BRIDGE INSPECTION HANDBOOK

EDITION 1

THE PROJECT FOR STRENGTHENING OF CAPACITY DEVELOPMENT ON BRIDGE MANAGEMENT SYSTEM IN THE REPUBLIC OF KENYA

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

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Edition 1

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DOCUMENT MANAGEMENT

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The content of the handbook is based on current practice in Kenya and latest practices in the road sector – locally, regionally and internationally.

Notification of errors and requests for amendments:

While all care and consideration has been applied in the compilation of this document, the Ministry accepts no responsibility for failure in any way related to the application of this manual or any reference documents cited in it.

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Request No.	Name	Organization	Chapter	Page	Section/ Clause	Ref. to: Figure/ Table	Type of request:	Request

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ABBREVIATIONS AND ACRONYMS

ASR	Alkali Silica Reaction
DSD	Double Surface Dressing
EDM	Electronic Distance Measurement (tool)
PC	Pre-Streessed Concrete
RC	Reinforced Conreate
SSD	Single Surface Dressing

1. INTRODUCTION

1.1 Background

Bridges are an important element of the road network. The road network should be looked at holistically considering the pavement, the alignment, drainage systems and bridges, road function and social-environmental aspects of the region being served by the road.

It is in these considerations that there is a need to strengthen the inspection and maintenance of the available bridges on our road network. Bridges can be the weakest link of the road network thus the need for emphasis on the importance of condition monitoring and evaluation and mainstreaming them into maintenance programs.

As new bridges are being built and old ones improved/replaced, inspections are carried out continuously and properly referenced to the particular bridge to ensure that the bridge inventory is kept up-to-date.

Currently, due to climate change, global warming and change of land use, some of the bridges are likely to be overtopped during the wet seasons thus disrupting socio-economic activities that facilitate economic growth. Systematic and continuous data collection, collation, analysis and reporting of the condition and functionality of the bridge is key to inform maintenance, improvement and/or replacement, if need be.

In recent years, many bridges have been damaged due to age, overloading and effects of flooding and inadequate maintenance thus increased need for regular inspection and maintenance.

For a sustainable management of the road and associated bridges, it is important to conduct routine inspection to ascertain the condition through simple visual inspection.

This handbook is therefore designed to be an aid for bridge inspectors, including those who possess basic qualification but are yet to be directly involved in bridge maintenance, when conducting visual inspections of bridges.

1.2 Scope of the Handbook

This handbook shall be used as an onsite guide to bridge inspections for the purpose of continuous updating of bridge inventory and condition status and monitoring of maintenance performance. The guide shall be applicable to 1) Principal, 2) Periodic, 3) Routine and 4) Emergency inspections.

1.3 Safety Precautions and Preparation for Bridge Inspection

1.3.1 Preparation for Bridge Inspection

- Notification and consultation of relevant authorities on the planned inspection
- Documents required
  - All the available inspection results and this handbook.
- Tools and equipment requirement

For a safe and reliable inspection ensure to bring the following:

- Helmets, safety goggles, safety belts, safety shoes, gloves, reflective cones/tapes, first aid kit, reflector jackets, ladder, umbrella, rain coat, wire brush and oxygen cans.
- Inspection hammers, measuring tool e.g., crack gauge, tape measure, EDM.
- Binoculars, camera, pole camera, flashlights, head lamp, mask (if required).
- Smart phone with functional inspection application

Note: When performing routine/daily inspections, keenly refer to the results of the previous bridge inspection to check the progress of any defect that might lead to a serious structural damage.

For more information refer to section 5.3 of the *Inspection Manual for Bridges* and Section 1.9 of the *Bridge Inspection Manual for ARBICS and PBC*.

1.3.2 Safety Precautions

Inspection in the box girder

- Be careful of heat stroke inside the box girder during the warm seasons.

- Exercise caution (if possible, measure the oxygen concentration) to avoid oxygen deficiency occurrence; open the manhole (maintenance hole) and wait for a minimum of 15 minutes before entering the box girder.

Inspection using an inspection path

- Check the corrosion condition of the inspection path.
- If corrosion of the inspection path is confirmed, take appropriate measures such as prohibiting access.

Corrosion of inspection paths

Inspection over the bridge

- Ensure clear signage are in place to warn approaching traffic.
- Avoid prolonged standing on/or too close to the carriageway
- Station traffic police/marshals to control traffic during inspection

Inspection under the bridge

Check out for:

- Any loose/detached/falling objects
- River flow levels, presence of harmful insects and animals
- Abnormal sound and/or vibrations
- And avoid wet slippery surfaces.

Bridge environment

- Establish the existence of service utilities that may compromise safety
- Check out on the prevailing weather condition upstream of the bridge.

2. FLOW OF INSPECTION

On-site inspections are carried out in the order of: Inspection of the road surface → side inspection → under the bridge inspection.

Refer to *Inspection Manual for Bridges*, Section 4.1.3 Performing Inspection, for details.

1. Inspection on the road surface
   - Check for damage that may interfere with traffic.
   - Check the alignment of the bridge to see if it is uneven.

2. Inspection from the side
   - Check the profile of the bridge.
   - Check if there is settlement of the piers/abutments and/or the misalignment of the main girder.

3. Inspection from under the bridge
   - Check the damage status (condition) of the bridge members visible from under the bridge.

Note: Should you find any damage that requires further detailed inspection, contact the relevant Department.

2.1 Checkpoints for Inspection on the Road Surface

Inspect the bridge in general from the road surface.

2.1.1 Road/Bridge Furniture (Railings, Protective Fences, Signs, Lighting, etc.)

- Is any furniture damaged by being knocked by vehicles/ vandalism?
- Are there any corrosion at the base of poles/signs and lighting lamps or any abnormal vibration?
- Are there any parts that might be dangerous for road users?

2.1.2 Road Surface (Surfacing)

- Are there any potholes, rutting, or large dents?
- Are there alligator cracks?
- Are there any large cracks in the direction of the bridge axis (longitudinal direction) or in the direction perpendicular to the bridge axis (transverse direction)?

Alligator Cracks

Pothole

Important points!

- Structural damage may be the cause if potholes or cracks occur repeatedly on the surfacing.
- Check the positional relationship between the damaged position of the underside of the deck and the damaged part of the surfacing.

2.1.3 Road Surface (Expansion Device [Expansion Joint])

- Is there any level difference or abnormal gap?
- Is it broken?
- Are there sediments blocking the joint movement?

[Example]

Joint gap

Warm season: Small gap
Cold season: Large gap

Level difference/abnormal gap

Breakage

Important points!

- Damage to the expansion joint may occur due to damage of the bearing or shoe seat, movement of the substructure, etc.

  If there is a level difference, you have to check the bearings and substructure while under the structure.

- Sediment accumulates in the clearance width of the joint over time as a result of siltation caused by moving vehicles thereby hindering the expansion and contraction of the joint.

  Remove the sediments, which may cause damage to the joint.

2.1.4 Drainage Facilities

- Are there any clogged drainage facilities?

Drainage function deterioration may cause water stagnation, vegetation growth etc. The sediment should be removed and cleaned to restore the drainage function.

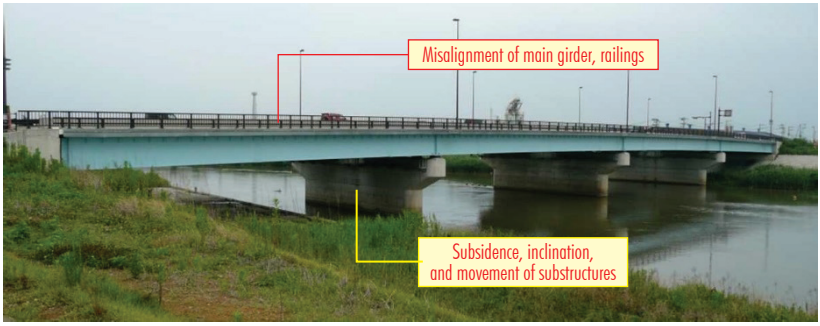
2.1.5 Abnormal Sound/Vibration

- Are there any abnormal sounds or excessive vibrations when vehicles pass over the bridge? This may be as a result of defects on girders, hence, further inspection of the members is recommended.

2.2 Check Points for Side Inspections

2.2.1 Bridge Profile

- Is there any misalignment of the main girder?
- Are there any problems with the alignment of the railings and kerb?
- Are there any subsidence, inclination, or movement of the substructure?



Look at the entire bridge to see if there is any misalignment

2.2.2 Drainage facility

- Is the drainage facility clogged, damaged or vandalized?
- Are there any large water leakage marks on the piers and abutments?

	
Damage to drains	Water leakage at the abutment

Important points!

- If there is water leakage, damage may have occurred on the support bearings, girder ends, expansion joints etc.
- It is necessary to check the cause of the water leakage, such as the condition of the water proof function from the expansion joint.

2.3 Checkpoints for Under the Bridge Inspections

2.3.1 Bearing Part

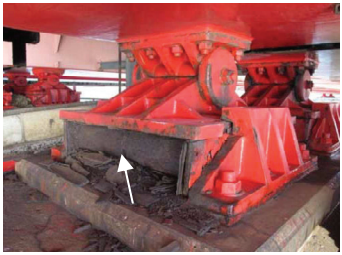
Bearing seat	◆ Is the defect on the mortar progressing? ◆ Are the cracks in the vicinity of the shoe seat progressing? ◆ Is there any siltation occurring around the seat?
Anchor bolt Set bolt	◆ Is there any looseness, falling off, or rupture? ◆ Is corrosion occurring?

Bearing body	◆ Is the side block roller defective? ◆ Is there any subsidence, movement, or inclination? ◆ Is corrosion occurring?
Amount of movement	◆ Is abnormal movement or rotation occurring?

