Bridge Inspection Manual

PART 1 – TECHNICAL INFORMATION

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

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.

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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

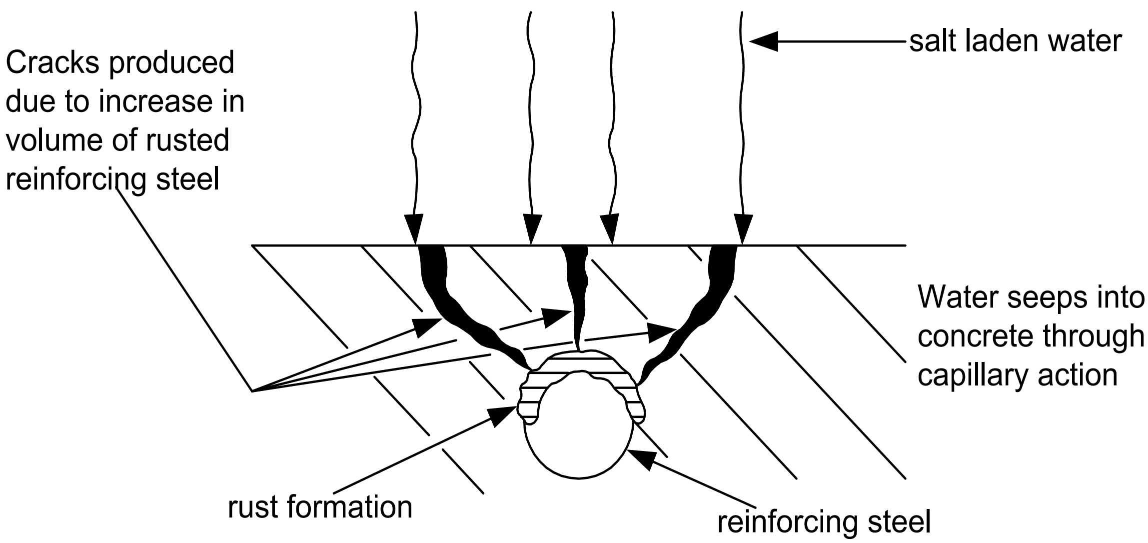


Figure 2.2.4(a) Process Leading to Corrosion of Reinforcement

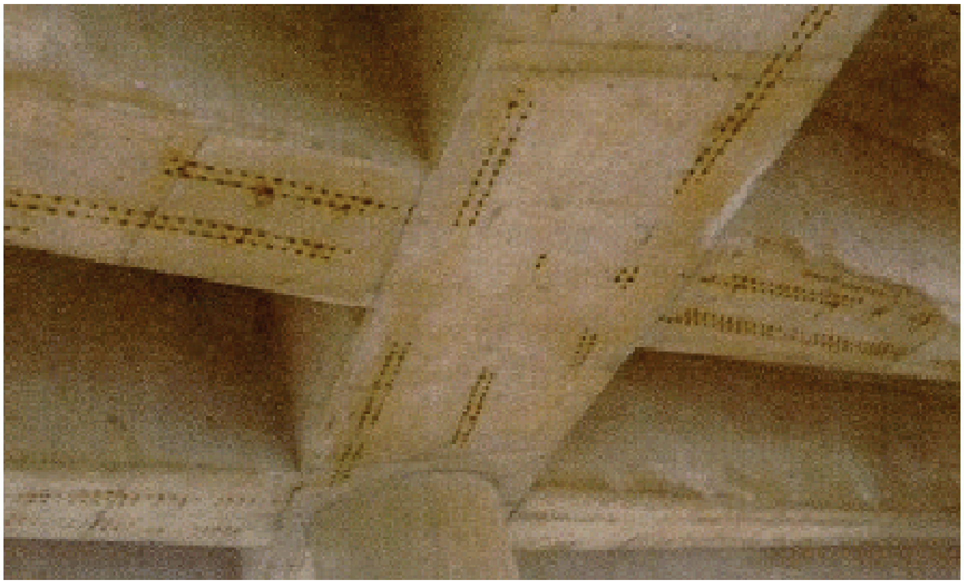


Figure 2.2.4(b) Light Stains on Concrete Surface Indicating Corrosion of Reinforcement

Figure 2.2.5 Very Severe Spalling and Delamination in Concrete Beams

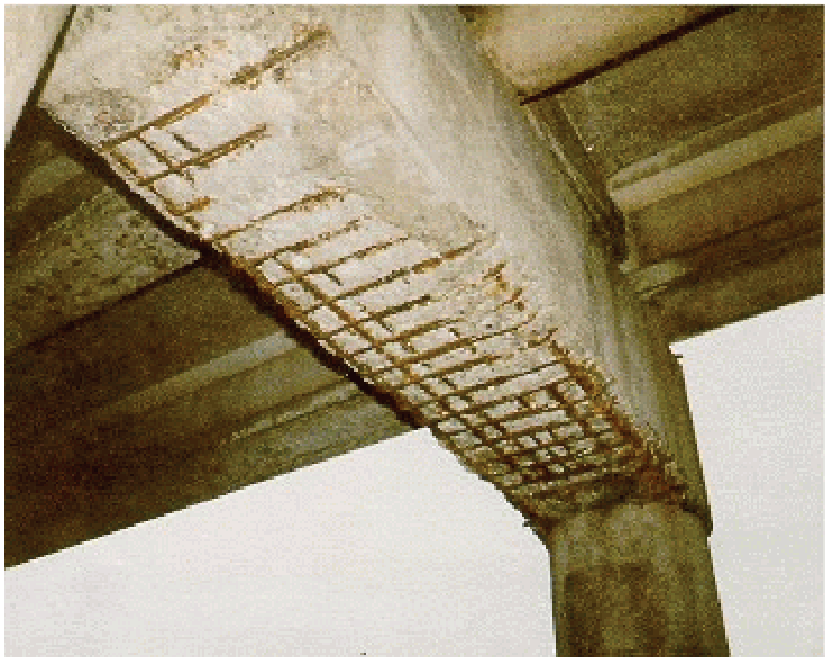


Figure 2.2.6(a) Very Severe Spalling in a Concrete Pier Cap due to Corrosion of Reinforcement

Figure 2.2.6(b) Severe Localized Spalling

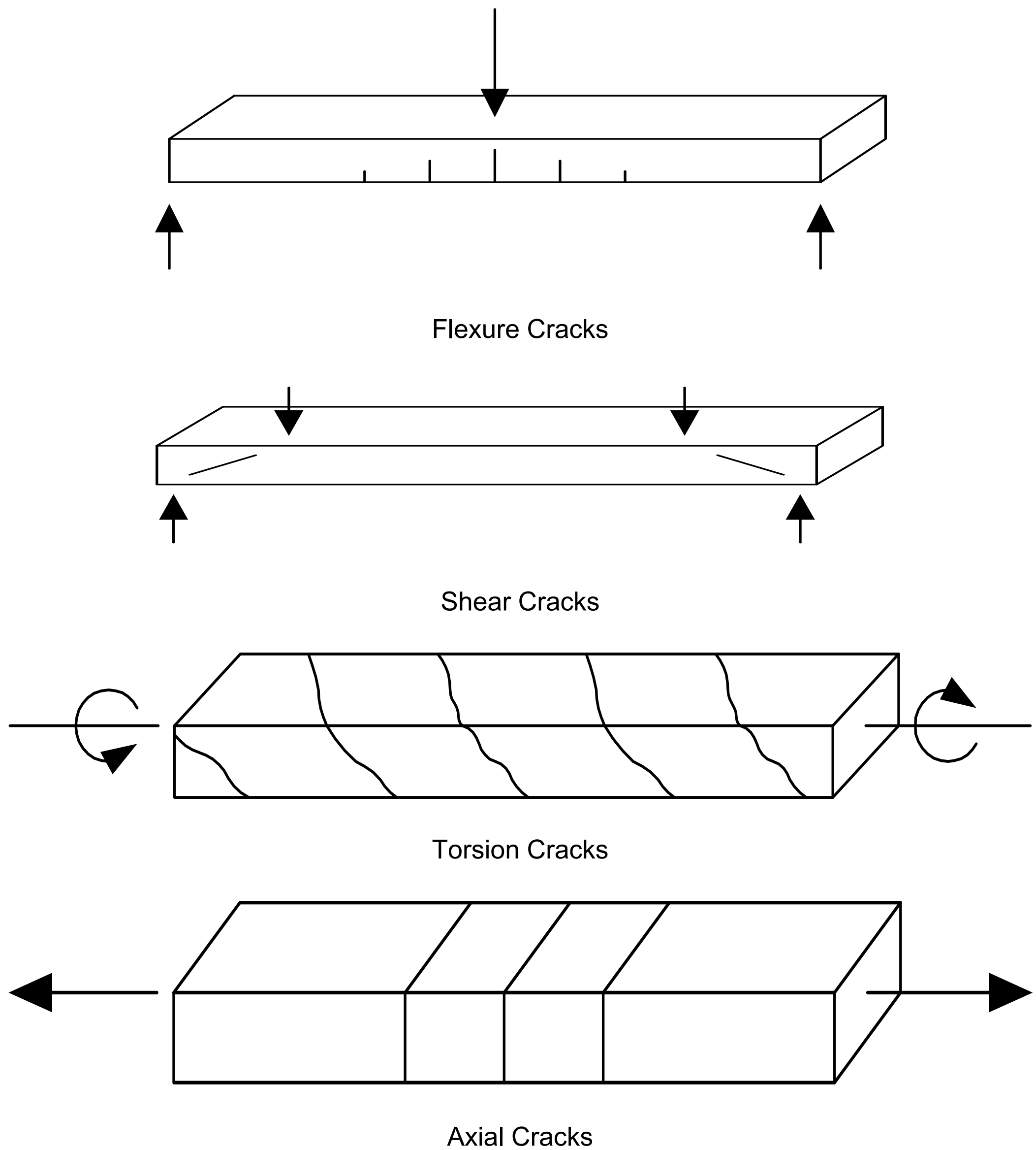


Figure 2.2.7(a) Cracks Caused By Loading

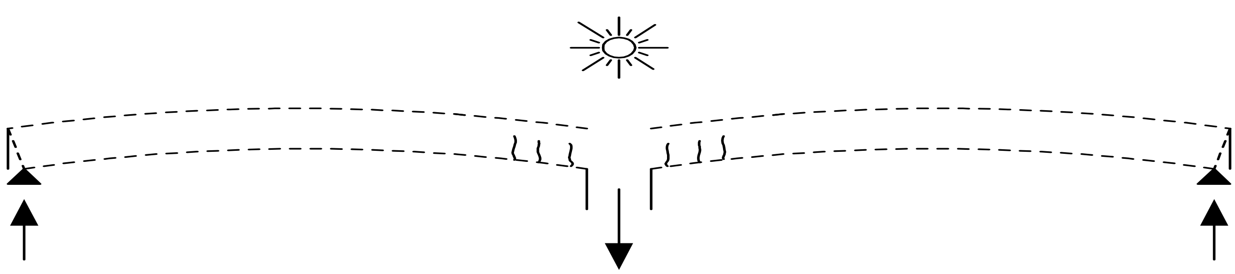


Figure 2.2.7(b) External Restraint-Induced Cracks
(due to temperature increase in top surface of beam)

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

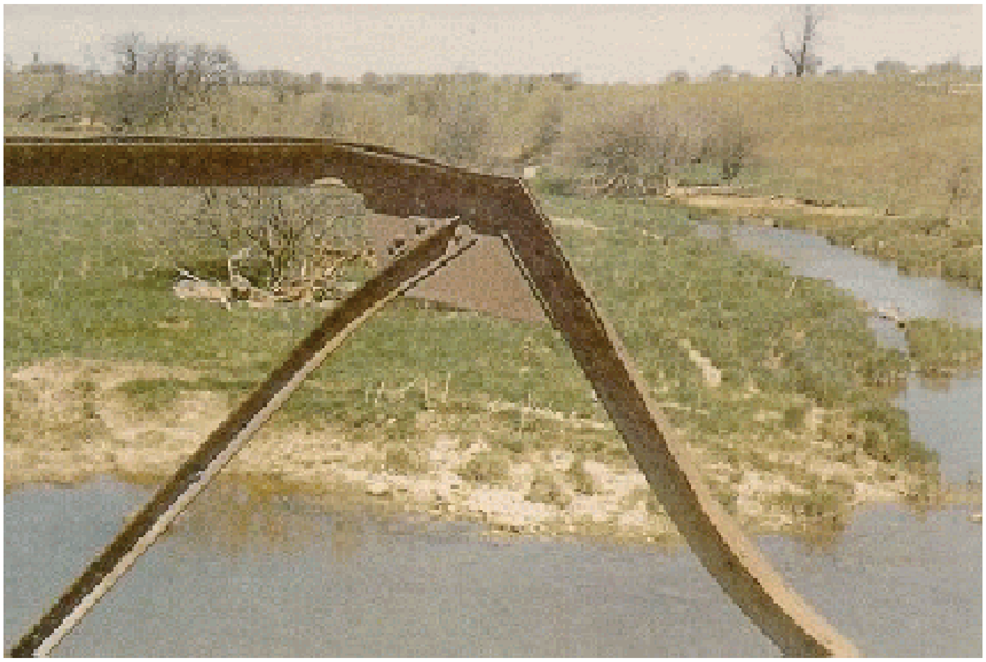
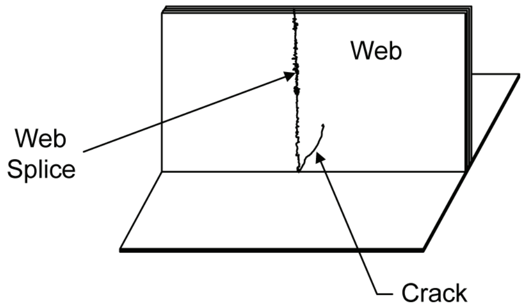
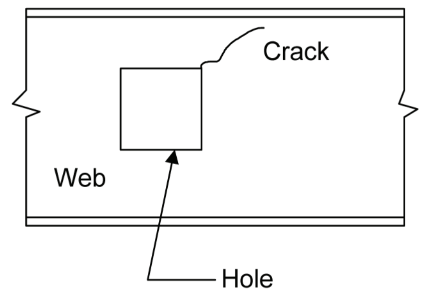


Figure 2.3.2 Very Severe Permanent Deformations caused by Impact

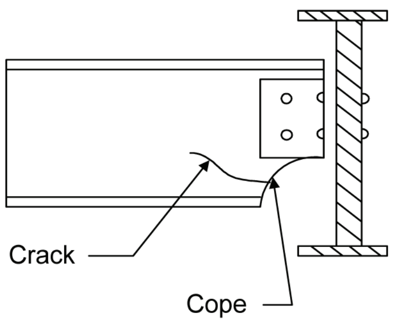
Figure 2.3.3(a) Very Wide Cracks in a Diaphragm



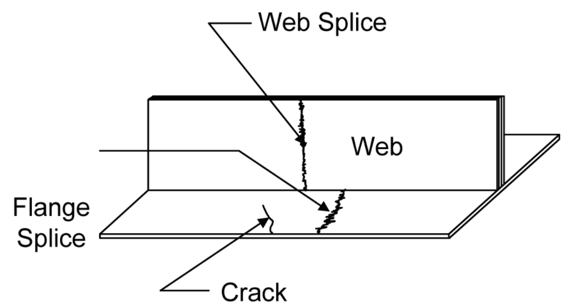
Crack in Web at Web Splice



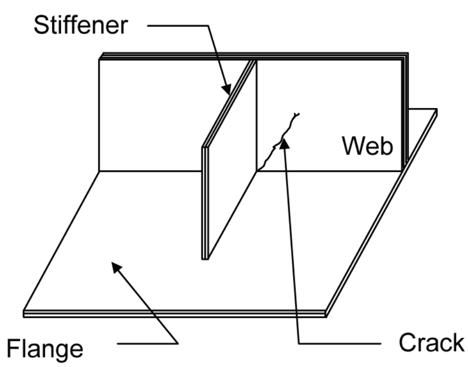
Crack at Hole in Web



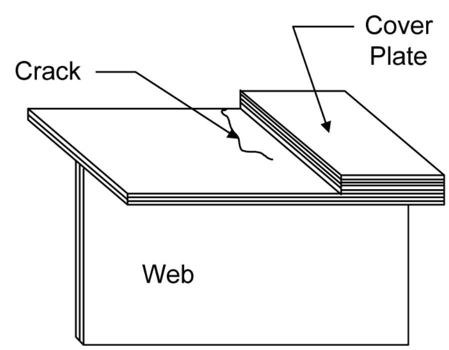
Crack in Cope of Web at a Connection



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

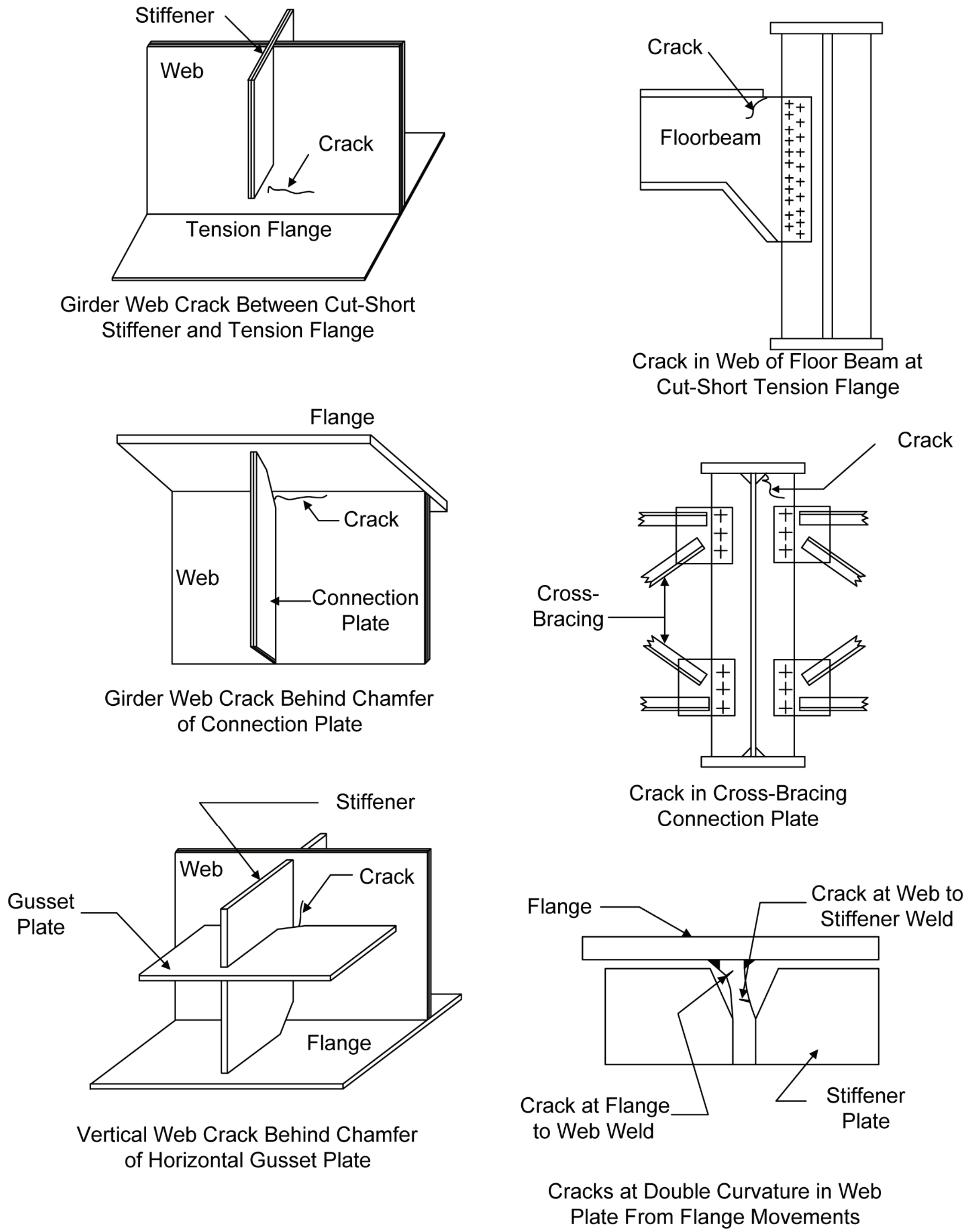


Figure 2.3.3(b) Common Crack Locations in Steel (cont'd)

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

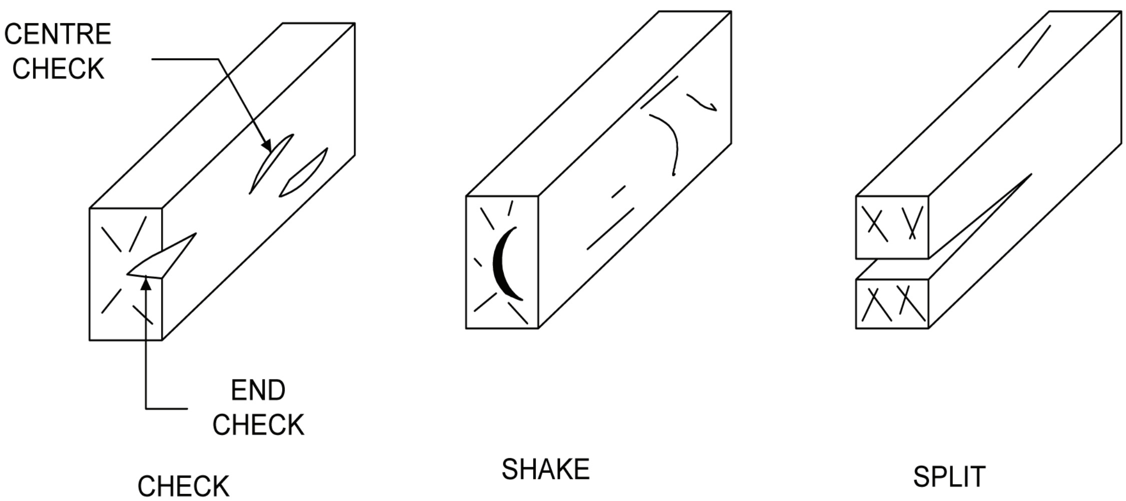


Figure 2.4.1(b) Checks, Shakes and Splits in Wood

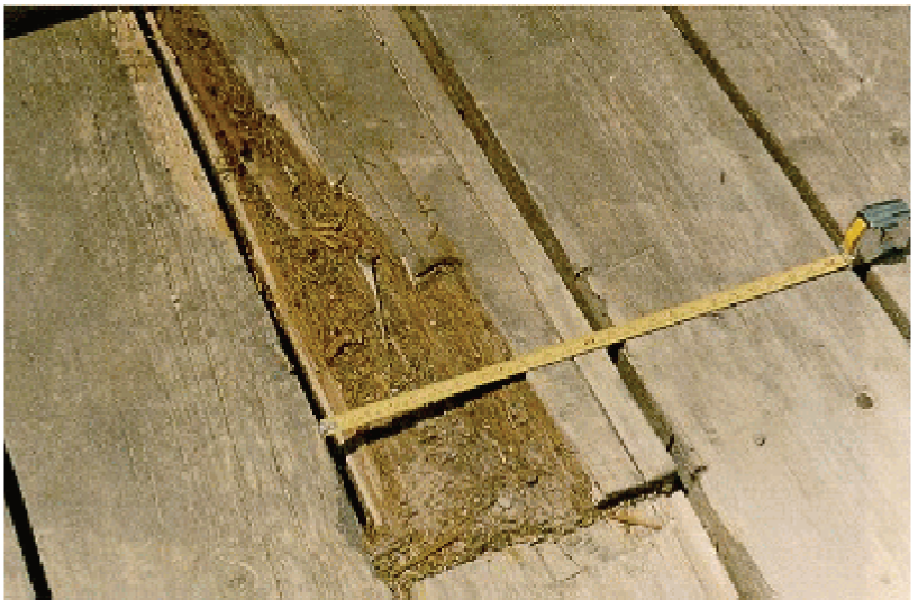
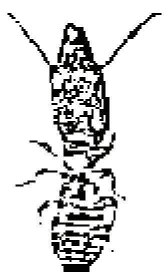
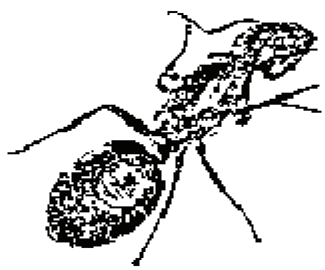


Figure 2.4.2 Very Severe Brown Rot



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.

