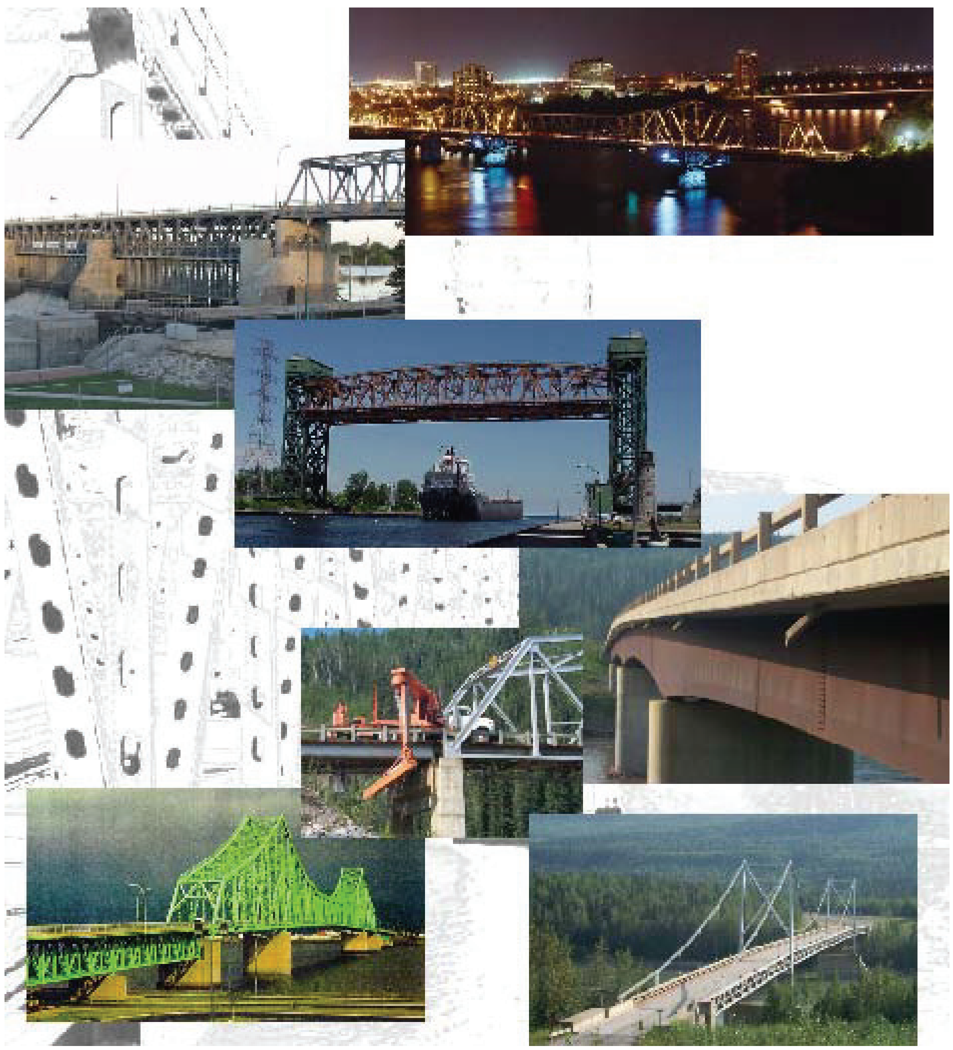
Bridge
Inspection Manual



Structures, Marine and Transportation

December 2010

Public Works and Government Services Canada
Travaux publics et Services gouvernementaux Canada
Canada

Bridge Inspection Manual

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CONTINUING RECORD OF REVISIONS

PWGSC BRIDGE INSPECTION MANUAL

This sheet should be retained permanently in this page sequence in the Manual.

All revised material should be inserted as soon as received and the relevant entries made by hand in the spaces provided to show who incorporated the *Revision* and the date this was done.

If this practice is followed faithfully it will be a simple matter to tell whether or not this copy of the Manual is up to date since all future *Revisions* will be numbered and dated.

Revision		Entered by	Date
No.	Date		
1	March 31, 2008		
2	January 4, 2010, pages B1-2, B1-4 and B1-6		
3	GENERAL December 2010		

BRIDGE INSPECTION MANUAL

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APPENDICES

ACKNOWLEDGMENTS

The contributions of the following are gratefully acknowledged:

- Public Works and Government Services Canada, Architecture and Engineering Services Headquarters Bridge Engineering Group, specifically, Mr. George Hibbert, P. Eng. and Mr. Alfred Chiang, P. Eng.
- Ministry of Transportation Ontario, Structural Office, and specifically, Mr. Ranjit Reel, P. Eng., Mr. Daniel Conte, P. Eng., Mr. Dino Bagnariol, P. Eng.
- McCormick Rankin Corporation, Dr. Roy Skelton, P. Eng., Mr. Anthony Wing, P. Eng., Mr. William Bohne, P. Eng.

March 2008 Update By

- Highways and Bridge Engineering, Public Works and Government Services Canada, Real Property Branch, Professional and Technical Services Management, Gatineau, Qc.

December 2010 Update By

- Structures, Marine and Transportation, Advisory and Practices (Professional Services), Public Works Government Services Canada, Real Property Branch, Professional and Technical Services Management, Gatineau, Qc.

PREFACE

This manual is largely reproduced (with permission) from the Ministry of Transportation Ontario (MTO) Ontario Structure Inspection Manual (OSIM) January 1991. Part 1 of the manual contains minor revisions only to reflect PWGSC inspections requirements. Part 2, Section 1 has been modified to suit PWGSC requirements and has been expanded to include examples of safety practices associated with bridge inspections. Part 2, Section 2, entitled Condition Rating System, has been rewritten in its entirety. The rating system adopted in **BIM** is very similar to the 1991 OSIM rating system but has been expanded to include a priority code for repairs, assessed on an individual structure basis. The remainder of Part 2 of OSIM has been modified to reflect the changes in the rating system, and has been included in **BIM** as Appendix A. Part 3 of OSIM – Programming Guidelines for Repairs and Rehabilitations has not been included. Part 4 of OSIM – Material Condition Surveys has been included as Appendix D and has been substantially expanded to include sections on Detailed Condition Surveys from the MTO Structural Rehabilitation Manual. Part 5 of OSIM – Underwater Inspections has been included as Appendix E in the **BIM** with some minor revisions.

Public Works and Government Services Canada gratefully acknowledges the assistance of MTO in the development of the *Bridge Inspection Manual* through the extensive use of OSIM and the Structural Rehabilitation Manual.

2008 Update

The manual was updated in March 2008 to ensure consistency with the Bridge Inspection and Structural Evaluation Policy.

One of the significant changes as a result of this update relates to the modification of the procedures relating to overall ratings of the structure. The overall structural condition as well as functional needs of the structures are to be assessed and rated on a scale of 1 to 6 with the lower end of the scale reflecting a closed, failed or unsafe structure and the high end of the scale representing no problems in terms of current codes and functional standards. This assessment should be based on sound engineering judgement taking into account the severity and extent of component deficiencies and their impact on overall structure. General guidelines are included in Part 2, Section 2, Condition Rating Systems of the updated version.

The title of Appendix B has been changed to Bridge Inspection Reports.

December 2010 Update

General revisions were made to the document and the format was updated.

INTRODUCTION

Bridge structures are key, and often, essential elements of the road network. Public safety is jeopardized, the efficiency of the network impaired, and the public inconvenienced whenever a structure fails or its load carrying capacity is reduced.

In the interests of public safety, cost effectively maintaining the structural integrity of federally owned bridges, and ensuring a minimum of traffic disruptions, Public Works and Government Services Canada (PWGSC) developed and implemented a comprehensive policy on bridge inspection and evaluation (May 2001). This policy contained provisions that all PWGSC owned bridges be inspected by qualified personnel at regular intervals, as specified in the policy.

To ensure national consistency of these inspections and the subsequent management of the structures, this manual was produced. It provides for a uniform standardized approach to detailed comprehensive inspections for PWGSC owned bridges across Canada.

Part 1 of the *Bridge Inspection Manual* (**BIM**) provides general details of inspection procedures, bridge components, material defects and performance related defects.

Part 2 of **BIM** sets out the requirements for general inspections, comprehensive detailed inspections and the rating systems to be used.

Appendix A of **BIM** provides specific requirements for the inspection of individual components.

Appendix B of **BIM** contains blank structure inspection forms and a sample completed inspection form.

Appendix C of **BIM** details traffic control procedures for inspections.

Appendix D of **BIM** details some of the typical destructive and non-destructive testing performed on structure components.

Appendix E of **BIM** outlines the requirements for underwater inspections.

This document is not applicable to Mechanical and Electrical components, such as those included in movable bridges.

GENERAL DEFINITIONS

Abutment – A substructure unit which supports the end of the structure and retains the approach fill. (*Culée*)

Auxiliary Component – Any component which does not share in the load carrying capacity of the structure. (*Élément accessoire*)

Bridge – Any structure having a span of 3 m or more that forms part of a highway or over, or under which the highway passes. (*Pont*)

Chord – The upper and lower main longitudinal component in trusses or arches extending the full length of the structure. (*Membrure*)

Coating – The generic term for paint, lacquer, enamel, sealers, galvanizing, metalizing, etc. (*Enduit*)

Culvert – Any bridge that is embedded in fill and is used to convey water, pedestrians or animals through it. (*Ponceau*)

Defect – An identifiable, unwanted condition that was not part of the original intent of design. (*Défaut*)

Deficiency – An identifiable, unwanted condition that was not part of the original intent of the design. (*Défectuosité*)

Department – The Department of Public Works and Government Services Canada. (*Ministère*)

Deterioration – A defect that has occurred over a period of time. (*Détérioration*)

Diagonals – Component which spans between the top and bottom chord of a truss or arch in a diagonal direction. (*Diagonales*)

Distress – A defect produced by repetitive loading. (*Défaillance*)

Engineer – A member or licensee of the Association of Professional Engineers of at least one of the Provinces. (*Ingénieur*)

Evaluation – The determination of the load carrying capacity of structures. (*Évaluation*)

Floor Beam – Transverse beams that span between trusses, arches or girders and transmit loads from the deck and stringers to the trusses, arches or girders. (*Poutres transversales*)

Highway – A common and public thoroughfare including street, avenue, parkway, driveway, square, place, bridge, designed and intended for, or used by, the general public for passage of vehicles, pedestrians or animals. (*Route*)

Lateral Bracing – Bracing which lies in the plane of the top or bottom chords or flanges and provides lateral stability and resistance to wind loads. (*Contreventement horizo*ntal)

Maintenance – Any action which is aimed at preventing the development of defects or preventing deterioration of a structure or its components. (*Entretien*)

Masonry – Structure made up of natural stones separated by mortar joints, usually in uniform courses. Masonry in existing structures is usually in retaining walls, abutments, piers or arches. (*Maçonneri*e)

Masonry, Ashlar – Stone worked to a square shape or cut square with uniform coursing height and vertical joints staggered. The stone has a minimum course height of 200 mm set in joints with an average thickness of 10 mm or less. (*Maçonnerie en pierres de taille*)

Masonry, Squared Stone – Stone in natural bed thicknesses or roughly squared stones with course height less than 200 mm and joints greater than 10 mm but not over 20 mm. (*Maçonnerie en bloc équarris*)

Masonry, Rubble – Stone masonry constructed with rough field stones or only roughly squared stones set in mortar joints with average thickness greater than 20 mm. Also any squared stone masonry in which the joints are greater than 20 mm, but less than 30 mm in thickness. (*Maçonnerie en pierres brutes*)

Minister – The Minister of the Department of Public Works and Government Services Canada or his/her nominee. (*Ministre*)

Owner – A person having jurisdiction and control over the structure. (*Propriétaire*)

Person – An individual, board, commission, department, partnership or corporation, and employees, agents, successors and assigns of any of them. (*Personne physique*)

Plans – All drawings, descriptions and specifications, being parts of the contract, and all drawings and descriptions produced by the constructor for the erection of a bridge or structure, and all revisions thereto. (*Plans*)

Portal Bracing – Overhead bracing at the ends of a through truss or arch and provides lateral stability and shear transfer between trusses. (*Contreventement de portique*)

Primary Components – The main load carrying components of the structure. (*Éléments principaux*)

Rehabilitation – Any modification, alteration, retrofitting or improvement to a structure sub-system or to the structure that is aimed at correcting existing defects or deficiencies. (*Remis en état*)

Repair – Any modification, alteration, retrofitting or improvement to a component of the structure which is aimed at correcting existing defects or deficiencies. (*Réparation*)

Retaining Wall – Any structure that holds back fill and is not connected to a bridge. (*Mur de soutènement*)

Secondary Components – Any components which helps to distribute loads to primary components or carries wind loads, or stabilizes primary components. (*Éléments secondaires*)

Sign Support – A metal, concrete or timber structure, including supporting brackets, service walks and mechanical devices where present, which support a luminaire, sign or traffic signal and which span or extend over a highway. (*Support de panneau de signalisation*)

Span – The horizontal distance between adjacent supports of the superstructure of a bridge, or the longest horizontal dimension of the cross-section of a culvert or tunnel taken perpendicular to the walls. (*Travée*)

Stringers – Stringers span between floor beams and provide the support for the deck above. (*Longeron*)

Structure – Bridge, culvert, tunnel, retaining wall or sign support. (*Ouvrage*)

Sway Bracing – Vertical bracing spanning between through trusses or arches, or outside of half-through trusses or arches and providing lateral stability and shear transfer between the trusses or arches. (*Contreventement oblique*)

Tunnel – Any bridge that is constructed through existing ground, and is used to convey highway or railway traffic through it. (*Tunnel*)

Verticals – Components which span between the top and bottom chords of a truss or arch in the vertical direction. (*Barres verticales*)

PWGSC – Department of Public Works and Government Services Canada. (*TPSGC*)

TAC – Transportation Association of Canada. (*ATC*)

CSA – Canadian Standards Association. (*CSA*)

Bridge Inspection Manual

PART 1 – TECHNICAL INFORMATION

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PART 1 – TECHNICAL INFORMATION

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SECTION 1 – STRUCTURAL INSPECTIONS

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1.1 General

1.1.1 Types of Inspection

For the types of inspections, refer to the current Real Property Branch Inspection and Evaluation Procedures for bridges.

For detailed inspection procedures, safety regulations, inspection equipment, etc., refer to Part 2, Section 1 – Inspections, in this manual.

For overall condition and functional ratings refer to Part 2, section 2, of this manual.

SECTION 2 – MATERIAL DEFECTS

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2.1 Material Defects

This section describes the defects that are normally found in concrete, steel, wood, masonry, aluminum, asphalt pavements and coatings. Each defect is briefly described and the causes producing it are identified. Severity levels, wherever possible, are established.

2.2 Concrete

Concrete is used in structures as plain concrete, such as in tremie or mass concrete, combined with conventional steel reinforcement as reinforced concrete, or prestressed using steel reinforcement.

Defects in concrete can often be attributed to the lack of durability of the concrete resulting from the composition of the concrete, poor placement practices, poor quality control or the hostile environment in which it is placed.

The following are the most common defects in concrete and are described below:

- Scaling;
- Disintegration;
- Erosion;
- Corrosion of Reinforcement;
- Delamination;
- Spalling;
- Cracking
- Alkali-Aggregate Reaction;
- Surface Defects.

2.2.1 Scaling

Scaling is the localized flaking or loss of a portion of the surface of concrete or mortar resulting from the cumulative effect of freezing and thawing. Scaling is common in non air-entrained concrete but can also occur in air-entrained concrete if the concrete is fully saturated. Scaling is more prevalent in poorly finished or overworked concrete that has too much fine aggregate and not enough entrained air near the surface. Scaling of concrete is illustrated in Figure 2.2.1.

Severity

Light	–	Loss of surface mortar to a depth of up to 5 mm without exposure of coarse aggregate.
Medium	–	Loss of surface mortar to a depth of 6 to 10 mm with exposure of some coarse aggregates.
Severe	–	Loss of surface mortar to a depth of 11 mm to 20 mm with aggregate particles poking out of the concrete and some particles lost.
Very Severe	–	Loss of surface mortar and aggregate particles to a depth greater than 20 mm.

2.2.2 Disintegration

Disintegration is the physical deterioration or breakdown of concrete into small fragments or particles. The deterioration usually starts in the form of scaling and is considered to be disintegration when it is allowed to progress beyond the level of very severe scaling. Disintegration may be caused by de-icing chemicals, sulphates, chlorides or frost. Disintegration of concrete is illustrated in Figure 2.2.2.

Severity

Light	–	Loss of section to a depth of up to 25 mm with some loss of coarse aggregate.
Medium	–	Loss of section to a depth of 25 mm to 50 mm with considerable loss of coarse aggregate and exposure of reinforcement.
Severe	–	Loss of section to a depth of 50 mm to 100 mm with substantial loss of coarse aggregate and exposure of reinforcement over a large area.
Very Severe	–	Loss of section to a depth of more than 100 mm extending over a large area.

2.2.3 Erosion

Erosion is the deterioration of concrete by water, sand or gravel scrubbing against the surface. Flowing ice is another form of erosion that can also cause damage. Erosion is sometimes combined with the chemical action of air and water-borne pollutants, which accelerates the breakdown of the concrete.

Erosion is usually an indication that the concrete is not durable enough for the environment in which it has been placed. Severe erosion of a concrete footing is shown in Figure 2.2.3.

Severity

Light	–	Loss of section to a depth of up to 25 mm with some loss of coarse aggregate.
Medium	–	Loss of section to a depth of 25 mm to 50 mm with considerable loss of coarse aggregate and exposure of reinforcement.
Severe	–	Loss of section to a depth of 50 mm to 100 mm with substantial loss of coarse aggregate and exposure of reinforcement over a large area.
Very Severe	–	Loss of section to a depth of more than 100 mm extending over a large area.

2.2.4 Corrosion of Reinforcement

Corrosion is the deterioration of reinforcement by electrolysis. The alkali content of concrete protects the reinforcement from corrosion. However, when chloride ions above a certain concentration are dissolved in water and penetrate through the concrete to the reinforcement, the protection breaks down and corrosion begins. In the early stages, corrosion may appear as a rust stain on the concrete surface. In the advanced stages, the concrete covering the reinforcement cracks, delaminates and flakes off, exposing heavily rusted reinforcement. The corrosion process is illustrated in Figure 2.2.4(a).

Severity

Light	–	Light rust stains on the concrete surface.
Medium	–	Exposed reinforcement covered with an even layer of light rust. Loss of reinforcing steel section less than 10%.
Severe	–	Exposed reinforcement with heavy rusting and localized pitting. Loss of reinforcing steel section between 10% and 20%.
Very Severe	–	Exposed reinforcement with very heavy rusting and pitting. Loss of reinforcing steel section over 20%.

2.2.5 Delamination

Delamination is defined as a discontinuity of the surface concrete, which becomes substantially separated but not completely detached from the concrete below or above it. The surface may appear to be solid, but if a hollow sound is heard when the surface is tapped or a chain is dragged across it, the concrete may have delaminated. Delamination is the result of corrosion of the reinforcing steel and subsequent cracking of the concrete. However, if the bars are closely spaced, the cracking extends in the plane of the reinforcement parallel to the exterior surface of the concrete. Delamination of a concrete beam is shown in Figure 2.2.5.

Delamination or debonding may also occur in concrete that has been patched or overlaid due to ongoing deterioration of the older concrete. This can happen even if the reinforcing steel has not rusted.

Severity

Light	–	Delaminated area measuring less than 150 mm in any direction.
Medium	–	Delaminated area measuring 150 mm to 300 mm in any direction.
Severe	–	Delaminated area measuring 300 mm to 600 mm in any direction.
Very Severe	–	Delaminated area measuring more than 600 mm in any direction.

2.2.6 Spalling

Spalling of a concrete structure occurs when a fragment of concrete becomes detached.

Spalling is a continuation of the delamination process whereby external loads and pressure exerted by corrosion of the reinforcing steel or the formation of ice in the delaminated area causes the delaminated concrete to break off. Spalled areas have sharp edges. Extensive severe spalling of a concrete beam and localized severe spalling of a concrete deck are illustrated in Figures 2.2.6(a) and 2.2.6(b) respectively.

Vehicular, ice flow or other impact forces on exposed concrete edges, deck joints or construction joints may also result in the spalling or breaking off of pieces of concrete locally.

Spalling may also be caused by excess compressive loading of the concrete, which breaks the top layer to the depth of the outer layer of concrete around the reinforcement. Spalling may also occur in areas of localized high compression.

Spalling may also occur in areas of localized high compressive load concentrations, such as at structure supports, or at anchorage zones in post-tensioned concrete.

Spalling may also occur in patched areas if the old concrete continues to deteriorate and the patch breaks off.

Severity

Light	–	Spalled area measuring less than 150 mm in any direction or less than 25 mm in depth.
Medium	–	Spalled area measuring between 150 mm to 300 mm in any direction or between 25 mm and 50 mm in depth.
Severe	–	Spalled area measuring between 300 mm to 600 mm in any direction or between 50 mm and 100 mm in depth.
Very Severe	–	Spalled area measuring more than 600 mm in any direction or greater than 100 mm in depth.

2.2.7 Cracking

A crack is a linear fracture which extends partly or completely through a concrete member. Cracks in concrete occur as a result of tensile stress. The tension is initially carried by the concrete and reinforcement until the amount of force exceeds the tensile strength (modulus of rupture) of the concrete. The concrete then cracks and all of the tension is transferred to the steel reinforcement. In reinforced and prestressed concrete, the width and distribution of cracks are limited by the reinforcement, whereas in plain concrete, there are no such limiting factors.

The build-up of tensile stresses and, therefore, cracks in concrete may be due to external loading, external restraining forces, internal restraining forces, differential movement and settlement, or corrosion of the reinforcement. External loads generate a system of internal compressive and tensile stresses in the members and components of the structure that is needed to maintain static equilibrium. Cracks resulting from external loading initially appear as hairline cracks and are harmless. However, as the reinforcement is further stressed, the initial cracks open up and gradually spread into numerous wider cracks. Figure 2.2.7(a) shows typical flexure, shear, axial and torsional cracks caused by external loading.

External restraining forces are generated if the concrete is prevented from moving freely in response to the effects of temperature, creep and shrinkage by restraint at the member supports. The restraint may consist of friction at the bearings, bonding to already hardened concrete or attachment to other components of the structure. Cracks resulting from the action of external restraining forces develop in a similar manner as cracks caused by external loading. Figure 2.2.7(b) shows restraint-induced cracking due to an increase in temperature on the top surface of a beam.

Internal restraining forces are produced by differential expansion or contraction of the outer surface of the concrete relative to the interior mass of the concrete, as in plastic shrinkage. The resulting surface cracks are normally shallow and appear as pattern cracks, checking and D-cracks. Figure 2.2.7(c) shows medium pattern cracking in an abutment wall.

Differential movement or settlement results in the redistribution of external reactions and internal forces in the structure. This may in turn add tensile stresses and therefore cause cracking in the concrete components of the structure. Movement cracks can be in any direction and of any width, ranging from fine cracks above the reinforcement due to formwork settlement to wide cracks resulting from foundation or support settlement. Figure 2.2.7(d) illustrates movement-induced cracks.

Corrosion of reinforcement produces the types of cracks described in 2.2.4. Corrosion-related cracks are illustrated in Figure 2.2.7(e).

Severity

Hairline cracks	–	less than 0.1 mm wide.
Narrow cracks	–	0.1 mm to 0.3 mm wide.
Medium cracks	–	0.3 mm to 1.0 mm wide.
Wide cracks	–	greater than 1.0 mm wide.

2.2.8 Alkali-Aggregate Reaction

Some aggregates react adversely with the alkalis in cement to produce a highly expansive substance called alkali-silica gel. The expansion of the gel and aggregate under damp conditions causes cracking and deterioration of the concrete. The cracking occurs through the entire mass of the concrete (Reference 1). Alkali-aggregate reactions are normally slow by nature, and the results may not be apparent for many years. Once the alkali-aggregate reaction starts, there are no remedial measures to stop or reverse the process of deterioration. The appearance of concrete affected by alkali-aggregate reactions is shown in Figure 2.2.8.

Severity

Light	–	Hairline pattern cracks, widely spaced, with no visible expansion of the concrete mass.
Medium	–	Narrow pattern cracks, closely spaced, with visible expansion of the concrete mass.
Severe	–	Medium to wide pattern cracks, closely spaced, with visible expansion and deterioration of concrete.
Very Severe	–	Wide pattern cracks, closely spaced, with extensive expansion and deterioration of concrete.

2.2.9 Surface Defects

The following surface defects (described below) can appear in concrete:

- Stratification;
- Segregation;
- Cold Joints;
- Deposits – efflorescence, exudation, incrustation, stalactite;
- Honeycombing;
- Pop-outs;
- Abrasion and Wear;
- Slippery Surface.

Surface defects are not necessarily serious in themselves; however, they are indicative of a potential weakness in the concrete, and their presence should be noted but not classified as to severity, except for honeycombing and pop-outs.

STRATIFICATION is the separation of the concrete components into horizontal layers in overwetted or overvibrated concrete. Water, laitance, mortar and coarse aggregates occupy successively lower positions. A layered structure in concrete will also result from the placing of successive batches that differ in appearance.

SECTION 2 – MATERIAL DEFECTS

SEGREGATION is the differential concentration of the components of mixed concrete resulting in non-uniform proportions in the mass. Segregation is caused by concrete falling from a height, with the coarse aggregates settling to the bottom and the fines on top. Another form of segregation occurs where reinforcing bars prevent the uniform flow of concrete between them.

COLD JOINTS are produced if there is a delay between the placement of successive pours of concrete and an incomplete bond develops at the joint due to the partial setting of the concrete in the first pour.

DEPOSITS are often left behind where water percolates through the concrete and dissolves or leaches chemicals from it and deposits them on the surface. Deposits may appear as the following:

Efflorescence – a deposit of salts, usually white and powdery.

Exudation – a liquid or gel-like discharge through pores or cracks in the surface.

Incrustation – a hard crust or coating formed on the concrete surface.

Stalactite – a downward pointing formation hanging from the concrete surface, usually shaped like an icicle.

HONEYCOMBING is the result of improper or incomplete vibration of the concrete which leaves voids in the concrete where the mortar failed to completely fill the spaces between the coarse aggregate particles. Figure 2.2.9 shows severe honeycombing in the underside of a deck slab.

Severity

Light – Honeycombing covering an area less than 150 mm in any direction.

Medium – Honeycombing covering an area between 150 mm to 300 mm in any direction.

Severe – Honeycombing covering an area between 300 mm and 600 mm in any direction.

Very Severe – Honeycombing covering an area greater than 600 mm in any direction.

POP-OUTS are shallow, typically conical depressions caused by small portions of the concrete surface breaking away due to frost action or the expansion of some aggregate. The shattered aggregate particles may be found at the bottom of the depression, with some of the aggregate still adhering to the popped-out cone.

Severity

Light – Pop-outs leaving holes up to 25 mm in diameter.

Medium – Pop-outs leaving holes between 25 mm and 50 mm in diameter.

Severe – Pop-outs leaving holes between 50 mm and 100 mm in diameter.

Very Severe – Pop-outs leaving holes greater than 100 mm in diameter.

ABRASION is the deterioration of concrete brought about by vehicles or snow-plough blades scraping against concrete surfaces, such as, decks, curbs, barrier walls or piers.

WEAR is usually the result of dynamic and/or frictional forces generated by vehicular traffic, coupled with the abrasive influx of sand, dirt and debris. It can also result from the friction of ice or water-borne particles against partly or completely submerged members. The surface of the concrete appears polished.

SLIPPERY CONCRETE SURFACES may result from the polishing of the concrete deck surface by the action of repetitive vehicular traffic.

Severity

There are no severity descriptions given for slippery concrete surfaces as this is a serious and potentially hazardous situation. Report to the regional manager or engineer immediately any evidence of a slippery concrete deck surface.

Figure 2.2.1 Severe Scaling in a Concrete Deck and Curb

Figure 2.2.2 Very Severe Disintegration of the Outer Surface of Concrete

Figure 2.2.3 Very Severe Erosion of a Concrete Footing

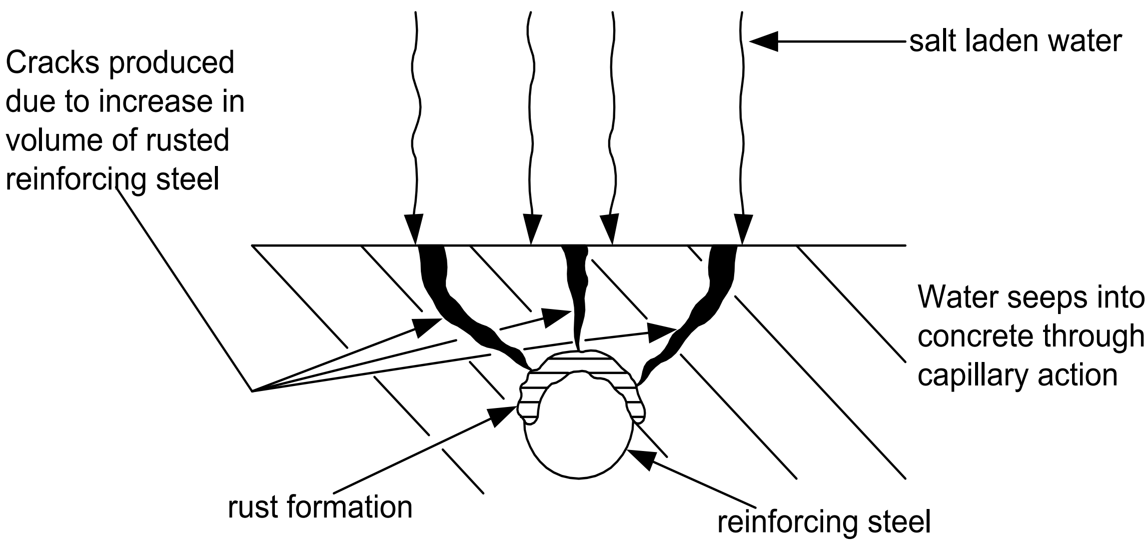


Figure 2.2.4(a) Process Leading to Corrosion of Reinforcement

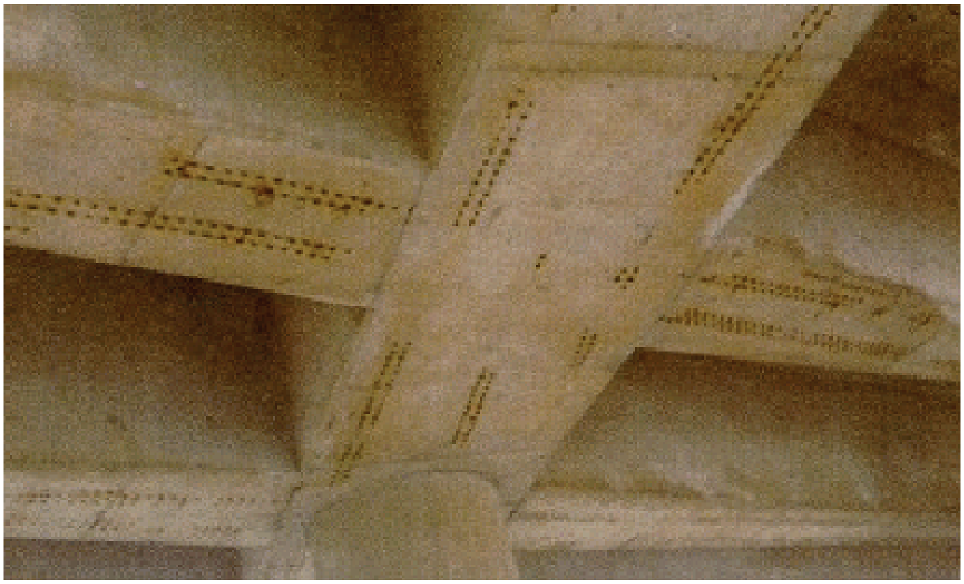


Figure 2.2.4(b) Light Stains on Concrete Surface Indicating Corrosion of Reinforcement

Figure 2.2.5 Very Severe Spalling and Delamination in Concrete Beams

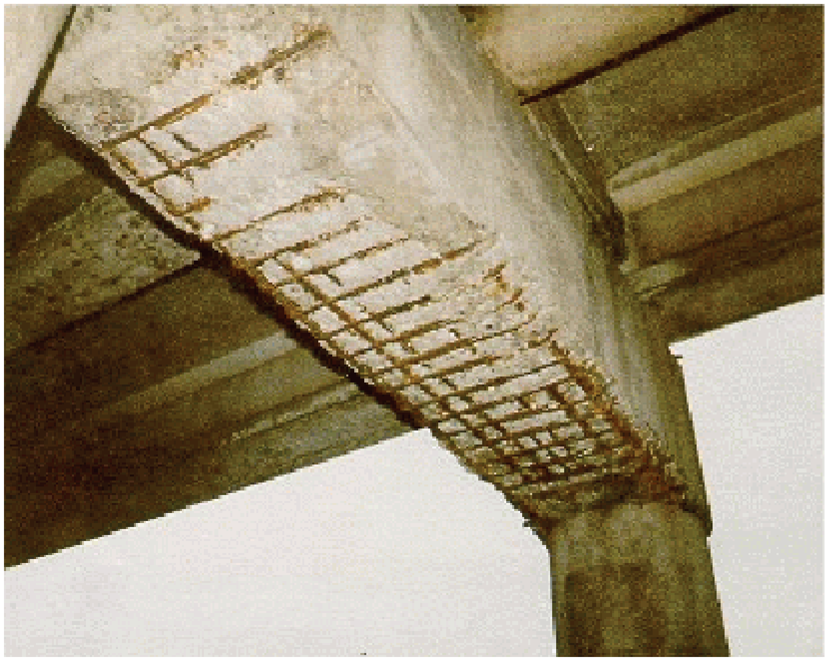


Figure 2.2.6(a) Very Severe Spalling in a Concrete Pier Cap due to Corrosion of Reinforcement

Figure 2.2.6(b) Severe Localized Spalling

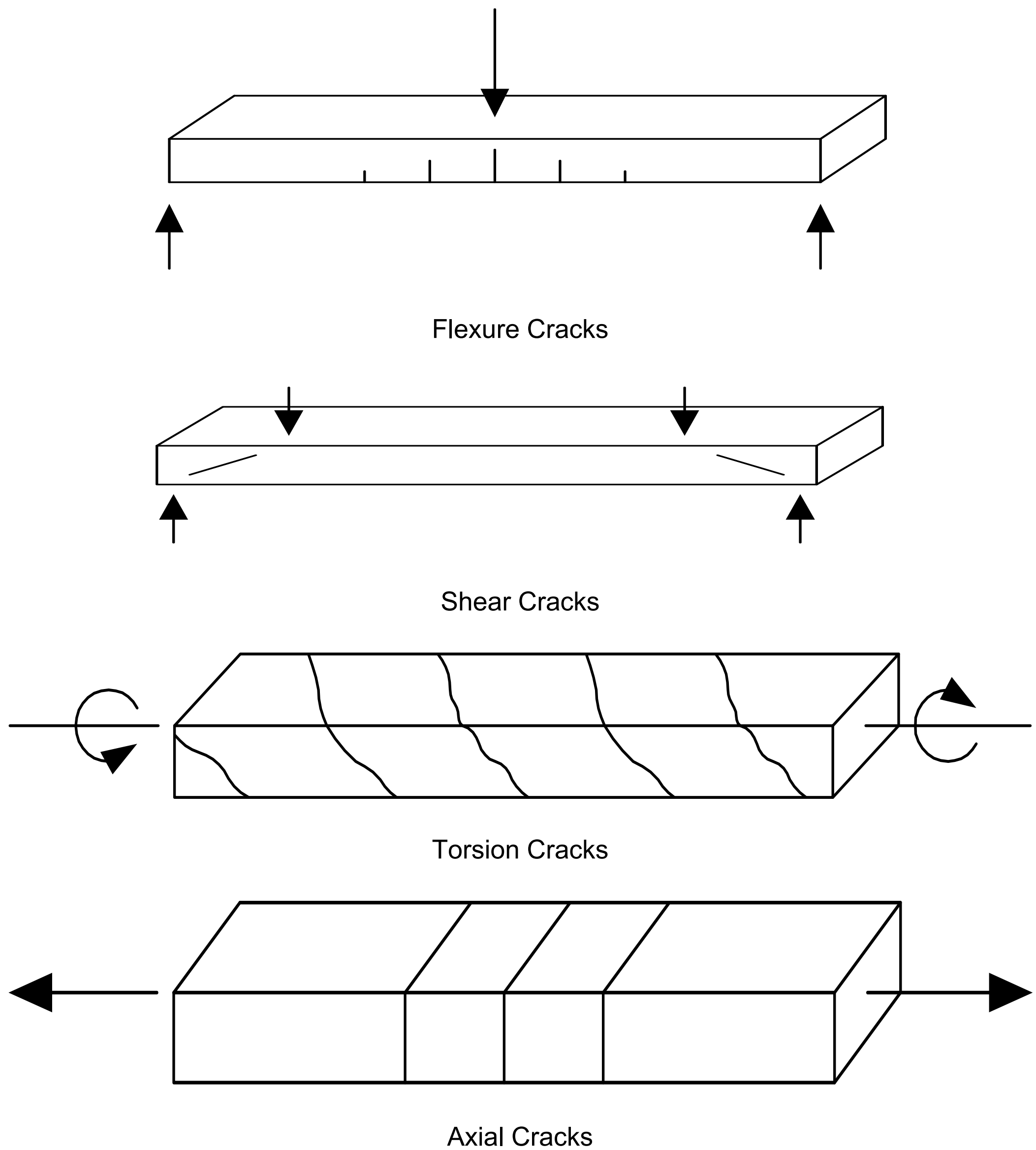


Figure 2.2.7(a) Cracks Caused By Loading

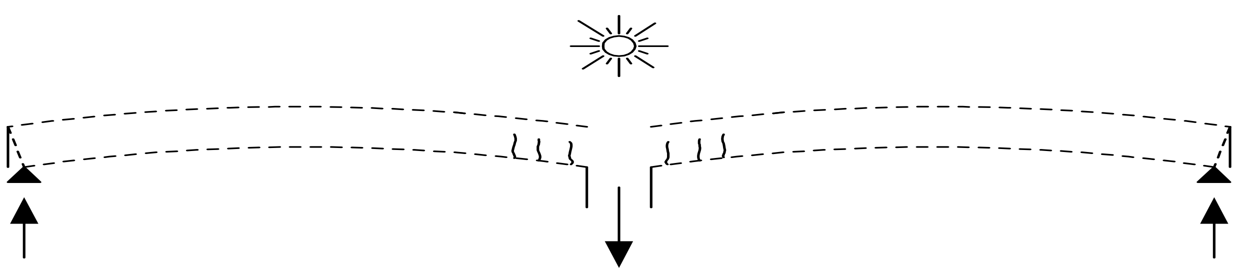


Figure 2.2.7(b) External Restraint-Induced Cracks
(due to temperature increase in top surface of beam)

Figure 2.2.7(c) Medium Pattern Cracks in an Abutment

Figure 2.2.7(d) Very Wide Movement Crack in an Abutment

Figure 2.2.7(e) Medium cracks due to Corrosion of Reinforcement

Figure 2.2.8 Severe Alkali-Aggregate Reaction

Figure 2.2.9 Severe Honeycombing on the Underside of a Deck Slab

2.3 Steel

The use of steel has progressed from cast iron, wrought iron, rivet steel and plain carbon steel to low-alloy atmospheric corrosion resistant steel (weathering steel) and notch tough low-temperature steel. Connection details have also evolved as steel has changed. Bolted or welded connections using high-strength steel bolts and advanced automated welding techniques reflect the present state of the art.

The following are the most common defects in steel and are described below:

- Corrosion;
- Permanent deformation;
- Cracking in welds and parent material;
- Loose connections.

2.3.1 Corrosion

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

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

Weathering steel, on the other hand, will form a relatively smooth rust layer, called a patina, which protects the underlying metal from further corrosion. However, in less than ideal circumstances, the patina may not form or may be penetrated and delaminated, resulting in progressive corrosion (References 2, 3).

For weathering steel to form a tightly adherent patina, the following conditions must be met:

- the steel must be exposed to intermittent wetting and drying cycles;
- corrosive contaminants, especially salt bearing water, must be absent;
- the steel surfaces must be kept clean and free of entrapped dirt, debris and moisture.

In addition to the above, mill scale is often left on weathering steel to "weather off", except where it is removed for appearance. However, if the mill scale is scratched, then the underlying metal may corrode.

Corrosion in steel is illustrated in Figure 2.3.1.

Severity

Light	–	Loose rust formation and pitting in the paint surface. No noticeable section loss.
Medium	–	Loose rust formation with scales or flakes forming. Definite areas of rust are noticeable. Up to 10% section loss.
Severe	–	Stratified rust with pitting of the metal surface. Between 10% to 20% section loss.
Very Severe	–	Extensive rusting with local perforation or rusting through. In excess of 20% section loss.

2.3.2 Permanent Deformation

Permanent deformation of steel members can take the form of bending, buckling, twisting or elongation, or any combination of these. Permanent deformations may be caused by overloading, vehicular collision, or inadequate or damaged intermediate lateral supports or bracing. See Figure 2.3.2.

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

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

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

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

Severity

As permanent deformations may be critical to the integrity of the member and/or structure, no severity ratings are given. However, the location of the deformation in the member, and of the member in the structure, should be recorded.

Photographs and measurements of the amount and extent of deformation shall be taken and recorded for analysis by an engineer.

2.3.3 Cracking

A CRACK is a linear fracture in the surface of steel or a weld. Cracks are mainly caused by fatigue and can, under certain conditions, lead to a brittle fracture.

A BRITTLE FRACTURE is a crack that runs all the way through the component that usually occurs without prior warning or plastic deformation. A brittle fracture may result at fatigue-prone details after initial fatigue cracking.

FATIGUE PRONE DETAILS are those details that are susceptible to the growth of fatigue cracks. Details in fatigue stress categories E and F, which are most susceptible to fatigue crack growth, are illustrated in References 9 and 10.

FRACTURE-CRITICAL COMPONENTS are components which are subject to tensile stresses in a single load path structure and the failure of which could lead to collapse of the structure.

Any attachment that has a length in the direction of tension stress greater than 100 mm and is welded to the tension area of a fracture-critical component must also be considered to be fracture critical.

The primary factors leading to fatigue cracking are: the number of applied stress cycles, which is a function of the volume of traffic; the magnitude of the stress range, which depends on the applied live load; and the fatigue strength of the connection detail, category A to W, as indicated in CSA S6. Cracks caused by fatigue usually occur at points of tensile stress concentration, at welded attachments or at weld termination points. Cracks may also be caused or aggravated by overloading, vehicular collision or loss of section resistance due to corrosion. Other contributing factors are stress concentrations due to the poor quality of fabricated details and the fracture toughness of materials used. Material fracture toughness will determine the size of crack that can be tolerated before fracture occurs.

Welded details are more prone to cracking than bolted or riveted details. Grinding welds down to make them smooth or flush with the joined metal surfaces improves fatigue resistance. Once cracking occurs in a welded connection, it can extend into other components due to a continuous path provided at the welded connection, possibly leading to a brittle fracture.

Bolted or riveted connections may also develop fatigue cracking, but a crack in one component will generally not pass through into the others. Bolted and riveted connections are also susceptible to cracking or tearing resulting from prying action, and by a build-up of corrosion forces between the parts of the connection.

Cracking which has resulted in a brittle fracture in a diaphragm beam is shown in Figure 2.3.3(a).

Common locations susceptible to cracking are illustrated in Figure 2.3.3(b). As cracks may be concealed by rust, dirt or debris, the suspect surfaces should be cleaned prior to inspection.

Severity

Cracks that run parallel to the direction of stress are usually not very serious; however, cracks that run perpendicular to the direction of stress are very serious. In either case, cracks in steel or connections should generally be considered serious, as a parallel crack may for a number of reasons turn into a perpendicular crack. Therefore, no severity description for cracks is given. Any crack should be carefully noted and recorded as to its specific location in the member and the location of the member in the structure. The length, width (if possible) and direction of the crack should also be recorded.

2.3.4 Loose Connections

Loose connections can occur in bolted or riveted connections and may be caused by corrosion of the connector plates or fasteners, excessive vibration, overstressing, cracking, or the failure of individual fasteners.

Loose connections are not always detectable by visual inspection. Cracking or excessive corrosion of the connector plates or fasteners or permanent deformation of the connection or members framing into it may be indications of a loose connection. Tapping the connection with a hammer is one method of determining if the connection is loose.

Severity

The severity of loose connections depends largely on the number of loose or missing fasteners relative to the total number in the connection. That ratio must therefore be established in order to determine severity. In the case of beam connections, the flange and web connections must be considered separately. Also, where several members meet at a common connection, the individual connection to each member must be considered separately. In addition, a sketch should be made showing the layout of the connection and the location of loose or missing fasteners.

Light – Up to 5% of fasteners loose or missing.

Medium – 5 to 10% of fasteners loose or missing.

Severe – 10 to 20% of fasteners loose or missing.

Very Severe – Over 20% of fasteners loose or missing.

Figure 2.3.1 Medium Corrosion of Steel Beams

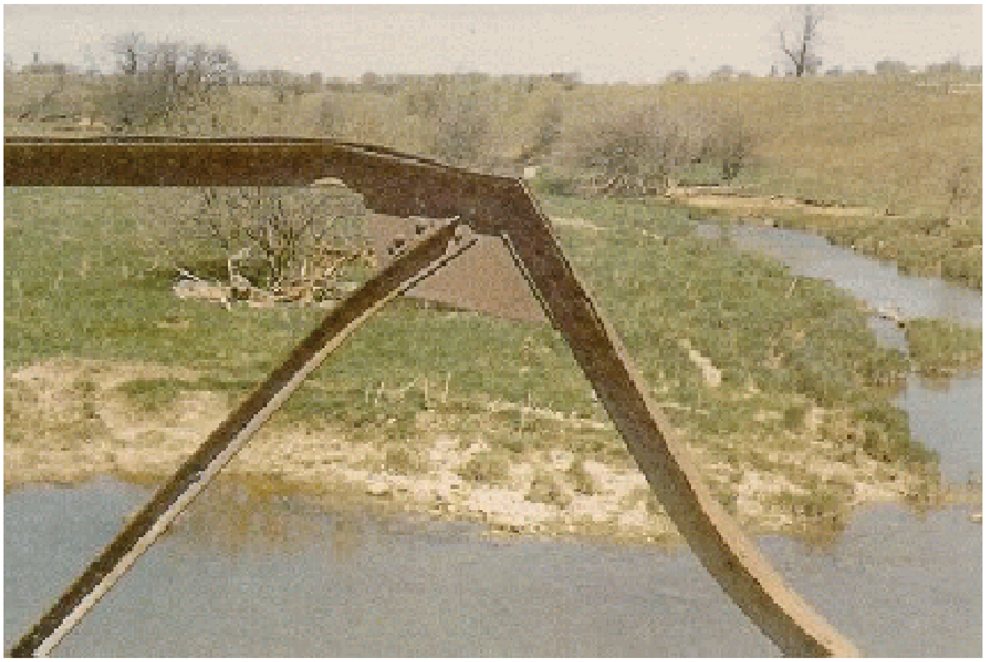
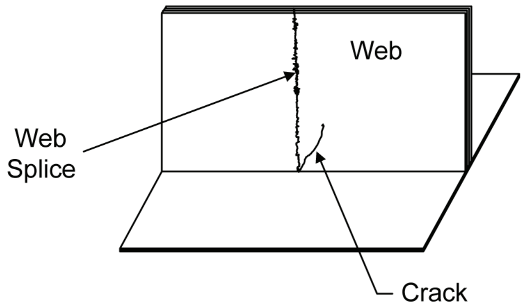
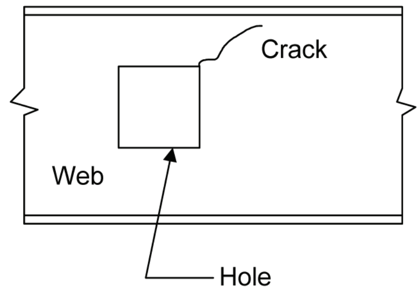


Figure 2.3.2 Very Severe Permanent Deformations caused by Impact

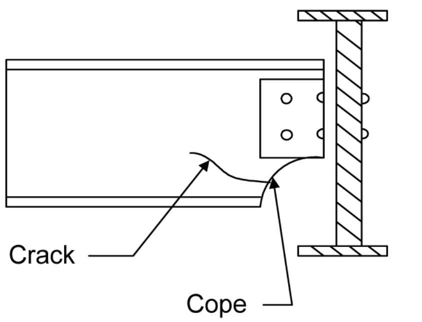
Figure 2.3.3(a) Very Wide Cracks in a Diaphragm



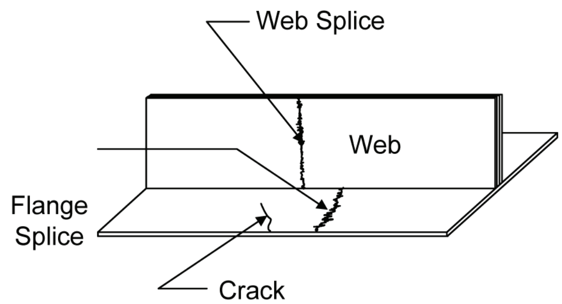
Crack in Web at Web Splice



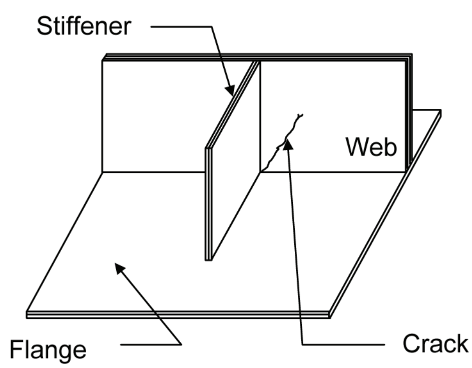
Crack at Hole in Web



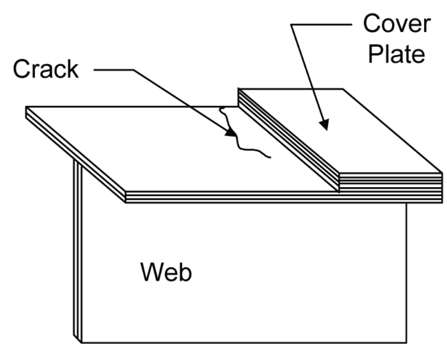
Crack in Cope of Web at a Connection



Crack in Flange at Flange Splice

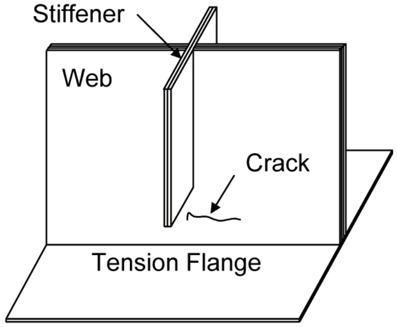


Crack in Web at Stiffener

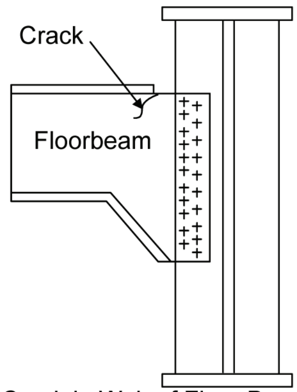


Crack at End Weld of Flange Cover Plate

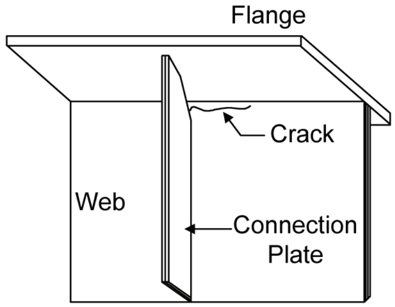
Figure 2.3.3(b) Common Crack Locations in Steel



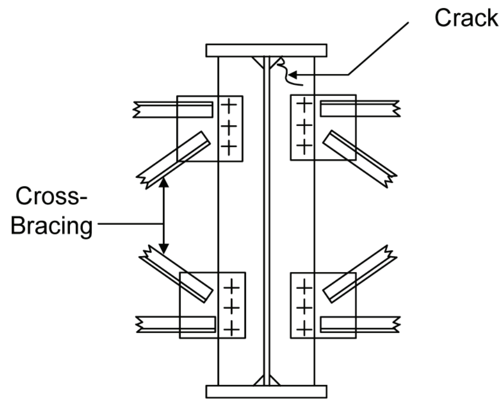
Girder Web Crack Between Cut-Short Stiffener and Tension Flange



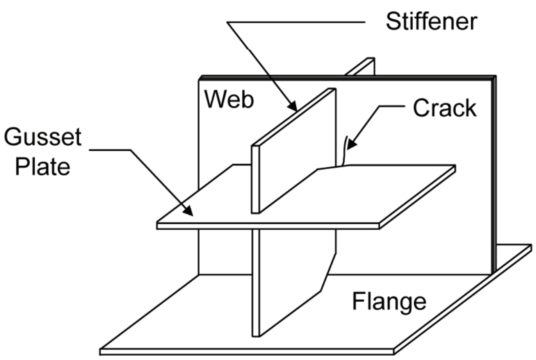
Crack in Web of Floor Beam at Cut-Short Tension Flange



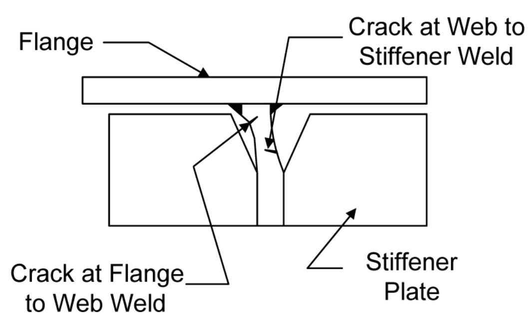
Girder Web Crack Behind Chamfer of Connection Plate



Crack in Cross-Bracing Connection Plate



Vertical Web Crack Behind Chamfer of Horizontal Gusset Plate



Cracks at Double Curvature in Web Plate From Flange Movements

Figure 2.3.3(b) Common Crack Locations in Steel (cont'd)

2.4 Wood

Wood was one of the earliest materials used for structures, and is still in common use today. This is largely due to its availability in a variety of structural sizes and ease of handling.

The following defects commonly occurring in wood are described:

- Weathering, checks, splits and shakes;
- Rot or decay;
- Insect damage;
- Abrasion and wear;
- Cracking, splintering, crushing and shattering;
- Fire and chemical damage;
- Loose connections.

2.4.1 Weathering, Checks, Splits and Shakes

Weathering is the gradual deterioration of wood due to exposure to sun, rain, wind, frost and atmospheric pollutants. Weathering of untreated wood is accompanied by softening of the surface layer, numerous small checks, splits and shakes, a grey discoloration and “barn-board” appearance. Treated wood weathers more slowly to a grey-brown colour and may exhibit a rough “wash-board” appearance. Light weathering is shown in Figure 2.4.1(a).

Checks are longitudinal tissue separations on the side grain of wood members.

Splits are more severe tissue separations extending from the side into the end grain.

Shakes are tissue separations which follow the annual growth rings and are usually visible on the end grain.

Checks, splits and shakes are illustrated in Figure 2.4.1(b).

Severity

Light	–	Tissue separations are short and extend for less than 5% into the member.
Medium	–	Tissue separations are long and extend for 5% to 10% into the member.
Severe	–	Tissue separations are long and extend for 10% to 20% into the member.
Very Severe	–	Tissue separations are long and extend for more than 20% into the member.

2.4.2 Rot and Decay

Rot or decay is the biological breakdown of wood caused by microorganisms called fungi. It is a gradual process that usually begins at a crack, a knot, a hole or the end of a piece of wood. The conditions needed for fungi to grow are sufficient moisture and oxygen and a favourable (warm) temperature. The absence of any of these conditions will greatly inhibit or completely prevent the growth of fungi. The most common method of reducing rot is to pressure treat the wood with preservatives.

The following areas are typically prone to decay:

- Wood in contact with soil;
- Wood at the water line;
- Areas water can be trapped, such as connections and bearing points;
- At checks, splits, shakes and cracks, which can allow moisture to penetrate the wood.

Three types of rot can be identified in wood: white rot, brown rot and soft rot.

White rotted wood has a bleached appearance, and in advanced stages the wood appears as a grey fibrous mass. The rot develops at or above ground contact and may attack both the surface and interior portions of the wood.

Brown rotted wood has a reddish-brown appearance, and in advanced stages the wood has a checked or crumbly surface. Brown rot develops at or above ground contact and may attack both the surface and interior portions of the wood.

Soft rotted wood has a soft, spongy surface, and in advanced stages the wood has a charred appearance. Soft rot usually develops below ground level or under water, and usually attacks only the surface of the wood.

The surface appearance of rotted wood is shown in Figure 2.4.2.

Severity

Light – Slight change in colour. The wood sounds solid and cannot be penetrated by a sharp object.

Medium – Surface is discoloured with black and brown streaks. The wood sounds hollow when tapped and offers limited resistance to penetration by a sharp object.

Severe – Surface is fibrous, checked or crumbly and fungal fruiting bodies are growing on it. The wood sounds hollow when tapped and offers little resistance to penetration by a sharp object.

Very Severe – The wood can be crumbled and disintegrated with ease.

2.4.3 Insect Damage

Defects in wood caused by insects are a consequence of tunnelling and boring by larvae or mature insects through the wood, resulting in loss of section. Termites, carpenter ants and wood-boring beetles are the most common insects that attack wood. They are shown in Figure 2.4.3(a), and the resulting appearance of insect-damaged wood is shown in Figure 2.4.3(b).

The severity of the insect damage can be judged by the number of holes and tunnels on the surface of the wood and by the number of insects around the area.

Severity

Light – Occasional entrance or exit holes are present. The wood is solid and cannot be easily penetrated by a sharp object.

Medium – Several entrance or exit holes are visible, and larvae or mature insects may be observed. The wood sounds hollow when tapped, and offers limited resistance to penetration by a sharp object.

Severe – Extensive tunnelling and holes are present in the wood. Larvae and insects are readily visible. The wood sounds hollow when tapped, and offers little resistance to penetration by a sharp object.

Very Severe – Extensive tunnelling, holes, larvae and insects present. Wood can be crumbled and is disintegrated with ease.

2.4.4 Abrasion and Wear

Abrasion is the deterioration of wood brought about by vehicles or snowplough blades scraping against wood surfaces, such as, decks, curbs, railings or piers.

Wear is usually the result of dynamic and/or frictional forces generated by vehicular traffic, coupled with the abrasive influence of sand, dirt or debris. It can also result from the friction of ice or water-borne particles against partly or completely submerged members. The surface of the wood appears worn and cracked with some loss of section. Wear of a wood deck and abrasion by ice are illustrated in Figures 2.4.4(a) and 2.4.4(b) respectively.

Severity

Light	–	Slight surface wear with less than 5% section loss.
Medium	–	Surface wear more noticeable with 5% to 10% section loss.
Severe	–	Loss of section between 10% to 20%.
Very Severe	–	Loss of section in excess of 20%.

2.4.5 Cracking, Splintering, Crushing and Shattering

Cracking, splintering, crushing and shattering are forms of physical damage which result from vehicular collision or from overloading of a member. Particularly susceptible are members already weakened by rot or insect attack.

A crack is an incomplete separation of the wood into two or more parts with or without space in between. Cracking across the grain is caused by flexural damage through overloading. Cracking along the grain may be due to shear failure or a continuation of a split.

Splintering is a series of localized tensile failures in the wood where fragmented parts of the wood may protrude from the surface.

Crushing is a form of permanent deformation where a portion of the wood has lost its elasticity. Crushing at the bearings occurs due to excessive compression. Crushing may also occur prior to a flexural failure.

Shattering is a combined form of crushing and splintering resulting from impact.

Crushing and splintering of wood due to vehicular impact is shown in Figure 2.4.5.

Severity

Light	–	Damage is mainly superficial with less than 5% section loss.
Medium	–	Considerable damage with 5% to 10% section loss.
Severe	–	Significant damage with 10% to 20% section loss.
Very Severe	–	Extensive damage with section loss in excess of 20%.

2.4.6 Fire and Chemical Damage

Fire damage is evidenced by charring and is usually confined to the wood surface. Connectors may sustain more damage from fire than the members connected. Such damage to connections is manifested by large deformations of the connector plates and fasteners, and by loose or misaligned joints.

Chemical damage may result from the use of non-preservative chemicals on the wood surface over a long period of time or where the wood comes into contact with corrosive chemicals resulting from accidental spills. Such damage affects the wood surface and metal connectors. The chemicals soften and weaken the wood. The effect on metal connector plates and fasteners is less critical except in certain circumstances (on fasteners with low corrosion resistance, for example).

Figures 2.4.6(a) and 2.4.6(b) shows fire and chemical damaged wood.

Severity

Light	–	Slight charring or softening of the wood surface with less than 5% section loss. Connectors unaffected.
Medium	–	Deeper charring or softening with 5% to 10% section loss. Connectors slightly loosened.
Severe	–	Section loss between 10% and 20% with several connectors loosened or deformed.
Very Severe	–	Extensive damage with section loss greater than 20% at critical locations. Many loose and severely deformed connectors.

2.4.7 Loose Connections

Wood members are normally connected with common wire nails, spikes, bolts, shear plates, split rings, metal framing connectors or glulam rivets.

Most connections are loosened due to repetitive or dynamic loads, wear or decay of members connected and corrosion of the connectors.

A loose connection joining wood members is shown in Figure 2.4.7.

Severity

The amount of section loss of the wood or the connector or the looseness of the connection may not always be visibly apparent. It is therefore not always possible to establish a scale of severity.

Where it is possible to determine the number of loose or missing fasteners, the severity should be based on their ratio to the total number of the fasteners in the connection. Where several members meet at a common connection, the connection to each member must be considered individually. In addition, a sketch should be made showing the layout of the connection and the location of loose or missing fasteners.

Light	–	Up to 5% of fasteners loose or missing.
Medium	–	5 to 10% of fasteners loose or missing.
Severe	–	10 to 20% of fasteners loose or missing.
Very Severe	–	Over 20% of fasteners loose or missing.

Where the severity cannot be measured by the number of loose or missing connectors, the dimensions of the observed gap between the components must be measured and recorded under the remarks for the connection on the inspection forms or noted and estimated where measurements cannot be made.

Figure 2.4.1(a) Light Weathering in Wood Members

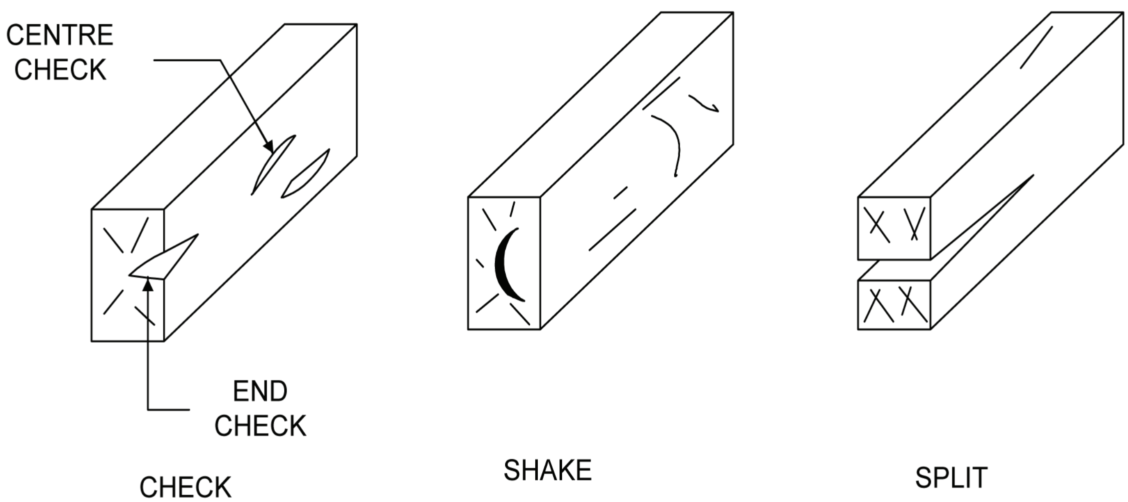


Figure 2.4.1(b) Checks, Shakes and Splits in Wood

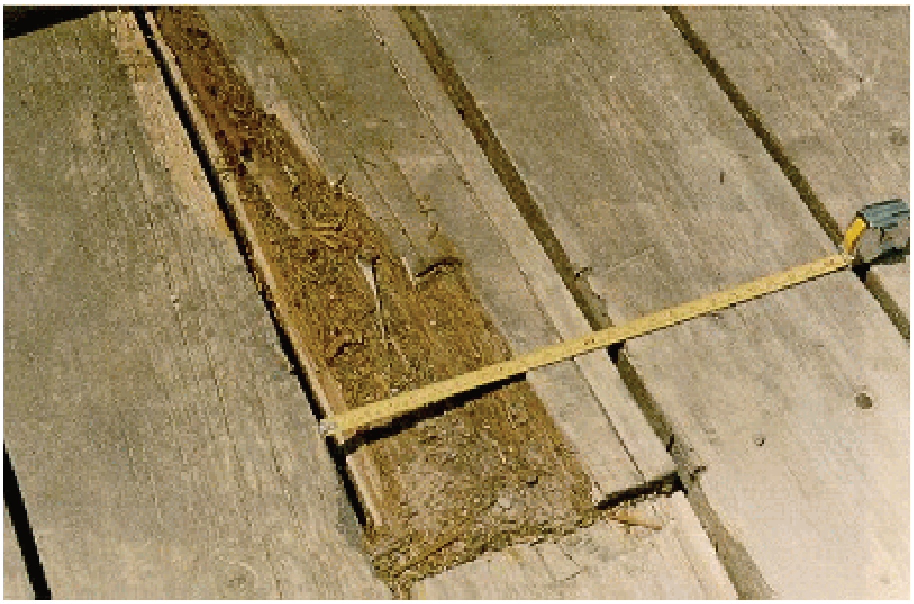
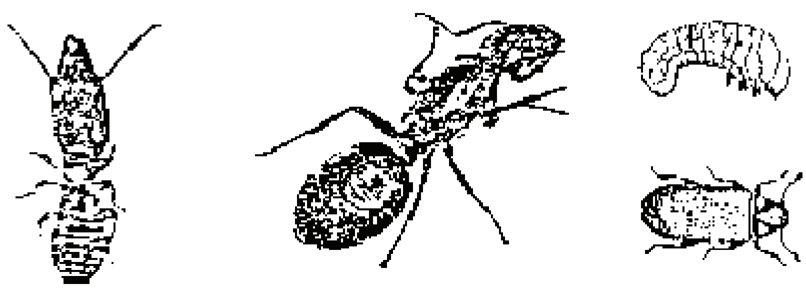


Figure 2.4.2 Very Severe Brown Rot



Termite | Carpenter Ant | Wood-Boring Beetle (larva and adult)

Figure 2.4.3(a) Wood-Boring Insects

Figure 2.4.3(b) Very Severe Insect Damage in Wood

Figure 2.4.4(a) Very Severe Wear in a Wood Deck

Figure 2.4.4(b) Very Severe Abrasion on a Wood Pile Due to Ice

Figure 2.4.5 Very Severe Crushing and Splintering of Wood Due to Vehicular Impact

Figure 2.4.6(a) Medium Fire Damage on Wood

Figure 2.4.6(b) Light Chemical Damage on Underside of a Wood Deck

Figure 2.4.7 Loose Connection in Wood (25 mm gap measured)

2.5 Masonry

Masonry is made of stones or bricks bonded together by mortar. Although not a common construction material today, masonry was used, usually in retaining walls, abutments, piers or arches, primarily in the 19th century while brick masonry was only rarely used in highway structures. Types of masonry construction are ashlar masonry, squared stone masonry and rubble masonry.

The following are the most common defects in masonry and are described below:

- Cracking;
- Splitting, spalling and disintegration;
- Loss of mortar and stone.

2.5.1 Cracking

A crack is an incomplete separation into one or more parts with or without space in between. Cracks develop in masonry as a result of non-uniform settlement of the structure, heat stress, frost action and overloading.

Cracks develop either at the interface between the stone and mortar following a zig-zag pattern when the bond between them is weak or go through the joint and the stone in a straight line when the mortar is stronger than the stone, as shown in Figure 2.5.1.

Severity

Hairline cracks	–	less than 0.1 mm wide.
Narrow cracks	–	between 0.1 and 0.3 mm wide.
Narrow cracks	–	between 0.3 and 1.0 mm wide.
Wide cracks	–	greater than 1.0 mm wide.

2.5.2 Splitting, Spalling and Disintegration

SPLITTING is the opening of seams or cracks in the stone leading to the breaking of the stone into large fragments.

SPALLING is the breaking or chipping away of pieces of the stone from a larger stone.

DISINTEGRATION is the gradual breakdown of the stone into small fragments, pieces or particles.

The splitting, spalling and disintegration of masonry is caused by frost, weathering and abrasion or by the action of acids, sulphates or chlorides, which cause deterioration in certain types of stones, such as limestone. Examples of splitting, spalling and disintegration of masonry are shown in Figure 2.5.2.

Severity

Light	–	Hairline cracks and minor loss of stone surface with up to 50 mm section loss.
Medium	–	Narrow cracks or chipping of stone with 50 mm to 100 mm section loss.
Severe	–	Spalling and disintegration of stone with 100 mm to 150 mm section loss.
Very Severe	–	Extensive spalling and disintegration of stone with more than 150 mm section loss.

2.5.3 Loss of Mortar and Stones

Loss of mortar is the result of the destructive actions of frost, erosion, plant growth or softening by water containing dissolved sulphates or chlorides. Once the mortar has disintegrated, loss of stones may occur. It should be noted that some structures are built without mortar.

Figure 2.5.3 shows evidence of loss of mortar in a masonry arch.

Severity

Light	–	Mortar lost from the joints in a few places, to a depth of 20 mm.
Medium	–	Mortar lost from the joints over an extended area, to a depth between 20 and 50 mm.
Severe	–	Extensive loss of mortar resulting in the loss of a few stones.
Very Severe	–	Extensive loss of stones jeopardizing the stability of the structure.

Figure 2.5.1 Wide Crack Through a Stone in a Masonry Pier

Figure 2.5.2 Very Severe Splitting, Spalling and Deterioration in Masonry

Figure 2.5.3 Very Severe Loss of Mortar and Stone in a Masonry Arch

2.6 Aluminum

Aluminum is often used in railings, splash guards, drainage systems, signs and sign supports.

The following are the most common defects in aluminum and are described below:

- Corrosion;
- Cracking;
- Loose connections.

2.6.1 Corrosion

Corrosion in aluminum is usually a uniform, gradual oxidation of the surface in the presence of air and moisture. Aluminum has a strong resistance to corrosion deterioration after the initial formation of aluminum oxide, a dense and very adherent film, which protects the underlying metal and inhibits further corrosion.

However, in less than ideal circumstances this protective layer may fail to form, or be penetrated and broken down to expose the underlying metal. The process of corrosion will then continue with progressive loss of section.

Factors affecting the corrosion process are the presence or exposure of the aluminum to de-icing salts, industrial fumes, water containing dissolved chemicals, bird droppings and surface scratches. Tight corners, especially around joints and connections, which entrap moisture and debris are particularly susceptible to progressive corrosion. In addition, contact with other metals and concrete results in galvanic and chemical corrosions.

GALVANIC CORROSION occurs in bi-metal joints. Where aluminum comes into contact with other metals, a galvanic cell is formed in the presence of an electrolyte, such as a salt solution, resulting in localized corrosion of the aluminum. Galvanic corrosion may affect the formation of the protective aluminum oxide film or cause the film to flake off. It is therefore necessary to place an inert spacer, either nylon or neoprene, between the two metals to prevent galvanic corrosion. Galvanic corrosion does not occur when aluminum is in contact with galvanized or stainless steel.

CHEMICAL CORROSION refers to the corrosion which takes place when aluminum comes into contact with concrete. When this happens, the aluminum reacts chemically with the lime in the concrete, resulting in progressive corrosion of the aluminum and loss of section. An inert spacer or bitumastic coating should be used between the concrete and aluminum to prevent chemical corrosion.

Figure 2.6.1 shows typical corrosion in aluminum.

Severity

Light	–	Discolouration, grey to grey-black mottled appearance. Roughened surface with light blistering. No noticeable loss of section.
Medium	–	Definite areas of corrosion are noticeable. Moderate blistering and surface pitting. Up to 10% loss of section.
Severe	–	Extensive blistering and overall pitting. 10% to 20% loss of section.
Very Severe	–	Very extensive blistering and overall pitting. Over 20% loss of section.

2.6.2 Cracking

A crack is a linear fracture in the aluminum which may extend partially or completely through the material. Cracks normally develop as a result of fatigue followed by brittle fracture and excessive corrosion. Cracks may also result from entrapped water freezing. Cracks begin on either the inside or the outside surface of a member and appear as hairline cracks on the surface. Since cracks may be concealed by corrosion by-products, dirt or debris, suspect surfaces should be cleaned prior to inspection. A crack in an aluminum component is illustrated in Figure 2.6.2.

Severity

Since cracks in aluminum are generally considered serious, no severity description is given. All cracks should be carefully noted and recorded as to their specific location in the member and the location of the member in the structure. The length, width (if possible) and direction of the crack should also be recorded.

2.6.3 Loose Connections

Loose connections may occur in bolted or riveted connections. Loose connections may not be detectable by visual observation. Tapping the connection and fasteners is one means of establishing whether the connection is loose.

Loose connections may be caused by corrosion, excessive vibration, overstressing or cracking of the connected members or fasteners.

Severity

The severity of loose connections depends on the number of loose or missing fasteners relative to the total number in the connection. A sketch should therefore be made showing the configuration of the connection and the location of the defective fasteners.

Light	–	Up to 5% of fasteners loose or missing.
Medium	–	5 to 10% of fasteners loose or missing.
Severe	–	10 to 20% of fasteners loose or missing.
Very Severe	–	Over 20% of fasteners loose or missing.

