GUIDELINES FOR INSPECTION, MAINTENANCE AND REHABILITATION OF CONCRETE BRIDGES

CHAPTER III

GUIDELINES FOR INSPECTION

3.1 The inspection of a bridge should be conducted in a systematic and organised manner. The activities scheduled during inspection of the bridge should be planned in detail including sequence of inspection. The inspector should:

- Work through a checklist prepared for the particular type of structure.
- Should be familiar with the details of the structure and as to how it is intended to function.
- Should study previous reports before conducting inspection, so that the condition of the defects noticed earlier could be checked.
- Should be aware of rectification work done earlier, the same should be inspected and its performance should be recorded.

3.2 Inspection should not be confined to only searching of defects that may exist, but also should include the range of anticipating problems and recognising these areas. During and following inspections it should be remembered that any deterioration has a cause, and it should be the aim of the engineer to determine the cause. If the cause is ignored, the deterioration will be repeated and progressively increased.

3.3 Effectiveness of an inspection depends on proper recording of actual state of affairs. Every point should be noted as soon as the observation is made without leaving it to the memory. Report must be clear and in sufficient details, supported with sketches and photographs, if required, so that complete evaluation and assessment of the condition of the structure can be made.

3.4 **Sequence of Inspection:** Bridge Inspection should follow a predetermined manner so as to minimise the possibility of any bridge component being overlooked. A typical pattern may be on the following sequence:

Foundation, Abutments, Wing/return walls, Piers, Bed blocks and bearings, Superstructure including soffit of the deck, Track, Drainage, Gangway, Parapets, etc., Expansion joints, Bridge approaches, Protective works

3.5 MEANS OF ACCESS:

In order to have an efficient inspection, it is essential to have access to all elements of the bridge structure. The means of access should not only ensure convenience of inspection but should also ensure safety of the inspecting officials. The quality of inspection will depend on the type of access provided. The type of access to be provided in a bridge structure depends on its individual requirements, its location, height above ground etc. It is preferable that as far as possible a proper means of access to all elements of the bridge structure be considered at the design stage itself.

3.6 SIGNS OF DETERIORATION IN CONCRETE STRUCTURE:

The reasons for deterioration are either physical or chemical process, which cause visible signs of damage. The inspectors should, therefore, in particular look for the following signs of deterioration.

3.6.1 Texture or colour of concrete:

The texture of concrete surface may indicate the possibility of a chemical attack by softening, leaching or in case of sulphate attack whitening of the concrete. Rust stains may indicate the corrosion of reinforcement/prestressing steel. In fire damaged structure, the colour of the concrete gives an indication of the maximum temperature reached.

3.6.2 Cracking:

3.6.2.1 Cracks in concrete do not always jeopardize the safety of a structure. Cracks may be the cause or effect of a fault or both. The possible effect of crack must be considered in the context of cause, location, environment and utilization of the structure. Consideration may have to be given to the fact that cracks influence the stiffness and dynamic response of a structure. Unforeseen cracks in prestressed concrete bridges may entail a risk of fatigue failure.

3.6.2.2 Cracks can be classified according to the primary cause as follows:

Cracks in fresh concrete: These can be caused by plastic settlement (slump cracking); plastic shrinkage; movement of formwork; or heat curing.

Thermal cracks: These cracks can be cased by heat of hydration; or by the influence of ambient temperature.

Shrinkage cracks: These can be due to restraint from the surrounding structural elements; drying from one surface; or different shrinkage rates or times.

Durability cracks: These can be caused by corrosion of steel; attack by sulphates; aggregate reaction (e.g. alkali-silica); or by freezing or thawing.

Cracks caused by loading: These can be due to bending; tension; shear; torsion; bond failure; or concentrated load.

Other cracks: These can be due to faulty construction (formwork misalignment and its premature removal), differential settlement of structure, impact on account of accident, chemical reaction, weathering, excessive loss of pre-stress, deficiency or corrosion of steel, Poisson effect due to high pre-stress levels, incorrect pre-stressing, errors in design and detailing, earthquake, fire, etc.