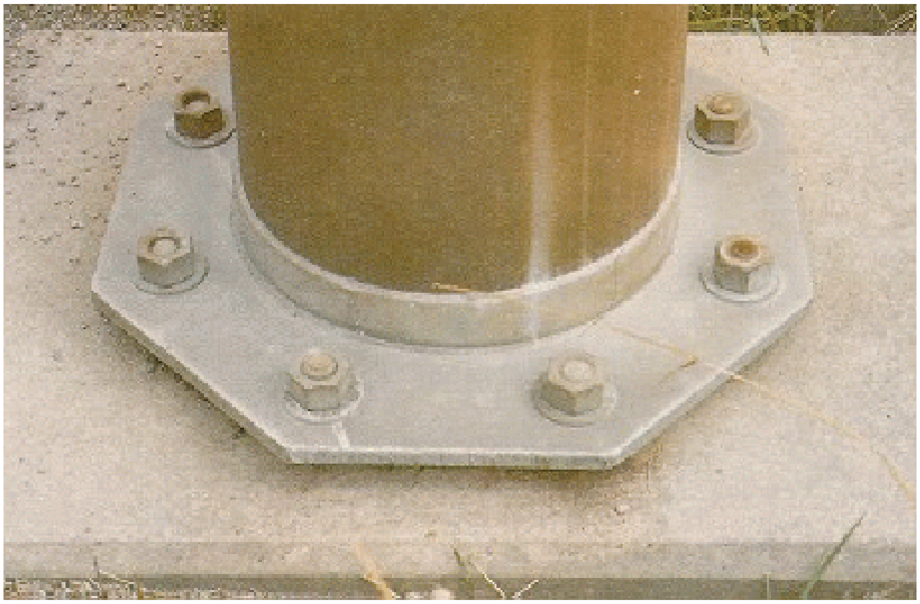


Figure 2.6.1 Light Corrosion

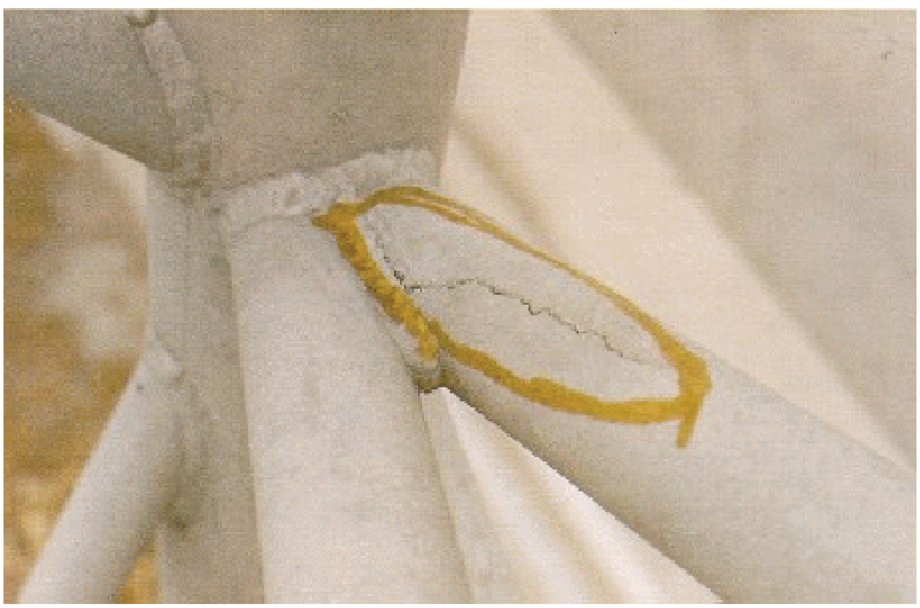


Figure 2.6.2 Wide Crack

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.

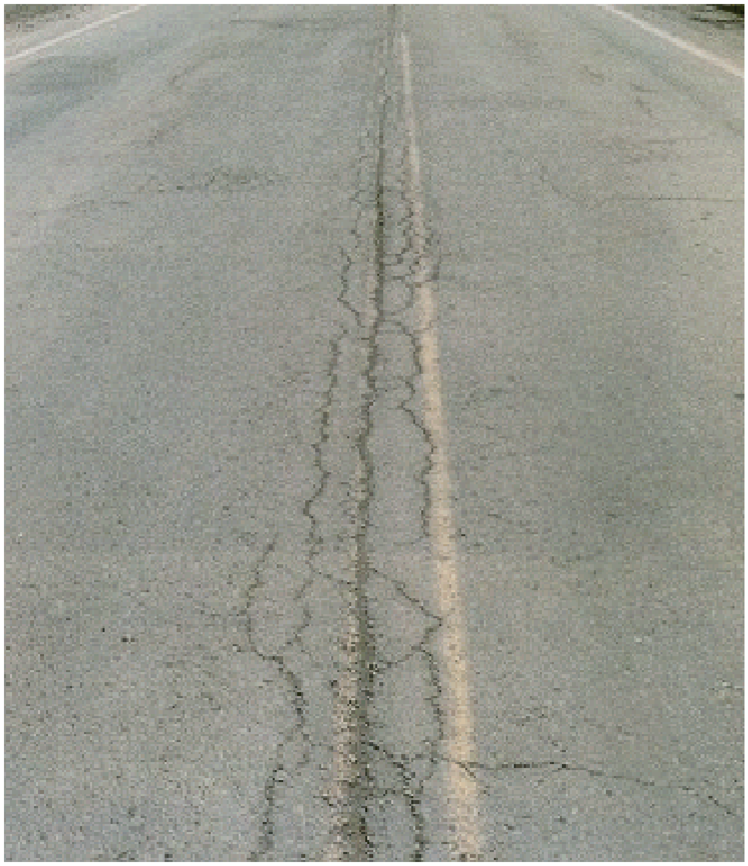


Figure 2.7.1(a) Medium Longitudinal Crack

Figure 2.7.1(b) Medium Transverse Crack

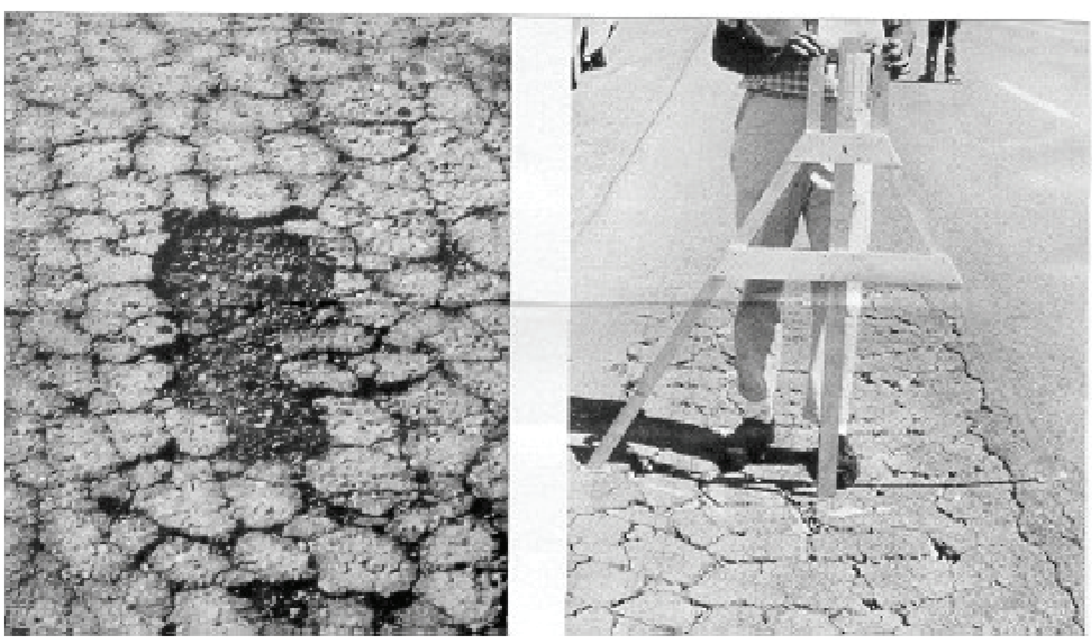


Figure 2.7.1(c) Severe Alligator Cracks

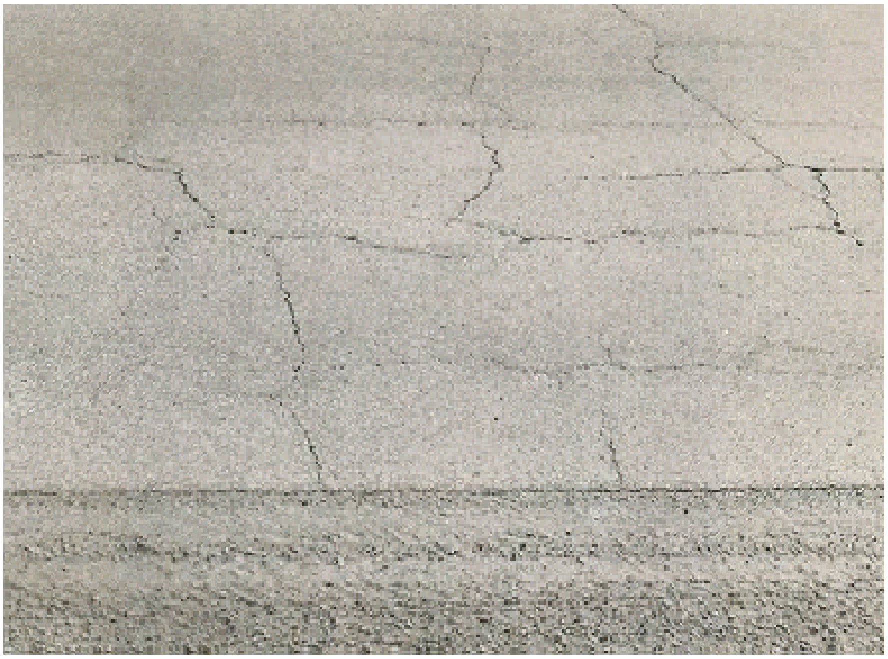


Figure 2.7.1(d) Light Map Cracks

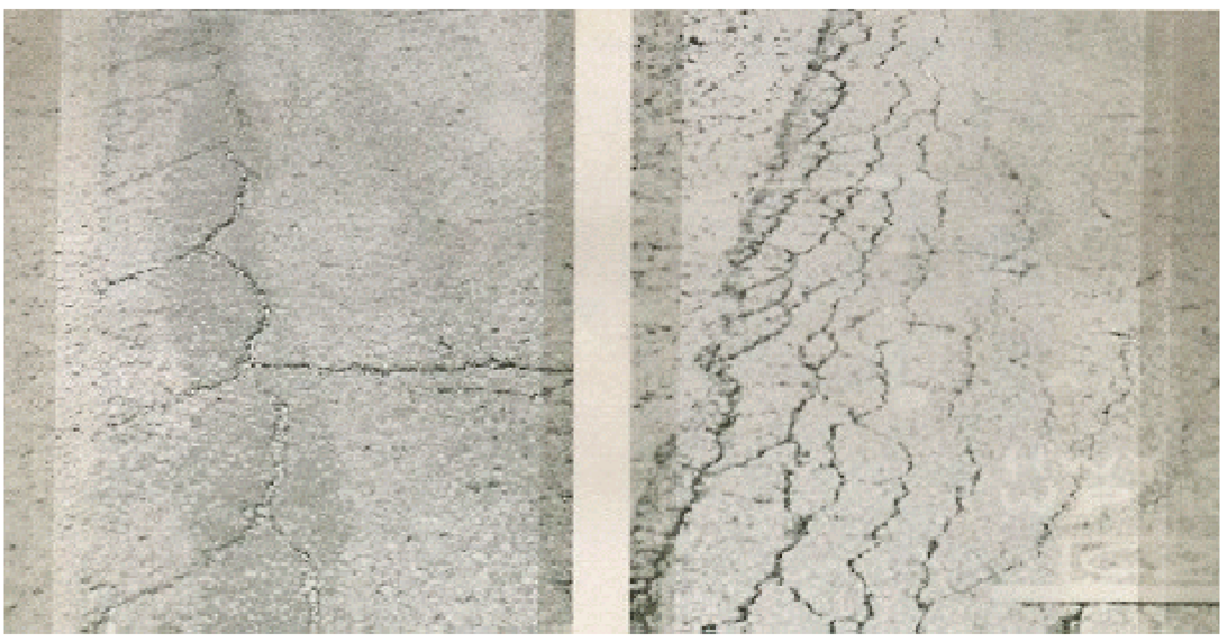


Figure 2.7.1(e) Medium Progressive Edge Cracks

Figure 2.7.2 Severe Ravelling

Figure 2.7.4 Severe Pothole

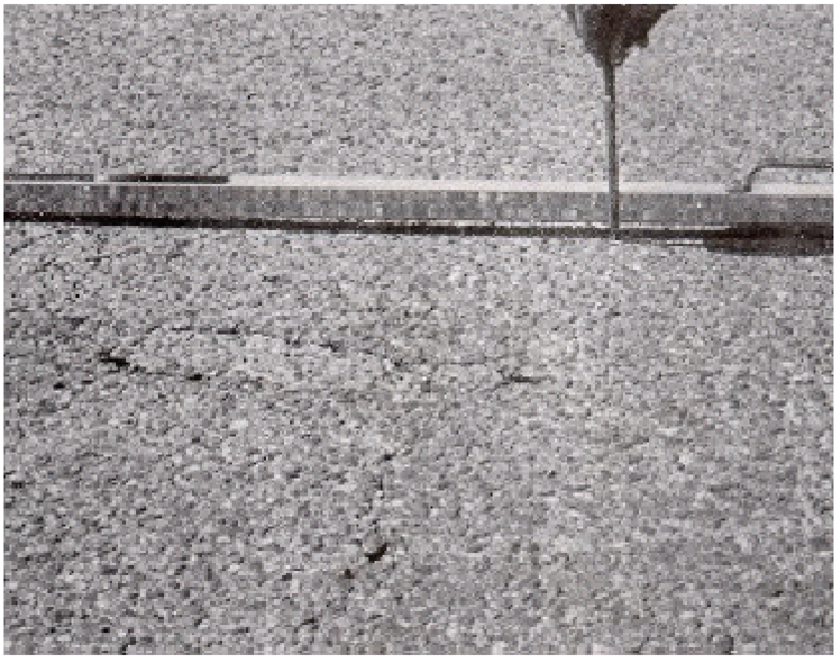


Figure 2.7.5 Medium Wheel Track Rutting

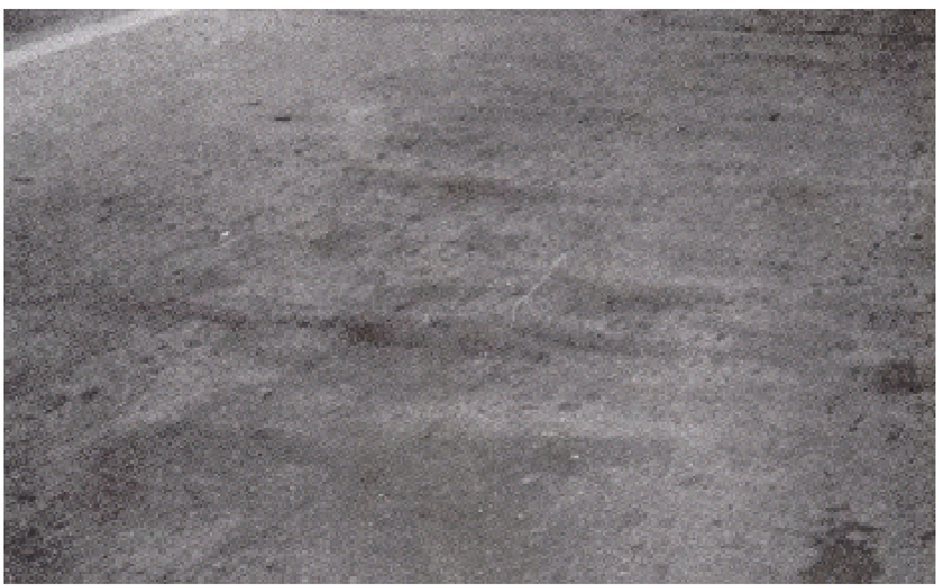


Figure 2.7.6 Severe Rippling

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

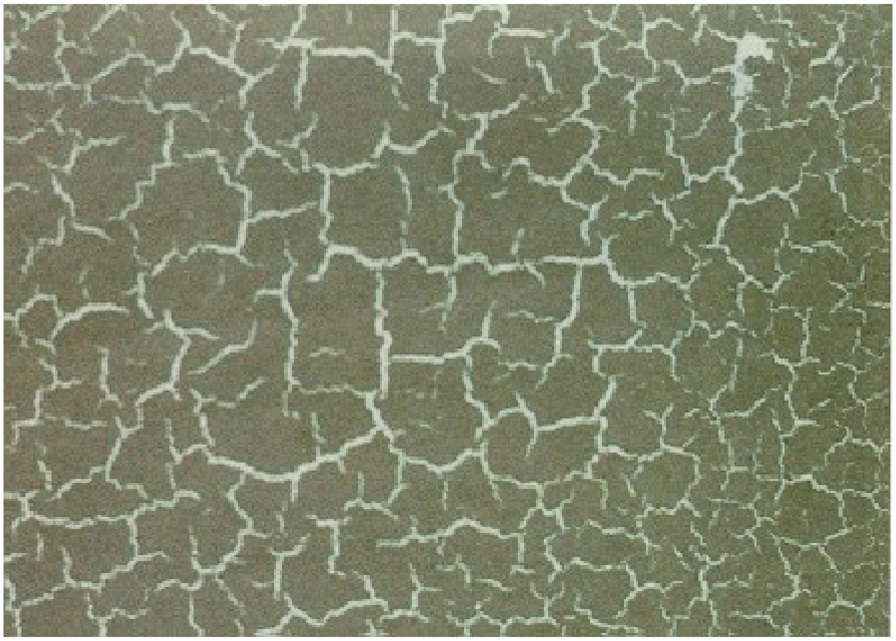


Figure 2.8.1(c) Alligatoring (typical mud crack pattern)

Figure 2.8.1(d) Chemical Attack

Figure 2.8.2(a) Undercutting

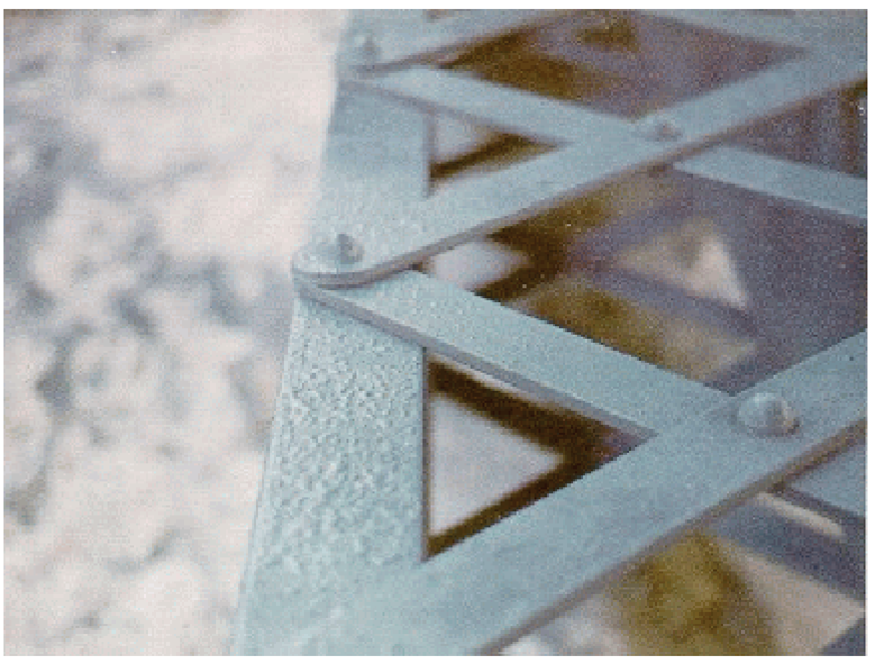


Figure 2.8.2(b) Blisters

Figure 2.8.2(c) Intercoat Delamination

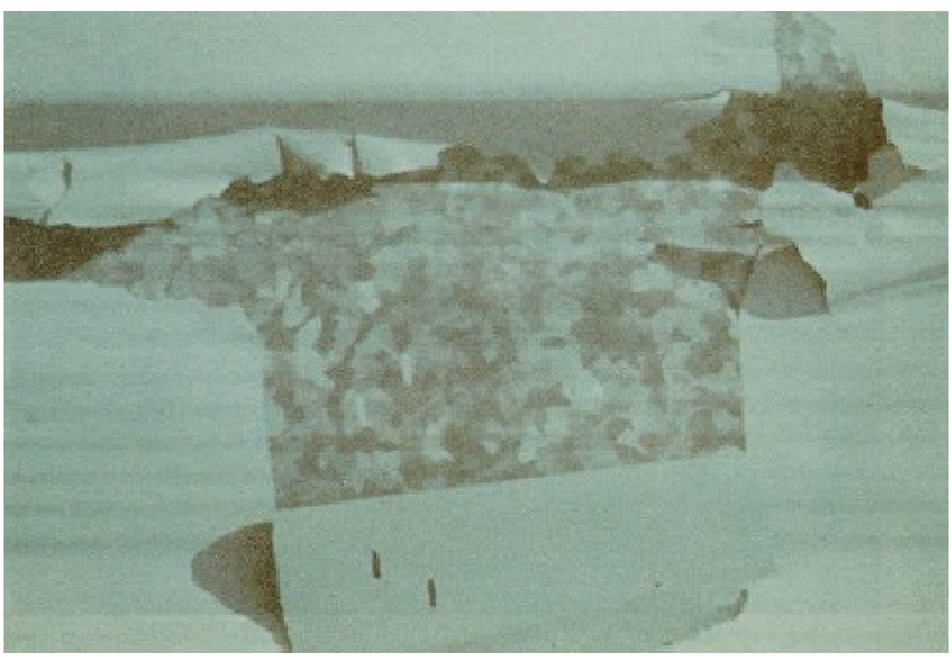


Figure 2.8.2(d) Peeling

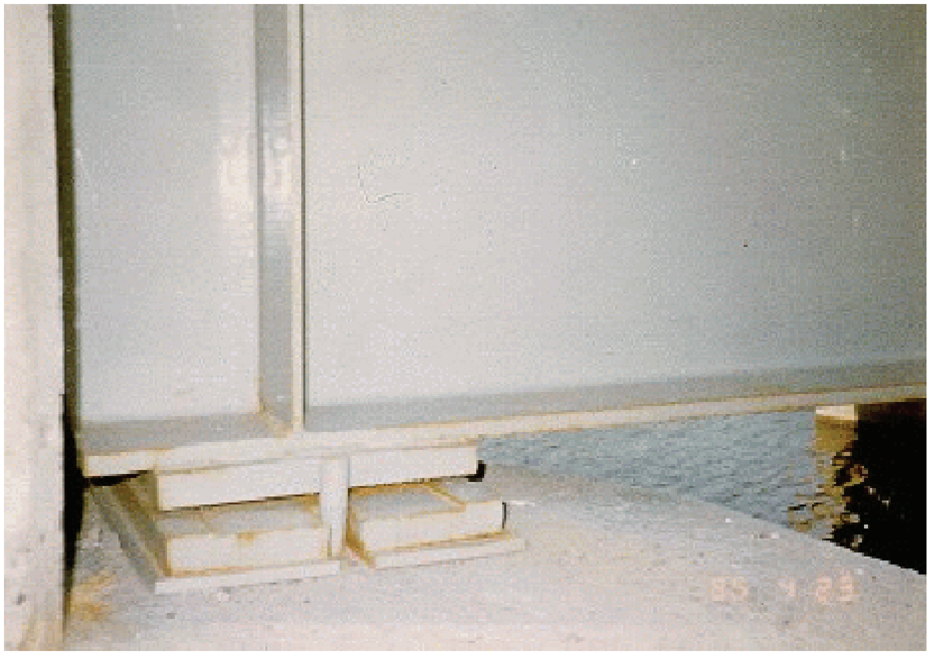


Figure 2.8.3(a) Edge Defects

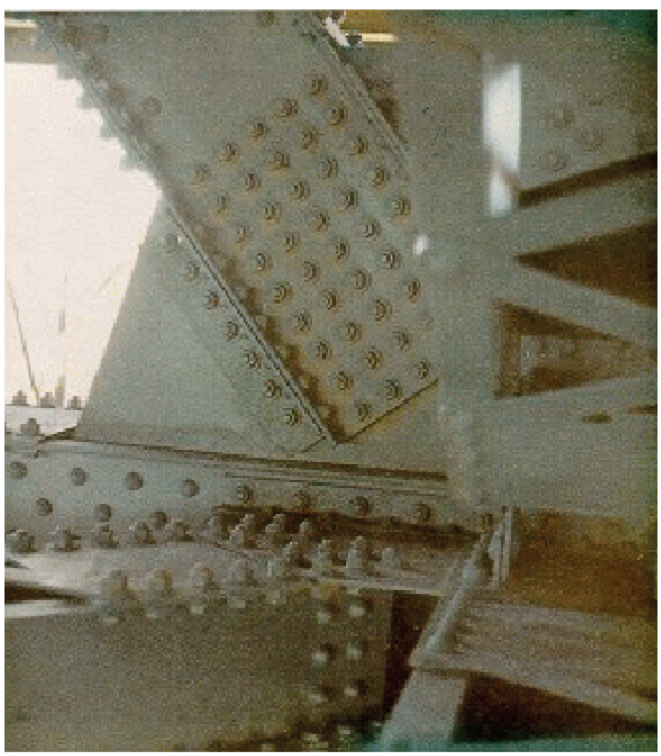


Figure 2.8.3(b) Shadows

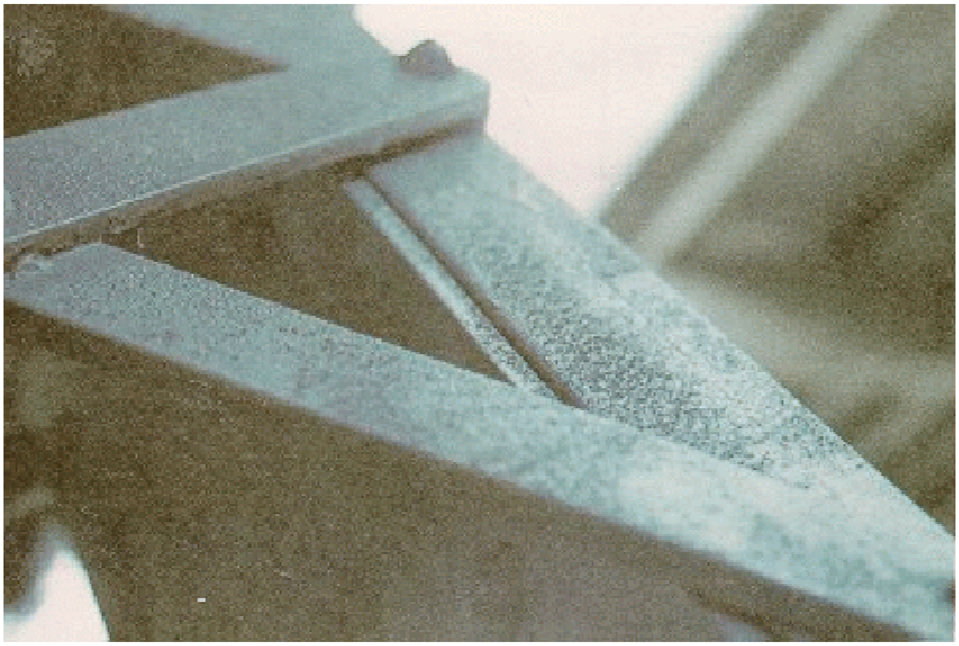


Figure 2.8.3(c) Overspray

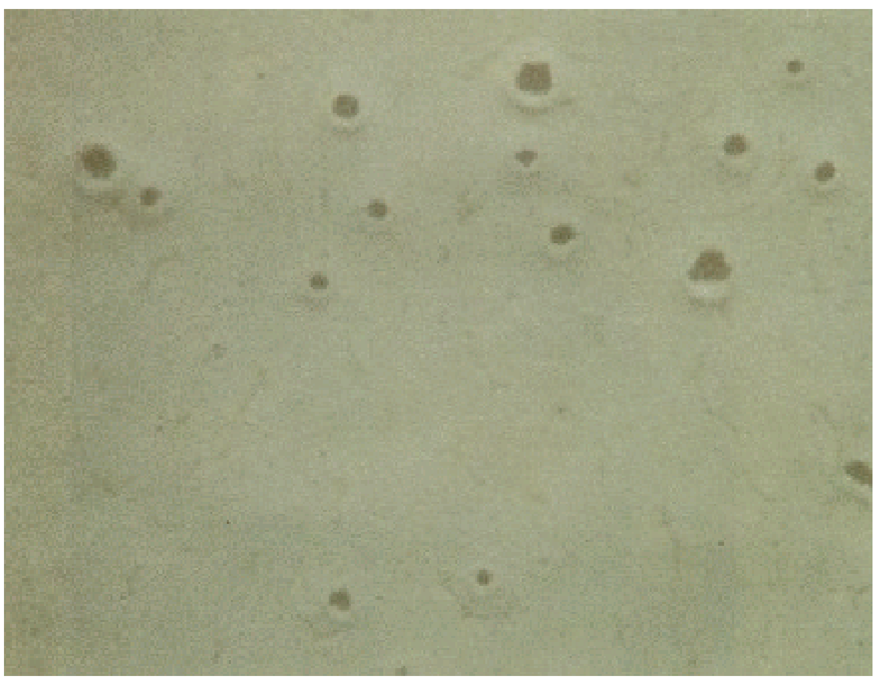


Figure 2.8.3(d) Pinholing

Figure 2.8.3(c) Runs and Sags

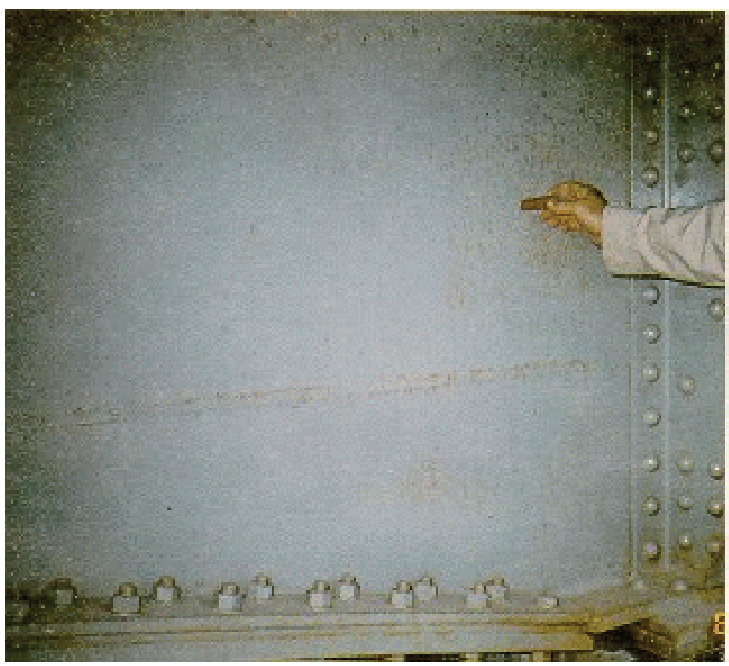


Figure 2.8.3(d) Pinpoint Rusting

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.

