3.0 CHAPTER 3 - STEEL

3.1 INTRODUCTION

Steel is a reliable and versatile construction material which has been used in the construction of medium and long span bridges. It has high tensile, compressive, and shear strengths, and behaves as nearly perfect elastic material within the usual working stress ranges. It has reserve strength and the ability to deform greatly beyond the yield point before failure. The major disadvantage of steel bridge construction is its susceptibility to corrosion, but this has been over come to a degree by improved protective coatings or chemical additives, and by the use of alloys in the steel itself.

The most common forms of defects and deterioration that occur in steel are corrosion, cracking, and distortion of members. Corrosion damage occurs in unprotected steel in the presence of oxygen and moisture. However, the corrosion is aggravated by continuous wet conditions and exposure to aggressive ions such as chlorides from deicing salts. The cracking that occurs is the result of fatigue and poor design details that produce high stress concentrations. Cracks can also occur as a result of poor welding techniques that are not compatible with the steel being welded. Distortion of members resulting in a bent or twisted member can be caused by a number of ways such as overloads, collision damage, thermal stress from frozen bearings, expansion joints, and fire. The sections presented here go into the details on chemical composition, modes of failure, causes of failure and deterioration, and inspection methods.

3.2 STRUCTURAL STEEL

3.2.1 MANUFACTURE OF STEEL

Steel is a man-made metal which is composed of 95 per cent or more iron. The remainder consists of small quantities of other elements, some of which are from the raw material itself, and some of which are added during the steel-making process. The elements which are found in steel and greatly affect its physical properties are carbon(C), manganese (Mn), phosphorus (P), sulphur (S), and silicon (Si). Other alloying elements which are added in minute quantities are copper (Cu), vanadium (V), nickel (Ni), chromium (Cr), and columbium (Cb). These elements will improve the mechanical properties, corrosion resistance, or both. The manufacture of steel involves a number of steps and processes before the new material is converted into the final product, steel. Some of the steps in the steel making process are as follows:

a. The raw material iron ore, limestone, and coke are first charged into the top of a blast furnace. In the blast furnace, solid fuel is burned with heated air blown in at the bottom, and the charge as it descends undergoes several reductions until it finally emerges at the bottom as "pig iron".

b. The "pig iron" is in turn converted into steel in a special steel making furnace (open hearth, basic-oxygen, or electric furnace).

c. Oxygen is essential in all steelmaking processes because it is used to oxidize excess elements such as carbon. The dissolved oxygen content of steel poured from the furnace is high enough so that when poured into the ingot molds it will react with carbon to form carbon monoxide gas which could be trapped in the steel ingot during solidification. To control the amount of dissolved oxygen, silicon or aluminum is added to the molten steel as a deoxidizer. Depending on the degree of deoxidization, steel with the highest degree of deoxidization is termed "killed steel"; intermediate degree of deoxidization is "semi-killed" steel; and "rimed" steel is the lowest degree of deoxidization. Structural steel is produced either as semi-killed or killed steel, depending on thickness or principal application.

d. The ingots are then re-heated in a "soaking pit" and then passed through the bloom mill, the breakdown mill, and finally the finishing mill where the product is shaped.

During the steelmaking process, a sample of molten metal is taken for a chemical analysis known as the "ladle analysis". This analysis is on the mill test-certificate covering the related "heat" of steel for one production lot of steel from a steelmaking unit.

The potential mechanical properties of steel are dictated by its chemical composition, but the final mechanical properties of the steel are strongly influenced by rolling practice, finishing temperature, cooling rate, and subsequent heat treatment. In the rolling process, the material passes through rollers revolving at the same speed in opposite directions. Rolling shapes the steel, reduces its cross-section, elongates it, and increases its strength.

3.2.2 CHEMICAL COMPOSITION OF STEEL

The chemical composition of steel is important since it determines the mechanical properties of the finished steel product and controls the degree of corrosion resistance and weldability of the material. For this reason, the aim of steel specifications is to set limits for the steel producer to meet the various requirements.

Some of the more common elements found in structural steel, and their effects on steel are as follows:

a. Carbon (C)
Carbon is the most important nonmetallic element in steel. Increasing the carbon content increases hardness, strength, and abrasion; but ductility, toughness, impact properties, and machinability decrease.

