcing bars	N	Not observed or very limited
				III	The spalling observed of components and corrosion/rupture of reinforcing bars widely.
				II	The spalling observed of components and corrosion of reinforcing bars limited.
				I	The spalling observed partially and limited to find no corrosion of reinforcing bars.
			Crack	N	Not observed or very limited and longitudinal crack width less than 0.4mm
				III	Serious crack and water leakage, concrete falls off due to the action
				II	Longitudinal/transvere crack width more than 1.0mm, or latticed crack with water leakage/freelime
				I	Longitudinal/transvere crack width between 0.4-1.0mm, or crack limited
			Subsidence	N	Not observed or very limited
				III	Any subsidence observed and serious damage
				II	Any subsidence observed and damage
				I	Any subsidence observed and damage limited
			Scouring	N	Not observed or very limited
				III	Embankment/river banks/bed errosion (>50% surface) in contact with risk to structural element stability
				II	Embankment/river banks/bed errosion (25%-50% surface) in contact with structural element with impact on stability
				I	Embankment/river banks/bed errosion (>25% surface) in contact with wingwalls and foundation
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
		Other (Masonry, Wooden, others)	Corrosion	N	Below 10% of the element's surface is affected
				III	The element's surface is entirely affected. There is section loss (over 20% of the thickness)
				II	Over 50% of the element surface is affected, with section loss (less than 20% of the thickness)
				I	Between 10% and 50% of the element's surface is affected

Category	Element	Material	Deterioration	Severity	Indicator
Sub-structure	Abutment	Other (Masonry, Wooden, others)	Deformation (leaning)	N	Not observed or very limited
				III	damage level 4 is not allowed since it may result to failure
				II	1% and above of the element's magnitude is affected
				I	0.10%-1% of the element's magnitude is affected
			Crack	N	Not observed or very limited and longitudinal crack width less than 0.4mm
				III	Serious crack and water leakage, concrete falls off due to the action
				II	Longitudinal/transvere crack width more than 1.0mm, or latticed crack with water leakage/freelime
				I	Longitudinal/transvere crack width between 0.4-1.0mm, or crack limited
			Subsidence	N	Not observed or very limited
				III	Any subsidence observed and serious damage
				II	Any subsidence observed and damage
				I	Any subsidence observed and damage limited
			Scouring	N	Not observed or very limited
				III	Embankment/river banks/bed errosion (>50% surface) in contact with risk to structural element stability
				II	Embankment/river banks/bed errosion (25%-50% surface) in contact with structural element with impact on stability
				I	Embankment/river banks/bed errosion (>25% surface) in contact with wingwalls and foundation
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
	Wing wall	Concrete	Honeycomb	N	Not observed or very limited
				III	<25mm deep without Reinf. Expossure (>50% surface)
				II	0-5mm deep (<50% of surface)
				I	Partially observed

Category	Element	Material	Deterioration	Severity	Indicator
Sub-structure	Wing wall	Concrete	Deformation	N	Not observed or very limited
				III	Deformation hampers functional/structural properties and results in serious accidents
				II	Active process with consequence on structural & functional properties, detectable visually, deformation >1% of abutment length, >5mm/m buckling
				I	Non-active process without consequence on structural & functional properties, hardly detectable visually <10mm
			Spalling	N	Not observed or very limited
				III	The spalling depth is over 100mm and wide area
				II	Spalling depth is over 100 mm.
				I	Spalling depth is between 10 and 100 mm.
			Spalling concrete showing reinforcing bars	N	Not observed or very limited
				III	The spalling observed of components and corrosion/rupture of reinforcing bars widely.
				II	The spalling observed of components and corrosion of reinforcing bars limited.
				I	The spalling observed partially and limited to find no corrosion of reinforcing bars.
			Crack	N	Not observed or very limited and longitudinal crack width less than 0.4mm
				III	Serious crack and water leakage, concrete falls off due to the action
				II	Longitudinal/transvere crack width more than 1.0mm, or latticed crack with water leakage/freelime
				I	Longitudinal/transvere crack width between 0.4-1.0mm, or crack limited
			Subsidence	N	Not observed or very limited
				III	Any subsidence observed and serious damage
				II	Any subsidence observed and damage
				I	Any subsidence observed and damage limited
			Scouring	N	Not observed or very limited
				III	Embankment/river banks/bed errosion (>50% surface) in contact with risk to structural element stability
				II	Embankment/river banks/bed errosion (25%-50% surface) in contact with structural element with impact on stability
				I	Embankment/river banks/bed errosion (>25% surface) in contact with wingwalls and foundation