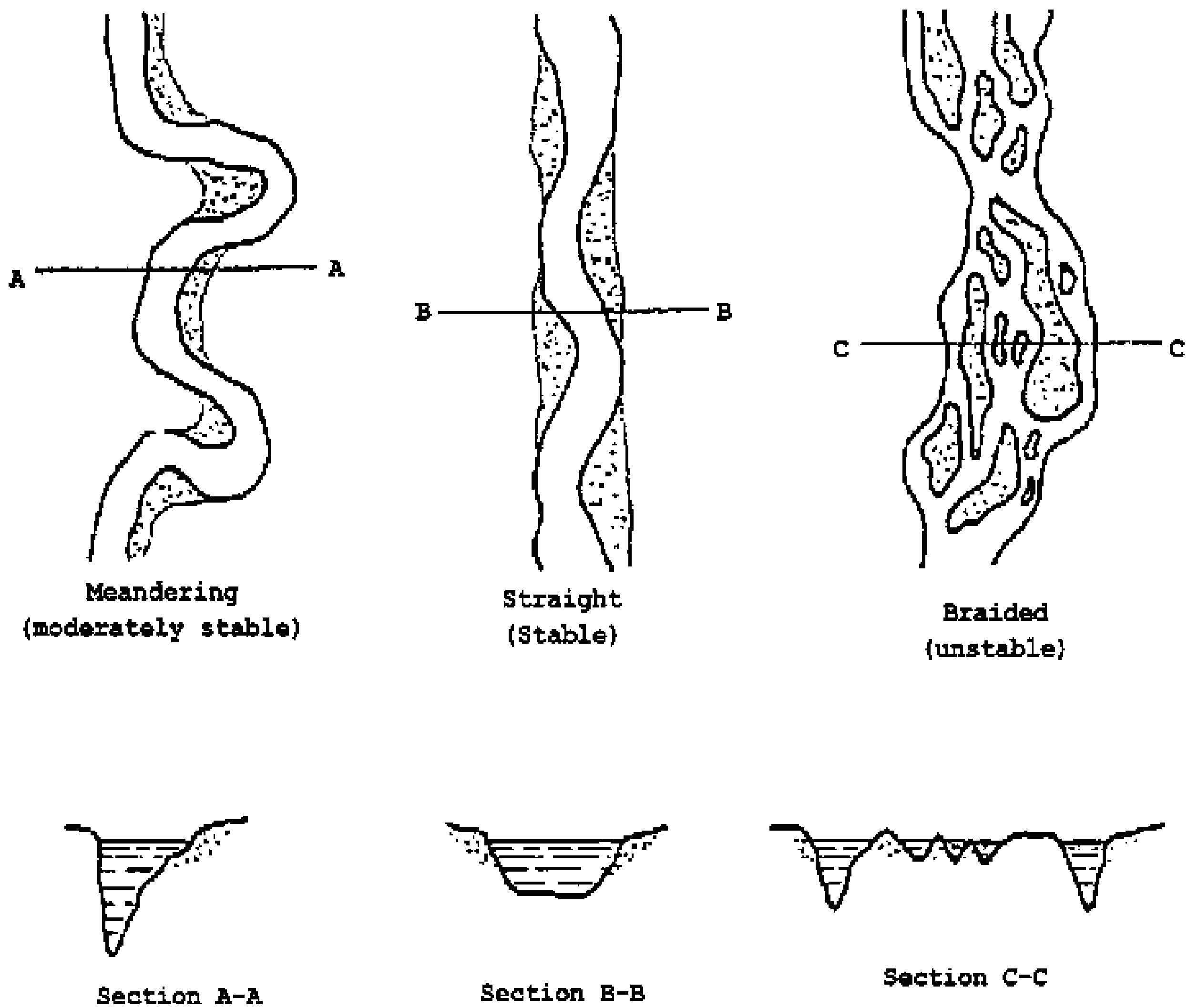
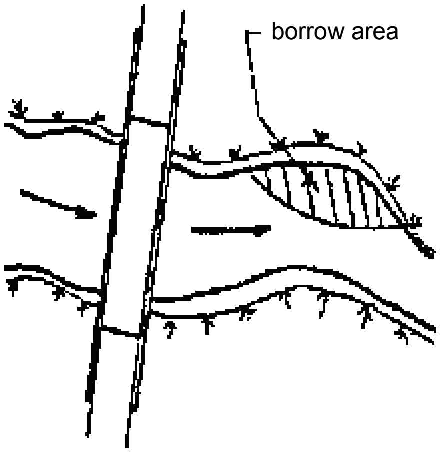
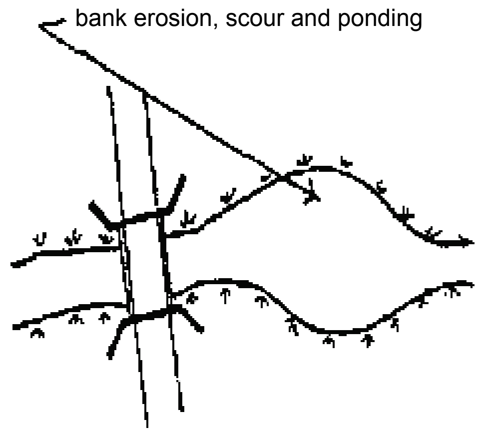


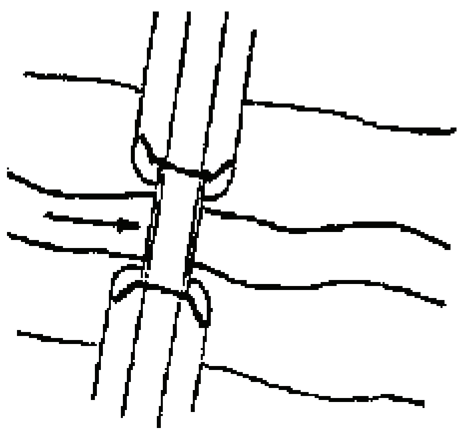
Figure 3.1 Principle Types of Waterways



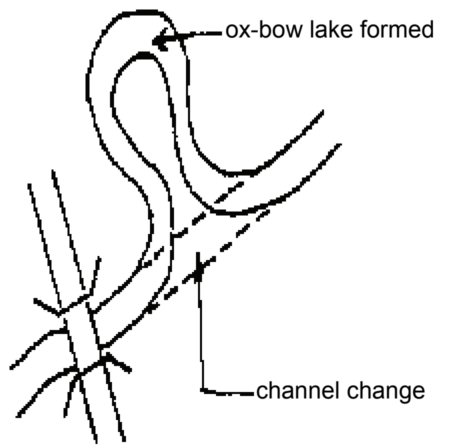
Removing large quantities of gravel from the channel bottom causes degradation upstream.



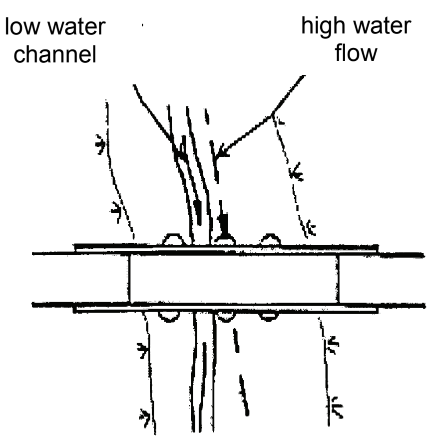
A firm channel bottom or constriction causes scour, bank erosion and ponding downstream.



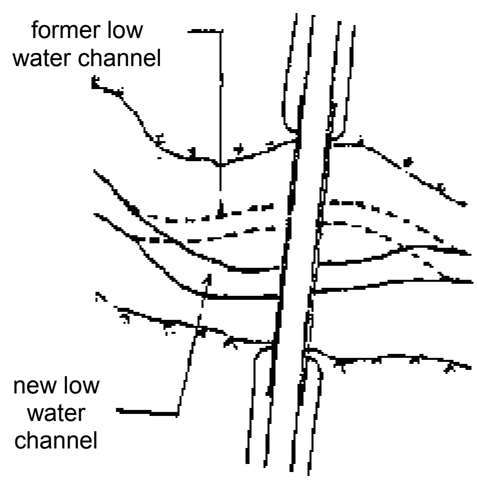
Channel constriction produces scour around the bridge during flood.



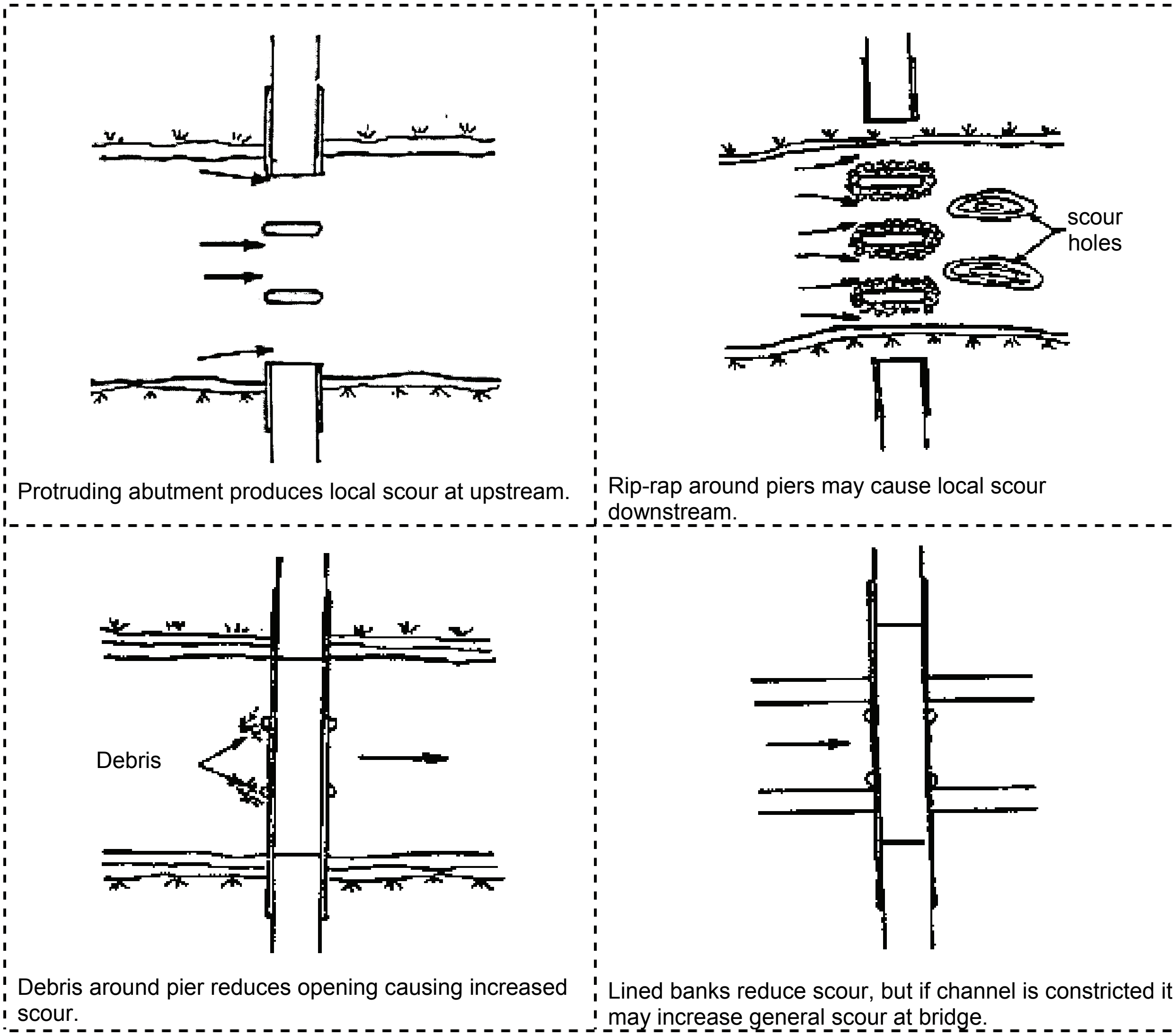
New channel cuts off ox-bow and steepens channel profile with increase in flow velocity.



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.

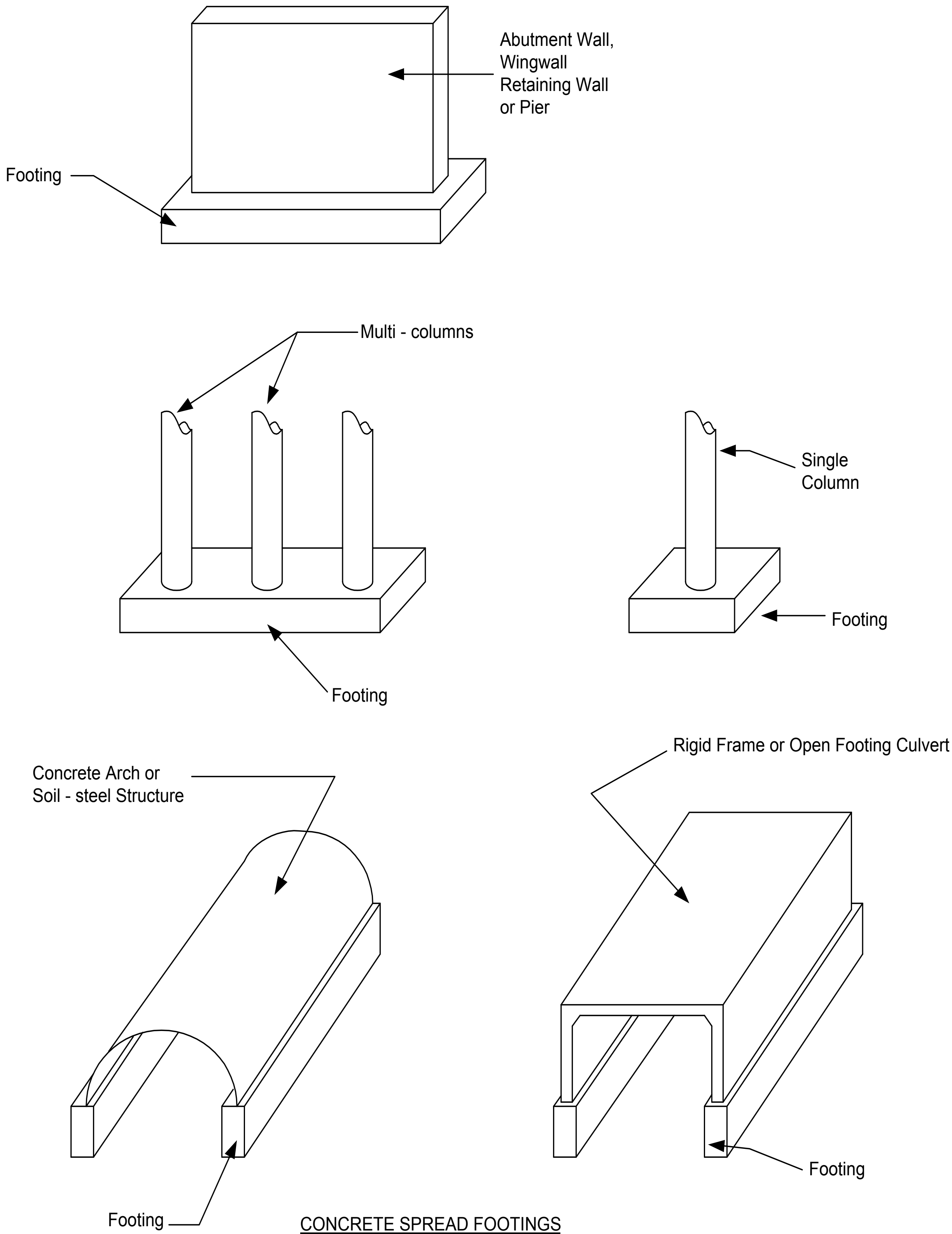
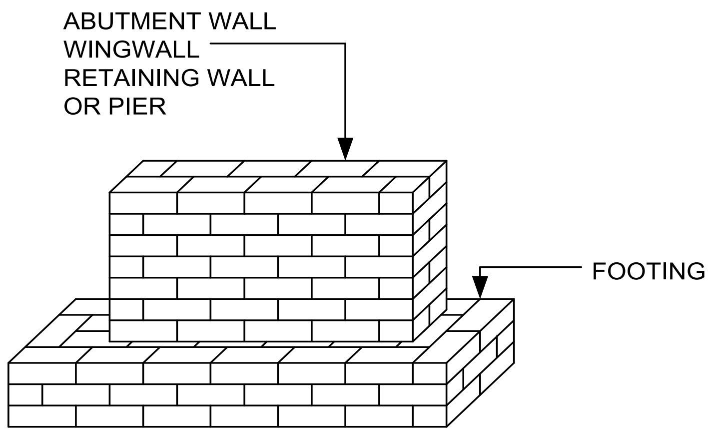
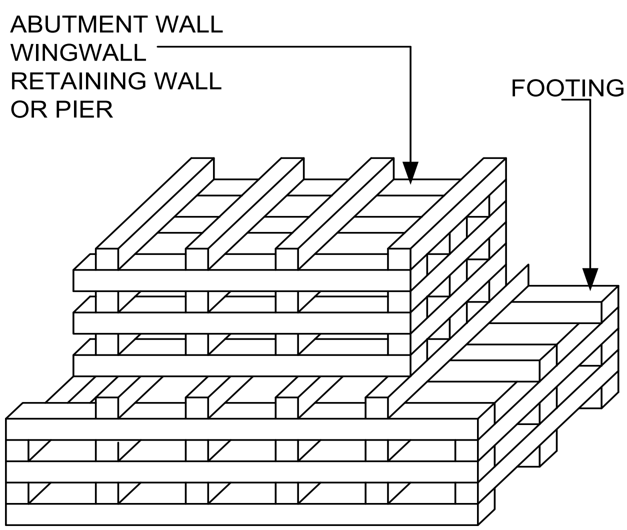


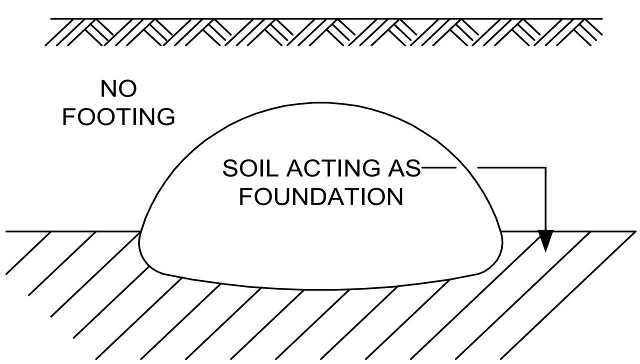
Figure 5.1.1(a) Typical Shallow Foundations