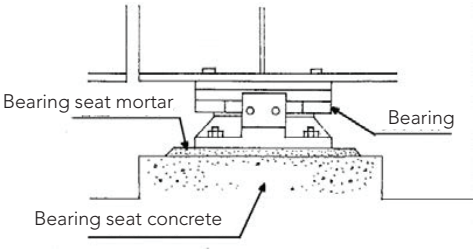
Damage to bearing seat mortar

Corrosion of bearing

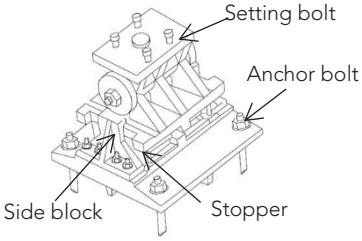
Abnormal movement

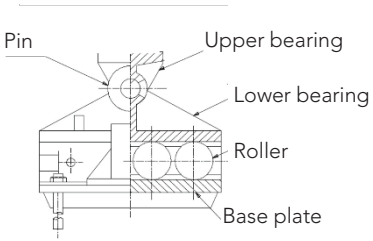


Corrosion of rollers



[Reference] Bearing structure





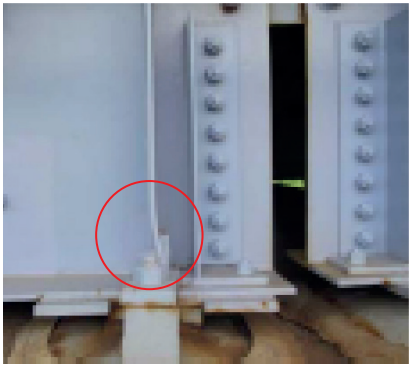
Steel bearing (Pin roller bearing)

Important points!
• Corrosion may cause malfunctioning by restricting the rotation and movement of bearings, which may cause cracks in the main girder. • Movable bearings can be marked with chalk to check if the bearings are moving. • Siltation may cause water stagnation that leads to corrosion of bearings

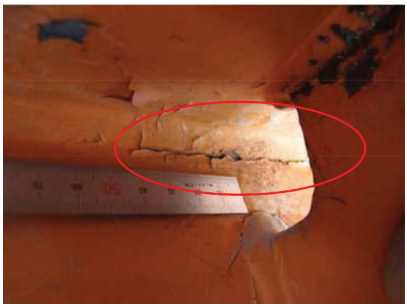
2.3.2 Steel Bridge (Plate Girder)

Girder end	• Is corrosion occurring/progressing?
Support point	• Is corrosion occurring/progressing? • Are there any paint film cracks or cracks in the sole plate weld? • Is there any deformation of the stiffener?
Cross beam and cross frame	• Are there any paint film cracks or cracks in the gusset weld? • Are there any paint film cracks or cracks at the top end of the stiffener? • Is there any deformation occurring?
Splice	• Is corrosion occurring/progressing? • Are there any loose or missing bolts?
Notch	• Are there any cracks in the coating film at the notch R?
Bolts	• Are there any loose, deformed, fractured or missing bolts?

Corrosion of girder edge

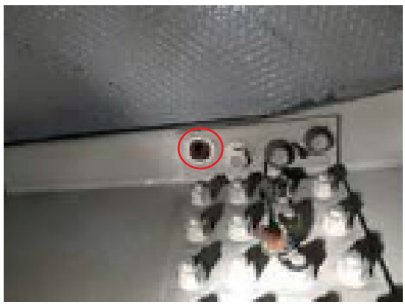


Deformation of the vertical stiffener

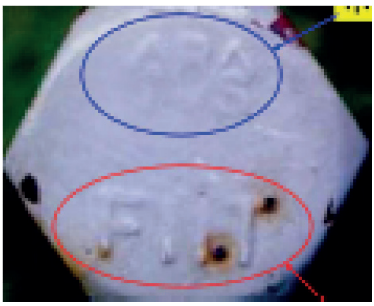


Crack at the upper end of the main girder web

Cracking of paint film on sole plate



Falling off of high-strength bolts



Bolt manufacturer's mark F11T
and stamping

Important points!

1. Corrosion of girder edge

   At the edge of the girder, corrosion is likely to occur due to water leakage from the expansion and contraction device, and cracks may occur due to the functional failure of the bearing.

2. Severe crack

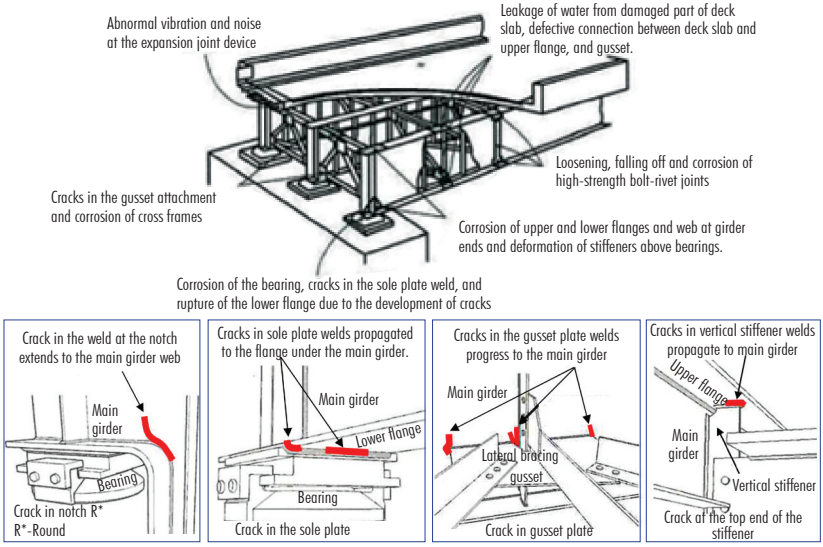
   Cracks on the main girder web flange and the fulcrum or sole plate. These cracks may impair structural safety and require emergency measures.

3. Delayed fracture of high strength bolts (F11T)

   The high-strength bolts may come loose or fall off due to delayed fracture. It is necessary to pay attention to the possibility of third-party damage as a result of the falling bolts, etc.

※ The standard of the bolt is stamped on the bolt head.

[Example] Damage Location Diagram <steel bridge beam>

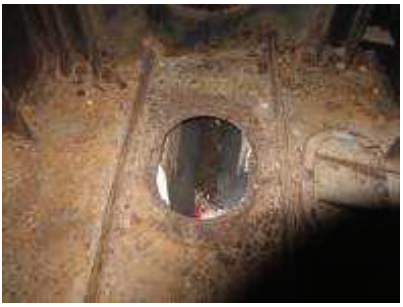


2.3.3 Steel Bridge (Box Girder)

Girder end	◆ Is corrosion progressing?
Fulcrum	◆ Is corrosion progressing? ◆ Are there any paint film cracks or cracks at the sole plate weld?
Cross beam	◆ Are there any paint film cracks or cracks on the web plate at the edge of the cross beam?
Splice	◆ Is corrosion progressing? ◆ Are there any loose or missing bolts?
Notch	◆ Are there any cracks on the coating film at the notch R?
Inside box girder	◆ Are there any cracks on the coating film? ◆ Is there stagnant water?

Longitudinal rib crack

Stagnant water inside the box girder



Corrosion inside the box girder

Others (bird's manure deposits)

When working inside the box girder, pay careful attention to the measures against oxygen deficiency. Open the manhole and wait for a while before entering the box girder.

Important points!

1. Water stagnation in box girder

   Stagnant water inside the box girder cannot be drained easily.

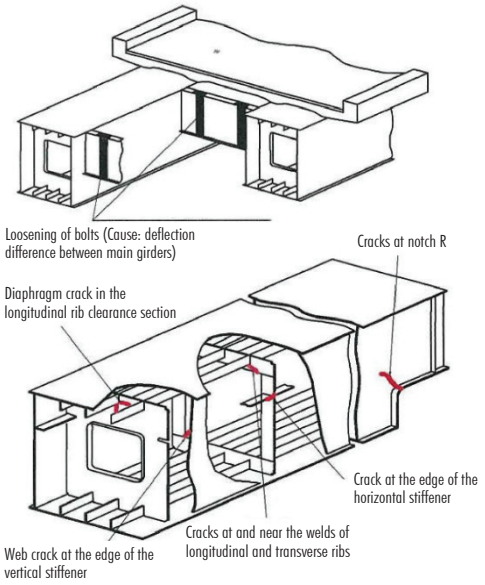
   You should check where the water is flowing from.

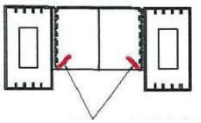
   Openings of diaphragms, attachments, etc.
   Clearance between manhole door, splice, etc.

2. Cracking, corrosion, etc.

   Special attention must be taken to check for cracks, corrosion, falling off of high-strength bolts, etc.

[Example] Damage Location Diagram <Steel Bridge Box Girder>





2.3.4 Steel Bridge (RC Deck)

Deck slab bottom surface	◆ Has spalling, peeling, or exposure to reinforcing bars progressed? ◆ are there cracks and/ or are they progressing? ◆ Is the direction of the crack uni-directional or bi-directional? ◆ Is there any leakage of water, free lime or rust juice from cracks?
Bonding part of the steel plate	◆ Is there corrosion of the steel plate and/ or is it progressing? ◆ Is the steel plate detaching? ◆ Have the sealant and anchor bolts dropped off?

Floor cracks (Uni-directional)

Floor cracks (Bi-directional)

Cracks with falling edges

Loosing of steel sheet adhesion

[Reference: Crack width of floor slab and degree of damage]

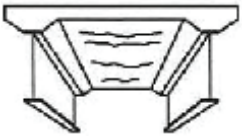
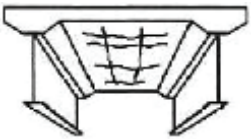
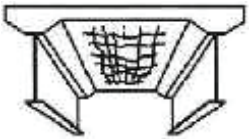
Care should be taken for cracks in the following values*.

- Crack width: Continuous edge falling at 0.2 mm or more
- Crack interval: 0.2 m or less, bi-directional or alligator shape.

Important points!

1. Relationship with damaged part of surfacing
   The deck slab may be damaged if potholes or cracks occur repeatedly on the surface.
2. Crack with water leakage
   If the *bi-directional* crack is accompanied by water leakage, special care must be taken as the damage can progress rapidly.