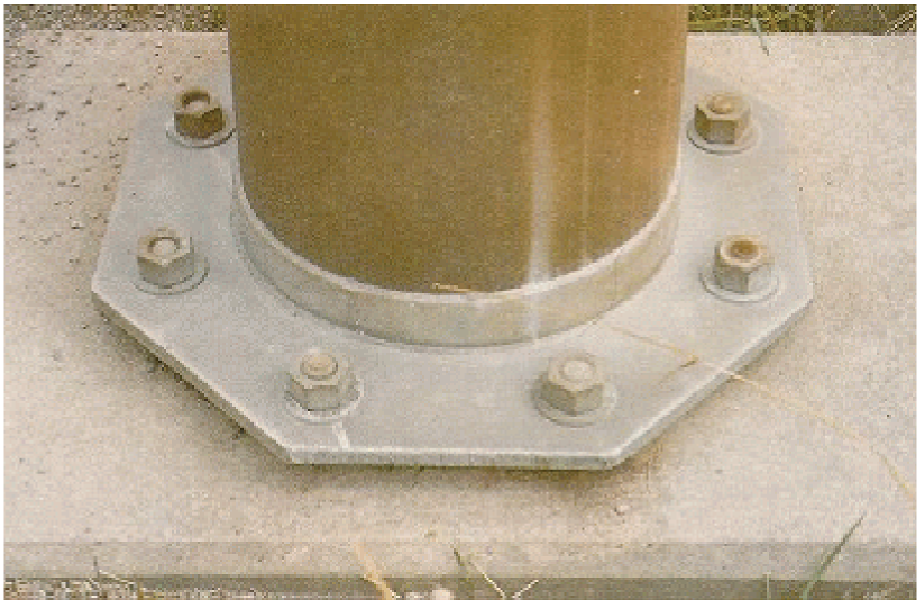


Figure 2.6.1 Light Corrosion

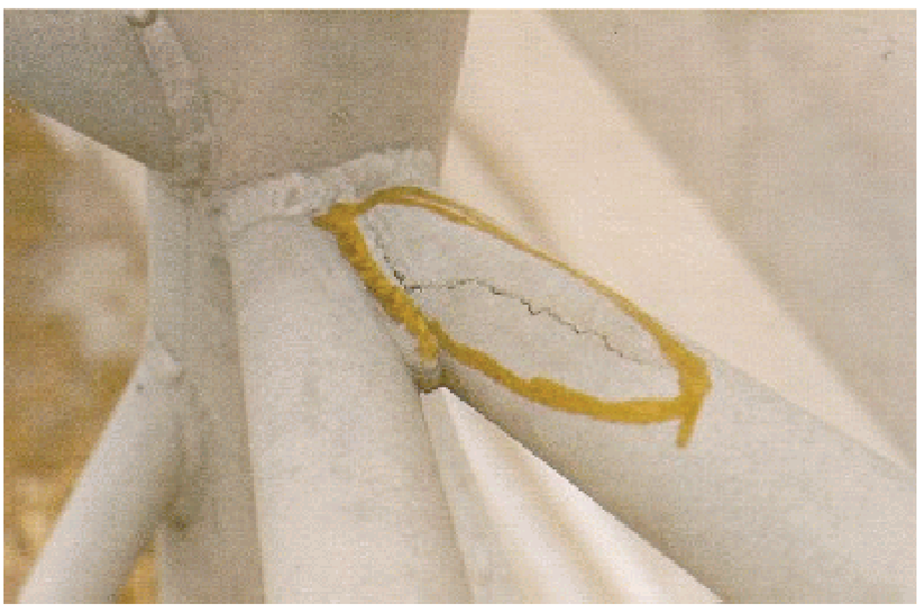


Figure 2.6.2 Wide Crack

2.7 Asphalt Pavement

Asphalt pavement is often used as a wearing surface on concrete, steel and wood decks. A waterproofing membrane is also often placed on the deck surface between the deck top surface and the asphalt pavement to provide protection to the deck surface against the infiltration of moisture and subsequent deterioration or decay.

Defects in asphalt pavements can be related to the lack of durability of the asphalt resulting from the composition of the asphalt, poor placement practices or the aggressive environment in which it is placed (Reference 4).

The following defects commonly occurring in asphalt pavements are described:

- Cracking;
- Ravelling;
- Loss of Bond and Delamination;
- Potholes;
- Wheel Track Rutting;
- Rippling;
- Flushing;
- Slippery Surface.

2.7.1 Cracking

A crack is a linear fracture extending partially or completely through the pavement. Cracking in pavements may be caused by any one or a combination of the following factors: the action of vehicular wheel loading; poor quality material; poor compaction; poor placement or quality control; frost action; poor drainage; shrinkage due to low temperatures; temperature susceptibility of the asphalt cement binder; and as reflection cracks, which are the extension of cracks in the surface below the pavement.

Cracks are distinguished by their appearance and direction. The following types of cracks are commonly observed in pavements: longitudinal, transverse, alligator, map, and progressive edge cracking.

LONGITUDINAL cracks are roughly parallel to the direction of travel and may be situated at or near the center of the wheel tracks, centreline roadway, mid-lane, or along pavement edges.

TRANSVERSE cracks are approximately at right angles to the pavement centreline and may extend partially or completely across the pavement.

ALLIGATOR cracks form a network of multi-sided polygons or blocks resembling the skin of an alligator. The block sizes typically range from 50 mm to 500 mm. They may occur anywhere in the pavement surface, and may be accompanied by depressions in the surface.

MAP cracks run randomly along the pavement, sometimes in a serpentine manner. They appear to consist of longitudinal and transverse cracks combined to form a ‘map’ pattern.

PROGRESSIVE EDGE cracks begin parallel to and usually within 300 mm of the edges of the pavement such as along curb edges and expansion joint dams. The cracks are either fairly straight and continuous or consist of crescent-shaped cracks in a wave formation. These cracks may progress significantly into the travelled portion of the pavement. Edge breaking of the pavement often results from these cracks.

The various types of pavement cracks are illustrated in Figures 2.7.1(a) to 2.7.1(e).

Severity

Light	–	3 mm to 10 mm wide single or multiple cracks.
	–	alligator pattern established with corners of polygon blocks fracturing.
	–	progressive edge cracking less than 600 mm from pavement edge, either single or two parallel cracks.
Medium	–	10 mm to 20 mm wide single or multiple cracks.
	–	alligator pattern established with spalling of polygon blocks.
	–	progressive edge cracking extending between 600 mm to 900 mm from pavement edges, multiple cracks with connecting cracks.
Severe	–	20 mm to 30 mm wide single or multiple cracks.
	–	polygon blocks in alligator cracking are beginning to lift leaving potholes.
	–	progressive edge cracking extending over 900 mm from pavement edge with alligatoring of pavement along edges.
Very Severe	–	Greater than 30 mm wide single or multiple cracks.
	–	a number of polygon blocks lifted off in alligator cracking.
	–	progressive edge cracking extending over 1200 mm from pavement edge with alligatoring of pavement along edges.

2.7.2 Ravelling

Ravelling is the progressive deterioration and loss of the pavement material from the surface downward. The surface appears to be breaking up into small pieces and loose aggregate. Ravelling can occur anywhere over the surface, but is most common along curb or sidewalk faces where salt-laden roadway drainage collects, and along wheel tracks due to traffic action on pavements embrittled and weakened through aging.

Ravelling of an asphalt pavement is illustrated in Figure 2.7.2.

Severity

Light	–	Noticeable loss of pavement material.
Medium	–	Shallow disintegration of the pavement surface with an open textured appearance.
Severe	–	Shallow disintegration of the pavement surface with small potholes. Very open textured appearance with loose material over the surface.
Very Severe	–	Deep disintegration of the pavement surface with numerous potholes. Very open textured appearance with loose material over the surface.

2.7.3 Loss of Bond and Delamination

Loss of bond and delamination may occur between the asphalt pavement and deck surface, between the waterproofing and the deck surface, between the waterproofing and asphalt pavement or between individual lifts of pavement.

Loss of bond and delamination is not directly visible on the pavement surface; however, they may often be detected by hammer sounding or chain drag. The accurate assessment of the extent or severity of these defects can usually only be determined by detailed deck survey methods such as thermography, radar, and removal of the pavement.

Severity

Light	–	Delaminated area measuring less than 150 mm, in any direction.
Medium	–	Delaminated area measuring between 150 mm and 300 mm, in any direction.
Severe	–	Delaminated area measuring between 300 mm and 600 mm, in any direction.
Very Severe	–	Delaminated area measuring more than 600 mm, in any direction.

2.7.4 Potholes

Potholes are bowl-shaped holes in the pavement caused by the penetration of water through the pavement and the subsequent heaving of the pavement due to freezing of the entrapped water and breaking up of the pavement due to traffic action. Pavements already deteriorated with such defects as alligator cracking and ravelling are prone to the occurrence of potholes.

A typical example of a pothole is illustrated in Figure 2.7.4.

Severity

Light	–	Holes measuring less than 150 mm in any direction or 25 mm in depth.
Medium	–	Holes measuring between 150 mm to 300 mm in any direction or between 25 mm to 50 mm in depth.
Severe	–	Holes measuring between 300 mm to 600 mm in any direction or between 50 mm to 100 mm in depth.
Very Severe	–	Holes measuring over 600 mm in any direction or over 100 mm deep.

2.7.5 Wheel Track Rutting

Wheel track rutting is the formation of longitudinal depressions in the pavement at the locations of the wheel tracks of vehicles resulting from the compaction and shoving of the pavement laterally under repeated vehicle traffic.

Wheel track rutting and its measurement is illustrated in Figure 2.7.5.

Severity

Light	–	Less than 10 mm deep.
Medium	–	From 10 mm to 20 mm deep.
Severe	–	From 20 mm to 40 mm deep.
Very Severe	–	Greater than 40 mm deep.

2.7.6 Rippling

Rippling is the formation of transverse undulations in the pavement surface consisting of closely spaced valleys and crests. Rippling is the result of poor bond of the pavement to the surface below with the subsequent action of wheel friction and braking forces moving the pavement 'mat' forwards, backwards and sideways.

Rippling of an asphalt pavement is illustrated in Figure 2.7.6.

Severity

Light	–	A few noticeable bumps.
Medium	–	Several bumps producing a rough ride.
Severe	–	Numerous bumps producing a very rough ride with possible loss of vehicle control.
Very Severe	–	Numerous bumps producing a very rough ride with difficulty in maintaining vehicle control and imminent danger of loss of vehicle control.

2.7.7 Flushing

Flushing is the migration of asphalt upwards to the pavement surface in pavements with too much asphalt in the mix. It commonly occurs in the wheel tracks, especially during hot weather, by the action of vehicle traffic pressing and squeezing the excess asphalt to the surface. Flushing of the surface of an asphalt pavement is illustrated in Figure 2.7.7.

Severity

Light	–	Visible colouring of the pavement surface occurring in localized areas.
Medium	–	Distinctive colouring of the pavement surface with excess asphalt free on the pavement surface.
Severe	–	Free asphalt gives the pavement surface a 'wet' look; vehicle traffic leaves visible tire marks and impressions on the pavement surface.
Very Severe	–	Excessive free asphalt on the pavement surface with a 'wet' look; footprints leave visible impressions in the pavement surface.

2.7.8 Slippery Asphalt Surface

Slippery asphalt surfaces may result from flushing or from the polishing of the coarse surface aggregates by the action of repetitive vehicular traffic.

Severity

There are no severity descriptions given for slippery surfaces as this is a serious and potentially hazardous situation. Where evidence of slippery surfaces is noted, the Project Manager/Engineer shall be notified.

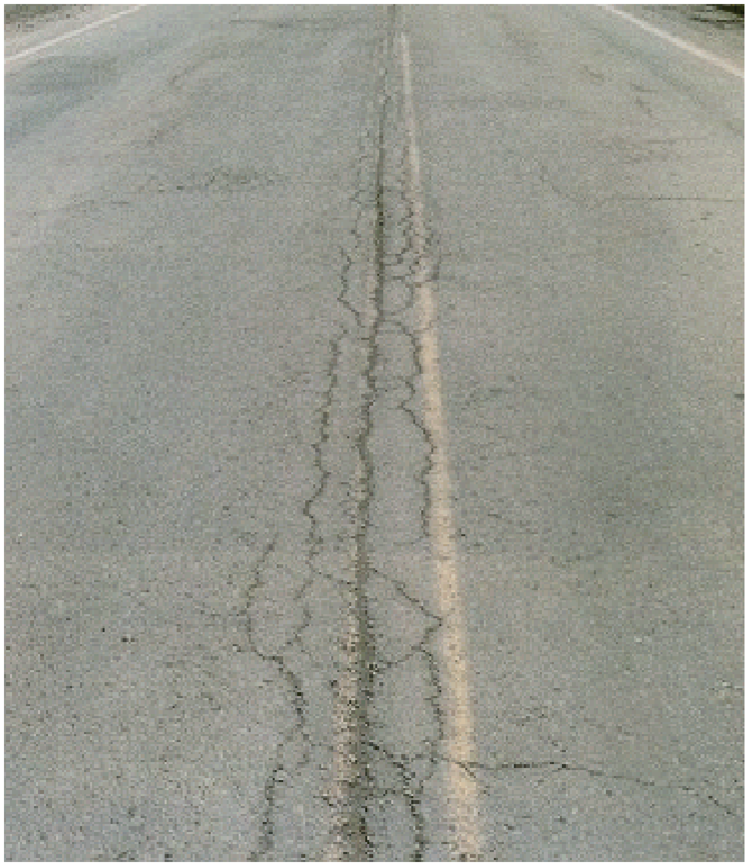


Figure 2.7.1(a) Medium Longitudinal Crack

Figure 2.7.1(b) Medium Transverse Crack

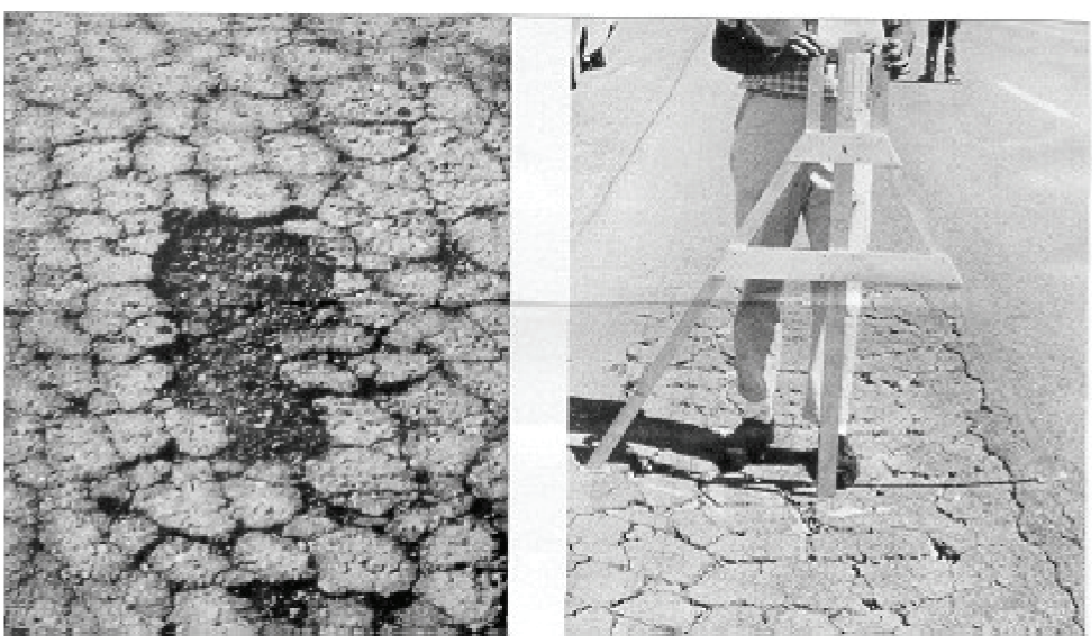


Figure 2.7.1(c) Severe Alligator Cracks

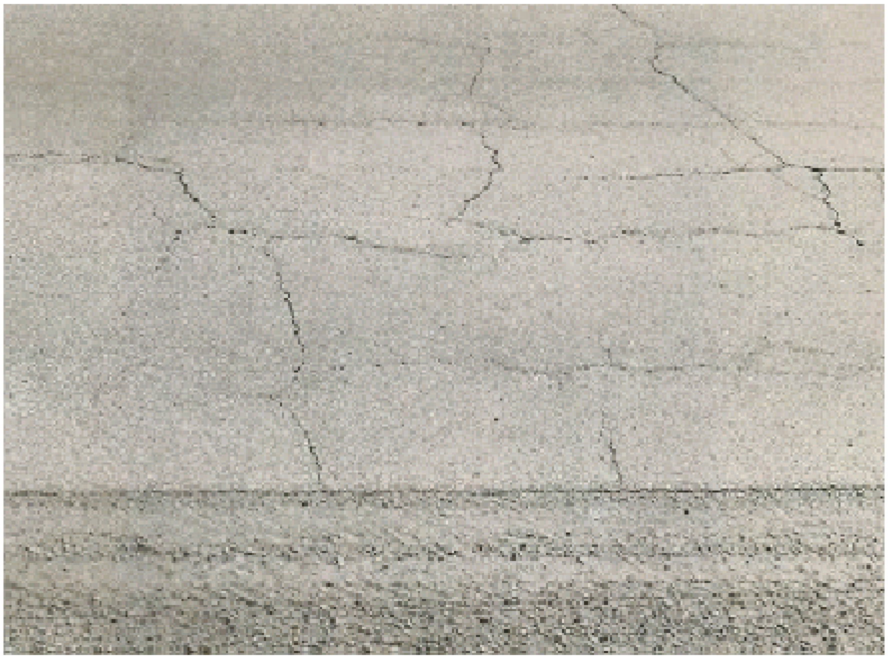


Figure 2.7.1(d) Light Map Cracks

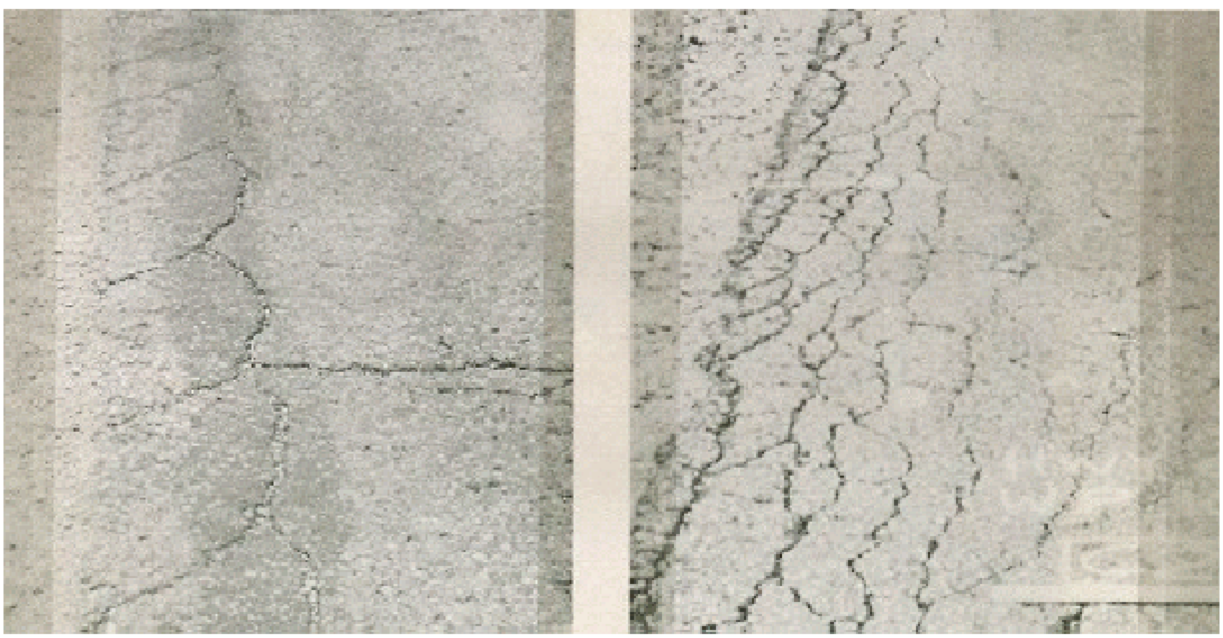


Figure 2.7.1(e) Medium Progressive Edge Cracks

Figure 2.7.2 Severe Ravelling

Figure 2.7.4 Severe Pothole

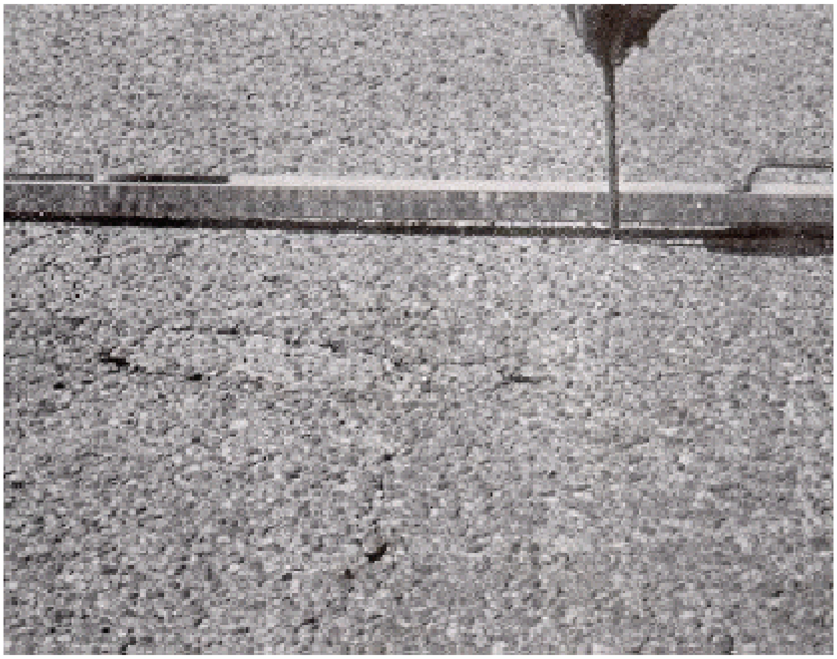


Figure 2.7.5 Medium Wheel Track Rutting

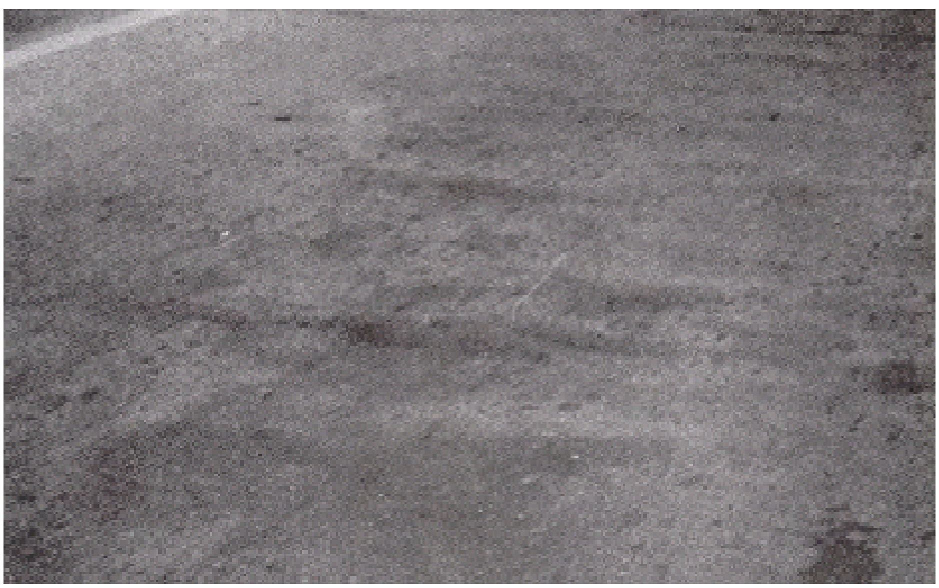


Figure 2.7.6 Severe Rippling

Figure 2.7.7 Severe Flushing

Figure 2.7.8 Slippery Surface

2.8 Coatings

Coating defects are not necessarily serious in themselves. However, they are indicative of a potential weakness in the coating and eventual loss of protection of the coated surface. Since there are no criteria for the severity of material defects in coatings, defects do not need to be classified. However, the presence of defects and the areas affected should be noted and recorded.

There are several types of material defects that commonly occur in coatings (References 5 to 8), which can be grouped into the following three categories:

(a) Coating-related Defects

Coating-related defects are defects which are related to the basic chemistry or composition of the coating and reaction of the coating materials with each other and the environment. Common coating-related defects are:

- Checking or crazing;
- Cracking;
- Alligatoring;
- Chemical attack;
- Chalking.

(b) Adhesion-related Defects

Adhesion-related defects are defects which are usually the result of incorrect coating selection, contaminated substrate or improper surface preparation. Common adhesion-related defects are:

- Undercutting;
- Blisters;
- Intercoat delamination;
- Peeling;
- Underfilm corrosion.

(c) Application-related defects

Application-related defects are defects which are usually the result of improper application of the coating. Common application-related defects are:

- Bridging;
- Edge defects;
- Shadows;
- Overspray;
- Pinholing;
- Runs;
- Sags;
- Pinpoint rusting.

2.8.1 Coating-related Defects

CHECKING or CRAZING usually appears as a fine network of minute cracks in a checkerboard pattern. This is a surface defect and does not necessarily penetrate the full depth of the coating. The defect is usually inherent in the coating, as some pigments combined with some binding agents will tend to cause checking or crazing. The defect may also be caused by weathering, including wetting and drying, heating and cooling, exposure to sunlight and contraction of the coating as it dries or cures (Figure 2.8.1(a)).

CRACKING may result from weathering or continued polymerization of the coating materials over time. An oxidizing or catalyzed coating applied over a very smooth surface may crack due to shrinkage and poor adhesion to the substrate. Cracking is an extension of the checking process and usually occurs in a linear pattern and penetrates all the way through the coating. The cracked coating tends to spall off, exposing bare substrate (Figure 2.8.1(b)).

ALLIGATORING occurs if a hard, brittle or oxidizing top coat is applied over an extensible base coat, such as an alkyd over an asphalt base. As the surface hardens and shrinks, very large irregular checks, usually several centimetres across, are formed on the surface in a characteristic alligator pattern but do not go all the way through the coating. If the surface is not over-coated with a compatible material, the process will continue until the defect penetrates all the way to the substrate (Figure 2.8.1(c)).

CHEMICAL ATTACK occurs when some coating materials react adversely with some air-borne chemicals and pollutants or may be the result of accidental spillage. Oil-based coatings such as alkyds are subject to damage by alkaline chemicals (Figure 2.8.1(d)).

CHALKING is a surface phenomenon of some coatings caused by exposure to solar radiation and weathering over a period of time. The result is that the coating takes on a chalky or powdery appearance. Chalking occurs because many basic resins will react with sunlight and many pigments will accelerate the process of weathering of the resin binder between the pigment particles, leaving the pigment particles free on the surface. Chalking is usually a surface defect and the coating is intact below the chalky surface. However, chalking can progress, and the thickness of sound coating can be reduced to the point where the substrate is exposed.

2.8.2 Adhesion-related Defects

UNDERCUTTING is the spread of corrosion underneath the coating from a break in the coating. It is usually caused by poor surface preparation and application of the coating over surfaces which have mill scale or patches of rust, oil, grease or dirt or are otherwise improperly cleaned. Undercutting can also be caused by application of the coating to surfaces that are very smooth or non-porous, resulting in poor adhesion of the coating. High water vapour permeability of the coating and penetration by oxygen and salts also promote undercutting (Figure 2.8.2(a)).

BLISTERS are dome-shaped projections which form when two coatings separate or a coating separates from the substrate. They are normally caused by solvents becoming trapped in or under the paint film or by water being drawn through the paint film by the osmotic forces exerted by hygroscopic salts at the paint/substrate interface (Figure 2.8.2(b)).

INTERCOAT DELAMINATION occurs where one coat separates from another and is usually related to poor coating application over contaminated surfaces or too long a drying or curing period between coats (Figure 2.8.2(c)).

PEELING is also the result of poor adhesion of the coating to either the substrate or a previously applied coating. It is a function of the tensile strength of the coating film itself: if the tensile strength of the film is greater than the adherence to the surface, the coating will tend to peel. Peeling between coats is usually caused by contamination of the surface of the previous coat (Figure 2.8.2(d)).

UNDERFILM CORROSION is the build-up of corrosion under the coating without a break in the coating. It is prevalent in coatings which oxidize on the surface, such as oil-based and alkyd coatings. These coatings oxidize over time to a point where they become porous to moisture, oxygen and chloride ions. Poor surface preparation, substrate profile and surface contamination contribute to this type of defect.

2.8.3 Application-related Defects

BRIDGING across inside corners where debris has accumulated occurs if the debris is not properly cleaned off before the coating is applied. The coating, upon curing, may shrink sufficiently to bridge over the area resulting in voids under the coating. Subsequent penetration by moisture and oxygen will result in coating failure.

EDGE DEFECTS are a result of the improper or insufficient application of coatings to sharp edges and corners. Coatings tend to pull away from sharp edges and corners due to surface tension on the coating. This results in a thinner coating in these areas and, consequently, loss of film thickness and protection (Figure 2.8.3(a)).

SHADOWS often occur around rivets, bolts and welds, and in other areas where there are abrupt changes in an otherwise smooth surface and where the coating is not applied in a sufficient number of different directions, resulting in incomplete coverage (Figure 2.8.3(b)).

OVERSPRAY occurs when paint particles fall on the surface outside the normal spray pattern. The result is a dry spray, since the particles are usually dry by the time they reach the surface. The resulting appearance is an area which is rough and dull and does not have the same sheen as other areas where the coating is properly applied. The dry spray will absorb solvent from the subsequent coats, resulting in poor adhesion. Overspray areas are also typically more porous, which means that early coating failure can result (Figure 2.8.3(c)).

PINHOLING can be caused by holding the spray gun too close to the surface, which results in air bubbles being entrained into the coating and voids forming throughout the depth of the coating. If pinholing occurs in one coat, it will also tend to occur in subsequent coats, thus providing a passage through the voids to the substrate. Pinholing usually occurs in fast-drying coatings (Figure 2.8.3(d)).

RUNS are a downward movement of a paint film in rivulets usually caused by overthinning, slow thinners and/or holding the spray gun too close to the surface and depositing too much paint at one time. The perimeter of the run is often accompanied by pinholing (Figure 2.8.3(e)).

SAGS are heavy thicknesses of paint which have slipped and formed curtains on the surface. They are caused by the same things that lead to runs, (Figure 2.8.3(e)).

PINPOINT RUSTING usually occurs when insufficient thickness of coating is applied over a blast cleaned substrate. The profile peaks lack proper protection and continue to rust (Figure 2.8.3(f)).

Figure 2.8.1(a) Checking

Figure 2.8.1(b) Cracking

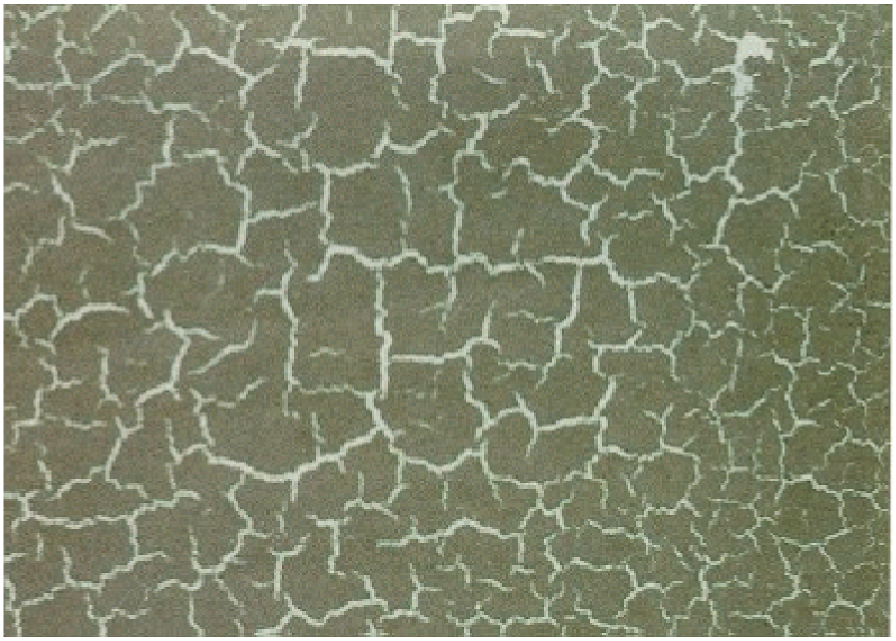


Figure 2.8.1(c) Alligatoring (typical mud crack pattern)

Figure 2.8.1(d) Chemical Attack

Figure 2.8.2(a) Undercutting

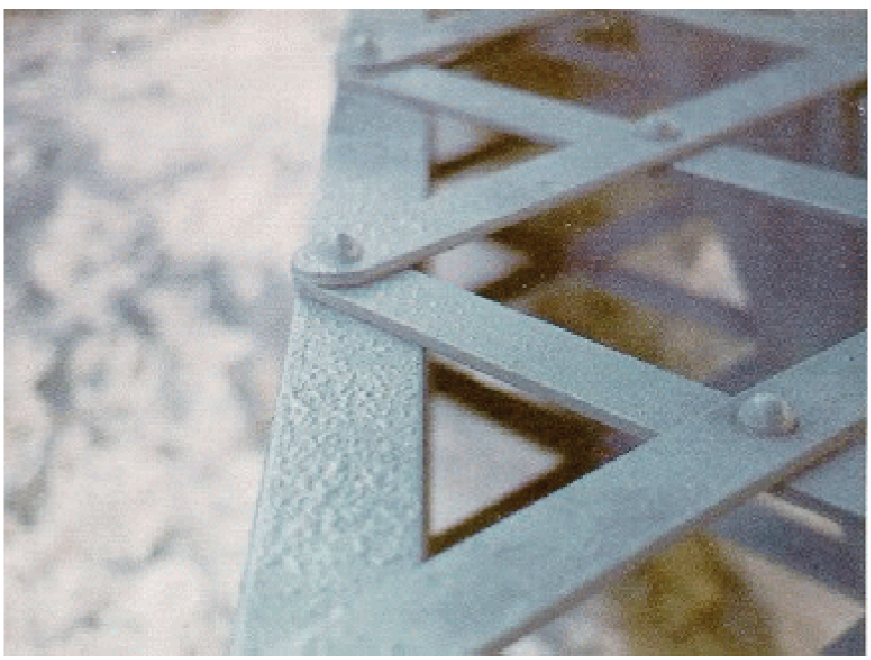


Figure 2.8.2(b) Blisters

Figure 2.8.2(c) Intercoat Delamination

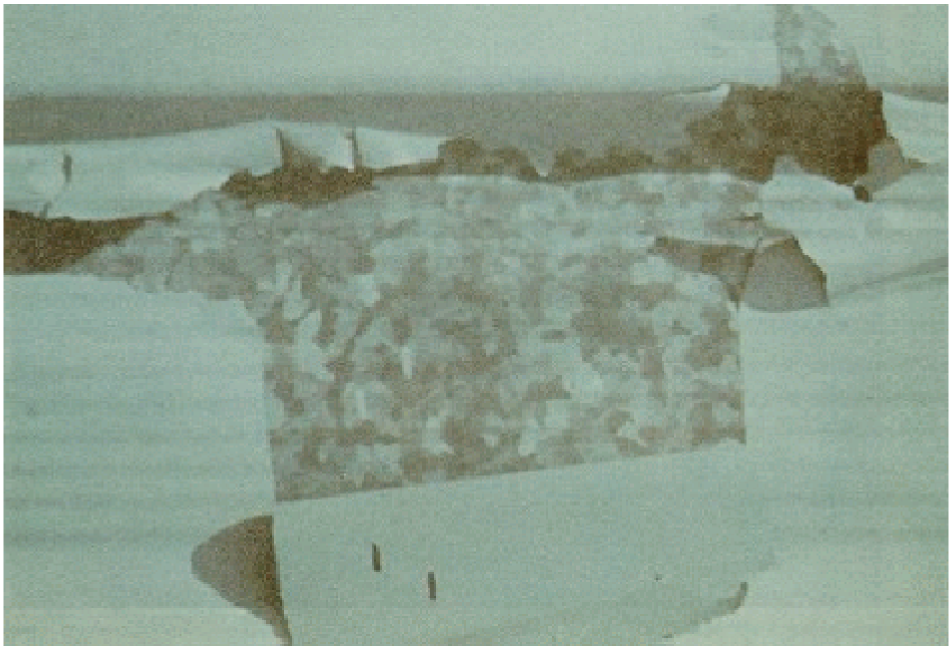


Figure 2.8.2(d) Peeling

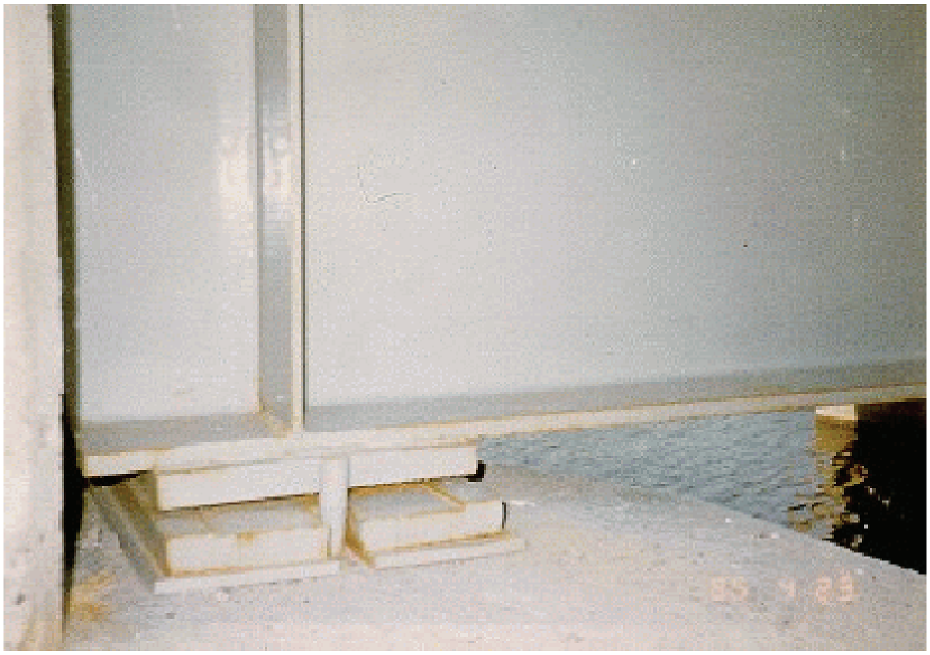


Figure 2.8.3(a) Edge Defects

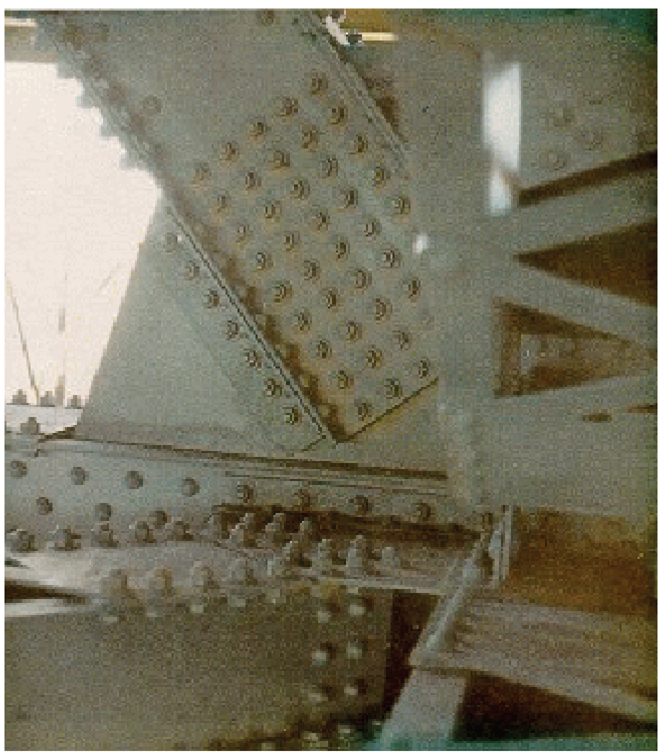


Figure 2.8.3(b) Shadows

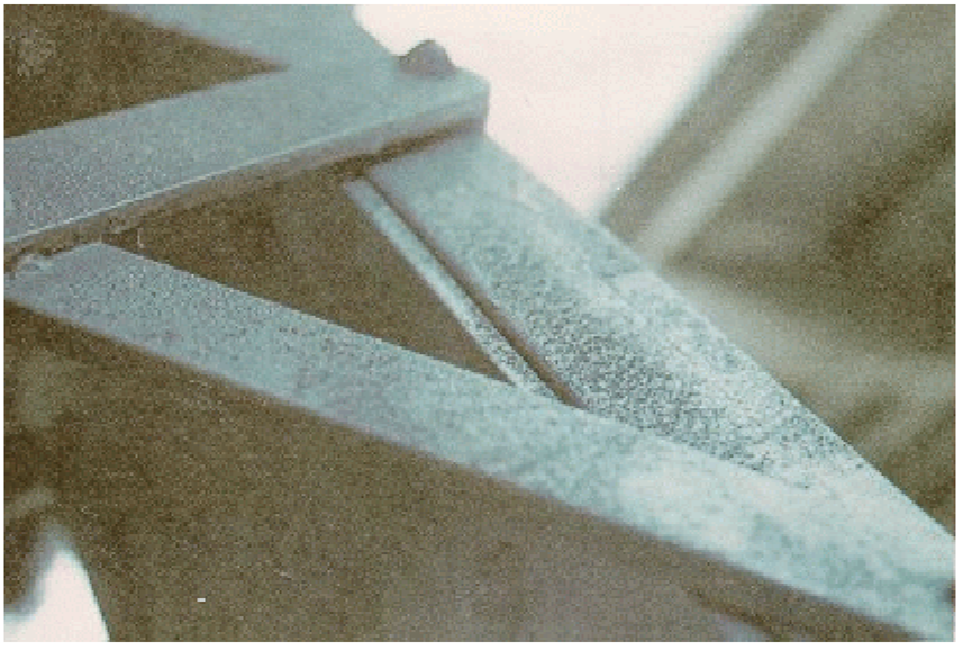


Figure 2.8.3(c) Overspray

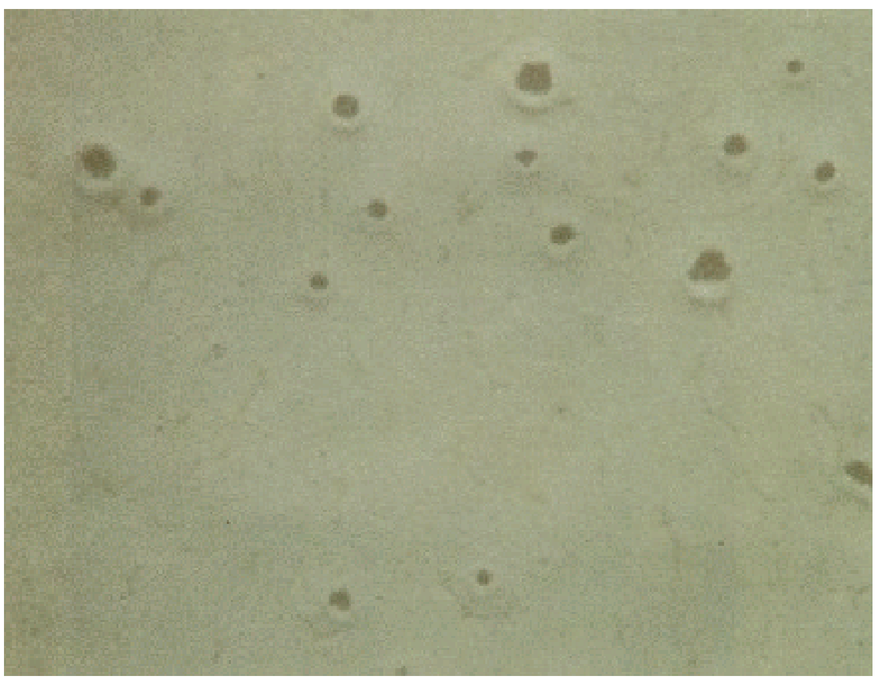


Figure 2.8.3(d) Pinholing

Figure 2.8.3(c) Runs and Sags

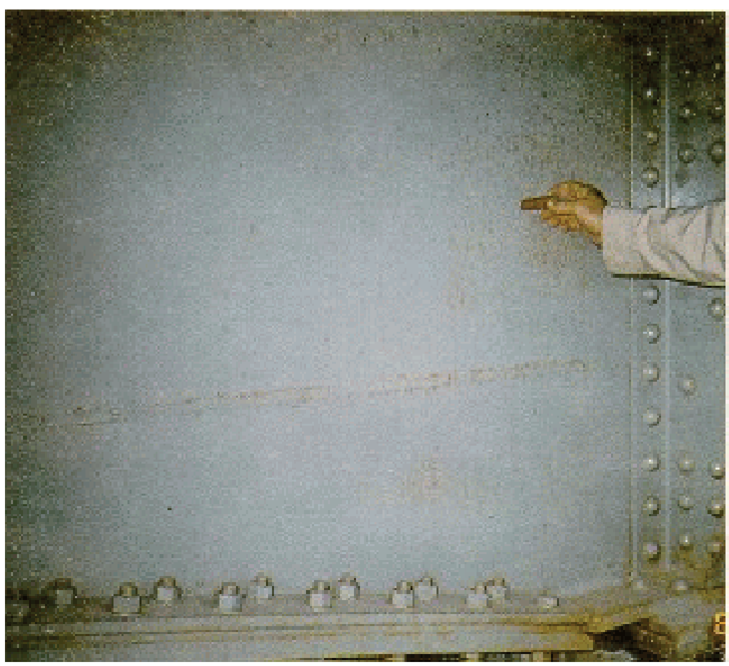


Figure 2.8.3(d) Pinpoint Rusting

SECTION 3 – WATERWAYS

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3.1 Waterways

For the purpose of this section, a waterway is defined as a body of water over or under which a structure is built. The defects produced in the waterway by the presence of structure components in or near the waterway are detailed in this section. Waterway are to be considered as primary components.

An assessment of the waterway and channel stability is important for determining the need for protective measures. A stable waterway and channel is one that does not change in size, form or location over time. They have fairly constant widths, well protected banks and narrow sand bars.

An unstable waterway and channel is one in which changes occur over time which are large enough to become a significant factor in the maintenance of structure components in and around the waterway and channel. All alluvial channels change to some extent over time and, therefore, have some degree of instability.

There are three principal types of waterway: meandering, straight and braided.

A meandering waterway is characterized by alternative S-bends which migrate laterally downstream. Bank erosion occurs on the outside radius while deposition occurs on the inside radius at each bend in the waterway. Meandering waterways may be unstable.

A straight waterway is one where the length of the waterway, measured down the centreline of waterway, divided by the length of the valley proper is less than 1.5. A straight waterway is usually not entirely free of meandering since the main current often alternates from side to side. Straight waterways are usually relatively stable.

A braided waterway is identified by numerous unstable interlacing channels separated by gravel or sand bars and small islands. Braided waterways are usually highly unstable.

The above three types of waterways are illustrated in Figure 3.1.

3.1.1 Material Defects in Waterways

SCOUR is the removal of material from the waterway bed or bank due to the erosive action of moving water in the waterway. Scour may be general or local. General scour is a result of constriction of the natural flow by the structure and is measured as the average depth below the original waterway bed. Local scour is caused by obstruction of the normal flow in the waterway by a structure or accumulated debris. Local scour is measured below the level of general scour.

DEGRADATION is the lowering of the waterway bed or the widening of the waterway channel as a result of continuous scour by the waterway and usually occurs when the sediment transport capacity of the waterway is enhanced by increased flow. Degradation often results from a natural increase in the slope of the waterway bed or artificial alterations. Lowering of the waterway bed can also lead to slumping and erosion of the banks and slope protection.

SEDIMENTATION is the raising of the waterway bed or the narrowing of the waterway channel as a result of the deposit of material by the waterway and usually occurs when the sediment transport capacity of the waterway is decreased. Sedimentation often results from a natural flattening of the waterway bed gradient or artificial alterations.

ICE can cause serious problems, the most common of which is ice jamming at the time of spring breakup. Ice piling against a structure can seriously damage the structure, and ice jams can lead to severe local scour by constricting the opening of the structure. Jams frequently result from ice floes piling up against unbroken ice where the waterway gradient flattens. The impact of ice floes can cause damage on the upstream side of the bridge.

PIPING is the subsurface removal of fine particles by water moving through the ground or embankments.

CHANGES IN ALIGNMENT may occur as the result of fluctuating water levels and changes in waterway velocity.

Figure 3.1.1 illustrates common material defects in waterways.

3.1.2 Performance Defects in Waterways

The severity of performance defects in waterways is determined by the ability of the structure opening to accommodate the waterway flow, the frequency of flooding near the structure and material defects of waterways that adversely affect other components of the structure.

BLOCKAGE of the waterway channel may occur as a result of accumulations of debris due to natural causes, beaver dams, or due to sedimentation of the waterway bed or banks. Large quantities of debris are carried down by relatively fast-flowing waterways having erodible banks. This debris is subsequently deposited when the waterway velocity decreases.

FLOODING over the structure and adjacent roadways occurs if the opening under the structure was not designed to accommodate the volume of water passing through it. Flooding may also occur as a result of channel blockage.

UNDERMINING is the progression of scour under a structure.

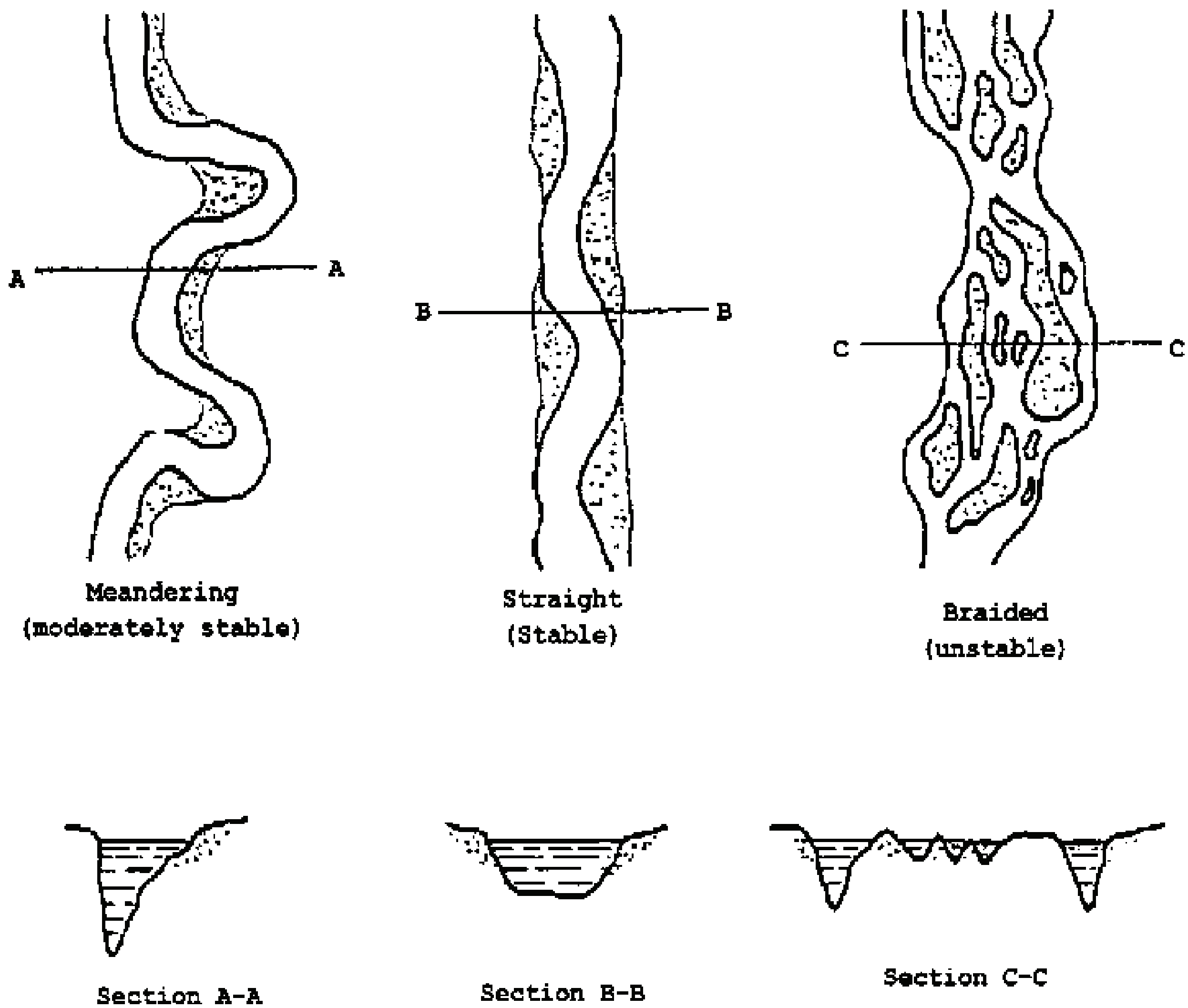
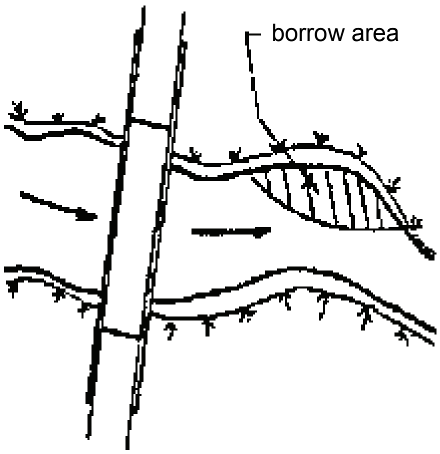
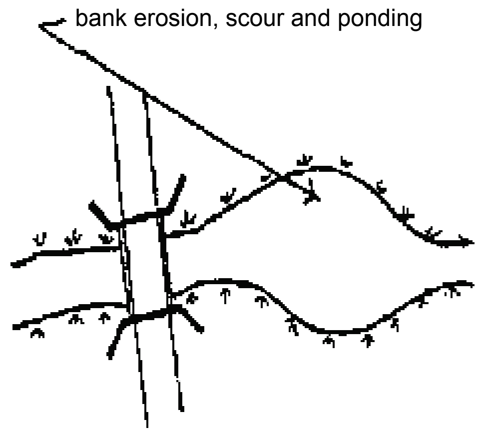


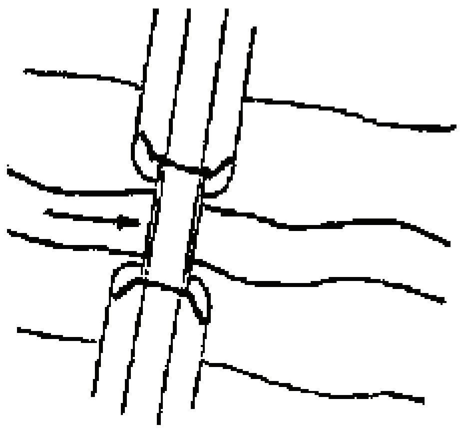
Figure 3.1 Principle Types of Waterways



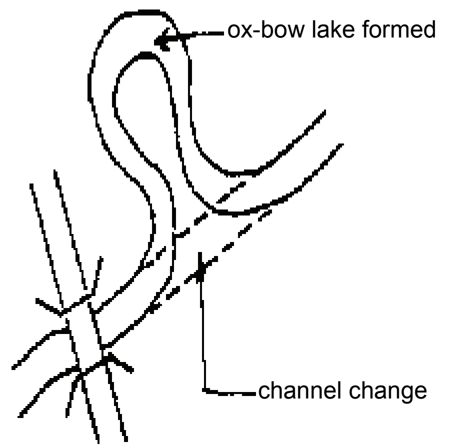
Removing large quantities of gravel from the channel bottom causes degradation upstream.



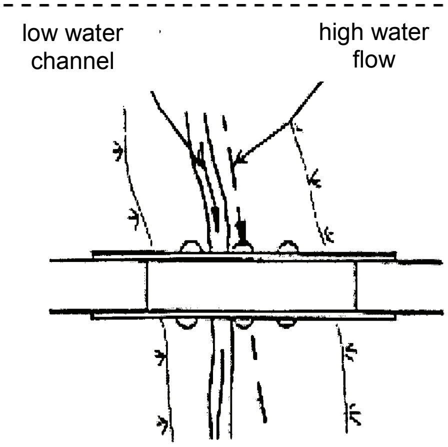
A firm channel bottom or constriction causes scour, bank erosion and ponding downstream.



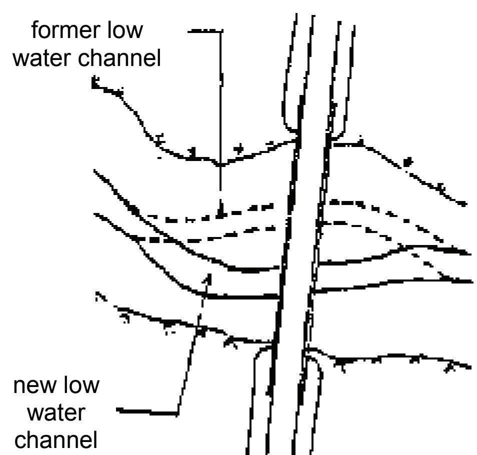
Channel constriction produces scour around the bridge during flood.



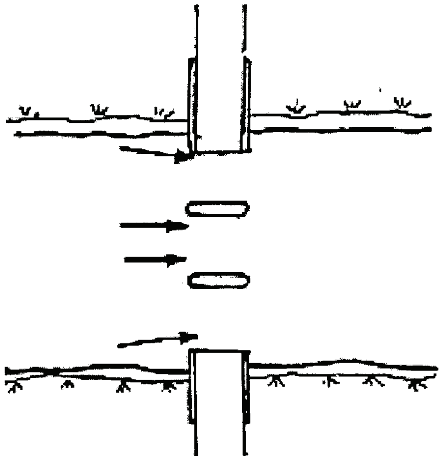
New channel cuts off ox-bow and steepens channel profile with increase in flow velocity.



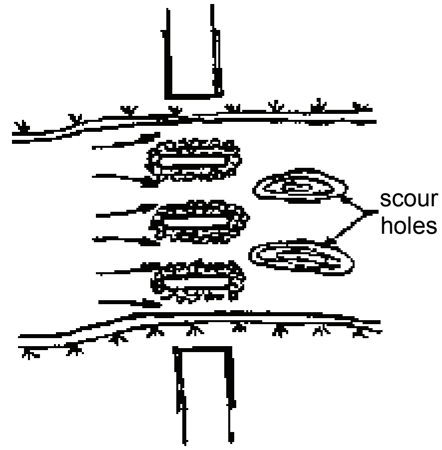
Scour around piers is influenced by location of pier to flow. Note change of flow at high water.



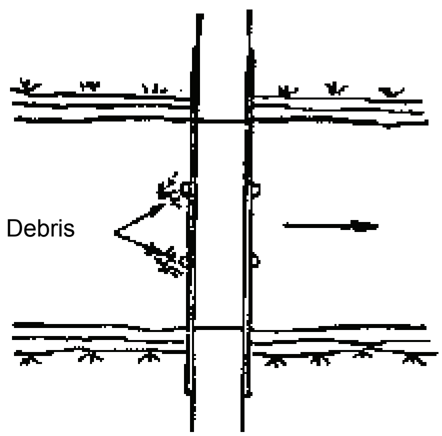
New water channel may be formed after a flood.



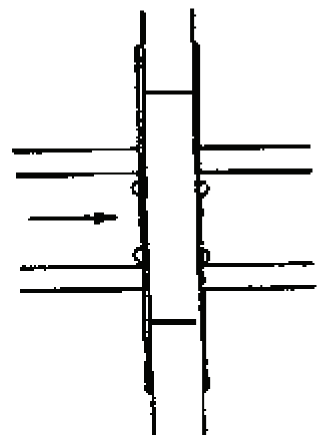
Protruding abutment produces local scour at upstream.



Rip-rap around piers may cause local scour downstream.



Debris around pier reduces opening causing increased scour.



Lined banks reduce scour, but if channel is constricted it may increase general scour at bridge.

Figure 3.1.1 Material Defects that may affect Waterways

SECTION 4 – EMBANKMENTS AND SLOPE PROTECTION

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4.1 Embankments

Embankments are sloped fills or cuts in the vicinity of the structure. The purpose of the embankment is to provide for a stable change of grade between the roadway and the surrounding ground surface, waterway or other roadways under the structure. Another purpose of the embankment is to provide support for the foundations where they are situated within the embankment.

Embankments are normally constructed from earth, rock or a combination of these materials. The sloping faces of embankments may be protected from the effects of erosion or scour by slope protection systems.

Embankments are to be considered as primary components if they support the foundation, otherwise, they are to be considered as secondary components.

4.1.1 Material Defects of Embankments

EROSION is the gradual wearing away or removal of material by surface drainage or wind. Sources of surface drainage potentially leading to erosion are leakage through expansion joints onto the embankment, runoff around the ends of wingwalls, discharge from deck drains directly above the embankment, and abutment and wingwall subdrains discharging onto the embankment.

PIPING is the subsurface removal of fines by movement of water through the ground or embankment.

SCOUR is the removal of material from the ground or embankment by subsurface or surface erosion.

4.1.2 Performance Defects of Embankments

Performance defects in embankments are related to their ability to maintain a stable grade separation between the roadway and the surrounding terrain without appreciable movement. Performance defects are also related to the ability of the embankments to provide support to the foundations without appreciable movements where the foundations are supported by the embankments.

MOVEMENT of embankments may consist of:

- settlement of embankment or roadway approaches;
- sliding of the slopes or toes of embankments;
- surface or deep seated slips.

Movement of embankments may result from:

- improper or inadequate compaction of fill;
- instability of the underlying soils;
- instability of the embankment material;

- loss of embankment material due to erosion, scour, piping, undermining, disintegration or other causes (e.g. burrows).

UNDERMINING is the progression of scour of the embankment or the waterway bed under the embankment.

4.2 Slope Protection

The purpose of the slope protection is to prevent the erosion or scour of the embankment and waterway banks in the vicinity of structures. A secondary purpose is to control the growth of grass and vegetation on steep slopes where mechanical equipment cannot be used safely.

The types of slope protections used most commonly are summarized in Table 4.2.

4.2.1 Material Defects of Slope Protection

- Loss of slope protection material;
- Disintegration or breakdown of material;
- Tearing of geotextiles;
- Corroded or broken wire mesh of gabion baskets.

4.2.2 Performance Defects of Slope Protection

Performance defects in slope protection are related to their ability to protect the embankments and waterway banks from erosion or scour and are reflected in the movements of slope protection systems.

Movements of slope protection may consist of:

- settlement of the slope protection;
- sliding of the slope protection.

Movements of slope protection may be caused by:

- movements of the embankments or the stream banks;
- material defects of the slope protection systems.

Type	Material Composition	Remarks
Organic	Grass, Brush, etc.	Used where large run-off is not expected.
Rip-Rap	Stones, Rubble.	Random, handlaid or grouted. Commonly used in streams.
Granular	Crushed stone or gravel.	Commonly used at grade separations.
Cast-in-Place Concrete	Reinforced concrete slab, 100 mm to 150 mm thick, divided into panels.	Commonly used at grade separations.
Precast Concrete	Interlocking slabs or elements.	Elements placed on permeable base which permits some seepage between elements.
Bituminous	Asphaltic concrete.	Compacted.
Wire Baskets (Gabions)	Wire mesh baskets filled with stones.	Commonly used near streams.
Bag Mortar	Premixed concrete bags stacked on each other.	Hand placed and allowed to set in place.
Geotextiles	Inorganic fabrics which allow penetration of water but no soil.	Normally used under other protections to prevent washing away of fines by subgrade seepage.

Table 4.2 – Slope Protection Systems

SECTION 5 – SUBSTRUCTURES

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5.1 Substructures

The following components are to be considered as substructures:

- Foundations;
- Abutments and piers;
- Retaining walls;
- Soil or rock under reinforced concrete box culverts or below springing lines of soil steel structures.

5.1.1 Foundations

Structures are normally supported on either shallow or deep foundations, based upon the depth to rock or soils with adequate capacity to support the loads from the structure.

(a) Shallow Foundations

Shallow foundations, footings, are used where rock or soil with adequate bearing capacity is at or near the ground surface.

Shallow foundations are normally made of mass concrete, reinforced concrete, wood or masonry. They are occasionally made of reinforced earth, gabions or cribs filled with stones or earth.

Shallow foundations in soils are placed below the local frost depth at the level of competent soil. In waterways they are normally buried to protect them against scour and may also have sheet piling as additional scour protection. Foundations on rock do not require frost protection or scour protection.

Typical examples of shallow foundations are shown in Figure 5.1.1(a).

(b) Deep Foundations

Deep foundations, piles or caissons are used where rock or soil, capable of carrying the structure loads, is overlain by softer material.

Commonly used piles are steel H piles, steel tube piles, timber piles, and reinforced or prestressed concrete piles. Caissons are normally made of large diameter tube piles or box sections made of concrete, steel sheet piles or H piles. They are sunk through ground or water for the purpose of placing the foundation at the prescribed depth and, subsequently, become part of the foundation. Steel tubes and caissons may be filled with concrete.

Piles or caissons may terminate with or without a footing, which may be located below ground or water level. Where piles or caissons extend to the level of the superstructure they should be inspected as piers or abutments as appropriate.

Typical examples of deep foundations are shown in Figure 5.1.1(b).

5.1.2 Abutments

Abutments consist of a number of components, each serving a specific purpose. These components are the foundation, abutment wall, ballast wall, wingwalls and the bearing seats.

In certain structures the abutment or some of its components may be missing, for example:

- abutments are not present in soil steel structures or in some concrete arches;
- in some continuous structures the end span is cantilevered out and has a curtain wall attached to it that retains the approach fill without the need of an abutment;
- the ballast wall and bearing seats are not needed for rigid frames, box culverts and some concrete arches.

Abutments are commonly made of mass concrete, reinforced concrete, or wood. Occasionally, masonry, steel piles, precast concrete, wire baskets, and reinforced earth have been used for their construction.

Typical examples of abutments are shown in Figure 5.1.2(a). Examples of structures without abutments are shown in Figure 5.1.2(b).

5.1.3 Piers

Piers consist of a number of components, each serving a specific purpose. These components are the foundation, pier shaft or columns, pier cap and the bearing seats.

Piers are commonly made of reinforced concrete, steel or wood. Occasionally, mass concrete, prestressed concrete, masonry, steel cribs, or gabions are used in their construction. They can be categorized as follows based on their design and configuration.

Shafts	–	concrete or masonry shafts with or without a pier cap;
Bents	–	concrete or steel columns with a pier cap;
Columns	–	single or multiple columns without a pier cap;
Trestles	–	braced wood or steel columns with a pier cap;
Cribs	–	wood or steel cribs, empty or filled with stone or earth;
Gabions	–	wire baskets filled with stones.

Typical examples of piers are shown in Figure 5.1.3.

5.1.4 Retaining Walls

Retaining walls consist of walls with or without foundations.

Retaining walls are commonly made of mass concrete, reinforced concrete and wood. Occasionally, masonry, steel piles, precast concrete, wire baskets, bag mortar and reinforced earth have been used for their construction. They can be categorized as follows based on their design:

Gravity Retaining Walls	–	mass concrete, masonry, timber cribs, concrete cribs, steel cribs, wire baskets and bag mortar.
Cantilever Retaining Walls	–	reinforced concrete, steel sheet piling, post and lagging (concrete, wood or steel or a combination of these).
Anchored Retaining Walls	–	mechanically stabilized wall systems and tie-back walls.

Typical examples of gravity, cantilevered and anchored retaining walls are shown in Figures 5.1.4(a), (b) and (c) respectively.

5.2 Primary Components

Foundations, abutment walls and piers are to be considered as primary components.

5.2.1 Material Defects of Primary Components

Material defects are as given in Section 2.

5.2.2 Performance Defects of Primary Components

Performance defects of foundations relate to their ability to support the components above them and to transmit the loads imposed on them to the rock or soil without appreciable movements.

Performance defects of abutment walls relate to their ability to provide adequate support to the superstructure and to retain the approach fills without appreciable movements.

Performance defects of piers relate to their ability to provide adequate support to the superstructure without appreciable movements.

Movements of foundations, abutment walls and piers may consist of vertical, longitudinal or transverse translations or rotations. Some of the common causes for these movements are:

- material defects leading to loss of strength of components;
- overloading from the superstructure;
- excessive earth pressures;
- excessive ice pressure;
- consolidation or failure of the soil;
- scour or erosion of the soil below the foundations;
- frost action.

It is important to determine if the component is stable or unstable as indicated by the rate of increase of movement.

5.3 Secondary Components

Ballast walls, wingwalls, retaining walls and bearing seats are to be considered as secondary components. The foundations of wingwalls and retaining walls are also to be considered as secondary components.

5.3.1 Material Defects of Secondary Components

Material defects are as given in Section 2.

5.3.2 Performance Defects of Secondary Components

Performance defects of bearing seats relate to their ability to provide adequate support to the bearings and, as such, are based on the loss of competent bearing area of the bearing seats.

Performance defects of ballast walls, wingwalls and retaining walls relate to their ability to retain the fill behind them without appreciable movements. Movements of the walls may consist of vertical, longitudinal or transverse translations or rotations. Some of the common causes for these movements are:

- material defects leading to loss of strength of the walls;
- overloading from the superstructure;
- excessive earth pressures;
- excessive ice pressure;
- failure of the soil or foundation;
- scour or erosion of the soil below the footings;
- frost action.

It is important to determine if the walls are stable or unstable as indicated by the rate of increase of the movements.