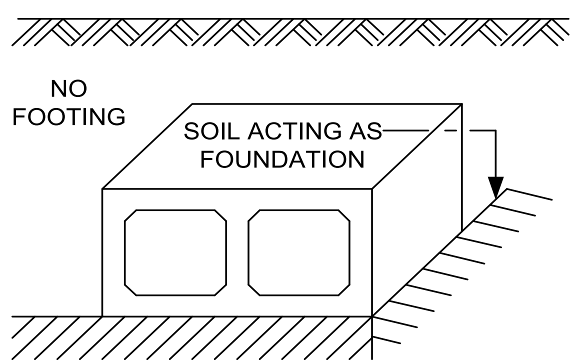
MASONRY FOOTING



WOOD CRIB FOOTING



SOIL STEEL STRUCTURE



BOX CULVERTS

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

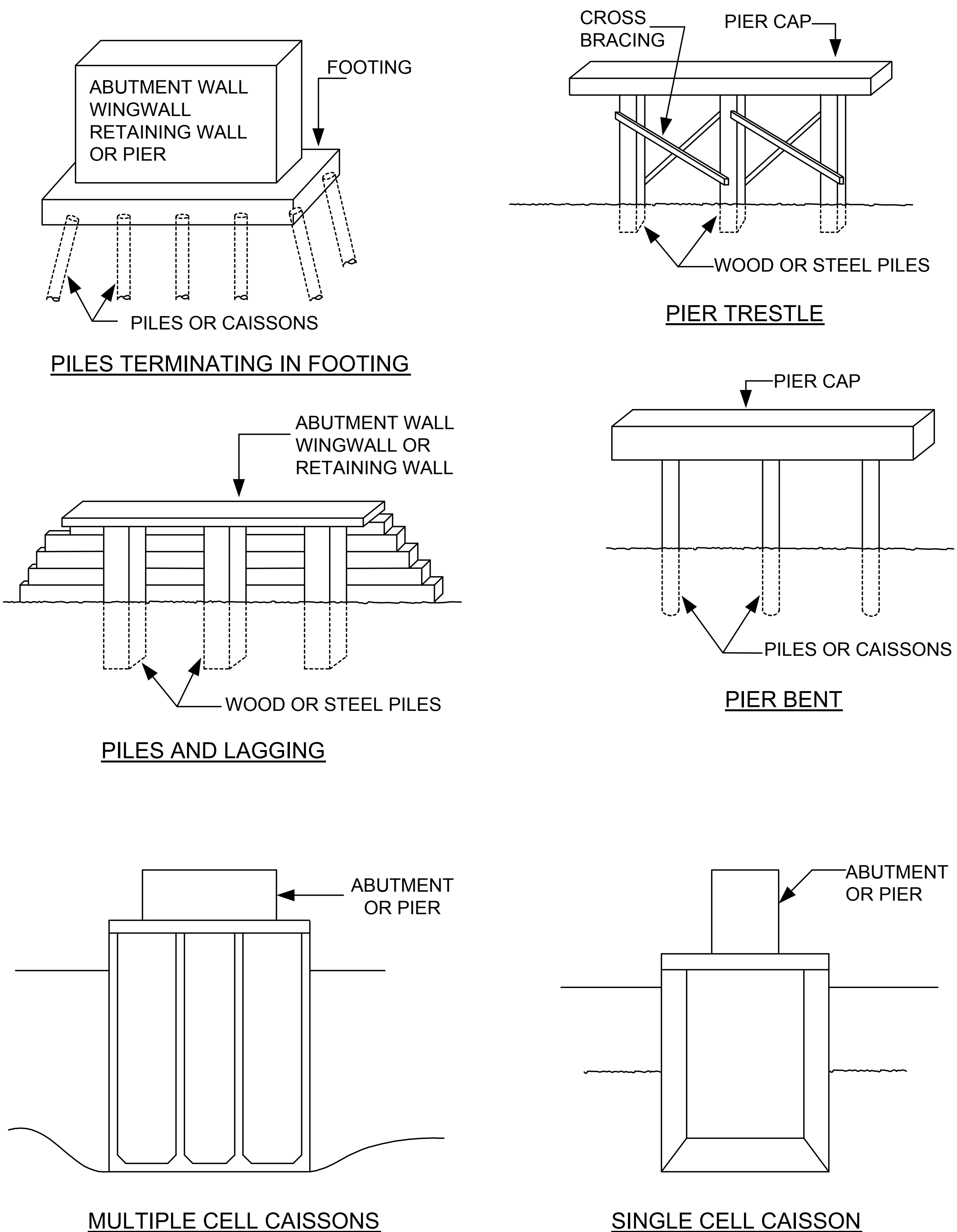


Figure 5.1.1(b) Typical Deep Foundations

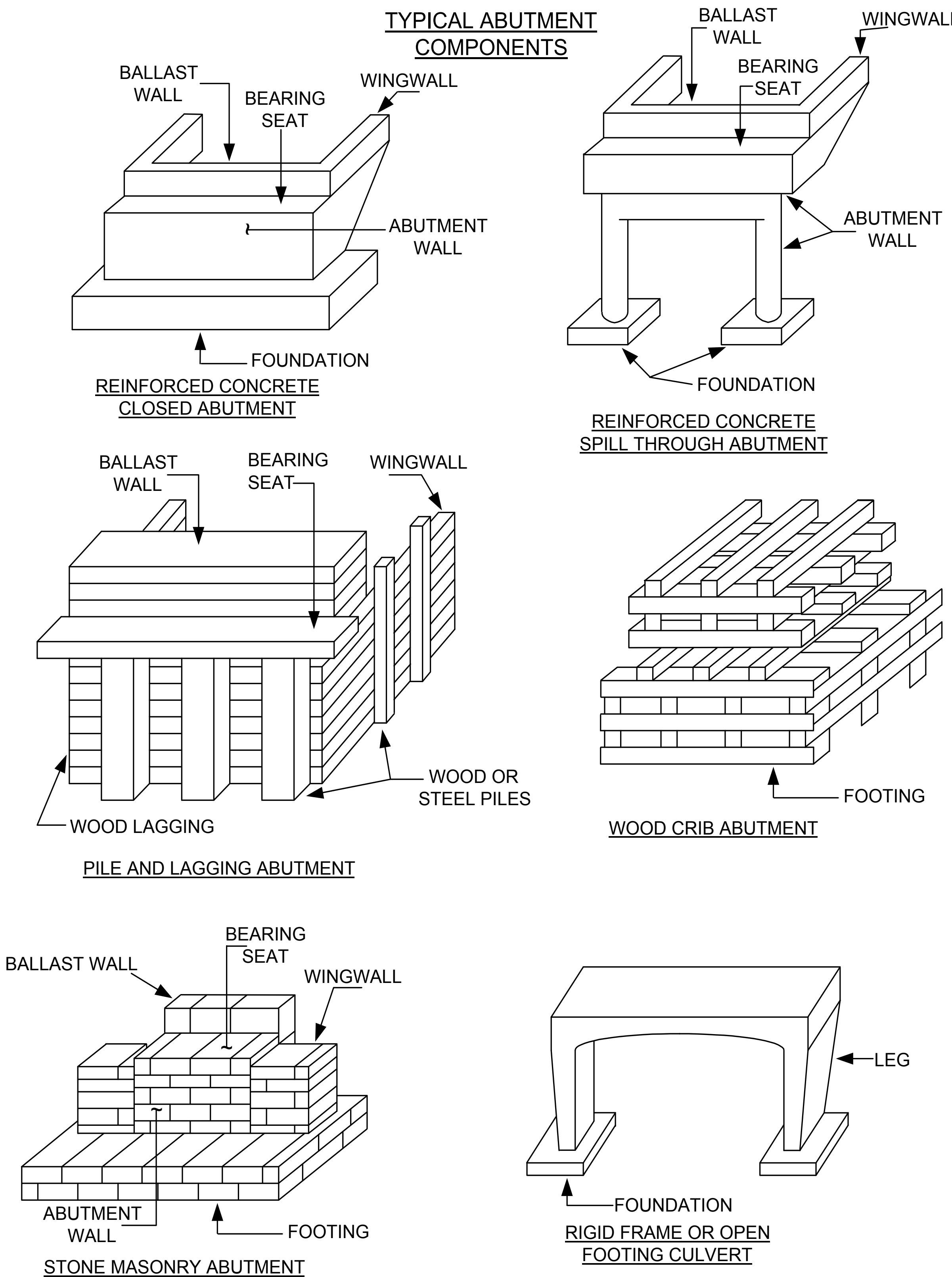


Figure 5.1.2(a) Typical Abutment Components

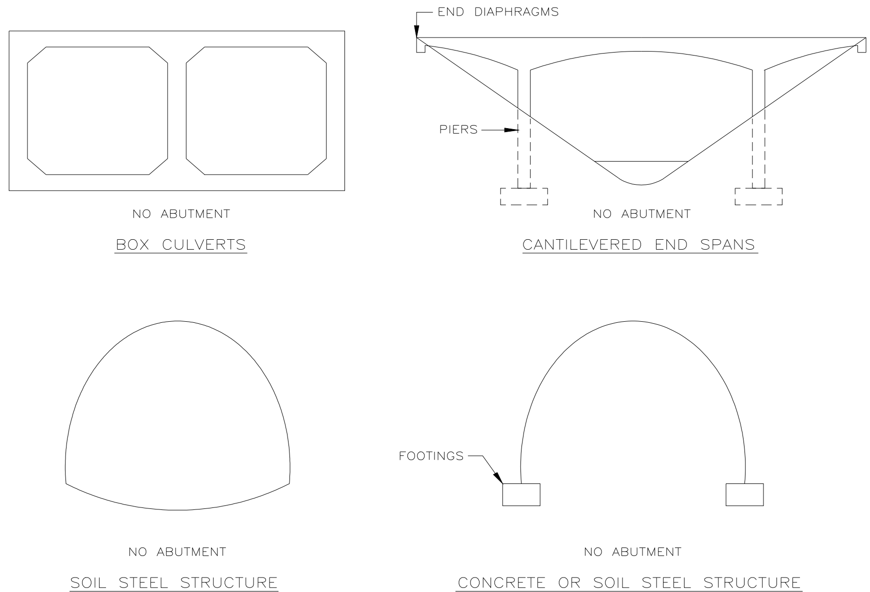


Figure 5.1.2(b) Structures Without Abutments

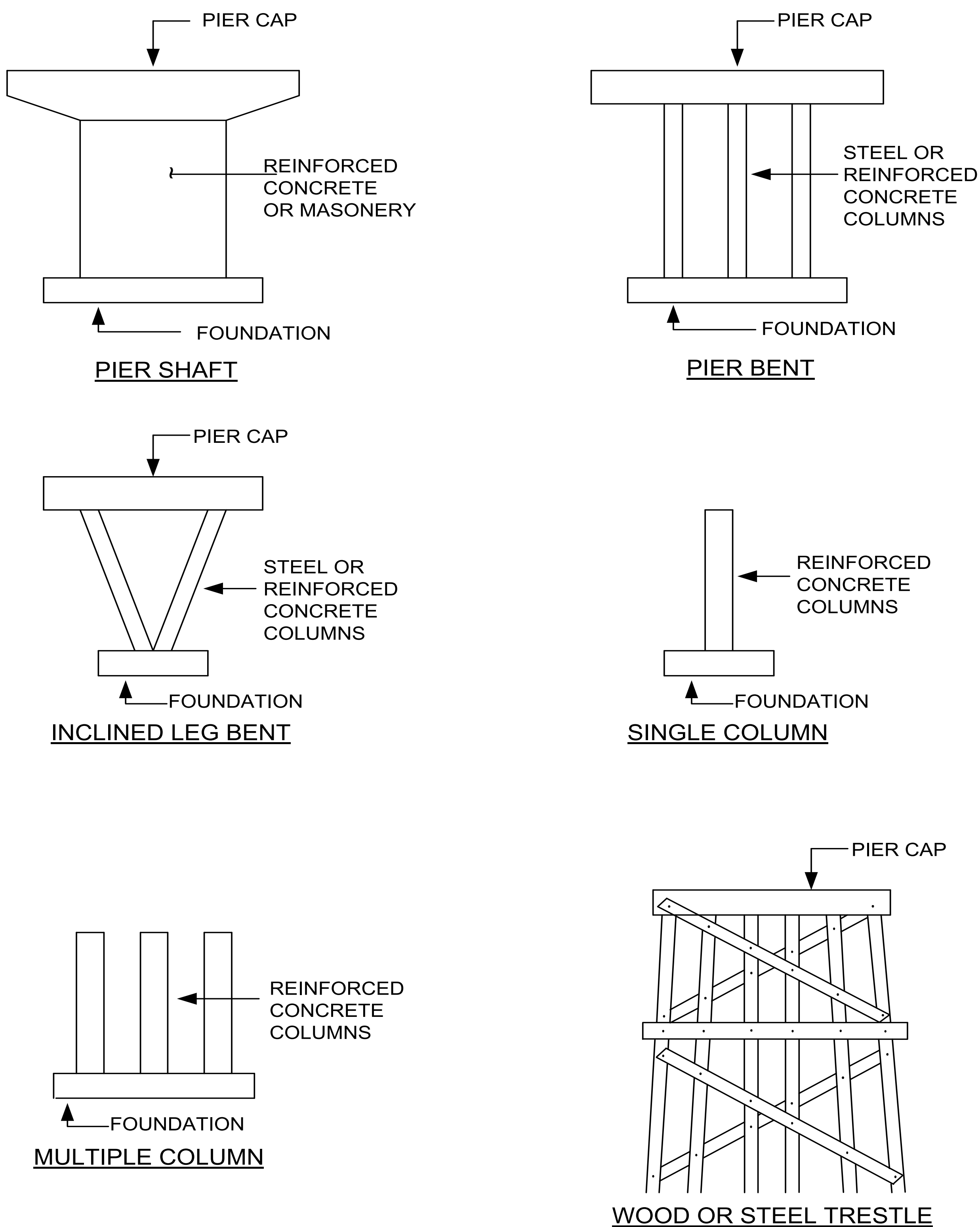


Figure 5.1.3 Typical Piers

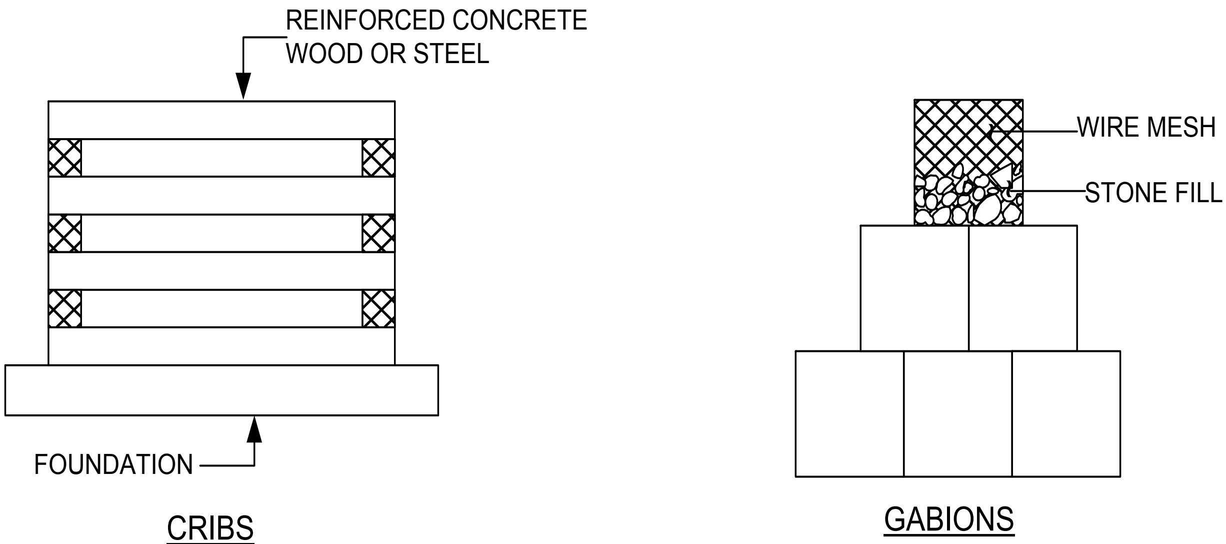


Figure 5.1.3 Typical Piers (cont'd)

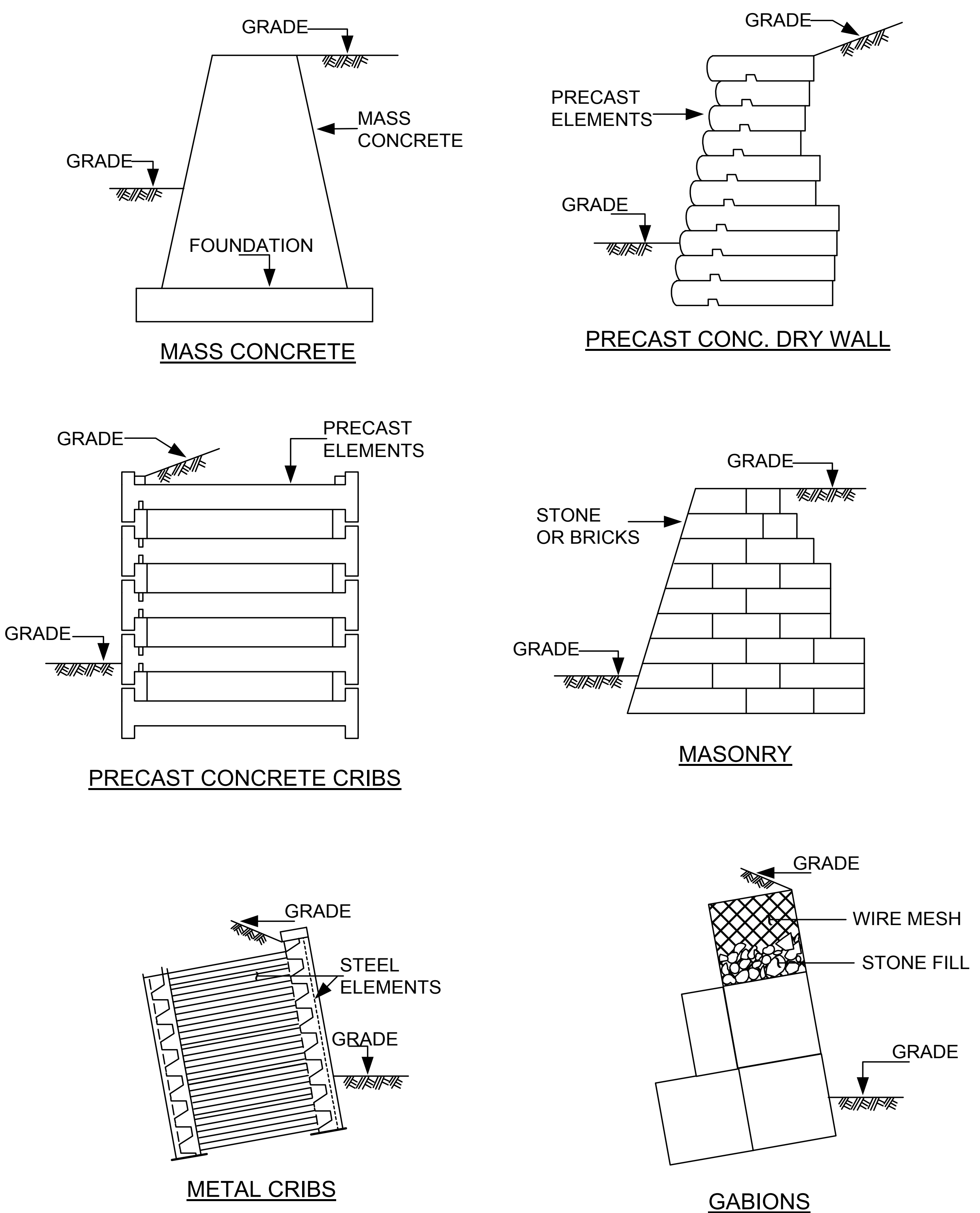


Figure 5.1.4(a) Typical Gravity Retaining Walls

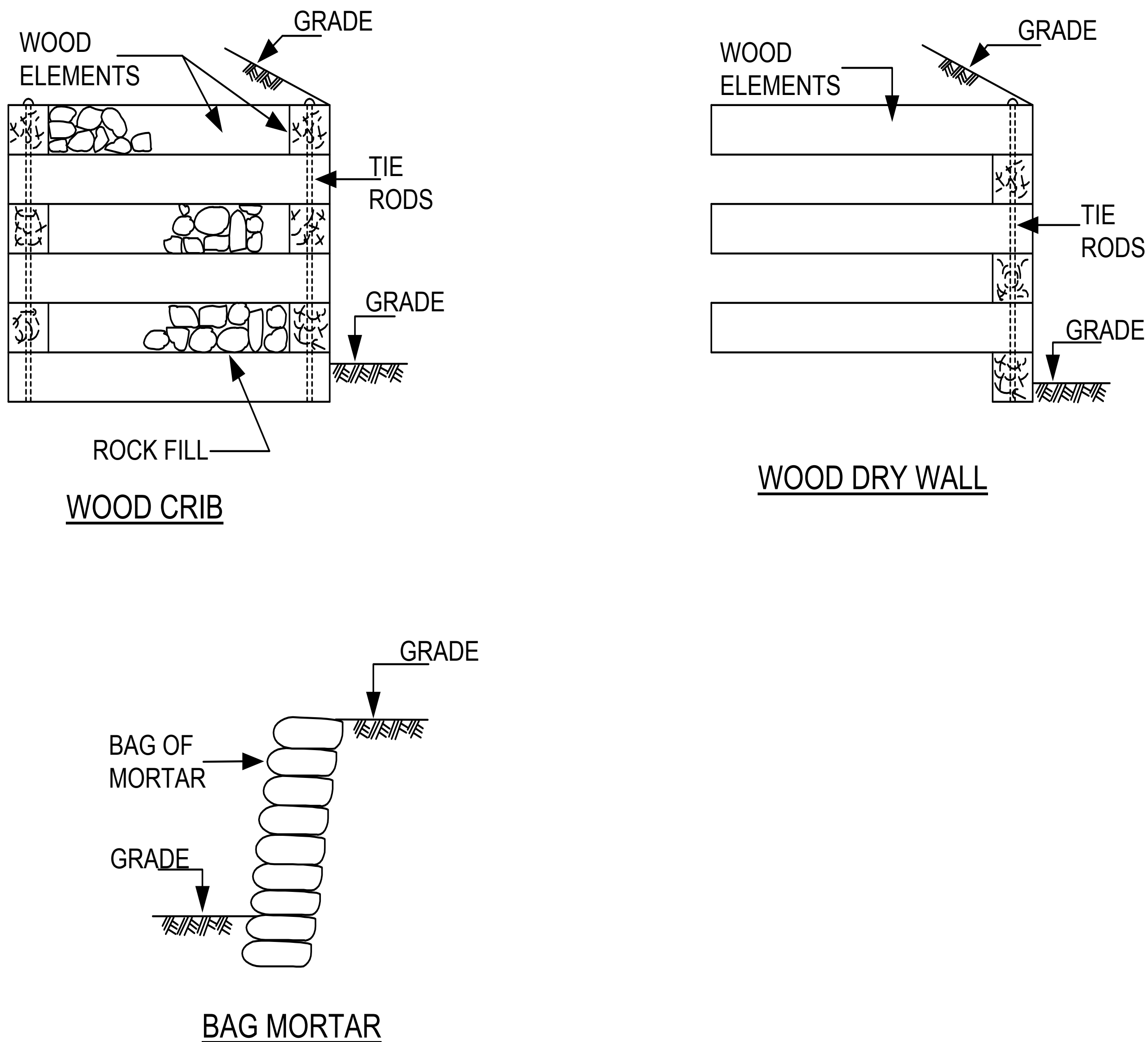


Figure 5.1.4(a) Typical Gravity Retaining Walls (cont'd)

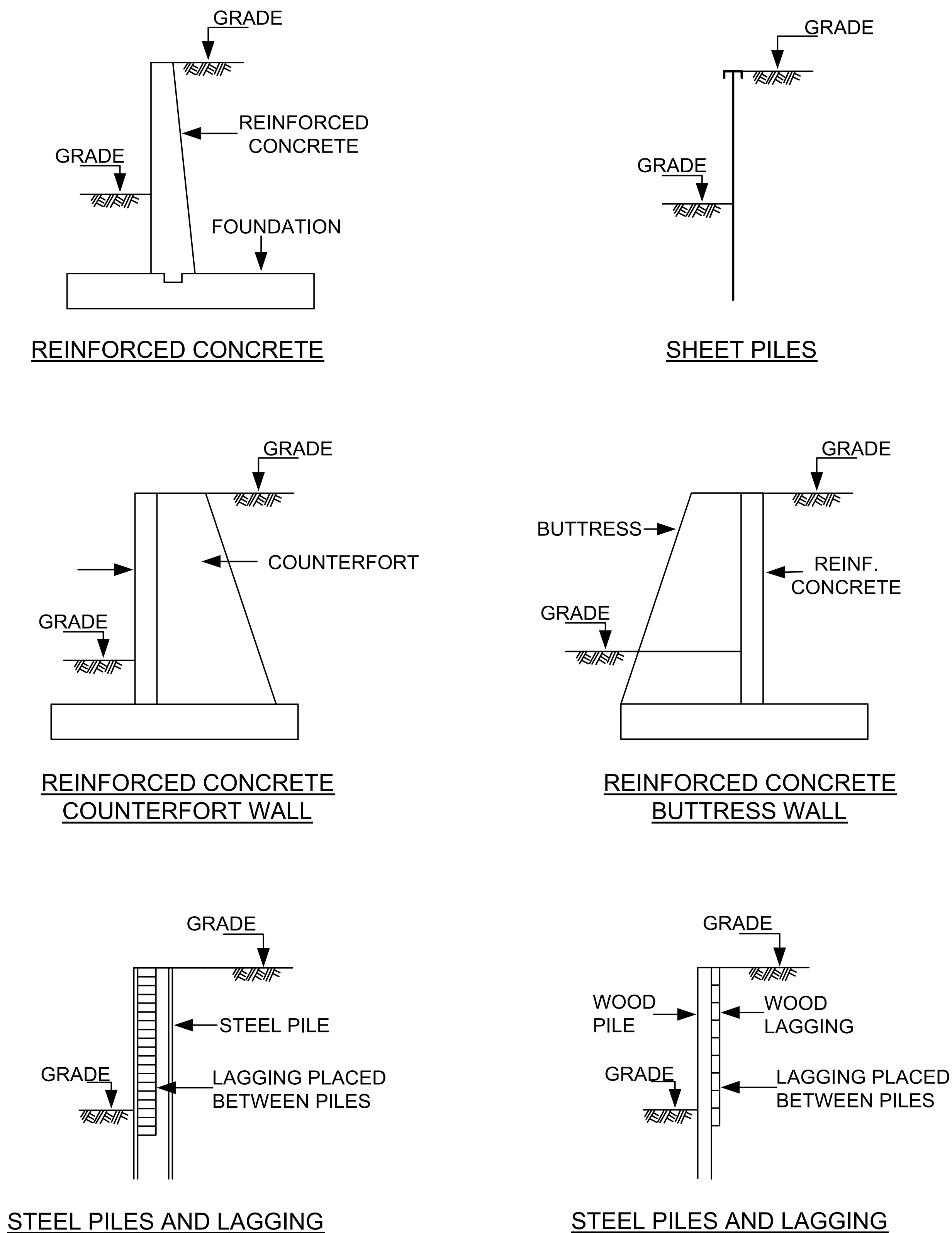
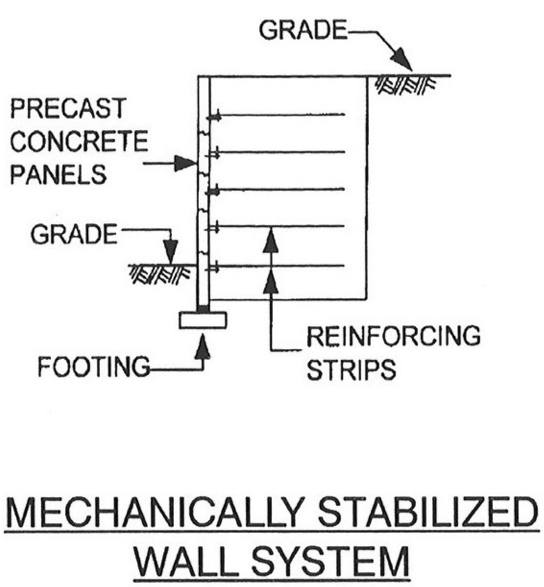


Figure 5.1.4(b) Typical Cantilever Retaining Walls



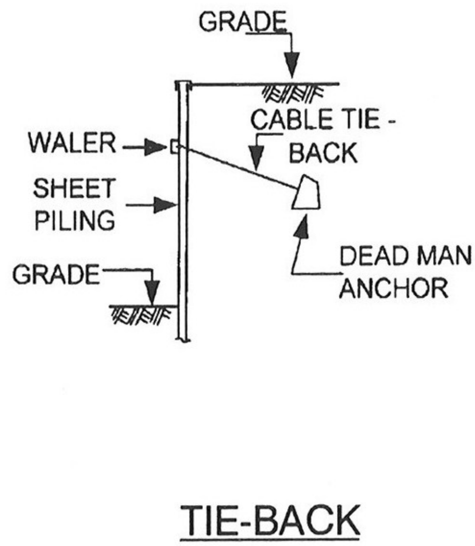


Figure 5.1.4(c) Typical Anchored Retaining Walls

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.

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.