In general, carbon steel may be divided into three classes, depending on the amount of carbon present: 1) Mild or low carbon steel is steel with less than 0.25 percent carbon content, 2) Medium carbon steel is steel with a carbon content of 0.25 to 0.50 percent carbon content, and 3) High carbon steel is steel with a carbon content of 0.50 to 0.90 percent.

b. Manganese (Mn)
Manganese will chemically interact with sulphur and oxygen to make it possible to roll hot steel in to shapes. It serves as a cleanser of molten metal by drawing these

impurities into the slag. It increases the strength, hardness, and machinability of steels, and also has a beneficial effect on steel by increasing its response to heat treatment.

c. Phosphorus (P)
Phosphorus increases strength, fatigue limit, and hardenability, but reduces ductility, weldability, and toughness. It improves machinability of steel high in sulphur, and under some conditions may help to increase corrosion resistance.

d. Sulphur (S)
Sulphur is added to steel to increase machinability. Because of its tendency to segregate, sulphur may decrease the ductility of low carbon steel. Its detrimental effect in hot rolling is offset by manganese.

e. Silicon (Si)
Silicon is mainly used in steel as a deoxidizer. In amounts greater than 2.5%, the silicon prevents the carbon from going into solution, causing the metal to become brittle and hard. This makes the steel susceptible to shocks and fatigue cracking.

f. Copper (Cu)
The addition of copper to low carbon steel (up to 0.35%) provides two benefits. It increases resistance to atmospheric corrosion and provides a slight increase in strength. It also increases hardenability, with only a slight decrease in ductility and little effect on notch toughness and weldability.

g. Vanadium (V)
Vanadium was originally used in steel as a cleanser, but is now employed in small amounts to make strong, tough, and hard low alloy steel. It increases the tensile strength without lowering ductility, reduces grain growth (fine grain structure), increases the fatigue-resisting qualities of steels, and improves response to heat treatment.

h. Nickel (Ni)
Nickel is soluble in iron, adds strength to the metal, and increases resistance to corrosion in the same way as copper, but is less effective than copper.

i. Chromium (Cr)
Chromium serves to increase strength, hardness, abrasion, and corrosion resistance. When mixed in correct proportions with phosphorus and copper, it develops a very dense oxide coating that inhibits further corrosion.

j. Other Elements
Columbium, molybdenum, and titanium are elements used in the production of stainless steel. They increase tensile strength, improve corrosion resistance, and resistance to creep.

3.3 TYPES OF STRUCTURAL STEEL

ASTM A36 steel was introduced in 1960, replacing the A7 (33 ksi) bridge steel of the previous 60 years. The advantages of A36 (36 ksi) was that it had a 10% increase in yield strength and it was weldable. A7 steel did not have the chemical composition to guarantee its weldability. The only A36 steel structure bridge constructed in Alberta with this material was the Red Deer River bridge on Highway 2 in 1962. A36 steel did not have the notch toughness and low temperature properties needed for a weldable bridge steel in Canada. CSAG40.8 44W was introduced about 1962 to fill this gap which provided good notch toughness characteristics. In 1973, CSA G40.21 "Structural Quality Steel" was introduced, and all CSA standards for structural steels that were in existence prior to the introduction of G40.21 were withdrawn. The metric version of the standard is G40.21M.

CSA Standard G40.21M "Structural Quality Steels" lists six types of steel:.

a. **Type G** - General construction steel that is basically carbon-manganese steel that has its chemical composition control at a minimum. Not all steel produced can be welded under normal field conditions.

b. **Type W** - Weldable steel is suitable for general welded construction. It is not suitable for low temperature service where notch toughness is a prime concern. In bridge construction, it is used in compression members.

c. **Type T** - Weldable low temperature steel is produced to a higher standard than Type W steel. In bridges, it is used in tension members and is suitable for low temperature application.

d. **Type R** - Atmospheric corrosion resistant structural steel is a low alloy steel which resists atmospheric corrosion. Thicknesses greater than 12 mm (1/2 inch) cause welding problems by creating brittleness in the heat affected zone. Therefore, Type R is not used in bridges.

e. **Type A** - Atmospheric corrosion resistant structural steel with improved low temperature properties, and high strength. These steels are used in bridge construction and can be field or shop welded in all thicknesses.

f. **Type Q** - Quenched and tempered low alloy steel plate which has high yield strength and good resistance to brittle, fracture, is easily welded, and widely used in plate girders.