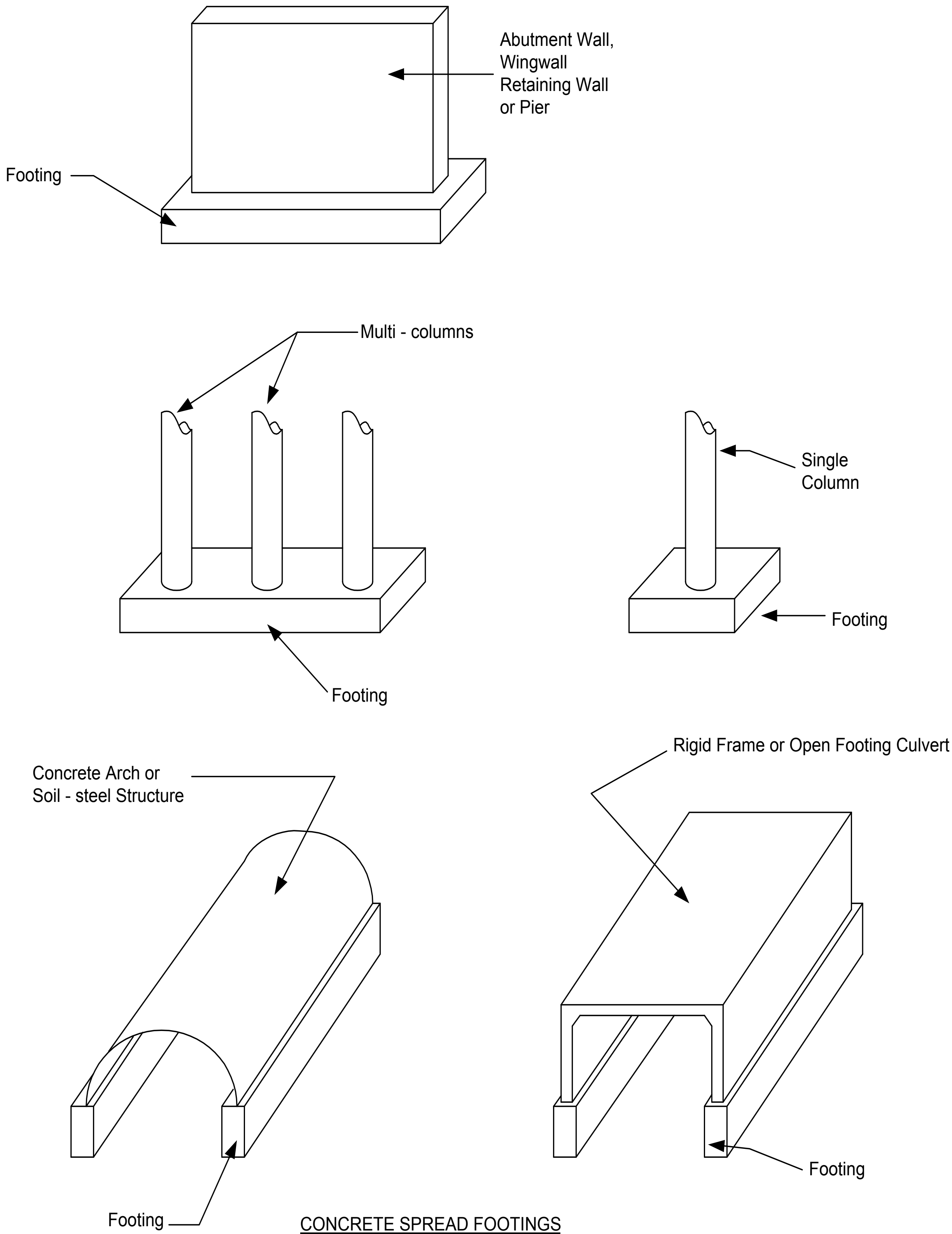
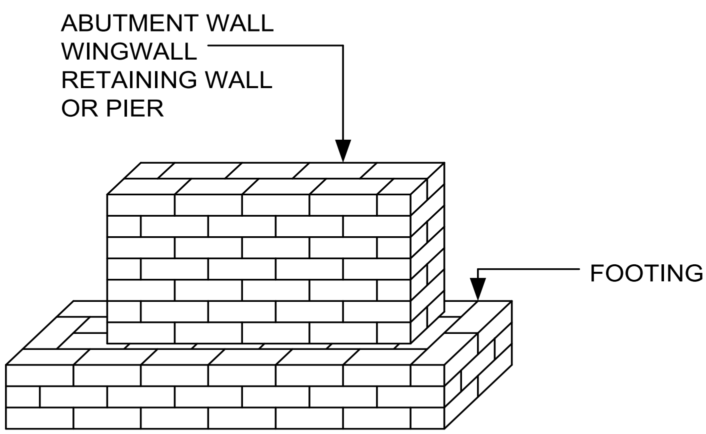
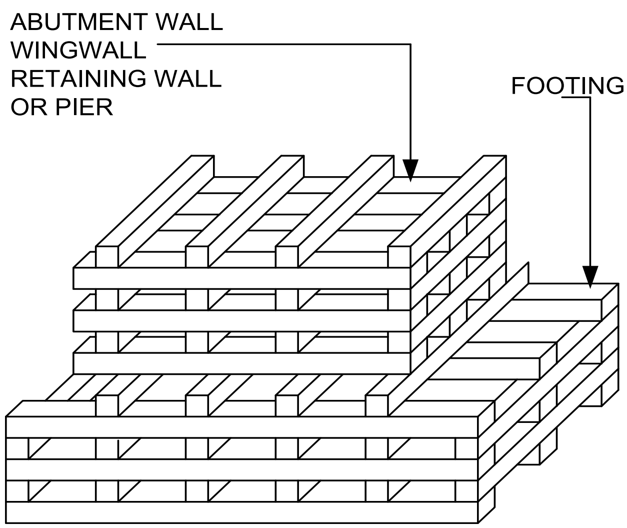


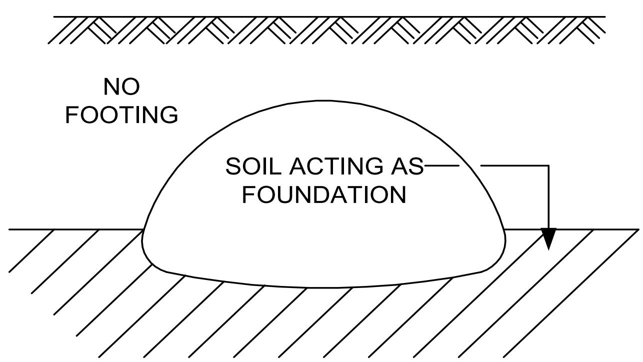
Figure 5.1.1(a) Typical Shallow Foundations



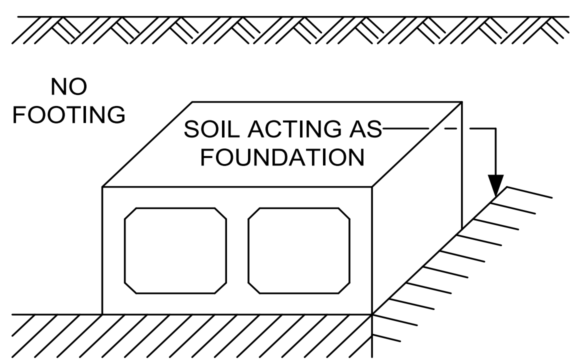
MASONRY FOOTING



WOOD CRIB FOOTING



SOIL STEEL STRUCTURE



BOX CULVERTS

Figure 5.1.1(a) Typical Shallow Foundations (cont'd)

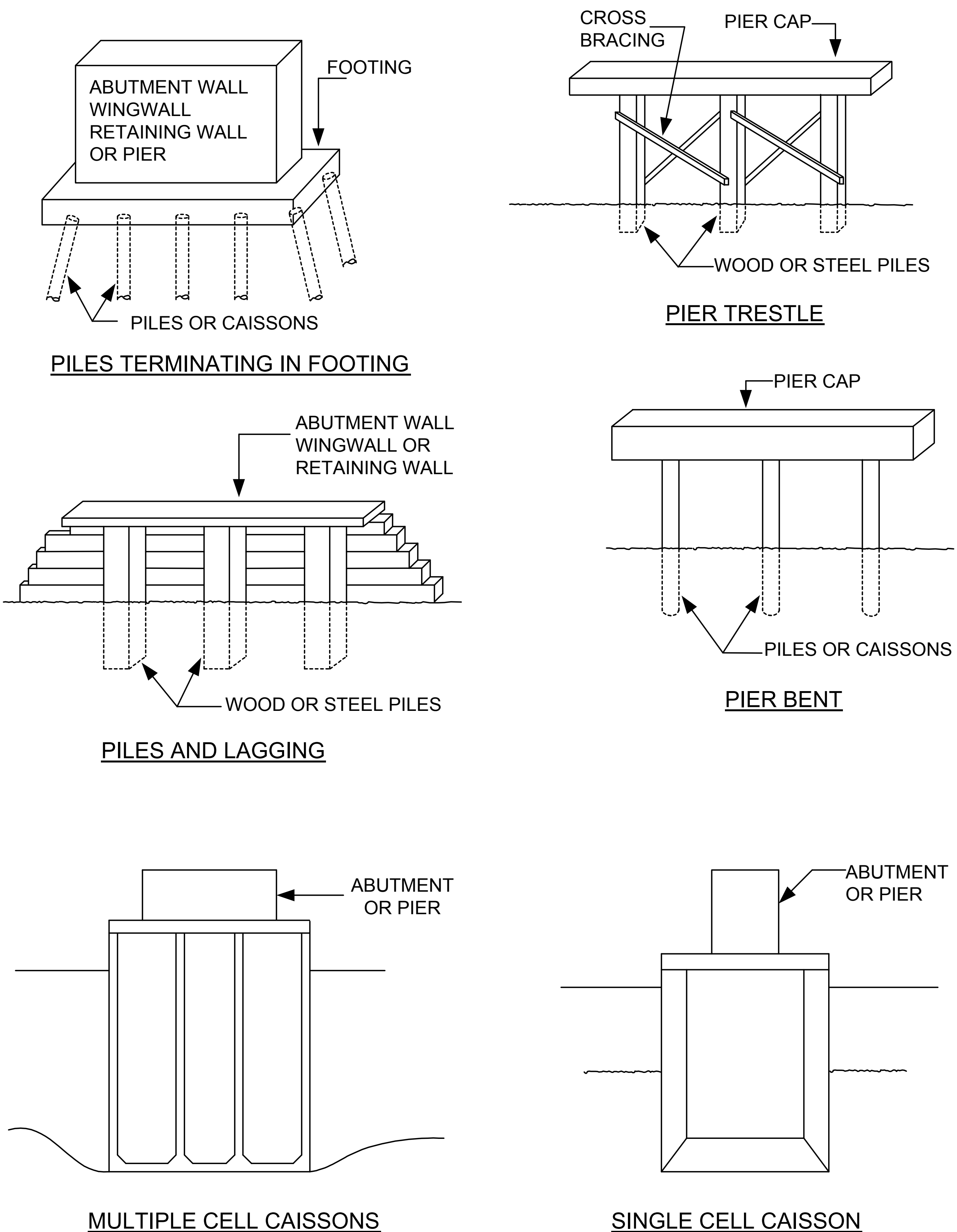


Figure 5.1.1(b) Typical Deep Foundations

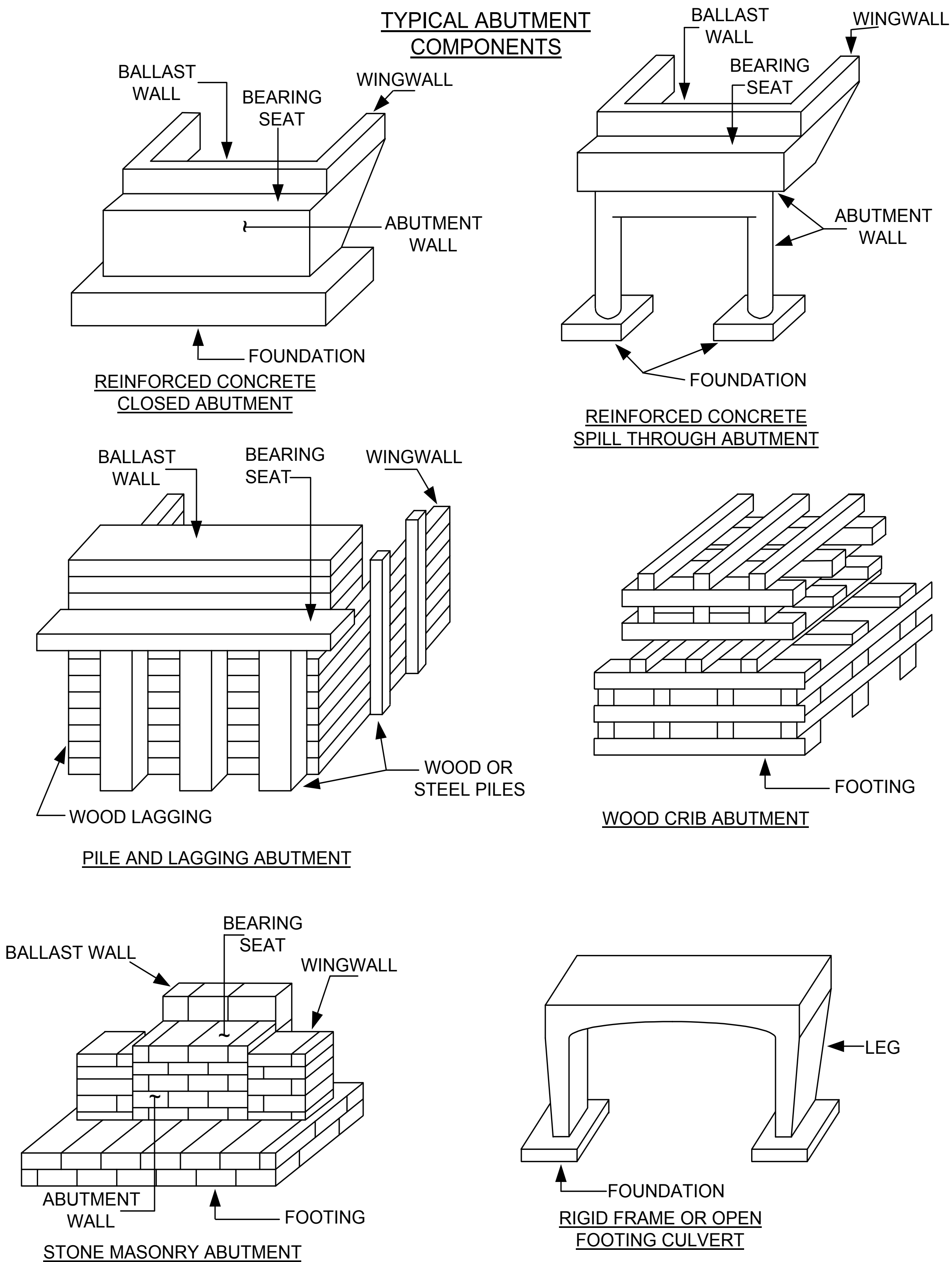


Figure 5.1.2(a) Typical Abutment Components

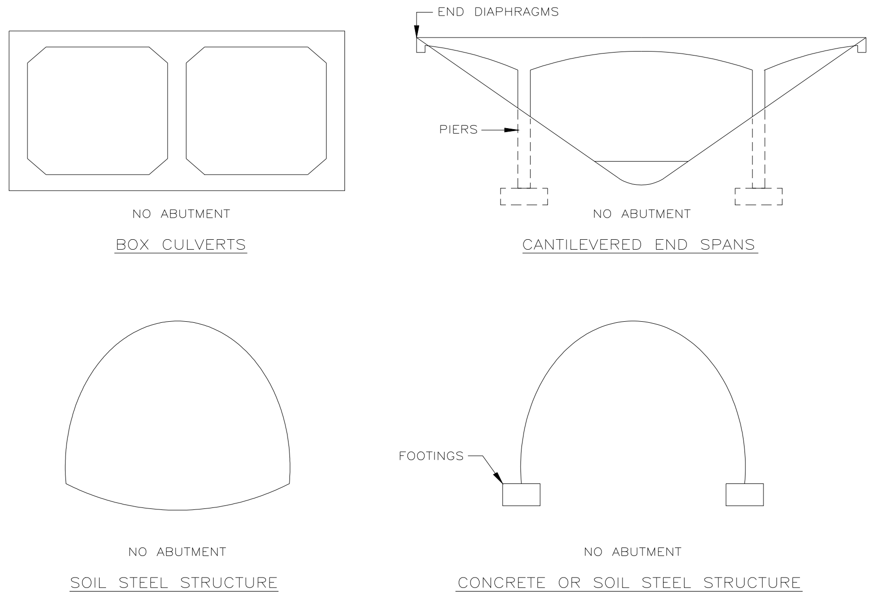


Figure 5.1.2(b) Structures Without Abutments

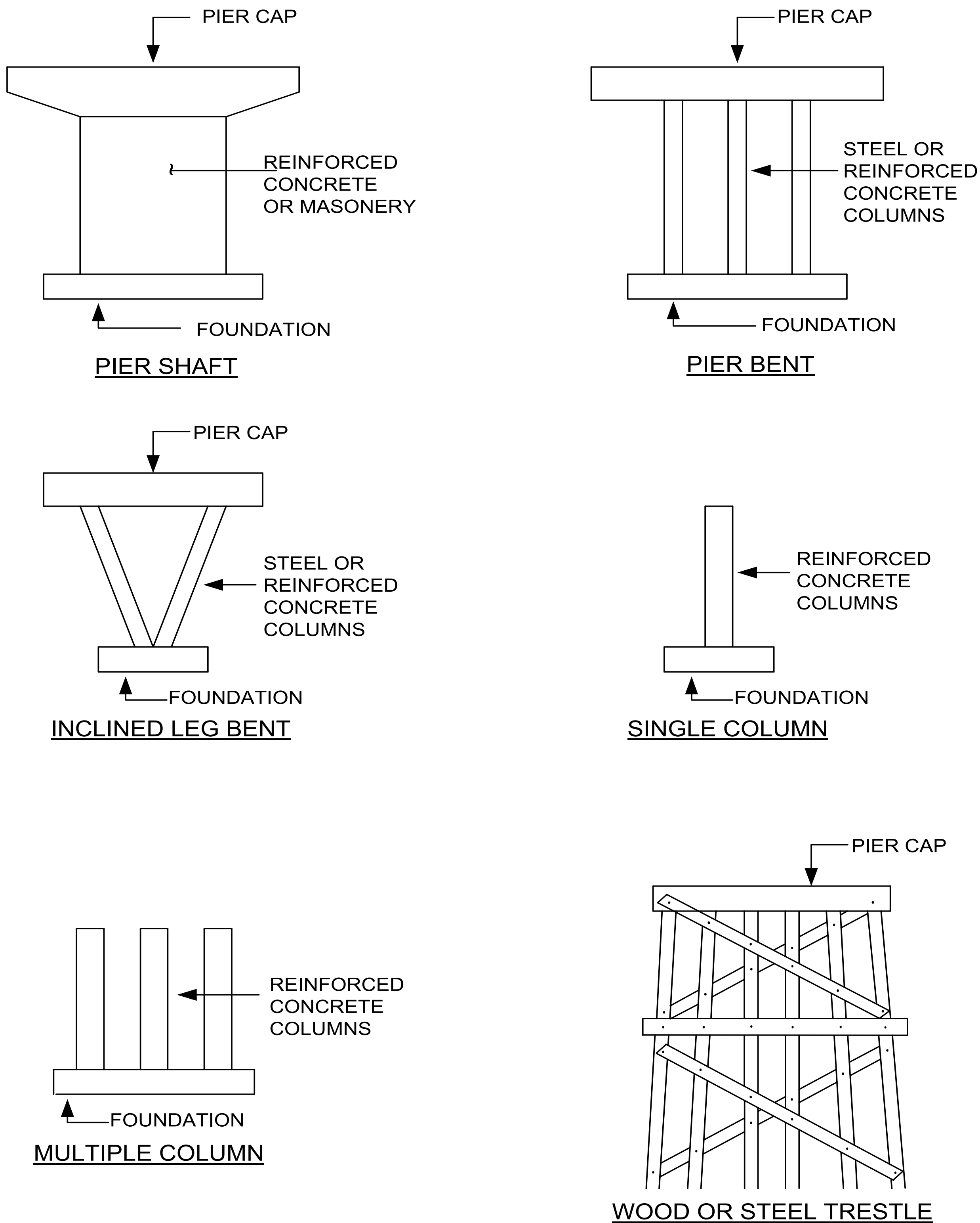


Figure 5.1.3 Typical Piers

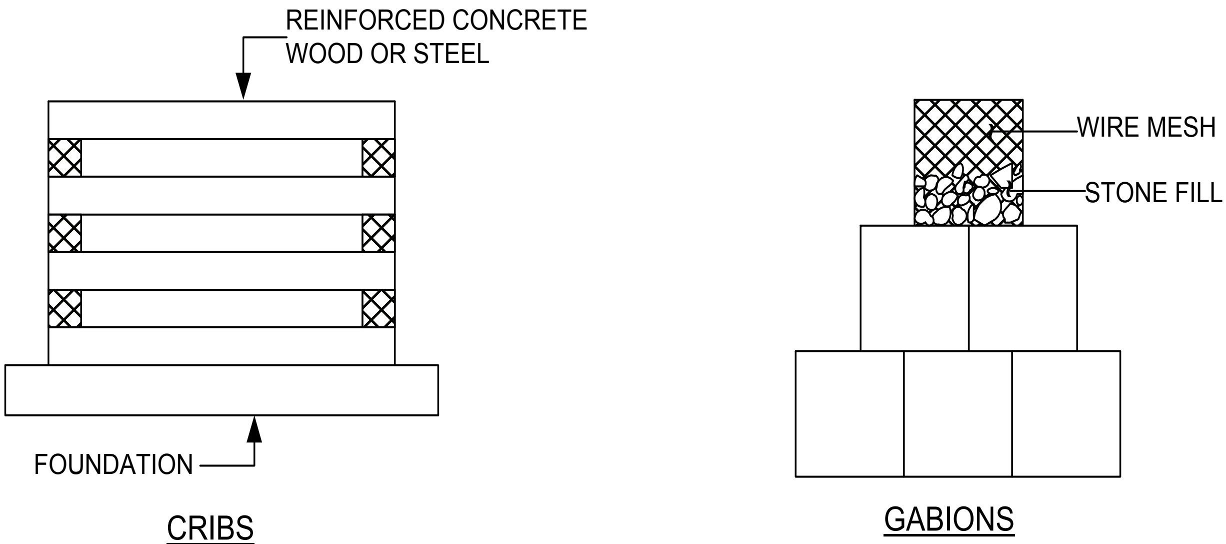
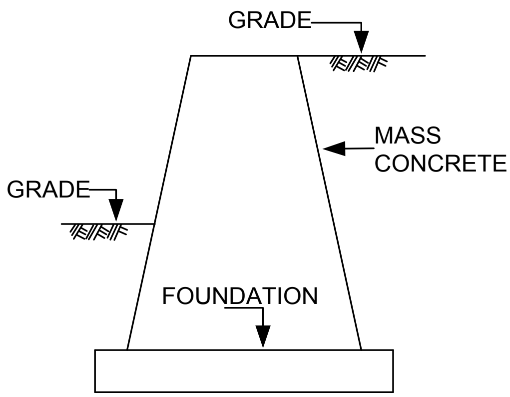
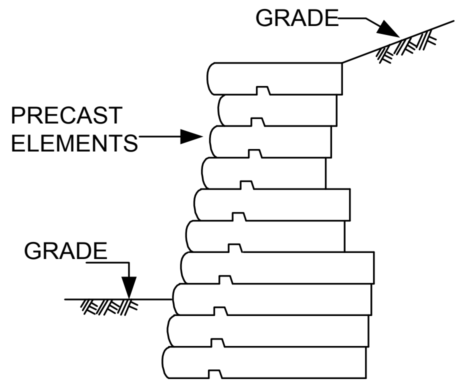


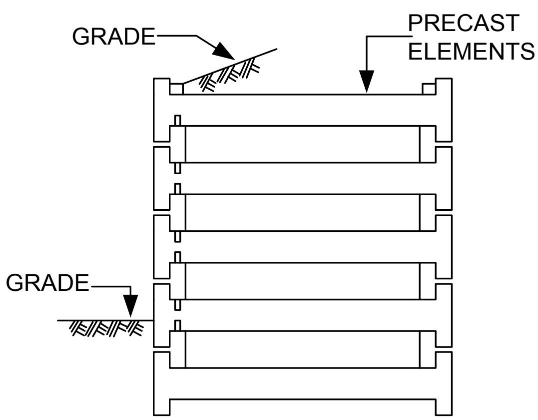
Figure 5.1.3 Typical Piers (cont'd)



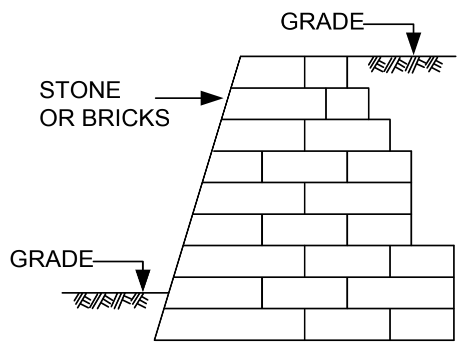
MASS CONCRETE



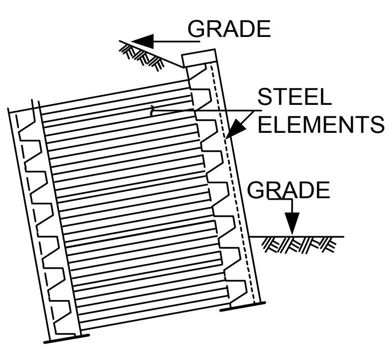
PRECAST CONC. DRY WALL



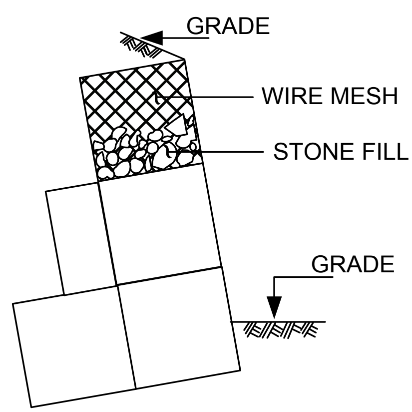
PRECAST CONCRETE CRIBS



MASONRY

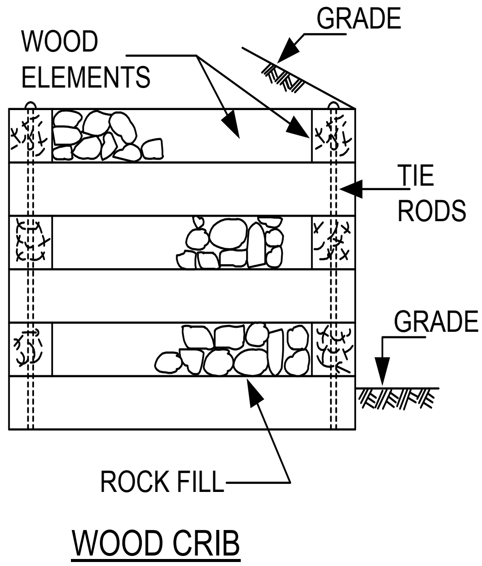


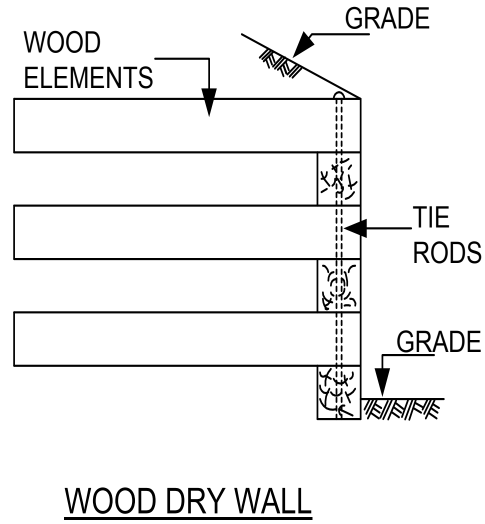
METAL CRIBS



GABIONS

Figure 5.1.4(a) Typical Gravity Retaining Walls





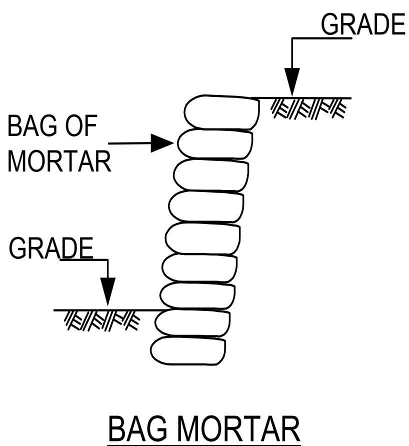


Figure 5.1.4(a) Typical Gravity Retaining Walls (cont'd)

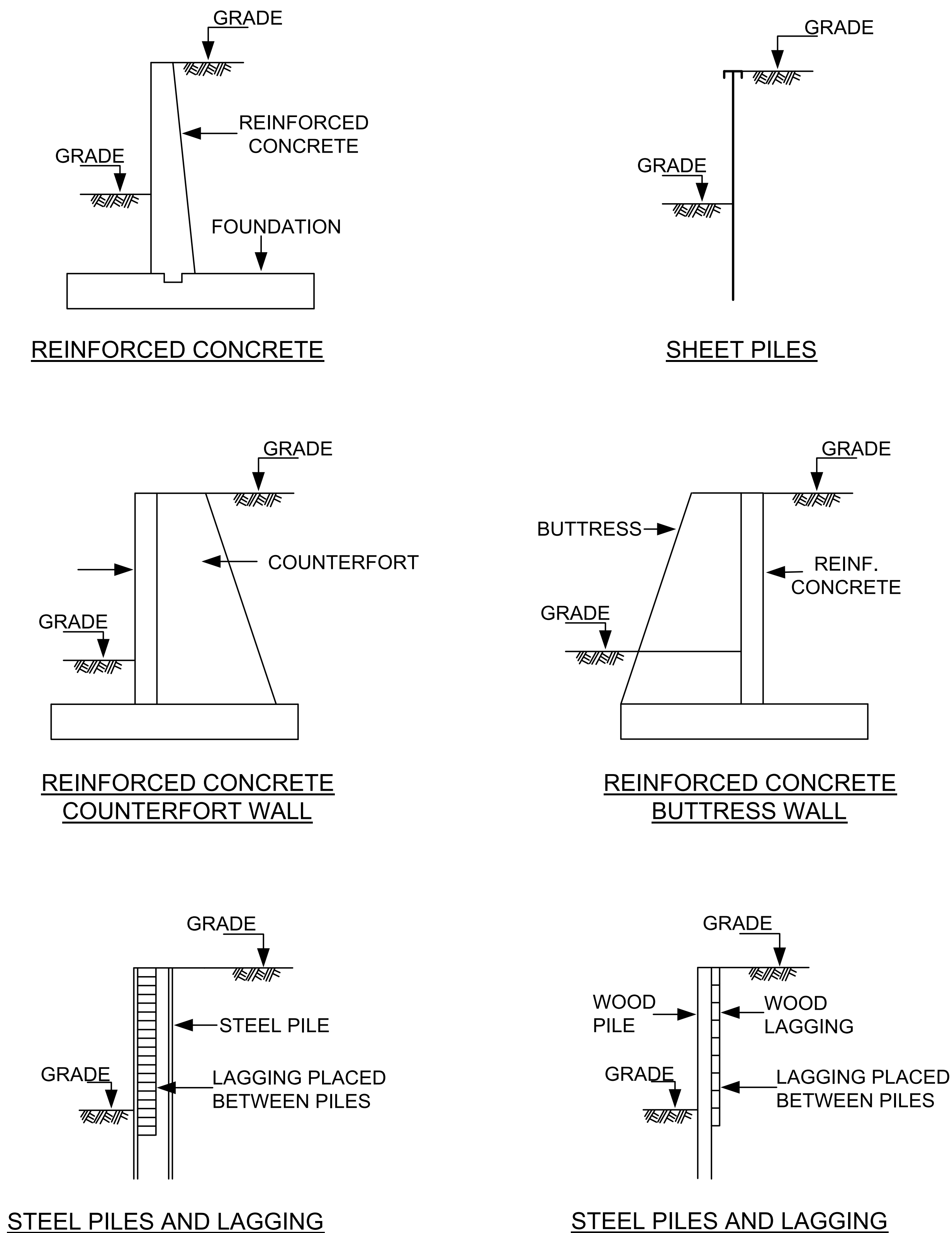


Figure 5.1.4(b) Typical Cantilever Retaining Walls

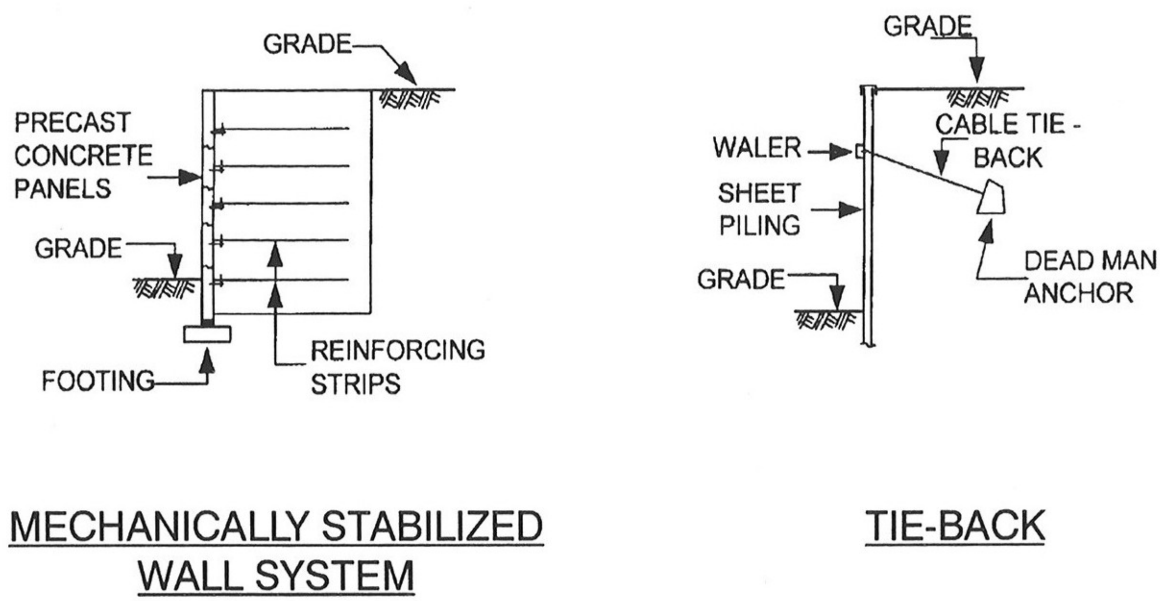


Figure 5.1.4(c) Typical Anchored Retaining Walls

SECTION 6 – BEARINGS

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6.1 Bearings

Bearings are normally located at the interface between the superstructure and substructure. In the case of suspended spans, they are located between the suspended span and the supporting superstructure. Bearings are not needed in some structures, for example, culverts and rigid frames. Bearings are not used in short span structures where the superstructure rests directly on the substructure.

Bearings are to be considered as secondary components except for the pin and hanger bearing which is to be considered as a primary component.

There are numerous types of bearings made of various materials that have been used in bridges over the years. Bearings usually consist of a number of parts which may include but not be limited to, the following:

- a levelling pad;
- a base plate sitting on the levelling pad;
- anchor bolts or pins to secure the base plate to the supports;
- the bearing itself;
- retainer bars or pins to prevent transverse movement of the bearing;
- a shoe plate attached to the underside of the superstructure.

Materials used in bearings are steel, rubber, neoprene, polymers, aluminum or a combination of these. In the past, lead, copper, bronze or iron were also used.

Bearings are subdivided into two main categories based on their capability for movement: fixed or expansion bearings. Fixed bearings do not allow for translation but may allow rotation. Expansion bearings allow for translation and may also allow rotation.

Bearings are grouped as follows and are illustrated in Figures 6.1(a) to 6.1(g).

(a) Steel Plate Bearings

Steel plate bearings may be used with or without translational and rotational capabilities depending on the number of parts provided.

- Fixity of base plate is provided by anchor bolts or pins;
- Translation is provided by steel plate sliding on concrete, bronze, copper or lead or by stainless steel plate sliding on a tetraflouraethylene (TFE) polymer;
- Rotation is provided by a compressible material, usually elastomeric or polyurethane.

(b) Elastomeric Bearings

Elastomeric bearings provide translation and rotation as a function of their stiffness. Thin pads up to 25 mm thick act as fixed bearings. Thicker pads act as expansion bearings and are often reinforced with steel or aluminum plates.

- Fixity is provided by pins or anchor bolts;
- Translation is provided by the pad;
- Rotation is provided by compression of the pad.

(c) Pot and Disc Bearings

Pot and disc bearings provide rotation. They may also provide translation.

- Fixity is provided by anchor bolts or pins;
- Translation is provided by the sliding of a stainless steel surface on a TFE surface;
- Rotation is provided by compression of a confined elastomer or polymer disc.

(d) Spherical and Cylindrical Bearings

Spherical and cylindrical bearings provide rotation. They may also provide translation. Cylindrical bearings rotate about the axis of the cylinder, while spherical bearings can rotate about any axis. A TFE sheet is often bonded to the lower surface.

- Fixity is provided by anchor bolts or pins;
- Translation is provided by sliding of a stainless steel surface on a TFE surface;
- Rotation is provided by the sliding of one curved surface over another.

(e) Rocker Bearings

Rocker bearings provide both translation and rotation.

- Fixity is provided by anchor bolts or pins;
- Translation is provided by tilting or rotation of the rocker;
- Rotation is provided by curved top or bottom surfaces.

(f) Roller Bearings

Roller bearings provide translation. They may also provide rotation.

- Fixity is provided by anchor bolts or pins;
- Translation is provided by rolling of the rollers on the base plate;
- Rotation for single rollers is provided by the curved surface of the roller. For multiple rollers, rotation is provided by a pin connection or curved surface in plate above the roller nest.

(g) Pin and Hanger Bearings

Pin and hanger bearings provide both translation and rotation.

- Translation is provided by movement of the hangers about pins in suspended and cantlivered girders;
- Rotation is provided by rotation about the pins.

SECTION 6 – BEARINGS

6.1.1 Material Defects of Bearings

Material defects in bearings, in addition to those given in Section 2, are:

- lack of lubrication where required;
- cracked or broken parts or plates;
- loose or missing assembly pins, bolts or nuts;
- bent, loose or missing anchor bolts or pins;
- worn pins, rollers, rockers or rolling surfaces;
- corrosion of any component parts including electrolytic corrosion of dissimilar materials in contact, such as, steel and aluminum or steel and bronze;
- cracks, splits or tears in elastomeric pads;
- elastomer leaking out of pots in pot bearings;
- scored TFE surfaces;
- scratched or damaged stainless steel surfaces;
- pulled out sliding plates.

6.1.2 Performance Defects of Bearings

The performance of the bearing is based upon its ability to support and transfer loads from the superstructure to the supports and to allow for or restrict translational or rotational movement of the superstructure at the bearing location.

The proper functioning of the bearing is vital to the performance of the structure as malfunction of the bearings may introduce detrimental stresses into other structure components.

The performance of the bearing with respect to movement is based upon either the restriction of movement for expansion bearing or the movement of fixed bearing and insufficient reserve for anticipated further movement of expansion bearings.

The amount of movement that a structure, and therefore the bearing, may be subject to is a function of the superstructure material, type of construction, expansion length from point of fixity and surrounding air temperature.

The amount of movement that a bearing can accommodate is a function of the type of bearing and the air temperature at the time the bearing was installed.

It may not be possible to exactly determine the expected movements that a bearing may be subject to or the reserve capacity of the bearing as the bearing may have been subjected to unaccounted movements such as movement of the abutment wall. In addition, the superstructure may have been jacked during rehabilitation and the bearing relieved of movement.

The performance of bearings with respect to load capacity and transfer is based upon the uniform contact of the bearing with the superstructure and substructure over the bearing surfaces and the ability of the bearing to carry the load without distress.

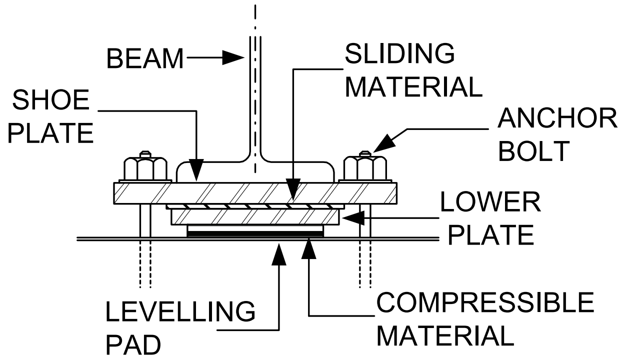


Figure 6.1(a) Steel Plate Bearing

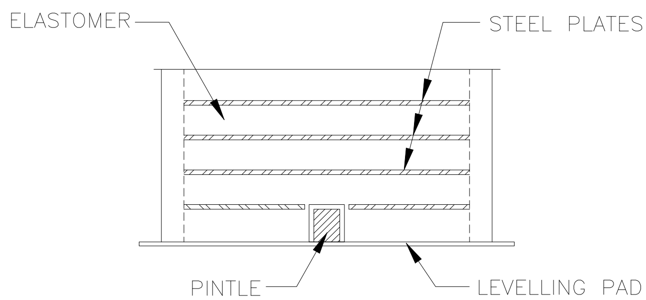
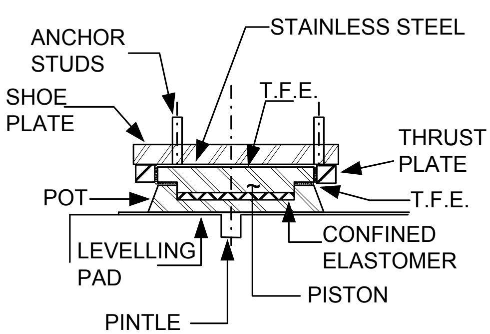
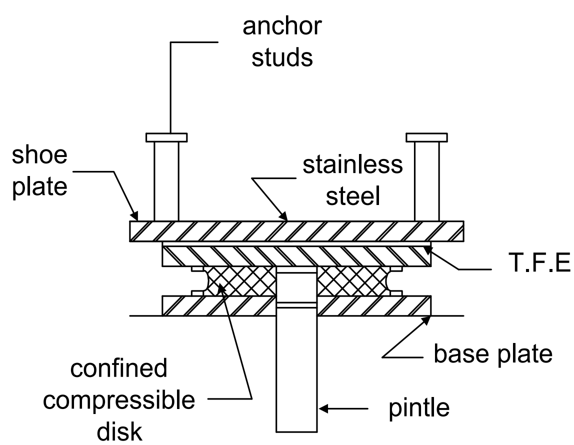


Figure 6.1(b) Elastomeric Bearing



Expansion Pot Bearing



Multi-Directional Disk Bearing

Figure 6.1(c) Pot or Disc Bearing

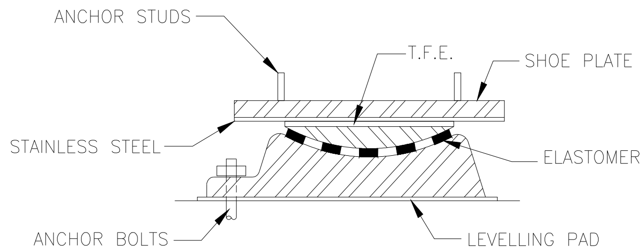


Figure 6.1(d) Spherical Bearing

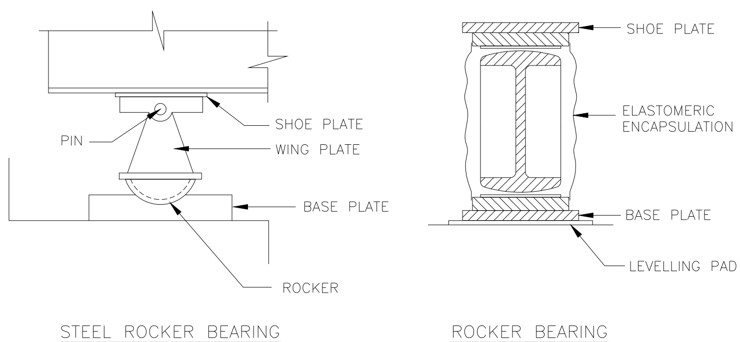


Figure 6.1(e) Steel Rocker Bearing

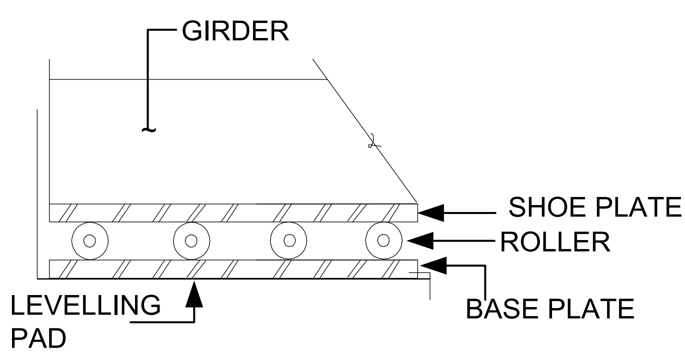


Figure 6.1(f) Expansion Roller Bearing

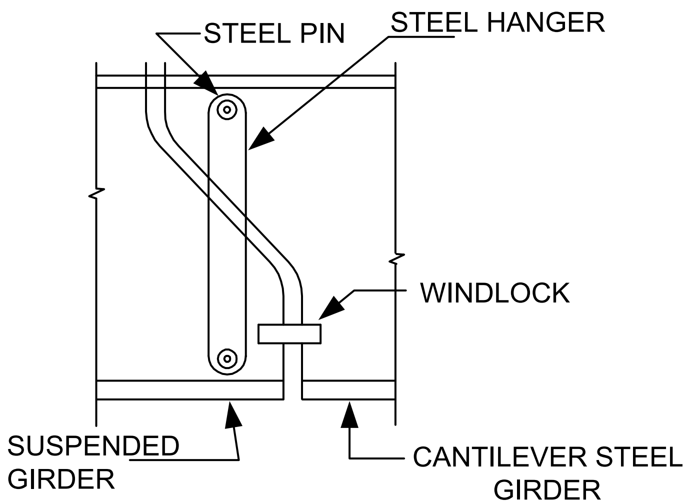


Figure 6.1 Typical Types of Bearings (cont'd)

SECTION 7 – JOINTS

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7.1 Joints

Joints in decks may occur between the deck and the abutment, over the piers between adjacent spans, or within the span at suspended spans.

Joints consist of the following parts, all of which may not be present at each joint.

- A gap to allow for movement;
- Armourings and anchorages on each side of the gap to protect the edges of the gap;
- Seals or sealants in the gap to prevent water from leaking through the gap;
- A trough under an open gap to catch drainage and dispose of it away from components under the gap.

Joints can be divided into open joints which permit the free flow of water and debris, and sealed joints which prevent the flow of water and debris through the joint. Joints can also be divided into expansion joints which accommodate longitudinal, transverse, vertical and rotational movements and fixed joints which accommodate rotational movements only.

Types of joints commonly used in structures are described below and illustrated in Figures 7.1(a) to 7.1(f).

(a) Open Joints

Open joints consist of an open gap whose edges may be protected by armouring.

Sliding plate joints have a flat steel plate bridging the gap of an open joint. The steel plate is welded to one armouring and is free to slide over the top surface of the other armouring.

Finger plate joints have two steel plates cut and arranged to form a series of intermeshing ‘fingers’ which are secured to anchorages on each side of the joint and cantilever over the open gap.

Drop-in-T joints have a ‘T’ section bridging the open gap and is supported on the armouring on each side of the joint.

(b) Poured-In-Place Joints

Paved-over-joints consist of any joint that has been paved over with asphalt pavement. To prevent random cracking of the asphalt pavement over the joint, a groove is sometimes cut or formed in the pavement and filled with a sealant.

Hot or cold poured bituminous or mastic asphalt joints consist of an inert filler placed in the joint gap to below the level of the finished grade, with a hot or cold poured bituminous or mastic asphalt sealant filling the remaining gap to the finished grade. These may be used with asphalt or concrete pavements.

Cold poured polyurethane joints consist of a formed groove in a concrete pavement which is filled with a cold poured polyurethane compound. This material is not used with asphalt pavements because of incompatibility between the bituminous and polyurethane materials.

Hot poured mastic asphalt systems consist of a plug seal placed in the joint gap and an adhesive waterproof membrane hot poured over the joint for a distance of about 450 mm on each side of the gap. Alternating layers of hot poured mastic asphalt and reinforcing mesh are then placed over the joint up to the level of the adjacent asphalt or concrete pavement. Additional hot poured rubberized material is also sometimes poured into grooves cut over the joint and between the mastic asphalt and adjacent roadway surface.

(c) Compression Seal Joints

Elastomeric seal joints consist of a precompressed extruded elastomeric seal bonded to the sides of the joint gap whose edges may be protected by armouring.

Ethylene vinyl acetate joints consist of a precompressed ethylene vinyl seal (looks like foam) bonded to the sides of the joint gap whose edges may be protected by armourings.

These joints allow for movements by changes in the amount of the precompression of the seal.

(d) Elastomeric Cushion Joints

Elastomeric cushion joints consist of a moulded steel reinforced elastomeric assembly that spans over the gap. These joints allow for movements by deformation of the moulding.

(e) Multiple Seal (Modular) Joints

Multiple seal (modular) joints consist of two or more elastomeric seals placed between three or more steel separation beams which are placed on steel support beams spanning across the joint gap. These joints are used where large movements are required.

(f) Strip Seal Joints

Strip seal joints consist of an elastomeric seal that is held in place by one of the following methods:

- pressfitted into preformed armourings;
- vertically bolted down with steel plate hold downs;
- vertically bolted down and the seal is integral with elastomeric armourings;
- horizontally bolted in and has steel armourings;
- clamping devices with stop bars.

These joints allow for movement by the flexing of the elastomeric seal.

7.1.1 Material Defects of Joints

Material defects of joints in addition to those given in Section 2 are:

- corrosion and delamination of steel components;
- pulling away or popping out of the seal or sealant;
- cracks, splits, tears or holes in the seal or sealant;
- loose or missing sections of the seal or sealant;
- abrasion, wear or aging of the seal or sealant;
- compression set or loss of resiliency of the seal or sealant;
- loss of bond between the seal or sealant and the adjacent pavement;

- shrinking away of the sealant from the adjacent pavement;
- loose, broken or missing bolts, nuts, washers or other anchorage devices;
- loose, bent, cracked, broken, missing or damaged finger plates, sliding plates, extrusions, support components or armourings;
- cracking of welds and welded connections;
- cracking, spalling or breaking up of the concrete, asphalt, or other material adjacent to the joint;
- softening or shifting of mastic asphaltic materials.

7.1.2 Performance Defects of Joints

The performance condition rating of joints is based upon their ability to:

- accommodate the movements of the superstructure;
- maintain the continuity of the roadway surface and support wheel loads;
- prevent the leakage of roadway drainage through the joint (sealed joints);
- channel surface run-off water away from primary and secondary components (open joints).

The performance of joints with respect to movement is based upon movement restriction and evidence of insufficient reserve for anticipated further movement.

The amount of movement that a structure, and therefore a joint, may be subject to is a function of the superstructure material, type of construction, expansion length from point of fixity and surrounding air temperature.

The amount of movement that a joint can accommodate is a function of the type of joint, and the air temperature and joint gap set at the time of installation.

It may not be readily possible to determine the exact amount of movement that a joint may be subject to or the capacity of the joint for movement as complete information on structure movements and joint capacity is often not directly available at the time of inspection. However, the relative size of the joint gap can be assessed with respect to the expansion length from point of fixity and air temperature at the time of inspection.

An incorrect joint gap is likely a symptom of improper functioning of the bearings or of movements of the abutments, pier or foundation. The inspector shall measure and record the joint gap and air temperature at the time of inspection.

The performance of joints with respect to roadway continuity is based upon the adverse effects that the misalignment of the joint components on either side of the joint may present to traffic.

Vertical misalignment can result in a bumpy ride across the joint and a potential hazard of loss of vehicle control. Vertically misaligned joints are also subject to damage by snow removal equipment.

Horizontal misalignment can result in binding or jamming of the joint and tearing of the joint seal or sealant.

The performance of joints with respect to watertightness, in the case of sealed joints, is based upon the extent of leakage of roadway drainage through the joint. Joint leakage can result in serious deterioration of the joint materials and other structure components located below the joint.

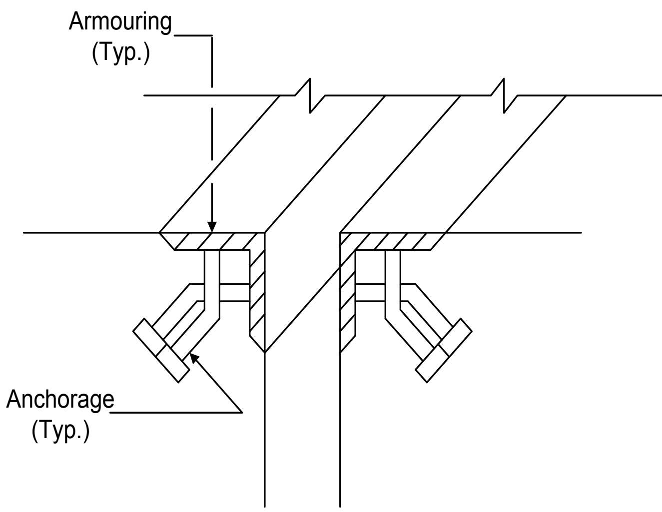
By definition, open joints permit the passage of water through them. However, it is not necessary that open expansion joint systems preclude adequate treatment of the surface run-off which passes through the joint.

SECTION 7 – JOINTS

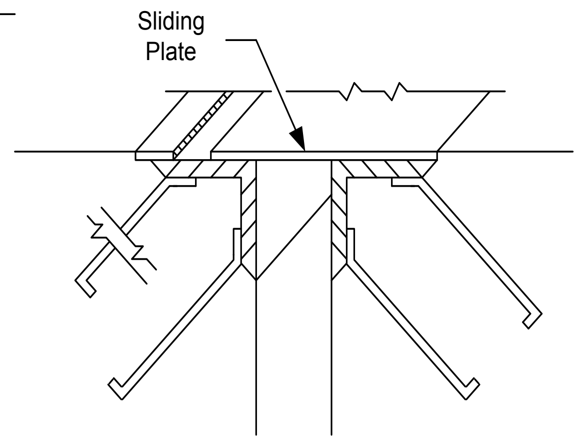
Properly detailed open joints will minimize the potential for deterioration of adjacent components arising from surface run-off. The performance of an unsealed or open joint is directly related to its ability to minimize this potential.

Deterioration can be minimized through the use of any or all of the following:

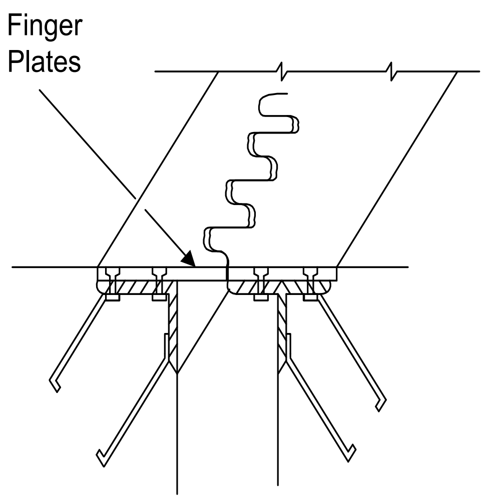
- drip stop details on the underside of the joint;
- collection gutters below joint (either suspended or formed in concrete in bearing seat areas;
- deflection plates;
- placement of deck drains close to and on the upgrade side of open joints;
- locating open expansion joints away from substructure components.



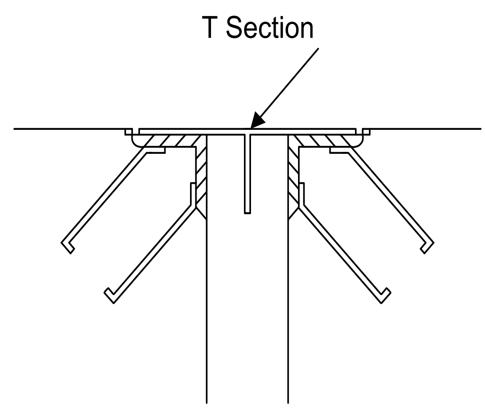
Open Gap Joint



Sliding Plate Joint



Finger Plate Joint



Drop-in-T Joint

Figure 7.1(a) Open Joints

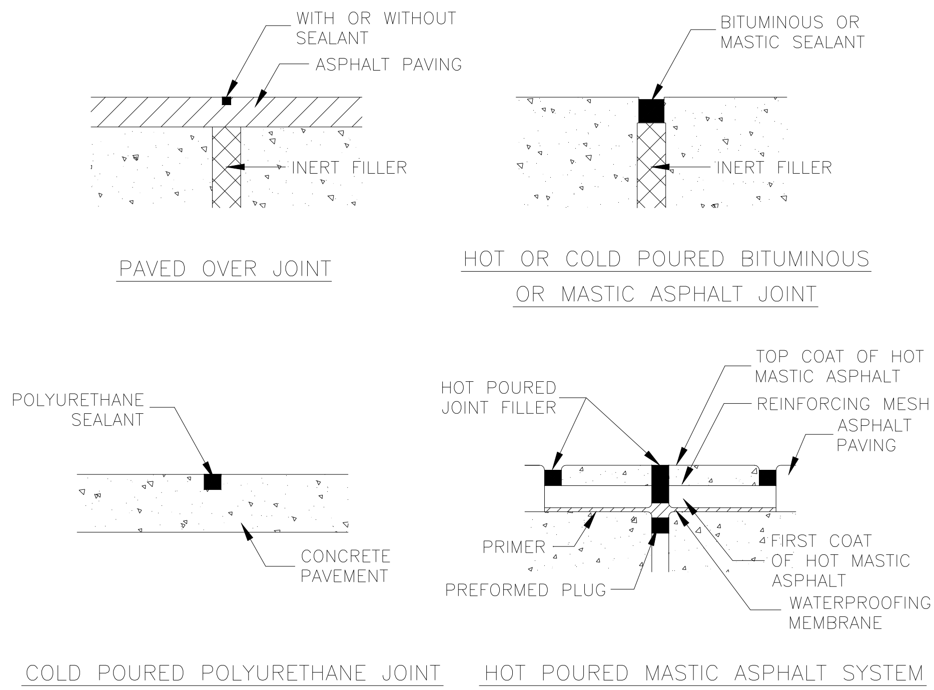


Figure 7.1(b) Poured-In-Place Joints

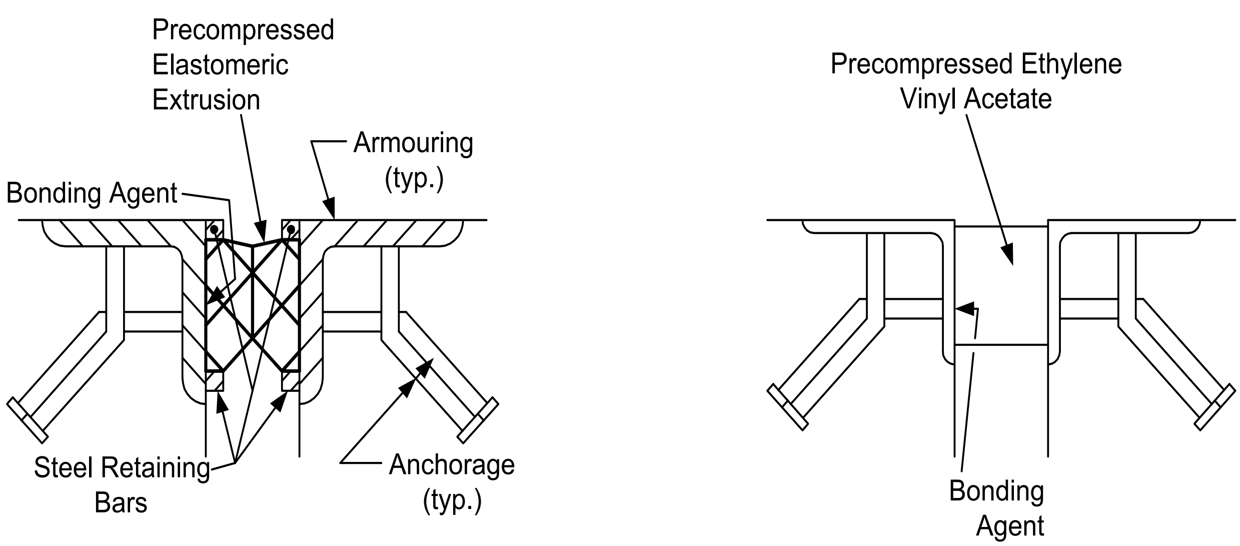


Figure 7.1(c) Compression Seal Joints

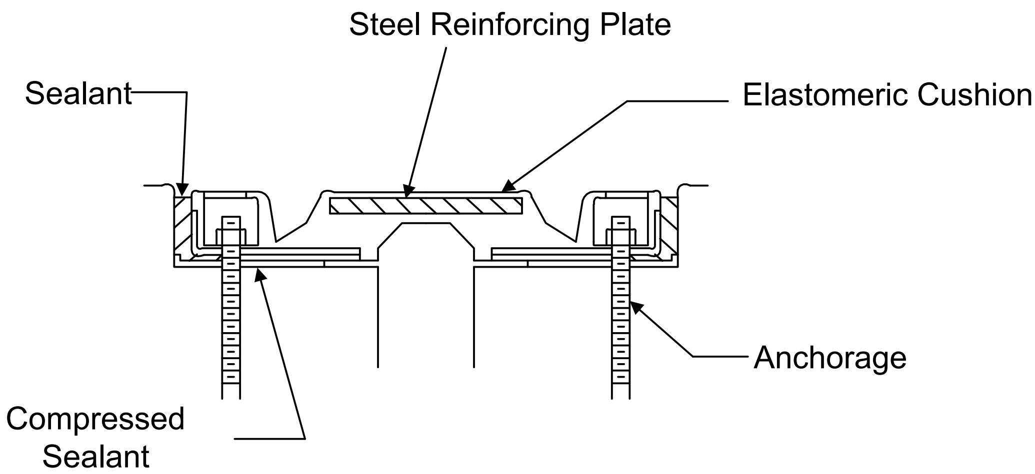


Figure 7.1(d) Elastomeric Cushion Joints

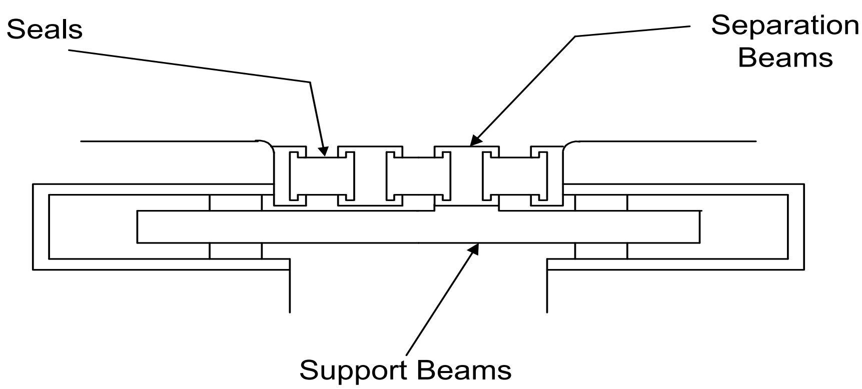
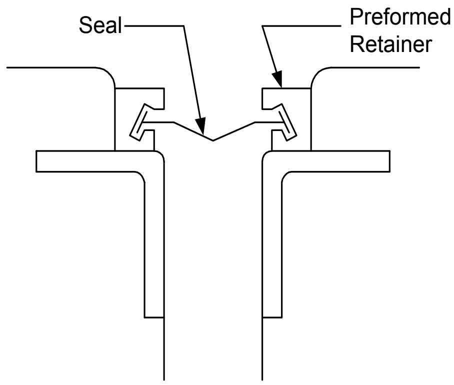
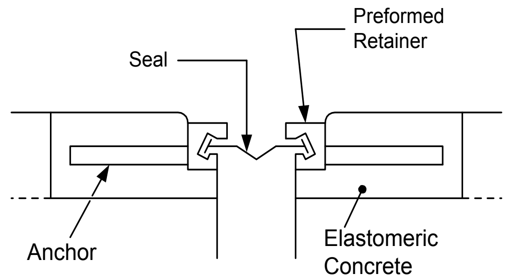


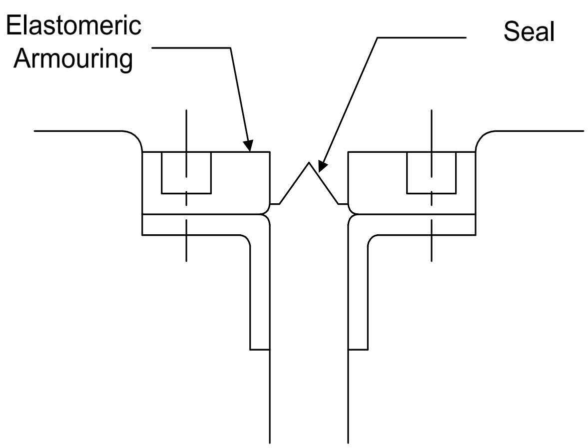
Figure 7.1(e) Multi-Seal Joints



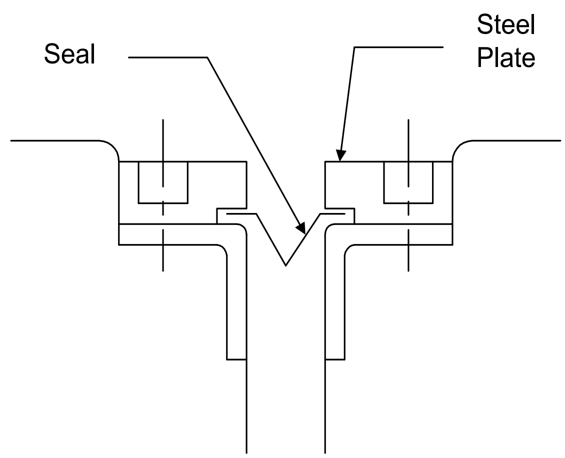
Strip Seal in Preformed Retainer



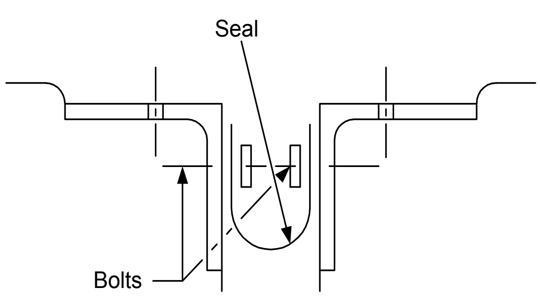
Strip Seal in Elastomeric Concerte



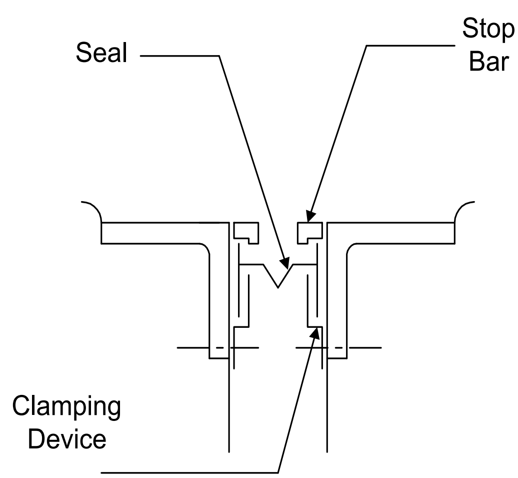
Strip Seal - Integral With Elastomeric Armouring



Strip Seal Vertically Bolted Down



Strip Seal Horizontally Bolted



Strip Seal in Clamping Devices

Figure 7.1(f) Strip Seal Joints

SECTION 8 – SUPERSTRUCTURES

Table of Contents

8.1 Superstructures

Superstructures normally consist of all components of structures supported on the substructures. The following components of superstructures are covered in this section:

- Beams and girders;
- Thick slabs;
- Trusses;
- Arches;
- Culverts;
- Soil Steel Structures;
- Movable bridges in fixed position;
- Suspension bridges;
- Stringers and floor beams under the decks;
- Diaphragms;
- Sway bracings;
- Lateral bracings.

Other parts of the superstructure, such as, decks, curbs, sidewalks, parapet walls, railings and expansion joints are covered in other sections of **BIM**.

Movable bridges shall be inspected and recorded by the type of the main load carrying components. Inspection of mechanical or electrical parts of movable bridges is not covered in **BIM**.

8.1.1 Beams and Girders

Beams and girders are made of reinforced or prestressed concrete, steel or wood.

Beams and girders may be simply supported, semi-continuous for live and superimposed dead loads, continuous over a number of spans or cantilevered beyond the support with a drop-in section added to complete the span.

Concrete beams or girders are cast-in-place or precast as one unit or in segments. They may be T-shape, rectangular or trapezoidal in shape and may have single or multiple voids of various shapes in them.

Steel beams or girders are rolled into standard shapes or built-up into I-shapes, rectangular or trapezoidal boxes by riveting, bolting or welding. They may be unstiffened or stiffened with vertical or longitudinal stiffeners. They may be erected as single units or in segments.

Wood beams or girders may be sawn, laminated or glued and are normally rectangular in shape. They are erected as single units but may sometimes be spliced together with steel plates, fasteners or gang-nail plates.

Decks are supported directly on beams and girders except in the case of half-through girders, in which the load from the deck is first transferred to stringers and floor beams and then to the girders.

Beams and girders may have diaphragms and lateral bracings between them. Concrete girders normally have solid concrete diaphragms whereas steel girders may have diaphragms made of steel beams, girders, channels or angles. Steel girders may also have lateral bracings made of steel angles or channels.

Beams and girders carry loads by flexural, shear or torsional resistance. Examples of typical beams and girders are illustrated in Figure 8.1.1.

8.1.2 Thick Slabs

Thick slabs are made of reinforced or prestressed concrete or a combination of these and may be simply supported or continuous.

They may be solid or contain round, rectangular or trapezoidal voids, and are normally cast-in-place. The deck slabs of rigid frames are considered as thick slabs.

The top surface of thick slabs acts as the deck and shall be inspected as detailed in Section 9.

Thick slabs carry loads by flexural, shear, torsion and axial forces depending on the fixity and configuration of the support systems. Examples of thick slabs used are illustrated in Figure 8.1.2.

8.1.3 Trusses

Trusses are made of steel or wood. A few trusses made of cast iron are still in existence.

Trusses may be single or multiple span and may be simply supported or continuous. They may also be cantilevered beyond the support with a ‘drop-in’ truss section to complete the span.

Trusses consist of top and bottom chords, verticals and diagonals.

Types of trusses commonly encountered are the through truss, half-through (pony) truss, deck truss and the Bailey bridge truss.

Through trusses are connected together across the top chords above the roadway level by transverse portals, sway frames and lateral bracings. The bottom chords are connected together below the roadway level by transverse floor beams which support longitudinal stringers and the deck. The bottom chords are also connected by lateral bracings below the deck.

Half-through trusses are not connected across the top chords, allowing for unrestricted overhead clearance. Sway braces or rakers are connected between the top chords and floor beams, or needle beams, to provide lateral restraint to the top chord. The bottom chords are connected together below the roadway level by transverse floor beams which support longitudinal stringers and the deck. The bottom chords are also connected by lateral bracings below the deck.

Deck trusses are located entirely below the roadway level. They may directly support the deck, or the deck may be supported on longitudinal stringers and transverse floor beams resting on the deck trusses. Adjacent trusses are also commonly connected by transverse cross bracing between the top and bottom chords, and by additional lateral bracing between the bottom chords.

Bailey bridge trusses are built of components that can be erected into a number of different types of trusses. The most common being the half-through type. Sway bracings, lateral bracings and floor systems for the Bailey bridges are similar to the half-through trusses described above.

Components of steel trusses consist of individual rolled sections or are built-up by bolting, riveting or welding several sections together. Older steel trusses may contain solid round or square bars or eye-bars, while more recent steel trusses may also contain tubular sections. Components of wood trusses are typically made from solid rough-sawn sections or are built-up by bolting or gluing several sections together. Steel rods are also often used for tension components in wood trusses.

Individual truss components are connected together at joints with splice plates or gusset plates fastened by pins, rivets, bolts, lag-screws, nails or by welding.

While their overall configuration may vary, trusses are built up of individual components interconnected in triangular arrangements in such a manner that the components resist applied loads axially, through compression or tension in the individual components.

However, depending on the degree of fixity at the connections, either actual or assumed, and on the location of the applied load on the member, some of the truss components may also be subject to flexural, shear or torsional loads. Trusses and common terminology used to describe their components are illustrated in Figure 8.1.3(a).

Typical temporary bridge configurations and components are shown in Figures 8.1.3(b) and (c). For a complete coverage of temporary bridges, consult The Bailey and Uniflote Handbook, Acrow Corporation of Canada.

8.1.4 Arches

Arches are made of concrete, steel, wood or masonry.

Arches may be single or multiple span and may be hinged or fixed at the supports. They may have an intermediate hinge at their crown.

Arches consist of arch ribs, top or bottom chords, verticals and diagonals.

Types of arches commonly encountered are the tied (bowstring) arch, through arch, open spandrel arch, filled spandrel arch and barrel arch.

Tied (Bowstring) arches are used where the soil is not capable of resisting the horizontal thrust of the arch rib. The bottom chord, or tie, may also support the deck system as they are usually at the same level. There may also be a system of portal or sway frames and lateral bracing between the arch ribs over the roadway. In steel tied arches there may also be a system of lateral bracing under the deck.

Through arches are used where the soil is capable of resisting the horizontal thrust of the arch. In this arch, the deck and floor system is suspended from the arch rib by hangers. The arch ribs are also connected together across the top by a system of portal and sway frames and lateral bracing. There may also be a system of lateral bracing under the deck.

Open spandrel arches are used where the soil is capable of resisting the arch thrust. In this type of arch, the deck is located above the level of the arch crown, and the deck and floor system is supported on columns carried down to the arch rib(s).

In steel spandrel arches there are two or more parallel ribs interconnected by a bracing system. Concrete spandrel arches may have several ribs interconnected with diaphragms, but are also commonly built with only one solid arch, the full width of the deck.

Filled spandrel arches are commonly used for short spans. End conditions are usually fixed. The arch is backfilled with earth, granular or other suitable fill which forms the base for the deck. The sides of this arch are closed by retaining walls and wingwalls.

Barrel arches are similar to the filled spandrel arches except that the sides are open and therefore there are no retaining walls.

Components of steel arches consist of individual rolled sections or are built-up by bolting, riveting or welding several sections together. Older steel arches may contain solid round or square bars or eye-bars, while more recent steel arches may also contain tubular sections.

In steel arches, the components are connected together at joints with splice plates or gusset plates fastened by pins, rivets, bolts or by welding. In comparison, concrete arches are usually constructed monolithically with the deck system, ties, railings, hangers, and arch rib rigidly connected.

While their overall configuration may vary, the arrangement and connection of their components and the degree of fixity at the supports and between the connections determines the distribution of applied loads internally in the arch and the transfer of load to the foundation or soil. The arch ribs resist applied loads mainly by compression and flexure. The arch ties resist loads mainly by tension and some flexure (depending on the location of the applied loads).

Concrete arches are usually monolithically cast, with the result that the interaction and stress distribution among the components is extremely complex. Also, when the arches have fixed ends they are very sensitive to differential settlement or rotation of the foundation, which may produce overstressing and cracking locally.

Arches and the common terminology used to describe them are illustrated in Figure 8.1.4.

8.1.5 Culverts, Tunnels and Soil-Steel Structures

Culverts and soil-steel structures are bridges embedded in fill. In most cases, they convey water through an embankment; however, occasionally they accommodate pedestrian, rail or vehicular traffic through the embankment.

A tunnel is a bridge constructed through existing ground. In most cases it accommodates pedestrian, rail or vehicular traffic. Occasionally, it is designed to convey water.

Culverts and tunnels may be made of concrete or wood. Soil- steel structures are comprised of corrugated steel pipe or plates and soil and are designed and constructed to induce a beneficial action between the structure and the soil. Soil-steel structures are constructed in several shapes such as round, ellipses, pipe arches, superspans, and may be constructed with or without ears or relieving slabs.

High embankments or fills may impose very large vertical and lateral earth loads on culverts and tunnels which can result in structural failure of the roof, floor slab or walls.

The strength of a soil-steel structure is derived from the interaction between the structure and the surrounding soil. Vertical loads from the overlying soil and traffic are transmitted by arching action to the underlying soil. If the side support is not provided due to inadequate placement, compaction or loss of soil or backfill material, then failure of the structure can result.

Culverts, tunnels and soil-steel structures are divided into two main types according to cross-section: open invert and closed invert. An open invert structure has a floor of natural soil, bedrock or other material that is not structurally integral with the walls. A closed invert structure is one where the floor is structurally integral with the walls.

Where these structures are used to carry water their basic components can be divided into inlet, barrel and outlet as shown in Figure 8.1.5(a). The inlet channels water into the barrel and the outlet channels the water back into the stream. The inlet and the outlet may also contain headwalls, cut-off walls, wingwalls, headerwalls and aprons to provide protection against scour and piping. The barrel and outlet may also contain drop-outlets, stilling basins, chutes and stepped flumes to dissipate the energy of the water before it re-enters the stream, as shown in Figure 8.1.5(b).

When a roadway is widened or when the road grade is raised, extensions to these structures may be built using different materials. It is therefore necessary to inspect the full length of these structures to determine the condition of the original structure.

Typical examples of culverts, tunnels and soil-steel structures are illustrated in Figure 8.1.5(c).

8.1.6 Diaphragms

Diaphragms are made of steel, wood or concrete components.

Diaphragms span between the primary load carrying components such as beams, girders, deck trusses, or are located inside box sections. They are normally located in the vertical plane.

Diaphragms may be solid, or built up from individual steel or wood sections which are assembled together to form x-frames or k-frames using rivets, bolts, nails or by welding.

Diaphragms can be distinguished as load bearing or non-load bearing. Load bearing diaphragms directly support superstructure reactions or are designed for jacking purposes. Non-load bearing diaphragms provide lateral support or restraint to other superstructure components.

Typical diaphragms are illustrated in Figure 8.1.6.

8.1.7 Sway Bracings

Sway bracings are made of concrete, steel or wood.

Sway bracings are the transverse bracings between primary components and are normally located in the vertical plane. In the case of half-through trusses the sway bracings are attached to the outside of each truss instead of between the trusses.

Sway bracings may be solid, or built up from individual steel or wood sections which are assembled together to form x-frames or k-frames using rivets, bolts, nails or by welding.

Typical sway bracings are illustrated in Figure 8.1.3(a) and Figure 8.1.4.

8.1.8 Lateral Bracings

Lateral bracings are made of steel or wood.

Lateral bracings are the transverse bracings between primary components such as beams, girders, trusses and arches and are normally located in the horizontal plane.

Lateral bracings are normally made from single components but sometimes may be made into frames.

Typical lateral bracings are illustrated in Figures 8.1.3(a), 8.1.3(c) and Figure 8.1.8.

8.2 Primary Components

The following are to be considered as primary components:

- beams, girders;
- thick slabs;
- truss top and bottom chords, verticals and diagonals;
- arch ribs, ties, vertical and diagonals;
- stringers and floor beams;
- load bearing diaphragms that directly support or transmit wheel loads;
- connections to primary components;
- barrel of culverts, tunnels and soil-steel structures.

8.2.1 Material Defects of Primary Components

Material defects are given in Section 2.

8.2.2 Performance Defects of Primary Components

Performance defects in primary components are related to their ability to support the dead and live loads imposed on them and to transmit those loads to the substructure without excessive deformations or vibrations.

8.3 Secondary Components

The following are to be considered as secondary components:

- Non-load bearing diaphragms that do not directly support or transmit wheel loads;
- Sway bracings;
- Lateral bracings;
- Connections to secondary components;
- Inlet and outlet treatments of culverts.