[Example] Damage Progress of Concrete Deck

Damage progress stage	
Stage 1 Cracks due to drying shrinkage may occur and develop multi-transverse parallel cracks (uni-directional) on the deck.	
Stage 2 Cracks caused by wheel loads may occur both in the longitudinal and transverse directions (bi-directional), and develop into grids.	
Stage 3 Stage in which bending moment cracks may be generated from the bottom surface penetrate to the upper surface due to repeated wheel loads.	
Stage 4 The stage where penetrating crack surfaces are worn and smoothed by a sliding-and-abrasion action and loses shear resistance.	

Stage 5 Stage where slippage occurs due to wheel load exceeding the reduced punching shear strength.	

2.3.5 Reinforced Concrete Bridge (RC Bridge)

T-girder	◆ Are there cracks and/ or are they progressing? ◆ Has spalling, peeling, or exposure to reinforcing bars occurred or progressed?
Deck bridge	◆ Are there cracks and/ or are they progressing? ◆ Has spalling, peeling, or exposure to reinforcing bars occurred or progressed? ◆ Is efflorescence and free lime visible?

	
Crack/spalling (T-girder)	Peeling/Reinforcing bar exposure
	
Cracks (floor slab bridges)	Efflorescence

Important points!

1. Salt damage

   Damage caused by salt progresses quickly and often develops again even after repair, so continuous inspection is recommended.

2. Reinforcement corrosion

   If water leakage from cracks is contaminated with visible rust juice, there is a concern that the load bearing capacity may be reduced due to corrosion of the reinforcing bars.

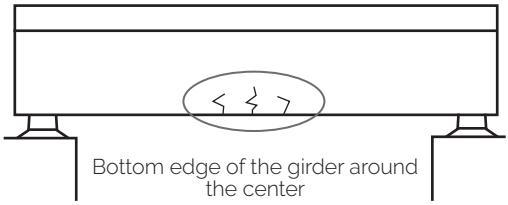
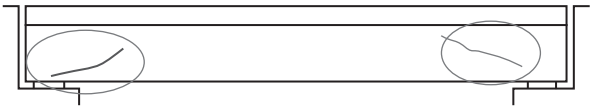
3. Damage to the hollow deck bridge

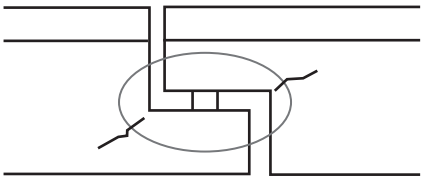
   If water leakage or free lime is observed in the hollow deck bridge, water may have stagnated inside.

[Reference] Points of Attention of Reinforced Concrete Bridges (RC Bridges)

Care should be taken for the crack width for the following values:

- If crack width is 0.3 mm or more
- Minimum crack interval: less than 0.5 m

Focus position	Point of interest
Center of the span ※Also common in PC bridges	 Bottom edge of the girder around the center
	Maximum bending moment position
Approximately 1/4 of the span from the edge support	
	Shear crack

Gerber hinge	
Cracking due to localized stress concentration	

2.3.6 Pre-stressed Concrete Bridge (PC Bridge)

Main girder	• Are there any cracks? • Has spalling, peeling, or exposure of the reinforcement occurred?
Filling concrete	• Are there any cracks? • Is there water leakage, free lime, rust juice? • Are there drop-outs of the filling part?
Segment joint portion	• Are there any cracks? • Are there any water leaks?
PC steel anchorage section	• Are there any cracks? • Is there water leakage, free lime, rust juice? • Is there any spalling of the mortar in the filling part concrete?

	
Spalling and peeling off	Cracks and free lime

	
Damage to the fixing section	Drop-out of filling concrete

[Reference: Crack Width and Degree of Damage in PC Structures]

Care should be taken for cracks in the following values.

- Maximum crack width: 0.2 mm or more
- Minimum crack interval: Less than 0.5 m

Important points!

1. Cracks along PC steel

   If cracks on the girder surface along PC steel are found, it can be;

   1. *A problem of grouting.*
   2. *A possibility of corrosion of the steel material*
   3. *Alkali Silica Reaction (ASR).*

2. Damage to the fixture

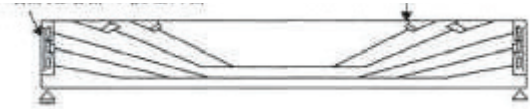
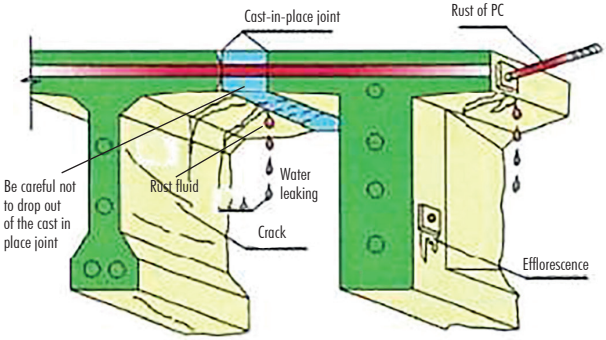
   Lateral clamping PC steel is not with sufficient concrete cover on the anchorage.

   Caution must be taken when spalling or peeling of concrete are observed.

   In this case, confirmation is required for the anchorage part with longitudinal tightening.

3. Dropping off of filling concrete

   Caution is required for PC T-girder bridges, because there is a possibility that the filled part may drop off.

[Example] Notes on concrete bridges (PC bridges)	
Focus position	Point of interest
Approximately 1/4 of the span from the supports	 Cracks along PC steel
Upper anchorage	 Crack or protrusion of notch
Cast in place joint/filling concrete/ edge of girder Lateral clamping PC steel	

2.3.7 Concrete Abutments and Piers

Bearing seat, Coping beam	• Is there any stagnant water or siltation occurring? • Is there any concrete damage occurring or progressing?
Frame, Column	• Are there any cracks? • Is peeling and exposure of reinforcing bars progressing?
Foundation	• Has settlement, inclination, or movement occurred? • Is there any abnormality or scouring in the river bed? • Is there damage of the slope protection at the abutments

Stagnant water on the bearing seat area

Alkali silica reaction

Peeling/Reinforcing Bar Exposure

Scouring

Important points!

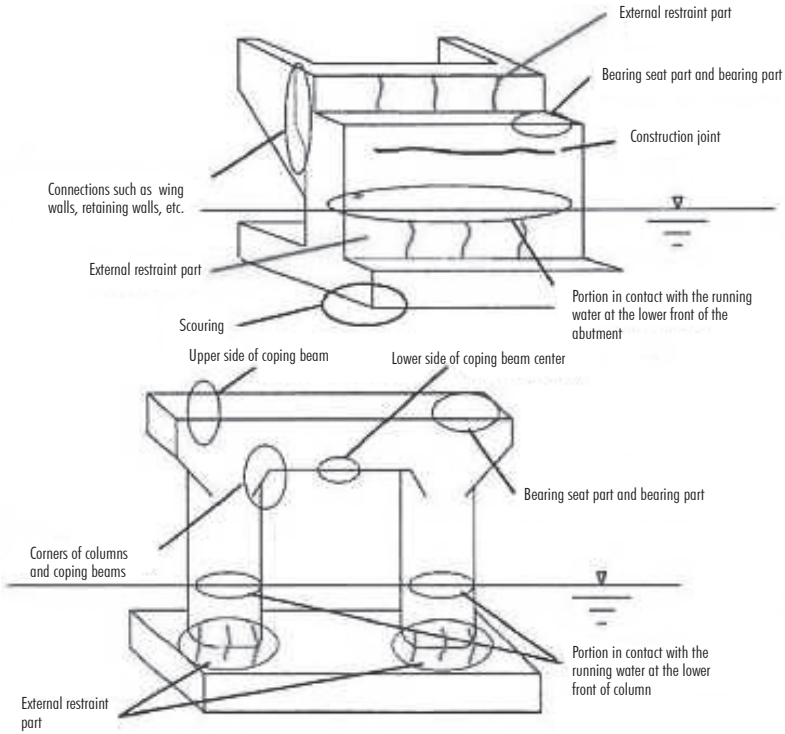
1. Alkali Silica Reaction (ASR)

   ASR, which is caused by water penetration, is suspected to be the cause of the alligator cracks. Watch out for corrosion or rupture of steel materials in areas where ASR has occurred.

2. Water leakage from the expansion joint

   In the case of water leakage from the expansion joint, cracks and wide spalling area in the bearing seats should be suspected.

[Example] Focus points of inspections for concrete abutments and piers



Focus position	Point of interest
Bearing seat, Bearing part	The dry-wet cycle conditions due to water leakage from expansion joint have an effect of aiding corrosion of the reinforcing bars and deterioration of concrete. This is the case especially when water stagnation on the bearing seat surface and siltation on the bearing part have occurred. It is necessary to remove the wet earth and sand, etc.
Upper side of the coping beam	This is a portion where maximum negative bending moment is generated as a cantilever beam. Attention should be paid to the upper side where reinforcing bars are concentrated .

Focus position	Point of interest
Column, Corners of coping beam	Cracks may develop at the node of the rigid frame member due to the sudden change of the stress direction.
Coping beam center lower side	Deformation may occur in the vicinity of this area since reinforcement is concentrated in the lower side of the beam against maximum positive bending moment.
Scouring	A vortex may be formed around the abutment and pier in the river causing erosion of the riverbed. Check for presence of abnormalities in the riverbed and pay attention to changes in the river flow.

2.3.8 Salt Damage to Concrete

- Deterioration in appearance

Deterioration phenomenon of salt damage (image)

- Cracks occur in the direction of the reinforcement.
- Rust juice seepage
- Peeling and spalling of concrete
- Internal steel exposure
- Deformation, displacement
- Cross-sectional reduction of the inner steel (not visible)

Crack in the direction of the reinforcement

Rust juice seepage

Concrete peeling and exposure of reinforcing bars

Important Points!

Detailed inspection

If suspected salt damage is found on a bridge along the coast where a large amount of airborne salt is present, a detailed inspection must be carried out.