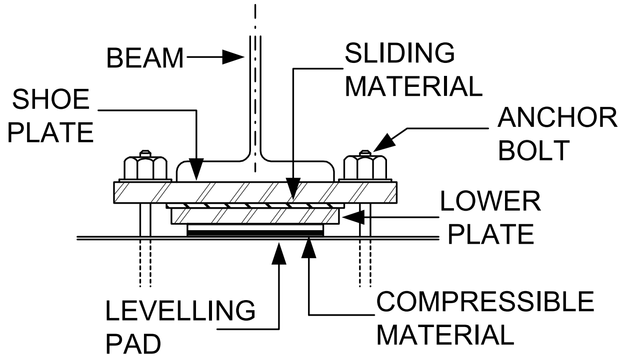


Figure 6.1(a) Steel Plate Bearing

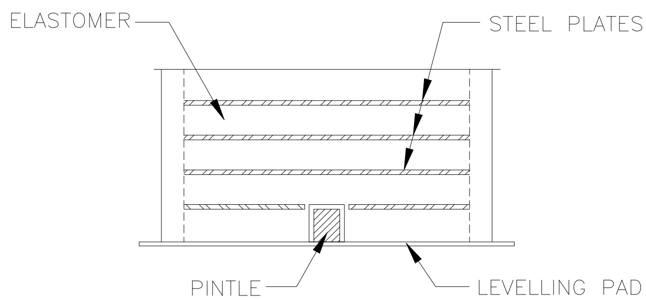
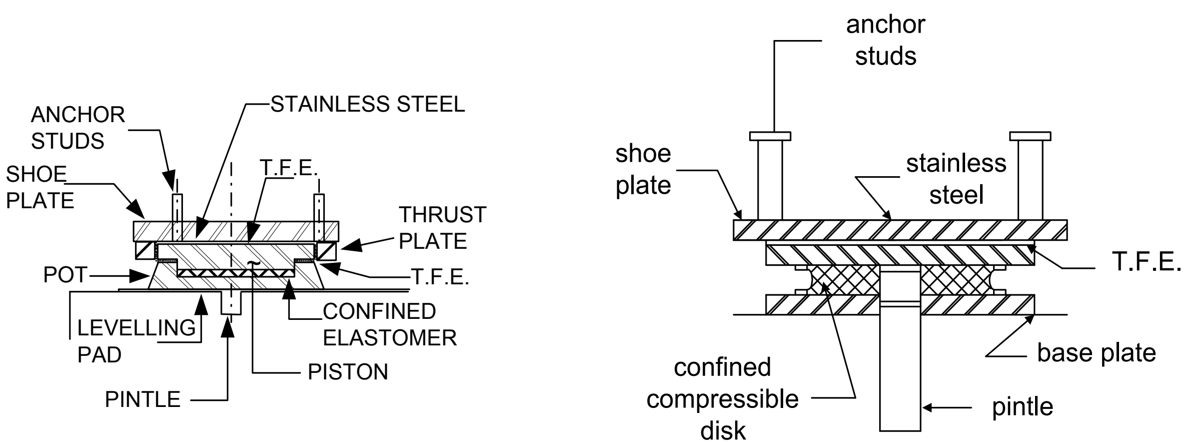


Figure 6.1(b) Elastomeric Bearing



Expansion Pot Bearing

Multi-Directional Disk Bearing

Figure 6.1(c) Pot or Disc Bearing

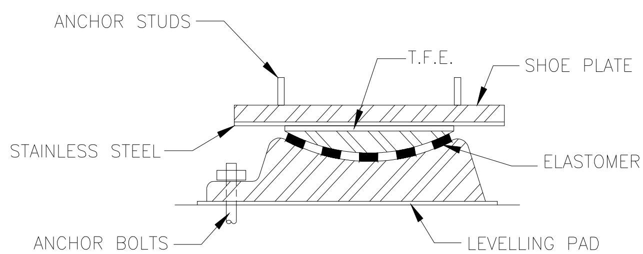


Figure 6.1(d) Spherical Bearing

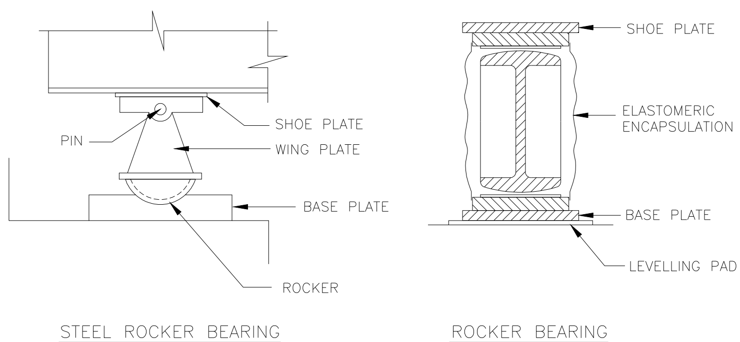


Figure 6.1(e) Steel Rocker Bearing

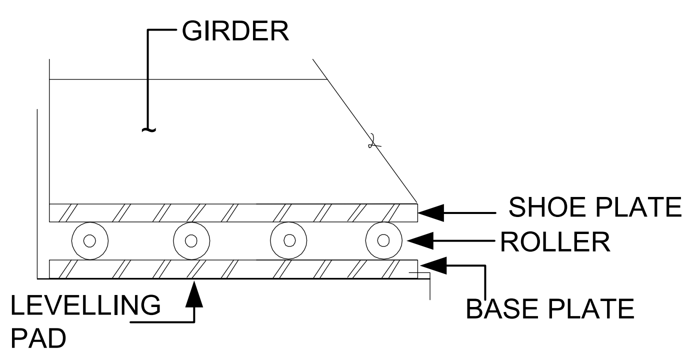


Figure 6.1(f) Expansion Roller Bearing

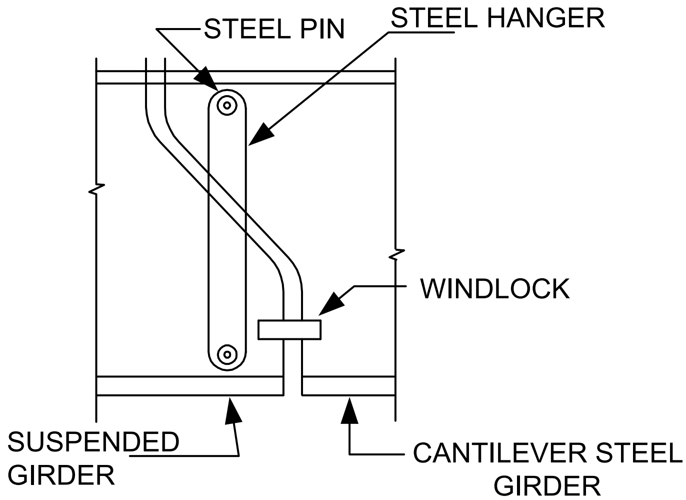


Figure 6.1 Typical Types of Bearings (cont'd)

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.

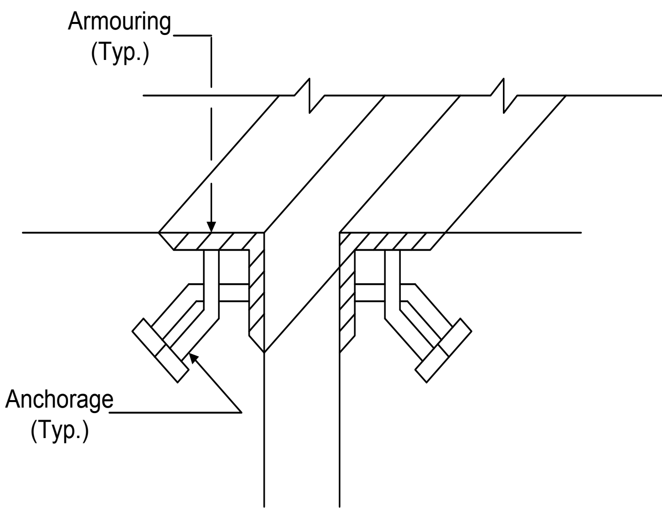
By definition, open joints permit the passage of water through them. However, it is not necessary that open expansion joint systems preclude adequate treatment of the surface run-off which passes through the joint.

SECTION 7 – JOINTS

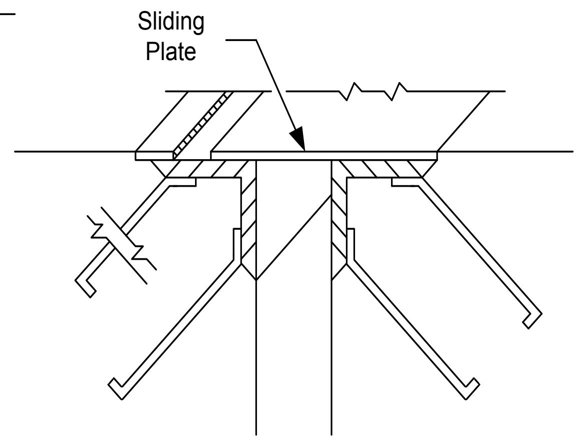
Properly detailed open joints will minimize the potential for deterioration of adjacent components arising from surface run-off. The performance of an unsealed or open joint is directly related to its ability to minimize this potential.

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

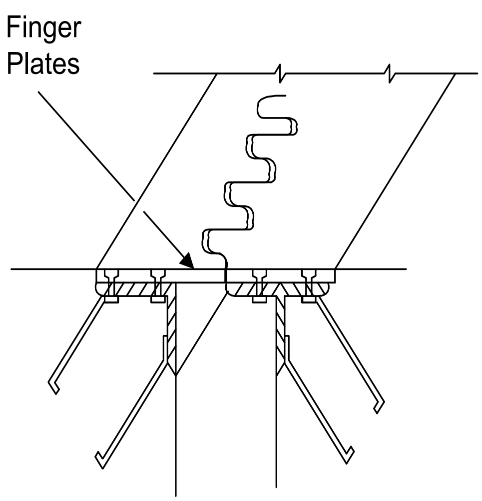
- drip stop details on the underside of the joint;
- collection gutters below joint (either suspended or formed in concrete in bearing seat areas;
- deflection plates;
- placement of deck drains close to and on the upgrade side of open joints;
- locating open expansion joints away from substructure components.



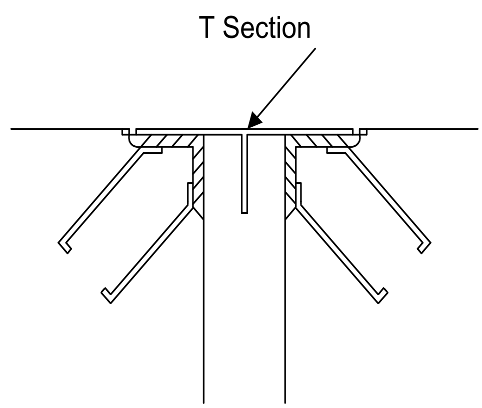
Open Gap Joint



Sliding Plate Joint



Finger Plate Joint



Drop-in-T Joint

Figure 7.1(a) Open Joints

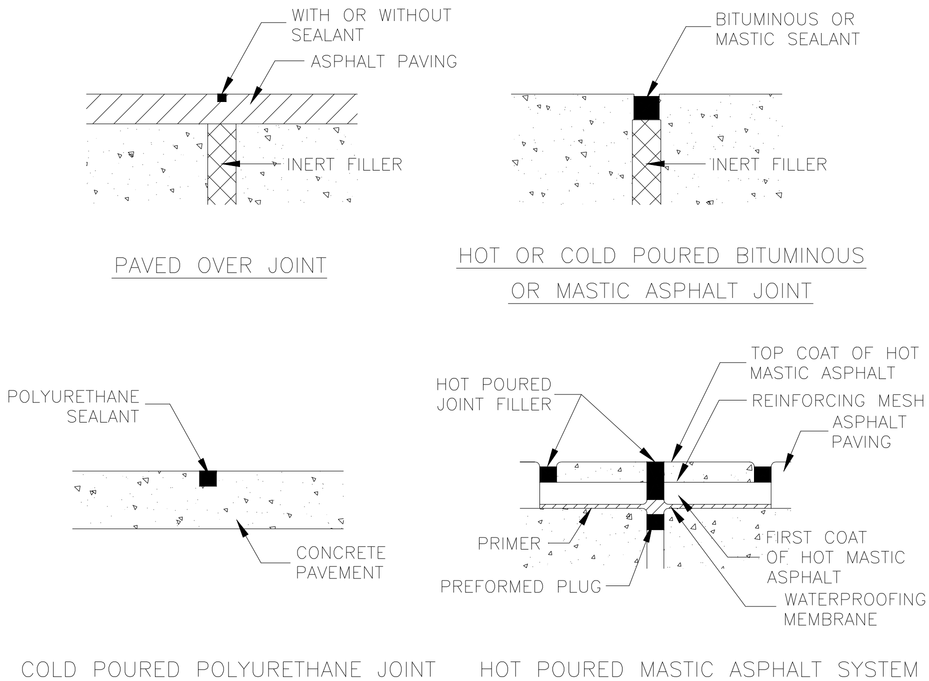


Figure 7.1(b) Poured-In-Place Joints

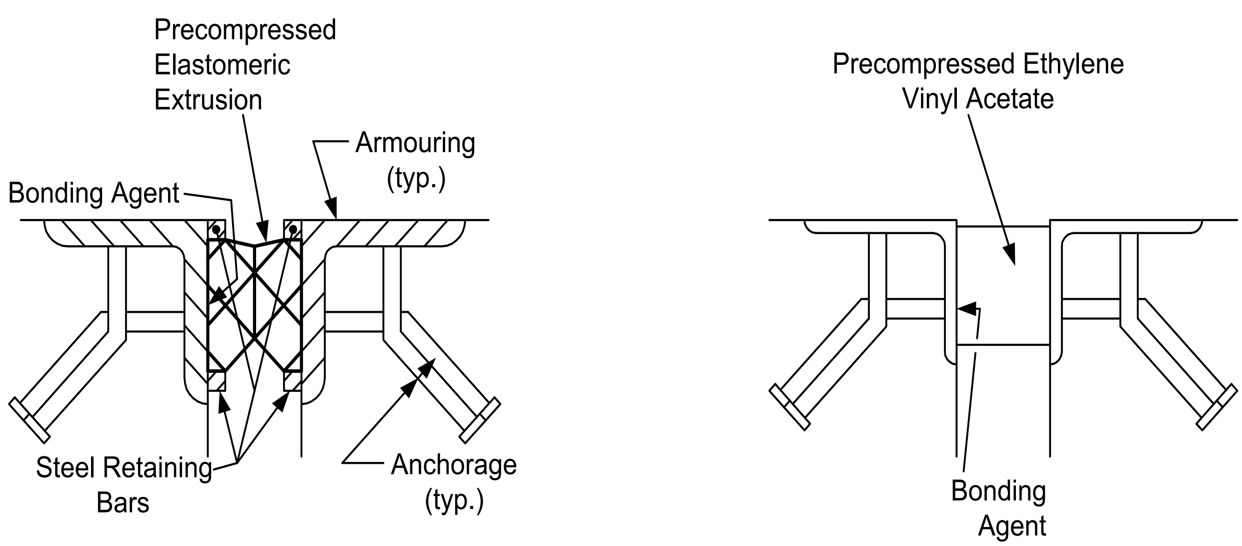


Figure 7.1(c) Compression Seal Joints

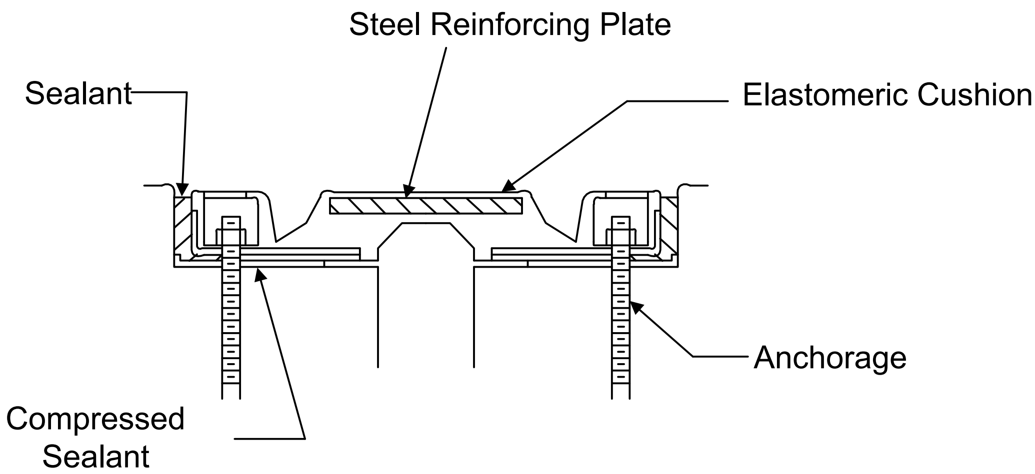


Figure 7.1(d) Elastomeric Cushion Joints

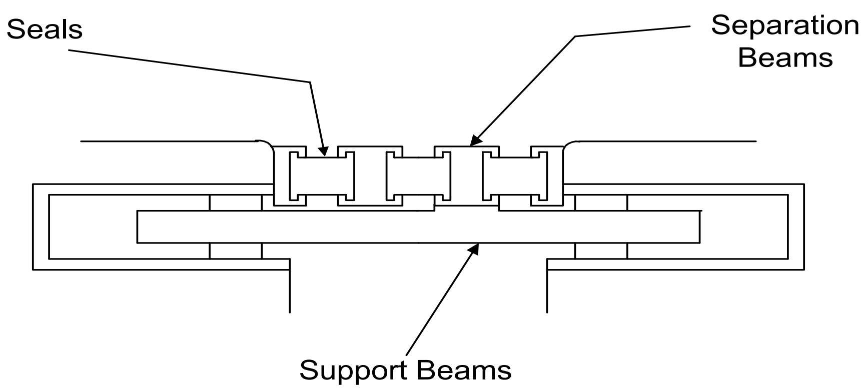


Figure 7.1(e) Multi-Seal Joints

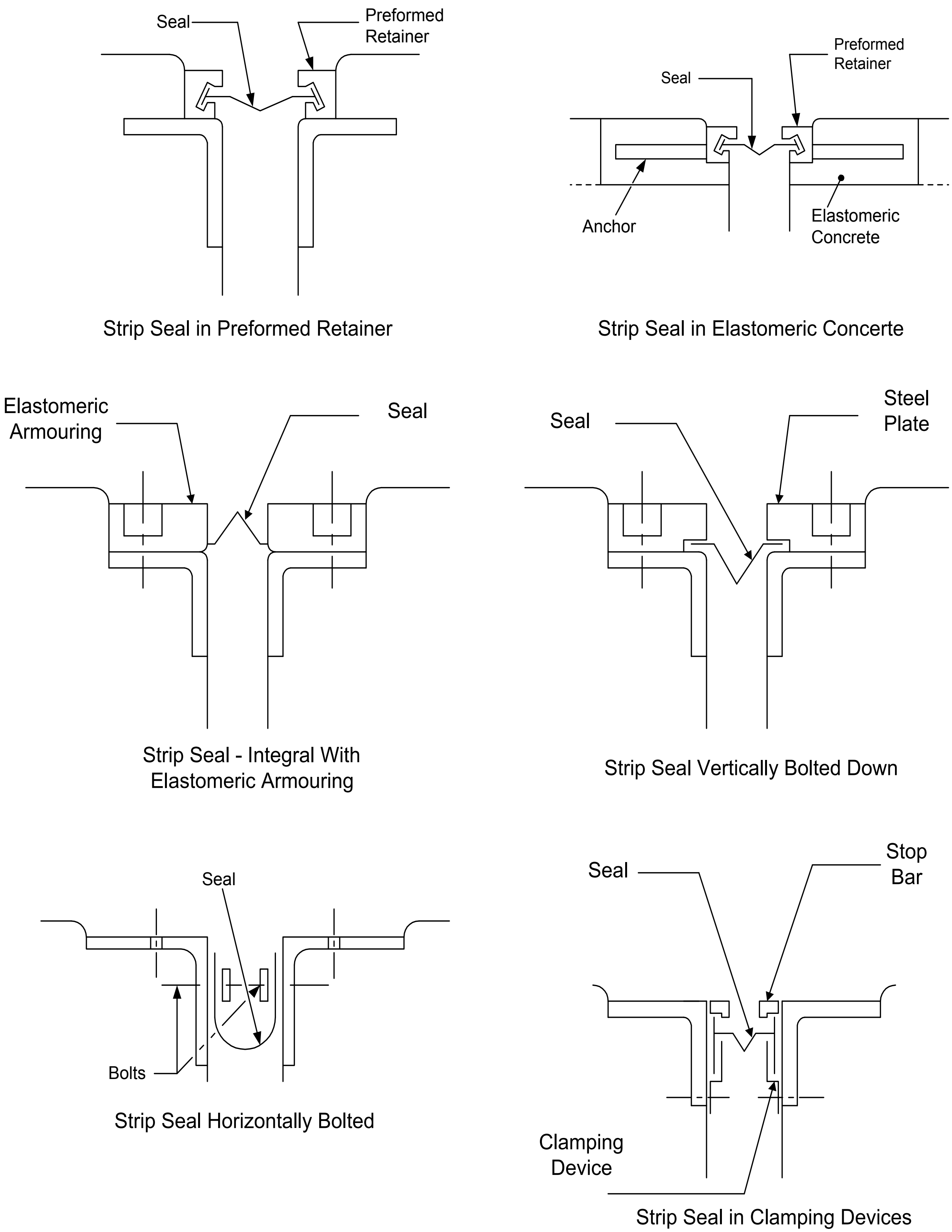


Figure 7.1(f) Strip Seal Joints

SECTION 8 – SUPERSTRUCTURES

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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.

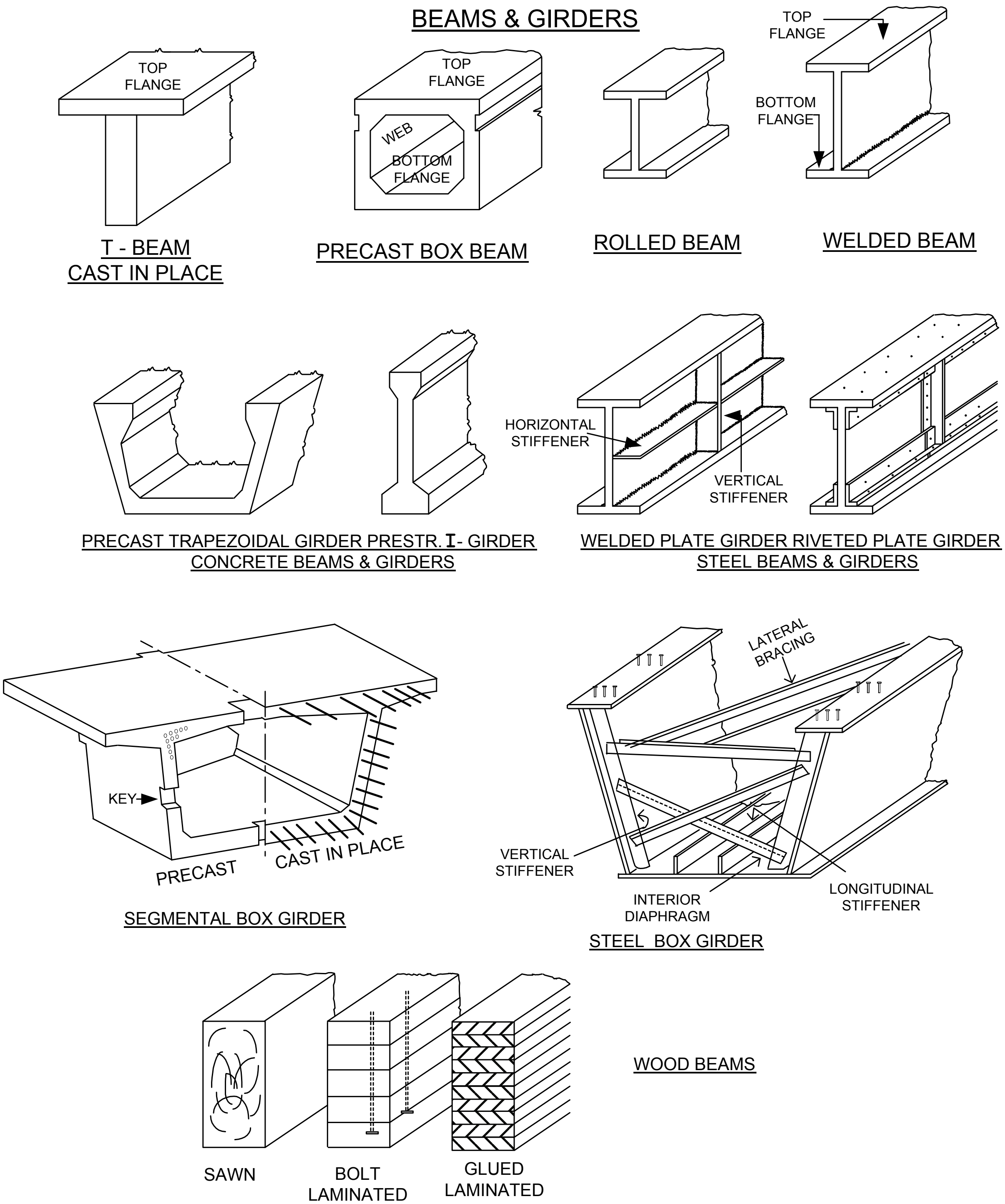
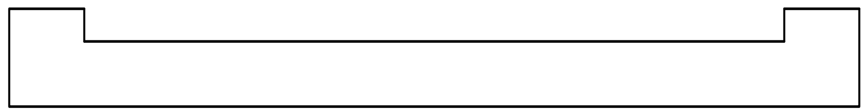
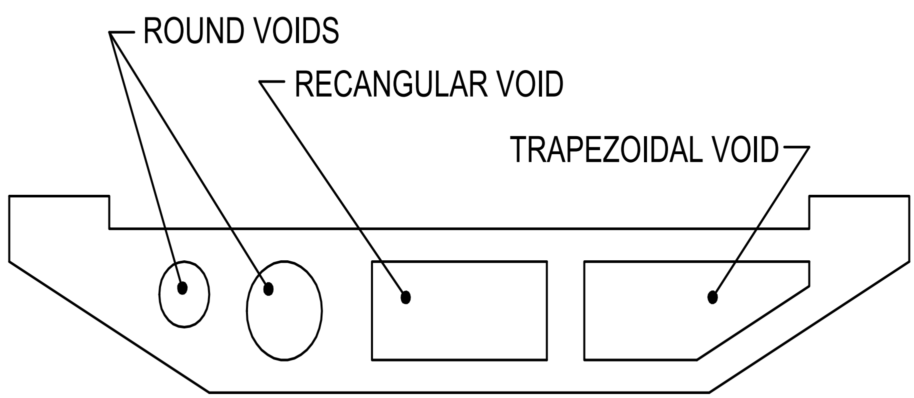