8.3.1 Material Defects of Secondary Components

Material defects are given in Section 2.

8.3.2 Performance Defects of Secondary Components

The performance condition rating of non-load bearing diaphragms is based upon their ability to restrict relative vertical and transverse movements between the primary components and thus transmit vertical and transverse loads between them without excessive or permanent deformations.

The performance condition rating of sway bracings is based upon their ability to restrict relative transverse and vertical movements between primary components and thus prevent lateral buckling of primary components.

The performance condition rating of lateral bracings is based upon their ability to restrict relative longitudinal and transverse movements between primary components and thus transmit longitudinal and transverse loads between them without excessive or permanent deformations.

The performance condition rating of inlet and outlet treatments of culverts is based upon their ability to provide for the functions they are designed for.

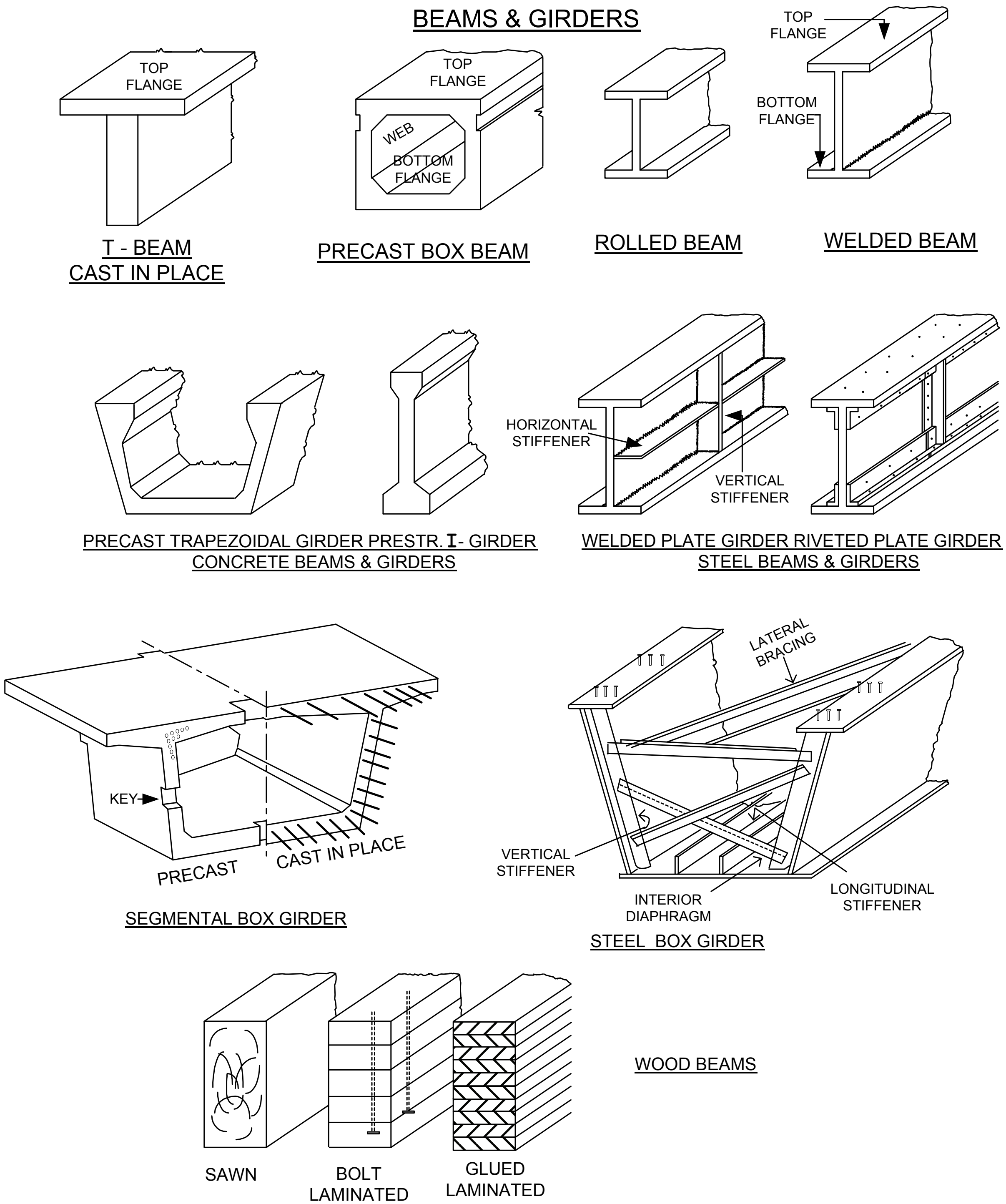
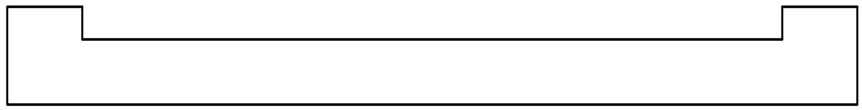
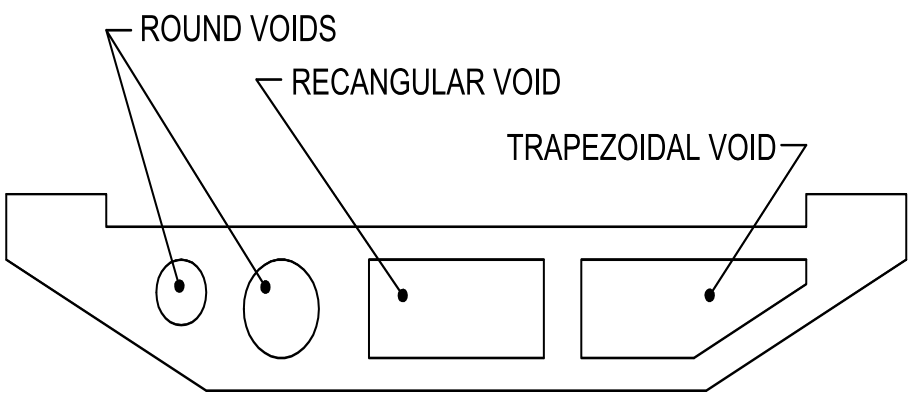


Figure 8.1.1 Beams and Girders



Solid Thick Slab



Voided Thick Slab

Figure 8.1.2 Thick Slabs

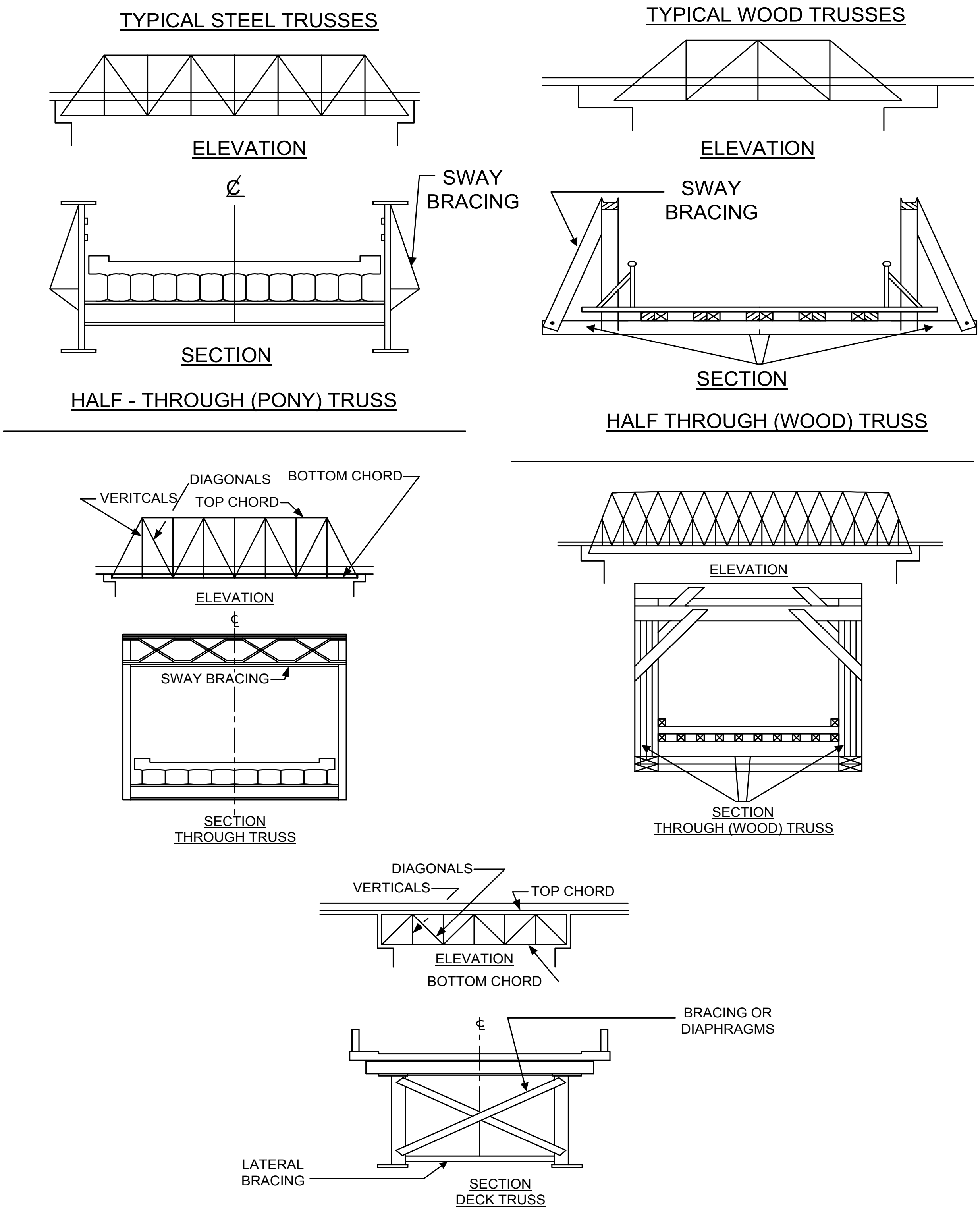


Figure 8.1.3(a) Trusses

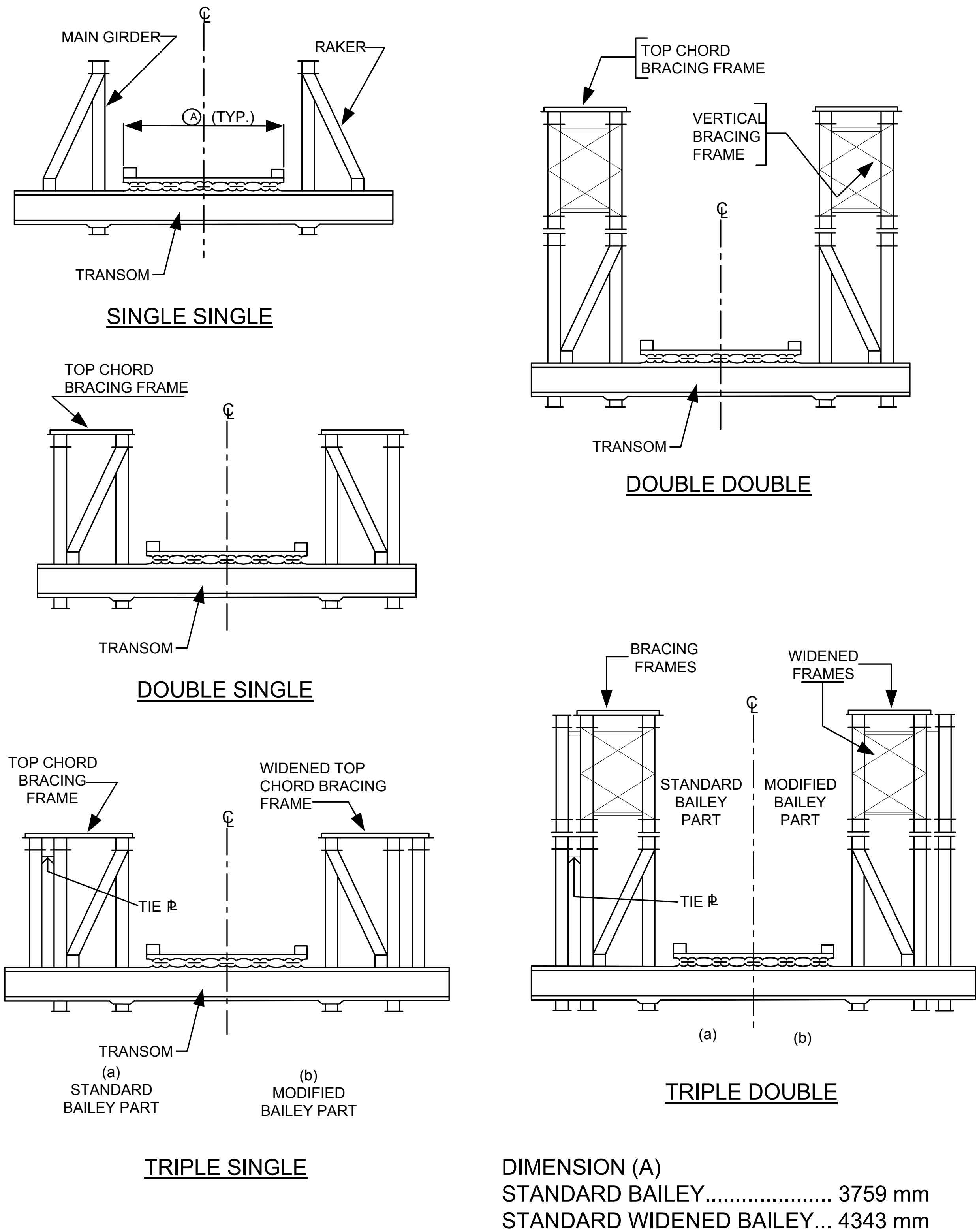


Figure 8.1.3(b) Typical Bailey Configurations

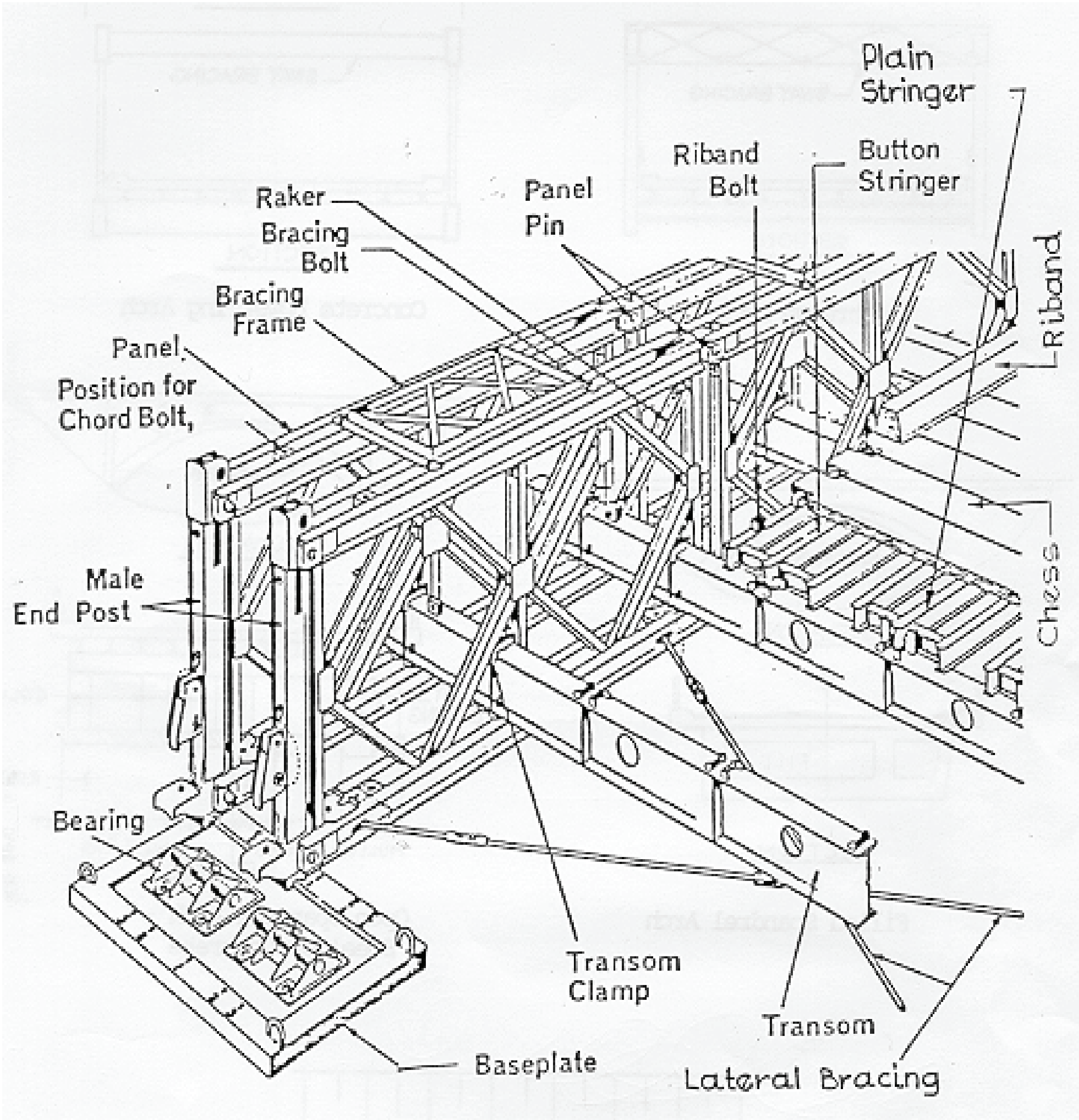


Figure 8.1.3(c) Typical Bailey Components

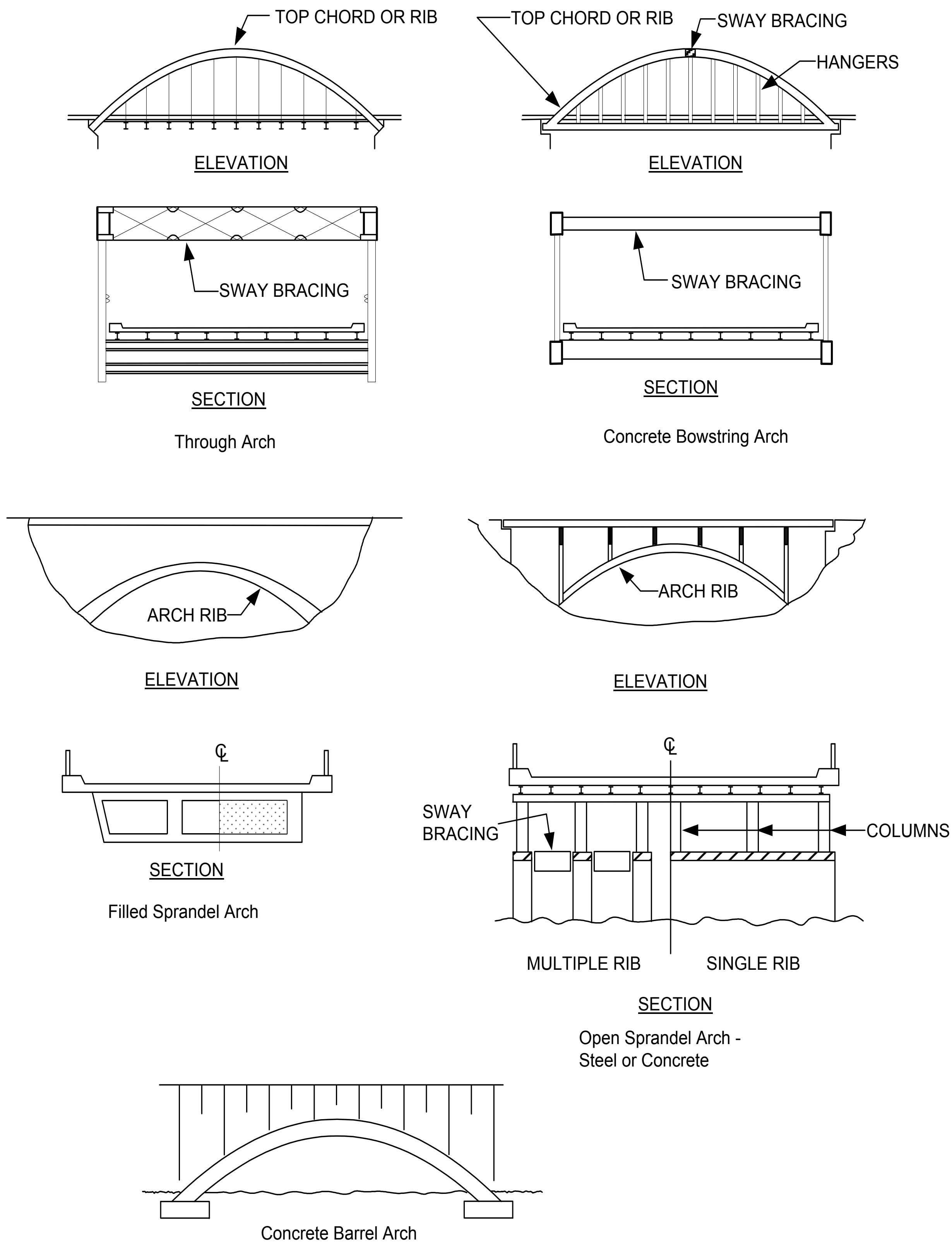


Figure 8.1.4 Arches

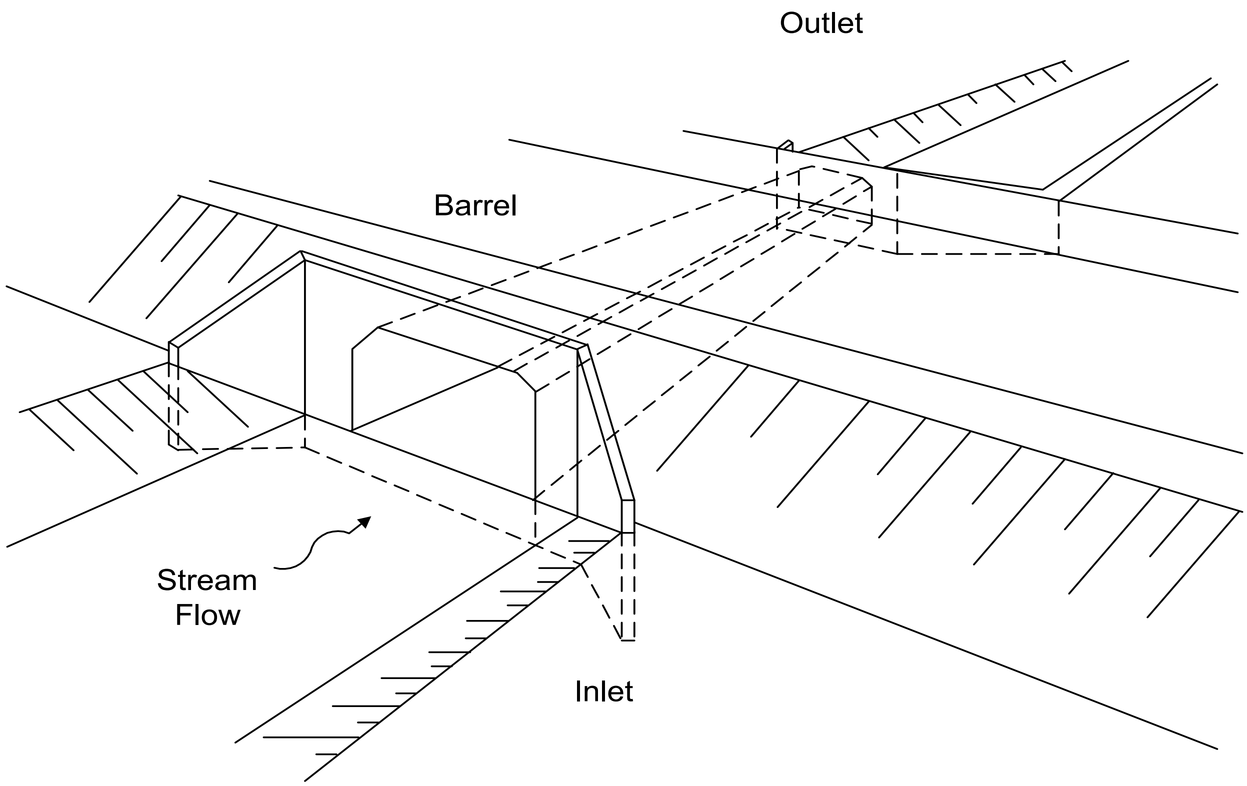


Figure 8.1.5(a) Basic Culvert, Tunnel and Soil-Steel Structure Components

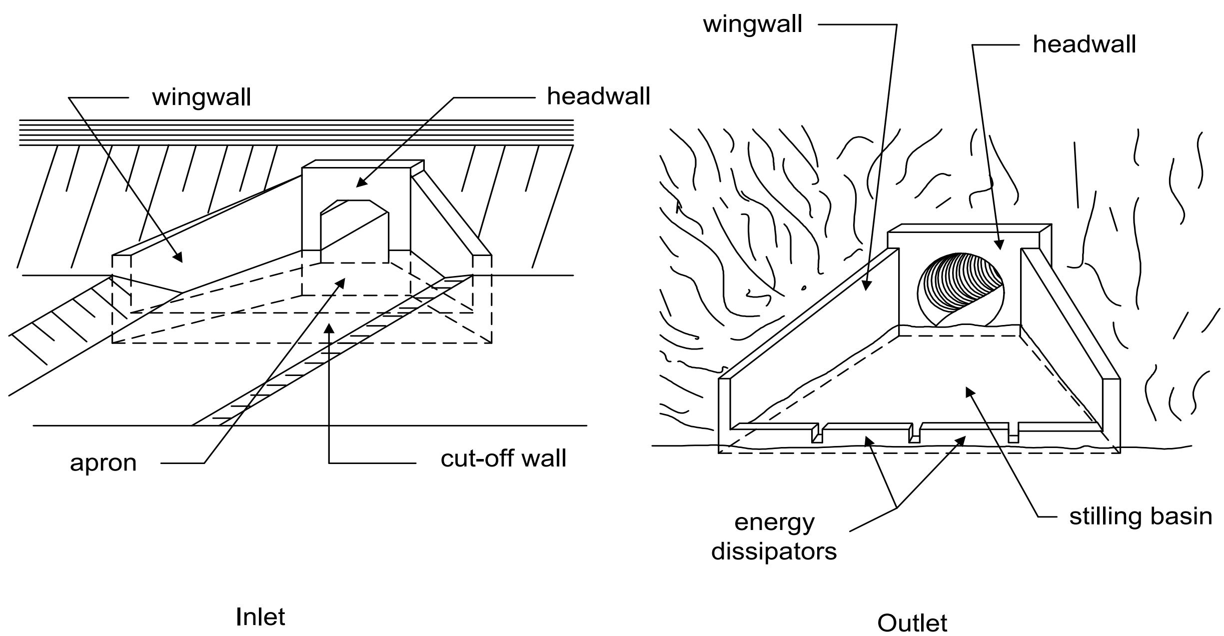
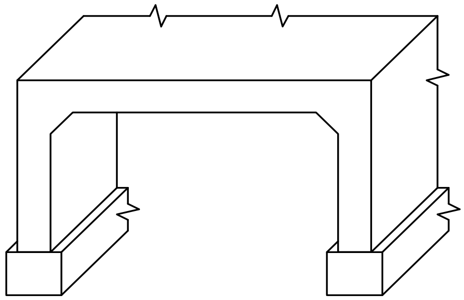
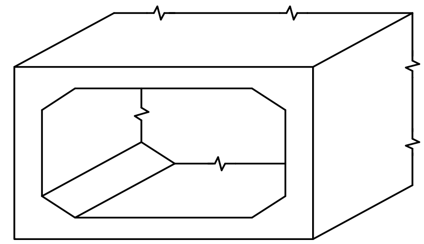


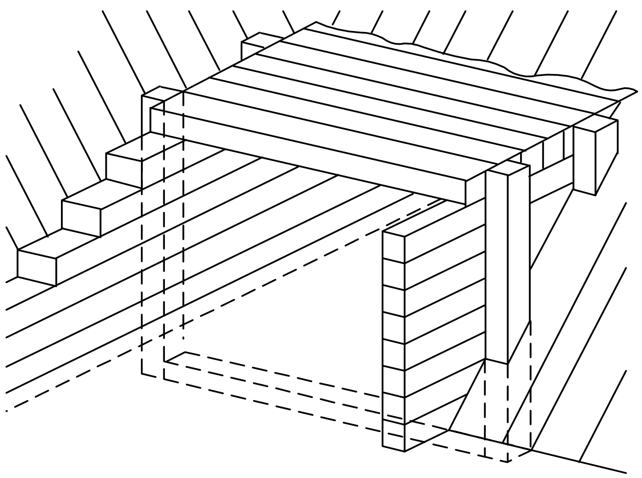
Figure 8.1.5(b) Typical Inlet and Outlet Components



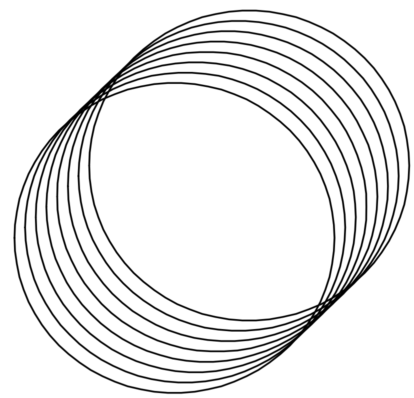
Open Footing Concrete Culvert



Concrete Box Culvert



Wood Culvert



Round Corrugated Pipe Culvert

Figure 8.1.5(c) Typical Culverts and Tunnels

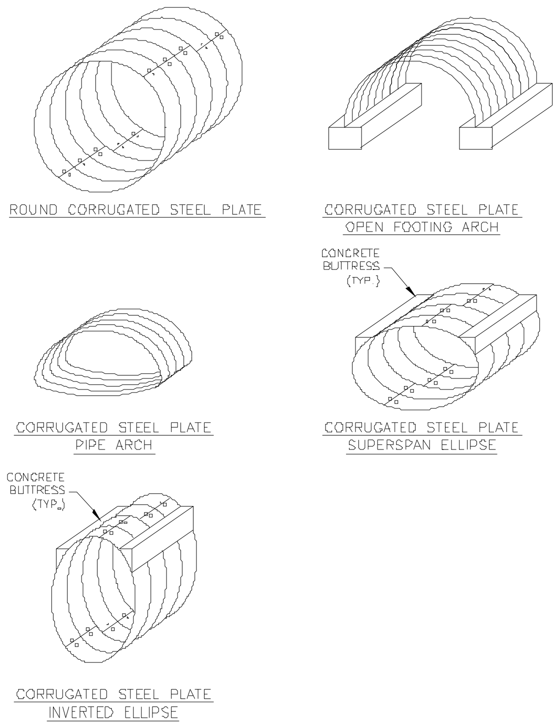


Figure 8.1.5(d) Typical Soil-Steel Structures

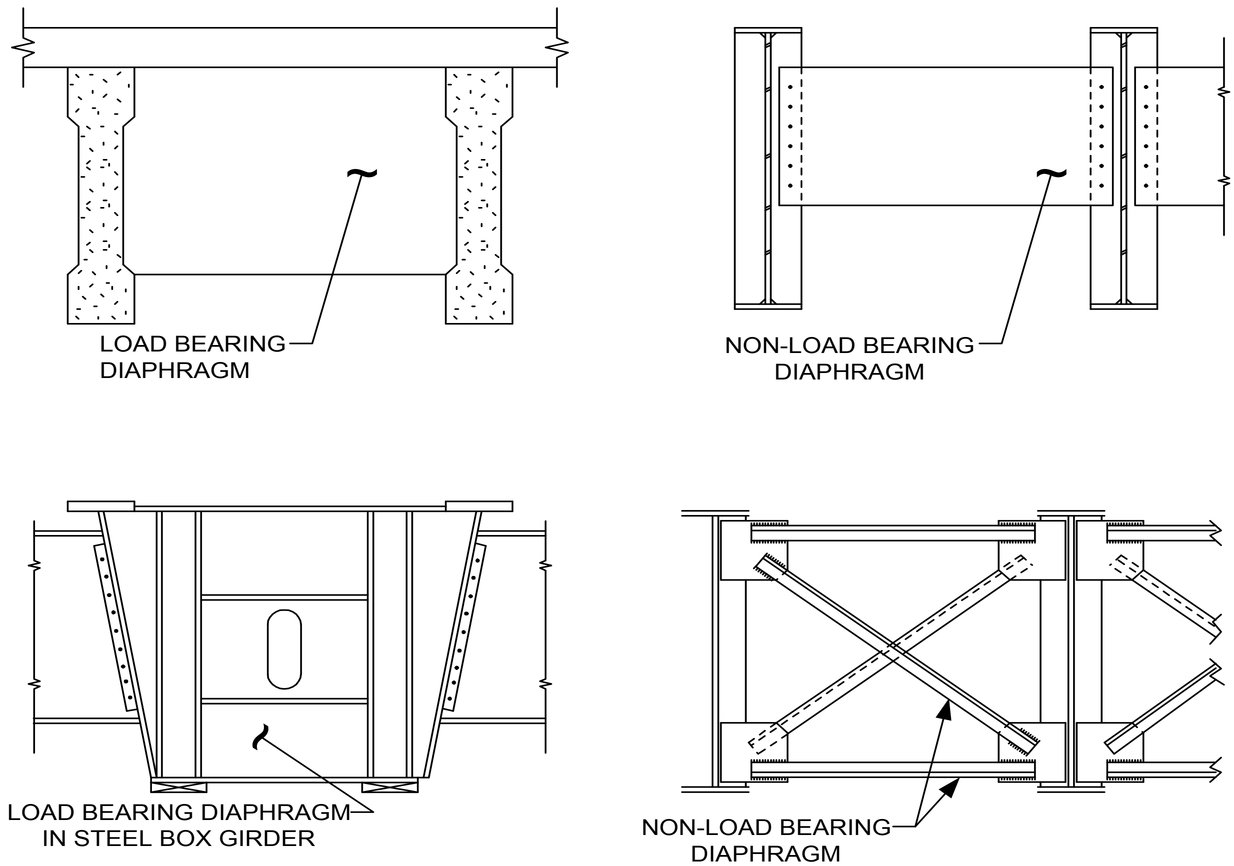


Figure 8.1.6 Diaphragms

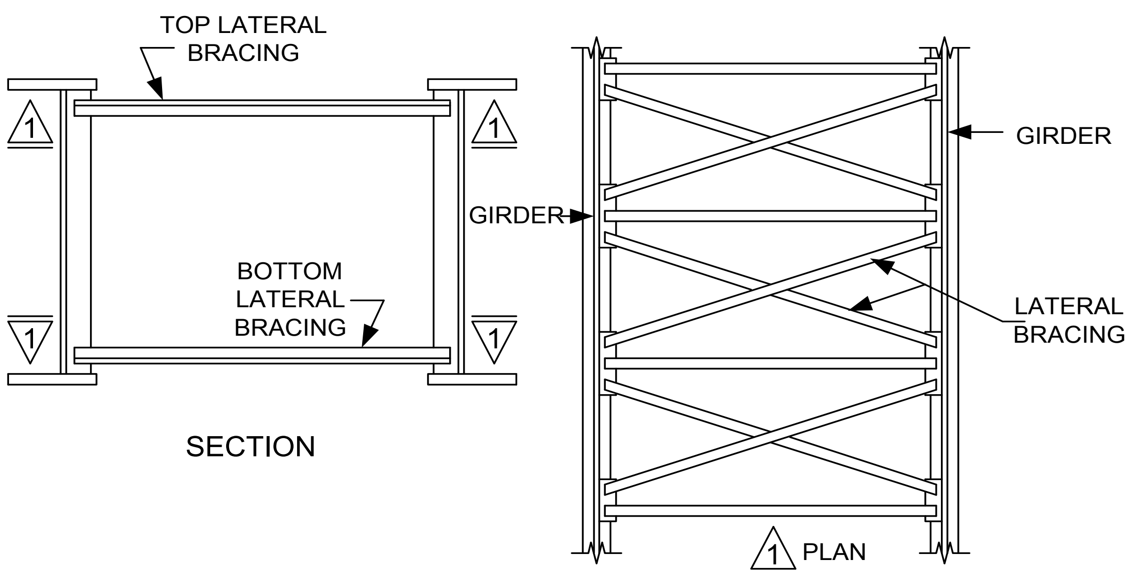


Figure 8.1.8 Lateral Bracing

SECTION 9 – DECK COMPONENTS

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9.1 Deck Components

The following components are considered in this section:

- Decks;
- Wearing Surfaces;
- Curbs and Sidewalks;
- Approaches and Approach Slabs and Ramps;
- Drainage and Deck Drains.

9.1.1 Decks

The types of decks commonly used are:

- Reinforced Concrete Decks;
- Wood Decks;
- Orthotropic Steel Decks;
- Open Grating Steel Decks; and
- Corrugated Metal Sheeting Decks.

Reinforced concrete decks are the most common type of deck used in structures. They are commonly cast-in-place but may also be pre-cast. This type of deck includes slab on beams, and the top surface of solid or voided thick slabs, or of rigid frames.

Wood decks are commonly used on secondary roads and rural highways. Types of wood decks commonly used include longitudinal and transverse laminated wood decks, prestressed wood decks, plank decks and composite wood and concrete decks.

Orthotropic steel decks consist of a flat steel top plate surface welded to a supporting system of steel girders, floor beams and ribs. Flat bars or studs are often welded to the top steel plate to improve the bond with the wearing surface.

Prefabricated steel grating is sometimes used as decking material. The open mesh grating panels are installed over a network of steel floor beams and stringers to form the riding surface. A variation of this deck is produced by placing a concrete infill slab over the grating to form a composite deck surface.

Corrugated metal sheeting decks have been used in a few cases. They are normally overlaid with asphalt or concrete wearing surface.

Figure 9.1.1 illustrates the types of decks commonly encountered.

9.1.2 Wearing Surfaces

The top surface of the deck is either left exposed and acts as the wearing surface or is protected by an additional wearing surface of asphalt or waterproofing membrane and asphalt.

Reinforced concrete and steel decks are typically covered with an asphalt wearing surface, with or without waterproofing. Wood decks are typically covered with an asphalt, concrete or wood planking wearing surface, normally without waterproofing.

Wearing surfaces are shown in Figure 9.1.1.

9.1.3 Curbs and Sidewalks

Curbs are located parallel to the side limits of the roadway and are constructed between 150 mm and 600 mm in width and extend between 150 mm and 250 mm in height above the roadway surface.

Sidewalks are located along the edge of the deck and elevated above the level of the deck. They are sometimes built on supports which cantilever beyond the deck limits. These supports shall be inspected as part of the sidewalks. The width of sidewalks usually ranges from 1500 mm to 2000 mm in high pedestrian volume urban areas and from 300 mm to 600 mm in low pedestrian volume rural areas.

Curbs and sidewalks can be constructed of concrete, wood, asphaltic concrete, steel, or precast masonry.

Typical examples of curb and sidewalk construction are illustrated in Figures 9.1.1 and 9.1.3.

9.1.4 Approaches, Approach Slabs and Ramps

Approaches for a length of 30 m beyond each end of the structure shall be inspected.

Approach slabs are located at each end of the structure; however, they may not be present at some structures on lightly travelled roads or on gravel roads.

Approach slabs, where present, are constructed upon the approach embankment. One end of the approach slab is anchored to the ballast wall or abutment wall, the other end rests upon the approach fill and is free to move.

In some cases approach slabs may be present but are typically paved over with asphalt.

Approach ramps are sometimes provided at the approach to temporary bridges.

A typical concrete approach slab is illustrated in Figure 9.1.4.

9.1.5 Drainage and Deck Drains

Surface drainage on structures is channelled along the curbs and drained through deck drains or allowed to drain off the deck. Drainage from the approaches is normally drained into drainage ditches or caught at catch basins before it reaches the structure.

Deck drains are usually located along the curb lines. Deck drains are typically made of steel, although concrete, aluminum, acrylonitrile butadiene styrene (ABS) and polyvinylchloride (PVC) are sometimes used as well. Steel drains are usually galvanized or made of atmospheric corrosion resistant steel. Deck drains are anchored to the deck by metal bars, or rely on their shape and bonding forces to secure them in place.

Deck drains vary in size and shape, and vary from single pipes to prefabricated pipe and catchbasin units. Deck drains can also occur individually or be interconnected to an extensive collection system terminating at storm sewers. In either case, deck drains must extend below or away from structure components below the deck to prevent water discharge or spray from falling on those components.

Deck drains, in concrete decks, normally have drainage holes at the interface between the deck top surface and the asphalt wearing surface to drain water that has penetrated through the wearing surface.

Concrete decks with dams at expansion joints usually have small diameter (25 – 40 mm) PVC tubes placed through the deck in front of the dams, flush with the deck top surface, to drain water which penetrates through the wearing surface.

Precast concrete box girders and steel box girders have drain holes in the bottom flange to drain off any water that finds its way into the boxes. These also serve to provide ventilation.

Figure 9.1.5 illustrates typical examples of drainage systems and deck drains commonly encountered.

9.2 Primary Components

Decks, wearing surfaces and sidewalks accessible to traffic shall be considered as primary components.

9.2.1 Material Defects of Primary Components

Material defects are as given in Section 2.

The top surfaces of exposed decks are directly subject to the adverse effects of weather, traffic and the use of de-icing salts and chemicals. This results in rapid deterioration of the decks.

Even with the added protection of the wearing surfaces, the deck top surfaces below the wearing surfaces of covered decks are often prone to similar deteriorations as exposed decks. Unfortunately, the wearing surfaces may hide these defects on the deck surfaces until they are well advanced.

9.2.2 Performance Defects of Primary Components

Performance of decks relate to their ability to support imposed live and dead loads, to transmit those loads to the supporting superstructure components, and to provide safe and smooth riding surfaces for traffic.

Performance of wearing surfaces relate to their ability to provide safe and smooth riding surfaces and to protect the underlying decks from deterioration.

Performance of sidewalks accessible to traffic relates to their ability to provide safe and comfortable passage for pedestrians, to support imposed live and dead loads, and to transmit those loads to the supporting superstructure components.

9.3 Secondary Components

Curbs, sidewalks not accessible to traffic, approaches, approach slabs and ramps are to be considered as secondary components.

9.3.1 Material Defects of Secondary Components

Material defects are as given in Section 2.

9.3.2 Performance Defects of Secondary Components

Performance of curbs and sidewalks relates to their ability to provide safe and comfortable passage for pedestrians, to support maintenance vehicle loads where applicable, and to protect structure components beyond the roadway limits from vehicular collision and damage. Curbs also serve to channel roadway surface drainage to deck drainage systems.

Performance of approaches, approach slabs and ramps relates to their ability to provide smooth transition for traffic onto and off the structure. Performance of approach slabs also relates to their ability to distribute live loads through the embankment and to the abutment wall.

9.4 Auxiliary Components

Deck drains, drainage ditches, gutters and catch basins shall be considered as auxiliary components.

9.4.1 Material Defects of Auxiliary Components

Material defects are as given in Section 2.

9.4.2 Performance Defects of Auxiliary Components

The performance of deck drains and drainage systems relates to their ability to remove water from the deck and approaches, and to direct and discharge it safely away from the structure and its components.

Trapped or ponded water is a safety hazard, particularly when frozen, as it can lead to loss of vehicle control. It can also increase the rate of deterioration of the deck and other components.

Inadequate discharge of approach drainage results in erosion of the approach fills and loss of support for structure components.

Deck drains and drainage systems discharging onto structure components result in rapid deterioration of those components.

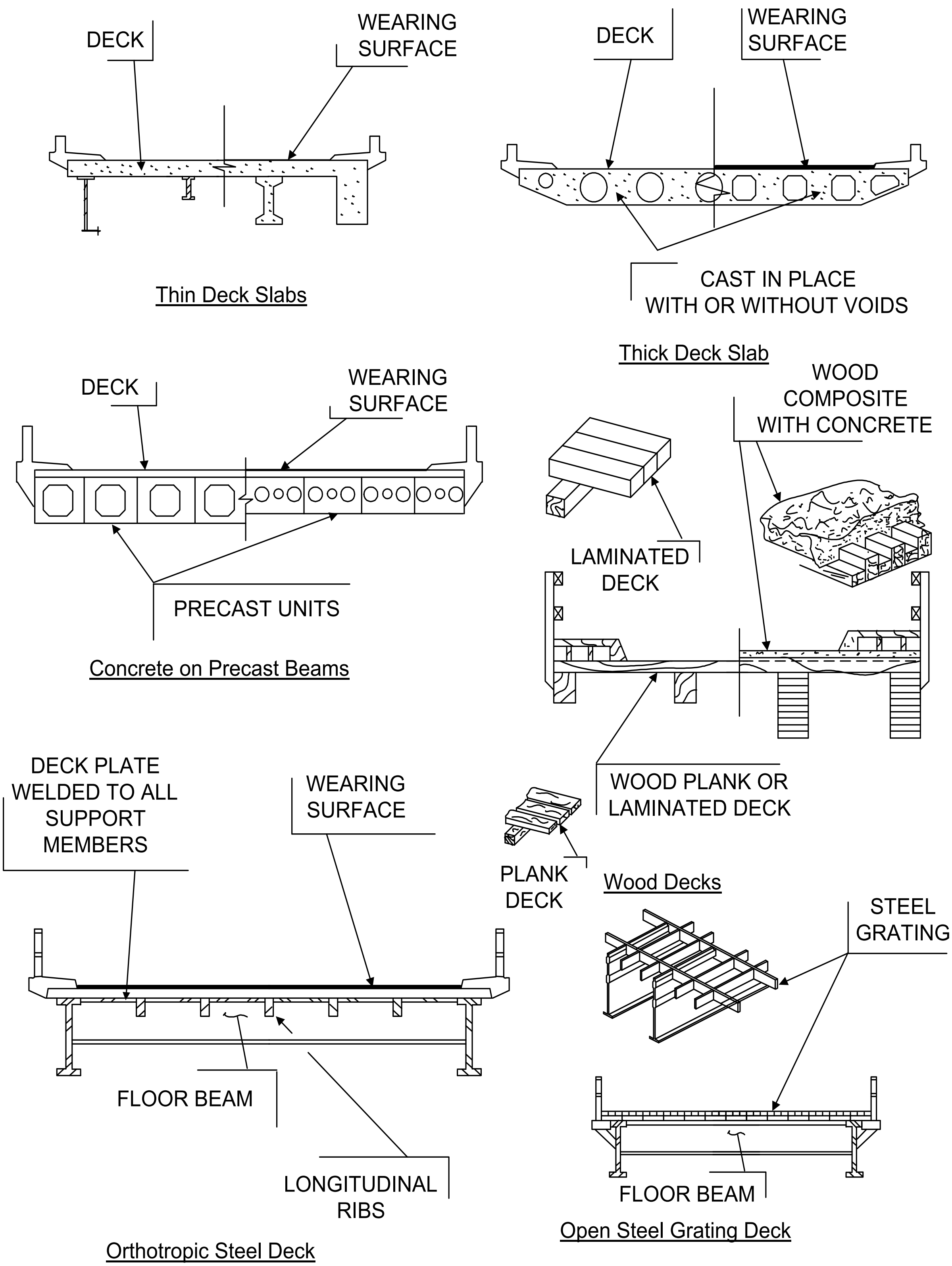


Figure 9.1.1 Typical Decks

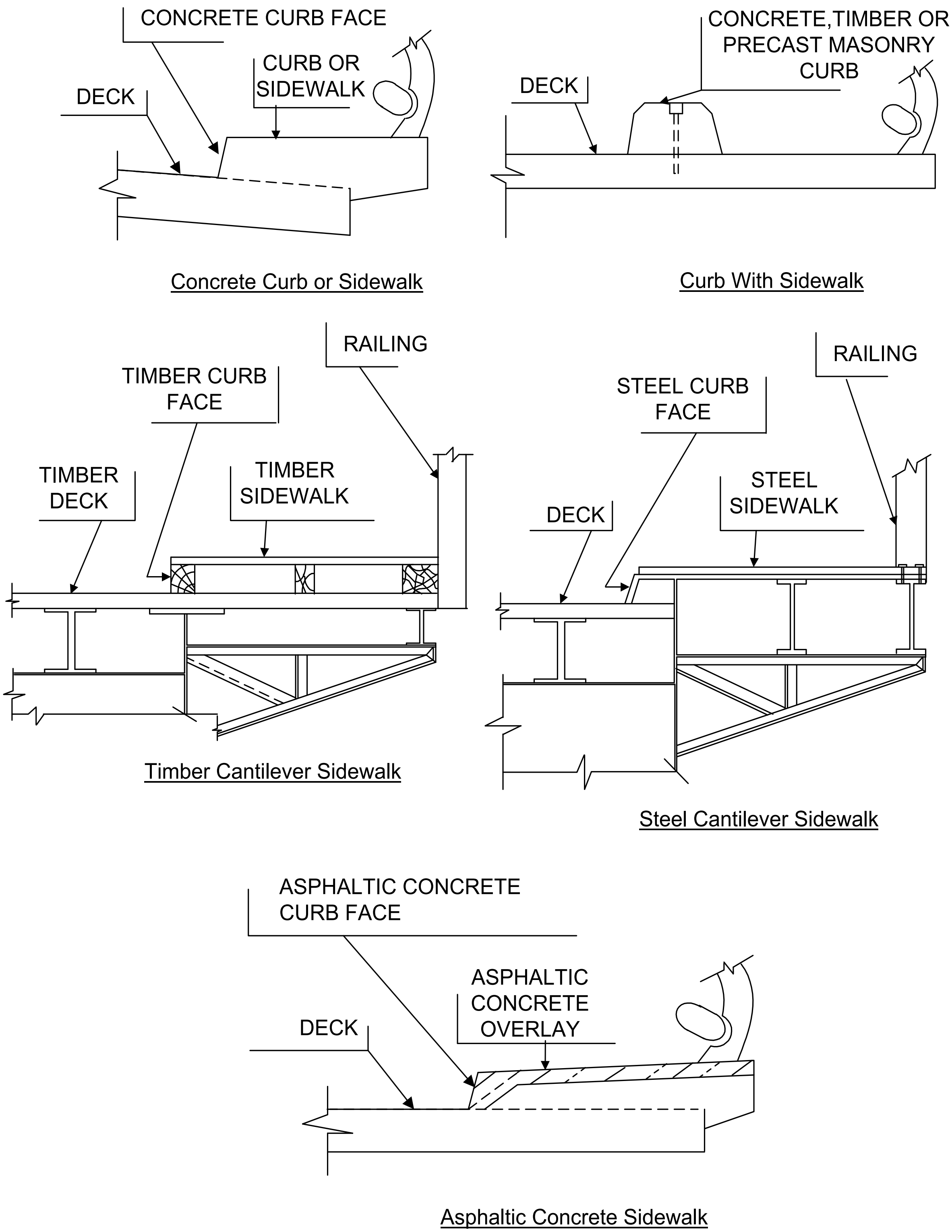


Figure 9.1.3 Typical Curbs and Sidewalks

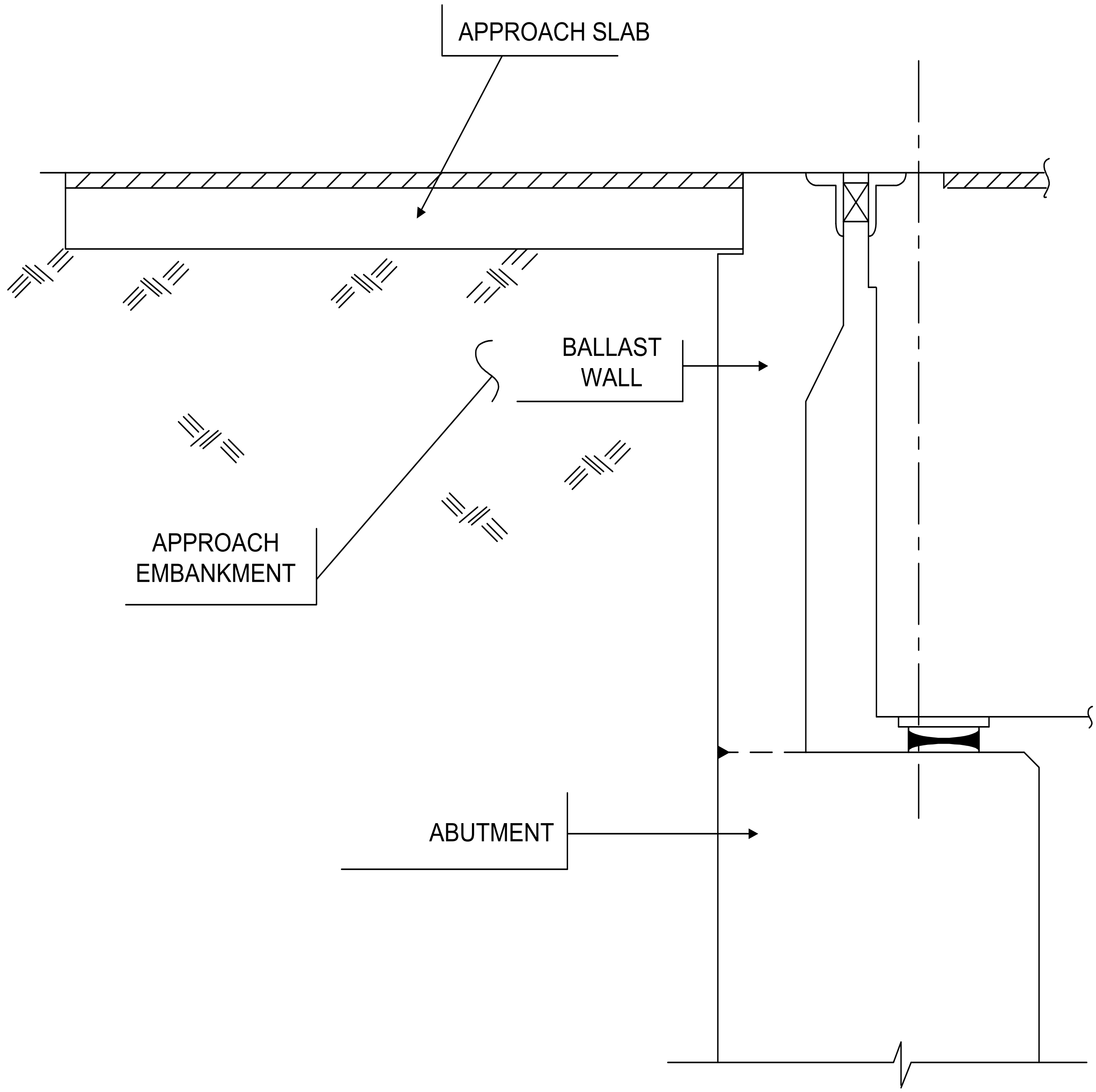


Figure 9.1.4 Concrete Approach Slab

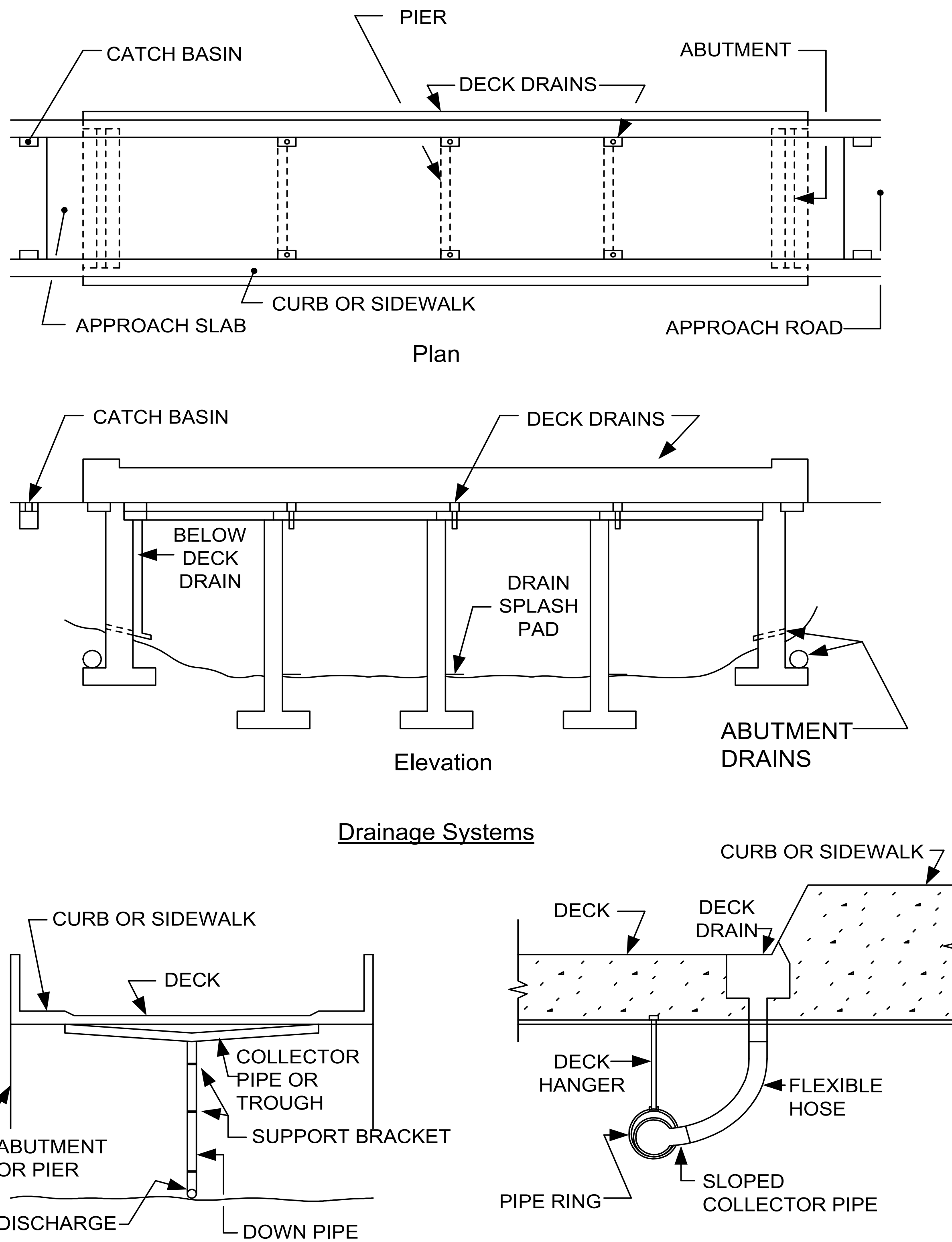
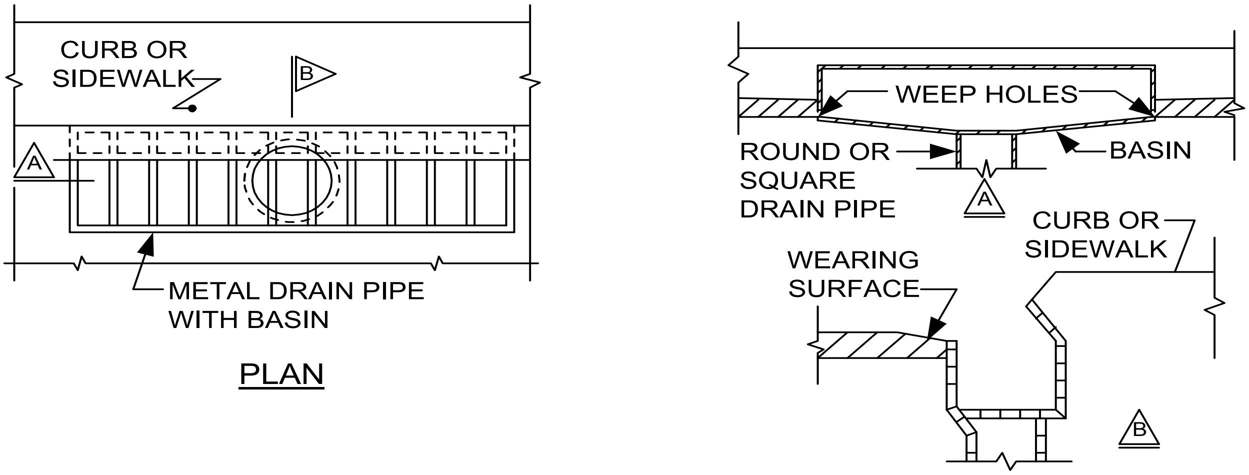
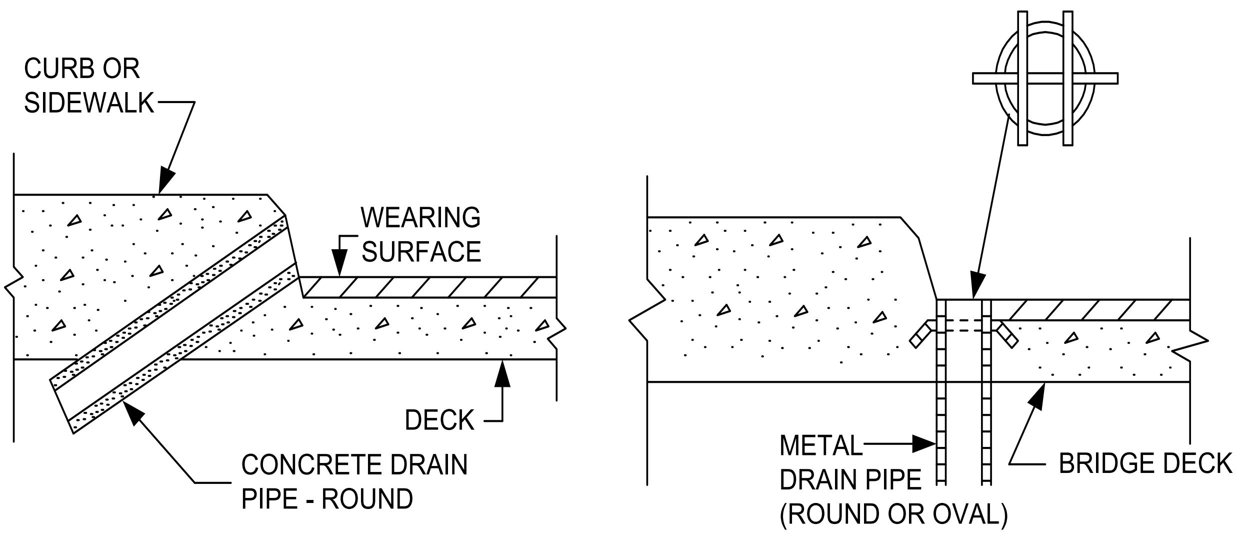


Figure 9.1.5 Drainage and Deck Drains



Drain Pipe With Basin



Drain Pipes Without Basins

Figure 9.1.5 Drainage and Deck Drains (cont'd)

SECTION 10 – RAILING SYSTEMS

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10.1 Railing Systems

Railing systems are to be considered as secondary components as they do not normally contribute to the capacity of the structure. However, there are some structures in which the parapet walls also act as the main beams. In those structures the parapet walls shall be considered as primary components.

Railing systems are located at the outermost side limits of the roadway or sidewalk, and may also be located along the median for separation of two way traffic. Railing systems and their end treatments on the structure approaches are also included in this section. Although they are not part of the structure itself, the condition of these components have a direct impact on the safety of the structure and may influence the scope and timing of structure rehabilitation.

Railing systems, post anchorages and rail connections are described below and illustrated in Figure 10.1.

(a) Parapet Walls

Parapet Walls are rectangular reinforced concrete walls. They commonly support posts and two tube rails or other rail configurations on them.

(b) Barrier Walls

New Jersey type barrier walls are reinforced concrete walls with a sloping front face. Parapet barrier walls are reinforced concrete walls with a vertical front face. Barrier walls on approaches may not be reinforced. Barrier walls typically vary in height from 680 mm to 1370 mm. Barrier walls 800 mm high may be equipped with top railings for pedestrians and cyclists.

(c) Railings

Railings consist of posts and rails and may be latticed, barred, balustered or other open web configuration. Railings have been commonly used in conjunction with curbs and sidewalks on structures with low volume or low speed traffic and on structures built before about 1960. Their use was generally discontinued around that time on highway structures due to the greater protection provided by the introduction of parapet walls and, later, barrier walls.

The following posts and railings are commonly encountered:

- concrete posts and concrete rails;
- concrete posts and steel rails;
- concrete posts and aluminum rails;
- concrete posts and steel flex-beam rails;
- steel posts and steel rails;
- steel posts and cable rails;
- steel I-posts and steel box beam rails;
- steel grillages;

- corrugated steel box filled with sand;
- aluminum posts and aluminum rails;
- wood posts and wood rails;
- wood posts and steel flex-beam rails;
- wood posts and steel cables.

In railings using cables, splices may be used to join lengths of cable. End fittings and anchor blocks may also be provided to allow for tensioning of the cables.

(d) Splash Guards

Splash Guards are designed to protect pedestrians and railings from vehicular salt and water splash and also to serve to guide pedestrian traffic. Splash guards are typically made from concrete, steel, aluminum or plastic.

(e) Post Anchorages

The method of anchoring posts depends on the post material and on the time of installation of the post relative to the construction of the deck or structure component to which it is connected.

Reinforced concrete posts are usually cast monolithically with the deck, curb or sidewalk, or are subsequently cast around reinforcing extending from them.

Steel posts are anchored by direct embedment or by anchor plates and bolts. Embedded posts are often set into a steel socket and caulked with hot poured sulphur and lead wool or grouted with non-shrink grout. Anchor plates and bolts are generally used when the post is installed on an existing structure component.

Square hollow steel posts commonly used for steel railings were often partially filled with concrete with a drainage hole made through the side of the post, just above the level of the concrete, to prevent bursting of the post due to the freezing of entrapped water. The top of the post was capped to prevent the entry of water.

Aluminum posts are secured to the deck, curb or sidewalk by anchor bolts. Nylon washers are required between the aluminum base plate and steel anchor bolts.

Wood posts are usually bolted to the side of the structure, or bolted in steel anchor shoes which are bolted down to the deck, curb or sidewalk.

(f) Rail Connections

Rails are secured to posts by bolts, set screws, nails, or reinforcing steel, depending on the combination of rail and post material:

- steel rails used with steel, concrete or wood posts are usually bolted to the post, steel rails sometimes pass through pre-drilled holes in steel posts;
- aluminum rails used with aluminum or concrete posts are usually bolted to the posts;
- concrete rails used with concrete posts are cast monolithically with the post, or may be precast;
- wood rails used with wood posts are usually nailed or bolted to the post;
- steel cable rails used with wood or steel posts are usually stapled to wood posts and bolted to or pass through pre-drilled holes in steel posts.

Sleeves are provided between sections of continuous tube rails and slotted holes are provided at bolted rail splices and rail to post connections to allow for thermal expansion and contraction of the rail, structure movements, and construction tolerances. These provisions do not apply for cable rails or for all concrete or all wood railing systems.

The ends of tube rails are capped to prevent water from entering and causing corrosion inside the rail.

(g) Approach Railing Systems

Guide rails on structure approaches are typically one of the following: steel beam, steel beam with channel, three cable, or box beam. The posts are typically wood or steel. On newer or rehabilitated structures, the most common approach railing configuration is steel beam guiderail which terminates at the structure and attaches to the end or front face of the parapet or barrier wall on the structure.

(h) Railing System End Treatments

New or rehabilitated structures on which the railing systems have been upgraded will typically have an end treatment on the approach guiderail or structure railing system. These end treatments are designed to absorb the impact from a collision, thus limiting damage to the vehicle and the structure or approach guiderail.

Structure end treatments are typically comprised of compartmentalized sections or containers within a steel beam guiderail or steel plate enclosure. These individual sections are filled with sand, water, or foam. As a vehicle strikes the end treatment, the force of the impact is absorbed and the material within the container is expelled. These end treatments are also commonly located on overpass piers.

Guiderail end treatments are comprised of steel beam guiderail on breakaway wooden posts which terminates in an end assembly. When the end assembly is struck by a vehicle, the energy is transferred to the posts, which break under the impact.

10.1.1 Material Defects of Railing Systems

Material defects are as given in Section 2. In addition, defects in railings using cables are:

- broken wires or entire cable;
- loose cables or inadequate cable tension;
- loose or corroded splices or fittings.

Material defects in end treatments are typically the result of vehicular impact. End assemblies usually require replacement after an accident, and the expelled material from the containers will limit the effectiveness of the end treatment until it is replaced.

10.1.2 Performance Defects of Railing System

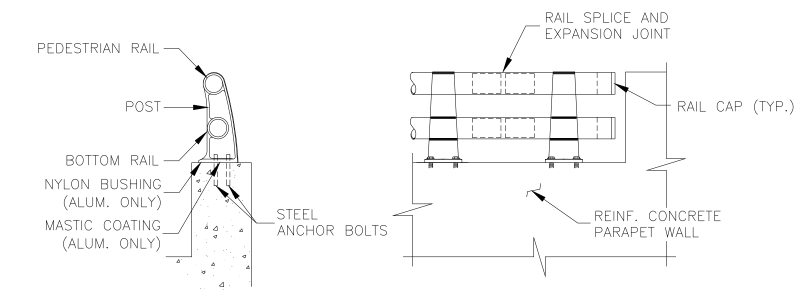
The performance of barrier walls and railings is based upon their ability to safeguard and guide vehicular traffic and pedestrians along the structure and to deter the accidental passage of vehicles over the side of the structure, into oncoming traffic or into other bridge components.

The performance of the top rail on parapet walls, barrier walls and railings is based on its ability to provide a handrail for pedestrians and cyclists, to withstand or absorb some vehicular impact and to provide lateral support for some types of railings.

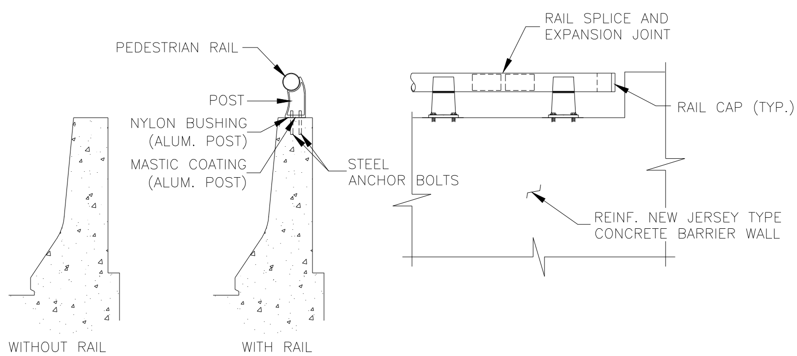
The performance of splashguards is based upon the protection provided to pedestrians or railing systems against salt and water splash directed by vehicles passing in adjacent lanes.

The performance of railing systems shall also be based upon their present condition with regards to their ability to meet the safety standards and other requirements in effect at the time they were originally installed.

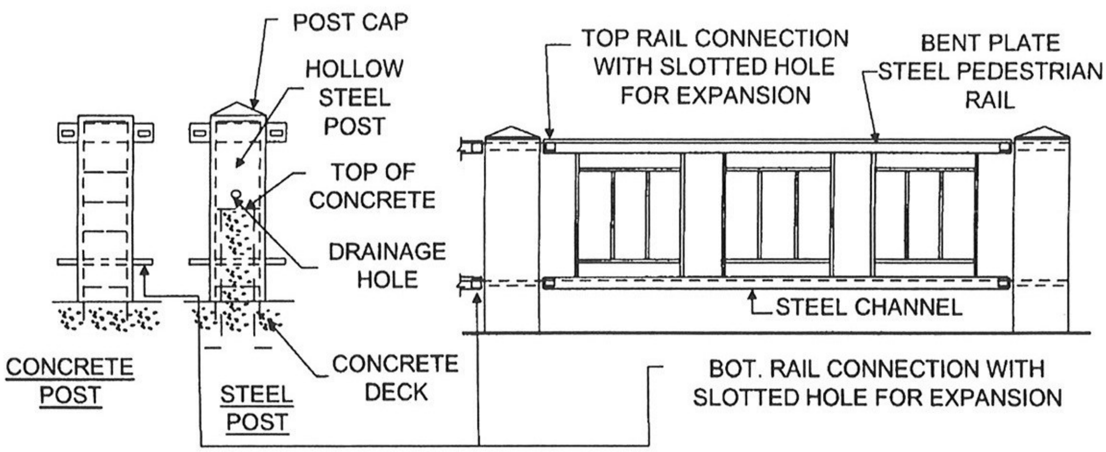
The performance of end treatments is based upon the ability to absorb energy during a collision, which is a function on the design speed limit and the number of sections comprising the end treatment.