If the above damage is observed visually and there is suspicion of salt damage, the following detailed inspection should be carried out and repair measures considered:

- Visual survey
- Corrosion rate survey
- Chloride ion content survey
- Neutralization depth survey

Steel corrosion rate survey

2.4 Inspection of Underwater or Submerged Structures

Equipment required for inspection of submerged or underwater structures: Diving gear (diving suit, face mask or helmet, oxygen tank & scuba set, weight belt, swim fins, underwater flashlight, underwater wristwatch, buoyancy compensator, depth gauge, pressure gauge), rulers, calipers, scrapers, hammers, pry bars. See table 5.3 of *Inspection Manual for Bridges*

- Only qualified persons should undertake underwater inspection.
- Access site by diving from shoreline or from a standby boat.

- Pay particular attention to the splash zone or tidal zone between the low and high tide levels
- Inspect the following structural elements: Pile caps, piles, piers, abutments and protection systems (e.g. pier crash barrier).

2.4.1 Inspection Process

- Map the channel profile
- Undertake a sounding test
- Observe the effect of wave action on the bridge and its approaches
- Check the condition of channel protection work and scour protective devices
- Document any erosion of approach fills and embankment
- Document scour near footing and under footing
- Document extent of exposure and No. of piles exposed
- Document soundness and section loss in piles and record remaining thickness for steel and timber piles
- Document condition of any bracings and connections (cathodic protection)
- Document any debris/driftwood buildup around piling
- Document any fire damage, impact damage or missing or broken piles & wire rope on protection systems (e.g. pier crash barrier)

3 MEASURES TO PREVENT THIRD PARTY INCIDENCES

3.1 Importance of Preventive Measures against Third Party Incidences and Damage to the Environment

It is important to note that while undertaking bridge inspections, there is a possibility of third party incidences occurring. Therefore, it is paramount for appropriate measures to be taken in order to mitigate against such incidences.

Such incidences may include:

i) Injuries to third parties (e.g. falling concrete sediment/debri, loose bolts/nuts, falling equipment etc.

ii) Inconveniences to third party (e.g. interruption of vehicular/ pedestrian traffic, delays due to re-routing of traffic etc.)

iii) Damage to environment (cutting/clearing of vegetation to access the bridge, disturbance of marine/wildlife while inspecting bridges in water bodies/animal parks, excessive noise etc.)

3.2 Typical Conditions in which Third-Party Incidences May Occur during Inspection

1. When a road crosses under the bridge.
2. When a railway crosses under the bridge.
3. When the bridge is located over a public space such as a park/ parking lots.
4. When a road is adjacent to the elevated section of a bridge.
5. Cordoning off the bridge section

3.3 Mitigation Measures to Reduce the Cases of Third Party Incidences during Inspection

1. Acquire relevant permits or inform relevant authorities of the exercise prior to undertaking the exercise
2. Issuing public notices prior to conducting of inspection exercises

3. Cordoning off the bridge section
4. Use of appropriate warning signs
5. Engaging of traffic marshals during the period of the exercise
6. Using Personal Protective Equipment (PPE) and safety measures such as safety nets, safety harnesses, utility belts

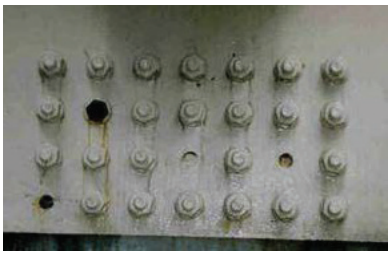
3.4 Typical Damages that May Lead to Third Party Incidences

Concrete spalling in the waterproof section

Concrete spalling of placing joint

Concrete spalling of piers and abutments

Sediment and concrete debris on the bearing seat surface



Breakage or falling off of bolts

Spalling at the corrosion point of steel bridges

4. EMERGENCY INSPECTION

The points for inspecting bridges immediately after a disaster such as earthquakes, debris flow and floods, accidents are summarized as follows:

- Points to be noted during patrols in abnormal situations,
- Points to be noted during on-site inspections,
- Previous damage susceptible to disaster.

1.	Points to be noted during patrols in abnormal situations
	Check while in the vehicle for any damage that may interfere with traffic and for any changes that may have occurred in the entire bridge.
2.	Points to be noted during on-site inspections
	When conducting on-site inspections after patrols in the event of an abnormality, areas susceptible to damage from disaster are inspected by visual inspections as closely as possible.
3.	Previous damage susceptible to disaster
	Of the damages already confirmed in the bridge during periodic inspection, special attention should be paid to the damaged parts that are susceptible to further damage after a disaster.

4.1 Points to Be Noted during Patrols in Abnormal Situations

The following items are checked during the emergency inspection.

1. Deflection of road surface, protective fence and kerbs
2. Level difference on the back of the abutment
3. Unusual opening of the protection fence
4. Abnormality of the expansion joint

If any abnormality is found, damage may have occurred in the following parts.

- Abutment
- Pier
- Bearing
- Girder end
- Cross beam, lateral bracing, cross frame

The areas to be checked and inspected intensively according to the details of the abnormality confirmed by the patrol at the time of the abnormality are as follows:

Check point	Focus point	Element to critically check
Deflection of road surface, protective fence and kerb	• Longitudinal linear misalignment • Linear misalignment/twist • Level difference of protection fence and kerb	Abutment Pier Bearing Cross beam, lateral bracing, cross frame
Level difference at back of the abutment	• Level difference on the road surface (subsidence on the back) and approach slab	Abutment Bearing
Failure of the protection fence	• Abnormal expansion joint space (excessive/no gaps) • Damage (deformation/ collapse) of support pole.	Abutment Pier Bearing Girder end Cross beam, lateral bracing, cross frame
Abnormality of the expansion joint	• Level difference (vertical direction) • Misalignment (perpendicular to bridge axis direction) • Abnormal expansion joint space (excessive/no gaps) • Other damages	

4.1.1 Items to Be Checked during Patrol in case of Abnormality (Specific Example)

1. Road surface, protective fence, and kerb
   i. Are longitudinal linear bends occurring?
   ii. Are plane linear bends occurring?
   iii. Is there any difference in level between the protective fence and the ground area?

<Examples of Damage>

Longitudinal linear misalignment

Parts requiring special inspection when abnormality is confirmed;

- Abutment
- Pier
- Bearing
- Cross beam, lateral bracing and cross frame

2. Level difference at the back of the abutment

i. Is there a level difference on the road surface?
ii. Has sinking of the edge of the approach slab occurred?

<Examples of Damage>

Level difference on the road surface behind the abutment

Parts requiring special inspection when abnormality is confirmed:

- Abutment

3. Failure of the protection fence

i. Are there any abnormal gaps (excessive gaps/no gaps)?

ii. Is it damaged? (deformation/collapse) of support pole

<Examples of Damage>

Breakage of the telescopic section

Parts requiring special inspection when abnormality is confirmed;

- Abutment
- Bearing
- Cross beam, lateral bracing and cross frame
- Girder edge
- Pavement

4. Abnormality of the expansion joint

i. Is there a level difference?

ii. Is there any misalignment?

iii. Is it damaged?

<Examples of Damage>

Level difference of the expansion joint

Deviation of expansion joint

Parts requiring special inspection when abnormality is confirmed;

- Abutment
- Bearing
- Cross beam, lateral bracing and cross frame
- Girder edge
- Pavement

4.2 Points to Be Noted during On-site Inspections

On-site inspections should include the parts listed below that are prone to damage from disaster.

It is necessary to inspect the position and contents outlined below intensively.

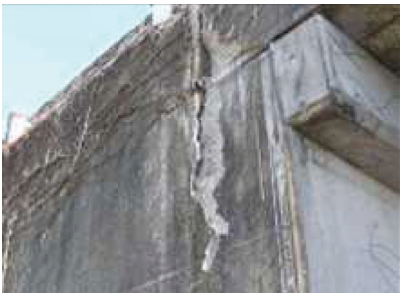
4.2.1 Abutment

1. Is sediment flowing out from the back of the abutment, etc.?
2. Are there any cracks in the parapet connection?
3. Is the vertical wall tilted?
4. Is the abutment settling or sliding?

<Examples of Damage>

Damage to the vertical wall

Sediment runoff from side of retaining wall



Cracking of parapet base

Impact on other parts and the need for immediate repair

1. Cracking of the parapet base may cause a level difference on the back of the abutment.
2. It may cause damage to the expansion joint or the bearing.
3. Recovery will be difficult if damage progresses when another disaster occurs.

※ If the displacement is large, immediate repair is required.

Anomalies appearing on the bridge surface	
	
Sinking of the back of the abutment	Abnormal clearance of expansion device (no gap)

4.2.2 Pier

1. Is the pier tilted?
2. Is there any spalling, exposure of reinforcement, or buckling of reinforcement on concrete cover?
3. Is the foundation settling or sliding?

< Examples of Damage>	
	
Flaking of covered concrete (Parallel part)	

Cracks in the column (shear cracks)

Crack in the column

Impact on other parts and the need for immediate repair

1. Defect on the pier may cause damage to the expansion joint or the bearing.
2. Recovery will be difficult if damage progresses when another disaster occurs.

※ If the displacement is large, immediate action is required.

Anomalies appearing on the bridge surface

Linear deviation (when there is excessive residual displacement/ foundation movement)

4.2.3 Bearing

1. Has the bearing fallen or subsided?
2. Are there any loose or broken bolts?
3. Are there any abnormalities around the anchor bar?
4. Steel bearing: Are there any wrinkles, ruptures, fall-offs, or deformations in the members?
5. Rubber bearing: Are there any rubber breaks, deformation residues, or cracks?
6. Is there a possibility of third-party damage caused by falling of members or debris caused by damage to the bearing?

<Examples of Damage>

Settlement and anchor bolt rupture

Side block rupture

Residual horizontal displacement of rubber bearing

Displacement of rubber bearing

Upper shoe stopper rupture

Abnormal clearance of movable bearing

Breakage of set bolt/side block mounting bolt

Loose set bolt

Impact on other parts and the need for immediate action

1. Failure of the bearings may lead to damage to the expansion and construction joint or the protective fence.
2. If the bearing is broken, immediate action is required because the girder may fall when another disaster occurs.

※ Tentatively support girders with saddle, etc.