CSA G40.21M also specifies nine minimum yield point strength (MPa) levels. The strength levels are 230, 260, 290, 300, 350, 380, 400, 480 and 700 MPa. Not all strength levels are available in each type of steel because of lack of application or because necessary alloy contents preclude a lower strength steel.

The grade of steel is identified by a number and a letter indicating the strength level and type of steel. Table 3.1 summarizes the grades, types, strength levels, and chemical composition of some of the steels mentioned above. For more complete information consult CSA Standards G40.20M and G40.21M.

Grade	Carbon (C) %	Manganese (Mn) %	Phosphorus (P) %	Sulfur (S) %
230G	0.26	1.20	0.05	0.05
260W	0.20	0.50/1.50	0.04	0.05
300W	0.22	0.50/1.50	0.04	0.05
350W	0.23	0.50/1.50	0.04	0.05
300T	0.22	0.80/1.50	0.03	0.05
350T	0.22	0.80/1.50	0.03	0.04
350R	0.16	0.75	0.05/0.15	0.04
350A	0.20	0.75/1.35	0.03	0.04
700Q	0.20	1.50	0.03	0.04
Grade	**Silicon (Si) %**	**Chromium (Cr) %**	**Nickel (Ni) %**	**Copper (Cu) %**
230G	0.35	--	--	--
260W	0.35	--	--	--
300W	0.35	--	--	--
350W	0.35	--	--	--
300T	0.15/0.40	--	--	--
350T	0.15/0.40	--	--	--
350R	0.75	0.30/1.25	0.90	0.20/0.60
350A	0.15/0.40	0.70	0.90	0.20/0.60
700Q	0.15/0.35	Boron 0.0005/0.005		

Table 3.1 Grade, Type, Strength Levels, and Chemical Composition of Steel

Note: (1) All percentages are maximum.
(2) Copper content of 0.20% minimum.

3.4 MECHANICAL PROPERTIES OF STEEL

Mechanical properties of structural steel are those properties of the material that are associated with elastic and inelastic reaction when force is applied, or that involve the relationship between stress and strain. The wide range of mechanical properties attainable in structural steel results largely from the fact that steel is a composite material. The significant constituents are a) the matrix iron, which is soft and ductile, and b) the particles of iron carbide which are extremely hard and strong. The strength, ductility, and toughness properties depend on three factors: 1) the relative amounts of the constituents, 2) changes in the nature of the soft matrix, and 3) the size, shape, and distribution of the hard particles dispersed within the matrix.

Some of the more important properties of steel are:

a. **Brittleness:** Brittleness in steel is the quality of the steel that leads to crack propagation without appreciable deformation in the steel before cracking takes place.

b. **Ductility:** The property of metal that permits large plastic permanent deformation before fracture by stress in tension. In a standard tension test, ductility is measured by the amount of elongation the specimen undergoes over a standard gauge length (8 inches or 2 inches). Ductility is the opposite of brittleness and steels range from brittle to ductile.

c. **Elasticity:** Elasticity is the property of a material by which it tends to recover its original size and shape after deformation.

d. **Fatigue Limit:** The fatigue limit of a material is the maximum stress that a metal will withstand without failure for a specified number of cycles of stress.

e. **Hardness:** Hardness is the resistance of a metal to plastic deformation by indentation or by other means such as scratching and abrasion. It is not a simple property because complex stress patterns develop during testing. However, hardness measurements can be made relatively easily and consistently to give an index of strength and structural coherence. There are numerous methods for measuring hardness, but the three most widely used are Brinell, Rockwell, and Vickers.

f. **Toughness**: The ability of a metal to absorb considerable energy and deform plastically before fracturing, is an important design criterion when structures are subjected to impact loads. At room temperature, common structural steel is tough and fails in a ductile manner, but at lower temperatures, a point is reached at which steel loses its toughness and fails in a brittle manner. This characteristic is measured by means of a Charpy V-Notch impact test (ASTM A673). The higher the transition temperature, the more brittle the metal becomes.

g. **Yield Point:** The yield point is the stress in a metal at which an increase in strain occurs without a proportional increase in stress. It is the point at which permanent deformation begins to occur.

h. **Yield Strength**: The stress at which a material exhibits a specified limiting deviation from proportionality of stress to strain.

i. **Tensile Strength:** The maximum tensile stress which a material is capable of sustaining. Tensile strength is calculated from the maximum load during a tension test carried to rupture and the original cross-sectional area of the specimen. It is also known as the ultimate strength.

j. **Weldability**: The weldability of a metal refers to the relative ease of producing a satisfactory crack-free, sound joint. Before welding is done on any members, the welding procedure for joining any type of steel should be based on the steel's actual chemistry, rather than the maximum alloy content allowed by the specification. This is because a mill's average production normally runs considerably under the maximum limits set by the specification.