Figure 8.1.1 Beams and Girders



Solid Thick Slab



Voided Thick Slab

Figure 8.1.2 Thick Slabs

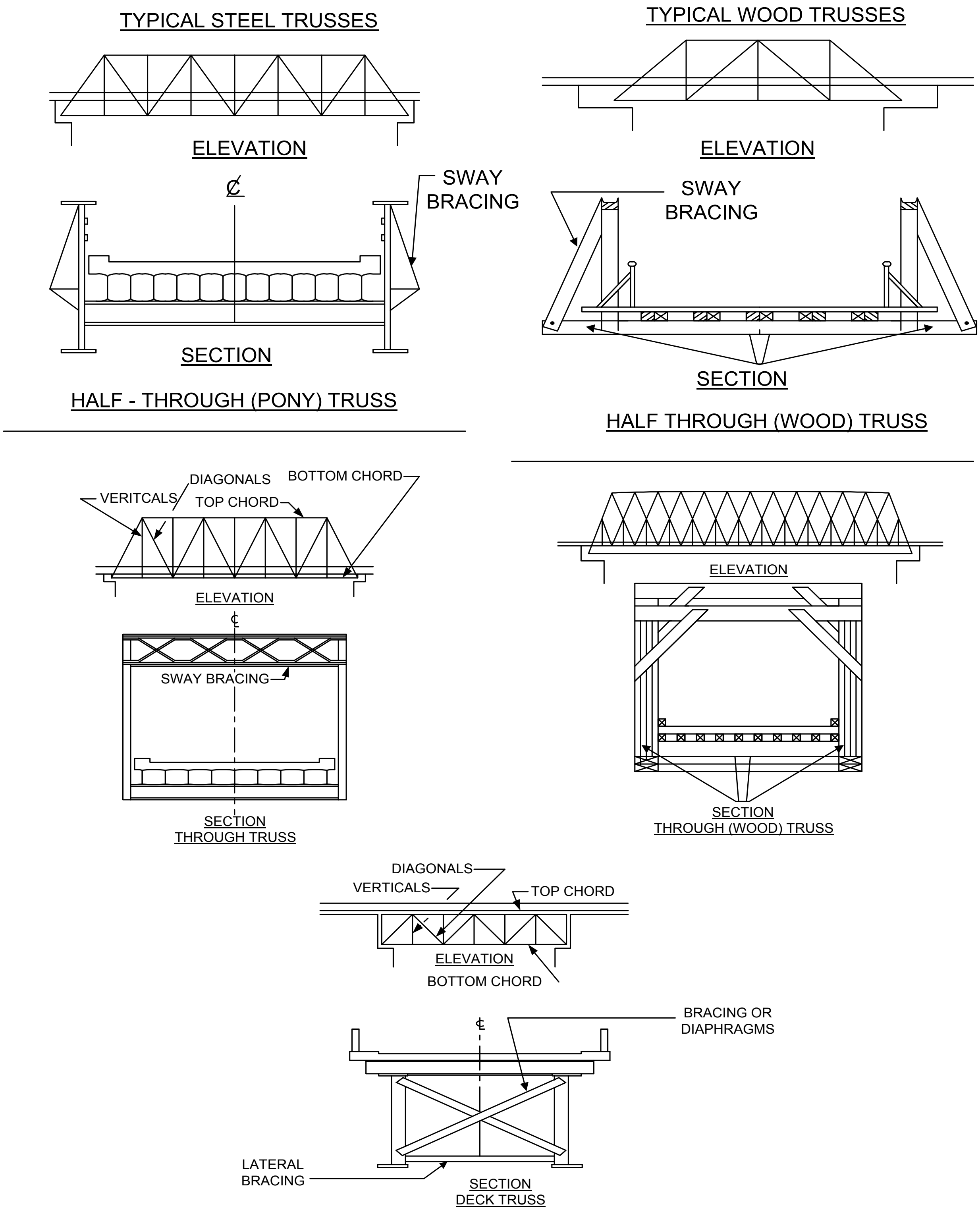


Figure 8.1.3(a) Trusses

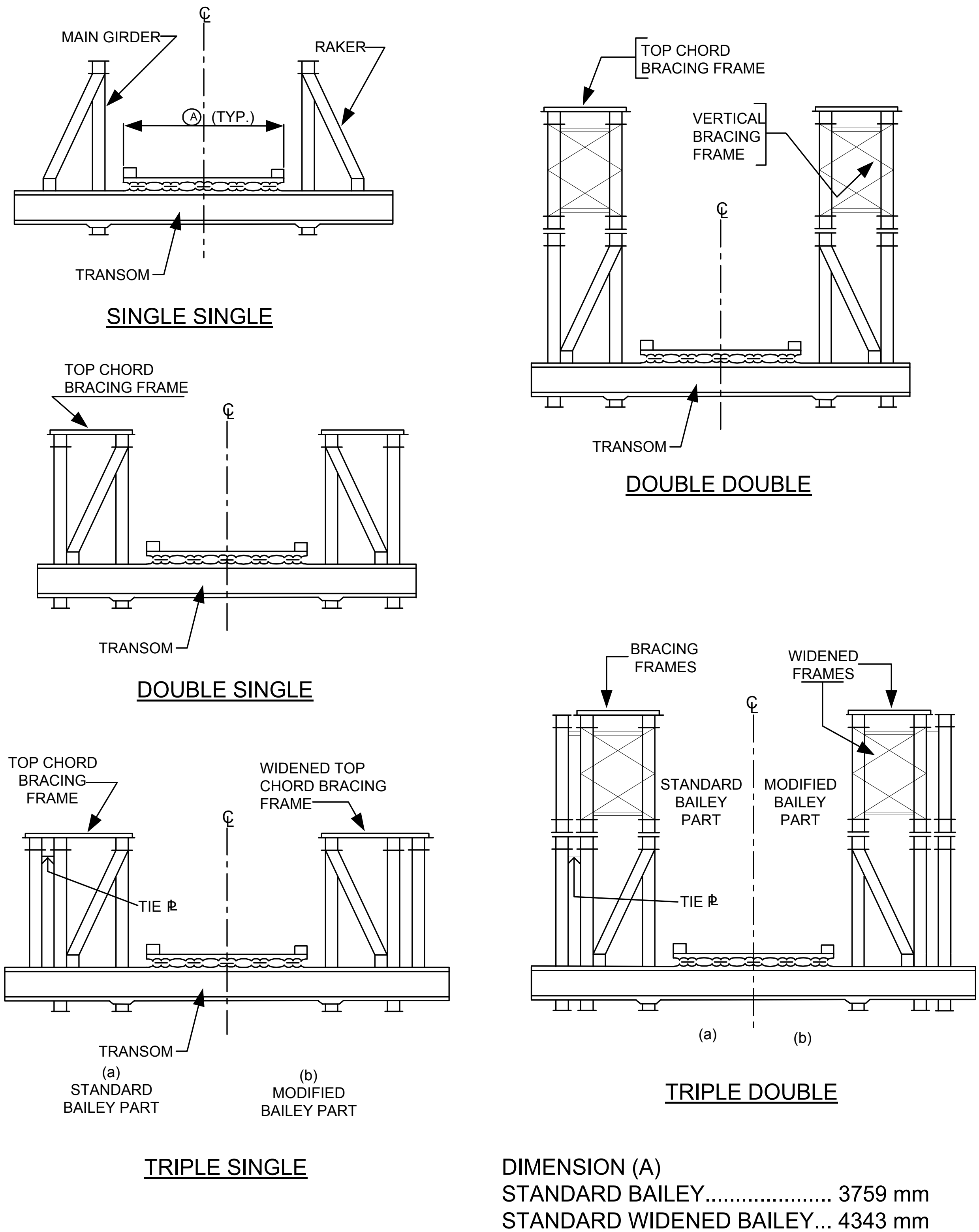


Figure 8.1.3(b) Typical Bailey Configurations

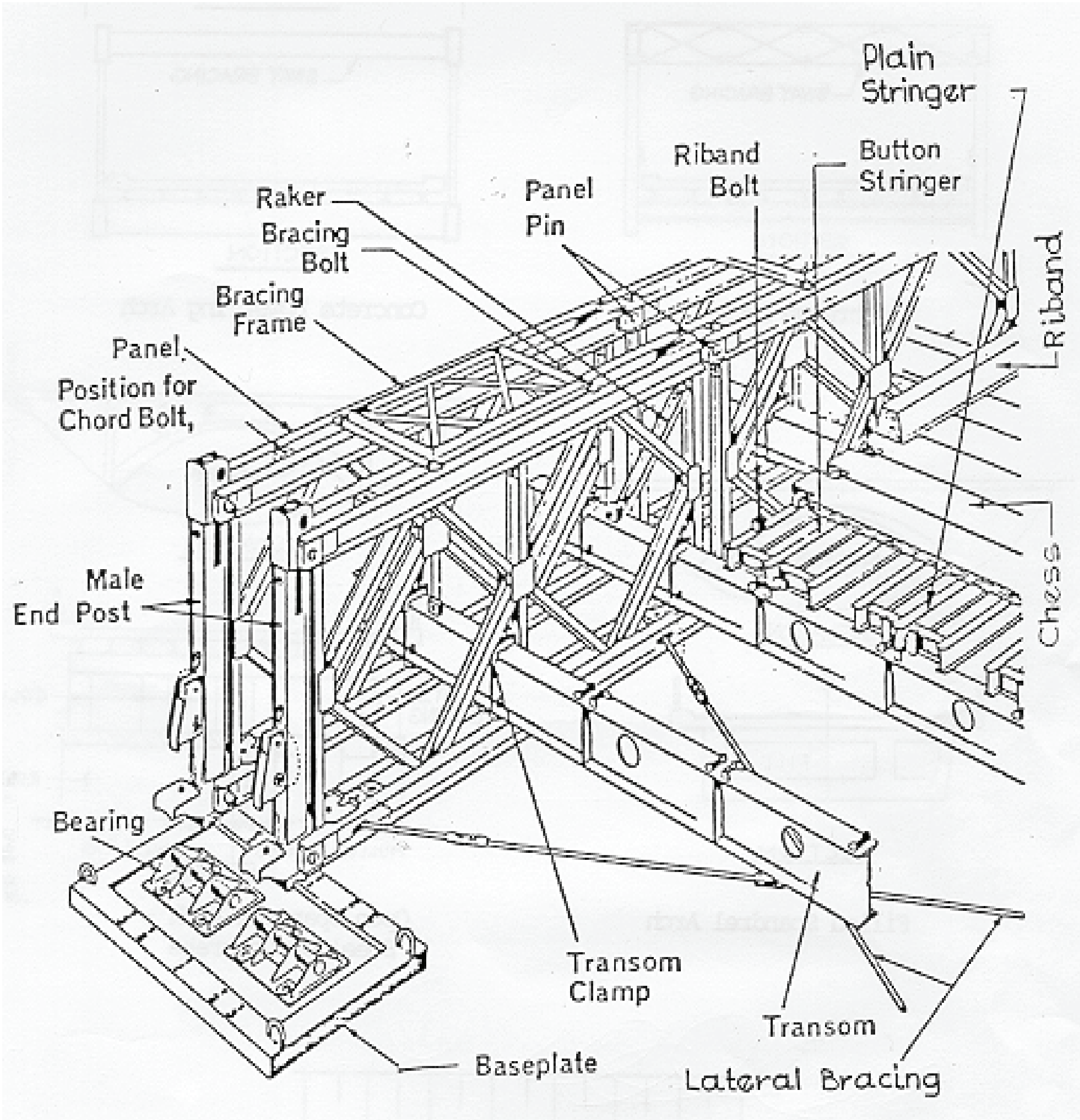
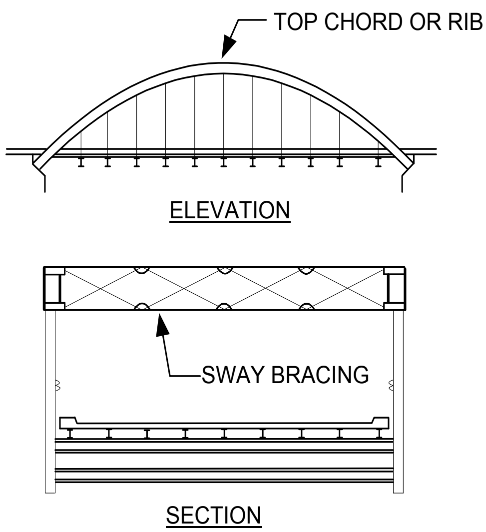
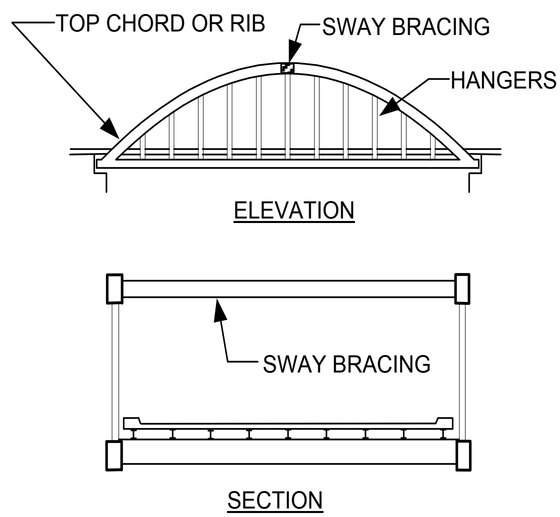


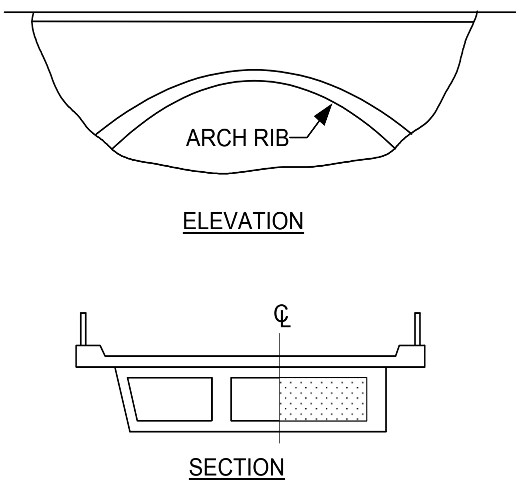
Figure 8.1.3(c) Typical Bailey Components



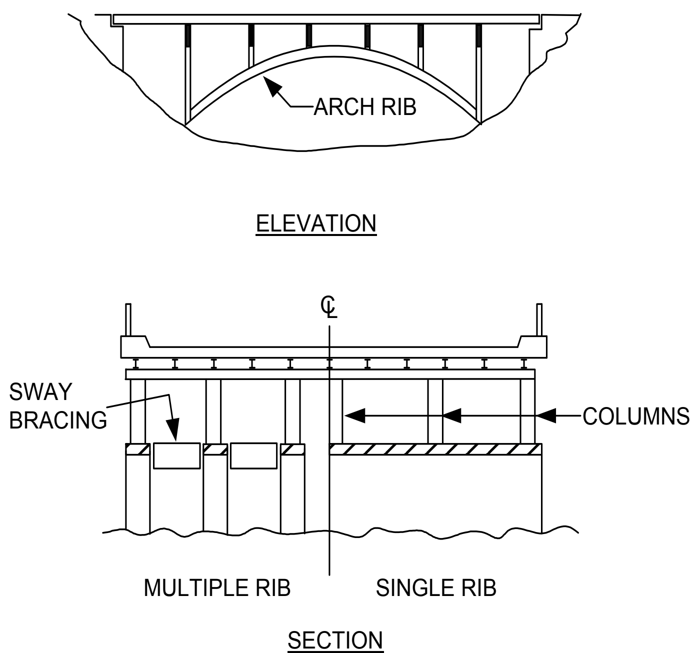
Through Arch



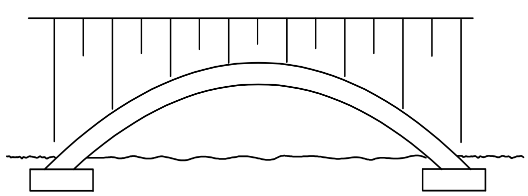
Concrete Bowstring Arch



Filled Sprandel Arch



Open Sprandel Arch -
Steel or Concrete



Concrete Barrel Arch

Figure 8.1.4 Arches

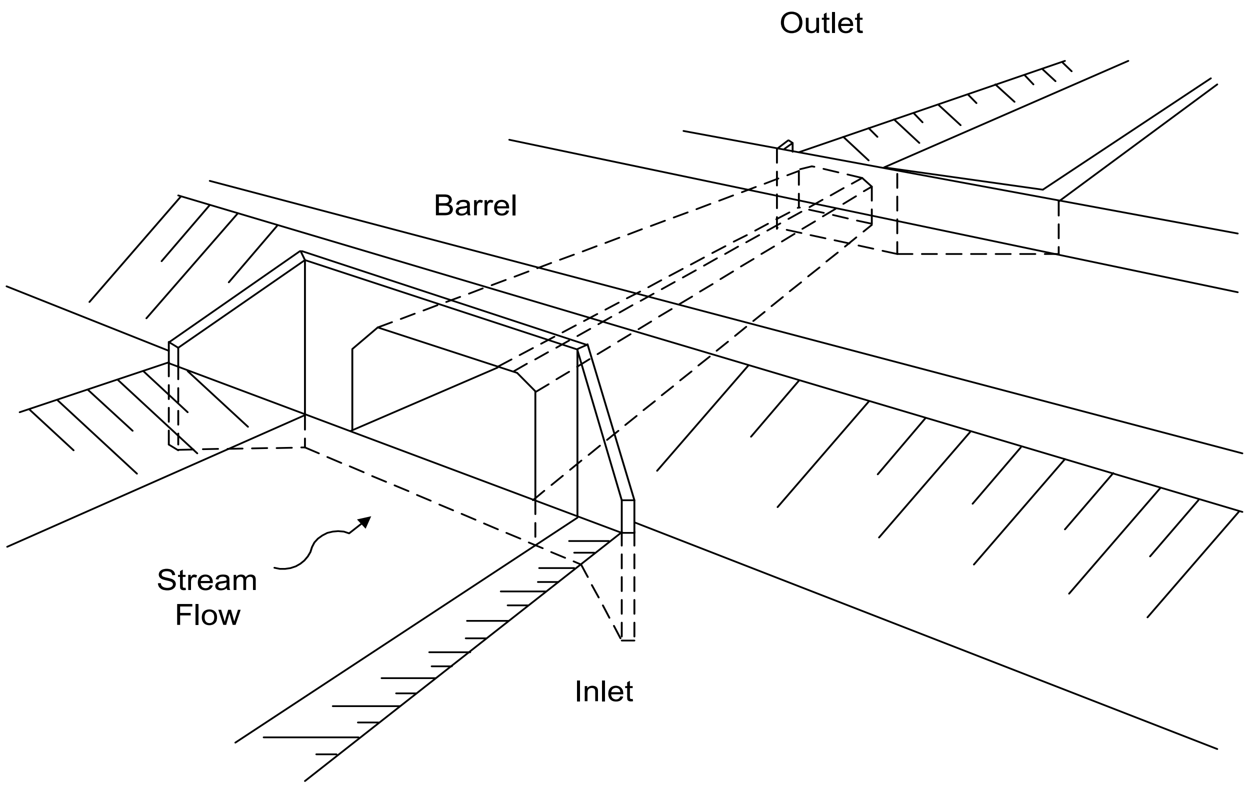


Figure 8.1.5(a) Basic Culvert, Tunnel and Soil-Steel Structure Components

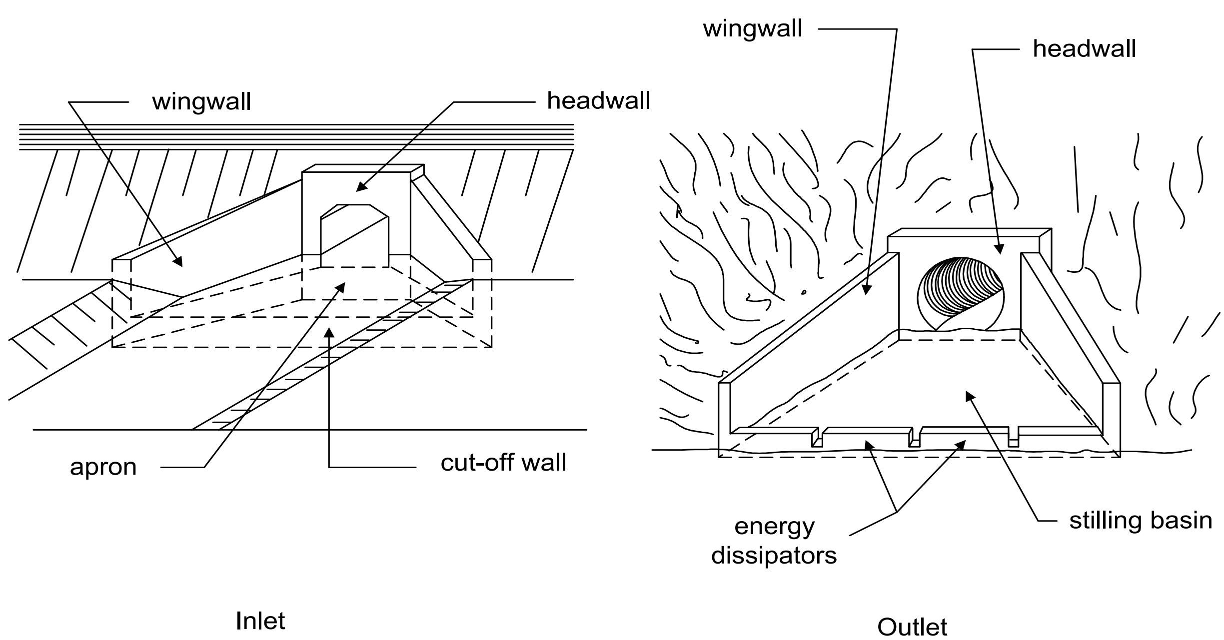
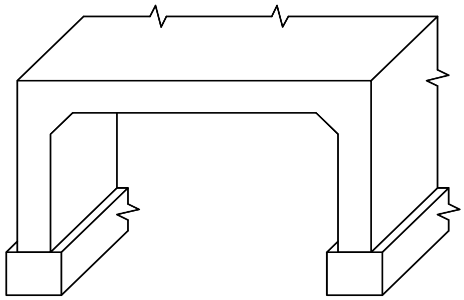
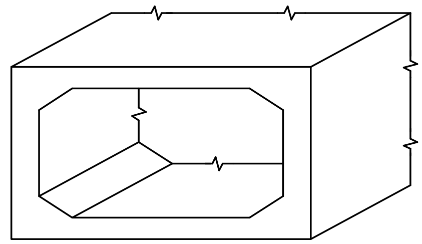


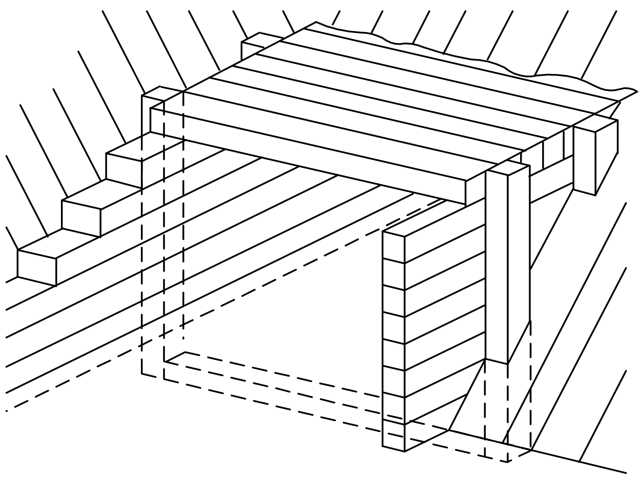
Figure 8.1.5(b) Typical Inlet and Outlet Components