Anomalies appearing on the bridge surface	
	
Step of the expansion joint	Deviation of expansion device
	
Abnormal clearance of expansion device	

	
Deformation of the expansion and contraction parts of the protective fence	Peeling of concrete due to collision in the wall rail

4.2.4 Girder End

1. Is there an excessive gap/collision between the girder and the backwall?
2. Does the main girder have a strange shape due to deflection and buckling?
3. Is the lower flange deformed?
4. Is there any deformation or buckling of the vertical stiffener?

<Examples of Damage>	
	
Buckling (rupture) of the web	Buckling of the vertical stiffener

Collision between the girder and the backwall

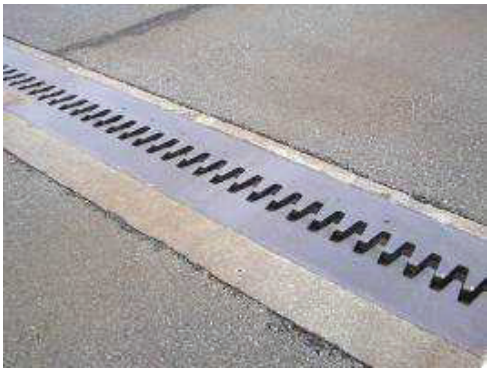
Deformation of the lower flange

Cracking of vertical stiffener and gusset

Impact on other parts and the need for immediate action

1. They may cause level difference or abnormal clearance of the expansion joint.
2. If the members buckle greatly, the girder may fall when another disaster occurs. so immediate action is required.

※ Provide temporary support to the main girder, etc.

Anomalies appearing on the bridge surface	
	
Level difference of the expansion joint	Abnormal clearance of expansion joint

4.2.5 Cross Beam, Lateral Bracing, Cross Frame

1. Are there any deformations, buckling, or breakage of the cross frame or lateral bracing?

<Examples of Damage>	
Steel bridge: Fulcrum of cross beam, fulcrum of lateral bracing and fulcrum of cross frame	
	
Buckling of the anti-tilt diagonal member	Buckling of lateral bracing

Concrete bridge: Horizontal girder on the fulcrum	
	
Damage to concrete on the end lateral girder	Damage to concrete edge of the cross girder

Impact on other parts and the need for immediate action

1. If the extent of deformation is pronounced, it may cause damage to the expansion/construction joint or the protective fence.

   ※In the event of a rupture of a member, temporary members, etc., must be installed in preparation for another disaster.

4.3 Previous Damage Susceptible to Disaster

If the following damages have been confirmed in the most recent routine inspection of the bridge, the damage may have progressed, so care must be taken during the on-site inspection.

[Previous damage susceptible to disaster]

- Abnormal clearance of the expansion joint, main girder, and bearing
- Wall thinning and cracking near the main girder fulcrum
- Functional deterioration of bearing

4.3.1 Bridges with Abnormal Clearance of Expansion Joint, etc.

<Inspection point>

1. Is there any damage to abutment backwall or vertical walls or fear of the bridge falling due to abnormal clearance between the expansion joint, main girder, and support?

<Example of Damage>

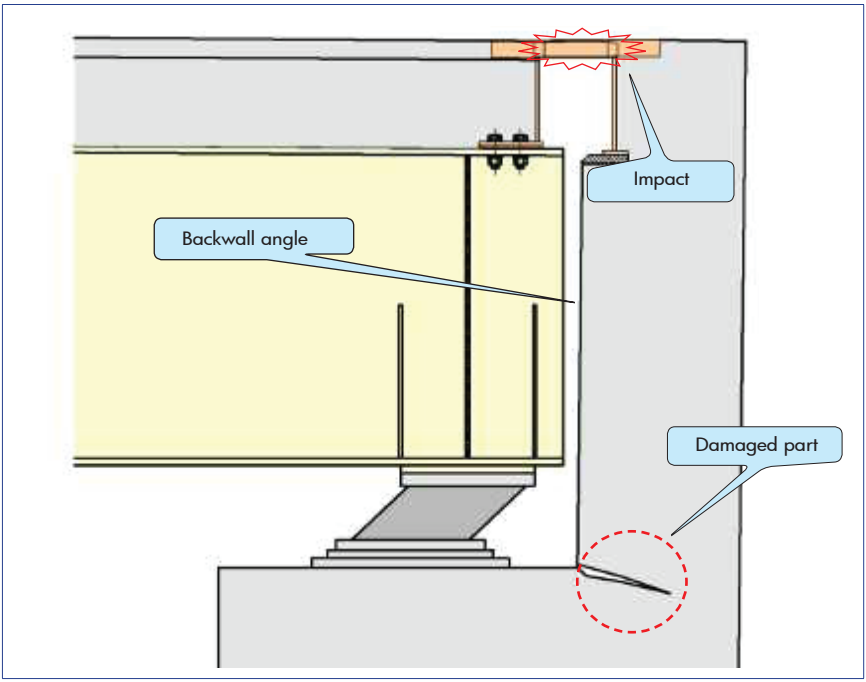
Abnormal clearance of expansion joint

Effects on other parts and the need for immediate action

1. Damage to the backwall and vertical walls may cause a step on the back of the abutment.
2. Recovery will be difficult if damage progresses due to another disaster etc.

※ If the displacement is large, immediate action is required.

Concept of backwall damage



4.3.2 Bridges with Wall Thinning (Bearing Stiffener/Web Plate/Flange) and Cracks in the Main Girder at the Fulcrum

<Inspection point>

1. Is there any deformation or crack in the wall thinning part due to corrosion?
2. Has the width and length of the crack increased?

<Examples of Damage>

Defective web due to corrosion wall thickness, effect on other parts and the need for immediate repair.

Effects on other parts and the need for immediate action

1. Damage to the expansion joint and protective fence may result. In addition, if cracks or deformations develop, there is a risk of a bridge falling.
2. In order to prevent the defect in a member progressing due to cracks or other causes, it is necessary to provide an emergency measure to temporarily support the main girder.

4.3.3Bridges where functional deterioration of bearings has occurred

<Inspection point>

1. Is the main girder deformed or cracked due to the functional deterioration of the bearing?
2. Is there any new damage to the bearing body?

<Examples of Damage>

Influence of corrosion wall thickness loss on other parts,

Impact on other parts and the need for immediate repair

1. On the upper and lower sections; if the moving function of the movable shoe is failing, it may cause damage.
2. If the main girder is cracked or deformed significantly, emergency temporary support of the main girder is required.

APPENDIX A.1: BASIC KNOWLEDGE OF BRIDGES

A.1.1 Classification of Bridge by Material

Steel bridge	Bridges whose girders are made of steel.
Concrete bridge	Bridges whose girders are made of concrete.
Reinforced Concrete bridge (RC bridge)	Bridges with reinforced concrete girders. Normally bridge girders are cast in place.
Pre-stressed Concrete bridge (PC bridge)	Bridges with girders and beams pre-stressed with steel wires and bars.

[Reference] Reinforced concrete (RC) and pre-stressed concrete (PC)

Concrete is resistant to compression and vulnerable to tension. Therefore, when concrete members are used as girder bridges, some kind of reinforcement is required on the side receiving tensile force.

Girders are divided into:

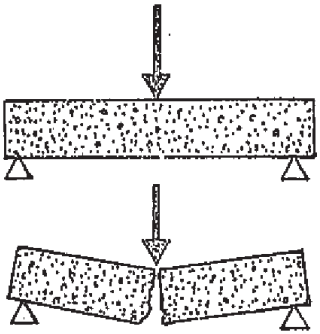
1. Reinforced Concrete (RC) which uses steel bars for reinforcement.
2. Pre-stressed Concrete (PC) which uses steel wires to resist against tensile forces on concrete girder.

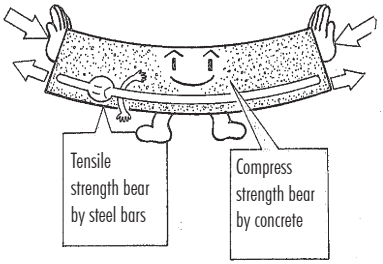
1. Reinforced Concrete (RC)

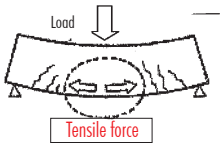
RC bridge (reinforced by steel bars, with tolerance of cracks on girders)

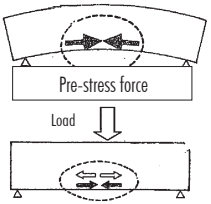
Concrete girders bend by receiving force from upwards. The upper side receives the compression force while the lower side receives the tensile force. Concrete is frangible when high tensile force is applied, the girder may develop cracks and collapse due to high tensile force. Normally tensile strength is 1/10 of compressed strength.

Steel bars are therefore, placed at the lower part of the girder to bare tensile force.







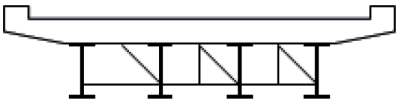
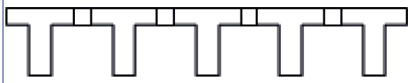
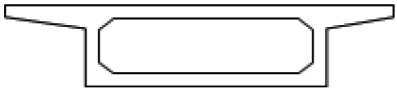
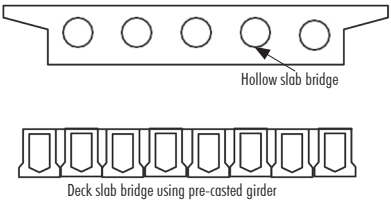


2. *Reinforced Pre-stressed Concrete (PC)*

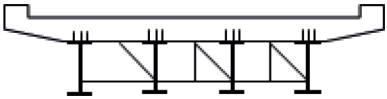
PC bridges (reinforced by PC steel wires, no tolerance of cracks)

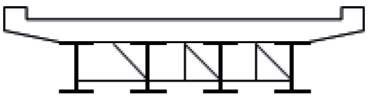
Pre-stressed concrete is a form of concrete where initial compression is given to the lower side of the concrete girder before applying the external load so that stress from external loads is counteracted in the desired way during the service period. This initial compression is introduced by high-strength steel wire or alloys (called 'tendons') located in the concrete section.