When steel members are welded, the weld is usually stronger than the parent material, and when samples are tested in tension, the zone of failure is usually in the parent material and not in the weld. The reasons why weld material has higher strength than the parent material are: (1) The core wire used in the electrode is of premium steel, held to closer specifications than the steel to be welded, and (2) there is complete shielding of the molten metal during welding. This, plus the scavenging and deoxidizing agents and other ingredients in the electrode coating, produces a uniformity of crystal structure and physical properties on a par with electric furnace steel.

Some of the structural shortcomings of welded construction are: (1) Distortions that result from differential cooling of the weld and its surrounding metal, and, consequently formation of hidden or "locked-up" stresses, which are quantitatively difficult to assess, and (2) brittleness of the weld or its surroundings at low temperatures.

3.5 DETERIORATION AND DAMAGE OF STEEL

3.5.1 CORROSION OF STEEL

The usually accepted definition of corrosion is limited to metals, and involves some kind of chemical reaction. Corrosion is then a deterioration or destruction, and a loss of material due to a chemical or electrochemical reaction with its environment. Because corrosion is an electrochemical process, the three basic elements necessary for corrosion are an anode, a cathode, and an electrolyte. These elements will cause a metal such as steel to oxidize or rust. Rust is then the conversion of metallic iron, through chemical or electrochemical reactions, into compound form. This compound may flake off the parent metal, and result in loss of section. Corrosion of unprotected steel can occur in the atmosphere, underwater, underground, chemical attack, or by electrolysis. Depending on the position in the electromotive force series, the corrosion tendency of a metal to corrode in a given environment can be identified. For steel, the tendency to oxidize is high in this series. The structure and composition of rust will vary with the amount of oxygen present, and may determine the rate of further corrosion. If the rust is hard, dry, and well-bonded to the metal surface, it may retard corrosion, but if it is loosely bonded and spongy, it will absorb oxygen, moisture, and salt to promote further corrosion activity. Once the rust has flaked off, the surface below the flaked area will corrode and promote further rusting.

3.5.1.1 Types of Corrosion

Steel components are subjected to many types of corrosion. A brief explanation of the corrosion process is as follows:

Galvanic Corrosion
Galvanic corrosion occurs when we have two dissimilar metals or dissimilar conditions of the same metal in electrical contact with each other, and exposed to an homogeneous electrolyte. The anode is formed when a less noble metal is dissolved and the more noble metal will act as the cathode. The corrosion current flows at the expense of the anode metal, which is corroded, whereas the cathode metal is protected from the attack. An example of this type of corrosion is steel and bronze.

Differential Environmental (Concentration Cell) Corrosion
The concentration cell corrosion arises from a difference in electrolyte composition. When the electrolyte is not homogeneous, the electrode in the dilute solution becomes the anode and the electrode in the more concentrated solution becomes the cathode. Differences in the composition or concentration in the electrolyte are the result of varying moisture conditions, oxygen concentrations, type of soils, and foreign matter in the electrolyte. This type of corrosion is associated with accumulation of moisture, dirt, soil, sand, gravel, and de-icing salts in contact with the steel.

Stress Corrosion
Stress corrosion is defined as corrosion due to residual or tensile forces which expose more of the grains in a stressed surface. As corrosion continues to penetrate the metal surface, stress and corrosion will start pitting and cause a small intergranular stress corrosion crack along the grain boundaries and eventually through the center of the grains. Examples of stress corrosion include localized attack of cold-worked such as sharp bends and punched holes.

Chemical Corrosion
Chemical corrosion is the result of direct attack by acids or diluted acids. Chemical particles which are formed in the atmosphere as the result of natural or industrial activities include chlorine, carbon dioxide, and sulfur. These chemicals can react with water or moisture in the air to form an acid film, and cause rapid deterioration.