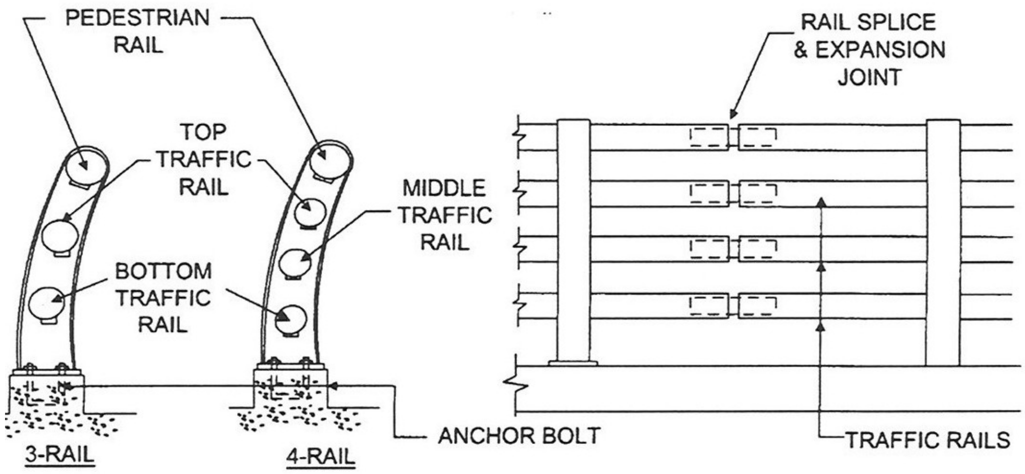
REINFORCED CONCRETE PARAPET WALL WITH RAILS



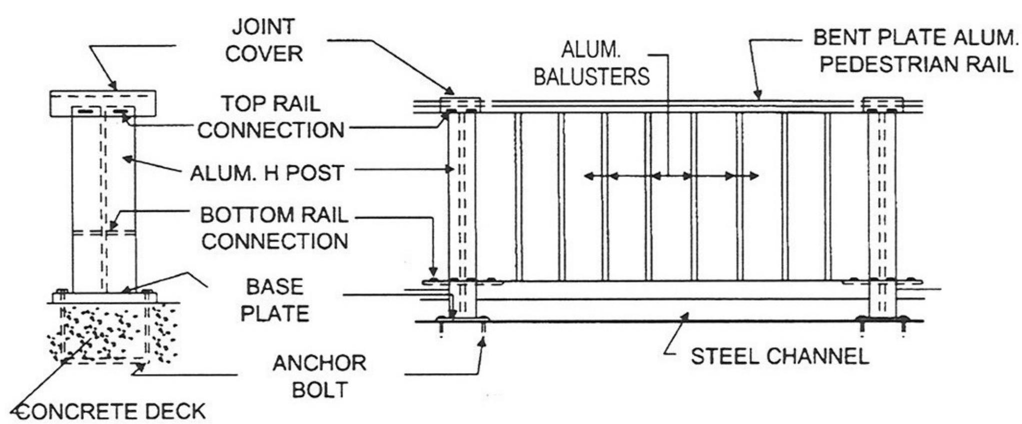
REINFORCED CONCRETE NEW JERSEY TYPE BARRIER WALL



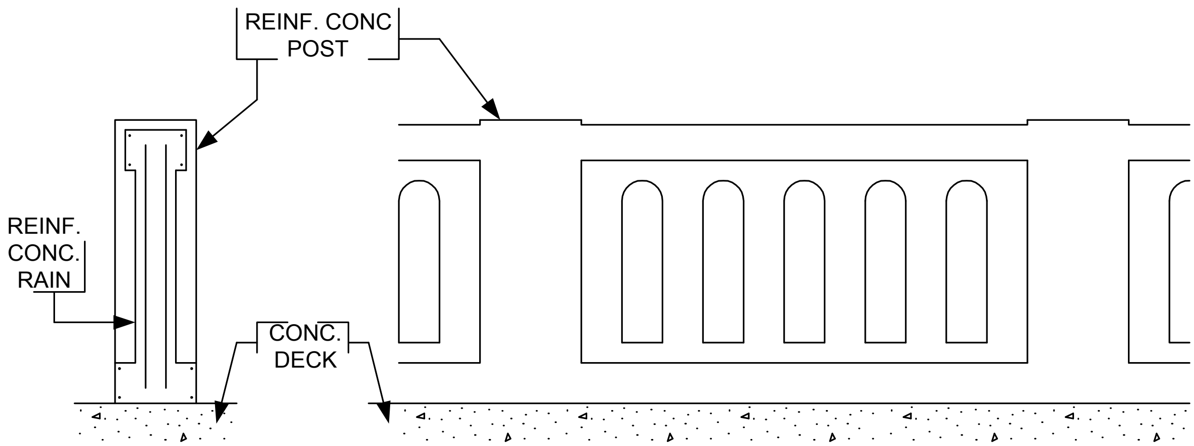
STEEL RAILING



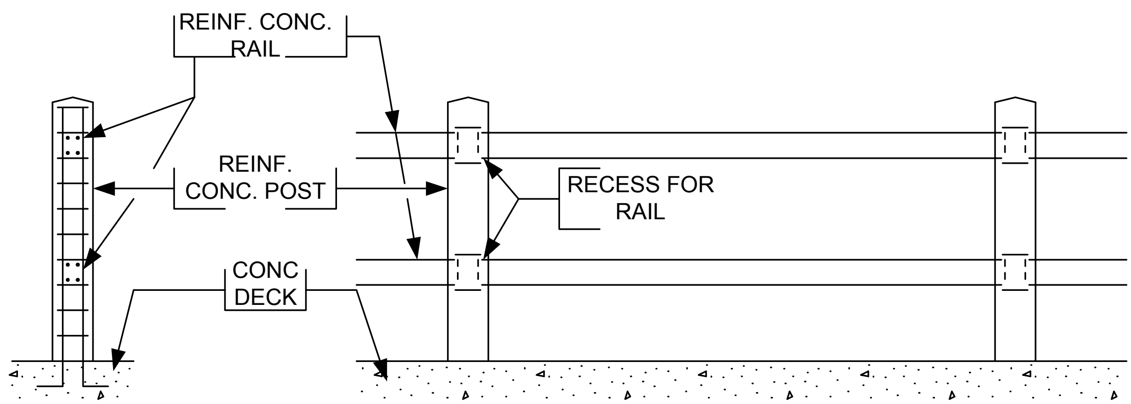
METAL RAILING (STEEL OR ALUMINUM)



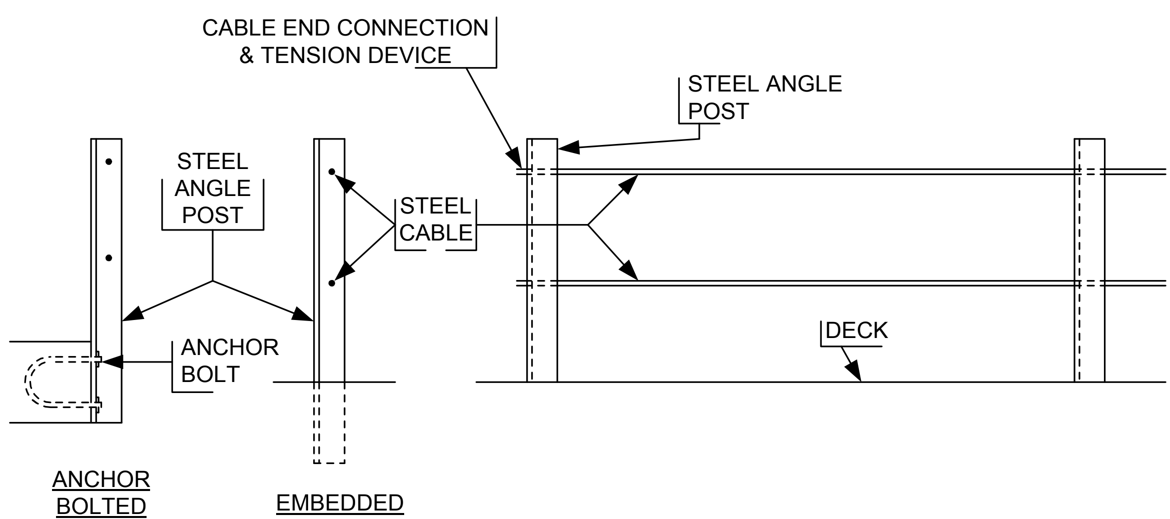
ALUMINUM RAILING



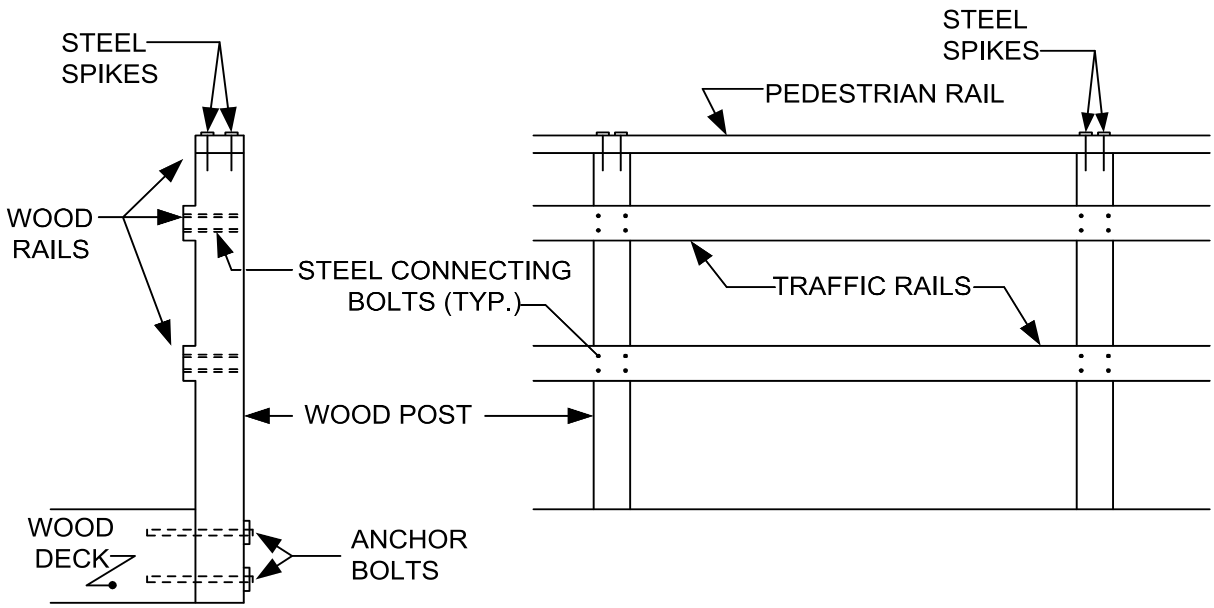
Reinforced Concrete Railing



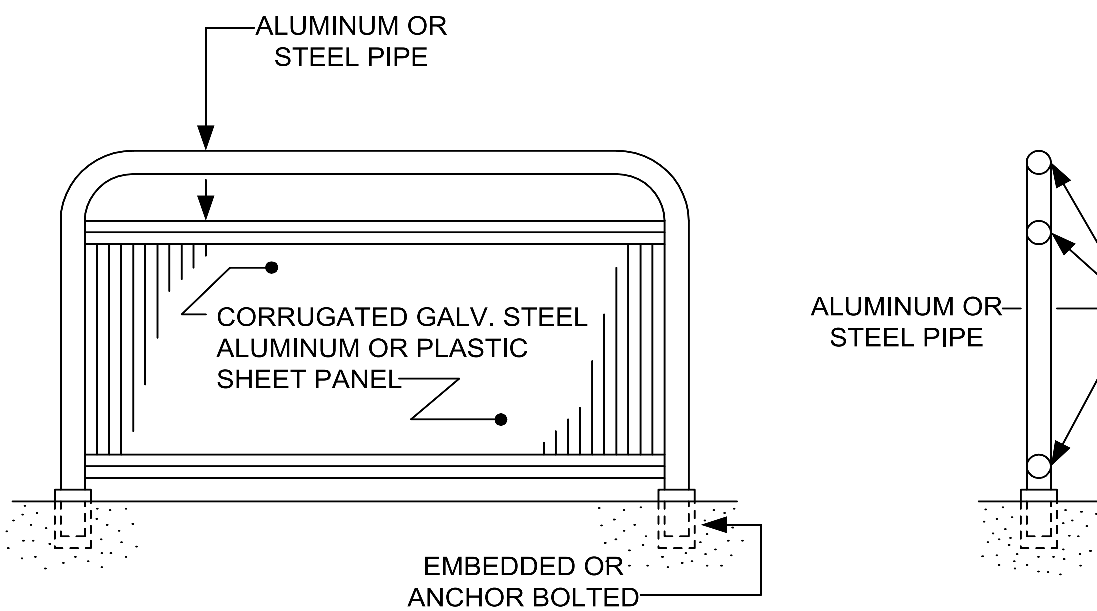
Reinforced Concrete Railing



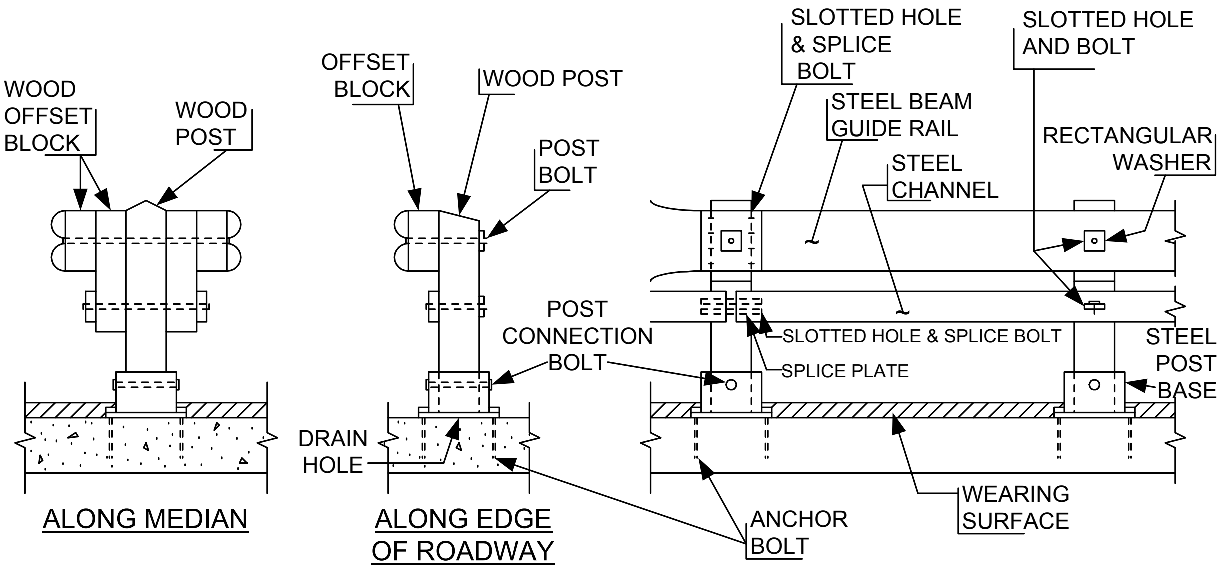
Steel Post and Cable Railing



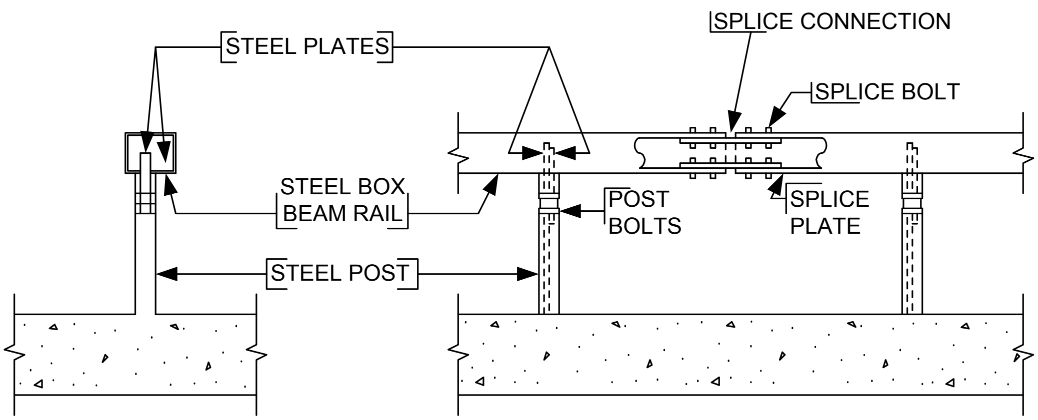
Wood Railing



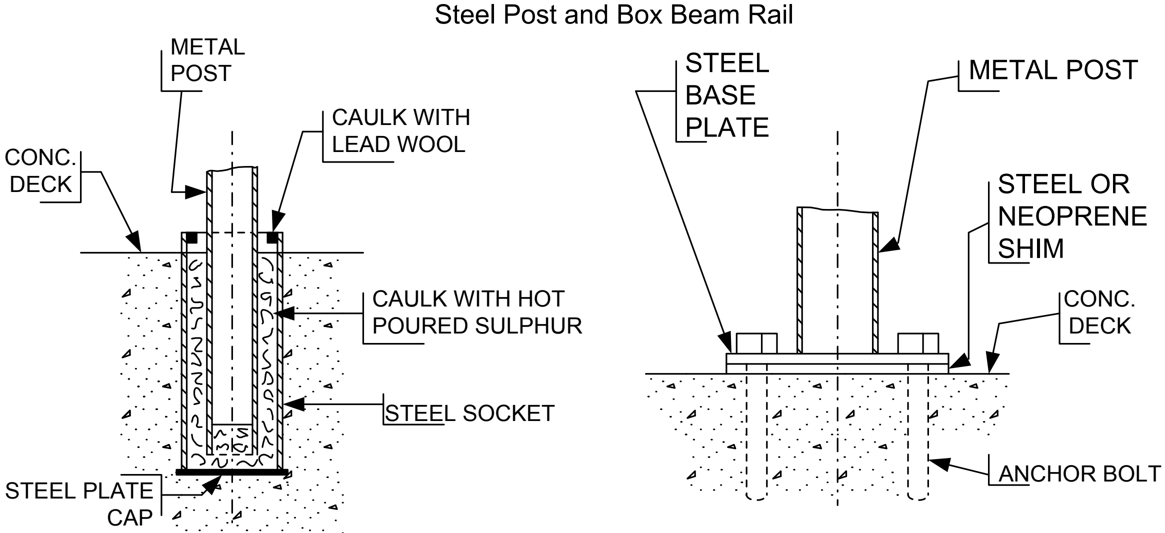
Railing With Splash Guard



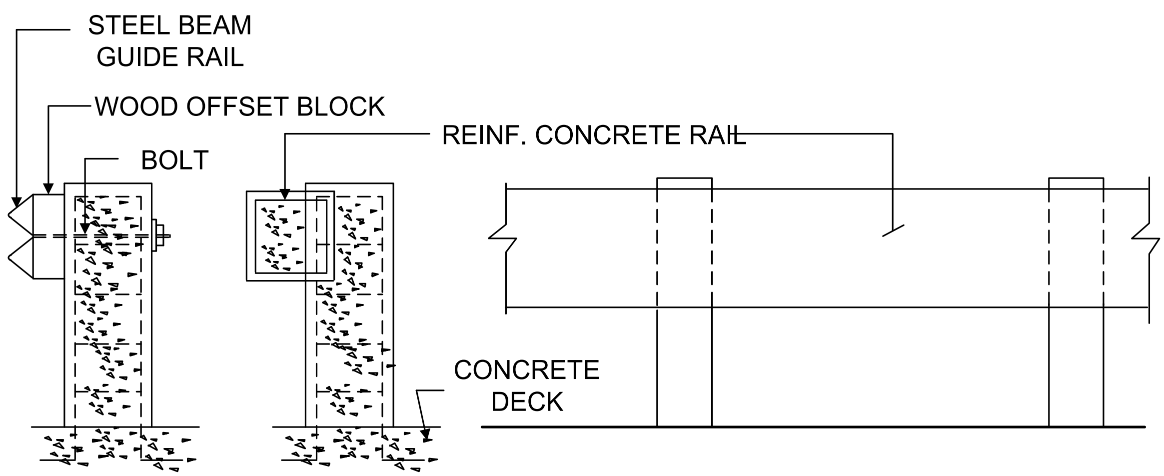
Wood Post and Steel Flex-Beam Rail



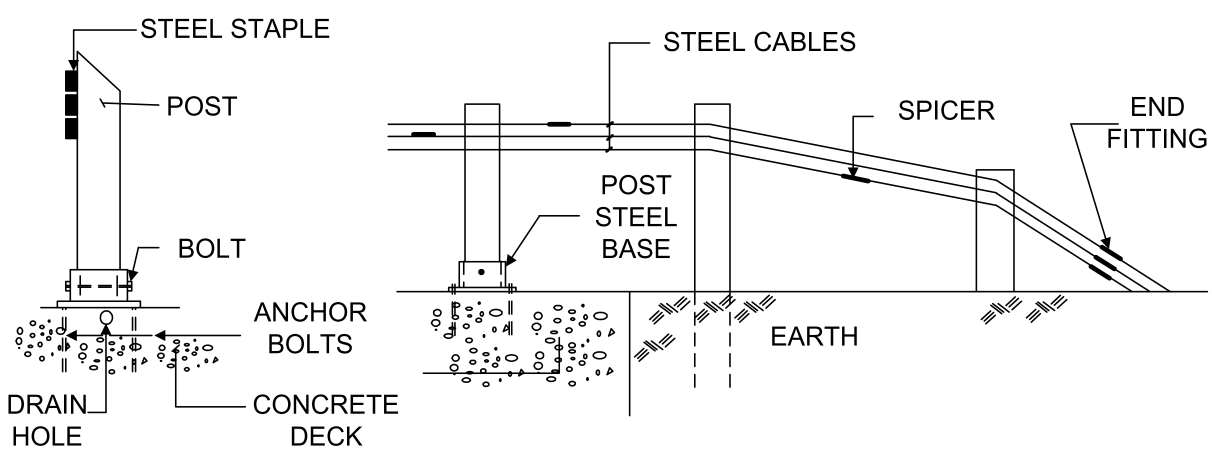
Steel Post and Box Beam Rail



Metal Post Anchorage Details



Concrete Post with Steel Flex-Beam and with Concrete Rail



Wood Post and Steel Cable

Figure 10.1 Railing Systems

SECTION 11 – STRUCTURAL STEEL COATINGS

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11.1 Structural Steel Coatings

Structural steel coatings are to be considered as primary or secondary components based upon the designation of the component that is coated.

Some typical coating systems are:

(a) 3 Coat Alkyd System (discontinued)

It consists of:

- red lead primer;
- second coat;
- top coat.

(b) High Build Alkyd System (discontinued)

It consists of:

- zinc chromate primer, one or two coats;
- high build alkyd top coat.

(c) Inorganic-Zinc/Vinyl System

It consists of:

- inorganic zinc primer;
- reduced vinyl wash second coat or proprietary tie coat;
- high build vinyl third coat;
- high build vinyl topcoat.

(d) Epoxy-Zinc/Vinyl System

It consists of:

- inorganic zinc primer;
- high build vinyl second coat;
- high build vinyl top coat.

(e) Aluminum-Filled Epoxymastic System

This system has been used since about 1982 on a number of coated steel bridges. It has also been used in selected locations on atmospheric corrosion resistant (weathering) steel, under expansion joints. It was discontinued in Ontario in 1988. It consists of two coats of aluminum coloured epoxy mastic.

(f) Inorganic-Zinc/Epoxy/Urethane System

It consists of:

- inorganic zinc primer;
- an epoxy second coat;
- urethane top coat.

(g) Epoxy-Zinc/Epoxy/Urethane System

It consists of:

- inorganic zinc primer;
- an epoxy second coat;
- urethane top coat.

(h) Hot Dip Galvanizing

It consists of zinc applied to steel in a variety of methods and has a fairly smooth, large grain, shiny to semi-dull surface appearance.

(i) Metallizing

It consists of a sprayed coating of zinc or zinc/aluminum and has a coarse or gritty surface appearance resembling sandpaper.

(j) Coal Tar Epoxy

This system has been used in the past on the inside of some box girders. It is black or dark brown in colour.

(k) Coal Tar for Piles

This system has been used in the past on the inaccessible areas of steel behind abutment diaphragms and on steel piles. It is black in colour.

(l) Inorganic Zinc/Acrylic /Acrylic

It consists of:

- inorganic zinc primer;
- acrylic mid coat;
- acrylic top coat.

(m) Epoxy- zinc/Acrylic/Acrylic

It consists of:

- Organic (epoxy) zinc primer;
- Acrylic mid coat;
- Acrylic top coat.

11.1.1 Material Defects of Coatings

Material defects are as given in Section 2.

11.1.2 Performance Defects of Coatings

The performance of coatings is based upon the ability of the coating to protect the component against deterioration resulting from direct exposure to elements in the environment such as moisture, deicing salts, and airborne abrasives, pollutants and contaminants.

This degree of protection may be provided by a less than desirable material condition of the coating; however, increasing material defects and deterioration will ultimately result in loss of protection provided by the coating or coating system.

The rate of deterioration of the coating depends on the degree of exposure of the component to the destructive elements.

In addition, where identical exposure conditions prevail, the following features can also affect the rate of deterioration of the coating, namely:

- horizontal surfaces usually deteriorate at a faster rate than vertical surfaces;
- outside corners and edges of components usually exhibit greater deterioration, as coating thickness is often less at these locations;
- poor surface preparation or inadequate coating thickness, usually due to poor workmanship or difficult accessibility of the surface.
- the amount of time the steel is damp and the degree to which the component is ventilated also has an effect.

SECTION 12 – SIGNS

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12.1 Signs

The configuration, number and placement of regulatory signs shall be in accordance with the applicable Federal and/or Provincial Highway Acts and Standards. The following is a summary of the signs most commonly used to indicate restrictions at structures. These signs are illustrated in Figure 12.1. For details on signage requirements, location, and spacing refer to the latest edition of the TAC "Manual of Uniform Traffic Control Devices for Canada".

(a) Narrow Structure Signs

The Narrow Structure sign should be used to indicate a bridge culvert, subway, overpass or similar structure having a clear roadway width on or under the bridge that is less than clear approach road width. Hazard Markers should be used with the narrow structure signs.

(b) One Lane Signs

Where the structure has a clear roadway width of less than 5 m, thereby permitting only a single lane of traffic, a tab sign reading "One Lane" should be added immediately below the Narrow Structure sign.

The "One Lane" tab sign may also be used where the structure roadway width is less than 5.5 m when commercial vehicles constitute a significant proportion of the traffic using the structure or when the alignment approaching the structure is poor.

(c) Hazard Marker Signs

Hazard Marker signs should be used to mark structure limits when they are within 2 m of the edge of the roadway in conjunction with the Narrow Structure sign.

Left or right hazard markers are erected with the stripes sloping at an angle of 45 degrees down towards the edge of the travelled portion of the roadway.

The right marker should always be used to the right of traffic and left marker to the left.

Left and right hazard marker should be used where traffic may pass on both sides of an obstruction.

(d) Low Clearance Signs

The Low Clearance signs, indicating low overhead clearance and showing the exact amount of clearance at low bridges, underpasses and other structures, should be used at all points where clearance from the roadway to the low point of the structure is less than 4.3 m.

The Clearance sign should be erected, if possible, on the structure just above the opening and over the centre of the roadway unless the clearance across the structure varies between the centreline and the curb or edge of pavement, in which case a second sign should be erected to indicate the lesser clearance. Where there is a difference in clearance across the structure and the roadway is considered "one lane" when used by trucks, there should be three signs posted: at the centreline and each edge of pavement.

(e) Maximum Weight Signs

Single maximum weight signs and multiple maximum weight signs should be erected to limit the gross weight on bridges approved by the Director of the National Office of RPB responsible for the management of bridges.

(f) Others

There may also be other signs at structures such as speed restriction, slippery when wet, Bailey bridge ahead, marine warning lights and signs.

12.1.1 Defects of Signs

The following are some of the typical defects in signs:

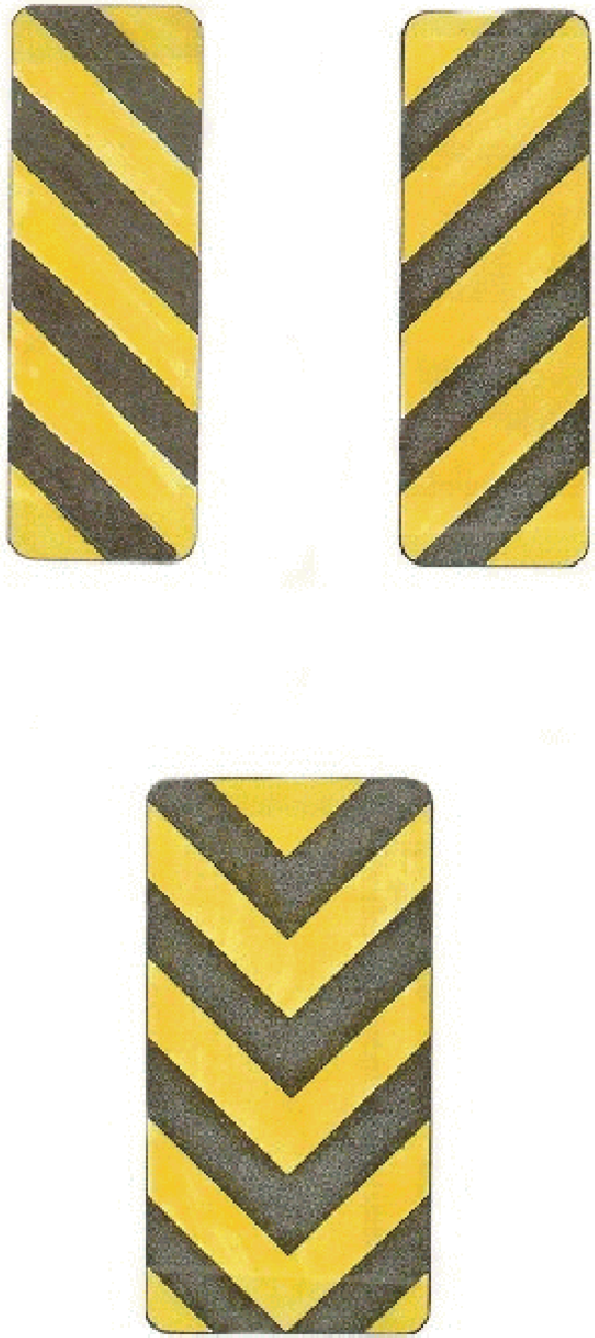
- loose, broken or missing components;
- illegible;
- not located according to standards;
- gives misleading, wrong or inaccurate information;
- not a standard sign.

(a) Narrow Structure Sign

(b) One Lane Sign

(c) Narrow Structure Warning Signs

(d) Structure Warning Signs

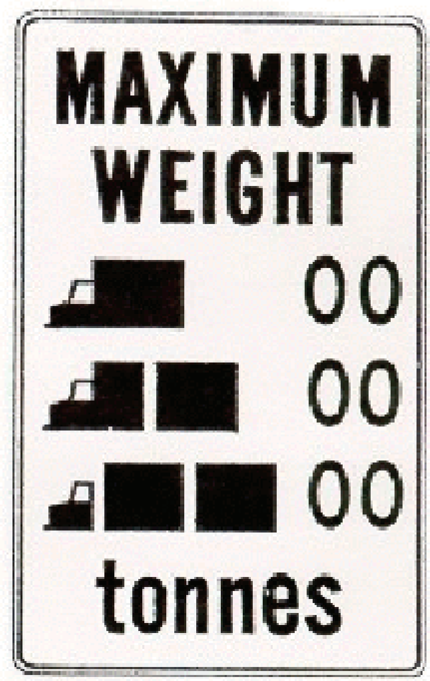


(e) Hazard Marker Signs

Clearance Sign

Advance Clearance Sign

(f) Low Clearance Signs



Single Posting Sign

Multiple Posting Sign

(g) Maximum Weight Signs

Figure 12.1 Signs

SECTION 13 – UTILITIES

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13.1 Utilities

Utilities most commonly hung from, attached to, or installed in the structure are:

- sewers;
- water mains;
- gas mains;
- telephone ducts;
- hydro lines.

A variety of attachments are used to install these utilities on the structure.

13.1.1 Material Defects of Utility Attachments

The following are some typical defects of utility attachments:

- loose, broken or missing components;
- corrosion;
- mechanical damage;
- other visually apparent defects which may cause the attachment(s) to fail resulting in loss of support.

13.1.2 Performance Defects of Utility Attachments

The performance of utility attachments is based on their ability to adequately support the utility without restricting the performance of the structure. The following are examples of how utilities attachments may influence the performance of a structure.

- Attachments and the utility may be sufficiently rigid to restrict free movement of the structure, particularly at expansion joint locations;
- Heavy utilities may be attached to light members reducing the ability of those members to resist intended loadings;
- Utilities affixed to the structure in such a manner as to encroach on the minimum clearance (both horizontal and vertical) to a highway, railway or navigable water or reduce freeboard.

Bridge Inspection Manual

PART 2 – INSPECTIONS

Public Works and Government Services Canada
Travaux publics et Services gouvernementaux Canada
Canada

PART 2 – INSPECTIONS

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SECTION 1 – INSPECTIONS

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SECTION 1 – INSPECTIONS

1.1 Structural Inspections

1.1.1 General

Components shall be assessed for material and performance defects. The type and extent of deterioration shall be recorded on the inspection forms in accordance with Appendix B – Inspection Report. Any unusual features or items shall be described in the space allotted for remarks. The components shall be given a condition rating and a priority code based on the material and performance condition of the component. The first time inspection shall act as the benchmarks for all further inspections and will permit an annual assessment of the rate of deterioration of components. Colour photographs shall be taken of significant defects.

1.1.2 Inspection Procedures

1.1.2.1 Comprehensive Detailed Inspections

Comprehensive detailed inspections of structures above water level shall consist of:

- A detailed inspection in accordance with Appendix A – Component Inspections and inspection forms completed in accordance with Appendix B – Inspection Reports;
- A detailed inspection of all components including those, which may require the use of, specialized access equipment (cherry picker, snorkel lift, below-deck inspection machine, scaffolding, swing stages, etc.) to view. All components shall be inspected at close range (hands on) except for massive concrete elements, which appear to be in good condition. Such elements may be inspected from their extremities (example, top and bottom of a tall pier);
- Components not visible or inaccessible at time of inspection shall be noted. The necessary provisions for inspection shall be identified and recommendations made for a proper inspection to be executed.
- Delamination and surface deterioration survey of concrete.
- Surface sounding for wood.
- Any or all of the following destructive or non-destructive tests on concrete, structural steel or wood as detailed in Appendix D – Material Condition Surveys and below may be recommended for future work based on field observations:

Concrete:

- Radar and Infrared Thermo graphic Survey;
- Impact – Echo Testing;
- Corrosion Potential survey;
- Concrete Cover Survey;
- Expansion Joint Survey;
- Concrete Coring and Testing Program;
- Asphalt Sawn Sample Program;
- Inspection of Catholic Protection Embedded Hardware and Catholically Protected Components;
- Conductive Asphalt Resistively Testing;
- Investigation of Fire Damaged Components.

Structural Steel:

- Liquid Penetration Testing;
- Magnetic Particle Testing;
- Ultrasonic Testing;
- Eddy Current Testing;
- Radiographic Testing.

Wood:

- Surface Testing by Probing, Pick Test or Paladin;
- Moisture Meter;
- Drilling and Coring;
- Shell-Depth Indicator Testing;
- Sonic Testing;
- Ultrasonic Testing;
- Radiation Testing.

1.1.2.2 Inspection of Underwater Components

An underwater inspection shall be performed on structure components in accordance with Appendix E, Section 4 and reported as required in Appendix B – Inspection Reports.

1.1.2.3 General Inspection

A general inspection shall be performed on structure components in accordance with Appendix A – Component Inspections. Components shall be visually assessed for material and performance defects. The extent of the deterioration shall be estimated but not measured. No physical testing is required except that accessible areas shall be sounded in areas where delaminations are suspected. Inaccessible components that are obstructed from view shall be noted as such during the General Annual Inspection. Colour photographs shall be taken of significant defects.

Where a structure has gone through a comprehensive detailed inspection according to the BIM, PWGSC shall supply the latest inspection reports. The type and extent of deterioration shall be visually assessed and compared with the condition and functional rating from the previous inspection. Additional deterioration or repairs that have been made since the last inspection shall be recorded. The condition rating and priority code shall be adjusted accordingly. For reporting, use the form in Appendix B – Inspection Reports.

1.1.2.4 Maintenance Inspections

Maintenance inspections comprise routine general visual observations by field maintenance personnel. The purpose of these inspections is maintenance-related only and reports must be kept at the local offices.

Daily or weekly inspections are visual general inspections performed from a vehicle, and are used to detect conditions which may adversely affect the comfort and safety of the travelling public. Examples of typical observations to be noted are as follows:

- Debris and litter on structures and approaches;
- Flooding and/or washouts (typically only with smaller structures and culverts);
- Regulatory and warning signs which are missing, damaged, turned, defaced or destroyed;
- Damaged guide rail on structures and approaches;
- Snow and ice accumulation on structures and approaches;
- Damaged or missing structures illumination; vehicular collisions on or with structures.

Once monthly, structures should be inspected on foot along both sides of the structures. Inspection of the underside should also be made, either by walking the length of the structure or from both embankments. Examples of typical observations to be noted are as follows:

- Accumulation of water, sand salt, debris or vegetation on the deck surface or in joints, deck drains, etc.;
- Debris or natural growth preventing free drainage of water away from the bridge, or free movement of watercourses;
- Brush preventing clear view of bridge or growing in contact with the bridge;
- Erosion of banks caused by water coming from deck drains, or around end of wing walls or by waterway;
- Damaged to structures which appears to be the result of accidents or vandalism;
- Settlement of slope paving and/or rip rap;
- Damaged, missing or misaligned barriers, guide rails, etc.;
- Settling or tilting at bridge approach slab;
- Changes in vertical alignment of bridge railing, curbs, deck, etc.;
- Noise emanating from structural components, such as expansion joints, bearings, or Bailey component;
- Frames and grates that are missing, damaged or not in place;
- Existence of surfaces defects, such as cracks, potholes, ravelling, shoving, etc.;
- Joint defects, such as: missing or deteriorating joint sealant material; steel finger-type joints, which show cracks, breaks in welds, loose anchorage, or hard objects wedged between the fingers;
- Existence of structural defects such as crack, buckles or kinks in steel members; splits or breaks in timber components; missing bolts or rivets. Evidence of punching in concrete decks; evidence of new cracks in concrete decks, piers, abutments, ballast walls or wing walls;
- Deterioration in the vicinity of the wave zone.

1.1.2.5 Special Inspections

These inspections, when deemed necessary, must be carried out by experienced maintenance personnel or qualified bridge inspectors, engineers and/or specialists during or immediately after the occurrence of the significant events listed below. These inspections may initially be undertaken by maintenance personnel to observe obvious defects or changes to the structure. Bridge engineers will be called in to ascertain the extent and implications of any damage to the structure and make a report.

Significant events requiring an unscheduled visual inspection include, but are not limited to:

- Vehicle/vessel collision with a structure;
- Component Distress/failure;
- Unusually high spring run-off;
- Heavy rainfall event in the catchments area;
- Prolonged periods of extreme temperatures;
- Significant earthquake (Richter 5 or greater) in general proximity;
- Concerns as a result of failure of a similar structure/component elsewhere;
- Unusual Permit Loads;
- Other special circumstances.

1.1.2.6 Monitoring Inspections

Monitoring inspections are intended to study and document a component deficiency/performance over an extended period of time, generally with a defined schedule. The inspection may include on-site observations and/or field measurements such as expansion joint gaps, settlements, translation or rotation of a bearing, crack widths and length in concrete or steel, scour, corrosion monitoring, etc.

Photographic records of on-site field observations should be maintained to allow comparison of change in condition over a period of time. Progressive records of any field measurements should also be maintained.

Trained and qualified personnel under the direction of a qualified bridge engineer must undertake monitoring Inspections

1.1.2.7 Condition Inspections

Condition Inspections are intended to assist in assessment of the state and performance of the individual components and the structure as a whole to determine the safe load carrying capacity of the structure. Additional information may be required in addition to that available from the Comprehensive Detailed Inspections. This may require additional destructive and non-destructive testing of materials as outlined in BIM.

The Bridge Engineer in charge of structural evaluation shall review the available plans, repair history and inspection data to assess and arrange to obtain the required additional information as may be necessary to assist in structural evaluation of the bridge.

1.2 Responsibilities of Inspectors

The Engineer performing, or directly supervising the inspection shall be responsible for the following:

- The thoroughness of the field inspection, the analysis and reporting of the findings, and the recommendations for corrective measures. All data recorded in the field shall be complete, legible, and unambiguous;
- Familiarizing themselves with the design and construction features of the structure in order to properly interpret what is observed and reported;
- Recognizing any structural deficiency, assessing its seriousness and probable cause;
- Recommending appropriate action necessary to maintain the bridge in a good and safe condition;
- Recognizing problems or potential problems which present a hazard to public safety so that appropriate preventive maintenance action can be taken promptly;
- Ensuring that proper safety practices are observed.
- Report immediately if an urgent action is required

1.3 Safety Regulations and Responsibilities

1.3.1 General

Structure inspections shall be carried out in such a manner to ensure the safety of the inspectors and public using the structure at all times. The safety practices implemented shall comply with the following:

- PWGSC Deputy Minister Directive 073: Occupational Health and Safety – Construction;
- Canada Labour Code, Part II;
- Canada Occupational Health and Safety Regulations;
- Provincial or territorial Labour and Occupational Health and Safety regulations, including all Worker's Compensation Board requirements;
- Manual of Uniform Traffic Control Devices or provincial equivalent.

In the case of a conflict between regulations, the most stringent of regulations shall govern.

Some bridge inspections involve working over, under and around water, working off of mobile equipment and swing stages, etc. In such cases, the specialized equipment required shall be operated by skilled personnel and in accordance with the latest issue of the following standards:

CSA Standard Z150	"Safety Code on Mobile Cranes"
CSA Standard Z271	"Safety Code for Suspended Platforms"
CSA Standard Z275.2	"Occupational Safety Code for Diving Operations"

All inspection and supervisory staff assigned to the inspection of structures must be trained in current safety practices and in the proper use of safety equipment. Courses in first aid and traffic control and protection are recommended and are actually now mandatory in some provinces.

1.3.2 Responsibility

1.3.2.1 Department

When the Department assumes the role of property owner, the designated departmental representative is responsible for ensuring that all federal and provincial/territorial regulations relating to construction occupational health and safety is adhered to in accordance with Deputy Minister's Directive 073: Occupational Health and Safety – Construction.

When the Department assumes the role of builder, the designated departmental representative is responsible for complying with the applicable federal and provincial/territorial statutes and regulations relating to the tasks to be undertaken in accordance with Deputy Minister's Directive 073: Occupational Health and Safety – Construction.

1.3.2.2 Inspection Supervisor

The engineer who supervises the inspection is responsible for ensuring that:

- inspection staff are aware of and follow policies and procedures affecting structure inspection safety;
- inspection staff are properly trained;
- inspection staff are adequately equipped with protective clothing, safety devices and equipment;
- safety devices and equipment are properly maintained and in good working condition.

1.3.2.3 Site Supervisor

The site supervisor is responsible for planning the inspection and ensuring that:

- adequate precautions are taken against hazardous situations;
- inspection staff follow the required safety policies and procedures;
- inspection staff wear required safety clothing and devices;
- safety equipment and devices are properly used;
- appropriate actions against any unsafe acts or situations are taken.

1.3.2.4 Inspectors and Auxiliary Personnel

Inspectors and auxiliary personnel are responsible for:

- following the established safety policies and procedures;
- wearing safety clothing and devices;
- using safety equipment properly;
- identifying and reporting any defective safety clothing, devices and equipment;
- identifying hazardous situations and taking appropriate measures;
- advising supervisor of any physical impairment that might affect his own ability to safely perform inspection duties.

1.3.3 Traffic Control

The purpose of traffic control devices is to warn motorists of work in progress, minimize risk of injury to the public and the inspection crew, and protect the inspection vehicles from collision damage.

All traffic control for bridge inspections shall be in accordance with the following:

- the Manual of Uniform Traffic Control Devices, Part D – Temporary Conditions (latest edition);
- federal, provincial or territorial health and safety, labour and traffic control regulations.

In the case of conflicting regulations, the most stringent regulation shall govern. A traffic control plan shall be submitted to the PWGSC Project Manager prior to the commencement of the field inspection.

At the start of the inspection, the site supervisor must have the necessary traffic control devices placed in accordance with the applicable standards and manuals.

Traffic control signs and cones, where applicable, must be placed so as to be clearly visible.

Where practicable, staff positioning or removing signs and cones should use the inspection vehicle with the roof light operating as a warning device.

Signs are to be covered or removed when the inspection crew is not working in the location where the signs are placed.

The site supervisor may adjust the number and/or placement of signs and traffic control devices to accommodate specific site situations. However, the minimum requirements must be met at all times.

For inspections requiring a lane closure, special vehicles and additional traffic control devices may be required.

1.4 Sample Safety Practices

The following sample safety practices are for information only. **They do not replace or supersede any of the regulations listed in Section 1.3.1.**

1.4.1 Staffing

1.4.1.1 General

For safety purposes, a structural inspection crew must be comprised of a minimum of two persons, one of whom will be designated as the site supervisor.

1.4.1.2 Water

Crews working in or around water of sufficient depth or current to pose a risk of drowning must be comprised of a minimum of three persons. At least two workers must be available for rescue operations, one of whom must be stationed away from the water but in continuous visual or voice contact with those in the water.

1.4.1.3 Ice

Crews working on ice must be comprised of a minimum of three persons. At least two workers must be available for rescue operations, one of whom must be stationed off the ice but in continuous visual or voice contact with those on the ice.

1.4.1.4 Confined Spaces

Crews working in confined spaces, such as steel box girders, must be comprised of a minimum of three persons. At least two workers must be available for rescue operations, one of whom must be stationed outside the confined space but in continuous visual or voice contact with those in the confined space.

1.4.1.5 Additional Staff Requirements

The site supervisor shall determine any additional staffing requirements based upon specific site conditions.

1.4.2 Planning

Inspections should be scheduled to avoid peak traffic periods and should be discontinued if they create a hazard to the inspection crew or the public or interfere unduly with the flow of traffic.

At the start of each inspection, the site supervisor must:

- review the work to be done as part of the particular inspection;
- discuss with the inspection crew the hazards inherent in the work to be done and establish appropriate ways of dealing with those hazards.

During the inspection, the site supervisor must:

- monitor changes in traffic volume, sight distances, water levels, ice conditions and atmospheric and weather conditions and take appropriate action, such as placing additional signs or cones or removing the inspection crew from the site.

1.4.3 Equipment

1.4.3.1 Inspection Vehicle

The inspection vehicle shall be clearly identified and shall carry, as a minimum, the following:

- one flashing orange roof light;
- two (2) portable "Men at Work" signs complete with flag poles and flags;
- three (3) 450 mm blaze orange traffic cones;
- fully equipped emergency first aid kit adequate for a crew of at least 6 people including a current edition of St. John Ambulance First Aid Manual.

1.4.3.2 Protective Clothing and Personal Safety Equipment

Each member of the inspection crew shall wear the following minimum amount of personal protective clothing whenever working on the right-of-way:

- safety hard hat with chin strap;
- fluorescent blaze orange vest with yellow reflective stripes (note that vest is not to be worn when working on railway tracks);
- safety footwear with steel toe, or steel toe and sole.

The minimum additional requirements for protective clothing and personal safety equipment for various hazardous situations are given below. Additional protective clothing and/or safety equipment shall be worn and/or used as directed by the site supervisor.

FALLING

The following additional safety equipment shall be used when there is a risk of falling over 3 m:

- safety net; or
- safety belt/harness with lanyard fastened to a fixed support or lifeline.

This safety equipment is not required when working on a bridge deck that has adequate railing protection.

WATER

The additional safety equipment listed in Table 1.4.3.2 must be used when there is a risk of workers falling into water or drowning as a result of the current or the temperature of the water.

The risk of falling into water is deemed not to exist if:

- the worker stays at least 2 m away from the edge of water, or from the edge of a steep slope leading into the water;
- the worker wears a safety belt with lanyard fastened to a fixed support;
- there is a guardrail, between the worker and the water.

Depth of Water	Safety Equipment
0 – 0.3 m	• no special equipment required
0.3 – 1.0 m	• safety floatation line across waterway • life jackets
1.0 – 1.5 m	• safety floatation line across waterway, approximately 8 m downstream from worksite • life jackets • ring buoy with 15 m of 9.5 mm rope • whistle, horn or 2-way walkie-talkie
more than 1.5 m	• safety floatation line across waterway approximately 8 m downstream from worksite • life jackets • safety belt/harness with lanyard fastened to a fixed support • boat and equipment for rescue • whistle, horn or 2-way walkie-talkie

Table 1.4.3.2

Notes

- The safety floatation line, shown in Table 1.4.3.2, is not required where there is no current in the water. If it is not reasonable or practical to put a safety floatation line across the waterway then alternative precautions shall be considered.
- On navigable waters the waterway authority shall be contacted prior to installation of a safety floatation line across the waterway.

ICE

The following additional safety equipment must be used when there is risk of workers falling through the ice:

- auger or equivalent;
- thermal floatation suit;
- change of clothes or blanket;
- ring buoy with 15 m of 9.5 mm rope;
- whistle, horn or two-way electronic communications device.

If there is a combination of open water and ice, the safety measures for working near water identified above also apply.

Ice can support the following loads:

Loads	Thickness (mm) Clear Blue Ice	Thickness (mm) Snow Ice
Workers in single file	75	115

Bore a hole with an auger to measure the thickness of the ice and visually assess the quality of the ice. Holes should be bored no more than 15 m apart. If there is a strong current or there are sewer outlets in the vicinity, the test holes should be closer.

Check the thickness of the ice with a long pole that can also be used to rescue anyone who falls through.

If the same path is always used to get to and from the work site, the thickness of the ice along the path should be checked regularly.

Structural inspections carried out from ice must be discontinued if:

- the minimum safe thickness is not met;
- the ice turns grey, which occurs after a thaw and indicates the presence of water;
- there is water on the ice;
- radial cracks develop;
- continuous cracking is observed or heard;
- sagging is observed.

CONFINED SPACES

The following additional safety equipment shall be used when in a confined space:

- air testing equipment;
- flashlight or other suitable lighting;
- whistle, horn or two-way electronic communications device.

Structure inspections in confined spaces shall not be carried out unless the air quality has been tested and found to be adequate.

OTHER HAZARDS

Hazard	Equipment
a) Eye injury	Safety glasses
b) Hand injury	Safety gloves
c) Hearing damage	Hearing protection
d) Damage to personal clothing	Coveralls

1.5 Inspection Equipment

1.5.1 Standard Equipment Carried by Inspectors

All inspection personnel are required to use and be thoroughly familiar with the operation of the following equipment when conducting general annual inspections:

- Binoculars;
- Digital Camera and Colour Film(s);
- Chalk and Markers;
- Inspection Forms, and Clip Boards;
- Flashlight;
- Length of Chain (2 m);
- Crack Comparator;
- Light Chipping Hammer;
- Measuring Tape (3 m);
- Measuring Tape (30 m);
- Plumb Bob;
- Pocket Knife;
- Boots, Hat, Gloves, Vest;
- Safety Cones and Flashing Light;
- Straight Edge (1 m);

- Air, Concrete and Steel Thermometers;
- Mirror on a Swivel Head with an Extension Arm;
- Range Poles;
- Safety Belts, Flotation Vest;
- Scraper;
- Sounding Line (lead line);
- Wire Brush.

1.5.2 Specialized Equipment Required by Inspectors

Certain locations on a structure may not be accessible for inspection during comprehensive detailed inspections without special equipment. In addition to the equipment listed in Section 1.4.1 above, the following is a partial list of some of the specialized access inspection equipment which may be required:

- Boat or Barge;
- Extension Ladder (3.5 m);
- Scaffolding – mobile, cable supported or stationary;
- "Snooper" or "Cherry Picker" – truck mounted inspection bucket on a hydraulically operated boom off a truck.

Detailed Condition Surveys on concrete components also require specialized equipment. A partial list of the equipment required is as follows:

- gasoline powered saw for sawing asphalt;
- gasoline powered electric generator, gasoline, extension cords;
- electric core drill with 100 mm diameter bits, core retrievers, water tank and necessary supply hoses;
- wet/dry vacuum cleaner;
- quick set concrete repair material and plywood forms for filling core holes;
- waterproofing membrane and cold mix asphaltic patching material (cold patch) for cores on asphalt covered decks;
- electric chipping hammer, electric drill, sponges and rags, chisel, wire brush, screwdriver, visegrips, copper sulphate half cell, voltmeter, and lead wire for corrosion potential survey.

This specialized equipment would not normally be required for general annual inspections. If such equipment is needed, then arrangements should be made by the inspectors to obtain this equipment as required. In many cases, the sawing and coring is done by a subcontractor who specializes in this type of work.

1.6 Systematic Inspection Procedures

1.6.1 Preparation Prior to Field Inspection

The inspector shall:

- Review structure records prior to commencement of any field work including design and construction details, "as-built" drawings, previous inspection reports, correspondence and details of repairs.

- Prepare inspection forms, as in Appendix B, for each structure to be inspected. An individual inspection report can be built up, for any structure, by the collection and amalgamation of the appropriate component sheets, as required, to completely describe the structure under consideration. The inspection report is thus complied to suit each individual structure being inspected.
- Develop a time schedule for the inspection and review specialized equipment requirements including traffic protection devices.
- Make arrangements with the Project Manager/Engineer for specialized equipment and traffic control devices, if required.
- Obtain permission from the railway company if the bridge is over railway tracks and mobile platforms or other special equipment is going to be used in the track area.

1.6.2 Site Inspection

The inspector is required to:

- Complete a brief overview of the structure and identify obstacles that may either interfere with the inspection or indicate a need for additional special equipment;
- Discuss inspection procedures with the foreman of the traffic crew so that lane closings and traffic detours, etc., are timed to suit inspection needs;
- Ensure that all signs, temporary barriers, protective screens, safety devices, etc., are in place.

Once the site has been secured, the inspection can proceed in a systematic fashion.

- Draw up a list of the names of the people on site during the inspection;
- Note the date, weather and temperature;
- Note any unusual conditions;
- Note any restrictions affecting the inspection;
- Draw up a list of special equipment used;
- Complete the general information portion of the inspection form;
- Complete the inspection forms for each component of the structure;
- Carry out the inspection in a systematic manner;
- Note and record observations and make sketches as appropriate;
- Take photographs, including general views of the structure and damaged areas, noting the locations photographed.

All components (primary, secondary and auxiliary) of the structure shall be inspected and rated.

1.6.3 Post Inspection Procedures

The inspector is required to:

- ensure that all inspection equipment and temporary traffic control devices are removed from the inspection site and the site is left in workmanlike order;
- draft an initial report confirming that the inspection is complete and identifying any components that require immediate repair, and inform the project manager or engineer of the corrective measures to be taken;
- draft a final report containing observations, ratings, photographs and recommendations and indicating the priority of repairs.

SECTION 2 – RATING SYSTEM

Table of Contents

2.1 General

Section 2 describes the principles and general application of the condition rating system used to assess observed defects in the materials and performance of individual components of a structure, and the overall general condition rating for the structure as a whole. Also included are guidelines for the application of a priority code for recommended repairs.

The material and performance condition rating comprises a numerical system in which a number from 1 to 6 (1 = very severe defects, 6 = new condition) is assigned to each component of the structure based upon the severity of the observed material defects or the ability of a component to perform its function within the structure. Both material and performance defects shall be considered for all components. The numerical rating assigned to a particular component(s) shall reflect the most severe condition of material defects or reduction of performance observed. The component(s) condition rating shall be assigned without consideration of the importance of the component(s) within the structure.

Components not visible or inaccessible at the time of the inspection shall be noted. The provision necessary for inspection shall be identified, and arrangements made for proper inspection to be carried out.

In addition to the condition rating, each defect is given a summary priority code for remedial action and scheduling. The priority code comprises an alpha character indicative of the urgency and nature of the required repairs to a component or the need for more detailed inspection. Recognition of the importance of the component within the structure shall be reflected in the assigned priority rating.

The overall ratings of the bridge, as an indicator of the overall structural condition (Condition Rating) and functional elements based on currently accepted standards (Functional Rating) should be provided. These ratings shall be based on sound engineering judgement, taking into consideration the severity and extent of deficiencies observed for various components.

2.2 Rating System for Components of a Structure

Both material and performance defects shall be considered for all components. The numerical rating assigned to a particular component shall reflect the most severe condition of material defects or reduction of performance.

2.2.1 Material Condition Rating for Components of a Structure

The material condition rating for the components of a structure reflects the condition of the component based upon observed defects in the materials of the component. Commonly occurring defects in materials typically used in structures are described and categorized as to severity in Part 1 of this manual.

The application of the material condition rating system to components depends on the type, location and severity of the defects. General guidelines based upon the severity and extent of observed defects are given in Figure 2.2.

Additional guidelines for the material condition rating of components are given in Appendix A, Sections A1 to A9, for material defects that cannot be generalized, and for exceptions to the general guidelines.

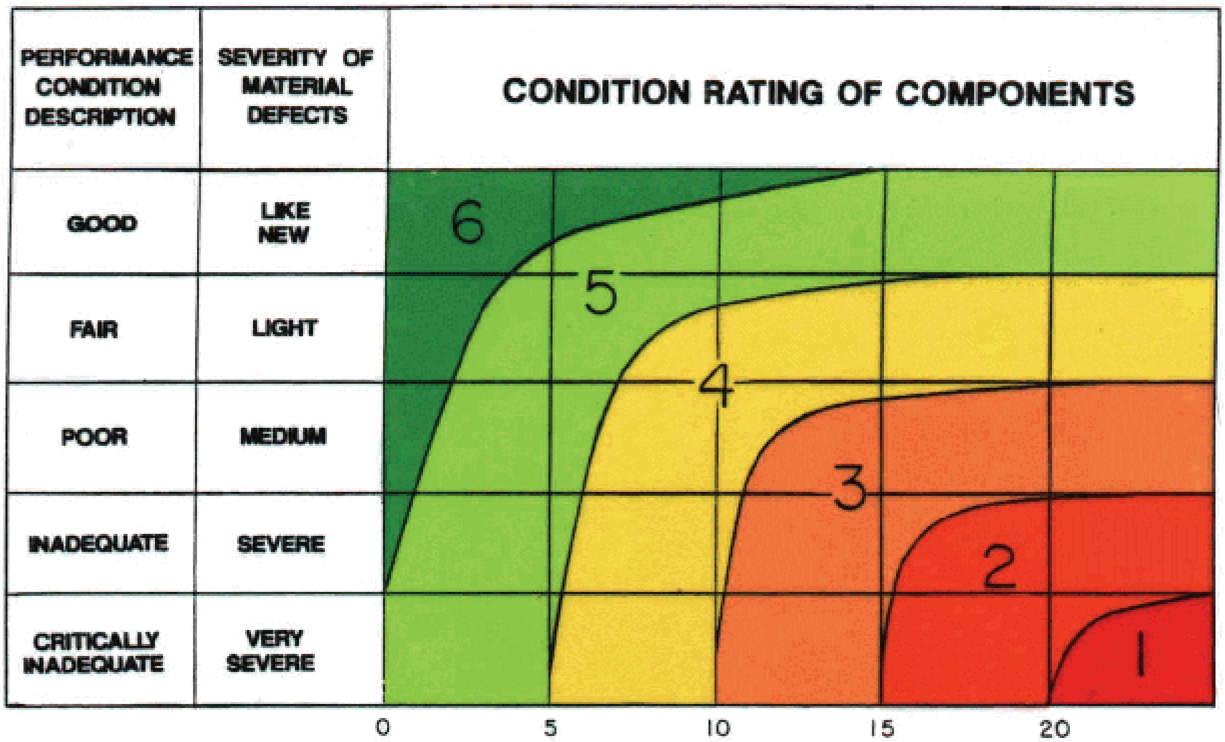
The material condition rating should represent the worst observed material condition of the component and shall be based on any one or a combination of the guidelines given under that rating. The inspector shall record the observed material defects and the causes producing those defects wherever possible. The inspector shall take measurements to quantify the extent (perhaps expressed as a percentage) and general location of the defects for all components; however, extensive measurements will not normally be required.

2.2.2 Performance Condition Rating for Components of a Structure

The performance condition rating for components of a structure describes the condition of the component based upon its ability to perform its intended function in the structure. General guidelines based on the percentage reduction in the capacity of the component to perform its intended function are given in Figure 2.2. Additional guidelines for the performance condition rating of components are given in Appendix A, Sections A1 to A9, for performance defects that cannot be generalized, and for exceptions to the general guidelines.

In most cases, the performance defect of a component is closely related to, or attributable to, defects in the component materials as material defects often lead to performance defects. The severity of the performance defect is not necessarily the same as the severity of the material defect.

In some cases, performance defects exist due to defects in design or construction and may not be directly related to material defects. Also, performance defects in a component may be the result of unexpected behaviour of the structure or due to performance defects in other components of the structure. The inspector shall record the observed reduction in performance and the causes producing those effects wherever possible.



% LOSS OF COMPONENT CROSS-SECTION, SURFACE AREA OR LENGTH AFFECTED AND/OR % REDUCTION IN PERFORMANCE CAPACITY

Figure 2.2 Condition Rating of Components

2.3 Priority Code for Component Repairs of a Structure

The priority code assigned to each component shall be one of the following:

U Urgent requires immediate attention and remedial measures to ensure public safety.

M Required work to be done as part of routine annual maintenance.

S Further study/investigations/surveys required prior to initiating repair programme.

A Repair and/or replacement to be done in less than 1 year.

B Repair and/or replacement to be done in less than 3 years.

C Repairs and/or replacement to be done in less than 5 years.

D Condition to be re-assessed at the next inspection.

All components shall be assigned a priority code indicative of the urgency and nature of recommended repairs, or need for further inspection. Performance related deficiencies should be considered to be of higher priority than material related defects. Nevertheless, the objectives of the recommended rehabilitation programme should be to address, where possible, all material and performance related defects.

Recognition of the importance of the component within the structure shall also be reflected in the priority rating assigned. Recognition of the importance of the component will be achieved by the classification of all components as either primary, secondary or auxiliary as given in Table 2.3. The classification is generally along traditional structural behaviour except for non-structural components, which should be classified as shown in Table 2.3.

In the event that the component condition rating indicates a significant level of deterioration or loss of performance, yet the recommended repairs are assigned a low priority, a brief written explanation shall note the component classification and nature of the deficiency.

Section of B.I.M. APPENDIX A	Primary Components	Secondary Components	Auxiliary Components
A1	• Streams		
A2	• Embankments supporting foundations	• Embankments supporting foundations	• Slope Protection
A3	• Foundations • Abutment Walls • Piers	• Ballast Walls • Wingwalls • Retaining Walls • Bearing Seats	
A4	• Pin and Hanger Bearings	• Other Bearings	
A5		• Joints	
A6	• Beams, Girders • Stringers • Floor Beams • Thick Slabs • Trusses • Arches • Culverts • Soil-steel structures • Load Bearing Diaphragms • Connections of primary components	• Non-load Bearing Diaphragms • Bracings • Connections of secondary components	
A7	• Decks • Wearing Surface • Sidewalks accessible to traffic	• Curbs • Sidewalks not accessible to traffic • Approaches • Approach Slabs	• Deck Drains and Drainage Systems
A8		• Barrier Walls • Railings	
A9	• Structural Steel Coatings on primary components	• Structural Steel Coatings on secondary components	
A10			• Signs
A11			• Utilities

Table 2.3 – Classification of Components

2.4 Overall Bridge Ratings

The Comprehensive Detailed Inspection Reports and the General Inspection Reports shall include:

- **Structural Condition Rating** – to provide an overall rating of the structure, taking immaterial and performance ratings of the individual components into consideration.
- **Functional Rating** – to provide an overall rating of the structure based on functional needs.

Whereas the following tables are intended to provide some guidelines, these should not be interpreted literally. Engineering judgement should be exercised based on severity and extent of deficiencies observed during field inspections and ratings assigned to individual components.

A brief explanation of the Overall Ratings should be provided in the Report.

Rating	Condition	Observations
6	Excellent	• New condition, minor imperfections – no repairs warranted; • Structure meets current CHBDC live loading and seismic requirements.
5	Good	• Structure meets current CHBDC live loading and seismic requirements; • Minor repairs required to secondary or auxiliary components; • Known problems relating to primary components but no repairs required; • Minor touch up coating required.
4	Fair	• Structure meets current CHBDC live loading; • Minor repairs required to primary components; • Significant repairs may be required to secondary or auxiliary components; • Minor scour problems; • Significant touch up coating required – no rust holes.
3	Poor	• Structure does not meet current CHBDC live loading; • Posted to within 15% of CHBDC live loading; • Repairs required to primary components and/or load carrying capacity is not compromised; • Medium scour problems; • Rust holes limited to secondary or auxiliary members.
2	Inadequate	• Structure does not meet current CHBDC loading; • Load posted more than 15% below CHBDC loading; • Significant scour problems; • Significant repairs and strengthening required to primary components to reinstate load capacity.
1	Critically Inadequate	• Inadequate to support vehicular loads; • Possibility of imminent failure; • Structure has failed or is closed to traffic; • Public safety is of concern.

Table 2.4(a) – Overall Bridge Rating: Structural Condition

Rating	Condition	Observations
6	Excellent	• New condition, minor imperfections – no repairs warranted; • Structure meets current CHBDC live loading and seismic requirements; • Structure meets TAC width and vertical clearance requirements; • Crash tested barriers at bridge and approaches – meet current requirements; • Traffic Capacity Level of Service: C; • Riding quality – excellent; • Approach geometric conditions meet current standards.
5	Good	• Structure meets current CHBDC live loading requirements; • Structure meets TAC width and vertical clearance requirements; • Crash tested barriers at bridge and approaches – meet current requirements, minor repairs required; • Traffic Capacity Level of Service: C; • Riding quality – Good; • Approach geometric conditions: Minor variations from current standards but generally acceptable.
4	Fair	• Structure meets current CHBDC live loading requirements; • Deficiency in terms of bridge width and/or vertical clearance per TAC requirements is less than 10%; • Approach or Bridge barriers do not meet current standards; • Repairs required at multiple locations (<20 percent); • Traffic Capacity Level of Service: D; • Riding quality – Fair; • Bridge or approaches posted at 10 km/hr below the normal highway speed; • Approach geometric conditions deficient in terms of horizontal or vertical alignment.
3	Poor	• Structure does not meet current CHBDC live loading; • Load posted to within 15**%** of CHBDC live loading; • Deficiency in terms of bridge width and/or vertical clearance per TAC requirements is more than 10%; • Approach and Bridge barriers do not meet current standards; • Repairs required at multiple locations (>20 percent but <50%); • Traffic Capacity Level of Service: E; • Riding quality – poor; • Approach geometric conditions deficient in terms of horizontal and vertical alignment; • Bridge and approaches posted at 20 km/h below normal highway speed.
2	Inadequate	• Structure does not meet current CHBDC loading; • Load posted to more than **15%** below CHBDC loading; • Deficiency in terms of width and/or vertical clearance per TAC requirements is more than 20%; • Non crash tested barriers, deficient in terms of original design strength requirements and/or more than 10% in terms of height requirements Repairs required at multiple locations (>50 percent); • Riding quality – very poor; • Traffic Capacity Level of Service: F; • Approach conditions deficient in terms of horizontal and vertical alignment; • Speed restrictions – posted at more than 30 km/h below normal highway speed.
1	Critically Inadequate	• Inadequate to support vehicular loads; • Possibility of imminent failure; • Structure has failed or is closed to traffic; • Public safety is of concern.

Table 2.4 (b) – Overall Bridge Rating: Functional

Bridge Inspection Manual

APPENDIX A – COMPONENT INSPECTIONS

Public Works and Government Services Canada
Travaux publics et Services gouvernementaux Canada

Canada

APPENDIX A – COMPONENT INSPECTIONS

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SECTION A1 – WATERWAYS

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A1.1 Waterways

Waterways shall be inspected within the limits of the structure, where possible, and for a distance of at least 30 metres upstream and downstream of the structure.

Waterways shall be inspected to determine if any condition exists that could potentially cause damage to the structure or surrounding area.

The inspector shall note and record if general maintenance of the waterway has been carried out. These include the cleaning of debris, branches, logs, trees, vegetation and beaver dams.

The inspector shall note if foundations in waterways which are susceptible to scour have adequate scour protection placed to the bottom of the foundation or to scour depth.

A1.1.1 Condition Rating of Waterways

The inspector shall determine and record the location and extent of the material and performance related defects identified in Part 1, Section 3. The following material defects shall be inspected with particular care:

- General scour or degradation of the waterway bed or banks;
- Local scour around the structure or components in or near the waterway flow;
- Local scour immediately downstream of the structure;
- Slumping or erosion of embankments due to percolation of water through the fill or scour of the toe of the embankment;
- Piping behind the structure abutments, wingwalls or retaining walls;
- Deterioration of existing wayway bank and shore protection systems.
- Changes in waterway channel or alignment which directs waterway flow against components not previously subject to the waterway flow;
- Aggradation of the waterway bed;
- Obstruction of the waterway by debris or vegetation growth;
- Soil pushed up the banks by ice shove, or ice gouges in the waterway banks or flood plain.

Where evidence of scour, degradation or aggradation exists arrangements shall be made to have elevations taken at 3 m intervals for a distance of 30 m upstream and downstream.

In addition to inspecting and recording the present condition of the waterway and channel, the inspector shall also record any significant changes that have occurred since the last inspection. Particular note shall be made of changes which have resulted in, may result in, or which indicate that existing foundation protection systems, especially around scour prone spread footings, are inadequate and require repair or improvement. If significant changes have occurred, then an investigation must be made into the potential harmful effects on the structure.

SECTION A1 – WATERWAYS

The performance condition rating of waterways is based on the adequacy of the opening under the structure to accommodate the waterway flow, on the frequency and extent of flooding at the structure, and on material defects in waterways that adversely affect the structure.

The geometry of the channel, the amount of debris carried during high water periods, and the adequacy of free-board are important considerations in determining the adequacy of the opening. Where large quantities of debris and ice are expected, insufficient free-board presents a serious threat of damage to structure components.

Ideally, waterways should be inspected during and immediately after periods of flooding, as the effects of high water will be most apparent at these times. Since this is not always possible, a knowledge of the heights of past floods from past records and other available information together with the recording of the height of high water marks during inspection are helpful in determining the adequacy of the waterway opening.

Degradation, aggradation, scour, flooding, shifting of waterway alignment or combinations of these are of particular importance, especially where the result is such that the waterway impacts against, or encroaches onto, previously unexposed structural components in the waterway channel causing damage to them, or resulting in scour of the foundations.

The inspector should note and record the water level; evidence of high water level and flooding; and, adequacy of the opening at the structure at the time of inspection. Where possible the distance between the soffit and the water level should be measured. Note that water levels at obstructions in the waterway, such as piers, may be artificially high at the upstream side and low on the downstream side.

The inspector shall note and record significant changes, natural or man-made, that have occurred in the waterway channel which are having or may have a harmful effect on the structure components in the waterway channel.

The inspector should look for the following evidence of high water levels, inadequate opening at the structure and adverse effects on other components of the structure.

- Scour or undermining of pier or abutment foundations;
- Channel changes which direct waterway flow against unprotected piers and abutments causing scour;
- Bending or buckling of the lower chord of steel trusses in the downstream direction by ice or heavy debris;
- Ice scars and damage to substructure;
- High water marks painted by PWGSC staff or conservation authorities;
- Coarse debris, such as branches and small trees, caught or wedged under the superstructure;
- Fine debris, such as grass and twigs, on fences, trees, embankments, structures, etc.;
- Wash lines on bare soil slopes;
- Mud or silt deposited on embankments;
- Marks and stains on structures.

The following work done after original construction to correct past performance defects in the waterway may also be observed. The inspector should note whether a problem still exists or whether the remedial actions taken are working satisfactorily.

- Underpinning of the foundations;
- Steel sheet piling driven around the foundations;
- Concrete floor, rock apron or random rip-rap placed around the foundations;
- Partial or complete rebuilding of the foundations.

Guidelines to assist the inspector in the rating of material and performance related defects of waterways are given in Table A1. Guidelines for performance related defects are listed in bold face type. These guidelines are in addition to those given in Part 1, Section 3.

A1.1.2 Examples of Defects and Ratings of Waterways

Typical examples of defects of waterways are shown in Figures A1.1.2(a) to A1.1.2(f). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating signed shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Rating	Observed Material and Performance Defects
6	• No observed material or performance related defects.
5	• **Probable maximum high water level within 0.5 m of soffit of superstructure;** • **Channel blockage reducing the opening under structure up to 5%;** • **Light damage to structure components by ice or debris carried by the waterway;** • **Waterway directed against previously protected structure components resulting in light material defects in those components;** • **Undermining and loss of support over up to 5% of foundation.** • A few locations of scour or degradation of the waterway bed or waterway banks but not exposing the foundations; • Slight scour at inlet or outlet of culverts and soil-steel structures; • Waterway alignment shifted but not encroaching against components previously not subject to waterway flow; • A few locations of aggradation not affecting the waterway flow at the structure.
4	• **Probable maximum high water level at soffit of superstructure;** • **Channel blockage reducing the opening under the structure by 5% to 10%;** • **Waterway directed against structure components resulting in medium material defects in those components;** • **Undermining and loss of support over 5% to 10% of the foundation;** • **Medium damage to structure components by ice or debris carried by the waterway.** • Numerous locations of scour or degradation of the waterway bed or waterway banks but not exposing the foundations; • Minor scour at the inlet or outlet of culverts and soil-steel structures; • Waterway alignment shifted and encroaching close to components not previously subject to waterway flow; • Several locations of aggradation marginally affecting the waterway flow at the structure.
3	• **Probable maximum high water level at top of deck;** • **Channel blockage reducing the opening under the structure by 10% to 15%;** • **Waterway directed against structure components resulting in severe material defects in those components;** • **Undermining and loss of support over 10% to 15% of the foundation;** • **Severe damage to components by ice or debris carried by the waterway.** • Scour or degradation of the waterway bed or waterway banks to the top of previously covered foundations; • Significant scour at the inlet or outlet of culverts and soil-steel structures; • Waterway alignment shifted with waterway flow directed at a component previously not subject to waterway flow; • Medium aggradation having a significant affect on the waterway flow at the structure.

Rating	Observed Material and Performance Defects
2	• **Probable maximum high water level above top of deck;** • **Channel blockage reducing the opening under the structure by 15% to 20%;** • **Waterway directed against structure components resulting in very severe material defects which may affect the strength or stability of those components;** • **Undermining and loss of support over 15% to 20% of the foundation;** • **Very severe damage to structure components by ice or debris carried by the waterway which may affect the strength or stability of those components.** • Scour or degradation of the waterway bed or waterway banks to below the top of previously covered foundations; • Severe scour at the inlet or outlet of culverts and soil-steel structures; • Waterway alignment shifted with waterway flow directly against most of a component not previously subject to waterway flow; • Aggradation having a severe effect on the waterway flow at the structure.
1	• **Probable maximum high water level above top of deck;** • **Channel blockage reducing the opening under the structures by more than 20%;** • **Waterway directed against structure components that has critically affected the strength or stability of those components;** • **Undermining and loss of support over more than 20% of foundation;** • **Very severe damage to structure components by ice or debris carried by the waterway that has critically affected the strength or stability of those components.** • Scour or degradation of the waterway bed or waterway banks to the bottom of previously covered foundations; • Extensive washouts around the inlet or outlet of culverts and soil-steel structures with loss of embankment fill; • Waterway alignment shifted with waterway flow directly against all of a component not previously subject to waterway flow; • Extensive aggradation very severely affecting the waterway flow at the structure.

Table A1 Condition Rating of Waterways
Guidelines for performance related defects are listed in bold face type.

Figure A1.1.2(a) Waterways

MCR 1 – Degradation of waterway bed to bottom of footing.
PCR 3 – Maximum high water marks above soffit of beams.
PC B – Monitor structure closely during extended periods of rain and after spring run-off.

Figure A1.1.2(b) Waterways

MCR 2 – Aggradation of right bank and erosion of left bank resulting in severe change in waterway alignment and flow at the structure.
PCR 3 – Waterway encroaching against wingwall and substructure with severe erosion of embankment and scour under more than 10% of the foundation.
PC B – Monitor structure closely during extended periods of rain and after spring run-off.

Figure A1.1.2(c) Waterways

MCR 4 – Medium aggradation and siltation of waterway bed with moderate growth of vegetation.

PCR 5 – Channel blockage reducing opening at structure by less than 10%.

PC M

Figure A.1.1.2(d) Waterways

MCR 3 – Aggradation of waterway bed having a severe effect on waterway flow at the structure.

PCR 2 – Partial blockage of the opening at the structure by up to 20%.