3.6.2.3 Structural and non-structural cracks: Cracks caused by loading and other cracks defined as above are structural cracks, which may lead to failure. While cracks in fresh concrete, thermal cracks, shrinkage cracks and durability cracks are non-structural cracks that may not have immediate effect on the load carrying capacity of the structure but will have influence on the durability of the structure leading to failure before its design life. The acceptable crack width is dependent of functional requirements and the cause of cracking. The admissible limits for theoretically calculated crack width is given in IRS Concrete Bridge Code. Cracks wider than the admissible limits should be sealed by injection.

3.6.2.4 Recording of cracks: Whenever, cracks are noticed the following should be recorded:

i) Location

ii) Width, depth and length of crack

iii) Type and pattern of crack, viz. longitudinal, transverse, diagonal vertical and random or map cracking

iv) Whether active or dormant

v) Behaviour under live load

While reporting the presence of cracks, the details should be described by sketches elucidated further by photographs wherever required for better appreciation. The observation of the earlier inspection should be referred for the purpose of determining whether crack propagation is continuing further or cracks are dormant. Dormant cracks indicate that the causes which led to the formation of cracks, are no longer existing. Dated tell tales should be extensively used to monitor the cracks.

3.6.2.5 Measurement of crack width and depth: For measurement of crack width a simple small hand-held microscope having graduated scale marked on the lens known as *'crack comparer'* may be used. Where greater accuracy of measurement of crack is required, *transducer* or *extensometer* or *strain gauges* can be used. Depth of crack can be measured either by Pulse Velocity Technique (ASTM C-597) or by taking cores from concrete. Continuous monitoring and recording of crack movements for 24 hours may be required for separating cracks caused due to temperature effects from that due to load effects.

3.6.2.6 Crack pattern and possible causes: When concrete is cracked, crack pattern can be quite informative. A mesh pattern suggests drying shrinkage, surface crazing and frost attack of alkali-aggregate reaction. In the case of corrosion of reinforcing / pre-stressing steel, the cracks are quite characteristic and distinct from those caused by other factors and run along the location of steel. Pattern of cracks generally found in various locations of different structural elements and possible cause for such cracks is given in the Table 3.1 below.

TABLE 3.1

Structural Element	Location	Crack pattern/ Direction	Possible cause
Soffit of slab or girder	End of span	Longitudinal	Bursting stress Lack of anchorage block reinforcement Alkali-Silica reaction in concrete
	Mid span	Longitudinal	Alkali-Silica reaction in concrete Broken tendons

		Transverse	Loss of prestress Excess of live load

Web	End of span	Diagonal	Sheer stress Loss of prestress
		Longitudinal	Alkali-Silica reaction in concrete Duct Floatation Broken tendons
Web (Cantilever/ Continuous girders)	Over support	Vertical	Loss of pre-stress
Top flange (I-girder or box girder)	Mid span	Transverse	Differential shrinkage
	Over support	Longitudinal	Alkali-Silica reaction in concrete Broken tendons
		Transverse	Differential shrinkage Loss of prestress Excess of live load

Note: *The above table is definitely not an exclusive list, however it is a clear demonstration that cracking in concrete could be due to multiple causes and before a diagnosis is made more information may be necessary involving simple monitoring by periodic measurements followed by tests.*

3.6.3 Spalling: A spall may be defined as the depression resulting from the separation/detachment of a fragment from the parent concrete by the action of blow, weather or pressure or by expansion within the concrete mass. A portion of concrete gets separated showing a fracture parallel/inclined to surface.

Spalling should be considered as a serious defect as it may cause local weakening of the structure and exposure of reinforcement and thus becoming further prone to speedy deterioration and failure of structure. An area of concrete that sounds hollow when struck with a hammer may be an indication of the existence of a fracture plane below the surface. This will give rise to spalling of concrete afterwards. Spalling is caused by:

(a) Corrosion of steel reinforcement or other embeddel metal.

(b) The freezing of cracked or porous concrete

(c) Chemical attack

(d) Poor quality concrete

(e) Insufficient reinforcement or its improper detailing

(f) Thermal shock due to fire

(g) Mechanical damage due to accident

(h) Bearing of a concrete member on another with insufficient joint width or with joints choked

(i) The bearing area being too close to the edge or end of a concrete member

Although the extent of spalling may be visually determined, the causes for potential spalling should be investigated by conducting tests for measuring electrical potential as well as chloride ion content of the concrete.