3.5.1.2 Corrosion Protection

Corrosion of structural steel elements in bridges is a major problem confronting bridge designers. To reduce maintenance and repair costs, corrosion control is essential. Some of the methods in which corrosion can be minimized are:

a. In the design stage, considerations should include selection of metals to suit the environment (weathering steel), minimize the galvanic action between metals (e.g. separate the contact surface of two different metals), provide adequate drainage to avoid ponding water, application of protective coatings.

b. Apply a protective coating over the base metal. This could be a passive coating which is less corrosive, such as nickel, copper, tin, or stainless steel.

c. Apply high quality epoxy paint coats, as well as having a repainting program.

d. Cathodic protection uses two basic types of systems which are sacrificial anode and impressed current method. It works on the principle that all corrosion on the structure will be halted if the electrical potential of the cathode areas is raised to the potential of the anodes. Once this has been accomplished, there is no current flow and therefore no corrosion can occur.

In the sacrificial system, magnesium, zinc, or aluminum is used as the anode and the steel becomes the cathode. They are interconnected by leads or indirect contact with each other. The sacrificial metals corrode more readily than the base steel. This system requires no external source of power, little maintenance, is simple to install, and has the flexibility to accept the installation of additional anodes. The disadvantage of this system is that the anode life and current output is limited, large numbers of anodes are required, and that it is not feasible for high resistivity areas.

The impressed system uses an external power source to establish a potential of sufficient magnitude. The power source is usually an alternating current which is converted to direct current by a rectifier. Since current flow does not depend on the potential of the anode and the metal structure, any suitable material may be used for the anode. Disadvantages of this system are that it depends on a power source, it requires a design against cathodic interference, and requires inspection and maintenance. The advantage of this system is that it has along life, wide range of voltages, and coverage is great from one installation.

3.5.2 FATIGUE OF STRUCTURAL STEEL

Fatigue is defined by ASTM E206-62T as "The process of progressive localized permanent structural change occurring in a material subjected to conditions which produce fluctuating stresses and strains at some point or points, and which may culminate in cracks or complete fracture after a sufficient number of fluctuations".

When we think of fatigue failure, we generally think of a failure due to old age. This is not necessarily the case anymore, as a new bridge structure can fail in fatigue if there are defects in the design, materials used, fabrication, and construction. These factors can attribute to the growth of fatigue cracks under live vehicular loads, once the bridge is in service. Failure of steel in fatigue is generally characterized by first, initiation of a crack and second, by the propagation of this crack through the material. Fatigue cracking and crack growth are promoted by a large range in fluctuating stresses rather than by the magnitude of the maximum stress. Therefore, in a structure, areas that are critical to fatigue are those where there are frequent stress reversals in the member that is subjected to cyclic loading.

3.5.2.1 Factors Affecting Fatigue Strength

The fatigue behavior of bridge structures and their members and connections are affected by a variety of factors, many of which produce interrelated effects. Some of the more important factors are material types, rate of loading, stress variations, residual stresses, size effect, geometry, and prior strain history.

Materials: In general, the fatigue strength of structural steel is not proportional to the ultimate tensile strength.

Rate of Loading: From laboratory tests only, it has been demonstrated that the rate or frequency of cyclic loading has no significant effect on fatigue strength when the frequency is less than 3000 cpm and the applied stresses are low. However, if the level of stress is high enough to cause plastic deformation with each cycle of loading, an increase in the speed of loading will produce a corresponding increase in fatigue failure.

Residual Stresses: Residual stresses are internal, locked-in stresses in the material produced by welding or rolling during fabrication of the steel member. These stresses can be either tensile or compressive. In the case where the location subjects the member to stress reversal, the residual stresses in the member will contribute to fatigue cracking and crack growth each time the stress cycle produces a tension component. On the other hand, the growth of cracks is stopped as a result of the crack propagating into areas that have low compression stress or residual compressive stress.

Size Effect: Laboratory results show that larger members show a fatigue strength less than smaller members due to the effect of size and strain gradient in the smaller member.

Geometry: Geometry has the greatest influence on the fatigue strength of steel. It is affected by the abruptness of the change in geometry, material type, and life or number of cycles. Sharp notches produce large strain concentrations resulting in low fatigue strength.

3.5.2.2 Out of Plane Distortion

The largest category of fatigue cracking in continuous steel plate girders is a result of out-of-plane distortion across a small gap, usually a segment of a girder web. Out-of-plane bending in the girder webs can cause crack propagation and fracture.