A.1.2 Classification of Bridges by Structure Type

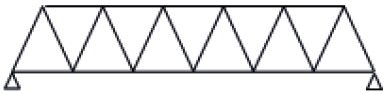
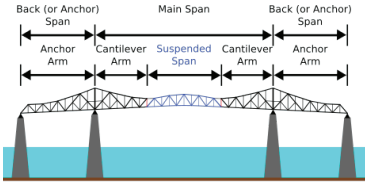
Structural type	Schematic diagram	Description
I-Shape girder (Plate girder bridge)		Girder bridges using H-shaped steel or plate girders (I-shaped steel) as main girders.
T-Shape girder		Girder bridges using two or more T-shaped cross section as main girders.
Box girder		Girder bridge whose main girder is a box-shape.
Steel deck girder		Girder bridges using steel plates stiffened with ribs to the deck slabs
Deck bridge		Bridges with modified slab as the main structure.

A.1.3 Classification of Bridge by Composite Structure of Girder and Deck Slab

Composite girder		Girder bridge designed with reinforced concrete deck slab and steel girder (PC girder) as an integrated structure. Compression stress on upper girder is shared with deck slab.

Non-composite girder		Girder bridges designed to bear loads on steel girders alone. Compression stress on upper girder is isolated from deck slab

A.1.4 Classification of Bridges by Type

Truss bridge		A bridge that uses trusses as the main structure of a bridge
Arch bridge		A bridge that uses an arch as the main structure of a bridge
Rigid frame Bridge		A bridge whose upper part and lower part are rigidly connected
Cable stayed bridge		A bridge structured to suspend girders obliquely with cables from the main tower
Suspension bridge		A bridge structured to hang cables and suspend girders.
Cantilever bridge		It is a bridge whose super-structure element is only anchored/supported at one of its ends. It is built with two cantilever that meet in the middle.

A.1.5 Classification of Bridges by Support Type

1. *Simply supported girder bridge*

   The most common type of bridge. The bridge is supported at each end of the girder independently by each span. The largest bending moment occurs at the center of the span and large tensile force occurs at lower part of girder; therefore, main steel reinforcement bars are arranged at lower part of the girders.

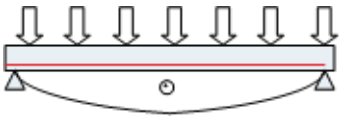
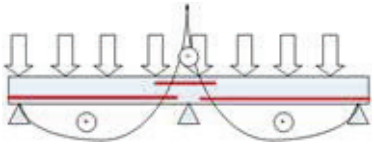
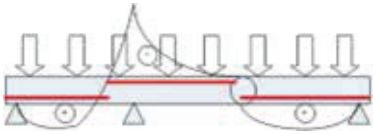
2. *Continuous girder bridge*

Continuous girder bridge is a bridge supported by a fulcrum(s) at intervals. So that, the long girder is supported by several fulcrums instead of lay-outing several short span simple supported girders.

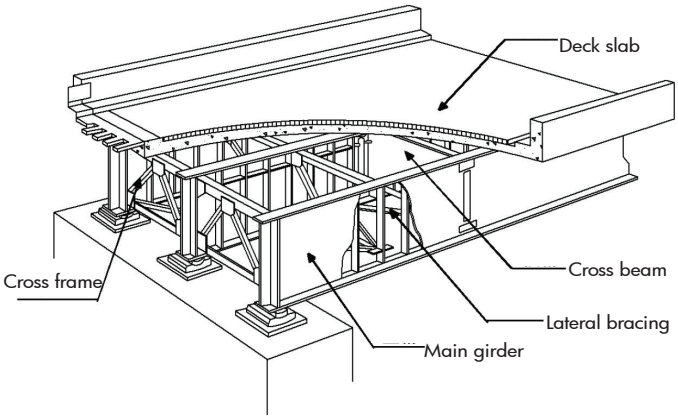
The largest bending moment occurs at the center span and at center fulcrums. Large tensile force occurs at the lower part of center span and at the upper part of center fulcrums. Therefore, it is essential to arrange reinforcement in the lower part of the girder at the center span, and upper part of the girder at the center fulcrums.

3. *Gerber's bridge*

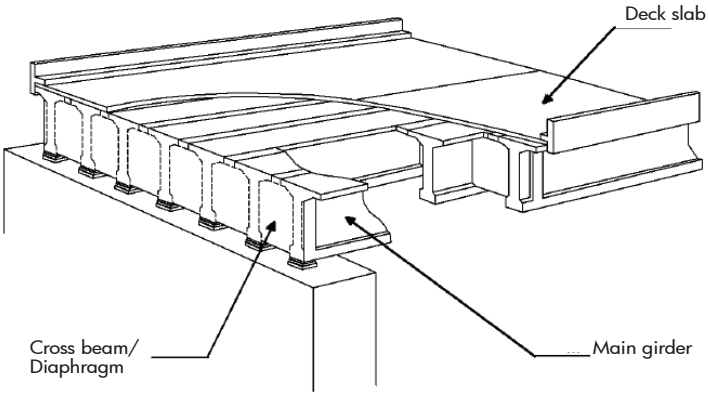
The structure has neutral characteristics in comparison to the above two types. This is a statically determinate structures due to the installation of the hinges in the spans.

	
Simple supported girder bridge	Continuous girder bridge
	
Gerber's bridge	

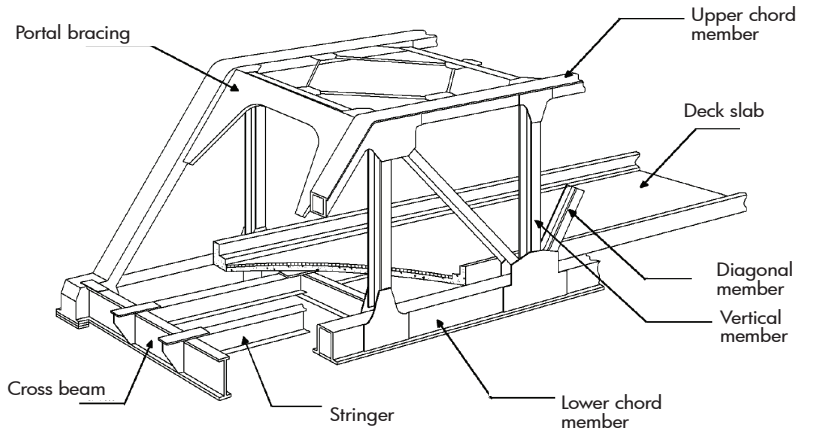
A.1.6 Name of the Superstructure



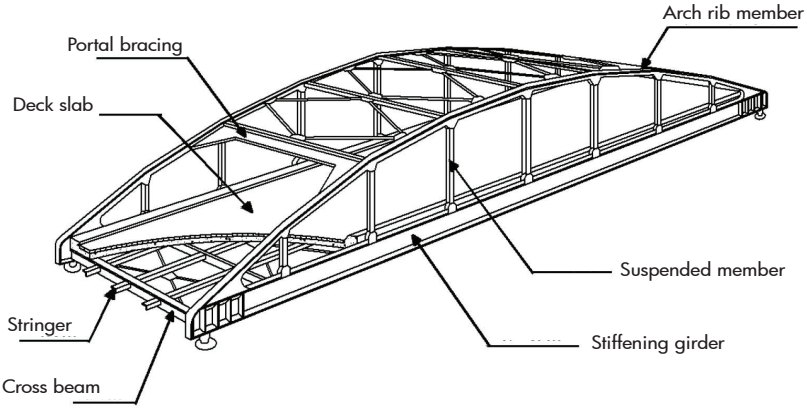
Steel plate girder bridge



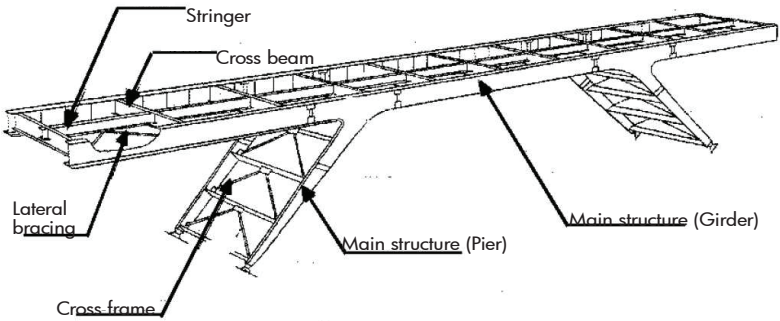
PC/RC T-girder bridge



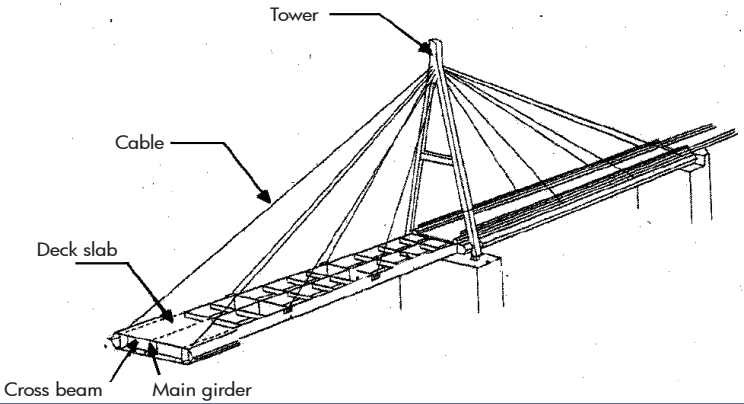
Truss bridge



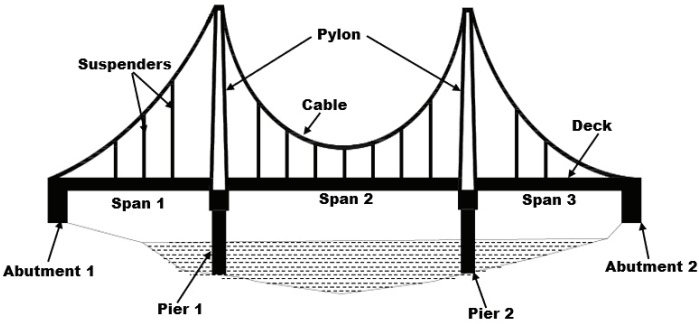
Arch bridge (Through type)