The location, depth and area/size of spalling should be noted. The general condition of the concrete at the fractured surface should also be examined including the condition of reinforcement, if exposed.

3.6.4 Delamination: Delamination is separation along a plane parallel to the surface of the concrete. These can be caused by corrosion of reinforcement, inadequate cover over reinforcing steel and fire. Besides visual inspection, tests for measuring cover and electrical potential should be carried out if delamination is significant. Bridge decks and corners of girders are particularly susceptible to delamination.

3.6.5 Scaling: It is the gradual and continuing loss of mortar and aggregate over an area. Scaling may be light, medium, heavy or severe depending upon the depth and exposure of aggregate. Scaling is usually observed where repeated freeze and thaw action on concrete takes place or when the concrete surface is subjected to cycles of wetting and drying or concentrated solution of chloride deicers. Location, area and character of scaling should be recorded.

3.6.6 Rust Streaks: Presence of rust/stain marks on side surface and bottom surface of prestressed concrete girders, closely following the pre-stressing cable profile indicate corrosion of prestressing cable and should be considered as a serious threat to the structural integrity of the member. Corrosion of tensioned or non-tensioned reinforcement is considered to be the most important deterioration of bridge girders.

The primary factors, which may influence the corrosion of steel in concrete, are:

i) pH value of concrete

ii) Chloride content

iii) Inadequacy of cover

iv) Permeability of concrete

v) Carbonation

vi) Exposure to aggressive environment

vii) Incomplete grouting of ducts of tendons

Besides, the HTS strands/cables are more prone to corrosion by phenomenon known as “stress corrosion’, which is dangerous because steel absorbs hydrogen ions leading to destroy of steel molecular structure. The cohesion between steel molecules is largely reduced and finally steel breaks under tension abruptly, without any plastic deformations.

3.6.7 Erosion: Mechanical action due to usage, weather and water leads to abrasive wear caused by sliding, scraping and/or percussion. The erosion caused due to abrasive action of ballast on deck top, or by high velocity river water in piers may even lead to formation of pocket or cavity.

3.6.8 Dampness: Dampness is an indication of improper drainage. In abutments it may occur due to blockage of weep holes. In Deck slabs it can occur due to blockage of drainage spouts or poor quality of concrete or failure of water proofing measures at wearing coat level.

3.6.9 Leaching: The leakage or seepage of water through cracks and voids in hardened concrete may dissolve calcium hydroxide and other such materials present in concrete. Leaching is the accumulation of salt or lime deposits (white in colour) on the concrete surface. These may be seen on underside of concrete decks. These indicate porous or cracked concrete. It causes staining, efflorescence and incrustation of cracks. Apart from its adverse effects on appearance, it can also pose corrosion threat to reinforcement because of gradual loss of alkalinity of concrete.

3.6.10 Loss of camber: Bridge Manual 1998 prescribes yearly recording of camber at centre of span vide Para 1107.15. However, recording of camber at every quarter point of the effective span including bearing centres would be desirable. The camber of prestressed concrete girders should be recorded and compared with the previously recorded values. Temperature has got great influence on the deflection. Therefore, temperature of girder should be recorded and the deflection should be measured near about the same temperature at which it was originally done. For camber measurement, method as given in Bridge Manual at Annexure 11/14 or any other suitable method may be adopted. Permanent marks on the surface of the girder are to be fixed where camber would be measured every time.

Loss of camber may be caused by: settlement, overloading, deterioration of concrete, reinforcement or tendons (due to stress corrosion). In case of prestressed concrete girders, loss of camber may be due to loss of prestress, which should be investigated.

3.6.11 Faults in design, material and workmanship: Faults in design, material and workmanship may increase the risks of excessive deterioration.

Faults in design include poor detailing; reducing the dimension of the concrete members below the minimum prescribed in the code; inadequate concrete cover; errors in calculation and human incompetence (resulting in an inadequate safety factor); incorrect design consideration of tendon curvature and/or structural curvature; the complex interaction of numerous parameters for impact and impulse loading and difficulty in predicting the structural response to these loads; inadequate assumptions of construction stage and temporary scaffolding and formwork.