It occurs in the negative moment region at the diaphragm connection plate near the top flange of the girder. The small gap is the portion of the girder web between the top of the fillet welds attaching the diaphragm connection plate to the web and the fillet welds attaching flange to the web. In general, the cracks form in planes parallel to the stresses from loading and are not detrimental to the performance of the structure, providing they are discovered and retrofitted before becoming perpendicular to the primary stresses from loads. See Figures 3.1 & 3.2.

The stresses at the web gap are several times larger than flange stresses and cracking may occur well within the design life of a bridge structure due to high cyclic stresses that occur under normal bridge loading. The loads may be within legal limits, but frequency of truck traffic is greater, and fatigue stresses accumulate.

Once out-of-plane distortion bending cracks are identified, it is extremely important that all similar locations on the structure also be carefully inspected to search for similar damage.

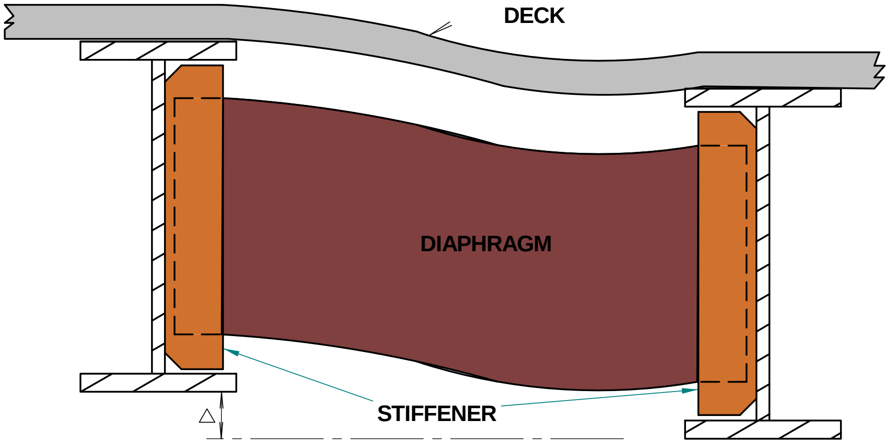

Figure 3-1 Out of Plane Distortion #1

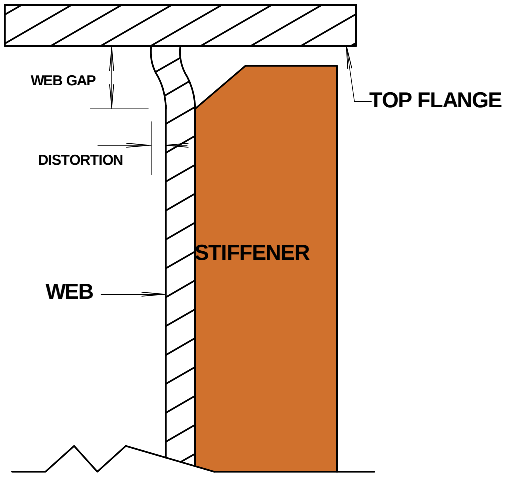

Figure 3-2 Out of Plane Distortion #2

3.5.2.3 Types of Fatigue Inspection

Two types of inspection methods are used to evaluate and identify fatigue problems on bridge structures: A) Periodic visual inspections which are done in the case where fatigue is not considered a serious problem, and B) Comprehensive fatigue evaluations where fatigue is a major concern i.e. the Structure is liable to fail. A brief summary of the two types of inspection is presented below. (NCHRP 123 and Journal of Structural Division. Vol.97, No. ST8, August 1971).

Periodic Visual Inspections: Visual inspection of bridges for fatigue cracks is the first step in the evaluation of fatigue cracks. This inspection is supplemental by nondestructive testing. Discovery of fatigue problems require action on the part of the inspector to notify the proper authority so that proper remedial measure can be undertaken. During the visual inspection of bridges for fatigue, one should look for:

1) Connection points that restrain certain parts of a beam to deflect normally under load.

2) Members that could be forced to carry unequal or excessive stresses as a result of loose connections.

3) Misaligned, bent, torn, or twisted members as a result of vehicular impact or overstressing.

4) Corrosion of a member with reduced cross-section resulting in a reduced load carrying capacity. This would render the member less resistant to repetitive and static stresses.