Category	Element	Material	Deterioration	Severity	Indicator
Sub-structure	Wing wall	Concrete	Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
		(Other (Masonry, Wooden, Others))	Corrosion	N	Below 10% of the element's surface is affected
				III	The element's surface is entirely affected. There is section loss (over 20% of the thickness)
				II	Over 50% of the element surface is affected, with section loss (less than 20% of the thickness)
				I	Between 10% and 50% of the element's surface is affected
			Deformation (leaning)	N	Not observed or very limited
				III	Deformation hampers functional/structural properties and results in serious accidents
				II	Active process with consequence on structural & functional properties, detectable visually, deformation >1% of abutment length, >5mm/m buckling
				I	Non-active process without consequence on structural & functional properties, hardly detectable visually <10mm
			Crack	N	Not observed or very limited and longitudinal crack width less than 0.4mm
				III	Serious crack and water leakage, concrete falls off due to the action
				II	Longitudinal/transvere crack width more than 1.0mm, or latticed crack with water leakage/freelime
				I	Longitudinal/transvere crack width between 0.4-1.0mm, or crack limited
			Subsidence	N	Not observed or very limited
				III	Any subsedence observed and serious damage
				II	Any subsedence observed and damage
				I	Any subsedence observed and damage limited
			Scouring	N	Not observed or very limited
				III	Embankment/river banks/bed errosion (>50% surface) in contact with risk to structural element stability
				II	Embankment/river banks/bed errosion (25%-50% surface) in contact with structural element with impact on stability
				I	Embankment/river banks/bed errosion (>25% surface) in contact with wingwalls and foundation

Category	Element	Material	Deterioration	Severity	Indicator
Sub-structure	Wing wall	(Other (Masonry, Wooden, Others))	Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
Sub-structure	Pier	Concrete	Honeycomb	N	Not observed or very limited
				III	<25mm deep without Reinf. Expossure (>50% surface)
				II	0-5mm deep (<50% of surface)
				I	Partially observed
			Deformation (leaning)	N	Not observed or very limited
				III	Deformation hampers functional/structural properties and results in serious accidents
				II	Active process with consequence on structural & functional properties, detectable visually, deformation >1% of abutment length, >5mm/m buckling
				I	Non-active process without consequence on structural & functional properties, hardly detectable visually <10mm
			Spalling	N	Not observed or very limited
				III	The spalling depth is over 100mm and wide area
				II	Partially depth is over 100 mm.
				I	Partially depth is between 10 and 100 mm.
			Spalling concrete showing reinforcing bars	N	Not observed or very limited
				III	The spalling observed of components and corrosion/rupture of reinforcing bars widely.
				II	The spalling observed of components and corrosion of reinforcing bars limited.
				I	The spalling observed partially and limited to find no corrosion of reinforcing bars.
			Crack	N	Not observed or very limited and longitudinal crack width less than 0.4mm
				III	Serious crack and water leakage, concrete falls off due to the action
				II	Longitudinal/transvere crack width more than 1.0mm, or latticed crack with water leakage/freelime
				I	Longitudinal/transvere crack width between 0.4-1.0mm, or crack limited

Category	Element	Material	Deterioration	Severity	Indicator
Sub-structure	Pier	Conrete	Subsidence	N	Not observed or very limited
				III	Any subsedence observed and serious damage
				II	Any subsedence observed and damage
				I	Any subsedence observed and damage limited
			Scouring	N	Not observed or very limited
				III	Embankment/river banks/bed errosion (>50% surface) in contact with risk to structural element stability
				II	Embankment/river banks/bed errosion (25%-50% surface) in contact with structural element with impact on stability
				I	Embankment/river banks/bed errosion (>25% surface) in contact with wingwalls and foundation
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
		(Other (Masonry, Wooden, others))	Corrosion	N	Below 10% of the element's surface is affected
				III	The element's surface is entirely affected. There is section loss (over 20% of the thickness)
				II	Over 50% of the element surface is affected, with section loss (less than 20% of the thickness)
				I	Between 10% and 50% of the element's surface is affected
			Deformation	N	Not observed or very limited
				III	Damage level 4 is not allowed since it may result to failure
				II	1% and above of the element's magnitude is affected
				I	0.10%-1% of the element's magnitude is affected