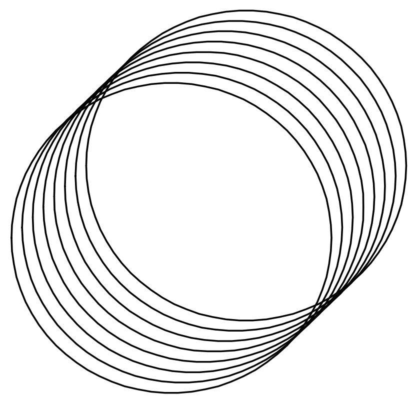
Open Footing Concrete Culvert



Concrete Box Culvert



Wood Culvert



Round Corrugated Pipe Culvert

Figure 8.1.5(c) Typical Culverts and Tunnels

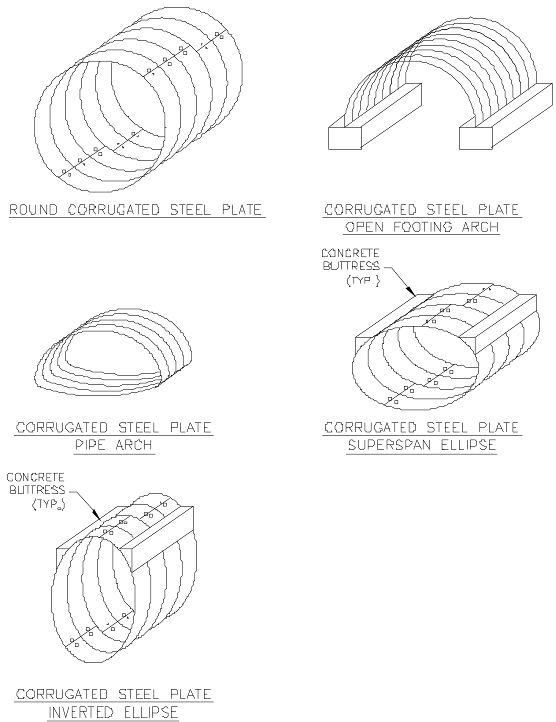


Figure 8.1.5(d) Typical Soil-Steel Structures

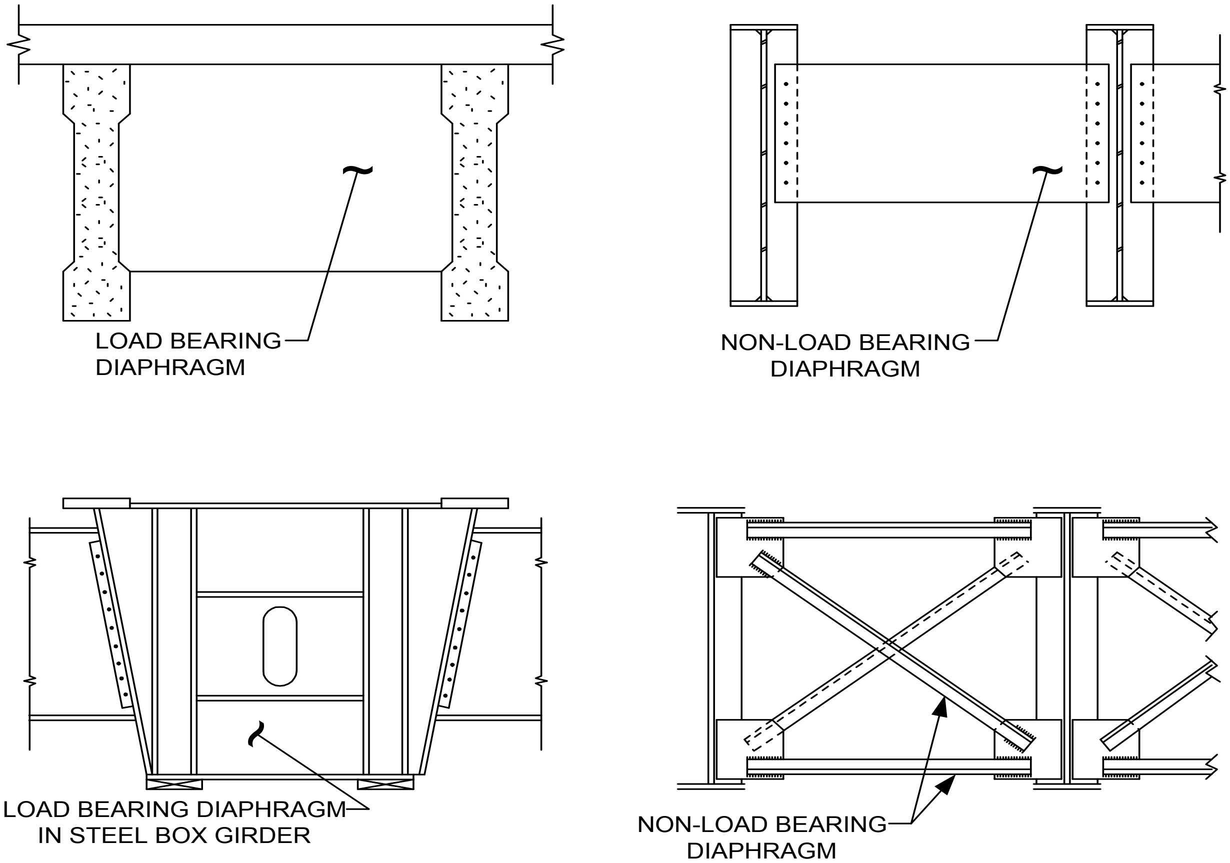


Figure 8.1.6 Diaphragms

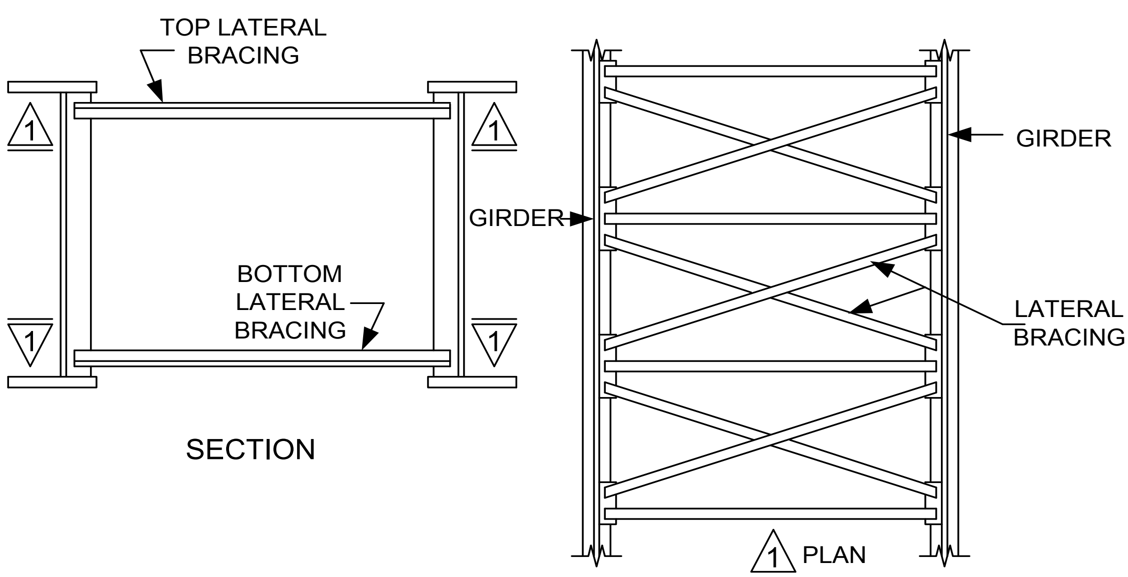


Figure 8.1.8 Lateral Bracing

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.

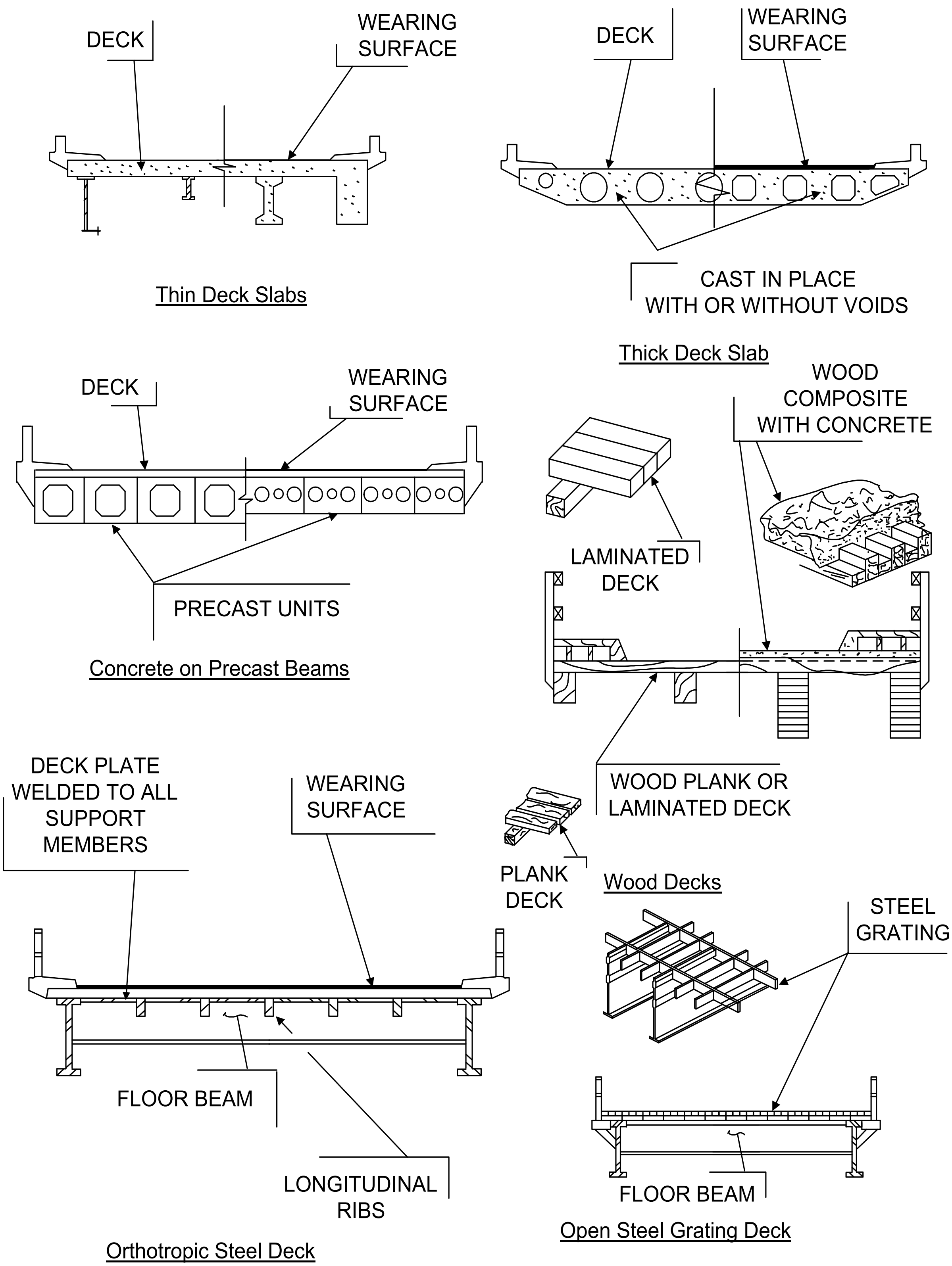


Figure 9.1.1 Typical Decks

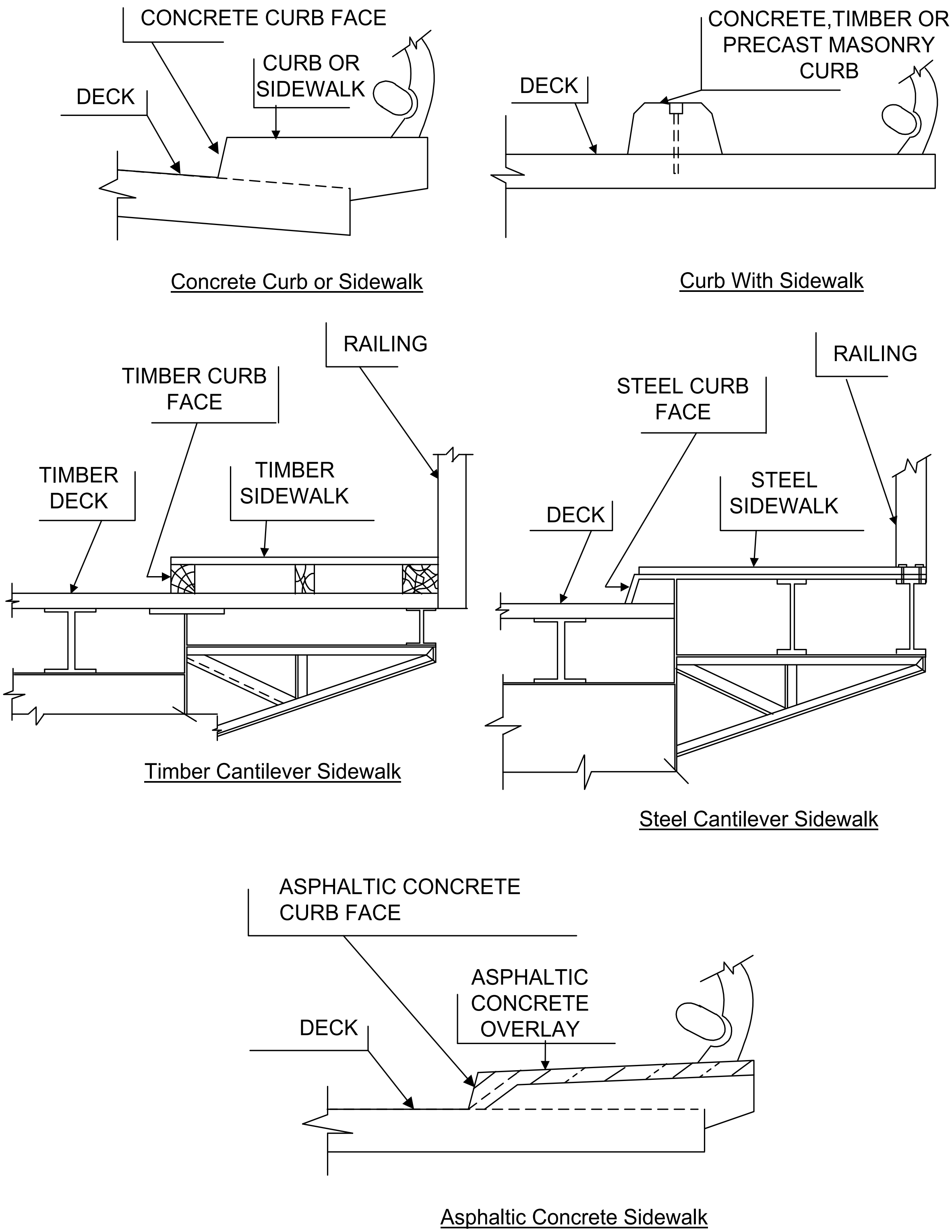


Figure 9.1.3 Typical Curbs and Sidewalks

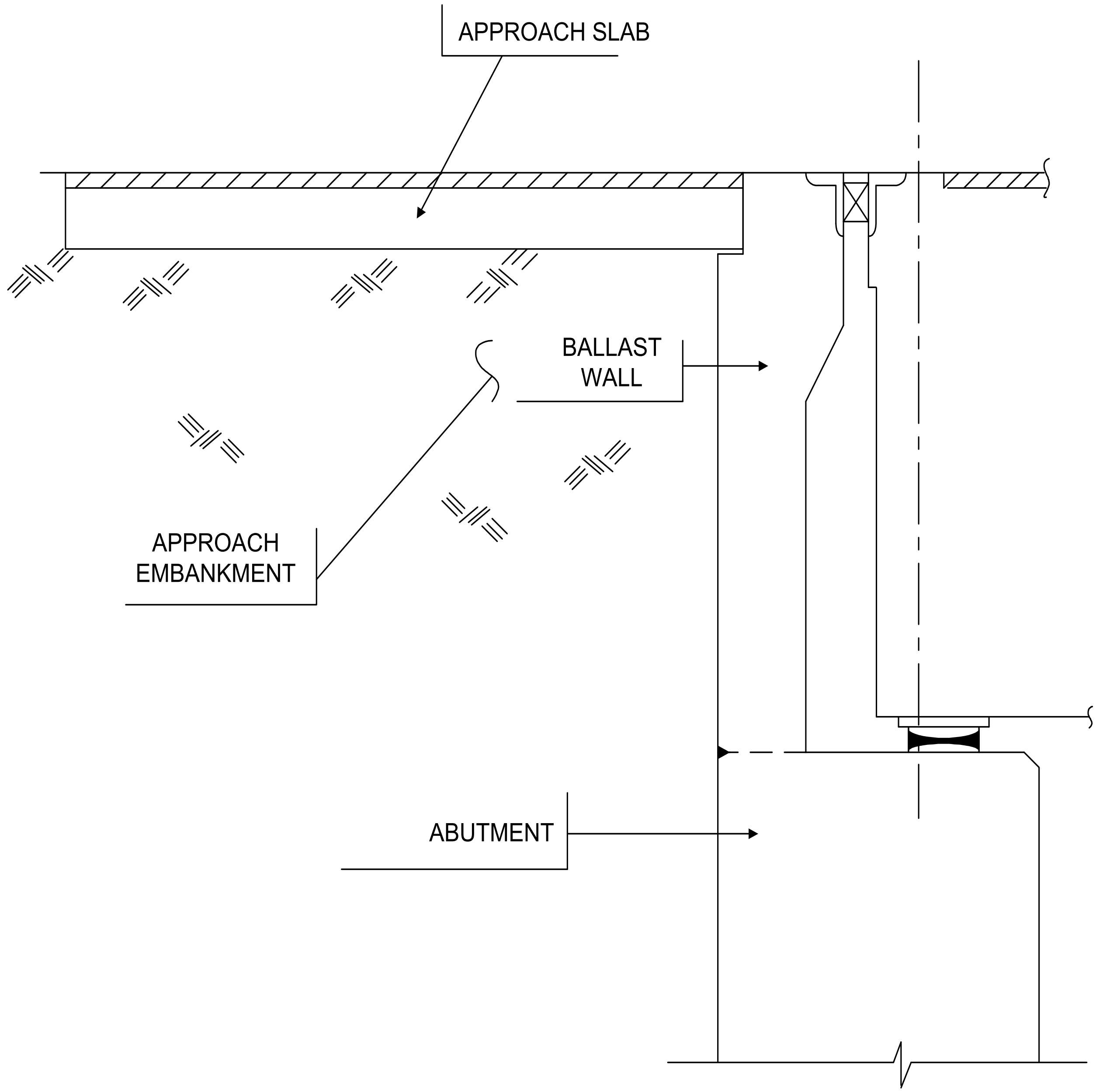


Figure 9.1.4 Concrete Approach Slab

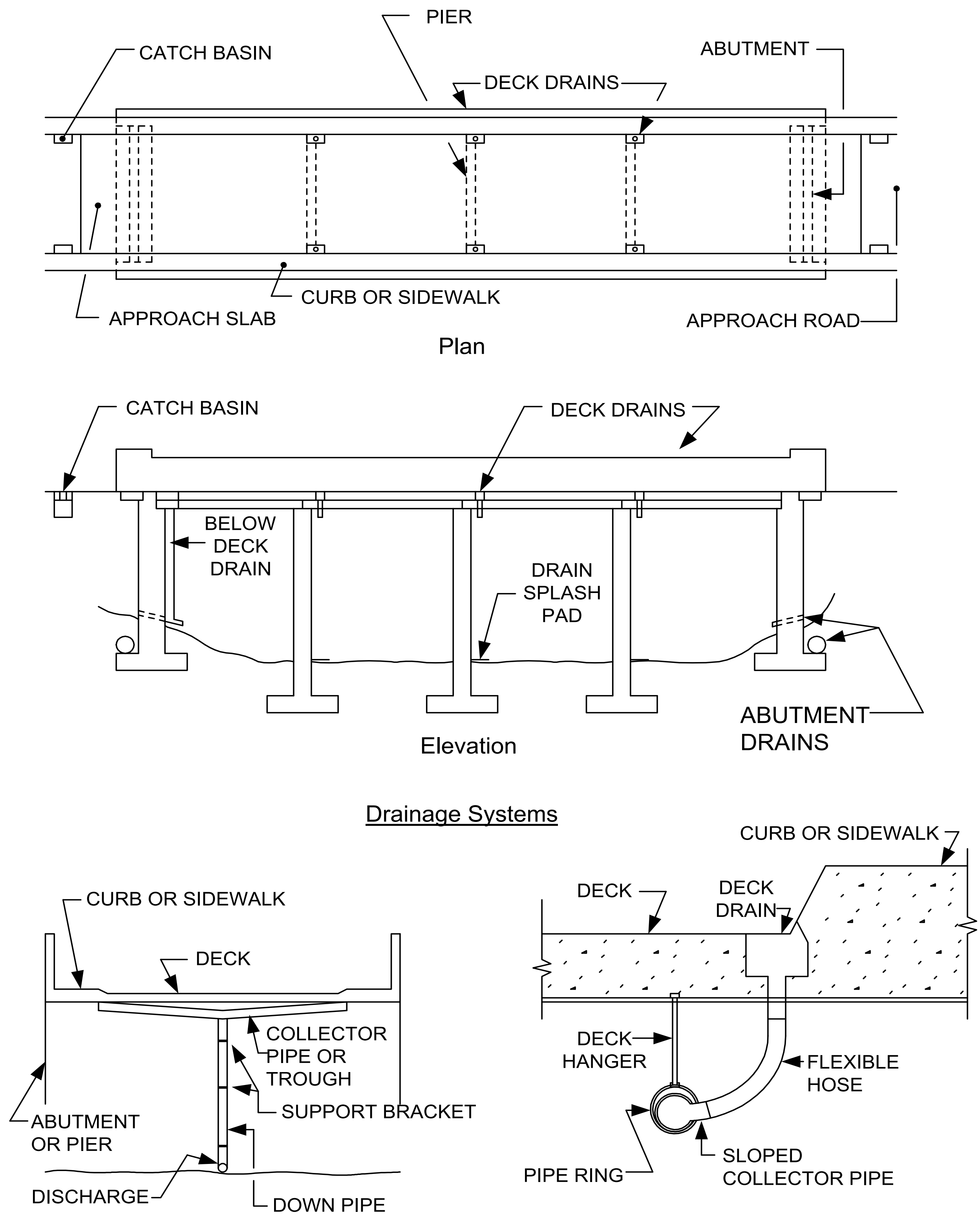
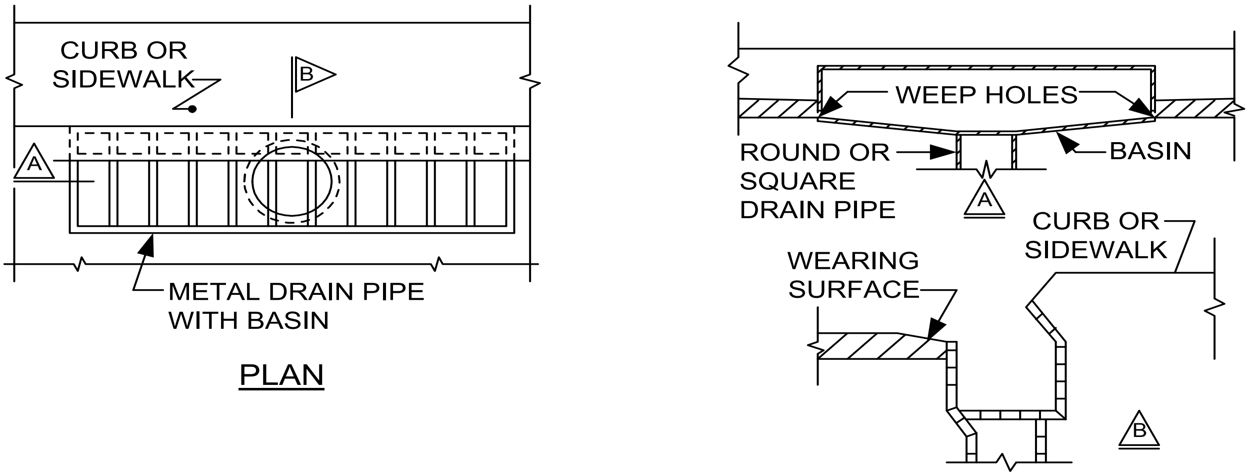
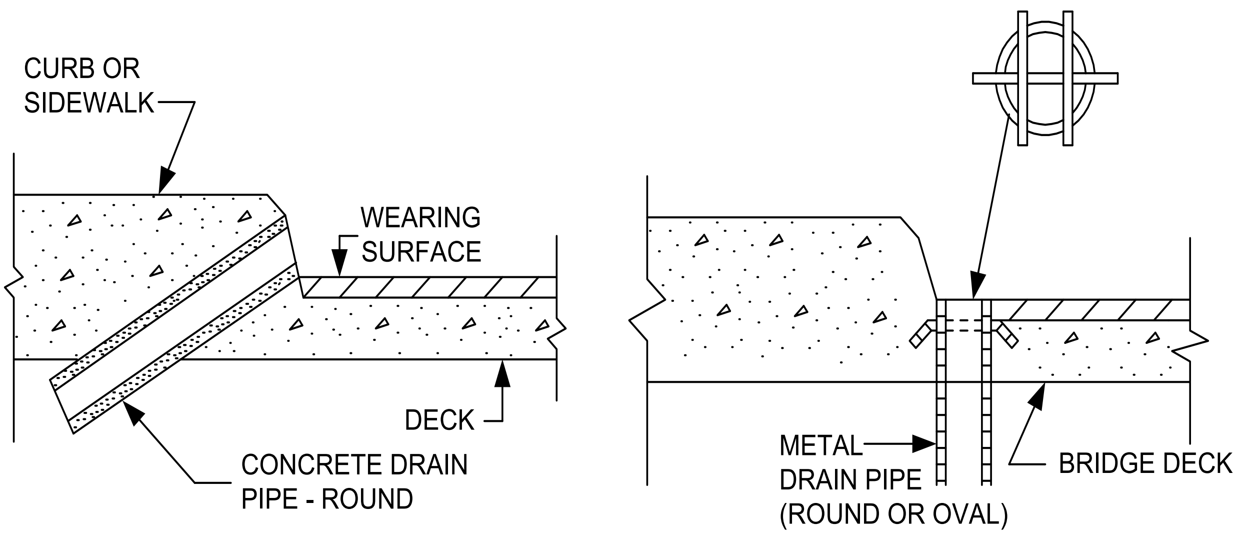


Figure 9.1.5 Drainage and Deck Drains



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

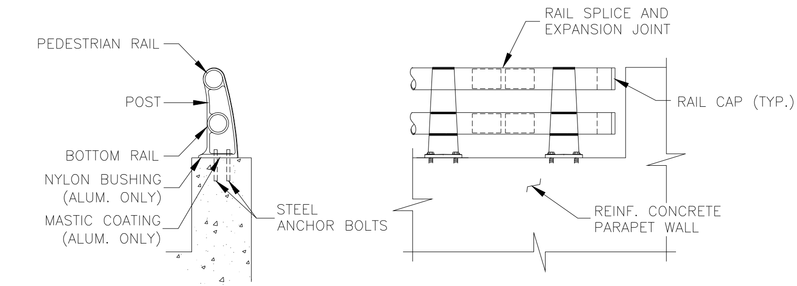
The performance of barrier walls and railings is based upon their ability to safeguard and guide vehicular traffic and pedestrians along the structure and to deter the accidental passage of vehicles over the side of the structure, into oncoming traffic or into other bridge components.

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.