PC C – Structure still protected by embankments.

Figure A1.1.2(e) Waterways

MCR 1 – Very severe deposition of debris and siltation of the waterway bed after a flood.
PCR 3 – Debris carried and deposited against structure after a flood causing substantial damage to piles, and blocking waterway flow.
PC M – Waterway bed easily accessible to maintenance crews.

Figure A1.1.2(f) Waterways

MCR 3 – Medium local aggradation of the waterway bed.
PCR 1 – Very severe damage to structure by debris carried during flood.
PC U – Initiate emergency inspection procedure. Upstream truss has failed.

SECTION A2 – EMBANKMENTS AND SLOPE PROTECTION

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A2.1 Embankments

Embankments shall be inspected in the vicinity of the structure for a distance of up to 30 m beyond the structure.

The inspector shall note and record if the general maintenance of embankments has been carried out in accordance. This includes sealing of tunnels made by animals, the control of brush and vegetation other than that planted for the purpose of prevention of erosion, and repairs to slopes that have eroded.

A2.1.1 Condition Rating of Embankments

The inspector shall determine and record the location and extent of material and performance related defects as outlined in Part 1, Section 4. The following performance related defects, which may indicate instability or movement of the embankment or which may result is loss of support for foundations supported on the embankment, shall be inspected with particular care.

- **settlement of embankment, slope protections or approach roadway;**
- **sliding failure of the toe or slopes of the embankment;**
- **surface or deep seated slips;**
- **loss of embankment material from under foundations.**

Guidelines to assist the inspector in the rating of observed material and performance related defects of embankments are given in Table A2.1. Guidelines for performance related defects are listed in bold face type. The guidelines given in Table A2.1 are in addition to the general guidelines given in Part 2, Section 2.

Rating	Observed Material and Performance Defects
6	• No observed material or performance related defects.
5	• **The embankment appears to be stable. Previous movement or loss of material may have occurred and has stopped, but may have affected, by up to 5%, support for or performance of other components.** • Up to 5% loss of material in embankment.
4	• **The embankment appears to be essentially stable. Previous movement or loss of material has occurred and has stopped, but has affected, by 5% to 10%, support for or performance of other components.** • 5% to 10% loss of material in embankment.
3	• **The embankment appears to be essentially stable. Previous movement or loss of material has occurred and may continue, and has affected, by 10% to 15%, support for or performance of other components.** • 10% to 15% loss of material in embankment; or, loss of material to the top of foundations.
2	• **The embankment appears to be unstable. Previous movement or loss of material has occurred and will continue and has affected, by 15% to 20%, support for or performance of other components.** • 15% to 20% loss of material in embankment; or, loss of material to below the top of foundations.
1	• **The embankment appears to be unstable. Movement or loss of material is continuing, and has affected, by more than 20%, support for or performance of other components.** • More than 20% loss of material in embankment; or, loss of material to the bottom of foundations.

Table A2.1 Condition Rating of Embankments
Guidelines for performance related defects are listed in bold face type.

A2.1.2 Examples of Defects and Condition Ratings of Embankments

Typical examples of defects of embankments are shown in Figures A2.1.2(a) to A2.1.2(c). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating assigned shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Figure A2.1.2(a) Embankments

MCR 3 – Many very deep, closely spaced gullies. Loss of embankment material to top of footing.

PCR 4 – Minor movement which has stopped, Embankment appears to be essentially stable, but slope protection or drainage improvements required.

PC C – Extensive grading and landscaping required. Too involved for maintenance crews.

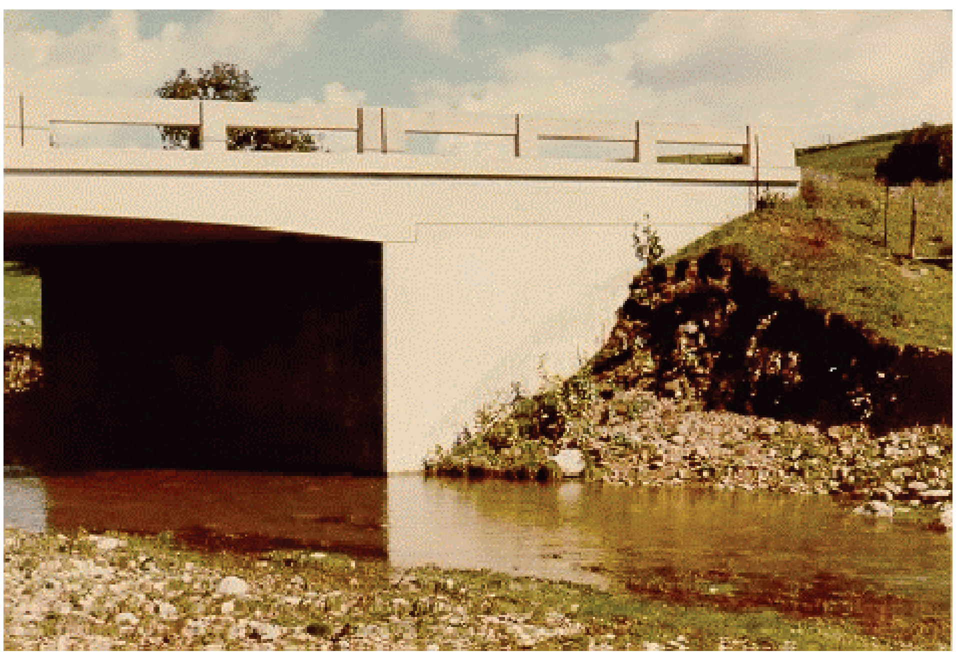

Figure A2.1.2(b) Embankments

MCR 1 – Loss of 30% to 40% of material due to scour at the toe of slope.

PCR 2 – Embankment appears to be unstable. Progressive failure of slope will continue.

PC B – Monitor closely during extended periods of rain and after spring run-off.

Figure A2.1.2(c) Embankments

Right Embankment	MCR 1	–	Scour of 30% to 40% of embankment.
	PCR 2	–	Embankment appears to be unstable. Progressive failure will continue.
	PC B	–	Monitor closely during extended periods of rain and after spring run-off.
Left Embankment	MCR 1	–	Scour of over 40% of embankment.
	PCR 1	–	Embankment has collapsed. Stability of approach is critically affected.
	PC A	–	Monitor closely until repairs are carried out.

A2.2 Slope Protections

Slope protections shall be inspected in the vicinity of the structure for a distance of up to 30 m beyond the structure.

The inspector shall check for, and record, if the general maintenance of slope protections has been carried out. This includes sealing of tunnels made by animals, the control of brush and vegetation other than that planted for the purpose of prevention of erosion, and repairs to slope protections that have settled or deteriorated for other reasons.

A2.2.1 Condition Rating of Slope Protections

The inspector shall determine and record the location and extent of material defects, including the loss of slope protection materials, as well as performance related defects, all as outlined in Part 1, Sections 2 and 4. In addition, the following material defects and performance related defects (listed in bold type) shall be inspected with particular care.

- **Movement, settlement or sliding of slope protection;**
- **Erosion of slope or embankment;**
- Loss of slope protection materials including vegetation and in particular loss of protection to foundations;
- Breakdown of rock or mortar in rip-rap or gabions;
- Corroded or broken wire mesh in gabions;
- Freeze-thaw damage to bag mortar;
- Tearing of geotextiles.

Guidelines to assist the inspector in the rating of observed material defects in slope protections are given in Table A2.2. Performance related defects are listed in bold face type. The guidelines given in Table A2.2 are in addition to the general guidelines given in Part 2, Section 2.

A2.2.2 Examples of Defects and Ratings of Slope Protections

Typical examples of defects in slope protection systems are shown in Figures A2.2.2(a) to A2.2.2(d). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating assigned shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Rating	Observed Material and Performance Defects
6	• No observed material or performance related defects.
5	• **A few areas of minor erosion, movement or settlement affecting less than 5% of the slope protection.** • Loss or deterioration of up to 5% of slope protection material.
4	• **Many areas of minor erosion, movement or settlement affecting 5% to 10% of the slope protection.** • Loss or deterioration of 5% to 10% of slope protection material.
3	• **A few areas of severe erosion, movement or settlement affecting 10% to 15% of the slope protection.** • Loss or deterioration of 10% to 15% of slope protection material.
2	• **Many areas of severe erosion, movement or settlement affecting 15% to 20% of the slope protection.** • Loss or deterioration of 15% to 20% of slope protection material.
1	• **Many areas of very severe erosion, movement or settlement affecting more than 20% of the slope protection.** • Loss or deterioration of more than 20% of slope protection material.

Table A2.2 Condition Rating of Slope Protection
Guidelines for performance related defects are listed in bold face type.

Figure A2.2.2(a) Random Rip-Rap Slope Protection

MCR 6 – No evidence of material deterioration.
PCR 5 – A few areas of minor settlement.
PC D – No recommended repairs at this time.

Figure A2.2.2(b) Grass Slope Protection

MCR 1 – Loss of grass over up to 20% of embankment.
PCR 5 – A few areas of minor erosion and settlement of the embankment.
PC M – Loss of grass protection not contributing significantly to erosion of embankment.

Figure A2.2.2(c) Cast-In-Place Concrete Slope Protection

MCR 6 – No material deterioration of concrete slabs.
PCR 4 – A few areas of minor movement and settlement.
PC C – Loss of material below slope protection will discontinue if expansion joint is repaired/resealed.

Figure A2.2.2(d) Precast Concrete Slope Protection

MCR 2 – Less than 20% of the slabs broken.
PCR 1 – Severe settlement and movement of 60% to 80% of the slope protection.
PC B – Abutment not in immediate danger of being undermined.

SECTION A3 – SUBSTRUCTURES

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A3.1 Substructure Components

The inspector shall note if the routine annual maintenance of the substructure components has been carried out. This includes the cleaning of the debris, vegetation growth, etc. and the washing down of salt deposits.

A3.1.1 Condition Ratings of Substructure Components

Where visible, the inspector shall determine and record the location and extent of material and performance related defects as described in Part 1, Sections 2 and 5.

The following should be inspected with particular care:

- Concrete Footings
    - Cracks in footings;
    - Loss of cross-section;
    - Inadequate scour protection around foundations in waterways.
- Piles
    - Scour under piled foundations, with progressive exposure of piles;
    - Loss or deterioration of cross bracings and their connections;
    - Splits in wood piles at drift pin locations;
    - Decay in wood piles at the water line; at splits and checks; where pier cap bears; and, where bracing is fastened;
    - Ice damage;
    - Deterioration of piers in the splash zone, and at and below the waterline;
    - Corrosion of steel piles.
- Cribs and Gabions
    - Damaged, missing or misaligned components;
    - Disintegration or loss of stone or earth fill;
    - Crushing of wood cribs where components bear on each other;
    - Corroded or broken wire mesh in gabions.
- Walls (abutments, ballast walls, wingwalls and retaining walls)
    - Vertical or horizontal cracks in concrete walls;
    - Horizontal cracks in walls under bearing seats;
    - Vertical and horizontal cracks or separations in mass concrete walls;
    - Transverse cracks across the top edge of wingwalls;
    - Shrinkage cracks and pattern cracks. These are not normally of concern but should be noted especially if there is leakage of water through them;
    - Seepage through cracks in concrete walls;
    - Plugged weep holes and drains in or behind the walls;

  - Areas of delaminated, spalled, or disintegrated concrete;
  - Areas of exposed reinforcement;
  - Deterioration of areas exposed to salt splash, spray, or salt water from leaking expansion joints and drains, or salt water falling over the curbs;
  - Ice damage to walls at waterline;
  - Erosion of concrete in or around waterways;
  - Siltation and migration of earth through the front face of reinforced earth walls.

- Piers
  - Vertical cracks in concrete columns or shafts;
  - Shrinkage cracks accompanied by salt penetration and damage;
  - Flexural or shear cracks in pier caps and in hammer heads;
  - Areas of scaling or disintegration of concrete;
  - Cracks in welds, flanges and webs where steel beams frame into steel pier caps;
  - Accumulation of debris and salt deposits on piers under deck expansion joints and related salt damage;
  - Salt spray damage on piers adjacent to roadways;
  - Ice damage to piers at waterline;
  - Erosion of areas in or around waterways;
  - Loose, damaged or deteriorated pier nosing;
  - Areas of delamination or spalling with exposed reinforcement;
  - Corrosion at joints, splices, bolts and rivets;
  - Loose connections at joints and splices.

- Bearing Seats
  - Scaling and disintegration of concrete bearings seats;
  - Spalling and exposed reinforcing;
  - Cracks through or under concrete bearing seats;
  - Deterioration of masonry or wood bearing seats;
  - Crushing of wood bearing seats;
  - Accumulation of debris and salt deposits on bearing seats under deck expansion joints.

The following performance related defects in substructure components may indicate movement of the substructure, loss of strength or loss of support for imposed loadings:

  - **Loss of strength or support for applied loads due to material defects;**
  - **Loss of material supporting foundations due to scour or erosion;**
  - **Consolidation or failure of underlying soil resulting in cracking or movement of foundations, abutments or piers;**
  - **Unusual or unexpected substructure movements occurring during the passage of heavy vehicles over the bridge;**
  - **Inability of the walls to withstand lateral earth pressures, as indicated by long, medium horizontal cracks in walls;**
  - **Loss of contact between piles and pile cap or pier cap;**
  - **Changes in the inclination of piles.**
  - **Rotational movement of pile caps and loss of full contact with piles.**

Indications of foundation movements are often not directly visible as most foundations are buried; however, foundation movements are reflected by the resulting defects in other components of the structure, such as:

- Out of plumb of walls, piles, piers or other components supported on them;
- Tapering or misalignment of cracks and joints in foundations, walls, piers or other components supported on them;
- Sudden drops or kinks in the structure profile over piers or walls when sighting along railings, beam or curb lines;
- Abnormally large or small openings or misalignment of deck expansion joints at abutments and piers;
- Abnormal displacements or inclinations of bearings;
- Abnormally large or small clearance between ballast wall and superstructure;
- Cracks in ballast wall.

It is important to determine if the movement has stabilized, as indicated by the rate of movement; and, to determine the effect of the movement on the component itself and on other components.

If it is evident that movement has occurred, then the following measurements should be recorded and compared with previous readings to establish the rate of movement:

- Foundation elevations and locations where possible;
- Pier and wall elevations, inclinations and their locations;
- Crack widths.

Where performance defects are suspected in foundations, walls, pier shafts and columns located in water, an underwater investigation should be requested.

The inspector shall also inspect the retaining walls and wingwalls for the following:

- length and height of the walls to ensure that they are adequate to prevent spills over the walls or around the ends of the walls;
- scour or erosion in front, behind or around the ends of walls.

Guidelines to assist the inspector in the condition rating of material and performance related defects in substructure components are given in Table A3. Guidelines for performance related defects are listed in bold face type. The guidelines given in Table A3 are in addition to the general guidelines given in Part 2, Section 2.

A3.1.2 Examples of Defects and Ratings of Substructure Components

Typical examples of defects of substructure components are shown in Figures A3.1.2(a) to A3.1.2(u). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating signed shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Rating	Observed Material and Performance Defects
6	• **No observed material or performance related defects.**
5	• **Previous movement appears to have stabilized and has not affected the performance of the component or any other component;** • **Slight loss in the strength of the component due to material defects;** • **Up to 5% loss of bearing seat area.** • Hairline cracks in reinforced concrete columns or pier caps; • Narrow cracks in reinforced concrete foundations, walls or pier shafts; • Medium cracks in mass concrete footings, walls or pier shafts; • A few cross bracing members in pile bents cracked or loose; • Light corrosion of wires in gabions; • Light deterioration of bag mortar; • Wall drains are partially plugged.
4	• **Previous movement appears to have stabilized but may have affected the performance of the component or other components to a minor extent;** • **Minor loss in the strength of the component due to material defects;** • **5% to 10% loss of bearing seat area.** • Narrow cracks in reinforced concrete columns or pier caps; • Medium cracks in reinforced concrete foundations, walls or pier shafts; • A few wide cracks in mass concrete footings, walls or pier shafts; • Many cross bracing members in pile bents cracked or loose; • Medium corrosion and broken wires in gabions; • Medium deterioration of bag mortar; • Numerous wall drains plugged.
3	• **Continuing movement that may have affected the performance of the component or other components to a minor degree;** • **Significant loss in the strength of the component due to material defects;** • **10% to 15% loss of bearing seat area.** • Medium cracks in reinforced concrete columns or pier caps; • Wide cracks in reinforced concrete foundations, walls or pier shafts; • Many wide cracks in mass concrete footings, walls or pier shafts; • A few cross bracing members in pile bents broken or missing; • Many wires broken in gabions with small loss of stone; • Severe deterioration of bag mortar.
2	• **Continuing movement that may have significantly affected the performance of the component or other components, and may have significantly affected the stability of the structure;** • **Severe loss in the strength of the component due to material defects;** • **15% to 20% loss of bearing seat area.** • A few wide cracks in reinforced concrete columns or pier caps; • Many wide cracks in reinforced concrete foundations, walls or pier shafts; • A few wide cracks, greater than 3 mm, in mass concrete footings, walls or pier shafts; • Many cross bracing members in pile bents broken or missing; • Many wires broken gabions with loss of some stone; • Very severe deterioration of bag mortar, several missing.
1	• **Continuing movement that may have critically affected the performance of the component or other components, and may have critically affected the stability of the structure;** • **Critical loss in the strength of the component due to material defects;** • **Over 20% loss of bearing seat area.** • Many wide cracks in reinforced concrete columns or pier caps; • A few wide cracks, greater than 3 mm, in reinforced concrete foundations, walls or pier shafts; • Many wide cracks, greater than 3 mm, in mass concrete footings, walls or pier shafts; • A pile broken in a pile bent; • Many wires broken in gabions with loss of many stones; • Many bags of mortar missing.

Table A3 Condition Rating of Substructure Components
Guidelines for performance related defects are listed in bold face type.

Figure A3.1.2(a) Foundation

MCR 5	–	Less than 5% loss of cross-section.
PCR 6	–	No apparent visible movement of footing, abutment or superstructure. Loss of section not affecting foundation capacity.
PC C	–	Type of repair required, although minor, not suited to annual maintenance.

Figure A3.1.2(b) Foundation

MCR	–	Foundation not visible.
PCR 4	–	Previous settlement of wingwall appears to have stabilized.
PC D	–	No recommended repairs at this time.

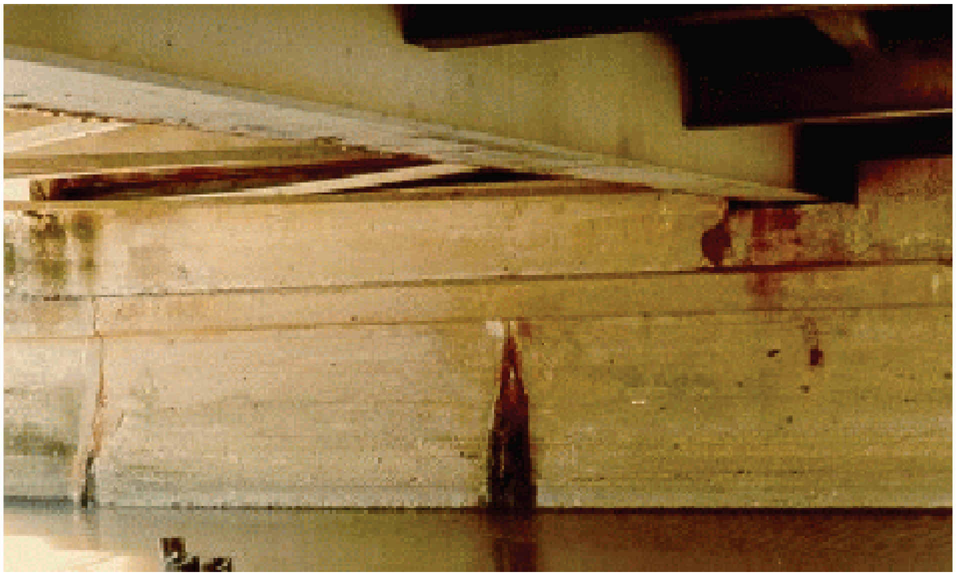

Figure A3.1.2(c) Foundation

MCR – Foundation not visible.
PCR 4 – Foundation movement appears to have stabilized. It has produced wide cracks in abutment but does not appear to have affected the stability of the abutment.
PC D – Monitor crack width using instrumentation techniques.

Figure A3.1.2(d) Foundation

MCR – Foundation not visible.
PCR 2 – Continuing increasing movement of foundation has affected stability of the pier and the superstructure.
PC S – Underwater inspection and geotechnical investigation required.

Figure A3.1.2(e) Concrete Abutment Wall

MCR 2 – Numerous medium cracks and several wide cracks with penetration of water through wall and efflorescence.
PCR 5 – Deterioration present may reduce the strength of the wall to a minor degree.
PC D – Repairs likely to be cosmetic only. Face wall if aesthetics important at particular site.

Figure A3.1.2(f) Wood Lagging – Abutment Wall

MCR 5 – Light weathering of wood.
PCR 5 – Slight movement of piles and lagging which appears to have stabilized, and with no apparent significant effect on other components.
PC D – No recommended repairs at this time.

Figure A3.1.2(g) Wood Crib – Abutment Wall

MCR 1 – Very severe crushing and splintering of wood.
PCR 1 – Continuing increasing movement and a loss of strength affecting the stability of the structure.
PC A – Monitor closely until repairs carried out.

Figure A3.1.2(h) Masonry Abutment Wall

MCR 4 – Medium loss of mortar.
PCR 6 – Wall appears to be satisfactorily supporting superstructure loads.
PC C – Repairs to mortar should prevent performance related defects.

Figure A3.1.2(i) Concrete Pier Column

MCR 2	–	Very severe delamination and spalling over 15% of the column, with exposed reinforcement.
PCR 4	–	Deterioration results in minor loss in strength of component.
PC B	–	Performance reduction will increase as corrosion of reinforcing steel continues.

Figure A3.1.2(j) Concrete Pier Cap

MCR 2	–	Very severe spalling and corrosion of exposed reinforcement.
PCR 5	–	Minor loss in capacity due to material defects.
PC B	–	Deterioration would be slowed dramatically by resealing joint above.

Figure A3.1.2(k) Steel Pier Bent Base

MCR 4 – Medium corrosion; 5% to 10% loss of section locally.
PCR 5 – Component capacity marginally affected by loss of section.
PC B – Refinishing may prevent further loss of section.

Figure A3.1.2(l) Wood Trestle

MCR 5 – Light decay in piles.
PCR 6 – No apparent evidence of movement. Piles satisfactorily supporting load without distress.
PC D – No recommended repairs at this time.

Figure A3.1.2(m) Masonry Pier

MCR 4 – Medium crack in stone.
PCR 5 – Previous movement appears to have stabilized.
PC D – No recommended repairs at this time.

Figure A3.1.2(n) Concrete Wingwall

MCR 5 – Narrow cracking with efflorescence.
PCR 6 – No apparent evidence of movement. Wall is satisfactorily retaining backfill.
PC D – Repairs likely to be cosmetic only. Face wall of aesthetically important at particular site.

Figure A3.1.2(o) Concrete Wingwall

MCR 1 – Very severe erosion and over 40% loss of cross-section.
PCR 1 – Very severe section loss and apparent continuing movement may critically affect the strength and stability of the wall.
PC U – Ensure that severe load restrictions are imposed on approaches. Monitor closely until temporary shoring in place.

Figure A3.1.2(p) Concrete Ballast Walls

MCR 5 – Light surface scaling.
PCR 6 – No performance defects.
PC D – No repairs recommended at this time.

Figure A3.1.2(q) Concrete Ballast Wall

MCR 2 – Very severe delamination, spalling and corrosion of exposed reinforcement.
PCR 3 – Continuing movement. Loss of section may moderately affect the capacity of wall to retain backfill.
PC B – Monitor closely until repaired.

Figure A3.1.2(r) Precast Concrete Retaining Wall

MCR 3 – Severe Cracking of Precast Units.
PCR 6 – No apparent evidence of movement. Wall satisfactorily retaining fill.
PC D – No repairs recommended at this time.

Figure A3.1.2(s) Bag Mortar Retaining Wall

MCR 5 – Minor loss of material at the joints.
PCR 5 – A few locations of local minor movement. Wall satisfactorily retaining fill.
PC M – Vegetation growth should be removed as part of routine annual maintenance.

Figure A3.1.2(t) Concrete Bearing Seats

MCR 4 – Medium cracking under the bearing seat.
PCR 6 – No loss of bearing area.
PC D – No loss of performance.

Figure A3.1.2(u) Concrete Bearing Seat

MCR 2 – Very severe disintegration of concrete.
PCR 3 – Less than 10% loss of bearing area.
PC C – Expansion joint repairs will slow further deterioration.

SECTION A4 – BEARINGS

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A4.1 Bearings

The inspector should note if routine annual maintenance of the bearings and the area around the bearings has been carried out. This includes the cleaning of the debris, vegetation growth, etc. and washing down of salt deposits.

A4.1.1 Condition Rating of Bearings

The inspector shall determine and record the location and extent of material and performance related defects described in Part 1, Sections 2 and 6. In addition, the following performance related defects (shown in bold type) and defects in other materials used in the bearings shall be inspected with particular care.

- **binding or jamming of expansion or rotational components due to corrosion, lack of lubrication or damage to sliding surfaces;**
- **observed movements are within the limit or capacity of the bearing;**
- **sufficient allowance for further anticipated movement;**
- **proper relative position of the upper and lower bearing surfaces according to the surrounding air temperature;**
- **movements causing distress in the bearing or its components, or in other structure components;**
- **complete and uniform contact of bearing surfaces with each other and with the superstructure and bearing seat;**
- **local or global overloading of bearing such as excessive bulging or compression of elastomeric pads or flattening of rollers;**
- **shift in alignment from original position;**
- adequate lubrication where required;
- cracked or broken parts or plates;
- loose or missing assembly pins, bolts or nuts;
- bent, loose or missing anchor bolts or pins;
- worn pins, rollers, rockers or rolling surfaces;
- electrolytic corrosion of dissimilar materials in contact such as steel and aluminum or steel and bronze;
- cracks, splits or tears in elastomeric pads;
- elastomer leaking out of pots in pot bearings;
- scored TFE surfaces;
- scratched or damaged stainless steel surfaces;
- pulled out sliding plates;
- cracking or spalling of grout pads and pedestals.

SECTION A4 – BEARINGS

Guidelines to assist the inspector in the rating of observed material and performance related defects in bearings are given in Table A4. Guidelines for performance related defects are listed in boldface type. The guidelines given on Table A4 are in addition to the general guidelines given in Part 2, Section 2.

A4.1.2 Examples of Defects and Ratings of Bearings

Typical examples of defects of bearings are shown in Figures A4.1.2(a) to A4.1.2(h). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating signed shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Rating	Observed Material and Performance Defects
6	• **No observed material or performance related defects.**
5	• **Bearing is capable of, or allows for, almost the complete movement required;** • **Bearing is not uniformly loaded but there is complete contact over the bearing area;** • **Bearing provides satisfactory support for superstructure under existing loading conditions.** • Hairline cracks in elastomeric pads; • Light scoring or scratches in TFE or stainless steel surfaces; • Light corrosion of steel components; • Anchor bolts are slightly bent; • Guide bars or thrust plates are slightly worn with up to 10% loose or missing nuts.
4	• **A minor amount of required movement is restricted by the bearing;** • **Bearing is not uniformly loaded with loss of contact at one corner;** • **Local bulging or flattening of bearing materials;** • **Bearing provides adequate support for superstructure under existing loading conditions.** • Medium cracks, or debonding of casing in elastomeric pads; • Medium scoring or scratches in TFE or stainless steel surfaces; • Medium corrosion of steel components; • Anchor bolts are severely bent; • Guide bars or thrust plates are moderately worn with 10% to 20% loose or missing nuts; • Up to 10% of bonded sliding surfaces debonded.
3	• **A significant amount of required movement is restricted by the bearing;** • **Bearing is not uniformly loaded with loss of contact over up to half the bearing area;** • **Severe bulging or flattening of bearing materials;** • **Bearing has moved from stable position or has deteriorated but provides fair support for the superstructure under existing loading conditions.** • Wide cracks in elastomeric pads; • Severe scoring or scratches in TFE or stainless steel surfaces; • Severe corrosion of steel components; • Anchor bolts are severely bent and cracked; • Guide bars or thrust plates are severely worn with 20% to 30% loose or missing nuts; • 10% to 20% of bonded sliding surfaces debonded.
2	• **Required movements are very severely restricted at the bearing;** • **Bearing is not uniformly loaded with loss of contact over more than half the bearing area;** • **Very severe bulging, flattening or crushing of bearing materials;** • **Bearing has moved from stable position or has deteriorated, with possible danger of loss of support for the superstructure.** • Very wide cracks in elastomeric pads; • Very severe scoring or scratches in TFE or stainless steel surfaces; • Very severe corrosion of steel components; • Up to 50% of anchor bolts are broken; • Guide bars or thrust plates are very severely worn with 30% to 40% loose or missing nuts; • 20% to 30% of bonded sliding surfaces debonded; • Internally confined compression/sliding material is squeezing out.

Rating	Observed Material and Performance Defects
1	• **Bearing is not capable of providing for any required movement;** • **Bearing is not uniformly loaded with loss of contact over almost all the bearing area;** • **Almost complete bulging, flattening or crushing of bearing materials;** • **Bearing is unstable or had deteriorated and is in imminent danger of tipping over, falling off the bearing seat or loss of support for the superstructure.** • Very wide cracks in elastomeric pads. Internal steel plates debonded; • TFE or stainless steel ripped or torn; • Very severe corrosion and delamination of steel components. Steel components are cracked; • More than 50% of anchor bolts are broken; • Guide bars or thrust plates are very severely worn with more than 40% loose or missing nuts; • 30% to 40% of bonded sliding surfaces debonded; • Internally confined compression/sliding material has squeezed out.

Table A4 Condition Rating of Bearings
Guidelines for performance related defects are listed in bold face type.

Figure A4.1.2(a) Steel Plate Sliding Bearing

MCR 5 – Light rusting.
PCR 3 – Anchor bolts near end of travel in slots of base plate. Minor allowance for further expansion of superstructure. Cleaning of debris around bearing required.
PC D – Monitor movement on a semi-annual basis.

Figure A4.1.2(b) TFE Elastomeric Bearing

MCR 3 – Anchor bolts severely bent.
PCR 2 – Movement of structure not adequately restrained with elastomer being squeezed out.
PC B – Other girders provide some additional restraint.

Figure A4.1.2(c) Laminated Elastomeric Bearing

MCR 4 – Medium cracks in elastomeric pad.
PCR 4 – Local bulging of elastomeric pad.
PC D – Surface defects only at this time.

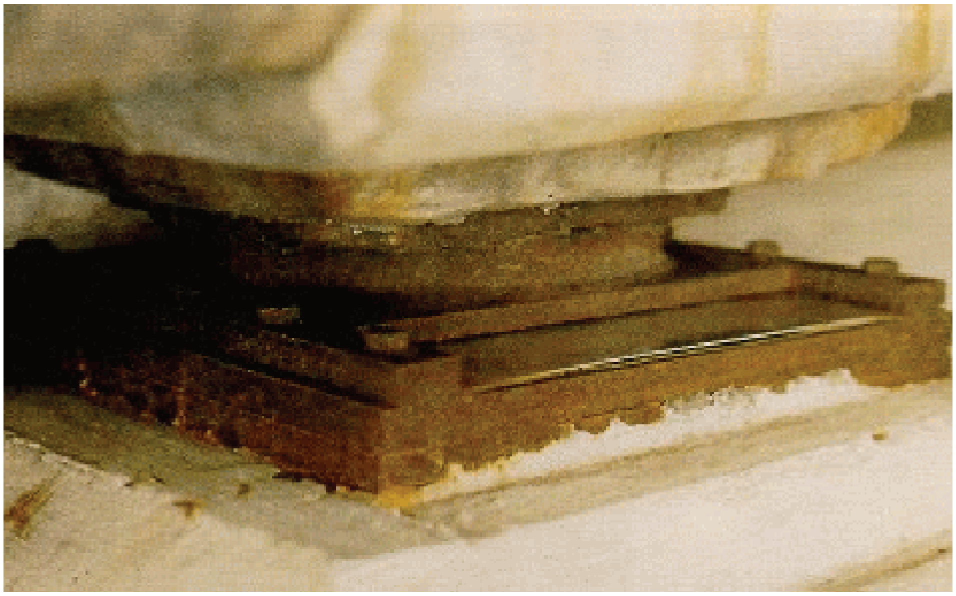

Figure A4.1.2(d) Disc Bearing

MCR 4 – Light rusting and stainless steel sliding plate is separating.
PCR 5 – Movement capacity slightly affected.
P.C. D – Monitor movement semi-annually. Movement range provided may be excessive.

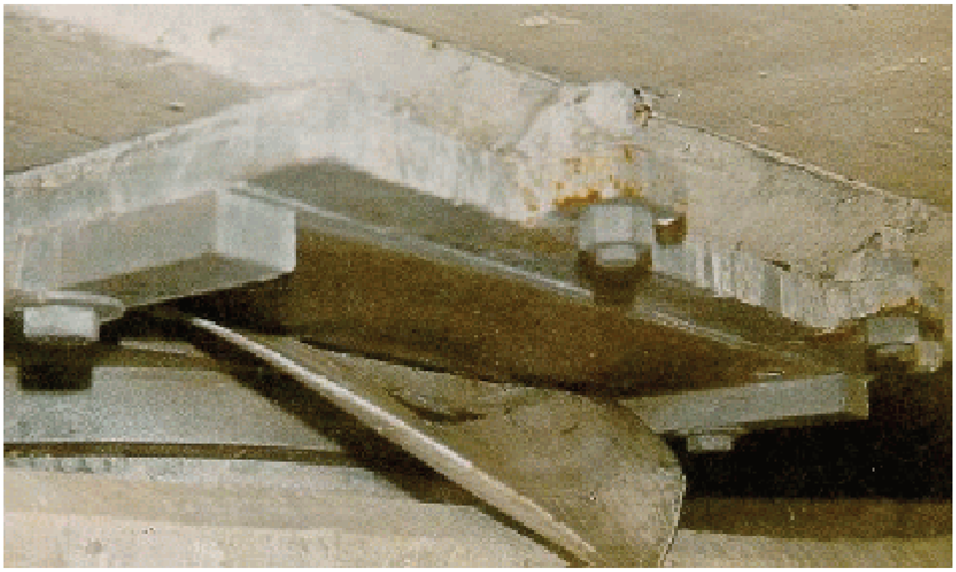

Figure A4.1.2.(e) Pot Bearing

MCR 1 – TFE squeezed out.
PCR 2 – Almost complete loss of sliding capability.
PC A – Primary components may be influenced by bearing restraint.

Figure A4.1.2(f) Steel Rocker Bearing

MCR 5 – Light corrosion.
PCR 2 – Rocker should be tilting toward the ballast wall based upon temperature of 20E C at the time of inspection. Rocker in danger of falling over during colder weather.
PC A – Monitor bearings movement until repaired.

Figure A4.1.2(g) Steel Rocker Bearing

MCR 6 – No material defects.
PCR 1 – Bearing in danger of collapse.
PC U – Monitor movement closely until repaired.

Figure A4.1.2(h) Roller Bearing

MCR 2 – Very severe corrosion.
PCR 1 – Rollers frozen. No capability for movement.
PC A – Primary components may be influenced by bearing restraint.

SECTION A5 – JOINTS

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A5.1 Joints

The inspector shall determine and subsequently record whether or not routine annual maintenance of the joint and the area around the joint has been carried out. This includes the cleaning out of salt, sand, dirt, stones, vegetation and any other debris from the joint.

A5.1.1 Condition Rating of Joints

The inspector shall determine and record the location and extent of material and performance related defects in the components of joints as outlined in Part 1, Sections 2 and 7. In addition, the following performance related defects (shown in bold type) and defects in other materials used in the joint, shall be considered.

- **vertical or horizontal misalignment across the joint;**
- **inadequate joint gap to accommodate anticipated further movement;**
- **surfacing materials have jammed in the joints during resurfacing of deck;**
- **material defects or construction problems resulting in leakage of the joint;**
- **deterioration of components below the joint due to joint leakage;**
- **design or construction problems not allowing proper movement of multi-seal joints.**
- **nonexistent or inadequate treatment of surface run-off through open joints;**
- pulling away or popping out of the seal or sealant;
- cracks, splits, tears or holes in the seal or sealant;
- loose or missing sections of the seal or sealant;
- abrasion, wear or ageing of the seal or sealant;
- compression set or loss of resiliency of the seal or sealant;
- loss of bond between the seal or sealant and the adjacent pavement;
- shrinking away of the sealant from the adjacent pavement;
- loose, broken or missing bolts, nuts, washers or other anchorage devices;
- loose, bent, cracked, broken, missing or damaged finger plates, sliding plates, extrusions, support components or armouring;
- cracking of welds and welded connections;
- cracking, spalling or breaking up of the concrete, asphalt, or other material adjacent to the joint;
- softening or shifting of mastic asphaltic materials.

Guidelines to assist the inspector in the rating of observed material and performance related defects in joints are given in Table A5. Guidelines for Performance related defects are listed in boldface type. The guidelines given on Table A5 are in addition to the general guidelines given in Part 2, Section 2.

A5.1.2 Priority Code for Repairs to Joints

Expansion joint systems are highly susceptible to damage, wear, and improper fabrication and placement techniques. Consequently, these systems have a history of performing inadequately.

The guidelines, given in Table A5 for assessing the condition rating of expansion joint systems, indicate that a condition rating of 1 should be applied to a joint assembly that is leaking over more than 20% of its length. In light of the above, it can be expected that, in general, joint systems will, most likely, have very low condition ratings.

The inspector shall consider carefully the potential for material and performance related defects of other components arising from leaking expansion joints in assigning the priority code rating to expansion joints. Repairs to expansion joints in areas where significant amounts of salt are used may be considered to be of higher priority than similar repairs in regions where salt is not used.

Replacement or modification of open joint systems shall also be treated in a similar manner. Where surface run-off water is poorly channelled away from components below the joint, and there is significant potential for deterioration of surrounding components, (i.e. high salt concentrations, structural steel components, poor cover to reinforcing steel in reinforced concrete components, etc.) replacement or modifications to open joint systems may be given a relatively high priority.

A5.1.3 Examples of Defects and Ratings of Joints

Typical examples of defects of joints are shown in Figures A5.1.3(a) to A5.1.3(g). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating signed shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Rating	Observed Material and Performance Defects
6	• No observed material or performance related defects.
5	• **Sealed joint is leaking over up to 5% of the joint length;** • **Unsealed joint with good treatment of surface run-off and minimal potential for defects in components below open joint;** • **Defects in armouring not affecting traffic safety over the joint;** • **Minor misalignment of the joint not affecting traffic safety across the joint.** • Cracks, splits, tears, holes or abrasions in up to 5% of the length of seal or sealants; • Seal or sealant debonded, pulled out or settled for up to 5% of the joint length; • Bolts, anchors, clamping devices or welds are loose, broken or missing over up to 5% of the joint length; • Slight defects and deterioration of the concrete end dams or pavement adjacent to the joint.
4	• **Sealed joint is leaking over 10% to 15% of the joint length;** • **Unsealed joints with fair treatment of surface run-off through joint or light material defects in components below open joint;** • **Defects in armouring which has a minimum effect on traffic ride and safety across the joint;** • **Significant misalignment of the joint which slightly affects traffic ride across the joint.** • Cracks, splits, tears, holes or abrasions in 5% to 10% of the length of the seal or sealants; • Seal or sealant is debonded, pulled out or settled over 5% to 10% of the joint length; • Bolts, anchors, clamping devices or welds are loose, broken or missing over to 5% to 10% of the joint length; • A few areas of medium defects or deterioration of the concrete end dams or pavement adjacent to the joint.

Rating	Observed Material and Performance Defects
3	• **Sealed joint is leaking over 15% to 20% of the joint length;** • **Unsealed joints with poor treatment of surface run-off through joint or medium material defects in components below open joint;** • **Defects in armouring which significantly affects traffic ride and safety across the joint;** • **Severe misalignment of the joint which significantly affects traffic ride across the joint.** • Cracks, splits, tears, holes or abrasions in 10% to 15% of the length of the seal or sealants; • Seal or sealant is de-bonded, pulled out or settled over 10% to 15% of the joint length; • Bolts, anchors, clamping devices or welds are loose, broken or missing over 10% to 15% of the joint length; • Numerous areas of medium defects or deterioration of the concrete end dams or pavement adjacent to the joint.
2	• **Required movements are very severely restricted at the joint;** • **Sealed joint is leaking over 15% to 20% of the joint length;** • **Unsealed joints with inadequate treatment of surface run-off through joint or severe material defects in components below open joint.** • **Defects in armouring which present a hazard to traffic safety across the joint;** • **Very severe mis-alignment of the joint which presents a hazard to traffic safety across the joint.** • Cracks, splits, tears, holes or abrasions in 15% to 20% of the length of the seal or sealants; • Seal or sealant is de-bonded, pulled out or settled over 15% to 20% of the joint length; • Bolts, anchors, clamping devices or welds are loose, broken or missing over 15% to 20% of the joint length; • Severe defects and deterioration of the concrete end dams or pavement adjacent to the joint.
1	• **Joint is jammed and not capable of providing any movement;** • **Sealed joint is leaking over more than 20% of the joint length;** • **Unsealed joints with critically inadequate treatment of surface run-off through joint or very severe material defects in components below open joint;** • **Defects in armouring which pose a danger to traffic safety;** • **Joint misalignment poses a dangerous threat to traffic safety.** • Cracks, splits, tears, holes or abrasions in over 20% of the length of the seal or sealants; • Seal or sealant is de-bonded, pulled out or settled over more than 20% of the joint length; • Bolts, anchors, clamping devices or welds are loose, broken or missing in over 20% of the joint length; • Very severe defects and deterioration of the concrete end dams or pavement adjacent to the joint.

Table A5 Condition Rating of Joints
Guidelines for performance related defects are listed in bold face type.

Figure A5.1.3(a) Finger Plate Expansion Joint

MCR 5 – Light rust.
PCR 1 – No room for further expansion, joint alignment poses danger to traffic.
PC B – Primary components performance altered by restricted movement.

Figure A5.1.3(b) Compression Seal Joint

MCR 1 – Seal popping out and cracked over 30% to 40% of joint length.
PCR 1 – Seal leaking over more than 40% of the joint length.
PC B – Priority rating dependent on potential for deterioration of surrounding components arising from leakage.

Figure A5.1.3(c) Paved-Over Joint

MCR 3 – Significant cracking of asphalt pavement.
PCR 1 – Joint is leaking over full length. Rough ride across joint.
PC C – Priority rating dependent on potential for deterioration of surrounding components arising from leakage.

Figure A5.1.3(d) Ethylene Vinyl Acetate Seal

MCR 5 – Light cracking of foam seal.
PCR 4 – Minor leakage over less than 10% of joint length.
PC D – Priority rating dependent on potential for deterioration of surrounding components arising from leakage.

Figure A5.1.3(e) Multiple Seal Joint

MCR 1 – Seal torn over 30% to 40% of joint.
PCR 1 – Leaking over 30% to 40% of joint.
PC C – Priority rating dependent on potential for deterioration of surrounding components arising from leakage.

Figure A5.1.3(f) Rubber Cushion Joint

MCR 4 – Rubber damaged over up to 10% of the joint.
PCR 2 – Leaking over up to 20% of the length of the joint.
PC D – Priority rating dependent on potential for deterioration of surrounding components arising from leakage.

Figure A5.1.3(g) Horizontally Bolted Seal

MCR 5	–	Light abrasion of the seal due to debris.
PCR 2	–	Deck movement severely restricted by debris.
PC M	–	Debris should be cleared as part of routine annual maintenance.

SECTION A6 – SUPERSTRUCTURES

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A6.1 Superstructure Components

The inspector should note if the routine annual maintenance of the superstructure components has been carried out. This includes the cleaning of debris, vegetation growth, etc. and washing down of salt deposits.

The inspector shall note and record on the structure drawings and in the inspection record/file the location of all fatigue prone details and fracture critical steel components, unless already previously identified and recorded.

A6.1.1 Condition Ratings of Superstructure Components

The inspector shall determine the location and extent of material defects as outlined in Part 1, Sections 2 and 8. The following material defects and performance related defects (shown in bold type) shall be inspected with particular care:

- **material defects leading to loss of section and strength, or which are indicative of inadequate strength of the component;**
- **detrimental modifications made subsequent to construction;**
- **misalignment, lateral deformation, warping, etc. of components;**
- **unanticipated or excessive vibration or deflection of components or connections under live loads;**
- **unanticipated movement at joints or connections between components;**
- **inadequate provision for the expansion or contraction of components;**
- **permanent deformations, especially in compression components;**
- **deformation of soil-steel structures such as flattening or peaking of the soffit or buckling of the shoulders or haunches;**
- **uplift of the ends of soil-steel structures;**
- **loss of fill behind the barrel walls of soil-steel structures;**
- **depressions and cracks in the roadway pavement above culverts and soil-steel structures;**
- **deformation of the roof slab, floor slab or walls of wood or concrete culverts;**
- **unexpected noise from components or connections under live load;**
- cracks in any material;
- quality of welds in fatigue prone and fracture critical details and components;
- cracking, spalling and corrosion of prestressing in prestressed concrete;
- water seepage through cracks with staining and surface deposits;
- cracks at welds, fatigue prone details, and in fracture critical components;
- deterioration of components at construction and expansion joints;
- loose or deformed component;
- loose, worn or missing bolts, rivets, or pins;
- deformations in riveted or bolted built-up sections due to corrosion forces;

- crushing and decay of wood components at bearing surfaces;
- loose bridging between wood stringers;
- detrimental modifications made subsequent to construction;
- deterioration of components under expansion joints;
- deterioration of components at pockets, connections and other details on which debris and salt deposits can accumulate;
- deterioration of components, alongside and above the roadway, which are susceptible to salt splash and spray;
- components accessible to direct hits by vehicles;
- plugged void drain holes;
- the condition inside box girders, at girder ends under expansion joints, and where water is entering through holes in diaphragms or cracks in the deck;
- the condition of stay-in-place steel forms, and the condition of the deck soffit where the forms have corroded;
- construction formwork or debris left inside box girders;
- areas where birds may be building nests: inside box girders, at connections in trusses and arches, at piers and abutments, and at diaphragms and bottom flanges of beams and girders;
- accident damage by vehicular impact;
- bailey bridge transoms not seated over the lugs and transom clamps not tight and not prevented from loosening;
- cracks in seating plates for transoms;
- bailey bridge end transoms not supported at intermediate points;
- bailey bridge end post pins not inserted;
- bailey bridge end posts not fully engaged on the bearings;
- loss of joint filler, open joints or cracks in culverts and soil-steel structures allowing ingress of water and fill;
- deterioration of drift pins in wood culverts;
- local crimping or buckling of corrugations in soil-steel structures;
- cracks or tearing at or along lines of fasteners in soil-steel structures;
- opening of lockseam joints or mechanical couplers in corrugated steel pipe.

Guidelines to assist the inspector in the condition rating of material and performance related defects in superstructure components are given in Table A6. Guidelines for performance related defects are listed in bold face type. The guidelines given on Table A6 are in addition to the general guidelines given in Part 2, Section 2.

A6.1.2 Examples of Defects and Ratings of Superstructure Components

Typical examples of defects of superstructures are shown in Figures A6.1.2(a) to A6.1.2(r). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating assigned shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Rating	Observed Material and Performance Defects
6	• No observed material or performance related defects.
5	• **Defects or deficiencies in a component, or modifications made to a component, which may reduce its capacity to safely carry applied loading, by up to 5%;** • **Deformations up to 1% of the span length in the soffit, haunches, shoulders or walls of soil-steel structures;** • **Slight noise from components when heavy truck crosses the structure.** • Hairline flexural or axial cracks in concrete components; • Narrow longitudinal or pattern cracks in concrete components, with light rust staining; • Medium vertical or transverse settlement cracks up to 0.5 mm in concrete culverts; • Crimping of corrugations over up to 5% of the length of soil-steel structures; • Pin-point rusting over the surface of soil-steel structures; Pin holes outside traveled roadway (up to 2% of area); • Gaps up to 1 mm wide between components in wood culverts.
4	• **Defects or deficiencies in a component, or modifications made to a component, which may reduce its capacity to safely carry applied loading, by 5% to 10%;** • **Deformations of 1% to 2% of the span length in the soffit, haunches, shoulders or walls of soil-steel structures;** • **Noticeable noise from components when heavy trucks cross structure.** • Narrow flexural or axial cracks, or hairline shear cracks propagating to ½ the height or depth of concrete components; • A few medium longitudinal or pattern cracks up to 1 mm in concrete components, with rust staining; • Medium vertical or transverse settlement cracks up to 1 mm in concrete culverts; • Hairline cracks at fastener locations or crimping of corrugations over 5% to 10% of the length of soil-steel structures; • Galvanizing worn off with light corrosion over the surface of soil-steel structures; Pinholes limited to less than 8 % of area; • Gaps up to 2 mm wide between components in wood culverts.
3	• **Defects or deficiencies in a component, or modifications made to a component, which may reduce its capacity to safely carry applied loading, by 10% to 15%;** • **Deformations of 2% to 3% of the span length in the soffit, haunches, shoulders or walls of soil-steel structures;** • **Loud noise from components when light trucks cross the structure.** • Medium flexural or axial cracks, or narrow shear cracks propagating to ¾ the height or depth of concrete components; • A few wide longitudinal or pattern cracks up to 2 mm in concrete components, with delamination in a few locations; • Wide vertical or transverse settlement cracks up to 2 mm in concrete culverts; • Narrow cracks at fastener locations, or severe crimping of corrugations, over 10% to 15% of the length of soil-steel structures; • Shallow pitting and corrosion scale over the surface of soil-steel structures, local perforations in invert; • Gaps up to 3 mm wide between components in wood culverts.

Rating	Observed Material and Performance Defects
2	• **Defects or deficiencies in a component, or modifications made to a component, which may reduce its capacity to safely carry applied loading, by 15% to 20%;** • **Deformations of more than 3% of the span length in the soffit, haunches, shoulders or walls of soil-steel structures;** • **Loud noise from components when light trucks cross the structure.** • Wide flexural or axial cracks up to 2 mm occurring with medium shear cracks in concrete components; • A few wide longitudinal or pattern cracks up to 3 mm in concrete components, with delamination and spalling at several locations; • Wide vertical or transverse settlement cracks up to 3 mm in concrete culverts; • Medium cracks at fastener locations, or severe crimping of corrugations, over 15% to 20% of the length of soil-steel structures; • Deep pitting, heavy corrosion scale and local perforations in invert of soil-steel structures (15-25%), Overall thin metal-easy puncture with chipping hammer; • Gaps greater than 3 mm wide between components in wood culverts; • Hairline cracks in steel components.
1	• **Defects or deficiencies in a component, or modifications made to a component, which may reduce its capacity to safely carry applied loading, by more than 20%;** • **Very severe deformations with local collapse of the soffit, haunches, shoulders or walls of soil-steel structures;** • **Loud noise from components when passenger vehicles cross structure;** • **Component is misaligned or has deformations such that it is unstable and is in imminent danger of partial or complete collapse.** • Wide flexural or axial cracks up to 3 mm occurring with wide shear cracks and spalling, in concrete components; • Cracking in pre-stressed concrete with evidence of corrosion of pre-stressing and delamination of concrete; • Wide longitudinal or pattern cracks greater than 3 mm in concrete components, with extensive delamination and spalling of concrete; • Cracks in structural steel components; • Wide vertical or transverse settlement cracks greater than 3 mm wide in concrete culverts; • Wide cracks at fastener locations, or severe crimping of corrugations, over more than 20% of the length of soil-steel structures; • Several locations of complete through corrosion in invert of soil-steel structures (area >25 %); • Wide gaps greater than 3 mm wide between components of wood culverts with complete separation between sections; • Narrow cracks in steel components.

Table A6 Condition Rating of Superstructure Components
Guidelines for performance related defects are listed in bold face type.

Figure A6.1.2(a) Reinforced Concrete Girders

MCR 3 – A few wide longitudinal cracks due to corrosion of reinforcement.
PCR 5 – Cracking has little effect on girder capacity.
PC D – Pronounced corrosion of rebar and spalling may not occur for several years.

Figure A6.1.2(b) Concrete T-Beam

MCR 2 – Full height, medium shear crack.
PCR 4 – Potentially inadequate beam capacity.
PC S – Evaluate shear capacity of T-beam.

Figure A6.1.2 (c) Steel Beam

MCR 2 – Very severe corrosion of web and bottom flange.
PCR 5 – Marginal loss of load carrying capacity.
PC B – Sealing of joint will slow deterioration dramatically.

Figure A6.1.2(d) Rigid Frame, Thick Slab

MCR 4 – Medium longitudinal cracks with water leakage and deposits on soffit.
PCR 6 – No loss of load carrying capacity.
PC D – Repair methods, other than waterproofing, will be largely ineffective.

Figure A6.1.2(e) Thick Slab

MCR 2 – Very severe pattern cracking with severe spalling and exposed corroded reinforcement.
PCR 5 – Material defects result in marginal loss of load carrying capacity.
PC D – Repairs to drain and waterproofing membrane should be given a relatively high priority. Repairs to slab not recommended at this time.

Figure A6.1.2(f) Floor Beam of Steel Through Truss

MCR 2 – Very severe corrosion with perforation of floor beam web.
PCR 1 – More than 20% loss of strength of floor beam.
PC B – Monitor web closely until repairs carried out.

Figure A6.1.2(g) Vertical Member of Steel Through Truss

MCR 2 – 15% to 20% of cross section removed to install guide rail.
PCR 1 – Over 20% loss of load carrying capacity due to loss of section, and subsequent buckling.
PC A – Consider load restriction until repairs carried out, monitor closely.

Figure A6.1.2(h) Steel Through Truss Connection

MCR 3 – 10% to 15% loss of cross section through corrosion.
PCR 3 – 10% to 15% loss of load carrying capacity.
PC S – Evaluate structure with reduced section properties. Assign relatively high priority to coating repairs.

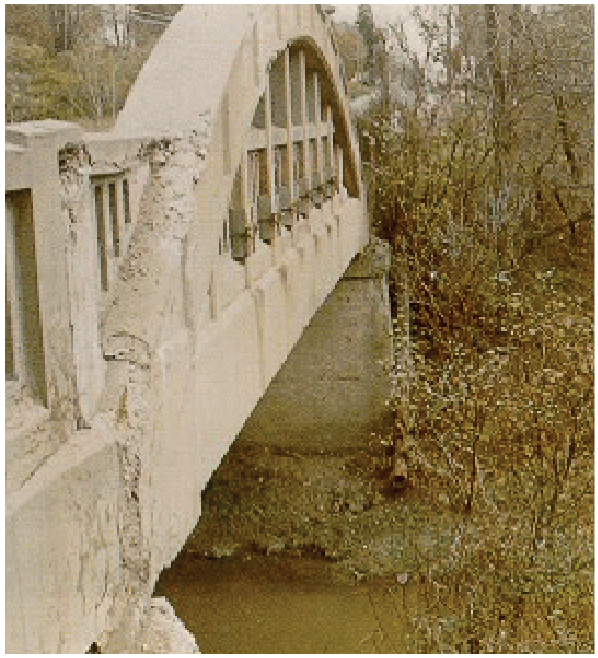

Figure A6.1.2(i) Concrete Bowstring Arch

MCR 2	–	Very severe scaling of arch rib.
PCR 5	–	Marginal loss of performance due to loss of 5% of cross-section.
PC C	–	Marginal loss of performance.

Figure A6.1.2(j) Concrete Spandrel Arch

MCR 2	–	Very wide crack in the arch rib.
PCR 5	–	Crack extends about 100 mm into the rib thus effecting less than 5% of the cross-section.
PC C	–	Marginal loss of performance.

Figure A6.1.2(k) Concrete Open Footing Culvert

MCR 5 – Light deterioration of concrete.
PCR 6 – Culvert supporting fill adequately.
PC M – Heavy vegetation growth should be cleared.

Figure A6.1.2(l) Multi-plate Pipe Arch

MCR 2 – Severe crimping of corrugations over 20% of the length of the structure.
PCR 3 – Possible indequate capacity to support applied loading.
PC S – Structure Evaluation necessary.

Figure A6.1.2(m) Multi-plate Pipe Arch

MCR 1 – Wide cracks along bolt line in the valley corrugations of the haunch lap joint.
PCR 2 – Severe local deformation has occurred. Present strength is just adequate, but local or general collapse of the pipe may occur suddenly.
PC A – Monitor closely until repairs/replacement carried out.

Figure A6.1.2(n) Wood Culvert

MCR 1 – Walls breaking up and soil entering into the waterway. Washout of fill behind the walls.
PCR 1 – Severe sway and continuing movement of the walls with possible sudden collapse.
PC U – Initiate Emergency Inspection procedures.

Figure A6.1.2(o) **Sway Bracing and Bottom Lateral Bracing**

MCR 5	–	Light corrosion of both bracing systems.
PCR 6	–	Bracings appear to provide satisfactory lateral support.
PC D	–	No recommended repairs to bracing systems at this time. See coating recommendations.

Figure A6.1.2(p) **Bottom Lateral Bracing**

MCR 5	–	Light corrosion over the surfaces of bracing angles.
PCR 6	–	Bracing appears to provide satisfactory lateral support.
PC D	–	No recommended repairs to bracing systems at this time. See coating recommendations.

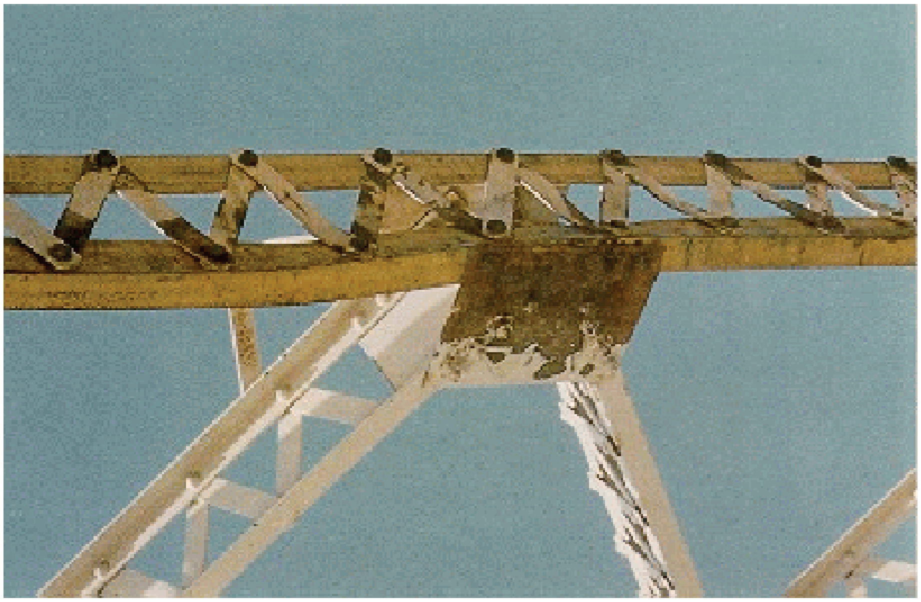

Figure A6.1.2(q) Top Lateral Bracing in Steel Through Truss

MCR 3 – Medium corrosion over 10% to 20% of connection.
PCR 2 – Between 10% to 20% loss of strength and ability to provide lateral support, due to deformation.
PC B – Bracing is secondary member only.

Figure A6.1.2(r) Sway Frame Connection

MCR 3 – Medium corrosion over more than 40% of the connection.
PCR 5 – Up to 10% loss of strength due to corrosion.
PC D – No recommended repairs to sway frame at this time. Relatively high priority should be assigned to recoating.

SECTION A7 – DECK COMPONENTS

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A7.1 Deck Components

The inspector shall determine and record if routine annual maintenance of the deck and wearing surface has been performed.

A7.1.1 Condition Rating of Deck Components

The inspector shall determine and record the extent and location of material and performance related defects as outlined in Part 1, Sections 2 and 9. The following material defects and performance related defects (shown in bold type) shall be inspected with particular care.

- **loss of section or capacity due to material defects;**
- **loss of protection to underlying surfaces due to defects in the wearing surface materials;**
- **loss in riding comfort and potential loss of vehicle control due to defects in the component material;**
- **overloading, either single or repetitive occurrence, resulting in permanent deformations of the deck or deck components.**
- **horizontal, vertical or rotational displacements or improper transitional details in curbs and sidewalks as they are hazardous to pedestrian and vehicular safety, and present obstructions to snow plows**
- **inadequate curb height, or loss of curb height for sidewalks due to the placement of an additional layer of wearing surface or deck overlay;**
- **water ponding on sidewalks, as it presents a safety hazard, especially if allowed to freeze;**
- **rough approaches, settlement or consolidation of approach embankments, or deterioration of the approach slabs or ramps, resulting in vehicles "bouncing" onto the bridge. In addition to applying excessive dynamic loading to the bridge, this may also result in difficulty in maintaining vehicle control;**
- **deck drains not provided where necessary, or have inadequate size of opening;**
- **deck drains and drainage systems improperly constructed with inadequate slopes or sharp directional changes;**
- **drainage system plugged or partially plugged and not allowing for free and unobstructed flow of water;**
- **drainage outlets discharging directly onto structure components or roadways below the deck;**
- **drainage outlets discharging directly onto embankment without proper provision for collecting, channeling and controlling of discharge with splashpads, spillways or gutters;**
- **inadequate provision for drainage at the structure approaches;**

- cracking, delamination and spalling of concrete;
- insufficient cover in reinforced concrete decks as evident where reinforcing is exposed at spalled areas;
- corrosion of reinforcing as evident from rust staining of concrete surfaces;
- deterioration of curbs and sidewalks at expansion joints;
- cracking, ravelling, potholes and breaking up of asphalt surfaces;
- defects in the deck soffit or stay-in-place forms;
- the accumulative elongation of composite steel grating decks resulting from the build-up of corrosion by-products in the individual cells.
- the breaking of welds, components and connections in steel decks;
- deterioration of joint between approach slab and abutment;
- the separation or breakage of the laminations under wheel loads in laminated wood decks;
- deterioration or defects in the anchorages and the condition of exposed prestressing steel bars in prestressed wood decks;
- loose or missing planks or laminations in wood decks and sidewalks;
- nails or spikes protruding out of wood decks;
- build-up of granular fill or debris on decks and sidewalks, particularly on structures with granular approaches;
- deck drain pipes or connections not securely connected or anchored;
- broken drain pipes or connections;
- cracks or holes, except where required, in the drainage system;
- no provision, such as holes in deck drains or drainage tubes, for drainage of the interface between concrete deck slabs and asphalt wearing surfaces.

Where the deck top surface is covered with a wearing surface, the inspector shall rate the condition of the wearing surface and deck soffit, not speculate on the condition of the deck top surface.

Defects in the deck top surface and waterproofing in asphalt covered decks can usually only be determined with some accuracy by the methods detailed in Appendix E, Section 1 – Concrete.

Guidelines to assist the inspector in the condition rating of observed material and performance related defects in deck components are given in Table A7. Guidelines for performance related defects are listed in bold face type. The guidelines given on Table A7 are in addition to the general guidelines given in Part 2, Section 2.

A7.1.2 Examples of Defects and Ratings of Deck Components

Typical examples of defects of deck components are shown in Figures A7.1.2(a) to A7.1.2(r). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating signed shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Rating	Observed Material and Performance Defects
6	• No observed material or performance related defects.
5	• **Deck is satisfactorily carrying and distributing load without distress;** • **Material defects which may have a marginal effect on deck performance;** • **Deck or wearing surface is slightly rough and provides a slightly rough ride.** • **Abrupt vertical or horizontal displacement of curbs and sidewalks up to 10 mm;** • **Sidewalk curb height between 140 mm and 150 mm;** • **Approaches provide a rough or slippery transition onto and off the structure but no difficulty in maintaining vehicle control;** • **Paved approaches have settled up to 10 mm adjacent to the bridge;** • **Granular approaches have settled by up to 20 mm adjacent to the bridge;** • **Suitable drainage provisions have not been provided at one or two locations;** • **Debris in deck drains and drainage system resulting in up to 20% reduction of opening;** • **Slight ponding of water around or between drains or on sidewalks;** • **Slight amount of water or windblown spray is discharged onto structure components;** • **Light erosion of fill or embankment due to drainage discharge;** • **Up to 20% of splash pads, spillways or gutters are incorrectly located or undermined.** • Light localized deterioration over up to 5% of any components.
4	• **Deck is adequately carrying and distributing load with no apparent distress;** • **Material defects which may affect deck performance locally;** • **Deck or wearing surface is uneven producing a rough ride but no difficulty in maintaining vehicle control;** • **Abrupt vertical or horizontal displacement of curbs and sidewalks up to 20 mm;** • **Sidewalk curb height between 130 mm and 140 mm;** • **Approaches provide a rough or slippery transition onto and off the bridge with slight difficulty in maintaining vehicle control;** • **Paved approaches have settled up to 20 mm adjacent to the bridge;** • **Granular approaches have settled by up to 40 mm adjacent to the bridge;** • **Suitable drainage provisions have not been provided at a few locations;** • **Debris in deck drains and drainage system resulting in 20% to 40% reduction of opening;** • **Minor ponding of water around or between drains or on sidewalks;** • **Slight amount of water or windblown spray is discharged onto structure components;** • **Minor erosion of fill or embankment due to drainage discharge;** • **20% to 40% of splash pads, spillways or gutters are incorrectly located or undermined.** • Medium defects over 5% to 10% of any component.
3	• **Some parts of the deck may not be capable of supporting heavy truck wheel loads;** • **Progressive medium to wide cracks with possible local overstress or material defects which affect deck performance;** • **Deck or wearing surface is uneven producing a rough ride with slight difficulty in maintaining vehicle control;** • **A slightly slippery deck or wearing surface;** • **Abrupt vertical or horizontal displacement of curbs and sidewalks up to 30 mm;** • **Sidewalk curb height between 120 mm and 130 mm;** • **Approaches provide a rough or slippery transition onto and off the bridge with marginal difficulty in maintaining vehicle control;** • **Paved approaches have settled up to 30 mm adjacent to the bridge;** • **Granular approaches have settled by up to 60 mm adjacent to the bridge;** • **Suitable drainage provisions have not been provided at several locations;** • **Debris in deck drains and drainage system resulting in 40% to 60% reduction of opening;** • **Significant ponding of water around or between drains or on sidewalks;** • **Significant amount of water or windblown spray is discharged onto structure components;** • **Medium erosion of fill or embankment due to drainage discharge;** • **40% to 60% of splash pads, spillways or gutters are incorrectly located or undermined.** • Medium to severe defects over 10% to 15% of any component.

Rating	Observed Material and Performance Defects
2	• **Some part of the deck may not be capable of supporting truck wheel loads, and in danger of punching through, or failing;** • **Progressive wide cracks with imminent local crushing, spalling or permanent deformation;** • **Deck or wearing surface is irregular producing a rough ride with moderate difficulty in maintaining vehicle control;** • **A moderately slippery deck or wearing surface;** • **Abrupt vertical or horizontal displacement of curbs and sidewalks up to 40 mm;** • **Material defects presenting difficulty for pedestrian passage;** • **Sidewalk curb height between 100 mm and 120 mm;** • **Approaches provide a rough or slippery transition onto and off the bridge with significant difficulty in maintaining vehicle control;** • **Paved approaches have settled up to 40 mm adjacent to the bridge;** • **Granular approaches have settled by up to 80 mm adjacent to the bridge;** • **Suitable drainage provisions have not been provided at many locations;** • **Debris in deck drains and drainage system resulting in 60% to 80% reduction of opening;** • **Severe ponding of water around or between drains or on sidewalks;** • **Substantial amount of water or windblown spray is discharged onto structure components;** • **Severe erosion of fill or embankment due to drainage discharge;** • **60% to 80% of splash pads, spillways or gutters are incorrectly located or undermined.** • Severe defects over 15% to 20% of any component.
1	• **Some part of the deck has punched through or failed;** • **Wide cracks with crushing, spalling or permanent deformations;** • **Deck or wearing surface is irregular producing a rough ride with extreme difficulty in maintaining vehicle control;** • **An extremely slippery deck or wearing surface;** • **Abrupt vertical or horizontal displacement of curbs and sidewalks over 40 mm;** • **Material defects presenting a safety hazard to pedestrians;** • **Sidewalk curb height below 100 mm;** • **Approaches provide a rough or slippery transition onto and off the bridge with extreme difficulty in maintaining vehicle control;** • **Paved approaches have settled by more than 40 mm adjacent to the bridge;** • **Granular approaches have settled by more than 80 mm adjacent to the bridge;** • **No drainage provision has been provided at any required location;** • **Debris in deck drains and drainage system resulting in over 80% reduction of opening;** • **Very severe ponding of water around or between drain or on sidewalk;** • **Outlets discharge directly onto structure components;** • **Very severe erosion of fill or embankment due to drainage discharge;** • **Over 80% of splash pads, spillways or gutters are incorrectly located or undermined.** • Very severe defects over 20% of any component.

Table A7 Condition Rating of Deck Components
Guidelines for performance related defects are listed in bold face type.

Figure A7.1.2(a) Exposed Concrete Deck of a Voided Slab

MCR 4 – Medium longitudinal cracks in deck top surface at the void locations.
PCR 5 – Cracking has a marginal effect on transverse load distribution.
PC D – Repairs not recommended at this time.

Figure A7.1.2(b) Exposed Concrete Deck

MCR 4 – Medium transverse cracks in deck top surface.
PCR 6 – Cracking has no significant effect on the load capacity or load distribution of the deck.
PC D – Repairs not recommended at this time.

Figure A7.1.2(c) Concrete Deck

MCR 4	–	Many locations of medium scaling and surface staining due to corrosion of reinforcement.
PCR 5	–	Deck is satisfactorily carrying load but provides a slightly rough ride around the deck joint.
PC S	–	Consider performing detailed deck condition survey.

Figure A7.1.2(d) Concrete Deck

MCR 3	–	Previously repaired delaminated areas, over 15% of the surface, are delaminating again.
PCR 5	–	Deck provides a slightly rough ride.
PC S	–	Carry out detailed deck condition survey.

Figure A7.1.2(e) **Soffit of a Thin Slab**

MCR 3 – Medium to wide cracks and defects over 10 to 15% of the soffit with local delamination and spalling of concrete over the top flanges of the floor beams and stringers.

PCR 4 – Material defects may affect deck performance locally.

PC S – Consider performing detailed deck condition survey.

Figure A7.1.2(f) **Asphalt Wearing Surface on Laminated Wood Deck**

MCR 1 – Very severe breaking up of the wearing surface with very severe deterioration of the deck laminates in many places.

PCR 2 – Some areas of deck will not support truck wheel loads and wearing surface is irregular, resulting in moderate difficulty in maintaining vehicle control.

PC S – Carry out deck evaluation and develop rehabilitation alternatives.

Figure A7.1.2(g) Concrete Curb

MCR 1 – Very severe spalling over more than 75% of curb length.
PCR 2 – Curb inadequate to prevent vehicles from climbing curb.
PC B – Curb is only secondary component.

Figure A7.1.2(h) Wood Curb

MCR 5 – Insignificant collision damage and deterioration of wood.
PCR 6 – Satisfactory curb height, with no displacements or projections.
PC D – No repairs recommended at this time.

Figure A7.1.2(i) Concrete Sidewalk

MCR 2 – Severe scaling and spalling with exposure of severely corroded reinforcement.
PCR 2 – Sidewalk surface irregular with large spalls and very severe scaling presenting difficulty for pedestrian passage.
PC B – Sidewalk is only secondary component.

Figure A7.1.2(j) Wood Sidewalk

MCR 5 – Light weathering of wood planks.
PCR 5 – Slightly slippery surface when wet.
PC D – No repairs recommended at this time.

Figure A7.1.2(k) Concrete Approach Slab

MCR 6 – No visible defects.
PCR 4 – Approach has settled by 20 mm adjacent to the bridge, and provides a rough transition onto the bridge.
PC C – Only minor loss of performance of secondary component.

Figure A7.1.2(l) Gravel Approach

MCR 9 – Not applicable. Gravel should be removed from the deck surface.
PCR 4 – Approaches are slightly rough and should be re-graded.
PC M – Gravel should be removed from the deck surface and approaches regraded.

Figure A7.1.2(m) Deck Drain (Hole in Deck)

MCR 3 – Medium deterioration, with a full depth wide crack, honeycombing and scaling of concrete at the drain location.
PCR 1 – A proper drain has not been installed. Discharge runs along soffit and onto structure components below.
PC B – Deterioration of primary components greatly affected by improper drain.

Figure A7.1.2(n) Steel Deck Drain

MCR 4 – Medium corrosion over 25% of drain.
PCR 6 – Drain flows freely and discharges well away from other components.
PC M – Maintenance painting of drain required.

Figure A7.1.2(o) Deck Drain With Basin

MCR 5 – Light corrosion of basin.
PCR 5 – Slight accumulation of debris in the basin, and evidence of slight ponding of water around the basin.
PC M – Clear debris from basin.

Figure A7.1.2(p) Drainage Collection System

MCR 5 – Insignificant and localized deterioration of drainage trough under deck joint.
PCR 6 – Slight accumulation of debris in the trough, not affecting the adequacy of the system.
PC M – Clear debris from trough.

Figure A7.1.2(q) Embankment Drainage

MCR 5 – Light corrosion of corrugated pipe deck drain. Drainage system on abutment in good condition.
PCR 2 – Pipe drain discharges directly onto embankment causing severe erosion.
PC M – Extend pipe and/or construct spillway.

Figure A7.1.2(r) Drainage Collection System

MCR 1 – Drain pipe broken off at connection.
PCR 1 – Drain discharging directly onto embankment causing very severe erosion.
PC M – Repair pipe and backfill slopes.

SECTION A8 – RAILING SYSTEMS

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A8.1 Railing Systems

The inspector shall note if routine annual maintenance of the railing system and components has been carried out.

A8.1.1 Condition Rating of Railing Systems

The inspector shall determine and record the location and extent of material and performance related defects as described in Part 1, Sections 2 and 10. The following material defects should be inspected with particular care.

- damage by collision or vandalism;
- loose, broken or missing bolts, welds, nails, staples and other devices used at connections;
- freedom of movement at rail joints and spliced connections;
- vertical or horizontal misalignment of walls, rails and railings;
- loss of tension and broken strands and cables in cable rails;
- movement or slippage of anchor blocks and splice connections in cables;
- lack of or deterioration of nylon bushings, neoprene pads, mastic coatings and other protections for aluminum components;
- missing or broken end caps on tube rails;
- missing or broken top caps on hollow steel posts;
- broken or damaged post bases and anchorages;
- lack of drainage holes in hollow steel posts;
- splitting or bursting of hollow steel posts;
- missing or improper connection of approach guide rail to the end of the parapet or barrier wall on the structure;
- loose handrails, slivers or projections that could be hazards to pedestrians.