Rigid frame bridge

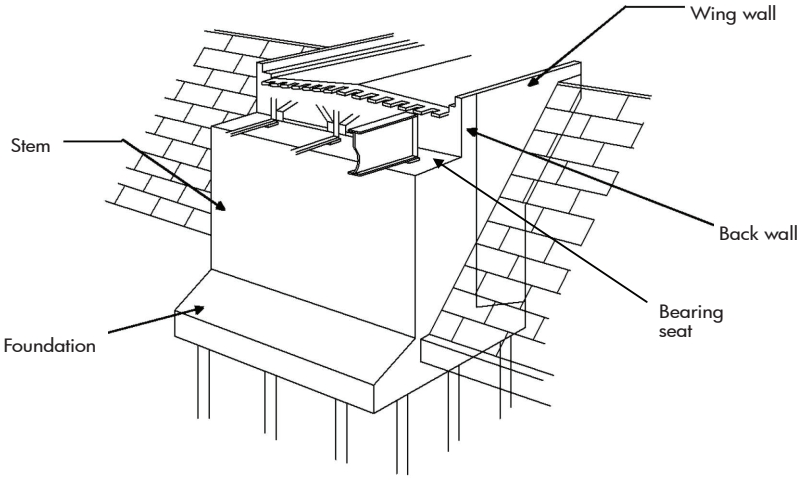


Cable stayed bridge

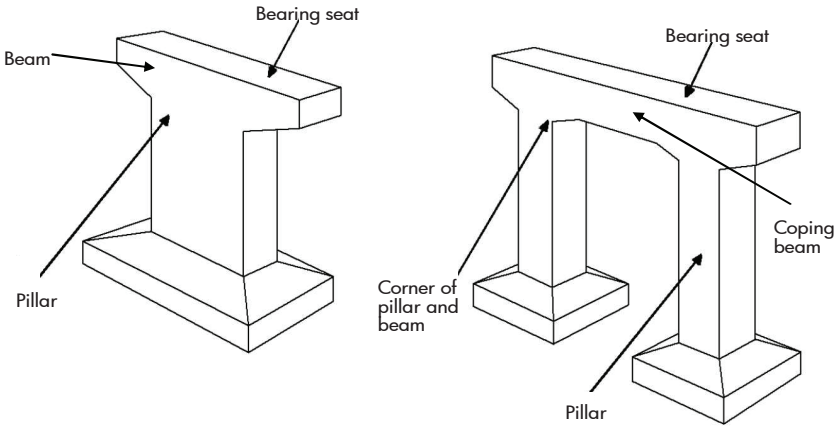


Suspension bridge

A.1.7 Components of the Substructure

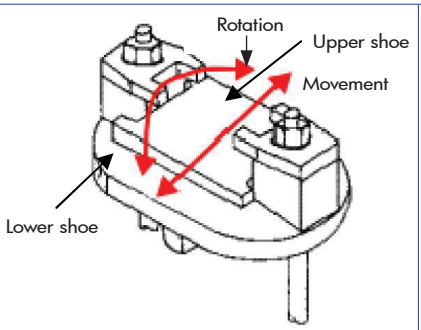


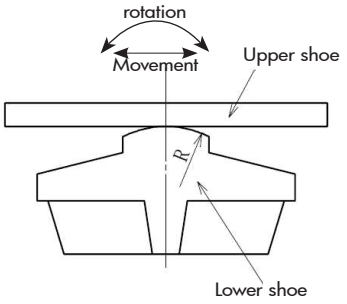
Abutment



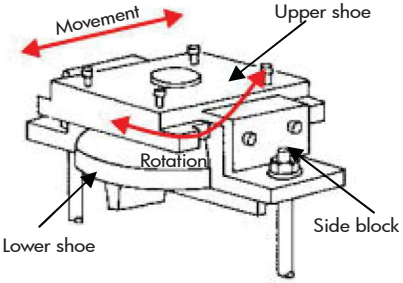
Bridge pier

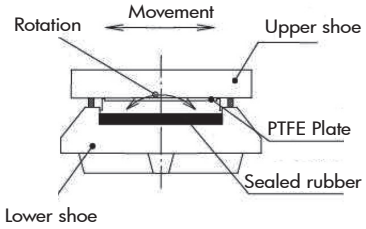
A.1.8 Type of Bearings



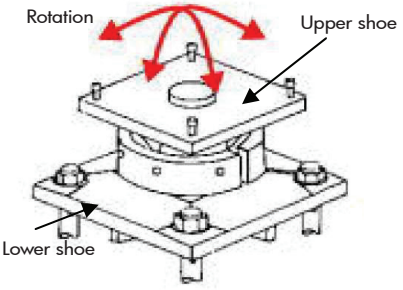


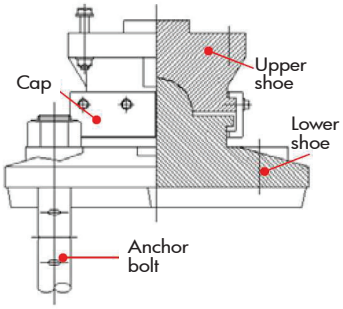
Line bearing



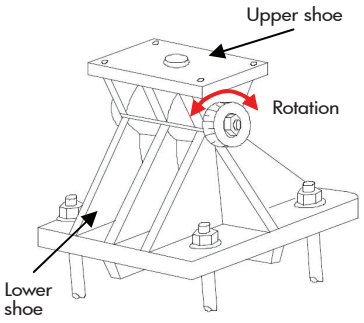


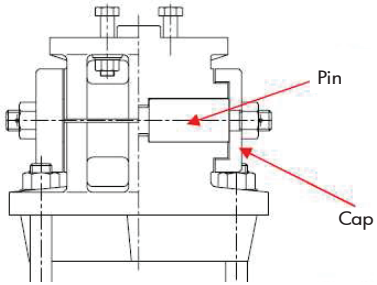
Bearing plate shoe



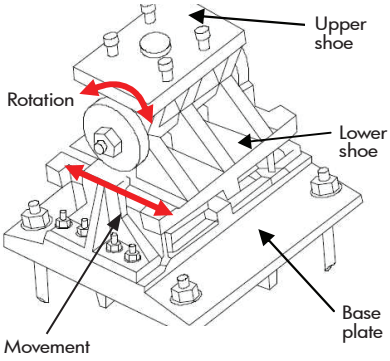


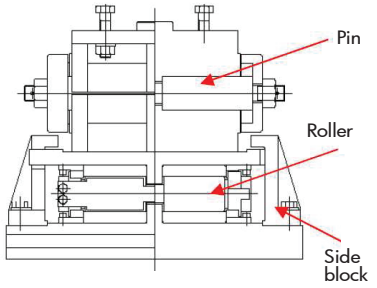
Pivot bearing



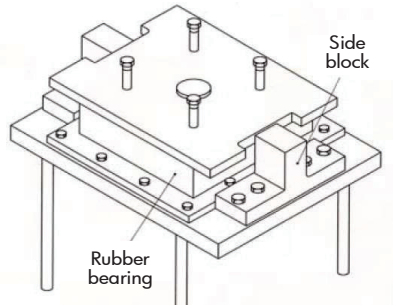


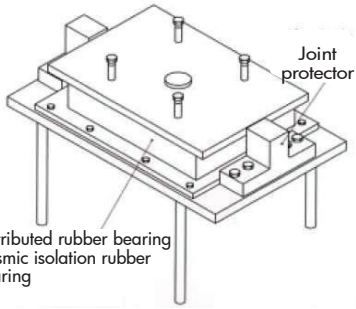
Pin bearing





Roller bearing

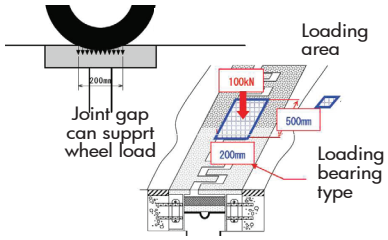




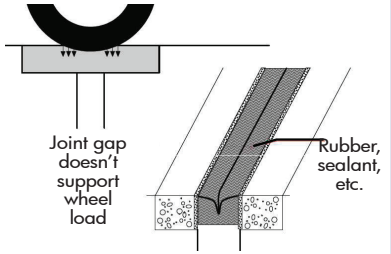
Rubber support

A.1.9 Types of Expansion Joints

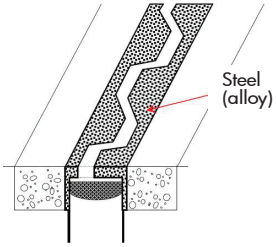
Expansion joint	Load bearing type	• Made of rubber • Steel(made of alloy) • Rubber + steel
	Butt type	• Made of rubber • Steel (made of alloy) • Rubber + steel
	Buried type	• Special composite material



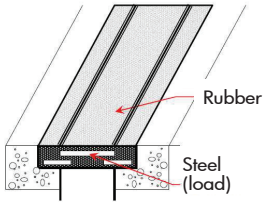
Load bearing type



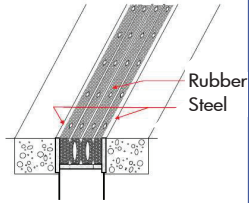
Butt type



Steel (made of alloy)



Made of rubber



Rubber + steel

A.1.10 Bridge Inspection Checklist

1	Checkpoints for inspection on the road surface	
	Road/Bridge (railings, protective fences, signs, lighting)	• Is any furniture damaged by being knocked by vehicles/vandalism? • Are there any corrosion at the base of poles/ signs and lighting lamps or any abnormal vibration? • Are there any parts that might be dangerous for road users?
	Road surface (surfacing)	• Are there any holes or large dents? • Are there alligator cracks? • Are there any large cracks in the direction of the bridge axis (longitudinal direction) or in the direction perpendicular to the bridge axis (transverse direction)?
	Road surface (expansion device [expansion joint])	• Is there any level difference or abnormal gap? • Is it broken? • Are sediments blocking the joint movement?
	Drainage facilities	• Are there any clogged drainage facilities?
	Abnormal sound/vibration	• Are there any abnormal sounds or excessive vibrations when vehicles pass over the bridge?
2	Checkpoints for side inspection	
	Bridge profile	• Is there any misalignment of the main girder? • Are there any problems with the alignment of the railings and kerb? • Are there any subsidence, inclination, or movement of the substructure?
	Drainage facility	• Is the drainage facility damaged/vandalized? • Are there any large water leakage marks on the piers and abutments?