Category	Element	Material	Deterioration	Severity	Indicator
Sub-structure	Pier	(Other (Masonry, Wooden, others))	Crack	N	Not observed or very limited and longitudinal crack width less than 0.4mm
				III	Serious crack and water leakage, concrete falls off due to the action
				II	Longitudinal/transvere crack width more than 1.0mm, or latticed crack with water leakage/freelime
				I	Longitudinal/transvere crack width between 0.4-1.0mm, or crack limited
			Subsidence	N	Not observed or very limited
				III	Any subsedence observed and serious damage
				II	Any subsedence observed and damage
				I	Any subsedence observed and damage limited
			Scouring	N	Not observed or very limited
				III	Embankment/river banks/bed errosion (>50% surface) in contact with risk to structural element stability
				II	Embankment/river banks/bed errosion (25%-50% surface) in contact with structural element with impact on stability
				I	Embankment/river banks/bed errosion (>25% surface) in contact with wingwalls and foundation
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
Bearing	Bearing	Main body (Steel)	Corrosion	N	Not observed or very limited
				III	The bearing and its attachment, the girder ends may collapse
				II	Significant corrosion with a decrease in plate thickness is progressing
				I	Corrosion is found in the bearing body, the bearing functions is reducted
			Deformation	N	Not observed or very limited
				III	The bearing body seriously damaged
				II	The bearing body damaged
				I	The paint on the bearing has deteriorated, and the pedestal concrete is spalling.

Category	Element	Material	Deterioration	Severity	Indicator
Bearing	Bearing	Main body (Steel)	Missing parts	N	Not observed or very limited
				III	The mounting bolt of the bearing is missed/broken or the support function is deteriorated
				II	The mounting bolt of the bearing is missed/broken
				I	Bolts are loosening.
			Rupture	N	Not observed or very limited
				III	Deformation/ mising parts found
				II	NA
				I	NA
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
		Main body (Rubber)	Crack	N	Not observed or very limited
				III	NA
				II	The rubber bearing body has noticeable cracks
				I	NA
			Deformation	N	Not observed or very limited
				III	The bearing body seriously damaged
				II	The bearing body damaged
				I	The paint on the bearing has deteriorated, and the pedestal concrete is spalling.
			Rubber breaks	N	Not observed or very limited
				III	Over 50% loss of surface has occurred preventing the structural behavoiur of the element
				II	Over 50% surface affected with over 20% loss of section or when 50% of the sonsidered area is affected but the elements structural behavoiur is not hampered
				I	10-50% percentage of sufrace affected with no loss of section found

Category	Element	Material	Deterioration	Severity	Indicator
Bearing	Bearing	Main body (Steel)	Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
	Around bearing		Corrosion	N	Not observed or very limited
				III	The element's surface is entirely affected. There is section loss (over 20% of the thickness)
				II	Over 50% of the element surface is affected, with section loss (less than 20% of the thickness)
				I	The base concret to be chipped
			Deformation	N	Not observed or very limited
				III	The bearing body seriously damaged
				II	The bearing body damaged
				I	The paint on the bearing has deteriorated, and the pedestal concrete is spalling.
			Stagnant Water	N	Not observed or very limited
				III	Always wet condition at bearing, water mark (penetrating surrounding area)
				II	Wet debris (entire location)
				I	parially water stagnant or observe mark of water stagnant. Soil or debris
			Sedimentation	N	Not observed or very limited
				III	Fully sedimented and wet
				II	Fully sedimented
				I	Sedimentation partial
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function

Category	Element	Material	Deterioration	Severity	Indicator
Embankments			Scouring	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
			Slope failure	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function
			Others	N	Not observed or very limited
				III	Urgent action
				II	Mid-term action
				I	Partialy damaged but maintain function

APPENDIX 6: SAMPLE RESULT SHEET FOR EMERGENCY INSPECTION

Name		**Inspection Date**	
Code		**Abnormal event type**	
Road		**Degree of anomalous event**	
Location		**Technical Investigator**	

Elements	**Members**	**Damage Condition**	**Flag Indicator**		**Photo File**
			existence	**nonexistence**	
A whole bridge		The bridge is collapsing		☑	
Superstructure	Main Girder/Slab	The bridge is damaged.(deformationn, crack)		☑	
Substructure	Wall/Foundation	The bridge is damaged.(settlement, movement, inclination, scouring, crack)		☑	
Bearings	Body/Bridge Seat	The bridge is damaged.(falling, destruction)		☑	
Road condition	Road surface	There are significant bumps on the road.		☑	
		Abnormal sound or vibration is occurring.		☑	
	Curb/Pavement	Significantly damaged.		☑	
	Expansion Joint	Gap is wide open.	☑		001.jpg
		Expansion Joint is badly damaged.	☑		002.jpg
	Railing/Barrier	Dangerous damage or deformation to road traffice users.		☑	
Other elements	Drainage	Badly damaged. Or water is accumulated on the bridge surface and overflows.		☑	
	Inspection facilities, Attachments, Retaining walls	Badly damaged.	☑		003.jpg
	others	Considered dangerous damage for traffice users.		☑	
Comprehensive evaluation		Neccesity for urgent measures	☑		
Points to note					