The rating of performance defects in the railing system shall be based upon its ability to withstand vehicular impact, or based upon the current integrity of the railing system as compared to the design requirements in effect at the time it was originally built.

Guidelines to assist the inspector in the rating of observed material and performance related defects in railing systems are given in Table A8. Guidelines for performance related defects are listed in bold face type. The guidelines given on Table A8 are in addition to the general guidelines given in Part 2, Section 2.

A8.1.2 Examples of Defects and Ratings of Railing Systems

Typical examples of defects of railing systems are shown in Figures A8.1.2(a) to A8.1.2(h). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating assigned shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

Rating	Observed Material and Performance Defects
6	• No observed material and performance related defects.
5	• **Defects or damage in the railing system, components or connections which do not affect its ability to protect vehicular or pedestrian traffic;** • **Railing system meets almost all safety and design requirements in effect at the time of installation. Requirements not met are not critical.** • Collision or vandalism damage over up to 5% of railing; • A few connections are slightly loose with up to 5% of fasteners loose, corroded, broken or missing in any connection; • Slight loss of cable tension or slight slippage of cable anchors and splices.
4	• **Defects or damage in the railing system, components or connections which may affect its ability to satisfactorily guard or guide vehicular or pedestrian traffic;** • **Railing system does not meet a few design or safety requirements in effect at the time of installation.** • Collision or vandalism damage over 5% to 10% of railing; • Several connections are slightly loose with 5% to 10% of fasteners loose, corroded, broken or missing in any connection; • Minor loss of cable tension or minor slippage of cable anchors and splices.
3	• **Defects or damage in the railing system, components or connections which affect its ability to resist the impact of heavy vehicles;** • **Railing system does not meet several design or safety requirements in effect at the time of installation.** • Collision or vandalism damage over 10% to 15% of railing; • Several connections are slightly loose with 10% to 15% of fasteners loose, corroded, broken or missing with possible minor movement of rail components; • A few broken cable strands, or significant loss of cable tension or slippage of cable anchors and splices in cable rails.
2	• **Defects or damage to the railing system or its components such that it will not resist the impact of light trucks;** • **Railing system does not meet many design or safety requirements in effect at the time of installation. Requirements not met may be critical.** • Collision or vandalism damage over 15% to 20% of railing; • Numerous connections are slightly loose with 15% to 20% of fasteners loose, corroded, broken or missing with significant movement of rail components; • Numerous broken cable strands with one broken cable in cable rails or severe loss of cable tension or severe slippage of anchors and splices.
1	• **Defects or damage to the railing system with missing sections or components which present a hazard to traffic;** • **Railing system does not meet any design or safety requirements in effect at the time of installation.** • Collision or vandalism resulting in some sections of the railing broken through or missing; • Very many connections are loose with over 20% of fasteners loose, corroded, broken or missing allowing for considerable movement of railing system components; • Many broken cable strands with one broken cable in cable rails or very severe loss of cable tension or very severe slippage of anchors and splices.

Table A8 Condition Rating of Railing Systems
Guidelines for performance related defects are listed in bold face type.

Figure A8.1.2(a) Parapet Wall

MCR 5 – For wall – Light defects.
MCR 4 – For railing and posts – collision damage over 20% of length.
PCR 6 – For wall. No performance defects.
PCR 1 – For railings and posts. Will not withstand further impact.
PC D – For wall, no repairs recommended at this time.
PC C – For railing and post, wall resists most of vehicle impact.

Figure A8.1.2(b) Barrier Wall

MCR 5 – Light scaling.
PCR 6 – No performance defects.
PC D – No Performance defects.

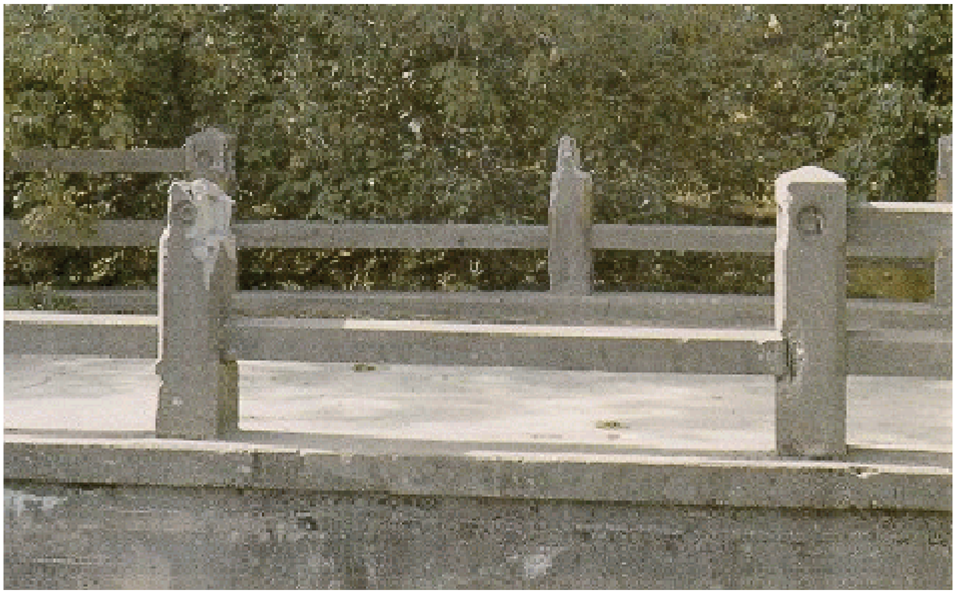


Figure A8.1.2(c) Concrete Railing

MCR 1 – Many broken rails and posts.
PCR 1 – Many missing sections. Railing provides no protection.
PC A – Railings are secondary components.

Figure A8.1.2(d) Concrete Railing

MCR 2 – Very severe disintegration of concrete.
PCR 3 – May not resist impact from heavy vehicles.
PC B – Railings are secondary components.

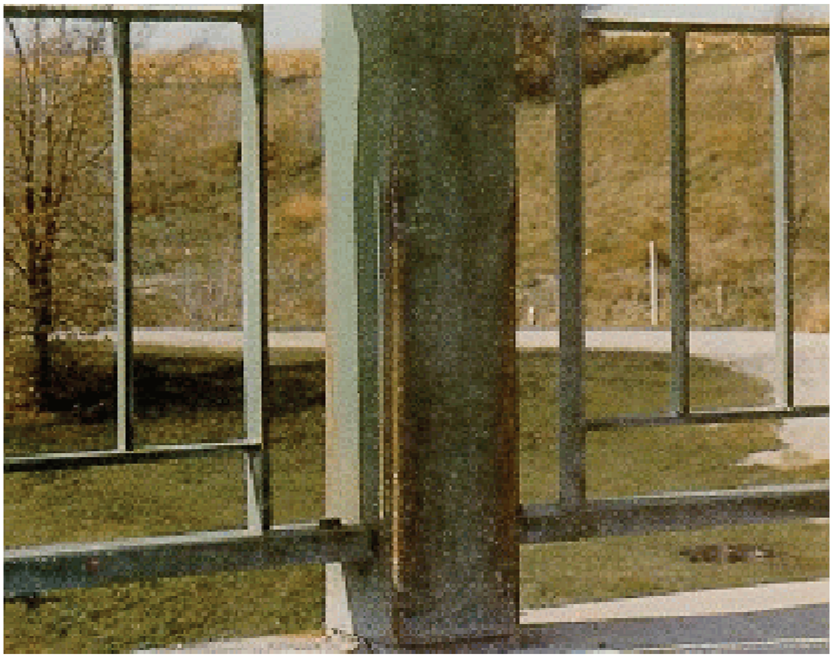


Figure A8.1.2(e) Steel Railing with Steel Posts (concrete filled)

MCR 2	–	Cracks in posts.
PCR 3	–	May not resist impact from heavy vehicles.
PC C	–	Railing may still govern ability of system to resist heavy vehicle impacts.

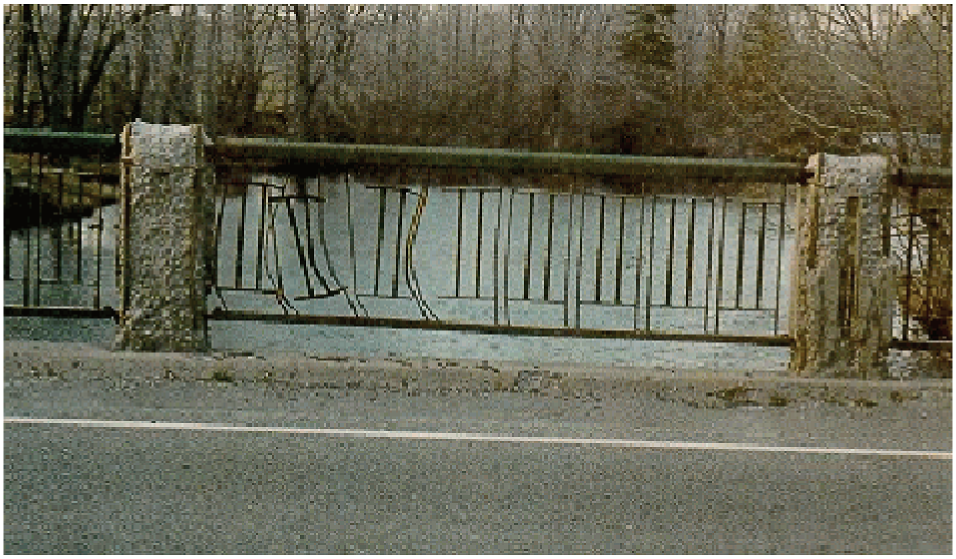


Figure A8.1.2(f) Steel Railing with Concrete Posts

MCR 1	–	Many broken areas.
PCR 1	–	Does not meet standards in effect at time of installation. Also a hazard to traffic.
PC A	–	Railings are secondary components.

Figure A8.1.2(g) Concrete Guide Rail

MCR1 – Very severe disintegration of concrete.
PCR 2 – May not resist impact by light trucks.
PC B – Railings are secondary components.

Figure A8.1.2(h) Steel Flex Beams

MCR 3 – Collision damage over 20% to 30%. of railing.
PCR 3 – Will not resist impact by heavy vehicles.
PC M – Repairs to guiderails can be performed by maintenance personnel

SECTION A9 – STRUCTURAL STEEL COATINGS

Table of Contents

A9.1 Structural Steel Coatings

The inspector shall note and record if the routine annual maintenance of the structure and coating system has been carried out. This includes the cleaning out of salt, sand, and any other debris off coated components, and touch-up of handrail and auxiliary component coatings.

A9.1.1 Condition Rating of Coatings

The inspector shall determine and record the location and extent of observed material defects and deterioration of coatings as described in Part 1, Sections 2 and 11. With multi-coat systems the inspector should note the condition of each visible layer.

The material condition of the coating is based upon the total area of material defects in the coating on a particular component. Multiple defects in the same area shall not be counted more than once.

The performance condition of the coating is based upon the loss of protection to the substrate as indicated by the percentage area of exposed metal, corrosion and corrosion by-products penetrating through the coating. A pen knife or scraper may be used to determine the actual surface area over which the coating has failed.

The rate of deterioration of the coating depends on the degree of exposure of the component to the deteriorative elements. Coatings on the following components and areas of structures incur more critical exposure and hence typically exhibit a greater degree of deterioration, and should be inspected with particular care:

- structure details, pockets and connections which collect, entrap and retain moisture, windblown deposits, animal wastes and miscellaneous debris;
- components below the discharge from deck drains and leaking joints;
- the inside of built-up sections;
- structure details where steel comes in direct contact with concrete;
- surfaces which face oncoming traffic;
- areas about 3 m above or alongside roadways subject to salt splash and spray.

Guidelines to assist the inspector in the condition rating of observed material and performance related defects in coatings are given in Table A9. Guidelines for material performance related defects are listed in bold face type.

Rating	Observed Material and Performance Defects
6	• **The coating or coating system is virtually intact; or may be cracked, peeled, flaked or worn, but with no exposed metal, corrosion or corrosion by-products present.** • No observed material defects.
5	• **Visible metal, corrosion, rust scale, rust nodules, blistering and loose primer is up to 5% of the component surface area.** • Defects over up to 5% of the surface of any components.
4	• **Visible metal, corrosion, rust scale, rust nodules, blistering and loose primer is between 5% and 10% of the component surface area.** • Defects over 5% to 10% of the surface of any component.
3	• **Visible metal, corrosion, rust scale, rust nodules, blistering and loose primer is between 10% and 15% of the component surface area.** • Defects over 10% to 15% of the surface of any components.
2	• **Visible metal, corrosion, rust scale, rust nodules, blistering and loose primer is between 15% and 20% of the component surface area.** • Defects over 15% to 20% of the surface of any component.
1	• **Visible metal, corrosion, rust scale, rust nodules, blistering and loose primer is over 20% of the component surface area.** • Defects over more than 20% of the surface of any component.

Table A9 Guidelines for the Condition Rating of Coatings
Guidelines for performance related defects are listed in bold face type.

A9.1.2 Visual Aids for Determining Condition Rating

The inspector shall use Figures A9.1.2(a) to A9.1.2(f) as visual aids in determining the extent of coating failures. The Figures, where applicable, compare the condition rating of a component to pictorial representations of percent rust as published by the Steel Structures Painting Council. The Vis2 pictorials are representative of rust but not blisters. Blisters should be treated as rust when determining the condition rating of the coating.

Figure A9.1.2(a)
Vis2 Pictorial: 1% Rust
Condition Rating 6: 0%-2% Rust

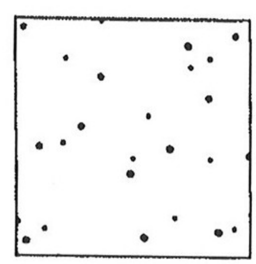


Figure A9.1.2(b)
Vis2 Pictorial: 3% Rust
Condition Rating 5: 2%-5% Rust

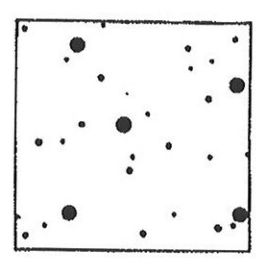


Figure A9.1.2(c)
Vis2 Pictorial: 10% Rust
Condition Rating 4: 5%-10% Rust

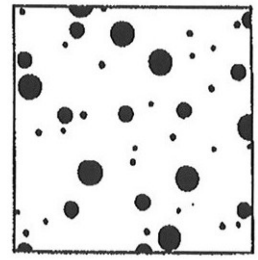


Figure A9.1.2(d)
Vis2 Pictorial: 16% Rust
Condition Rating 3: 15%-20% Rust

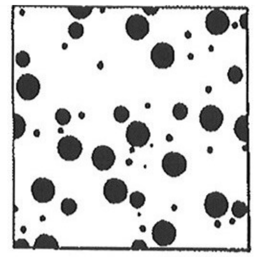


Figure A9.1.2(e)
Vis2 Pictorial: 33% Rust
Condition Rating 2: >20% Rust

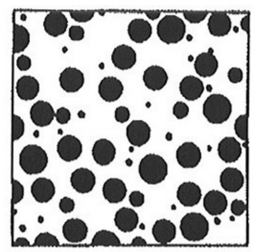
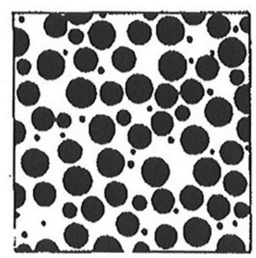


Figure A9.1.2(f)
Vis2 Pictorial: 50% Rust
Condition Rating 1: >20% Rust



A9.1.3 Priority Code for Repairs to Coating Systems

Although a coating's breakdown may be insignificant when first inspected, deterioration is progressive and increases relatively linearly between the 0.1% – 0.3% surface rust mark. If coating repairs are delayed unduly, then the defective area will probably be significantly larger when re-coating is eventually carried out in subsequent years.

Figures A9.1.3(a) and A9.1.3(b) indicate how rapidly coatings deteriorate if not maintained and how this then translates into section loss.

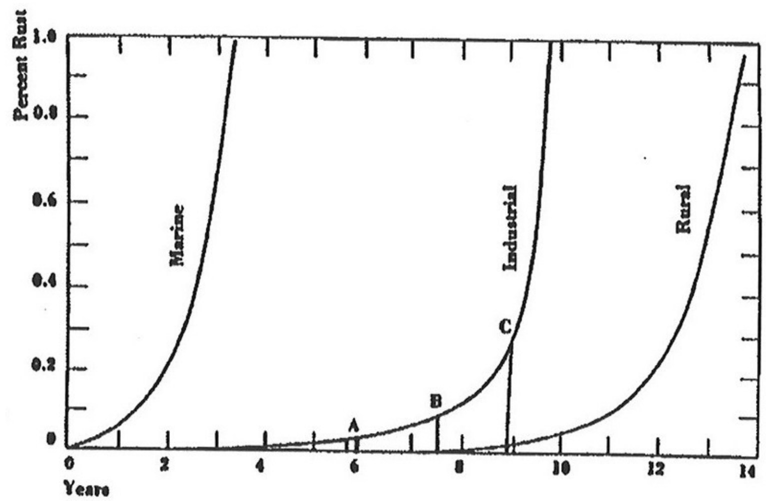


Figure A9.1.3(a) Performance Curves of Oil/Alkyd/SP2

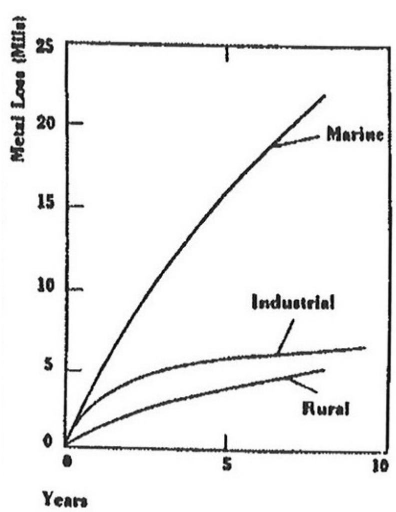


Figure A9.1.3(b) Corrosion of Base Carbon Steel

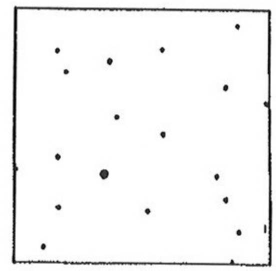
Figure A9.1.3(a) is for an oil/alkyd coating but similar curves were reported for other coatings in different environments. The points A, B, C refer respectively to 0.03%, 0.1% and 0.3% rust (Ref. 17). The graph shows that at about 0.3% rust the coating breakdown accelerates rapidly. This 0.3% is around the lower limit of condition rating 6.

As shown in Figure A9.1.3(a), the rate of deterioration of coating systems varies significantly depending on its exposure, application techniques employed, substrate surface preparation and configuration of the substrate. Consequently, it may not be cost effective to recoat bridge components after a predetermined, fixed period of time. Therefore, the inspector shall assess the level of corrosion and coating deterioration and subsequently make recommendations as to the necessary corrective procedures to be performed within a given time frame as indicated by assigning a priority code to the repairs.

As the primary reason for coating steel is to prevent section loss, coating systems should be repaired or reapplied prior to reaching 10% visible metal or rust. Many organizations use far more stringent criteria.

The Steel Structures Painting Council criterion falls between 0.03% – 0.3% rust see Figure A9.1.3(c)) while the British Iron Steel Research Association use 0.1% rust. The SSPC has determined that metal loss may occur beyond the 10% rust mark which is the upper limit of condition rating 4.

Figure A9.1.3(c)
Vis2 Pictorial: 0.3% Rust



If the combined area of visible metal, corrosion, blistering and base primer exceeds 10% of the total surface area of the primary components, then recoating on abrasive blast cleaned surfaces should be recommended. As this surface preparation is extremely expensive, it is economically advantageous to repair coatings before serious coating deterioration or corrosion occurs. The inspector shall, therefore, recommend that touch-up repairs to coating systems be carried out prior to deterioration reaching 5%. This level of deterioration is represented by the upper limit of condition rating 5.

A9.1.4 Examples of Defects and Rating of Coatings

Typical examples of defects of coatings are shown in Figures A9.1.4(a) to A9.1.4(f). Condition ratings for both performance (PCR) and material (MCR) related defects are identified below each photograph to familiarize the inspector with the inspection methodology. The numerical condition rating assigned shall appear as a single entry on the inspection form and reflect the most severe condition of material defects or performance reduction. Priority Codes (PC) for repairs to each component shall also be assigned.

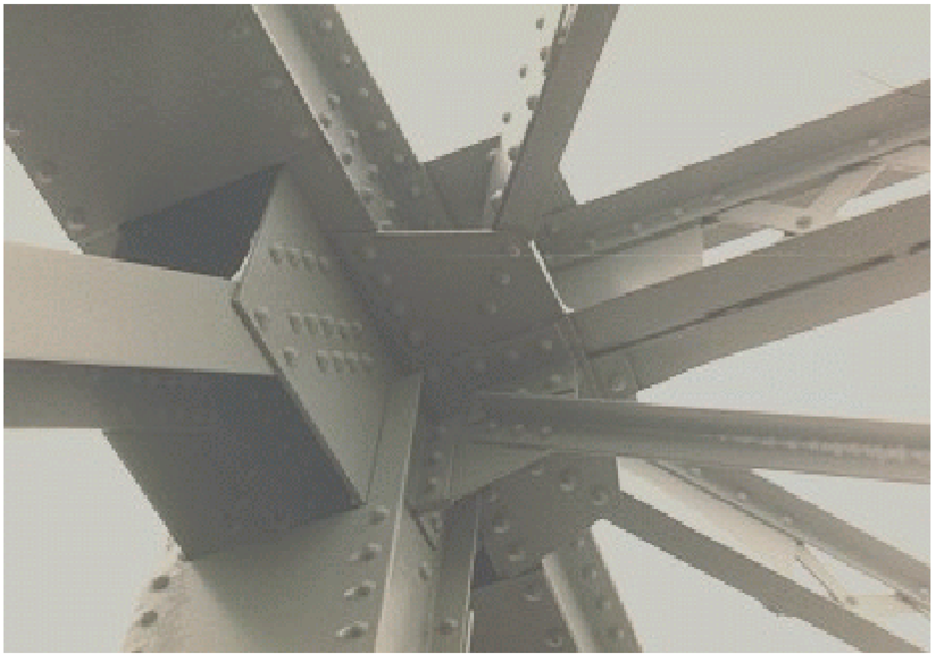


Figure A9.1.4(a) Through Truss – Connection of Primary Components

MCR 6 – No defects in coating material.
PCR 6 – No defects in coating performance.
PC D – No repairs recommended at this time.

Figure A9.1.4(b) Connection of Primary Components

MCR 4 – Coating is peeling over 5% to 10% of component surfaces.
PCR 5 – Medium corrosion over about 5% of components.
PC A – At upper limit of deterioration for touch-up type repairs. If carried out quickly, touch-up still feasible.

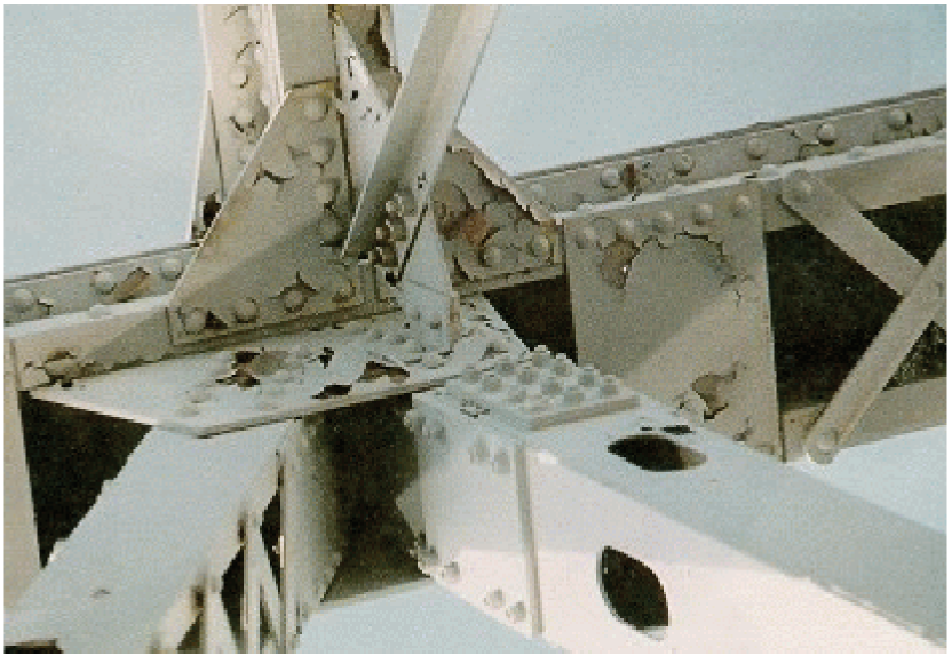


Figure A9.1.4(c) Through Truss – Connection of Primary Components

MCR 3 – Coating has peeled off over 10% to 20% of component surfaces.
PCR 5 – Light corrosion over about 5% of component surfaces.
PC B – Touch-up repairs not feasible due to extent of material defects but performance still adequate.

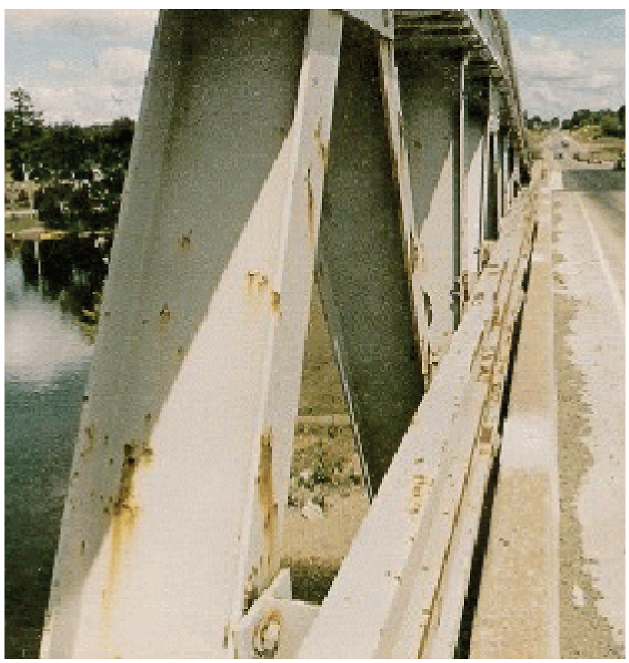


Figure A9.1.4(d) Steel Pony Truss

MCR 5 – Material defects over less than 5% of component surface.
PCR 5 – Corrosion over less than 5% of surface area of primary component.
PC A – At upper limit of deterioration for touch-up type repairs. If carried out quickly, touch-up still feasible.

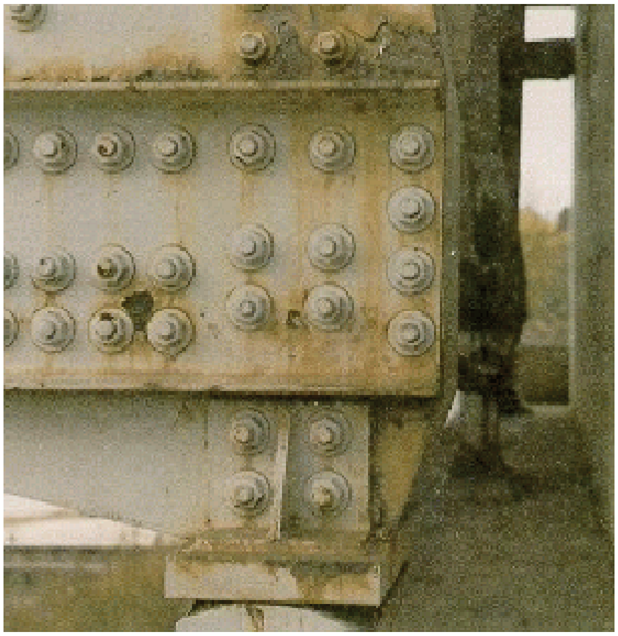


Figure A9.1.4(e)　　Truss Primary Connection at Abutment Bearing

MCR 4 – Material defects over 5% to 10% of the connection surface.
PCR 4 – Corrosion over 5% to 10% of the connection surface.
PC B – Recoating required within 3 years.

Figure A9.1.4(f)　　Railing

MCR 3 – Material defects over 20% to 30% of component surface.
PCR 3 – Corrosion over 20% of the surface of secondary component.
PC B – Deterioration too extensive for maintenance touch-up but railing is only secondary component.

SECTION A10 – SIGNS

Table of Contents

A10.1 Signs

The inspector shall record if signs are loose, missing, illegible, improperly placed, or do not meet standard requirements. The inspectors shall also assess the need for erecting new signs where applicable.

Material and performance defects of signs are not to be rated, however, the inspector should report the defects to the Project Manager/Engineer or appropriate authority.

SECTION A11 – UTILITIES

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A11.1 Utilities

The inspector shall determine and record if attachments are loose, missing, severely corroded, damaged or have other defects that would endanger the utilities in any way. In addition, the inspector shall assess whether or not the utility is restricting the performance of the structure as outlined in Part 1, Section 13.

Material or performance defects of utilities and their attachments to the structure are not to be rated, however, the inspector shall report the defects to the Project Manager/Engineer (or appropriate authority) and the appropriate utility company.

Bridge Inspection Manual

APPENDIX B – INSPECTION REPORTS

Public Works and Government Services Canada
Travaux publics et Services gouvernementaux Canada
Canada

APPENDIX B – INSPECTION REPORTS

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SECTION B1 – INSPECTION REPORTS

Table of Contents

B1.1 Inspection Reports

The inspection reports shall include the appropriate forms provided in this section shall be modified to suit each structure.

B1.1.1 Format

The inspection forms to be included in the report are comprised of five (5) sections as follows:

- Structure Description;
- General Information;
- Observations;
- Recommendations;
- Photographs.

B1.1.1(a) Structure Description

The following information shall be included on a single page, double fold out page or multiple pages, as appropriate to ensure clarity of information:

- Structure name;
- Location;
- Year Constructed;
- Photograph of bridge in elevation;
- Elevation indicating overall structure and individual span lengths;
- Structure articulation;
- Cross-Section indicating principal dimensions;
- Brief written description of major structure components;
- Date and year of existing evaluation report.

B1.1.1(b) General Information

The following general information shall be provided and/or repeated:

- Structure Name;
- Location;
- Year Constructed;
- Original Designer;
- Whether or not plans of structure are available;
- Date and Author of previous inspection report;
- Date of Current Inspection;
- Weather conditions during inspection;
- Inspector’s name and department;

- Special equipment used in inspection;
- Previous General Condition Rating;
- Current General Condition Rating;
- Previous Functional Rating;
- Current Functional Rating.

B1.1.1(c) Observations
A brief written description of the condition of each component, regardless of its condition shall be provided together with the component condition and priority ratings.

B1.1.1(d) Recommendations
The inspector shall prepare a brief itemized description of the recommended repairs.

B1.1.1(e) Photographs
Photographs of significant areas of deterioration are to be included in the inspection report. In addition, photographs of the general condition of key components of the structure are important even if structure is in good condition. Four photographs per page maximum, two per page preferred.

B1.1.1(f) Cost Estimates
Cost estimates of recommended repairs (Comprehensive Detailed Inspection Reports only).

B1.1.1(g) Management Plan
Ten years Structure Management Plan (Comprehensive Detailed Inspection Reports only).

B1.1.2 Inspection Forms
The following pages contain the inspection forms. MCR/PCR forms are required for Comprehensive Detailed inspections only. The MCR/PCR form shall be modified, as required, to suit the structure configuration and number of components.

INSPECTION FORM

NAME: ______________________________

LOCATION: ______________________________

YEAR CONSTRUCTED: ______________________________

Place a photograph of bridge in elevation here.
Identify below which elevation is shown.

__________ ELEVATION

Sketch bridge in elevation here.
Identify below which elevation is drawn.

__________ ELEVATION

Sketch cross-section here.

SECTION

NOTES:

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________

INSPECTION FORM

NAME: ______________________________
LOCATION: ______________________________
YEAR CONSTRUCTED: ______________________________
TYPE OF INSPECTION: ______________________________

Original Design: ____________________ Drawings Available: ____________

Previous Inspection Report Date: ______________________________
Author: ______________________________
Current Inspection Date: ______________________________
Inspector: ______________________________
Temperature: ______________________________
Weather: ______________________________
Special Access Equipment: ______________________________
Previous Overall Rating: Structural: __________ Current Overall Rating: Structural: __________
Previous Overall Rating: Functional: __________ Current Overall Rating: Functional: __________

ELEMENT	OBSERVATION	Condition Rating	Priority Code
WATERWAY: (P)			
EMBANKMENTS: (P, S)			
SLOPE PROTECTION: (A)			
ABUTMENTS: (P)			
RETAINING WALLS: (S)			
PIERS: (P)			
BEARINGS: (S)			
GIRDERS: (TRUSSES, ARCHES, ETC.): (P)			
COATINGS: (A)			
FLOOR SYSTEM: (P)			
DECK: (P)			
DECK JOINTS: (S)			
DECK DRAINS: (A)			
CURBS AND SIDEWALKS: (P, S)			
RAILINGS: (S)			
APPROACHES: (S)			
UTILITIES: (A)			
SIGNAGE: (A)			

NOTE: P = Primary S = Secondary A = Auxiliary

INSPECTION FORM (cont'd)

NAME: ____________________

RECOMMENDATIONS

1. ____________________
2. ____________________
3. ____________________
4. ____________________

MCR/PCR FORMS

PROJECT TITLE AND NUMBER: ______________________________

STRUCTURE: ______________________________

Element	Previous MCR	Previous PCR	New MCR	New PCR	Comments
Primary Components					
Streams					
Embankments supporting foundations					
Foundations					
Abutment Walls					
Piers					
Pin and Hanger Bearings					
Beams, Girders					
Stringers					
Floor Beams					
Thick Slabs					
Trusses					
Arches					
Culverts					
Soil-steel structures					
Load Bearing Diaphragms					
Connections of primary components					
Decks					
Wearing Surface					
Sidewalks accessible to traffic					
Structural Steel Coatings on Primary Components					

MCR/PCR FORMS (cont'd)

PROJECT TITLE AND NUMBER: ______________________

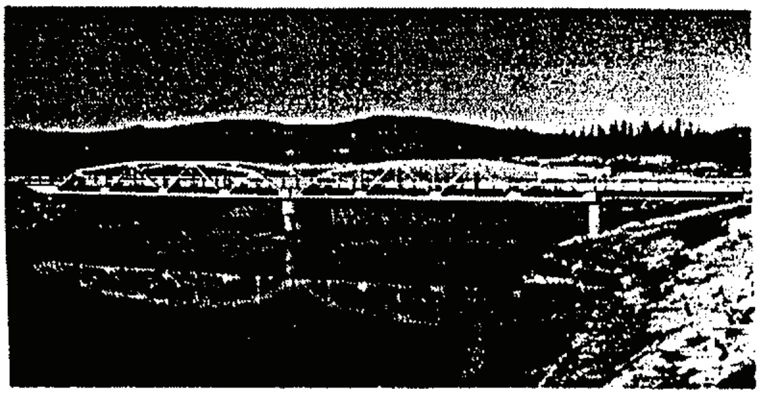
STRUCTURE: ______________________

Element	Previous MCR	Previous PCR	New MCR	New PCR	Comments
Secondary Components					
Embankments not supporting foundations					
Ballast Walls					
Wingwalls					
Retaining Walls					
Bearing Seats					
Other Bearings					
Joints					
Non-load Bearing Diaphragms					
Bracings					
Connections of secondary components					
Curbs					
Sidewalks not accessible to traffic					
Approaches					
Approach Slabs					
Barrier Walls					
Railings					
Structural Steel Coatings on Secondary Components					
Auxiliary Components					
Slope Protection					
Deck Drains and Drainage Systems					
Signs					
Utilities					

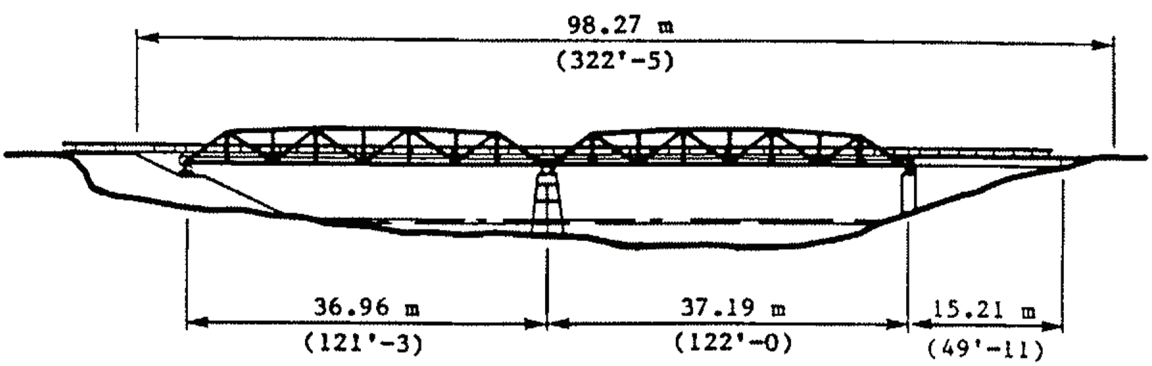
B1.1.3 Examples of Completed Inspection Forms

The following pages contain an example of the completed inspection forms.

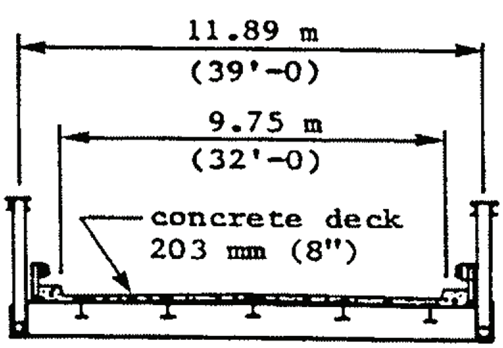
NAME: _________________ BRIDGE
LOCATION: ALASKA HIGHWAY, km xxxxxxxx
YEAR CONSTRUCTED:



WEST ELEVATION



WEST ELEVATION



SECTION

NOTES:

1. Reinforced concrete abutments on steel H-piles.
2. Reinforced concrete piers on timber piles.
3. Steel pony trusses.
4. Reinforced concrete deck on rolled structural steel floor system

NAME: ____________BRIDGE
LOCATION: ALASKA HIGHWAY, km xxxxxxxx
YEAR CONSTRUCTED:
TYPE OF INSPECTION: General Inspection

Original Design: PWC   Drawings Available: Yes

Previous Inspection Report Date: August 20xx
Author: John Doe, PWGSC Bridge Engineering A&ES
Current Inspection Date: August 20xx
Inspector: Mike Doe, P. Eng., PWGSC, Bridge Engineering, A&ES
Temperature: 10° C
Weather: Sunny
Access Equipment: Boat
Previous Overall Rating: Structural 4   Current Overall Rating: Structural 2
Previous Overall Rating: Functional 4   Current Overall Rating: Functional 4

ELEMENT	OBSERVATIONS	Condition Rating	Priority Code
WATERWAY: (P)	Meandering river on an alluvial plain, no evidence of flooding. Debris at northwest pier reducing opening by 10%–15%.	3	M
EMBANKMENTS: (S)	0.5–1.0 m deep eroded gullies both sides.	5	M
SLOPE PROTECTION: (A)	Vegetation growth scarce, slopes very flat, erosion significant.	1	M
ABUTMENTS: (P)	Good condition, no observed material or performance defects.	6	D
RETAINING WALLS: (S)	Not applicable.		
PIERS: (P)	Top of southeast pier tilted northward.	4	S
BEARINGS: (S)	The south elastomeric bearings are squeezing out. The bearing stiffeners are off centre from the anchor bolts by about 75 mm. It appears that the span has moved toward the river by this 75 mm. The girder fixed bearings have been repaired recently and are in good condition. The rocker expansion bearing on the south east pier is tilted toward adjacent fixed bearings at about 10°–15°. The bearings on the north west pier are in good condition. The bearing on the north west abutment is in good condition.	2	B
GIRDERS: (TRUSSES, ARCHES, ETC.): (P)	No observed material or performance defects in trusses or approach span girders	6	M
COATINGS: (P, S)	No observed material or performance defects.	6	M
FLOOR SYSTEM: (P)	No observed material or performance defects.	6	D
DECK: (P)	The cast-in-place deck has 10% – 15% delamination. There are 30 – 40 concrete patches. There are narrow transverse cracks on deck surface at a spacing of about 1 per metre.	3	S

NAME: xxxxxxxxxx BRIDGE (cont'd)

ELEMENT	OBSERVATIONS	Condition Rating	Priority Code
DECK JOINTS: (S)	The south abutment expansion joint is open 145 mm. The original plans indicate 75 mm. The north pier joint has lost its seal. No deterioration of components below joints at this time but is potential for deterioration. The remaining joints are in good condition.	1	C
DECK DRAINS: (A)	Two deck drains plugged with small logs (auxiliary component).	1	M
CURBS AND SIDEWALKS: (S)	No sidewalks, curbs in good condition.	6	D
RAILINGS: (S)	2 timber spacer blocks missing on west side.	5	M
APPROACHES: (S)	No observed material or performance defects.	6	M
UTILITIES: (A)	Not applicable.		
SIGNAGE: (A)	Not applicable.		

NOTE: P = Primary S = Secondary A = Auxiliary

RECOMMENDATIONS

1. Deck: Detailed deck condition survey required.
2. Piers: Monitor movement of south piers.
3. Bearings: Replace southeast abutment elastomeric pads and extend bearing seat.
4. Deck Joints: Replace seals/joints once monitoring of pier undertaken and movement requirements determined.
5. Railings: Replace timber blocks in rail.
6. Deck Drains: Remove debris from drain.
7. Waterway: Remove debris from pier.
8. Embankment: Place fill in eroded areas.
9. Slope Protection: Spread seed to promote vegetation growth.

Bridge Inspection Manual

APPENDIX C – TRAFFIC CONTROL

Public Works and Government Services Canada
Travaux publics et Services gouvernementaux Canada
Canada

APPENDIX C –TRAFFIC CONTROL

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SECTION C1 – TRAFFIC CONTROL

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C1.1 Traffic Control

All traffic control for bridge inspections shall be in accordance with the following:

- PWGSC Deputy Minister Directive 073;
- the Manual of Uniform Traffic Control Devices, Part D – Temporary Conditions (latest edition);
- provincial or territorial health and safety, labour, and traffic control regulations;
- any other relevant federal or provincial regulations.

Where required by provincial or territorial regulation, a traffic control plan shall be submitted for approval prior to the commencement of the field inspection. All traffic control procedures shall be in place prior to the commencement of the field inspection. **In case of conflicting regulations, the most stringent regulation shall govern.**

Bridge Inspection Manual

APPENDIX D – MATERIAL CONDITION SURVEY

Public Works and Government Services Canada
Travaux publics et Services gouvernementaux Canada
Canada

APPENDIX D – MATERIAL CONDITION SURVEY

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INTRODUCTION

Routine visual inspections provide a convenient method of assessing the overall condition of a structure and a general appreciation for its rate of deterioration. However, visual inspections do not reveal hidden defects in components, such as delaminations, reinforcing steel corrosion, and poor concrete clear cover that may compromise the integrity of a structure. In addition to routine visual inspections, there are detailed methods of testing structural components that may be performed during site investigations. These tests are typically done as part of a Detailed Condition Survey (see Section 1.1) prior to the rehabilitation of a structure to supplement data from visual and preliminary inspections and aid in the determination of the method of rehabilitation. Detailed tests are divided into two primary categories: non-destructive testing (NDT) and destructive testing (DT).

Non-destructive testing is a term used to describe a process which allows materials and structures to be examined for defects without compromising the structural integrity of the component.

Destructive test methods are still widely used, as they permit a visual inspection of the interior of a structural component. Samples taken as a result of destructive testing can be analysed in the laboratory, yielding results that are more reliable than NDT methods. Although these methods are highly reliable, the resultant defects, even if properly repaired, may become the focal points of future deterioration.

All of the various NDT and DT techniques can be applied in the field to identify and evaluate defects, although some are more suitable than others. The following sections describe each of the procedures, along with advantages and disadvantages of each.

SECTION 1 – CONCRETE

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1.1 Detailed Condition Survey

A detailed condition survey is carried out only after a concrete component has been identified for rehabilitation. The data collected is then used to establish the rehabilitation method and to prepare contract documents. The procedure for carrying out a detailed condition survey involves the observation and recording of surface defects and may also involve any of the tests detailed in Section 1.

Components that require rehabilitation are identified in the general annual or comprehensive detailed inspection reports. Procedures for these inspections are given elsewhere in BIM.

Candidates for a detailed condition survey will typically consist of the top surface of deck slabs included in paving contracts that have not been rehabilitated in the last 15 years. The detailed condition survey should not be carried out on bridge decks containing epoxy coated steel or bridge decks that were constructed after 1975 with a waterproofing membrane and protection board. A radar and/or infrared thermographic survey (Reference 3) should be carried out on the top surface of those decks.

A detailed condition survey will still be required on these bridges if any significant deterioration is identified by radar or infrared surveys and if the wearing surface and deck soffit show signs of significant deterioration. The corrosion potential survey portion of the detailed condition survey shall not be carried out on decks with epoxy coated steel.

Other elements such as the structure components, decks, foundation components and parapet walls requiring rehabilitation should be determined by PWGSC. A detailed condition survey may not be necessary if the need for replacement of a structurally deficient component is established by an evaluation of the load carrying capacity or by other means.

The detailed condition survey should be carried out no more than two years prior to the proposed rehabilitation. Where a project is deferred, so that the detailed condition survey is more than four years old at time of construction, it may be necessary to update the original survey. Sufficient additional information should be gathered to update tender quantities and to ensure that the most effective method of repair is recommended. Various components of a Detailed Condition Survey are summarized below.

1.1.1 Radar and Infrared Thermographic Survey

These surveys can detect scaling, debonding, delaminations, concrete cover to reinforcing steel, and asphalt thickness. The data from these surveys should be used to:

- supplement data from visual and preliminary investigations to determine which asphalt covered decks should be rehabilitated;
- determine the location of concrete cores and sawn samples during the detailed condition survey;
- supplement data from detailed condition surveys for asphalt covered decks to finalize selection of rehabilitation method and to improve the design estimate for tender item quantities.

These surveys should normally be carried out prior to the detailed condition surveys.

On asphalt covered decks where cathodic protection is one of the rehabilitation options and where a radar survey has not previously been carried out, a radar survey should be done before finalizing the method of rehabilitation. Cathodic protection is used on decks with high corrosion potentials and relatively small areas of delaminations and therefore it is essential to find the extent of the delaminations.

1.1.2 Delamination and Surface Deterioration Survey

A detailed condition survey of a reinforced concrete bridge deck shall always include a survey of the material defects and deterioration in the wearing surface (concrete or asphalt) and the deck soffit. In addition, a delamination survey shall also be carried out on all exposed concrete wearing surfaces of the bridge deck, curbs, medians, sidewalks, inside faces of concrete barrier/parapet walls and expansion joint end dams. A delamination survey should also be carried out on the deck soffit in areas where it is anticipated that major concrete repairs will be required.

A delamination and concrete surface deterioration survey shall be carried out on all exposed concrete components that require concrete rehabilitation. The area and location of patches, spalls, exposed reinforcement, honeycombing, wet areas, and other observed defects shall be recorded. If repairs to cracks using injection techniques are anticipated, the surface deterioration survey should also include measuring the depth of medium and wide cracks. The width of cracks shall be measured using a crack comparator. Stained or leached cracks shall be recorded.

On asphalt covered decks, the general conditions of the asphalt and cracks wider than 3 mm shall be recorded. Any defects in the surface which may be indicative of deterioration in the concrete decks shall be recorded.

1.1.3 Corrosion Potential Survey

The detailed condition survey for reinforced concrete deck surfaces shall always include a corrosion potential survey except where it is known that the reinforcing steel is epoxy coated. Normally a corrosion potential survey is not carried out on the deck soffit; however, a limited survey should be carried out in areas where the deck soffit is deteriorating due to leaking expansion joints and/or salt splash. A corrosion potential survey shall also be carried out on the inside concrete faces of concrete barrier systems, curbs, sidewalks and medians where significant spalling and corrosion staining has been observed.

Additional corrosion potential readings of the bridge deck obtained via drilled holes through curbs, medians or sidewalks shall be specified when the rehabilitation work will involve widening of the deck and the existing deck beneath the sidewalks and curbs is to form the new riding surface.

On bridge decks that are cathodically protected with a conductive asphalt system, the corrosion potential survey shall be limited to the locations of the sawn samples as the conductive asphalt would affect the readings obtained at the drill hole locations. The cathodic protection system should be de-energized for a minimum of four weeks prior to the commencement of the survey to allow the reinforcing steel to depolarize.

A corrosion potential survey should be carried out on piers and abutments located under open expansion joints and joints that are leaking and in areas where these components are exposed to salt splash.

1.1.4 Concrete Cover Survey

A covermeter survey shall be carried out for all exposed concrete bridge decks as part of the detailed condition surveys (excluding update surveys). The concrete cover survey should also be specified for concrete curbs, sidewalks, median and the inside faces of concrete barrier/parapet walls when low or variable concrete cover is suspected due to observed rust stains and cracking on the surface, or spalls with exposed reinforcing steel.

A covermeter survey is required for other concrete components when low or variable concrete cover is suspected due to observed rust stains and cracking on the surface, or spalls with exposed reinforcing steel.

The covermeter readings may also be required to calculate tender quantities.

1.1.5 Expansion Joint Survey

An expansion joint survey shall always be included with a first time detailed deck condition survey. In the case of update surveys, an expansion joint survey is not required if it has been completed as part of the original deck condition survey.

The expansion joints shall be visually assessed for material and performance defects as described elsewhere in the BIM and the type and extent of the deterioration shall be recorded. Although no physical testing is required, measurements to determine the joint dimensions shall be taken and recorded on the summary sheet.

The dimensions of each joint are required even where there is no armour or seal because new joints are usually installed as part of the rehabilitation contract. All joint gaps should be measured perpendicular to the line of the joint.

Where the joint has been paved over, the asphalt must be removed at the curbs and at the centreline of the highway in order to measure the joint gap.

There may be exceptional circumstances, such as the use of sliding plates, where it is not possible to measure the joint gap. However, the engineer should be aware of this situation from the review of the plans and should make a note on the form in the section for remarks.

The deck temperature shall be taken 50 mm below the surface on exposed concrete decks and at the asphalt-concrete interface on asphalt-covered decks. The ambient temperature shall be the shade temperature, usually taken below the structure.

Sketches of typical sections of the expansion joint in the curb or sidewalk area as well as the driving lane area are required. The sections shall show any steel angles, steel cover plates, dimensions of concrete end dams and other pertinent information.

The width of the top of the ballast wall shall be measured. If the ballast wall is paved over, the asphalt must be removed at one location for each abutment in order to measure this width.

The thickness of asphalt at the concrete end dams shall be measured at the curbs and at the centreline of highway on the bridge deck. Asphalt shall be removed by coring or other suitable methods.

The quality of concrete in the deck, curbs and ballast walls adjacent to the joint shall be noted under remarks.

1.1.6 Concrete Coring and Testing

Concrete coring and testing shall always be carried out when a detailed condition survey is carried out on a deck for the first time. The need for coring and testing for update surveys shall be determined on an individual basis for each structure. The number of cores required shall be determined in the field based on Table 1.

Additional cores should be specified for the following:

- where the rehabilitation work will involve removal of curve or sidewalk, at least one core shall be taken from each side of the bridge to establish the quality of the bond with the deck slab;
- a minimum of one core should be taken from curbs, sidewalks, medians and inside faces of barrier walls when a corrosion potential survey is specified.
- unless otherwise known, one core shall be taken to establish whether a concrete approach slab is present.

The requirements for coring for components other than bridge decks shall be determined on a individual basis. Normally, no more than 3 cores are required from each component. The diameter of the cores shall be 100 mm. However, 25 mm, 50 mm and 75 mm diameter cores may be specified in areas of closely spaced reinforcing steel where it is structurally undesirable to core through the reinforcing steel.

The following criterion shall be used to determine the number of cores required for components other than bridge decks:

- a minimum of one core shall be taken for chloride analysis when a corrosion potential survey is carried out;
- a minimum of one core shall be taken for air void determination if the surface of the component shows signs of extensive scaling and structure has been built after 1958;
- a minimum of one core shall be taken to determine soundness of concrete when the surface of the component is extensively disintegrated or exhibits signs of alkali-aggregate reaction;
- if crack repair work using injection techniques is anticipated, cores may be required to determine depth and orientation of the crack if this information cannot be obtained using feeler gauges or other methods. If the cracks are in the soffit of beams and where it is impractical to take cores due to the congestion of reinforcement or prestressing cables, concrete cover to the reinforcement or prestressing cables should be removed to ascertain their condition;
- if the condition of the ballast walls are suspect, at least one core should be taken from the ballast wall to assess the condition of the concrete in areas that cannot be visually assessed.

1.1.7 Asphalt Sawn Samples

Asphalt sawn samples shall always be taken whenever a detailed condition survey is carried out on an asphalt covered deck. The number of sawn samples required shall be determined in the field based on Table 2.

1.1.8 Inspection of Cathodic Protection Embedded Hardware

The components to be tested shall be identified by PWGSC. The components identified are based on the AC resistance test results obtained by PWGSC during routine monitoring. Guidelines for assessing the performance of embedded hardware are described in the Cathodic Protection Manual for Concrete Bridges (Reference 1). The components to be tested shall be listed in the Consultant's Agreement.

1.1.9 Conductive Asphalt Resistivity Test

When the anode AC resistance test is required on a structure protected with the conductive asphalt cathodic protection system, cores of the conductive asphalt layer should be tested for electrical resistivity. The number of cores to be tested is determined by PWGSC and shall be identified in the Consultant's Agreement. The testing of the cores for electrical resistivity will be carried out by a laboratory approved by PWGSC.

A two nail resistance check of the conductive asphalt shall also be taken at several locations. The number of resistance checks shall be determined and shall be identified in the Consultant's Agreement.

1.1.10 Investigation of Fire Damaged Concrete

The requirements for investigating fire damaged concrete are contained in ASTM Report STP 169B, "Significance of Tests and Properties of Concrete and Concrete-Making Materials" (Reference 5).

1.1.11 Cathodically Protected Components

Prior to the commencement of concrete coring and sawcutting of asphalt, all embedded wire, anodes, probes and reference cells shall be located as per the layout given in the cathodic protection drawings. If possible, the location of cores and sawn samples shall be a minimum 2 metres from embedded wires or components; a cable locator should be used to confirm location of embedded wires if cores and sawn samples are to be taken within the 2 metre limit. Care shall be taken to avoid cutting the wires or damaging the cathodic protection hardware. Any damaged wiring shall be repaired.

The system should be de-energized for at least four weeks prior to the commencement of the survey.

1.1.12 Sequence of Operations

Prior to carrying out the detailed condition survey, considerable preparation is required to ensure that the field investigation will be well organized.

In advance of the field investigation, pertinent features of the structure should be identified and the requirements for grid layout, sampling and data collection, equipment, manpower, and traffic control should be determined.

Existing plans of the structure and as-constructed drawings should be reviewed. A copy of the latest inspection report should be obtained. Any previous surveys should be viewed.

The typical sequence of operations for conducting a detailed condition survey is shown below. Some tasks can be performed simultaneously where crew size allows. Cores should not be taken until corrosion potential testing is complete so that the concrete surface remains dry. If cores are to be taken in wheel tracks, they should be done early so that the concrete used to repair the core hole can set before the lane is opened to traffic.

In early spring or late fall when temperatures in the early morning are too low for corrosion potential measurements, the delamination survey and component inspection can be the first operation.

The results of the corrosion potential survey and radar survey shall be used to establish the locations for taking the additional cores and sawn samples and shall be used to determine the number of samples to be taken.

The detailed visual inspection of components not requiring a detailed condition survey and photography may be carried at the completion of the detailed condition survey or simultaneously if crew size allows.

The following sequence of operations generally applies to a detailed condition survey of decks with an asphalt wearing surface:

- set up traffic control;
- lay out grid;
- establish ground location(s) for corrosion potential survey;
- anode resistance test, if applicable;
- drill holes for corrosion potential survey and measure asphalt depths;
- carry out corrosion potential survey;
- inspect soffit and plot deterioration;
- sawn samples;
- take cores;
- delamination survey on curbs and sidewalks;
- plot deck surface deterioration;
- carry out expansion joint survey and record drainage details.

1.2 Non-Destructive Testing Methods

1.2.1 Delamination Survey

Delaminations in concrete are detected by striking the surface and noting the change in sound being emitted. Steel chains and hammers are typically used for detecting delaminations in concrete by hand.

The chain drag method is generally used in detecting delaminations on exposed horizontal concrete surfaces, and has been found to be the most suitable for detecting delaminations on the top surface of bridge decks. The chain is moved from side to side in a swinging motion along the surface of the concrete. Sound concrete emits a ringing sound during the chain drag. A dull sound indicates that a delaminated area has been encountered. A heavy chain (2.2 kg/m with 50 mm links) has proven to be the most suitable, especially in areas where there is interference from traffic noise.

A chain drag is also well suited to horizontal surfaces such as the top of pier caps. It is useful as a quick method of identifying potentially debonded areas in asphalt covered decks that may require further investigation.

Hammers are used to detect delaminations on vertical and overhead surfaces. Delaminations are indicated by a change in the normal ringing sound to that of a dull sound. If the striking object is highly resonant, the difference between delaminated and sound concrete may be difficult to distinguish. Therefore, care must be taken when interpreting the sound produced.

Advantages

- Portable and inexpensive;
- Quick and simple method of application;
- Few limitations on size and shape of component being inspected;
- Effective method of determining relative area of deterioration.

Disadvantages

- Depth of deterioration unknown;
- Not possible to determine the degree of internal deterioration of concrete or reinforcing steel;
- Possible false readings depending on resonance of component.

1.2.2 Concrete Cover Survey

A concrete cover survey can be carried out on all exposed concrete surfaces, and is usually performed when low or variable concrete cover is suspected due to observed rust stains and cracking on the surface, or spalls with exposed reinforcing steel.

The concrete cover over the outer layer of the reinforcing steel is measured with a pachometer (covermeter). The probe of a pachometer measures the disturbance in a magnetic field and the magnitude of the disturbance is proportional to the size of the bar and its distance from the probe. The probe must be oriented parallel to the top layer of reinforcing steel (size and orientation obtained from existing drawings). Typically, the location of readings are related to a pre-determined reference grid laid out on the component. On asphalt covered decks, readings should be taken in areas where sawn asphalt samples have been removed (see Section 1.3.3). Once all readings are completed, a mapping of the concrete cover may be made. This mapping may influence the method of rehabilitation used (extensive areas of poor cover may be refaced or encased, as opposed to repaired). If there is a significant change in readings at adjacent points, intermediate readings should be taken to confirm the results.

Existing drawings of many older structures are no longer available. Accordingly, the pachometer may be used to determine the orientation of the top bars by rotating the probe at several locations until a sharply defined minimum reading is obtained. This indicates the probe is directly above the bar, and the orientation of the bar coincides with the longitudinal axis of the probe.

Advantages

- Portable and inexpensive;
- Quick and simple method of application;
- Few limitations on size and shape of component being inspected;
- Effective method of determining depth of concrete clear cover.

Disadvantages

- Ineffective on components with epoxy coated reinforcing steel;
- Magnetic particles in concrete may give erroneous readings;
- On some instruments the calibration tends to drift. Therefore, to ensure precision, instrument must be periodically calibrated at a known bar location or on an exposed bar.

1.2.3 Impact-Echo Testing

With impact-echo testing, spring mounted steel spheres are used to introduce low frequency stress waves into a concrete component. The waves propagate through sound, heterogeneous concrete with minimal distortion or deflection of the waves due to the aggregates or reinforcing steel. When the waves encounter a substantial change in acoustical impedance (such as the far exterior face of the component or delaminations, cracks, or voids) the waves reflect back to the surface. Surface displacements caused by the reflected waves are recorded by a transducer located adjacent to the point of impact. Knowing the velocity of the wave, and the length of time for the wave to be reflected, the overall depth of the component or the depth to the internal flaw can be determined. Figure 1.2.3 shows a schematic diagram of the impact-echo technique.

Impact-echo techniques are effective in determining the location and extent of cracks, voids, delaminations, honeycombing, and voids in post tensioned grouted tendons. Debonding of waterproofing membrane from a deck surface can also be detected. Debonding of concrete layers, and an assessment of bond strength between concrete patches/overlays and the parent concrete can be determined from this method. Impact-echo testing has also proven effective on asphalt and masonry.

When minor debonding or light rusting of reinforcing steel is encountered by the wave, the change in acoustical impedance is not sufficient to reflect the wave. Instead, the wave will distort around the flaw, and be reflected once it strikes a major flaw or the far face of the component. The flaw will be detected as an apparent increase in the thickness of the component (due to the additional travel time of the wave). The wave response for detecting voids in post-tensioned grouted ducts is similar.

It is important to realize that impact-echo techniques cannot perform blind tests to determine the internal conditions of a component, and should be used only to identify suspected defects or investigate discreet elements of a structural component. For example, the wave response for an increase in member thickness and light corrosion of reinforcing steel are very similar. It is therefore necessary that personnel involved in the survey have a thorough understanding of the principles of impact-echo testing.

Advantages

- Portable;
- Quick and effective method of application;
- Destructive tests such as corrosion potential surveys sawn asphalt sample surveys may be lessened or eliminated;
- May also be effectively used on asphalt and masonry;
- Available software removes the requirement for transposition of field notes.

Disadvantages

- Tests can effectively search only for suspected defects;
- Extensive experience required for proper interpretation of the data (typically, external agencies are retained to perform the survey and analyse the data);
- Tests are most effective when performed in conjunction with other NDT or DT tests.

Standards

ASTM C 1383-98a — Standard Test Method for Measuring the P-Wave and the Thickness of Concrete Plates Using the Impact-Echo Method.

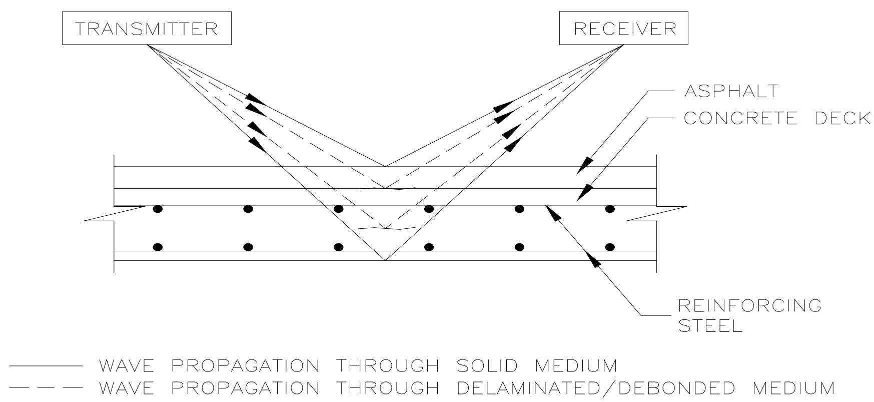


Figure 1.2.3 Impact-Echo Testing

1.2.4 Radar Testing

The principles of ground penetrating radar are very similar to those of impact-echo testing. A continuous electromagnetic signal is generated from a transmitter above the surface of the component. When discontinuities are encountered, the signal will be reflected. Unlike impact-echo technology, radar signals will differentiate between concrete and reinforcing steel in sound concrete. Accordingly, radar testing can determine the depth of cover to reinforcing steel regardless of the condition of the steel.

Because the electromagnetic pulse is continuous, radar echoes will be reflected from each of the different materials within a component. On a survey of a bridge deck, signals will typically be received from the top and bottom of asphalt, the asphalt/concrete interface, top and bottom mats of reinforcing steel, the bottom of the deck, and any flaws (such as delaminations, cracks, voids) in the concrete. Like impact-echo testing, material thickness may be determined from the velocity/transit time relationship of the signal.

Radar testing is not dependant on direct contact with the surface of the component being tested. Equipment can be mounted on a vehicle and readings taken while the vehicle is in motion. Proprietary software is available to compile the data and the results for analysis.

Advantages

- Equipment can be hand held (for use on substructure or vertical components) or vehicle mounted (for use on decks);
- Surveys of decks can be completed much quicker than with a standard pachometer, reducing traffic control and lane closure requirements typical of other methods of testing;
- Testing procedure is independent of environmental conditions (can be done in the rain);
- Associated software permits quick, convenient data compilation (eliminates the need for field recording and transcribing field measurements).

Disadvantages

- Equipment and software is proprietary (typically, external agencies are retained to perform the data collection and analysis);
- Tests are most effective when performed in conjunction with other NDT or DT tests.

Standards

ASTM D 6087-97e1 Standard Test Method for Evaluating Asphalt Covered Concrete Bridge Decks using Ground Penetrating Radar.

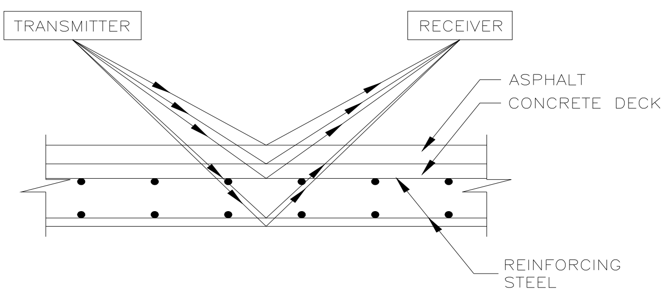


Figure 1.2.4 Radar Testing

1.2.5 Infrared Thermography

Infrared thermography is based on the principle that concrete has a very low coefficient of thermal conductivity. As a result, sound, heterogeneous concrete is required for an even transfer of heat through the concrete. Internal discontinuities parallel to the surface, such as delaminations, result in the formation of a layer of air between adjacent delaminated surfaces. This layer inhibits heat transfer to the concrete below and reflects the heat back into the concrete above the discontinuity. As a result, the temperature in concrete above a discontinuity is higher than the surrounding sound concrete.

Advantages

- Surveys of decks can be completed quickly (due to vehicle mounted equipment), lessening interruptions to traffic;
- Associated software results in quick, convenient data compilation.

Disadvantages

- Weather restraints (sunny, dry surface, temperature 15 °C and rising);
- External agencies are typically retained to perform the tests;
- Tests are most effective when performed in conjunction with other NDT or DT tests.

Standards

ASTM D4788-88(97) Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography

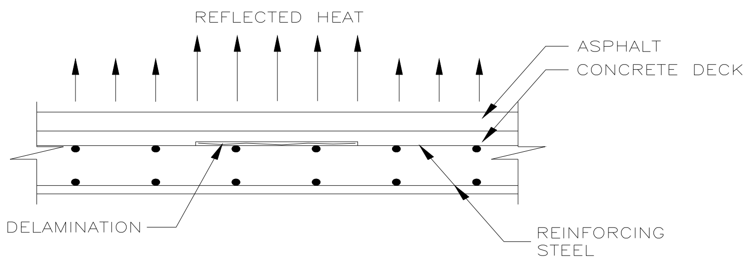


Figure 1.2.5 Infrared Thermographic Testing

1.3 Destructive Testing Methods

1.3.1 Corrosion Potential Survey

The corrosion potential survey is used to measure corrosion activity of reinforcing steel. Corroded reinforcing steel has a higher resistance to the passage of electrical current. An electric current is passed through the reinforcing steel and the corrosion activity is measured by comparing the potential of the reinforcing steel with the potential of a standard reference cell using a copper sulfate electrode (CSE). The lower the voltage passing through a section of the deck, the greater the corrosion of the surrounding reinforcing steel. Concrete in areas with half cell potential more negative than -0.35 volts generally has a high chloride concentration at the level of the reinforcing steel, and a 90% probability of corrosion activity. Therefore, the purpose of the survey is to establish the -0.35 V contour which will determine the limits of corrosion activity.

The corrosion potential survey should not be carried out on components with epoxy coated reinforcing steel. Since corrosion activity is a function of temperature, readings shall not be taken when the air and concrete temperature is lower than 5°C. The concrete temperature shall be measured in a shaded area of the structure.

Advantages

- Applicable to members regardless of their size or depth of cover to the reinforcing steel;
- Test method may be used at any time during the life of a concrete member;
- Tests can be performed, and results interpreted, by PWGSC personnel;
- Half cells may be performed on both horizontal and vertical surfaces.

Disadvantages

- Concrete or asphalt must be surface dry (no free standing water) prior to the test;
- Test is time consuming (waterproofing and asphalt must be removed prior to the test, usually be drilling holes through asphalt);
- Extensive traffic control is required;
- Survey can not be done on components with epoxy coated reinforcing steel;
- Air temperature must be 5°C and rising;
- Erroneous readings may be obtained near the edge of decks.

Standards

ASTM C876-91	Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete

1.3.2 Concrete Cores

1.3.2.1 General

A pachometer shall be used to avoid coring through the top mat of steel. However, in areas of high corrosion potential with sound concrete some cores should be taken through the steel to observe the condition of the rebar. Cores shall not be taken through prestressing steel, utility ducts, embedded cathodic protection components (including cables) or in areas immediately below or above the bearings. The cores shall be long enough to carry out the required tests and shall extend below the top mat of reinforcing steel.

Where the concrete being cored is in poor condition and is broken into several fragments, the juxtaposition of the pieces shall be recorded, by either a sketch or identification of individual pieces so that the core can be pieced together in the laboratory. Cracks in the concrete core caused by the coring operation should be identified as such.

The inside of the core hole shall be examined carefully for horizontal cracks and the condition of the concrete. The condition and orientation of any rebar located in the side of the hole shall also be recorded.

Each core shall be given a number which identifies the structure and its location in the structure. The location and the number of the cores shall be referenced. It is a good practice to complete the dimensions and observations of the core in the field, since this reduces the possibility of errors in identifying cores.

1.3.2.2 Bridge Deck Riding Surface

The number of cores required is specified in Table 1. Some cores may be taken before the completion of non-destructive testing. When this is done the coring operation shall be contained and any excess water shall be vacuumed frequently. Care shall be taken to prevent water from the coring operation interfering with the corrosion potential measurements and sawn sample operation.

Cores shall be taken in areas where deterioration is suspected; i.e. near curbs, in areas of poor drainage, at cracks or wet spots in the soffit, in areas of high corrosion potential, in areas of delaminations identified by radar survey (if available), and at cracks in the asphalt surface. However, it is also intended that the cores be representative of the condition of the concrete. Consequently, some cores shall also be taken from areas which are thought to be sound. Sound cores will, in any event, be required for physical testing. At least one core, free from reinforcing steel, shall be used for compression testing.

The total number of cores required will not be known until the corrosion potential survey is completed. The additional cores required shall be concentrated in the areas that according to the radar survey are delaminated or in areas with corrosion potentials more negative than -0.35 volts.

At least one core shall be taken from each span and where the structure has been widened, a sufficient number of cores shall be taken from old and newer portions of structures to carry out the physical testing. One of the cores shall be taken the full depth of a thin deck slab.

At least 3 cores shall be taken full depth through the top slab of thick voided concrete slabs that are not post-tensioned and do not have provisions for access to inspect the inside of the voids.

The cores should be taken in the areas of suspected deterioration for the purpose of photographing the underside of the slab.

Wearing Surface	Deck Area (m²)	N° of Cores – First Time Survey				N° of Cores – Update Survey			
		Basic	Extra (Note 1)	Min	Max	Basic	Extra (Note 1)	Min	Max
Asphalt	<300	1 per 100 m² of deck area	1 per 25 m² of HCP and delam area	6	9	1 per 300 m² of deck area	1 per 50 m² of HCP and delam area	3	4
	300 to 1000	1 per 100 m² of deck area	1 per 25 m² of HCP and delam area	10	20	1 per 300 m² of deck area	1 per 100 m² of HCP and delam area	5	8
	>1000	1 per 100 m² of deck area	1 per 50 m² of HCP and delam area	15	n/a	1 per 500 m² of deck area	1 per 100 m² of HCP and delam area	7	n/a
Concrete	<500	1 per 200 m² of deck area	1 per 50 m² of HCP area	6	10	1 per 500 m² of deck area	1 per 100 m² of HCP area	3	7
	>500	1 per 100 m² of deck area	1 per 100 m² of HCP area	10	20	1 per 500 m² of deck area	1 per 200 m² of HCP area	3	10

Note 1: Extra number of cores are based on the area of high corrosion potential (HCP) more negative than -0.35 volts calculated statistically and the area of delaminated (delam) concrete identified by radar or infrared Survey. If area of HCP and delam exceeds 50% of the deck area, the number of extra cores shall be based on 50% of the deck area.

Table 1 – Requirements for Coring Decks

When coring a deck with an asphalt wearing surface which has a poor bond between concrete and asphalt, it is advisable to remove the asphalt from the core bit before drilling the deck slab so that the asphalt is not broken inside the bit. Where asphalt thickness is in excess of 100 mm; it is sometimes necessary, in order to retrieve the concrete core, to remove a 150 mm diameter core from the asphalt prior to taking the 100 mm diameter core in the concrete. Cores are not to be taken within the sawn sample areas except where a core without reinforcement (for testing compressive strength) cannot otherwise be secured. More cores are usually taken from asphalt covered decks because it is more difficult to establish the condition of the concrete deck slab.

On bridge decks that are protected with the conductive bituminous overlay system of cathodic protection, the conductive asphalt layer in the cores must be completely intact for cores to be tested for electrical resistivity. One core sample should be taken next to anode with high resistance.

1.3.2.3 Concrete Components, Excluding Bridge Decks

Cores shall be taken in sound areas to carry out the required testing and in deteriorated areas to determine the condition of the concrete substrate. The diameter of cores taken from columns should be sized to suit size and spacing of reinforcing steel to avoid cutting the bars.

If cores are required in cracked areas, the width, depth and orientation of the crack should be noted. At least one core should be taken through cracks that visually appear contaminated. The presence of any calcite deposits, rust stains or any other deleterious material in the crack shall be recorded and photographed.

1.3.3 Asphalt Sawn Samples

Sawn samples are removed from asphalt covered decks to establish the condition of the concrete deck, the presence and condition of waterproofing materials, and to check the cover to reinforcing steel. The size of the sawn samples shall be a minimum 250 mm x 250 mm. The sample shall be removed by dry sawing in order to determine if and how much moisture is present beneath the asphalt.

Sawn samples shall not be taken over embedded cathodic protection components, including cables, unless otherwise specified in the Consultant's Agreement.