5) Connections such as floor beam to girder or stringer connection that have sharp reentrant or coped sections that are susceptible to cracking.

6) Stress raisers such as rivet or bolt holes, toes of fillet welds, changes in section, rough flame cut edges and mechanical indentations, and welded details should be given particular attention.

7) Poorly repaired areas and strengthening details can reduce the fatigue resistance of the structure. This can be due to improper welding or cutting procedures used in the repair.

8) Excessive vibration.

9) Excessive tension in both secondary and main structural members.

10) Loose or displaced members, pins, supports, and frozen expansion type bearings in old structures contribute to fatigue problems.

11) Members that are subjected to stress reversal and in areas where residual tensile stresses are present.

Although some secondary structural members such as sway and lateral bracings are considered to be stress free, cracks have been found that could propagate into the primary member. Since the purpose of secondary members is to stiffen the main structural member, a reduction in stiffness by fatigue cracks could lead to load shedding. This load shedding is the transfer of load to adjacent members that could result in accelerated cracking in them.

Field inspection experience has shown that the typical locations where fatigue cracking has occurred are:

1) Tension members such as diagonals, hangers, and bottom chord eye bars in bridge trusses subjected to cyclic loading.

2) Splices at chords.

3) Coped hangers or mid panel verticals at chord connections.

4 Connections of long hangers.

5) Connection detail at the joint between the portal connection and top chord.

6) Connection detail for lateral bracing.

7) Pins and members that have been weakened by corrosion.

8) Stress raisers such as rivet or bolt holes. The cracks generally run transverse to the direction of the stress.

9) Welding repairs.

10) Cover plates, reinforcements, or other attachments that are welded to the structural member.

11) The connection detail at fixed bearings and expansion bearings.

12) Stringer webs and stringer floor beam connections.

3.5.2.4 Comprehensive Fatigue Evaluations

Comprehensive fatigue evaluation is a more detailed examination of the bridge structure which includes visual inspection, nondestructive testing, and fatigue analysis of possible locations susceptible to cracking. The evaluation procedure includes the following:

1) Determine the locations that have the greatest stress range and number of cycles analytically. These locations include ends of cover plates, connections at stringer to floor beams, floor beams to girders, and truss member connections.

2) Estimate past and future loading conditions so that stress levels and cycles of loading can be evaluated to determine if it fulfills the design considerations. Field instrumentation with strain gauges can provide the actual stress in the member.

3) Evaluate the fatigue behavior of the structure based on actual tested stress data and frequency of loading.

4) The analysis will allow an estimate of current crack experience as well as future crack growth.

5) After this analysis a visual inspection and nondestructive testing should be undertaken to confirm the fatigue areas. Follow-up inspection should be taken in these areas using ultrasonic methods, etc.

3.5.3 BRITTLE FRACTURE OF STRUCTURAL STEEL

Brittle failures of structural steel are low-ductile fractures that occur without plastic deformation and at relatively low stress levels. The fracture usually occurs at stress levels below the yield-strength of the steel and can propagate at stresses lower than 20 per cent of the yield strength. Brittle failures can be identified by the lack of ductility and V shaped appearance of the structure surface.

Some of the major factors affecting brittle fractures are:

a. The chemical composition of the steel is important as it affects the transition temperature and energy-absorbing capacity of the steel. Therefore the lower the carbon content, the greater the notch toughness and energy absorbing capacity of the metal. Of course, notch toughness must be balanced with the requirement of other strength parameters that call for increased carbon content. At the same time, adding other elements such as silicon (Si) will increase the strength of steel and lower the ductility transition temperature.

b. Residual stresses locked into the structure member as a result of welding can promote brittle failure at low temperatures and low stresses.
Discontinuities or flaws such as laps, seams, cracks, splits, laminations, pits, inclusions, undercut, weld cracks, and incomplete fusions could lead to brittle fractures.

c. A drop in temperature increases the strength of the steel but decreases its notch toughness.

d. The production of thicker plates requires fewer rolling passes, they cool slower, and the finishing rolling temperature is higher than that for thin plates. This results in a higher transition temperature making thicker plates more brittle.

e. Dynamic loading of the bridge structure may provide a transition temperature slightly higher than if the structure was subjected to static loads or slow bending on the same member.

f. Cold working as a result of impact damage causes the metal to strain beyond its yield point resulting in an increase in the transition temperatures.

g. Under some conditions, repeated loadings may tend to increase the possibility of brittle fracture.