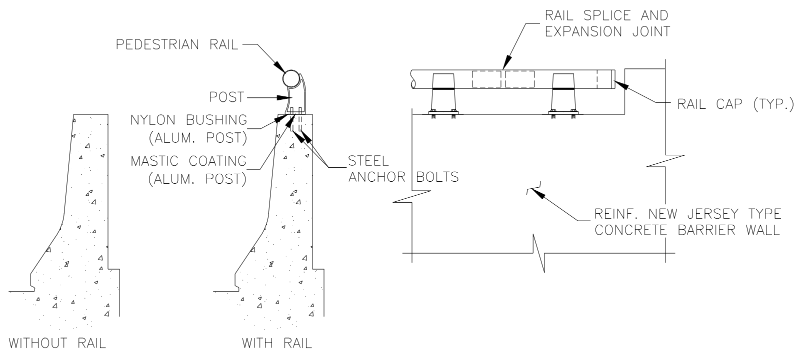
The performance of splashguards is based upon the protection provided to pedestrians or railing systems against salt and water splash directed by vehicles passing in adjacent lanes.

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.

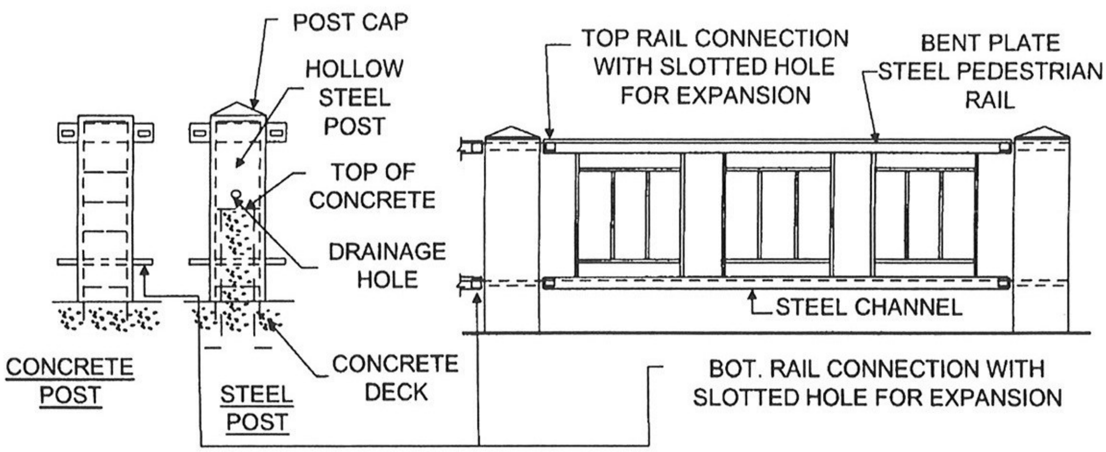
The performance of end treatments is based upon the ability to absorb energy during a collision, which is a function on the design speed limit and the number of sections comprising the end treatment.



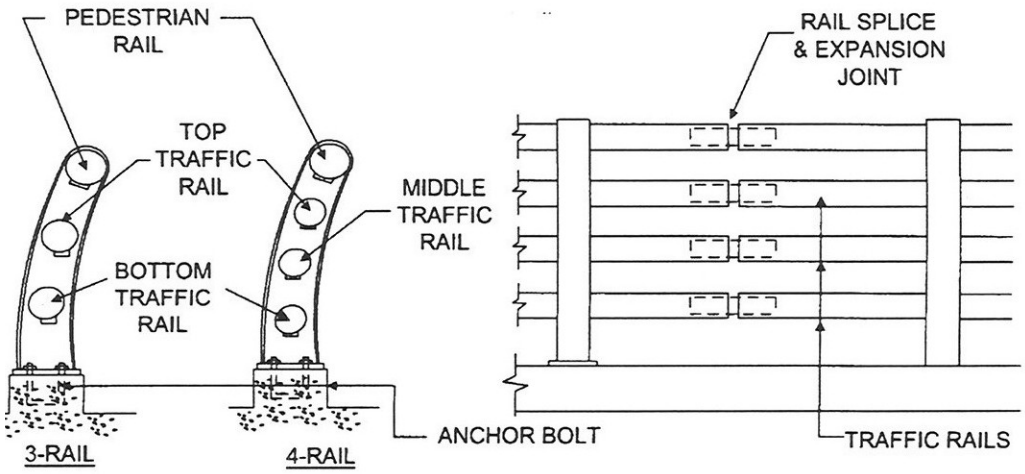
REINFORCED CONCRETE PARAPET WALL WITH RAILS



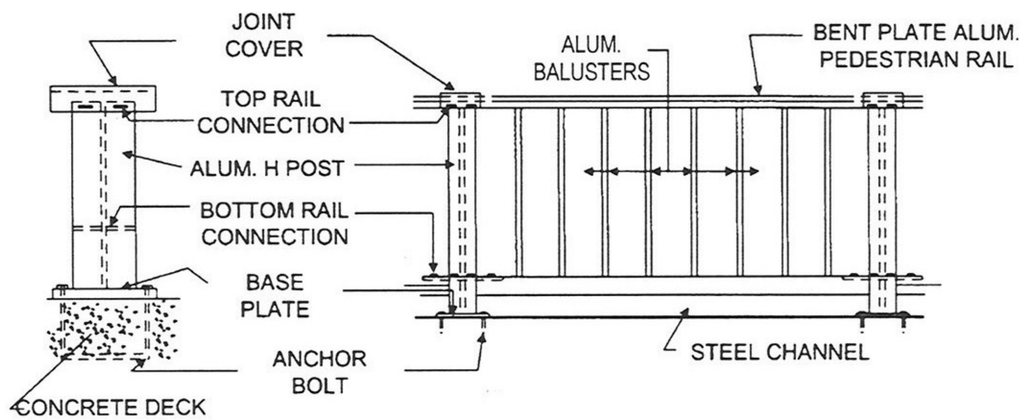
REINFORCED CONCRETE NEW JERSEY TYPE BARRIER WALL



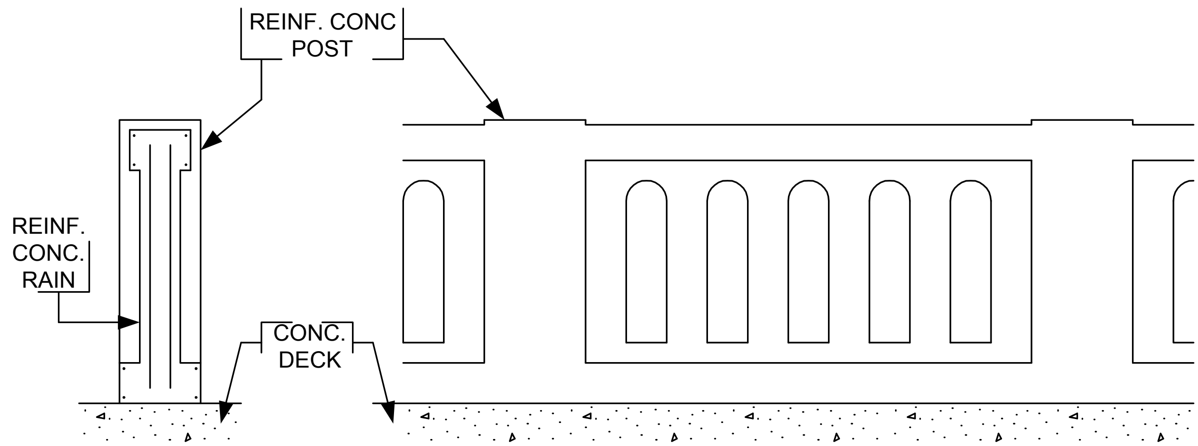
STEEL RAILING



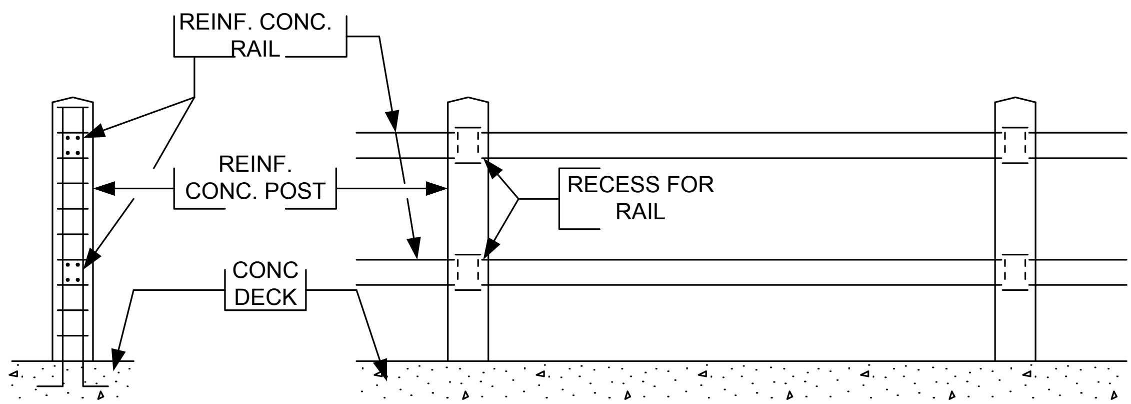
METAL RAILING (STEEL OR ALUMINUM)



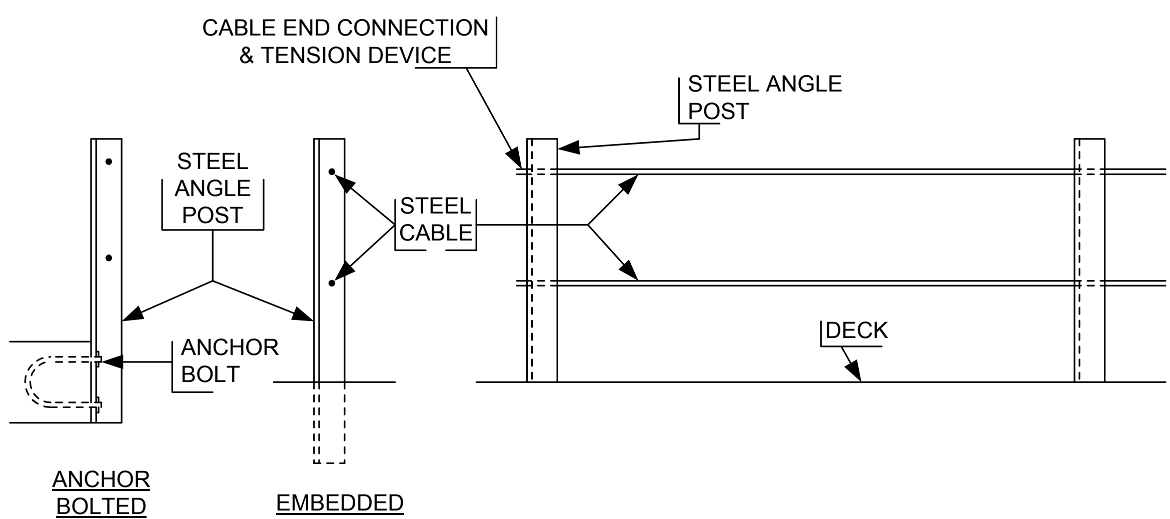
ALUMINUM RAILING



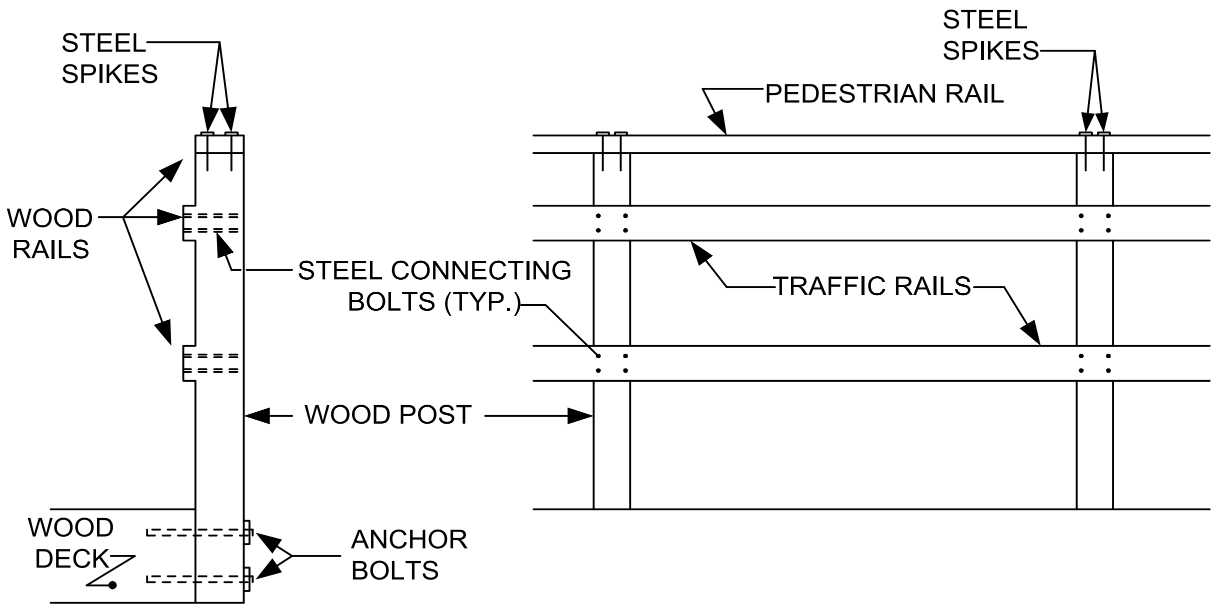
Reinforced Concrete Railing



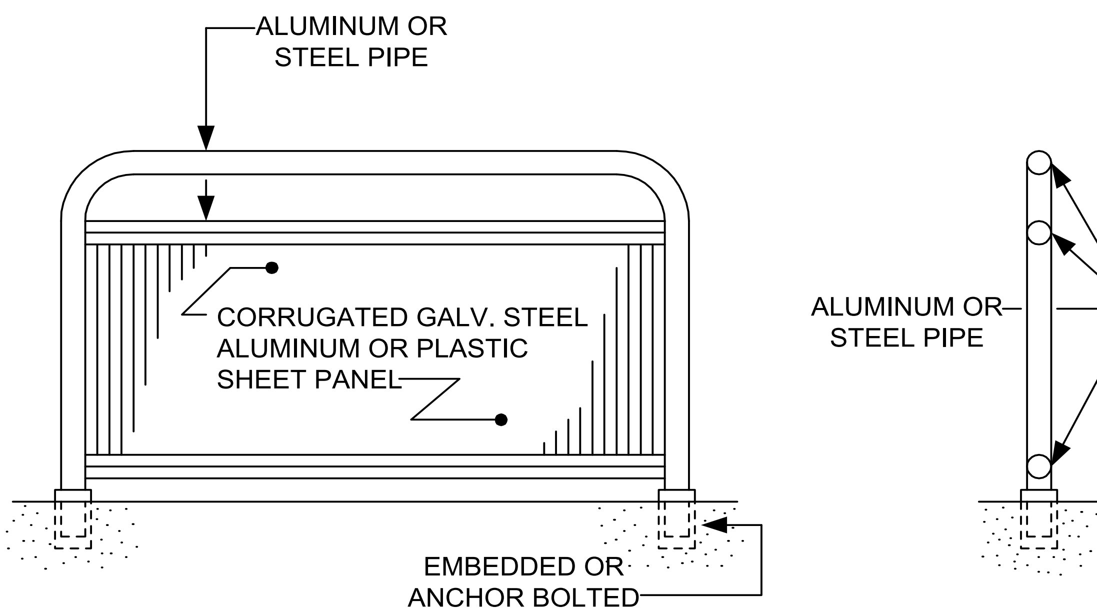
Reinforced Concrete Railing



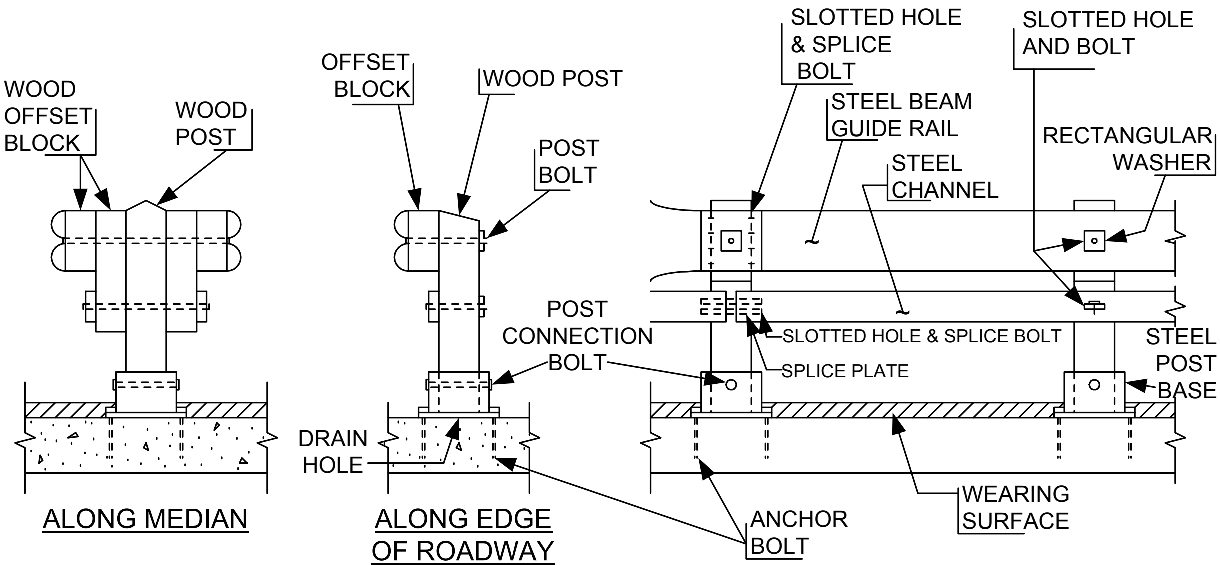
Steel Post and Cable Railing



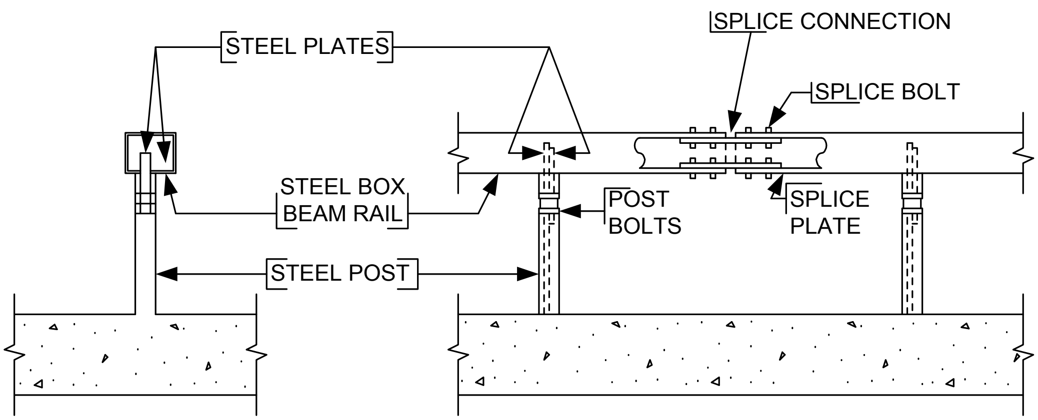
Wood Railing



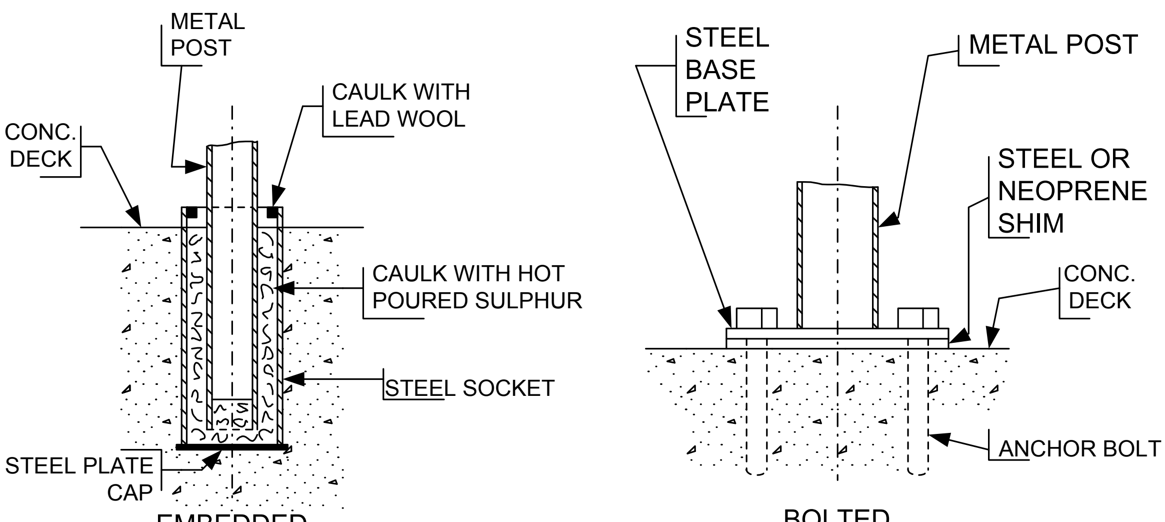
Railing With Splash Guard



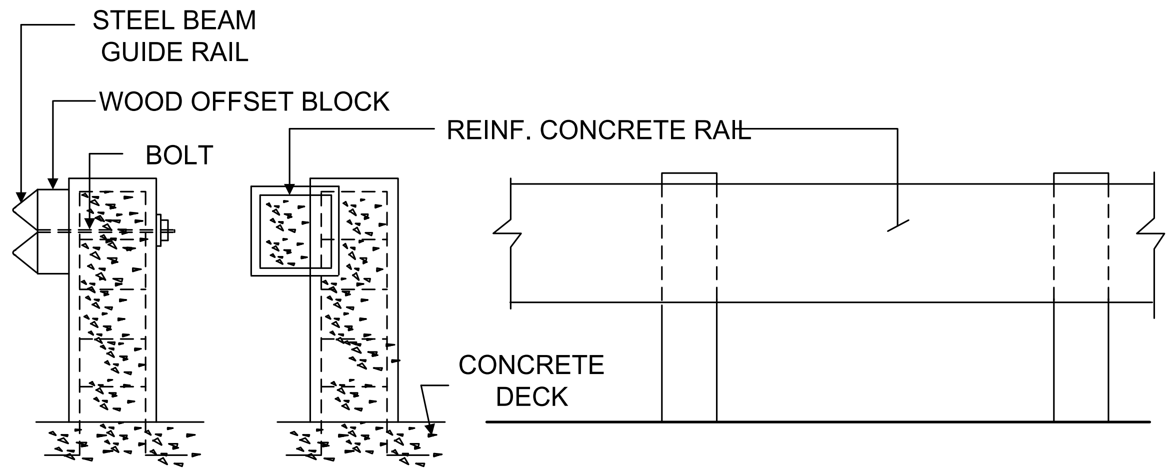
Wood Post and Steel Flex-Beam Rail



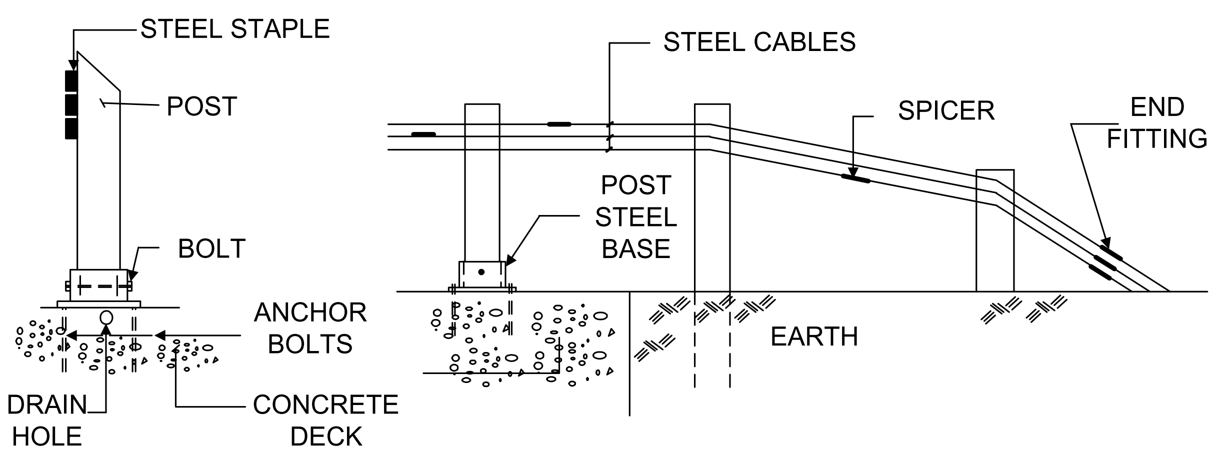
Steel Post and Box Beam Rail



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.

WA-24S
600 mm x 300 mm

WA-24SF
600 mm x 300 mm

(a) Narrow Structure Sign

(b) One Lane Sign

WA-24T1
600 mm x 300 mm

WA-24T1F
600 mm x 300 mm

(c) Narrow Structure Warning Signs

WC-23T
600 mm x 300 mm

WC-23TF
600 mm x 300 mm

(d) Structure Warning Signs

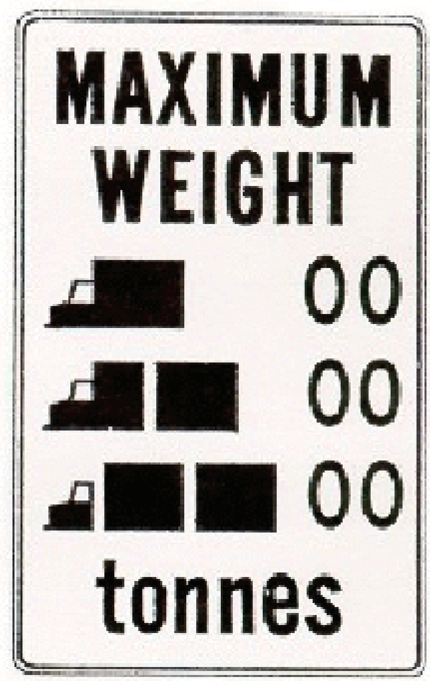
(e) Hazard Marker Signs

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

Table of Contents

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.