Prior to sawcutting, the depth of asphalt shall be established from adjacent drill holes for half-cell survey (allowance should be made for partial penetration of drill into concrete surface. The depth of sawcutting shall be such that there will be no damage to the concrete surface and reinforcing steel.

The number of sawn samples required is specified in Table 2. As sawn samples provide considerably more information on the degree and type of surface deterioration than cores, the sawn samples shall be concentrated in areas of suspected deterioration. They can be especially useful in investigating the condition of the deck slab at cracks in the asphalt, above the areas of deterioration in the soffit, in areas of deterioration identified by radar or infrared surveys (if available) and in areas of high corrosion potential. At least one sample is to be removed from the area adjacent to the curb. A minimum of one sawn sample is required per span.

On structures that are protected with the conductive asphalt system of cathodic protection, at least two sawn samples shall be located in wheel paths. Sawn samples should also be taken in areas where the conductive asphalt has been patched to assess the type of patch and the condition of concrete.

The total number of sawn samples required will not be known until the corrosion potential survey is completed. The additional sawn samples required shall be concentrated in areas that according to the radar or infrared survey are scaled, delaminated, or areas that have corrosion potentials more negative than -0.35 volts.

The condition of the concrete and waterproofing are of greater significance than the condition of the asphalt. Consequently, photographs shall be taken to show clearly the condition of the concrete surface. This may involve cleaning the concrete surface of asphalt residue. Care should be taken during asphalt removal to ensure that concrete surface is not damaged by the breakers used for removal.

Sawn sample information shall be recorded in the field. The location shall be given with respect to the corrosion potential grid lines. The concrete cover to the top layer of reinforcing steel shall be measured using a pachometer. The depth of asphalt and waterproofing shall be recorded. The concrete in the sample area shall be sounded for delaminations.

Common defects in waterproofing membranes not covered by BIM are described below:

- inadequate thickness at time of construction;
- excessive thickness resulting in shoving of the pavement;
- lack of adhesion to the deck or asphalt;
- moisture present beneath the waterproofing;
- penetration of the membrane by aggregate from the bituminous overlay;
- migration of the membrane into the bituminous overlay;
- rotting of the fibreglass in some fibreglass-asphalt emulsion systems;
- embrittlement in mastic waterproofing.

Deck Area (m²)	N° of Sawn Samples – First Time Survey				N° of Sawn Samples– Update Survey				
					Deck Waterproofed		Deck Not Waterproofed		Min
	Basic	Extra (Note 1)	Min	Max	Basic	Extra (Note 1)	Basic	Extra (Note 1)	
<1000	1 per 200 m² of deck area	1 per 50 m² of HCP and delam area	6	10	1 per 500 m² of deck area	1 per 100 m² of HCP and delam area	1 per 200 m² of deck area	1 per 75 m² of HCP and delam area	3
>1000	1 per 200 m² of deck area	1 per 100 m² of HCP and delam area	10	n/a	1 per 300 m² of deck area	1 per 150 m² of HCP and delam area	1 per 100 m² of HCP and delam area	1 per 100 m² of HCP and delam area	6

Note: Extra number of sawn samples is based on the area of high corrosion potential (HCP) more negative than -0.35 volts calculated statistically and the area of delaminated (delam) concrete identified by radar or infrared survey. If area of HCP and delam exceeds 50% of the deck area, the number of extra samples shall be based on 50% of the deck area.

Table 2 – Requirements for Sawn Samples

1.4 Physical Testing of Concrete

The intent of the physical testing program is to obtain an assessment of the quality and durability of the concrete. This is done by testing cores for strength, chloride content, and, in some cases, air void system. The number of cores tested varies with the size of the component and in the case of decks, the degrees of deterioration. All testing must be done in laboratories approved by PWGSC.

Specific requirements for core testing are given in Table 3. The number of cores to be tested may vary from component to component. The number of cores to be tested for bridge decks is given in Table 4.3 The number of cores requiring testing for components other than the deck is given in the Consultant's Agreement.

Test	Compressive Strength	Chloride Content	Air Void System
Test Method	CAN3-A23.2-14C (moist condition)	*MTO (Reference 4)	ASTM C457
Laboratory Approval	CSA	CSA	CSA
Other Requirements	Choose core without steel and with L/D >1.0. Preferably L/D >1.5.	Core should be taken from area exposed to chlorides and areas of high corrosion potential*	Only for structures built in 1958 or later.

* Where significant deterioration exists on the deck soffit, the full length core shall be tested by measuring the chloride content in alternate 10 mm thick slices.

Table 3 – Requirement for Testing Cores

Test	Deck Size	N^{o} Cores		
		First Time Survey		Update Survey
		Min.	Max*	
Compressive Strength	<500 m^2	1	2	1 (optional)
	500 to 2000 m^2	2	4	
	>2000 m^2	4	6	
Chloride Content	<500 m^2	1	2	1
	500 to 2000 m^2	2	3	
	>2000 m^2	3	4	
Air Void**	<250 m^2	1	1	1 (optional)
	250 to 1000 m^2	2	2	
	>1000 m^2	3	3	

* The maximum number will apply to decks in poor condition.

** Test on air void system to be carried out on decks built in 1958 and later.

Table 4 – Requirements for Testing Cores from Decks

1.4.1 Compressive Strength

The cores should be selected to represent the compressive strength of the concrete in the component. They should preferably be free from steel, though this may not always be possible. The cores must be conditioned in water for 48 hours prior to testing. Results shall be reported after correcting to an equivalent L/D ratio of 2.0 using the factors given in Table 1 of CAN3-A23.2-14C.

The cores from bridge decks shall be selected to represent the range of compressive strength of the concrete. Where the concrete is of a uniform, good quality, only the minimum number of cores should be tested.

1.4.2 Chloride Content

Cores tested for acid soluble chloride determination shall be from areas prone to salt exposure or to leakage from expansion joints. The chloride content is measured on samples taken from alternate 10 mm thick slices to a depth of 90 mm. The chloride content of slices near the 90 mm should have similar values for at least one core. If values are not similar, additional slices should be tested beyond the 90 mm depth for one of the cores tested until values are similar in two consecutive slices.

The chloride content of the concrete will usually be highest adjacent to an external surface. Where the test results produce an unexpected profile through the thickness of the concrete, a duplicate determination shall be made to verify anomalous values.

One core for acid soluble chloride determination in decks shall be from an area near the curb since the chloride content is frequently highest in concrete near the curb. At least one core in an area of high corrosion potential should also be tested for chlorides.

1.4.3 Air Void System

An air void determination is not required for structures built prior to 1958 because the concrete can be assumed to be non-air entrained. On decks with scales concrete, at least one core should be tested in the area of scaling.

Where an air void determination is required either the Linear Traverse or the Modified Point Count Method may be used. The values of air content, specific surface and spacing factor are to be reported. Paste content may be determined by measurement (Modified Point Count Method) or from the original mix proportions. Where the paste content is not known it is to be assumed to be 27%, but this assumption must be noted.

1.5 Resistivity Testing of Conductive Asphalt (Cathodic Protection)

When specified in the Consultant Agreement, the conductive asphalt shall be tested for electrical resistivity. The tests shall be carried out on cores with the conductive asphalt layer completely intact. The number of cores to be tested shall be specified in the Consultant Agreement.

1.6 Significance of Test Results

1.6.1 Compressive Strength

The compressive strength results shall be compared with the strength specified on the original drawings. Wide variations in strength may indicate local areas of deterioration. Values of less than 20 MPa represent poor quality concrete. It should be noted that concrete damaged by frost action, usually exhibited as horizontal cracks in the upper portion of the core, may register a high compressive strength but still be of poor quality.

1.6.2 Air Content

Concrete is normally considered to be properly air entrained if the air content exceeds 3%, the spacing factor is less than 0.20 mm and the specific surface exceeds 24 mm^2/mm^3.

1.6.3 Chloride Content

The chloride threshold value necessary to depassivate embedded steel and permit corrosion (in the presence of oxygen and moisture) is usually taken to be 0.20% by mass of cement. For a typical cement factor of 300 kg/m^3 this corresponds to a chloride content of 0.025% by mass of concrete.

The actual measured values of acid soluble chloride content shall be given in the report. However, the role of "background" chlorides, which are measured by the test method but do not contribute to corrosion, must be considered in preparing the summary of significant findings. Therefore, it is necessary to correct the results for the "background" chloride content.

The background chloride content for the component surveyed shall be taken as the lowest value for all the cores tested for chloride content from that component. This lowest value should be similar in two successive slices of a core. If a previous condition survey has been carried out, the previous chloride data should be reviewed for comparison purposes. The lowest value should be compared with the anticipated background value taking into account the type of aggregate and admixture used, before it is accepted as the background value. Normally, the background value should not exceed 0.07% by mass of concrete.

The background chloride content shall be deducted from all chloride content test results for that component to determine the depth of chlorides that contribute to corrosion. An example of determining the corrected chloride content is given in Table 5. In the example, the corrosion of reinforcing steel can occur if the concrete cover to reinforcing steel is less than 70 mm.

Horizon (mm)	Measured Value (%)	Corrected for Background Content (%)
0 – 10	0.307	0.268
20 – 30	0.207	0.168
40 – 50	0.101	0.062
60 – 70	0.064	0.025
80 – 90	0.049	0.010
100 – 110	0.040	0.001
120 – 130	0.039*	0.000

* The background chloride content of 0.39 should be the lowest value from all cores tested.

Table 5 – Establishing the Corrected Value for Acid Soluble Chloride Ion Content

Advantages

- Permits visual inspection of condition of concrete component and reinforcing steel;
- Destructive testing of cores yields actual in-situ strength parameters of component.

Disadvantages

- Invasive procedures may compromise the local integrity of the member.

Standards

CAN3-A23.2 14C	Obtaining and Testing Drilled Cores for Compressive Strength Testing.
ASTM C457	Standard Practice for Microscopical Determination of Air-Void Content and Parameters of Air-Void System in Hardened Concrete.

1.7 Post Inspection Procedure and Treatment

Prior to repairing core holes, the sides of the hole must be cleaned and any water removed. The concrete around reinforcing steel exposed for a corrosion potential survey must be clean of dust and debris. Concrete is then repaired by tamping a stiff mixture of approved concrete repair material in layers until the hole is filled level with the concrete surface. On decks that have a waterproofing membrane, a disc of Bituthene HDG preformed waterproofing material shall be cut to fit the core hole and shall be fastened with mastic to the concrete. Cold mix asphalt is then compacted into core hole or sawn asphalt sample to a level slightly above the bituminous surface.

1.8 References for Testing of Concrete

1.8.1 Ministry of Transportation of Ontario Publications

1. Cathodic Protection Manual for Concrete Bridges, Manual SO-14, 1993.
2. Ontario Highway Bridge Design Code (OHBDC), Third Edition.
3. The Application of Radar and Themography to Bridge Deck Condition Surveys, MAT-90-11.
4. Method of Testing for Acid Soluble Chloride Ion in Concrete.

1.8.2 Non-Ministry Reference Publications

1. ASTM Report STP 169B – Significance of Tests and Properties of Concrete and Concrete Making Materials.
2. Manual of Uniform Traffic Control Devices for Canada, Fourth Edition.
3. CAN/CSA A23.2-17C Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding.
4. CAN/CSA A23.2 – 24C Pulse Velocity Through Concrete.

SECTION 2 – STRUCTURAL STEEL

Table of Contents

2.1 Non-Destructive Testing Methods

A wide variety of techniques have been devised among which the most commonly used, in addition to visual inspection, are:

Liquid penetrant or dye penetrant	(LP)
Magnetic particle	(MP)
Ultrasonic Testing	(UT)
Eddy Current testing	(ET)
Radiographic	(RT)

Of the five methods presented, none can satisfactorily identify all defects, each has its limitations and the accuracy that can be achieved with all the equipment under laboratory conditions can seldom be obtained in the field due to normally unfavourable site conditions.

Defects in structural steel that can be identified using non-destructive testing procedures are classified in three categories;

Primary Inherent Defects

The materials used in the manufacture of steel structures – plates, forgings, castings, structural shapes, etc. conform to the applicable standards which permit minor surface discontinuities and non-significant internal defects which are smaller than the minimum reference size. They remain in the finished product but usually have little impact on the strength of the member. Since they are smaller than the maximum permissible defect they are generally of no concern in a structure.

Secondary Fabrication Defects

The fabrication assembly, construction, finishing, and installation processes used to produce the final product may introduce different defects or discontinuities to the structure. These are usually, but not always, identified through quality control procedures and are rectified by the fabricator. However, these defects should always be considered and eliminated by some process of elimination.

In-Service Defects

During service, cyclic stresses or excessive loading can cause metal fatigue, leading to cracks which may propagate and ultimately result in the failure of the component. Corrosion attack on unprotected metal surfaces reduces thickness and corrosion pitting combined with cyclic stresses induces stress corrosion cracking.

Primary and secondary defects remaining in the finished structure may, due to their shape, location and service environment, become stress raisers and compromise the integrity, strength and service life of the structure.

2.1.1 Liquid Penetrant Testing

Liquid penetrant method is commonly used in both shop and field to reveal defects that are open to the surface. It is simple to carry out, involves little time, is inexpensive and is easily interpreted. The process consists of the following:

The surface of the metal is carefully cleaned with a wire brush or by water blasting to remove all loose scale, rust, etc. followed by solvent cleaning to remove any surface contaminants. Grinding or sanding of the surface may burr over or otherwise obscure defects.

A liquid penetrant, a brilliantly coloured penetrating oil, is applied to the cleaned surface and allowed to seep into the surface defects for thirty minutes or more.

Excess penetrant is then removed and a developer agent is sprayed onto the surface.

The developer dries to a white chalky coating and remains unchanged in the absence of any defects. Where surface defects do exist, the penetrant is drawn to the surface by capillary action and stains the developer.

The surface can then be visually examined for cracks or other surface defects which will be revealed by brightly coloured stains on the white surface.

The dwell time of the penetrant can be varied to detect cracks of different widths, the finer the crack the longer the dwell time. Fluorescent penetrants can be used with ultraviolet light to detect cracks wider than about 3 microns. The sequence for liquid penetrant application and typical images are shown in Figure 2.1.1.

Advantages

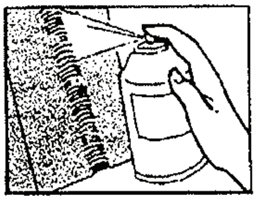
- Highly portable;
- Relatively inexpensive;
- Can be applied to a wide variety of non-porous surfaces;
- Rapid method of inspection;
- Results can be recorded photographically;
- No special equipment required;
- Results are visually apparent.

Disadvantages

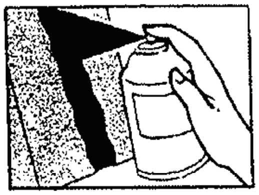
- Does not indicate depth of flaw;
- Surface must be accessible;
- Cannot detect any sub-surface defects;
- Test site must be cleaned thoroughly before inspection;
- Post cleaning may be necessary.

Standards

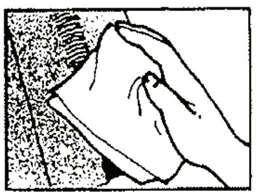
CGSB 48-GP-9M	Certification of Non-Design Personnel
CGSB 48-GP-12M	Liquid Penetrant Inspection
ASTM-E-165	Standard Practice for Liquid-Penetrant Inspection Method
ASTM-E-1770	Standard Method for Visible-Penetrant Examinations Using the Solvent Removable Penetrant



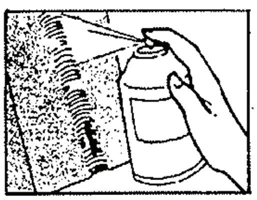
Clean



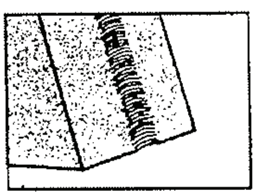
Apply Red Penetrant



Wipe Off Excess



Apply White Developer



Inspect for Red Marks on Surface

Figure 2.1.1 Steps required for applying liquid penetrant

2.1.2 Magnetic Particle

Magnetic Particle Testing is used to detect surface and near surface defects.

When a ferromagnetic material is subjected to a magnetic field, magnetic flux lines are generated in specific directions, depending on the placement of the contact electrodes or magnetic poles. When a defect within the field lies generally at right angles to the flux lines, the field will be distorted and some of the magnetic flux will leak out of the steel at the defect. Fine magnetic particles (low retentivity iron powder) distributed over the surface are attracted by the leakage field and held magnetically to form an outline of the defect.

The area to be examined is magnetized by two current carrying copper prods held against the surface of the component, a short distance apart to produce a circular magnetic field. As only defects which are perpendicular to the magnetic flux lines, can be detected, the prods must be moved about and re-positioned to ensure that all defects are located regardless of orientation.

Both AC and DC electric current is suitable for magnetizing steel components. Surface defects are most readily detected with AC magnetization. DC magnetization provides greater penetration for detection of subsurface defects.

Electromagnetic yokes produce suitable magnetic fields and are highly portable.

Figure 2.1.2a shows units used for producing a magnetic field and Figure 2.1.2b illustrates how the yokes are used in conjunction with particle application for inspection.

Advantages

- Portable and inexpensive;
- Can detect fine and shallow surface cracks;
- Fast and relatively simple to apply;
- Few limitations on size and shape of parts or structures;
- Surface cleanliness and cleaning methods not as important as for liquid penetrant method.

Disadvantages

- Surfaces must be reasonably smooth to avoid non-relevant indications;
- Requires removal of surface materials which may interfere with the ability to magnetize the area. (Generally, the area should be cleaned of debris and loose materials. Non-conductive coatings must be removed where the prods contact the metal);
- Only detects surface defects with certainty, does not indicate depth of cracks and defects.
- Some sub-surface defects are detectable but indications are diffused;
- Direction and strength of the magnetic field is critical, flux lines should be normal to the plane of a defect;
- Prod method of magnetization can cause arc burns and possible cracks;
- Demagnetization is necessary when magnetic particles may interfere with working metal surfaces, threads on bolts or subsequent painting operations;
- Can only be applied to accessible surfaces.

Standards

CGSB 48-GP-8M	Certification of Non-Destructive Testing Personnel
CGSB 48-GP-11M	Manual on Magnetic Particle Inspection
ASTM-E109-80	Dry Powder, Magnetic Particle Inspection
ASTM E709	Standard Practice for Magnetic Particle Examination

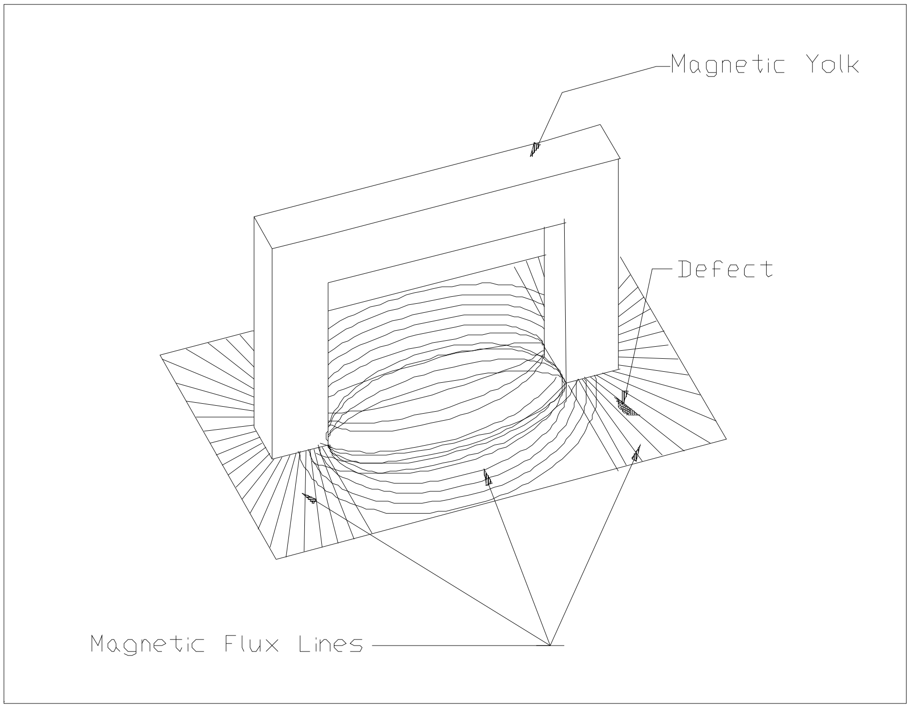


Figure 2.1.2a Typical units used for generating magnetic fields to locate any defects. Top: Yoke; Bottom: Prods.

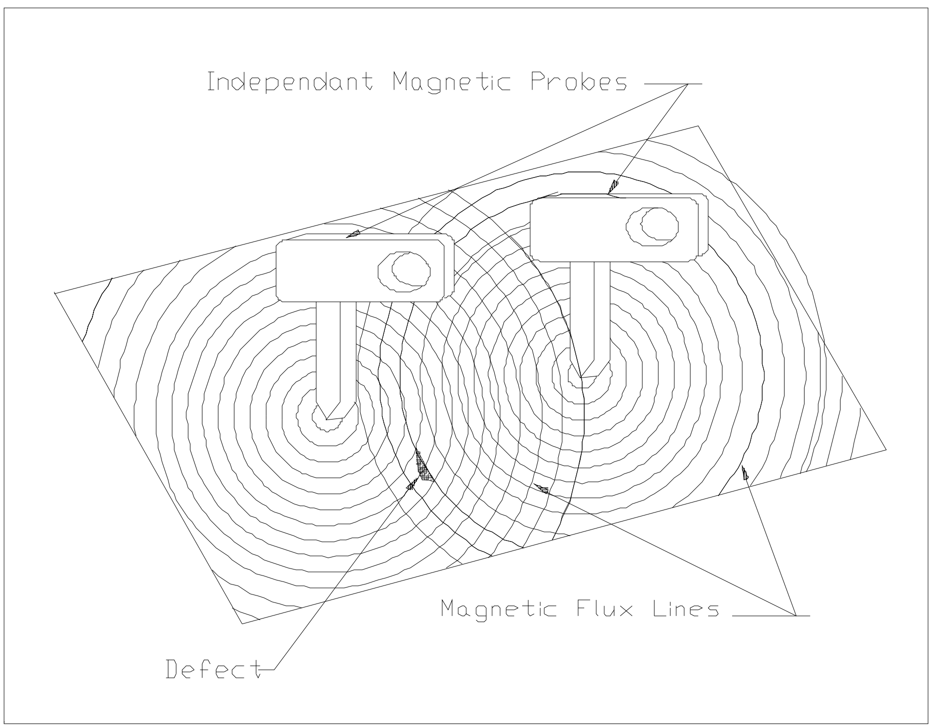


Figure 2.1.2b Typical application of magnetic particles and field generator (yoke).

2.1.3 Ultrasonic Testing

Ultrasonic testing is a method in which high frequency sound waves are introduced into a material for the detection of surface and internal defects. They pass through the material and are reflected at interfaces or boundaries such as flaws such as cracks, slag inclusions, porosity etc., or the back surface of the material. The reflected waves returning to the source can be displayed as pulses or signals on the screen of a cathode ray tube. The pulses or signals relate to the transit time of the sound. The travel time of the returning pulses is a measure of the distance to the interface of the defect.

The ultrasonic method is used to detect cracks and various other types of planar defects in wrought materials, to examining welds in fabricated components for cracks, slag inclusions and porosity, and for measuring residual wall thickness of corroded components.

The ultrasonic system is comprised of a high frequency pulse generator, transducer, receiving amplifier and CRT screen. These components allow for detection and location of defects. By various scanning movements in the area of a defect, orientation, size, shape and nature can be determined through interpretation of the reflected pulses displayed on the screen of the instrument. Ultrasonic systems can detect discontinuities that are larger than one half of the wave length of the signal. A system operating at 5MHz will detect defects larger than about 0.5 mm.

A schematic of ultrasonic testing is shown in Figure 2.1.3.

Advantages

- Detects the depth and location of cracks and planar defects;
- Very sensitive and can detect small defects such as inclusions;
- With adjustments in procedure (angle-beam method and contact pulse reflection) can detect internal defects and fatigue cracks;
- Few restrictions on size of work piece;
- Ideal for testing wrought materials and welds;
- Requires access to one surface of the test piece;
- Equipment is relatively inexpensive;
- Can be fully automated for scanning uniform shapes.

Disadvantages

- Rough or uneven surface must be ground smooth;
- Interpretation of results dependent on skill, knowledge and experience of operator;
- No permanent record of the observations (methods have been recently developed to digitize the screen image which can then be computer enhanced and/or printed);
- High noise levels are produced by coarse grain structures such as cast iron which reduce test efficiency.

Standards

CGSB 48-GP-7M	Certification of Non-Destructive Testing Personnel
CGSB 48-GP-6M	Recommended Practices for Ultrasonic Examination of Structural Welds
ASTM E164	Standard Recommended Practice for Ultrasonic Contact Examination of Weldments

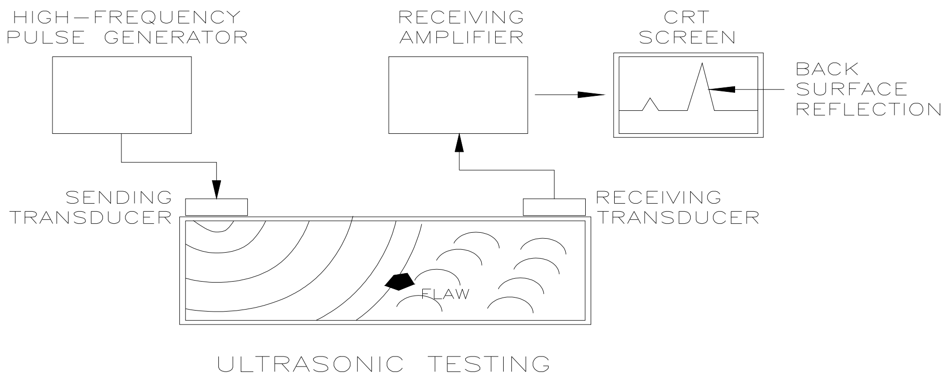


Figure 2.1.3 Schematic of ultrasonic testing equipment.

2.1.4 Eddy Current

Eddy current testing is a method based on the principles of electromagnetic induction. The component or part thereof to be tested is placed within or adjacent to a coil which is excited by an alternating current.

As the induced current fluctuates, an eddy current is produced which flows in a closed loop inside the test material. The flow of this eddy current is affected by the electrical properties of the part and the existence of defects distorts the electromagnetic field within the part.

When defect free material is being tested the eddy current flow remains uniform. In the presence of a crack or other defect, the eddy current flow is impeded and changes direction, which in turn alters the electromagnetic field. Eddy current instruments are designed to detect and monitor these changes.

Advantages

- Can be used for rapid inspection of planar shapes;
- Ideally suited for non-ferrous materials;
- Contact of coil or probe with surface not necessary but a consistent separation must be maintained;
- Thin, uniform coatings do not have to be removed;
- Detects very small discontinuities;
- The size of the defect can be estimated;
- No couplants or post cleaning needed;
- Good method for sorting materials, checking heat treatment and detecting hardness variations.

Disadvantages

- Not suitable for complex shapes;
- Shallow penetration of parts, detects surface and subsurface defects only;
- Needs reference samples for comparison purposes;
- Material must be electrically conductive;
- Surfaces must be smooth and uniform;
- Skilled and experienced technicians required to interpret the indirect test results.

Standards

CGSB 48-GP-13M	Standard for Certification of Non-Destructive Testing Personnel
CAN/CGSB 48.14-M86	Advanced Manual for Eddy Current Test Method

2.1.5 Radiographic Testing

This method is based on the ability of ionizing radiation in the form of X-rays or Gamma Rays to penetrate solid materials to produce an image on film or a fluorescent screen (Figure 2.1.5). The radiation is mostly absorbed when passing through sound and thick metal while it will pass more readily through cracks, defects and thinner material. Any differences in density due to inclusions or gas cavities or thickness variations in the part being examined cause differences in the absorption rates of the penetrating radiation. The resulting images on the film appear in various shades of grey, depending upon the amount of radiation reaching the film. Since cracks or defects absorb less of the available radiation they create a darker image than the sound material.

Under ideal field conditions, radiographic inspections can be used on most types of solid materials to reveal defects with depths or thicknesses greater than about 2% of the thickness of the material being examined. Cracks with depths of about 1.0 mm or more should be detected under normal conditions when the plane of the crack is parallel to the direction of radiation.

Advantages

- Well suited for the detection of open cracks and internal defects particularly in welds (inclusions and porosity);
- Detects cracks oriented approximately parallel to the axis of the rays;
- Permanent record of defects can be produced on film;
- Image is geometrically correct relative to the size, shape and location of the defect and area examined;
- Method and equipment well known and accepted;
- Gamma ray equipment is more portable while the less portable x-ray equipment can produce better contrast and definition of defects.

Disadvantages

- Equipment is hazardous and subject to rigid government controls. GAMMA RADIATION CANNOT BE TURNED OFF! Radiation sources must be heavily shielded;
- Not able to determine the depth of a defect;
- Cannot detect defects oriented perpendicular to the axis of the rays. Varying degrees of detection capabilities for other orientations relative to the axis of the rays;
- Both faces of test area must be accessible;
- Equipment is bulky and may be difficult to use in areas with limited space or restricted access;
- Not well suited to the detection of fine, tight cracks;
- Testing is expensive, particularly in the field.

Standards

CGSB 48-GP-4M	Certification of Non-Destructive Testing Personnel
CGSB 48-GP-5M	Manual on Industrial Radiography

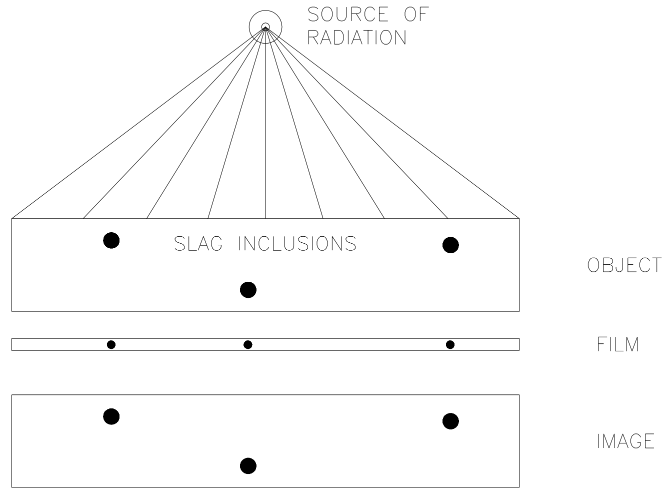


Figure 2.1.5 Schematic of typical radiographic equipment.

2.1.6 Comparison of Non-Destructive Methods

All of the foregoing non-destructive testing techniques can be used to evaluate defects in bridge structures but some are more readily used than others. Which method or methods that are to be used will depend entirely upon the information to be derived.

Liquid penetrants are ideally suited in confirming the presence of a surface defect such as a crack which has been identified by some surface anomaly during a visual inspection. The technique will confirm a discontinuity on the surface of a component and show its size but with no indication of the depth. It is not particularly suited for a comprehensive testing program of welds and assemblies.

Magnetic particle testing is a simple method for quickly evaluating extensive welds and surface areas. It too is most suited for detecting surface discontinuities although some sub-surface defects may also be detected if they are close to the surface. As with liquid penetrants, this method will delineate the aerial extent of a defect but will provide no indication of the depth.

Ultrasonic techniques provide a means to identify and measure both surface and subsurface discontinuities quickly and economically although specific procedures are required that are unique to the component under test. Defects within the material appear as anomalies on the screen and through interpretation by the testing technician, the size of the defects can be estimated.

Eddy current testing will provide accurate detection of surface and near surface defects but requires the surface to be quite smooth; any irregularities complicates the interpretation of the results. This method is ideally suited to shop inspection of large planar surfaces but as the geometry of the component under test becomes more complex the observations become more difficult to interpret. The success of this technique is highly dependent upon the experience and expertise of the testing technician.

Radiography is a major non-destructive testing method which is routinely applied to the examination of welds and assemblies. It is ideally suited to the detection of voids, inclusions, porosity, open cracks etc., where both faces of the component are accessible.

A photographic image of a defect is produced illustrating its extent but not its depth. The equipment is expensive and requires special precautions to protect against radiation hazards.

A comprehensive non-destructive testing program of steel bridge components should be carried out whenever the members are cleaned to bare metal. At this time, a thorough visual examination of all exposed surfaces and connections can be implemented. Before initiating non-destructive testing, other criteria should be examined first. The presence of fatigue critical details, structural evaluation, the age of the structure, the extent of the quality assurance during construction and the extent of past testing should be considered before NDT is implemented. If the areas show signs of failure magnetic particle testing should be used to examine these areas. Additionally, 30% of the welds, surfaces and critical areas should also be examined. The results of these evaluations may identify the need for radiographic examination of some components. Eddy current testing may be required under unique circumstances.

Table 2.1.6 give a relative comparison of each to assist the user in selecting a suitable method for a particular application.

	Inspection Method				
	Liquid Penetrant	Ultra-sonic	Magnetic Particle	Eddy Current	Radiography
General					
Surface Cracks	F	P	G	G	N
Deep Surface Cracks	G	G	G	G	F
Internal Cracks	N	G	N	N	F
Internal Voids	N	F	N	N	G
Welds					
Internal Cracks, Lack of Fusion and Penetration	N	G	P	N	G
Slag Inclusions and Porosity	N	F	N	P	G
Surface Cracks	G	P	G	G	P
In-Service					
Fatigue Cracks	G	G	G	G	P
Stress Corrosion	G	G	G	N	F
Corrosion Pits	F	G	N	N	G

Legend: G – Good F – Fair/Marginal P – Poor N – Not Suitable

Table 2.1.6 – Comparison of Non-Destructive Methods

2.2 References for NDT of Structural Steel

American Society for Metals, Metals handbook. Non-destructive inspection and quality control. ASM, Metals Park, OH 12.

American Welding Society, Guide for the non-destructive inspection of welds. ANSI/AWS B.1.10-86, AWS, Miami, FL.

American Welding Society, Structural welding code steel, ANSI/AWS D1.1-90, AWS, Miami, FL.

ASTM Designation: E94 Standard guide for radiographic testing. 1990 Annual book of ASTM standards, vol. 03.03, ASTM, 1989.

ASTM Designation: E1032 Standard method of radiographic examination of weldments. 1990 Annual book of ASTM standards, vol. 03.03, ASTM, 1985.

FWHA Ultrasonic testing inspection, Federal Highway Administration, Washington, DC.

SECTION 3 – WOOD

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3.1 Methods of Detection of Defects in Wood Components

Wood components develop decay from many causes outlined in Part 1, Section 2, Material Defects, of this manual. There is potential for decay which results from the reaction between wood and iron giving rise to loose connections not adequately covered.

Methods for detecting deterioration in wood described herein are separated into two groups; namely, those which identify exterior or surface deterioration, and those which are used to assess deterioration in the body of the wood.

There is no single tool or method that can accurately determine the extent and severity of deterioration. Of the methods discussed, none can satisfactorily identify all defects, and each has its limitations. Usually, the information derived by using a number of simple tools (Figure 3.1) and methods together can provide a relatively accurate assessment of the extent of defects and deterioration in wood.

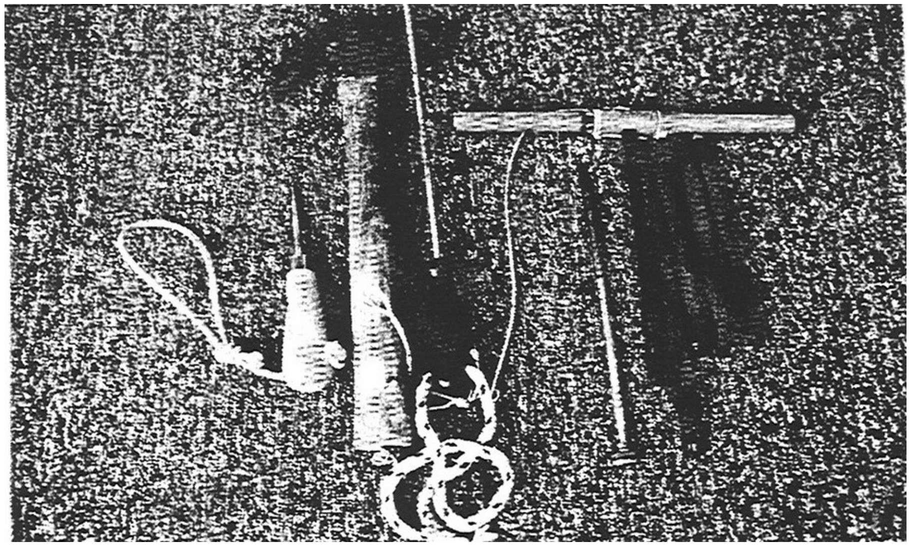

Figure 3.1 **Typical tools used for testing wood condition. Left to Right: pick, hammer, probe, coring tool, boring tool and treated wood plugs.**

3.2 Methods of Detection of Surface Deterioration

3.2.1 Probing

Probing with a pointed tool, such as a knife, awl or screwdriver, can locate decay near the surface of the wood. Decay is indicated by excessive softness and ease of penetration of the probe. Although the actual procedure is simple, experience is required to distinguish decay from water-softened wood which is otherwise sound. In addition, pressure treated wood may be sound on the surface but rotted beyond the treated layer.

Advantages

- Simple and quick procedure.

Disadvantages

- Some soft species, such as cedar, may be particularly difficult to assess using this method;
- Interpretation of results subject to experience of investigator;
- May not detect interior decay.

3.2.2 Pick test

In this test, a pointed pick, screwdriver or awl is driven a short distance into the wood, transverse to the grain, to pry out a sliver of wood from near the edge of a component. Sound wood has a fibrous structure and pries out as long splinters, while decayed wood breaks abruptly and crumbles into small pieces.

Advantages

- Simple and quick procedure.

Disadvantages

- A large sliver of wood has to be removed for each test and leaves local damage to the treated surface. This must be repaired;
- May not detect internal decay.

3.2.3 Pilodyn

A pilodyn (Figure 3.2.3) is a spring-loaded pin device that drives a hardened steel pin into the wood. The depth of pin penetration is used as a measure of the degree of decay.

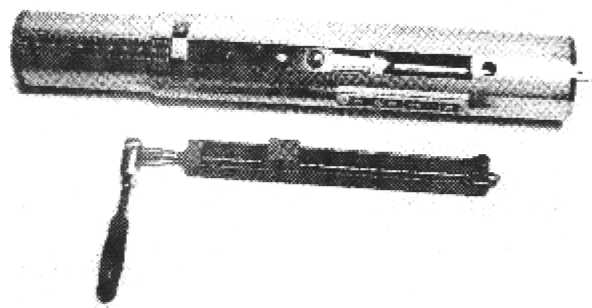

Figure 3.2.3 Typical Pilodyn used for assessing wood condition.

Advantages

- Can provide a relatively accurate calibrated/quantitative assessment of depth of decay;
- Simple and easy to use.

Disadvantages

- Equipment has to be calibrated, and results have to be corrected for moisture content and wood species;
- May not detect internal decay.

3.3 Methods of Detection of Interior Deterioration

3.3.1 General

Interior deterioration is more difficult to locate because there may be no visible evidence on the surface of the component. Several methods that can be useful in identifying probable decay are described. With each of these, the existence and extent of the problem should be confirmed and defined with core samples.

3.3.2 Sounding

Sounding is a commonly used method and involves striking the surface of the component with a hammer, or other similar object, and assessing the resulting tonal quality. A dull or hollow sound may indicate the presence of internal voids due to decay. However, other factors may be present which may make clear identification difficult.

Advantages

- Quick and simple to apply;
- Can readily identify very severe deterioration.

Disadvantages

- Results are subject to interpretation by inspector;
- Cannot detect wood in incipient or intermediate stages of decay;
- Cannot determine the extent of decay. Suspect decay must be verified by other methods such as boring and coring.

3.3.3 Moisture Meter

A moisture meter measures the electrical resistance of the wood between two metal pins which are driven into the surface. The resistance measured is then correlated to the moisture content in the wood. A centre probe between the pins indicates the depth of penetration of the pins. The pins are removable and available in various lengths for determining moisture contents to depths up to 75 mm into the wood. The holes left by the pins can be repaired by treating with preservative.

A measure of the moisture in wood will provide an indication of conditions that are conducive for decay. Moisture contents in excess of about 30% indicate conditions suitable for decay. If the measurements are carried out after a severe or prolonged period of dry weather, then moisture levels of 20 to 25 percent may be cause for concern.

An alternative instrument to check for moisture is a shigometer. The shigometer uses a pulsed current to measure changes in electrical conductivity associated with wood decay. A small hole is drilled into the wood and a probe is inserted into the hole. The probe measures zones or regions of decreased resistance. If the readings drop 50% to 75% to that of sound wood, the region is drilled and cored to determine the extent and nature of the decay.

Advantages

- Highly portable and easy to use;
- Can determine areas where decay is suspect or possible.

Disadvantages

- Does not directly detect decay;
- Must be calibrated and corrected for temperature conditions;
- Suspect areas must be evaluated by core sampling;
- Small holes left by the pins, potential areas for wood decay.

3.3.4 Drilling and Coring

Drilling and coring are the most positive means to confirm the presence of internal voids and decay, and to determine the thickness of the remaining sound material.

In drilling, a hand drill with a 10 mm to 20 mm diameter bit is used to drill a hole into the wood. Zones or pockets of decay and deterioration are noted by ease of drilling and by examination of wood shavings. Although power drills may be faster, a hand drill is more suitable, giving the inspector better control and feel in detecting soft pockets.

Coring with an Increment Borer produces a length of solid core from the wood which can be directly examined for decay and tested. The equipment used for coring and extraction of a wood core is shown in Figures 3.3.4.

Drilling and coring are generally used to confirm suspect areas of decay identified by other methods (sounding, moisture meter etc.), and to determine the extent or limits of decay, in terms of depth and area. Drilling is often used to establish evidence of decay followed by coring to define the limits of decay and extraction of samples for further laboratory analysis. Culturing provides a simple method for assessing potential risk of decay. The presence of fungi is indicative of wood in an early stage of decay and in need of treatment.

Drill bits and borers must be sharp. Dull tools will break, crush and splinter the wood making interpretation of samples and results difficult.

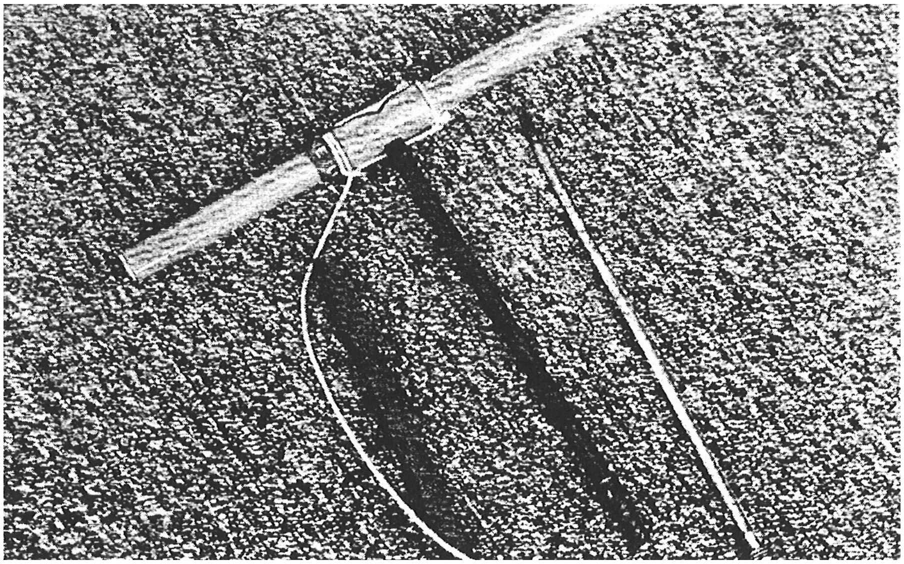

Figure 3.3.4 Equipment used or boring and coring. The piece of pressure treated wood is used as a plug to repair damage done by boring.

Advantages

- Relatively simple and portable tools involved;
- Drilling provides a rapid initial assessment of interior deterioration;
- Coring produces a sample which can be further analyzed in detail in the laboratory;
- The core can be used to determine the depth and extent of existing preservative treatment and sound wood;
- The inspection hole is useful for the insertion of a shell depth indicator, to obtain further data.

Disadvantages

- Interpretation of shavings and cores subject to experience of inspector, or must be sent to approved laboratory for analysis;
- The surface treatment is interrupted by the inspection hole which must be treated and plugged.

3.3.5 Shell-Depth Indicator

A shell-depth indicator is a metal bar or rod which is notched or hooked at one end and inscribed with ruled markings along its length (Figure 3.3.5). The hooked end is inserted into the inspection hole and pulled back along the side of the hole. As it is removed, the hook will be easily pulled through voids and decayed areas but will catch on the edges of solid sections. The inspector can thus determine the depth and extent of decay and remaining solid portions as read from the ruler markings.

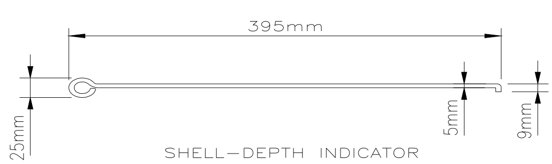

Figure 3.3.5 Schematic of a shell-depth indicator.

Advantages

- Highly portable and easy to use;
- Can determine depth of decay;
- Can be used to estimate residual strength.

Disadvantages

- Needs to be used in conjunction with drilling or coring

3.3.6 Sonic Testing

Several methods, including sonic wave velocity, acoustic emission and stress wave analysis have been used for examining wood. These methods typically involve the use of devices which emit and pick up sound waves as they travel over the surface and through the depth of the medium, and have been discussed elsewhere in detail. The variations in the travel time of the sound waves are recorded and can be related to the residual strength of the member. No direct indication of decay is obtained.

The basis for these methods is that the characteristics of a sonic wave are altered in some fashion as it passes through decayed and softer areas. With further development, these methods will offer a significant advancement in the accurate detection of decay and deterioration.

Advantages

- Can determine the approximate location and area of deterioration through differential application;
- Portable;
- Calibrated to give the residual strength of the component.

Disadvantages

- Still developmental to some extent;
- Cannot be used in the saturated zone at the water line;
- Requires special training in the use of the equipment;
- Core samples must be obtained and analyzed to confirm decay or deterioration and to determine the cause.

3.3.7 Ultrasonic Testing

Ultrasonic testing of timber is similar to sonic testing in that the variations in travel time of sound waves is measured and evaluated to provide an indication of the residual strength of a member. High frequency sound waves are induced into the wood by means of a transducer and picked up by another mounted on the opposite side.

Advantages

- Can determine the approximate location and area of deterioration;
- Can be used to evaluate the saturated zone at the water line;
- Portable.

Disadvantages

- Still developmental;
- Requires special training in the use of the equipment and in the interpretation of the observations;
- Core samples must be obtained and analyzed to confirm decay or deterioration and to determine the cause.

3.3.8 Radiation

The most common type of radiation used to detect wood defects is x-rays. The rays are passed through the wood and picked up on a sensitized film or plate placed on the opposite side of the area under examination. The different densities in the wood, such as at hard knots and soft decayed pockets, alter the amount of x-rays that will either pass easily through the wood or be partially absorbed. The resulting images of light and dark areas on the film identify these locations.

Advantages

- Useful in detecting defects and deterioration, particularly small tunnels and cavities caused by insect infestation;
- Permanent record showing the location, size and shape of defects and deteriorated areas.

Disadvantages

- Use of specialized, high cost equipment, requiring special training;
- Use of hazardous equipment subject to government controls.

3.4 Post-Inspection Procedure and Treatment

Several of the inspection methods and tools described involve the removal or destruction of a portion of the wood. These locations, such as at drill and probe holes, will become entry holes for insects and decay. All the surfaces at these locations must be thoroughly treated with an approved preservative following the inspection. Holes should be plugged for their full length with treated wood plugs or dowels, slightly larger in diameter than the hole.

Generally, treatment with creosote or copper naphthenate is sufficient for bridge components.

Failure to carry out a post inspection treatment can result in development or acceleration of decay at inspection locations.

A summary of the methods typically used for detection of defects and deterioration in wood is given in Table 3.4 This table is provided for the purposes of relative comparison of each method, and to assist the user in selecting a suitable method for a particular application.

	Surface Deterioration		Internal Deterioration		
Inspection Method	**Exterior**	**Shallow Depth**	**Voids**	**Insect Attack**	**Decay**
Probing	G	F	N	N	N
Pick Test	G	F	N	N	N
Pilodyn	G	G	N	N	N
Sounding	N	G	F	P	F
Moisture Meter	G	G	N	P	P
Drilling and Coring	N	N	G	F	G
Shell Depth Indic.	N	N	G	F	G
Sonic	N	N	F	F	F
Ultrasonic	N	N	F	F	F
Radiation	N	N	G	F	G

Legend: G – Good F – Fair/Marginal P – Poor N – Not Suitable

Table 3.4 – Comparison of Methods for Detecting Deterioration in Wood

3.5 References for NDT of Wood

ASCE technical Committee on Wood, Evaluation, maintenance and upgrading of wood structures, A Guide and Commentary. Prepared by the Subcommittee on Evaluation, Maintenance and upgrading of Timber Structures under Technical Committee on Wood, ASCE, 1982.

Core H.A. and Cote W.A. Wood structure identification. 2nd ed. Syracuse University Press, Syracuse, NY, 1979.

JANEY J.R. Guide to investigation of structural failure. Report prepared for ASCE Research Council on Performance of Structures, ASCE, 1986.

Bridge Inspection Manual

APPENDIX E – UNDERWATER INSPECTIONS

Public Works and Government Services Canada
Travaux publics et Services gouvernementaux Canada
Canada

APPENDIX E – UNDERWATER INSPECTIONS

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SECTION 1 – INSPECTION OF SUBMERGED COMPONENTS

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1.1 General

A significant number of bridges are built over waterways with abutment or pier foundations either partially or totally submerged. These components cannot be thoroughly evaluated from the water surface and must be occasionally inspected below to determine their condition and state of deterioration.

The underwater environment, in fresh water, is generally benign to all usual construction materials. Conditions beneath the surface of the water are relatively constant throughout the year and vary insignificantly from year to year. Material which is continuously submerged remains saturated and there is little oxygen available to promote deterioration. The pH of most surface water is close to neutral and temperatures below the surface vary over a narrow range between a minimum of approximately 0° to a maximum of about 20°C.

The rate of deterioration of construction materials continuously submerged in fresh water in general is no greater, and usually much less, than in the atmosphere. This does not apply to portions of the structure in the wave zone that are frequently exposed to the most severe conditions of both water and atmospheric environment. Conditions encountered here are conducive to rapid deterioration. Despite the fact that steps are normally taken to mitigate deterioration (concrete is air entrained, steel is painted with protective coatings and timber is pressure treated with a wood preservative), this area must be carefully inspected. Any deterioration in the structural component occurring below the water surface will be evident at the water line and this area should be observed during all routine inspections.

Another critical area for all structures founded in water is at the interface with the material underlying the foundation. Here, deterioration of the construction materials is not a significant problem compared to the potential for erosion of the waterway bed under and around the foundation.

The underwater environment may be considered as hostile to the personnel performing the inspection. It is cold, particularly when one is submerged for an extended period of time, usually dark, and frequently loaded with sediment which inhibits or completely restricts light penetration and visibility.

SECTION 1 – INSPECTION OF SUBMERGED COMPONENTS

A wide variety of methods have been developed for underwater inspection. These techniques range from low water wading, skin diving, and diving with SCUBA or a surface supported air supply. Each method has particular applications and can provide reliable information on the condition of the structure. The use of divers using SCUBA or a surface supply is regulated by the respective provincial or territorial Department of Labour and these diving regulations are rigidly enforced.

During any underwater investigation, all structural components are visually inspected, where visibility permits, or examined tactually. Observed conditions are recorded through notes and taped recordings of voice communications between the diver and the surface, underwater photography with a hand held still camera or video, or with a remotely operated robot (when conditions demand its use). Remote observations can also be made using sonar or ground penetrating radar.

1.2 Safety

Working on or near the water in any capacity involves a great degree of risk and precautions must be taken to ensure the safety of all personnel. The inspection team should be comprised of no less than three persons who are always in visual contact and each must wear an approved personal floatation device. Additional safety procedures which must be followed are identified in Part 2, Section 1.3 of this manual.

Inspection work performed by a diver, whether with SCUBA or a surface air supply, requires the team to be comprised of at least three persons: the diver, a stand-by diver, and a tender. One of them must be identified as the Dive Supervisor who must not enter the water while the work is in progress. In addition, the Regulations clearly identify the minimum equipment requirements as well as safety precautions. The ultimate responsibility for the safety of the workers lies with the employer so it is incumbent upon the owner to ensure that those employed for this work are competent and qualified.

1.3 Training and Experience

Visibility beneath the water surface is often restricted and the entire bridge component may not be visible. The overall condition must therefore be pieced together from a series of observations of discrete segments. A meaningful assessment will depend upon the inspector's ability to understand what is seen or felt, and how it relates to the overall structure and its integrity. The underwater inspector should be knowledgeable in bridge design and construction details and should know where to look for specific problems and common defects. Alternately, a diver lacking this experience must be in direct voice contact with a knowledgeable and experienced inspector on the surface who can direct the investigation and evaluate the observations during the course of the work.

All underwater investigations should be carried out under the direct supervision of a Professional Engineer who can certify the completeness and correctness of the work.

When the inspection is carried out by a diver, all members of the diving team must be fully trained in the use of all diving equipment and devices and in the performance of underwater work.

1.4 Non-Destructive Testing of Underwater Structures

Non-destructive testing techniques similar to those used above water can be applied to quantify any defects identified below the water surface, but in each case the equipment and procedures require modification. These techniques are listed again with considerations for underwater use.

1.4.1 Ultrasonic Testing

Ultrasound techniques can be used effectively under water. When used underwater, the transducers must be enclosed in a waterproof housing. The method is used extensively to determine the residual thickness of metal sections when only one surface is exposed or when quick, accurate measurements are required of any steel component. Because the water provides a sound connection between the transducer and the section being measured, a couplant is not required.

Ultrasonic testing of concrete under ideal conditions is difficult to successfully carry out. This is due to the unique cracking patterns that develop in the material and block the sound waves. These problems are compounded underwater and although it can be used, the results are not always reliable.

When this technique is used for wood inspection, the equipment must be calibrated for saturated timber material. Residual strength of the timber can be determined through the application of empirical methods and formulas which are dependent upon the wood species. Relative measurements can be made for a single component by comparing observations from a questionable area to those from a known sound location within the same member. Care and experience are required to assess the results obtained.

1.4.2 Magnetic Particle Inspection

Magnetic particle testing techniques are also used underwater for cracks or discontinuities in the surface of components. The process is the same as used on the surface except the magnetic particles are in a water suspension of fluorescent dye (Figure E1.4.2). The flux leakage at the defect creates an accumulation of the coloured particles indicating location and size. This deposit can be measured and photographed to create a permanent record. The surface is then cleaned with a wire brush or a water-jet.

Figure E1.4.2 Underwater Magnetic Particle Inspection

1.4.3 Eddy Current

Eddy current techniques can be used effectively underwater to locate defects in or near the surface of conductive components, as described in Appendix D, Section 2.1.4. Ultrasonic methods are then required to quantify the size and extent of noted defects or deficiencies. The method requires a skilled diver who is also a highly trained testing technician to use the equipment and interpret the results. The advantage of this system is that surface preparation is not as critical as with other methods.

1.4.4 Radiography

Radiography is not readily adapted for underwater use and is not normally used in this environment. When conditions require the degree of detail available through the use of this technique, gamma radiation is most readily utilized but all water must be evacuated between the radiating source and the object under test.

1.4.5 Sounding

Tonal qualities of sound produced in timber and concrete, underwater, by a hammer are different than those produced above water. The difference will be noted when comparing sound wood or concrete to that harbouring significant decay. Sounding may identify the presence of decay and can provide a rapid indication of the extent of significant deterioration.

1.5 Destructive Testing of Underwater Structures

1.5.1 Coring

Coring of concrete is partially destructive and consideration must be given to repair the cavities produced where cores are removed. Cores can be tested in accordance with approved procedures to verify and correlate data obtained by other means. They can be obtained underwater with purposely designed drills or from the surface by drilling vertically downward through the structure.

SECTION 2 – EQUIPMENT AND TOOLS

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2.1 Hand Tools

To effectively carry out an underwater inspection, the diver must have available an assortment of hand tools to facilitate cleaning, chipping, sounding, measuring etc. Most of the hand tools normally used during structural inspections above water can be used for underwater inspections. Those most commonly employed underwater are illustrated in Figure E2-1.

Many of the tools used in a Level 1 Inspection to determine and quantify deterioration are also utilized in a Level 2 Inspection to determine limits of probable deterioration or deficiencies, and for quantifying size, location, distribution and severity. Where samples of material are required, power tools may be needed for cutting or coring. Extensive problems may require two or more divers in the water at the same time who must be in direct voice contact with each other.

2.2 Power Tools

Work of any nature underwater is physically demanding and where excessive effort is needed to achieve results, power tools should be considered. These can include high pressure pumps where extensive cleaning is required, and pneumatic and hydraulic power tools such as saws and drills. The latter must be designed to contain all effluent to avoid environmental contamination.

2.3 Photography

Where possible, all deterioration or defects that are identified should be photographed. The diving inspector should be equipped with an underwater camera or a land camera in a water-tight housing. To record small details such as cracks in structural members or pits due to corrosion, a close-up lens is required. A “clear-water” prism is to be used where visibility is reduced due to sediment or suspended solids.

Underwater video systems provide another means for recording observations. These must be produced with a real time commentary by the diver describing what is being recorded. In addition, a referencing system must be used to graphically identify the location on the structure of what is being viewed on the screen.

Remotely operated vehicles equipped with a video camera provide a means for the inspector to visually inspect the submerged portions of a structure without putting a diver in the water. The equipment must be used with some form of grid system to monitor the location. All observations must be interpreted immediately by the inspector and recorded on the tape as it is produced.

2.4 Notes and Observations

The most practical means for recording observations made underwater by a diver is to record voice communications during the inspection on tape. In addition, the diver should be equipped with some means to produce sketches, while submerged, that will illustrate the observations.

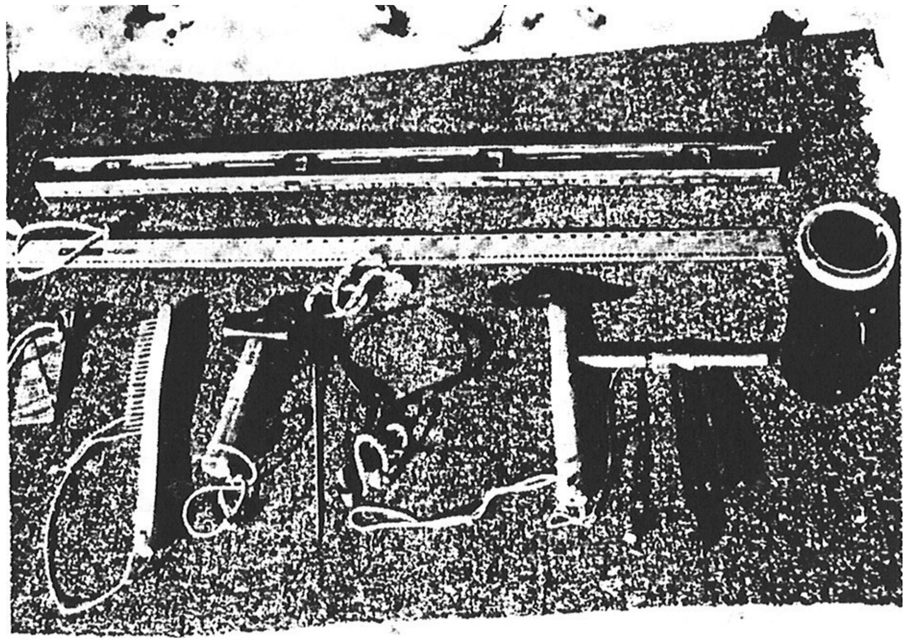

Figure E2-1 Typical Hand Tools for Underwater Inspections

SECTION 3 – INSPECTION PROCEDURES

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3.1 Existing Data

Before an underwater inspection is carried out, the Inspector should review the as-built or construction drawings of the structure, details of any restoration or rehabilitation work carried out on the submerged portions, and all previous inspection reports in order to monitor the progress of known defects or deterioration.

3.2 Wading

Where the water depth is relatively shallow (less than one metre), the river bottom is reasonably hard and there is little or no current, the submerged components can be inspected during the regular comprehensive detailed inspection with chest waders and a personal floatation device. The critical area for observations is at and immediately below the water line, and this can be readily inspected while wading. In clear water, observations below the surface can be made with the use of a simple viewing tube (Figure E3.2) or with a conventional face mask. Where visibility below the surface is limited, the critical area can be examined tactually. During a wading inspection, the condition of the waterway bed adjacent to the structure can also be evaluated.

3.3 Diving

An underwater visual inspection in shallow, clear water may be carried out from the surface by an inspector who is competent and comfortable when skin diving with a face mask, swim fins and a snorkel. The critical area at the surface will be clearly visible, as should the waterway bed at the base of the foundation.

Although skin diving is not regulated by provincial or territorial labour laws, it must be carried out in a manner that will not jeopardise the safety of the diver. The skin diver must be tethered to a float on the surface or to another member of the inspection team on shore or in a boat.

Where the depth is more than one metre, particularly where there is limited visibility, most underwater inspections will be carried out by a diver equipped with a SCUBA or a surface air supply. With this equipment there are few limitations. The diver can work at any depth and under most conditions of flow and visibility.

Underwater inspections can be carried out most readily using SCUBA due to its convenience and mobility but under some circumstances a surface air supply will be essential for a thorough examination of the submerged portions of a structure. The type of equipment needed for the specific site must be identified through a Site Reconnaissance Survey by the Diving Supervisor before commencing the inspection to determine water depths, flow conditions, unusual potential hazards, underwater visibility, special tool or inspection procedure requirements, etc.

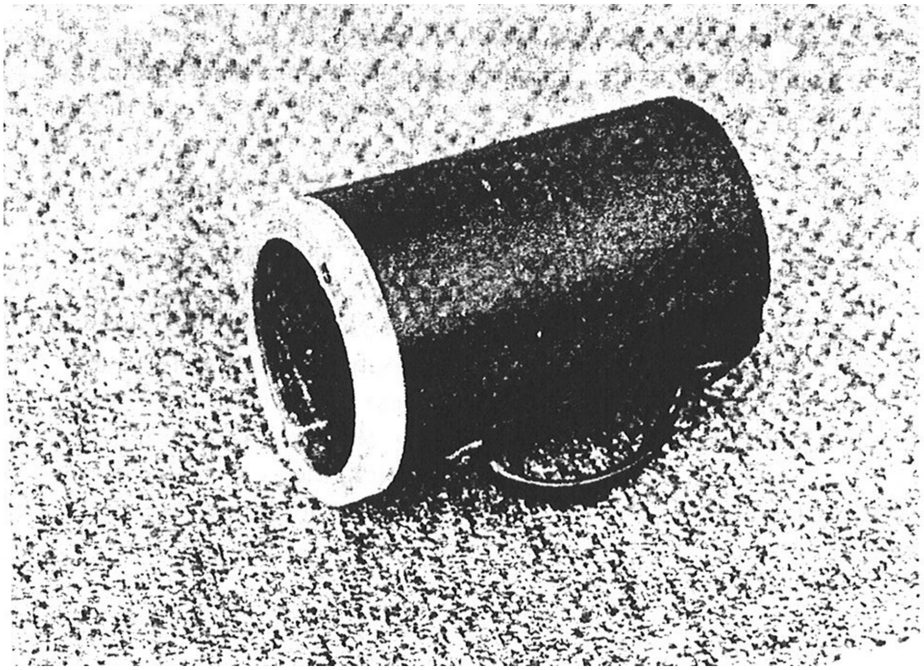

Figure E3.2 Underwater Viewing Tube

SECTION 4 – LEVELS OF INSPECTION

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4.1 Levels of Inspection

With all structures in fresh water, deterioration of underwater components is generally going to occur at and just below the water surface and at the interface with the soil. The most severe deterioration of all materials will be in the wave zone where they are exposed to the deleterious affects of both the water and the atmospheric environment. Erosion of the waterway bed and undermining of the structure is the greatest concern at the bottom. Between these two locations, little if any significant problems due to deterioration will develop, with the exception of the following:

- acidic waterways, which may result in deterioration of all submerged components and dictate the need to assess all exposed surfaces;
- masonry structures, which can experience the softening and loss of mortar from all the joints in the exposed surfaces;
- zebra mussel infestation. These animals are found in the continuously submerged zone below that is not affected by seasonal conditions such as exposure, wave action and abrasion from ice and debris.

When an underwater inspection is to be performed, the initial approach should be a visual inspection using simple, non-destructive testing techniques. This should identify and describe any deficiencies in sufficient detail for a structural evaluation of the problem and should form the basis for any further detailed inspection. The level of detail required will dictate the procedures and equipment to be used.

4.2 Level 1 – General Inspection

A Level 1 inspection will provide a visual or tactile examination of the exposed underwater surfaces of a structure in sufficient detail to detect major damage or deterioration and to confirm the continuity of all structural elements. It will provide a general assessment of the condition of the submerged components and will identify the need for a more detailed inspection.

At the surface, abrasion resulting from floating ice and debris will usually provide a clean surface for observations. Below the wave zone, representative areas at known locations for potential problems such as welds, pile interlocks, connections and connectors may require cleaning with a scraper and a wire brush to remove algae or other aquatic growths in order to expose the substrate.

Concrete and timber structures can be sounded with a hammer to provide a qualitative assessment of the materials beneath the surface. In the wave zone, timbers are to be carefully probed for indications of internal decay.

The interface between the structure and the waterway bed will be examined for indications of active or incipient erosion. Where there is active erosion, characteristic depressions will be observed at the upstream face of the bridge piers and abutments. Where the waterway bed is in a state of dynamic stability, material being brought into the site over a period of time is essentially equal to that being carried away. Probing of the bottom with a steel rod to evaluate the relative density of the waterway bed material may indicate the depth of active scour under flood flow conditions. Any observed signs of erosion are to be noted and measured.

Structural deficiencies will be apparent in the exposed portions of the structure. The extent of any such defects should be traced below the water surface.

The size and location of any observed defects or deficiencies should be noted. Significant structural defects are to be measured and photographed in sufficient detail to facilitate a preliminary structural assessment to evaluate their impact on the safety and integrity of the structure. This assessment will confirm the need for a Level 2 Inspection.

Where excessive corrosion is found or suspected, macro photos of the cleaned surface are required for evaluation and future comparisons.

4.3 Level 2 – Comprehensive Detailed Inspection

A Level 2 Inspection is a highly detailed inspection of critical structural elements where extensive repairs or possible replacement is anticipated. It will be carried out in response to the structural evaluation of deficiencies identified by a Level 1 Inspection or to investigate obvious underwater deterioration or defects manifested in the structure above the surface. This will usually entail extensive cleaning of the structural elements to remove all algae and bio-fouling, obtaining detailed measurements and photographs, and possibly non-destructive testing of apparent defects or critical components. Sampling of materials for analysis and testing may also be required. These procedures will be at identified defective areas or at locations which are representative of the critical submerged portions of the structure. The specific procedures to be used will be dependent upon the type of material and its position in the structure.

4.3.1 Steel Elements

The detailed inspection of steel structures will be directed primarily toward the joints and fasteners, with particular attention being given to welds and the adjacent heat affected zones and known stress raisers. Cleaning of the components will be carried out with a wire brush or a water-jet to expose bare metal for a careful and thorough visual examination. Where defects are identified or suspected, the area can be further examined using non-destructive evaluation techniques such as ultrasound, magnetic particle or eddy current as described in Section 1.4 of this manual and below.

The extent of corrosion will be noted and where it appears to be excessive, the residual thickness of the material should be measured. Mechanical fasteners will be examined for corrosion and tested for tightness.

Where the structure is comprised of standard rolled sections, measurements of representative elements can be obtained using conventional measuring devices once the exposed surfaces have been cleaned. Flanges of "H" piles can be measured using an outside calliper, vernier calliper or a micrometer. Where it is necessary to determine the web thickness, a modified calliper may be used in conjunction with a vernier calliper.

Members with only one exposed surface such as pipe piles or sheet piles can be measured using ultrasound. Discreet pits in the surface of the component should be measured for depth using a pit gauge (Figure E4.3.1). The density of the pitting should be recorded photographically.

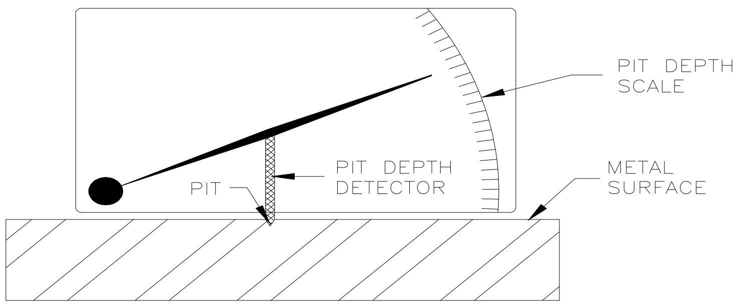

Figure E4.3.1 Pit Gauge

4.3.2 Concrete Structures

Deterioration of concrete due to exposure in fresh water is normally insignificant and a detailed inspection will be primarily to define construction defects or physical damage. This will entail careful visual examination (with photographs) of observed problems and some non-destructive evaluation techniques (specified elsewhere in this manual) to define the area of concern.

Where general deterioration of the concrete surfaces is occurring due to high or low pH of the water, the condition will be apparent near the surface where specific tests can be carried out.

4.3.3 Masonry

The joint pattern in masonry structures materially limits the use of non-destructive testing procedures. A qualitative assessment of the mortar joints can be made using a chisel or screw driver and the masonry components can be sounded with a hammer.

To quantify any observations requires core drilling vertically downward because of the extreme care required to recover the mortar in the joints.

4.3.4 Wood

The standard non-destructive and destructive testing procedures and equipment used to collect data on wood components above water, as detailed in Section 1.4 can be used directly or modified for use underwater.

SECTION 5 – SCOUR INVESTIGATIONS

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5.1 Scour Investigations

Bridge components in or adjacent to waterways need to be investigated to determine if the bridge is scour critical. A scour critical bridge is one with abutment or pier foundations which are unstable due to scouring of the waterway bed or which potentially may become unstable due to scour.

Each bridge should be rated on its propensity for damage due to scour based on:

- Hydraulic capacity relative to the flood potential of the tributary basin and observed floods;
- Geotechnical evaluation of the site;
- Water velocity through the structure under "bank full" condition and the design flood;
- Hydraulics of the watercourse considering upstream and downstream reaches;
- Erodability of the waterway bed;
- Stability of the watercourse, i.e. does it have a tendency to meander.

Based on soil types and the water velocity through the bridge opening, the following scour potential ratings should be applied. The following values represent only the potential for scour, and are to be used as a guide for the determination of scour critical bridges.

Waterway Bed Material	Bank Full Velocity	Rating
Granular and Silt	<1 m/s 1-2 m/s >2 m/s	5 3–4 2
Clay/Till	<2 m/s 2-3 m/s >3 m/s	5 4 3
Shale Limestone Granite	>3 m/s >5 m/s	4 4 6

A rating of 6 indicates scour will never be a significant problem whereas a rating of 3 or less indicates the need for further investigations and possible protective measures. In addition to the foregoing scour rating, each structure must be rated based on performance and material related defects in accordance with Section A1 of Appendix A as a result of scour and its impact on the travelling public.

5.2 Inspection Procedures for Scour

5.2.1 Probing

Where the erosion potential of a bridge site is great (rated 3 or lower) the waterway bed may be in a state of dynamic stability with a continuous bed load moving through the site. Under these conditions there can be very significant erosion during a flood but as the flow diminishes the waterway bed is re-established at or close to its original condition. Where this condition is suspected, the waterway bed must be carefully evaluated by probing or through various geotechnical techniques that can produce a sub-bottom profile of undisturbed soil.

5.2.2 Diver Inspections

A visual examination of the waterway bed by a diver will indicate if active erosion is occurring and will identify exposed piles or the underside of spread footings. Where the waterway bed is in a state of dynamic stability and infilling of erosion features has occurred, probing of the bottom adjacent to abutments and piers may reveal loose sediments as well as the depth to sound material.

5.2.3 Sounding

The waterway bed, both upstream and downstream of the structure and within the water passages should be sounded where any potential exists for scour. Sounding is best obtained by using a recording type echo sounder with particular attention being given immediately adjacent to the abutments and piers. The position of all observations should be related to the centreline of the bridge. Where the scour rating is 3 or lower, the waterway bed should be re-sounded after every spring freshet and all other significant flood events. If the waterway bed stabilizes at an elevation that does not threaten the stability of the structure the soundings can be scheduled at five year intervals and after any major flood event.

The area of concern should extend approximately 30 m upstream and downstream from the face of the bridge.

A narrow beam transducer (5° or less), operating at a frequency of 200kHz or more will produce a reasonably accurate indication of the bottom profile. A wider beam angle will result in more extraneous signals due to reflections off the vertical surface and will be more difficult to interpret.

A scanning type sonar with a rotating head can also be used to trace down the face of a pier and across the waterway bed, identifying any cavities beneath the foundation.

Sonar equipment is reasonably portable and can generally be mounted in or on any type of boat. The results are graphically recorded on a strip chart as a permanent record and these are easily interpreted. However, weed growth on the bottom will affect the accuracy of observations and air in the water will materially affect the signal, sometimes obscuring it completely.

5.2.4 Sub-Bottom Profiler

A sub-bottom profile can frequently be obtained using sonar operating in the range of 50kHz or less. Such equipment will obtain reasonable penetration of the loose sediments on the bottom but with some loss of detail.

The equipment is similar in every respect to conventional sonar although some expertise is required for interpretation of the data.

5.2.5 Ground Penetrating Radar

Ground penetrating radar is a relatively new procedure for geotechnical investigations and its applications are being rapidly expanded. It is well suited to sub-bottom profiling from a boat, or from surface ice. Its greatest advantage over sonar is that the signal is not affected by entrained air.

The equipment is considerably more bulky than sonar and considerable expertise is required for computer enhancement of the recorded data and for the interpretation of the results.

5.3 Corrective Actions

If the scour investigations and assessment indicate that the stability of a structure is jeopardised, then appropriate actions should be taken to mitigate the problem. This will usually be in the form of armour stone or rip-rap placed on the waterway bed in close proximity to the bridge components.

Any proposed method of control will require a hydraulic analysis of the watercourse downstream of the structure and through the bridge openings to determine its impact on the capacity of the water passages and on the stability of the waterway bed beyond the protection.