Faults in materials include use of poor quality or incorrect type of cement, aggregate, admixture, or water (i.e. chloride, sulphate or sugar content).

Faults in workmanship may occur during the following process:

i) Storage of materials

ii) Installation of scaffolding and formwork

iii) Batching: in particular, the addition of excess water in order to make placing and compaction easier, may reduce the strength of the concrete and increase its permeability.

iv) Mixing (mixing time may be inadequate)

v) Compaction – This may result in honeycombed patches and low strength.

vi) Placing reinforcement – This may result in cracks, reduced load carrying capacity or more frequently, inadequate cover.

vii) Curing – Cracks may be caused through early shrinkage and increased concrete permeability thus reducing the protection provided to the reinforcement.

3.7 LOCATIONS TO BE SPECIALLY LOOKED FOR DEFECTS:

Table 3.2 below lists out the salient defects, which should be specially looked for during general/routine inspection of various elements of concrete bridge superstructure.

Table 3.2

LOOK	
AT	FOR
All over	§ General condition of the structure and prestressed components in particular § Condition of concrete § Cracks § Corrosion signs
	§ Scaling of concrete § Spalling of concrete § Efflorescence § Condition of construction joints
Anchorage Zone (at both ends)	§ Cracks § Rusting § Condition of cable end sealing
Top and bottom of deck slab	§ Cracks § Delamination § Blocking of drainage § Worn out wearing coat (once in 5 years) § Damage by abrasive action of ballast (once in 5 years) § Seepage § Corrosion signs § Leaching § Scaling § Damage due to accident or any other causes
Support point of bearings	§ Whether the seating of girder over bearing is uniform § Condition of anchor bolts, if any § Spalling/crushing/cracking around bearing support (Bottom of girder immediately above bearing should also be inspected for such effects)

Top and bottom flange of I-girder	§ Spalling/scaling § Rust streak along reinforcement/cable § Cracks
Bottom slab in box girder	§ Cracks § Spalling/scaling § Corrosion signs § Drainage
Webs	§ Cracks § Corrosion signs
Diaphragms	§ Cracks of junction § Diagonal cracks at corners § Diagonal/vertical cracks around opening § Conditions of diaphragm opening
Junction of slab and girder in case of I-girders	§ Separation
Drainage spouts	§ Clogging § Physical condition § Adequacy of projection of spout on the underside
Joints in segmental construction	§ Cracks § Physical appearance § Corrosion signs
Expansion joints	§ Check whether the expansion joint is free to expand and contract § Condition of sealing material i) Hardening/cracking in case of bitumen filler ii) Splitting, oxidation, creep, flattening and bulging in case of elastomeric sealing material
	§ Condition of sliding plates – check for corrosion, damage of welds, etc. § Debris in joints § Alignment checking § Distortion
Bearing: General for all type of bearings	§ Check whether the bearing is free to move/rotate in different directions as envisaged in design § Check whether the bearings are fully and evenly seated § Check whether all the bearings are at same level § Physical condition § Cleanliness

Metallic Bearings	§ Rusting/corrosion § Unusual tilting of rollers § Rollers jumping off the guides § Condition of grease, when last greased/whether needs replacement § Condition of anchor bolts, whether in position and not loose.
Elastomeric bearings	§ Flattening § Splitting/tearing § Bulging § Oxidation § Non uniform thickness other than that which may be the result of normal rotation § Displacement (longitudinal or lateral) from original position

3.8 INSPECTION TOOLS:

3.8.1 For Routine Inspection: Tools normally required for visual inspection are as under:

i) Clip Boards, chalks, markers etc.

ii) Tapes

iii) Feeler gauge

iv) Straight edge, plump bob, spirit level

v) Thermometer

vi) Inspection mirror

vii) Magnifying Glass

viii) Pocket knife, wire brush

ix) Inspection cum chipping hammer

x) Caliper

xi) Chisel

xii) Torch light

xiii) Screw drivers, pliers, hammer, torque wrench

xiv) Helmet, safety belt

xv) Piano wire with clamps and weights

xvi) Microscope

xvii) Camera

xviii) Crack meter

xix) Binocular

3.8.2 For Detailed Inspection and Special Inspection: Tools mentioned above should generally be adequate. However, tests described in Chapter IV may be required to be conducted in special cases for evaluation of the state of concrete.