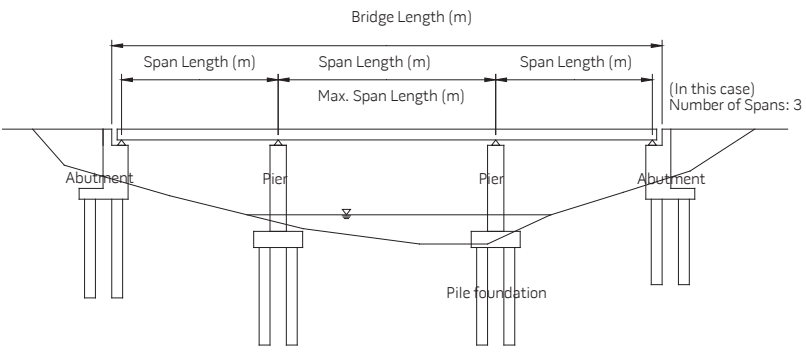
3	Checkpoints for under the bridge inspections	
Bearing part		
	Bearing seat	• Is the defect on the mortar progressing? • Are the cracks in the vicinity of the shoe seat progressing? • Is there any siltation occuring around the seat.
	Anchor bolt Set bolt	• Is there any looseness, falling off, or rupture? • Is corrosion occurring?
	Bearing body	• Is the side block roller defective? • Are there any subsidence, movement, or inclinations? • Is corrosion occuring?
	Amount of movement	• Is abnormal movement or rotation occurring?
Steel bridge (plate girder)		
	Girder end	• Is corrosion occuring/progressing?
	Support point	• Is corrosion occuring/progressing? • Are there any paint film cracks or cracks in the sole plate weld? • Is there any deformation of the stiffener?
	Cross beam and cross frame	• Are there any paint film cracks or cracks in the gusset weld? • Are there any paint film cracks or cracks at the top end of the stiffener? • Is there any deformation occurring?
	Splice	• Is corrosion occuring/progressing? • Are there any loose or missing bolts?
	Notch	• Are there any cracks or cracks in the coating film at the notch R?
Steel bridge (box girder)		
	Girder end	• Is corrosion progressing?

	Fulcrum	• Is corrosion progressing? • Are there any paint film cracks or cracks at the sole plate weld?
	Cross beam	• Are there any paint film cracks or cracks on the web plate at the edge of the cross beam?
	Splice	• Is corrosion progressing? • Are there any loose or missing bolts?
	Notch	• Are there any cracks on the coating film at the notch R?
	Inside box girder	• Are there any cracks on the coating film? • Is there stagnant water?
Steel bridge (RC deck)		
	Deck slab Bottom surface	• Has spalling, peeling, or exposure to reinforcing bars progressed? • Are there craks and/or are they progressing? • Is the direction of the crack unidirectional or bi-directional? • Is there any leakage of water, free lime or rust juice from cracks?
	Bonding part of the steel plate	• Is there corrosion of the steel plates and/or is it progressing? • Is the steel plate detaching? • Have the sealant and anchor bolts dropped off?
Reinforced Concrete bridge (RC bridge)		
	T-girder	• Are there cracks and/or are they progressing? • Has spalling, peeling, or exposure of reinforcing bars progressed?
	Deck bridge	• Are there cracks and/or are they progressing? • Has spalling, peeling, or exposure of reinforcing bars occured or progressed? • Is efflorescence or free lime visible?

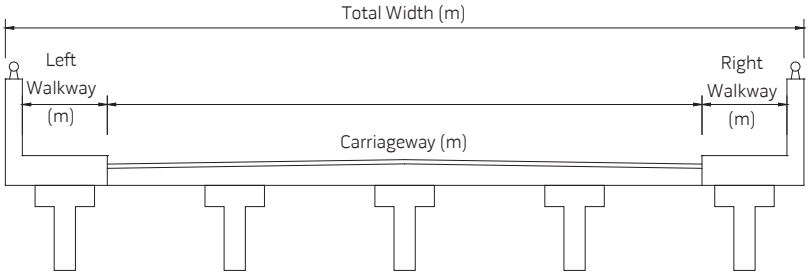
Pre-stressed Concrete bridge (PC bridge)		
	Main Girder	• Are there any cracks? • Has spalling, peeling, or exposure of reinforcement occurred?
	Filling concrete	• Are there any cracks? • Is there water leakage, free lime, rust juice? • Are there drop-outs of the filling part?
	Segment Joint portion	• Are there any cracks? • Are there any water leaks?
	PC steel anchorage section	• Are there any cracks? • Is there water leakage, free lime and rust juice? • Is there any spalling of the mortar in the filling part concrete?
Concrete abutments and piers		
	Bearing seat, Coping beam	• Is there any stagnant water or siltation occurring? • Is there any concrete damage occuring or progressing?
	Frame, Column	• Are there any cracks? • Is peeling and exposure of reinforcing bars progressing?
	Foundation	• Has settlement, inclination, or movement occurred? • Is there any abnormality or scouring in the river bed?

A.1.11 Definition of Each Dimension

1) Each length and each width



Bridge length



(In this case) Number of Girder: 5

Bridge width

A.1.12 Superstructure

i. Superstructure material

1. Concrete

2. Steel

3. Timber

4. Masonry

A pedestrian bridge made from glass fiber reinforced plastic.

5. Others

ii. Superstructure type

	
1. Girder	2. Slab girder
	
3. Truss	4. Arch
	
5. Frame (Rigid frame)	Suspension bridge

	
6. Cable-stayed	7. Others

iii. Deck material

	
1. Concrete	2. Steel
	
3. Timber	4. Others (If present)

iv. Surfacing type

	
1. Asphalt concrete	2. DSD or SSD
	
3. Concrete	4. No surfacing

A.1.13 Substructure (Abutment and Column/Pier

i. Substructure material

	
1. Concrete	2. Steel

	
3. Timber	4. Masonry
	These piers are made of titanium
5. Others (If present)	

ii. Substructure type – column/piers

	
1. Wall type	

2. Single column

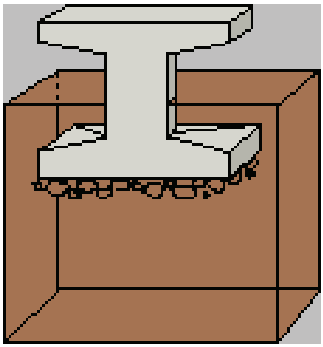
3. Multi columns

4. Others

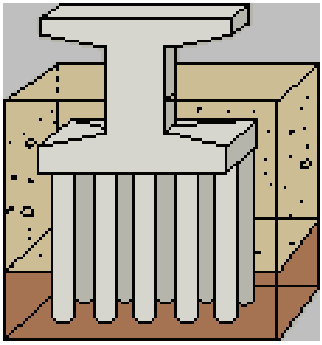
iii. Substructure type – abutment

	
1. Full-retaining (h>5m)	2. Semi-retaining (h<5m)
	
3. Spill through (open)	4. Others

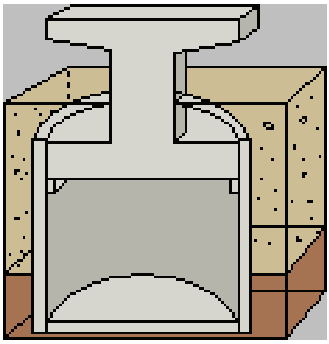
A.1.14 Foundation

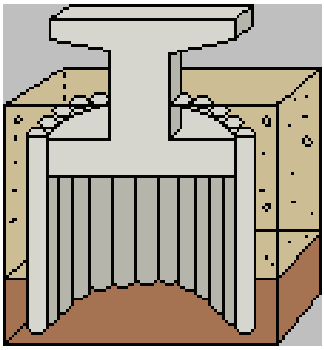


1. Spread foundation



2. Pile foundation





3. Others

A.1.15. Bridge Accessories

1. Bearing

2. Expansion joint

3. Bridge railing

4. Attachment

APPENDIX A.2: DEFECTS LEVELS AND BRIDGE CONDITION RATING

A.2.1 Defects Levels

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

The defects can be rated under 4 levels as shown in the table.

Defect Level	Description	Recommended action
N	No defect found or defect is minor	• No action nor 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)

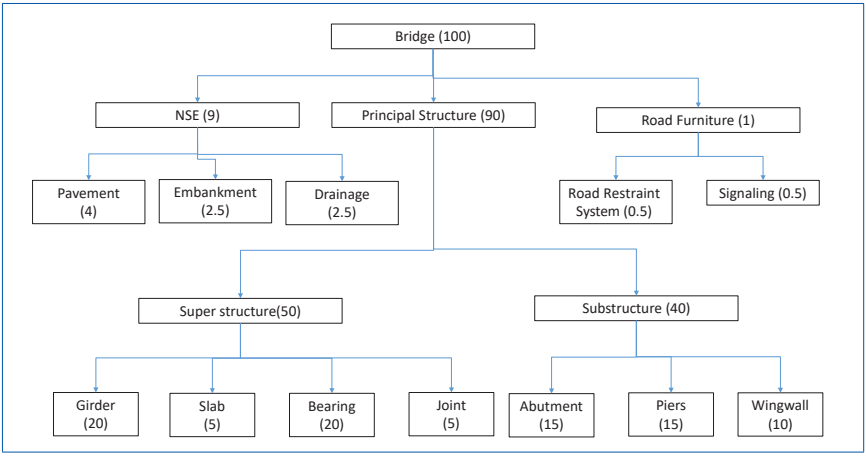
A.2.2 Bridge Condition Rating

i) 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 Furniture. The three major components are then divided into sub-components and allocated donated points as shown.



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.

ii) 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.

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.

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'.

Summary of bridge condition ratings for both the Routine Inspection and Principal Inspection is shown in the table.

Principal Inspection						**Routine Inspection**	
Stage	Score/ Rating	Damage Description	Action/ Response time	Overall Condition Category		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 minor 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