In addition to tools specified in para 3.8.1 above, further reference to Annexure 11/15 of Indian Railway Bridge Manual may be made in this regard.

3.9 INSPECTION REPORT:

3.9.1 The bridge inspection documentation for various types of inspection should be as under:

i) **Routine Inspection:** Observations of General Inspection should be recorded in the Bridge Inspection Register as is being done as per para 1101 and Annexure 11/3 of IR Bridge Manual.

ii) **Detailed Inspection:** Observations of Detailed Inspections should be recorded in a separate register called "Register for Detailed Inspection for Concrete Bridges." This register will have one page for the construction and design details of the bridge as per Annexure A (Sheet 1) and one page for each span for Detailed Inspection as per Annexure A (Sheet 2). In case of any defect, description of the defects along with sketches and photographs etc. should also be enclosed. In case any remedial measure has already been taken, it should also be recorded along with comments regarding its performance and effectiveness.

Reports of detailed inspection should be accurate and factual, and where there is any uncertainty relating to the condition of any components or the structure as a whole, it should be clearly stated in the report. It should be sufficiently complete to allow a reasonably accurate assessment of the structural load capacity or with other related information based on which detailed analysis of its capacity may be carried out at Head Quarter. It should also provide sufficient information for programming of any maintenance or other work, if required.

iii) **Special Inspection:** Observations of Special inspection in case of distressed Bridges should be recorded on separate register called "Distressed Bridge Register". As regards the Special Inspections, which are to be done in case of accidents, immediately after severe earthquakes or heavy floods etc. observations should be recorded as a separate note.

3.10 Follow Up Action on Inspection:

The following procedure for follow up action on various types of inspection should be taken:

i) **Routine Inspection:** The follow up action should be taken as specified vide para 1101 and 1103 of IRBM.

ii) **Detailed Inspection:** The follow up action should be taken as in case of steel structures vide para 1102 of IRBM.

iii) **Special Inspection:** The action should be taken as considered necessary based on the inspection by the Sr. DEN, in-charge in consultation with other superior officers where necessary. If any bridge calls for urgent action or inspection at a higher level for deciding further course of action, special report enclosing extracts of inspection note etc. should be submitted immediately following inspection.

3.11 ORGANISATION AND TRAINING

3.11.1 The following organisation may be used for various types of inspection:

i) **Routine Inspection:** The primary responsibility of the maintenance of a bridge structure rests with Division as brought out in para 1005 of IRBM. The Permanent Way Inspector/ Works Inspector as well as the Assistant Engineer shall conduct the general Inspection every year and shall take the remedial action as found necessary according to existing procedures. They may refer problems to the Divisional Engineer/Sr. Divisional Engineer for his advice. Any repair work or remedial measures resulting from the inspection shall be carried out promptly by the Divisional Authority.

ii) **Detailed Inspection:** Detailed inspection shall be carried out by Bridge Inspectors as prescribed vide para 1002 of IRBM. Bridge Inspectors should be adequately trained for RCC and PSC bridge inspection. Inspection report should be forwarded to Headquarters through coordinating Sr.DEN.

Any repair work or remedial measures will be carried out by the Division.

iii) **Special Inspection:** Special inspection is need based and shall be carried out in circumstances as described in para 2.2.3. In case of problem bridges, requiring use of special techniques or where assistance of the Headquarters has been requested by the Division, the inspection shall be carried out by specially trained officers/staff for this purpose.

3.11.2 Training: Officers and Inspectors entrusted with the Detailed Inspection should have adequate training. Training curriculum/programme shall lay more emphasis on practical aspects of the inspection; theoretical aspects, covering material properties, analysis and evaluation shall also be covered briefly. Evaluation would include assessment of the extent of gravity of various types of defects noticed during inspection. Training should also include imparting knowledge of various methods of remedial measures for rectifying different kinds of defects.

In case of non-destructive testing equipment, training on its technical details and use by the manufacturer should be made part of procurement.