3.5.4 CONSTRAINT INDUCED FRACTURE

Failure is not due to fatigue stresses or the number of stress cycles but caused by brittle cleavage fracture, which occurs very suddenly with no prior signs of cracking. It propagates through the girder at a fast rate. It is primarily due to:

- High levels of tri-axial constraint at the crack-like geometrical condition at the weld intersection of gusset plate and vertical stiffener.
- Stresses are elevated well beyond the yield point and stress intensities exceed the fracture toughness of the web material.
- Visual evidence of the defect may not be observed, however microscopic level of flaw triggers the fracture.

Examples of failure mode with brittle fracture are:

- Hoan Bridge in Milwaukee Wisconsin had a full depth fracture in one girder and the second girder had a 1 metre long fracture.
- Schuylkill River Bridge in Montgomery County Pennsylvania had a severed bottom flange and a partial fracture into the web.

These fractures were all similar with intersecting welds or small gaps between intersecting welds. Small gap welds are defined as those whose weld toes come within 6 mm of each other. See Figure 3.3.

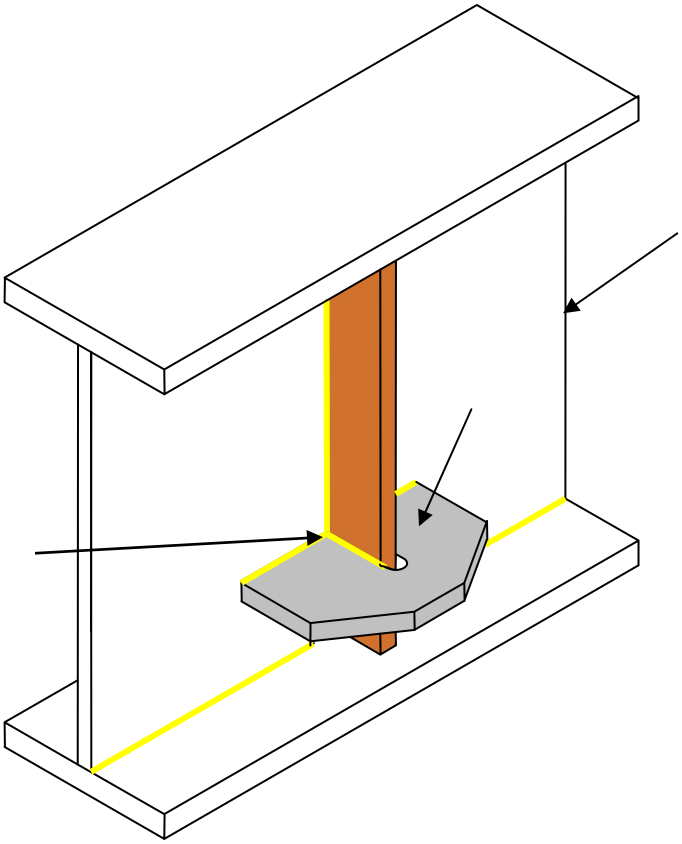

Figure 3-3 Constraint Induced Fracture

3.5.5 FIRE DAMAGE

Although structural steel does not support combustion, elevated temperatures have a detrimental effect on the physical and mechanical properties of structural steel. Fire protection for bridges is not required, but the possibility of members exposed to intense heat for a short period of time is a possible hazard.

In general, the effect of heat on structural steel results in a decreased yield strength almost linearly from its value at 21 degrees C (70 degrees F), to about 80% of that value at 427 degrees C (800 degrees F). At 538 degrees C (1000 degrees F), the yield stress is about 70% of its value at 21 degrees C (70 degrees F), and approaches the working stress of the structural members. Tension and compression members are permitted to carry the maximum working stresses if the average temperature does not exceed 538 degrees C (1000 degrees F),and provided compression members do not buckle. The effect of heat on the tensile strength results in a slight increase in strength followed by a continuous rapid decrease. Bridge elements subjected to high heat can cause members to sag, buckle, or twist, and cause rivets and bolts to fail at the connections. The paint is usually burnt off and the steel shows a darker colour than normal.

3.5.6 VEHICULAR IMPACT

Each year, a number of bridges are either hit by vehicles, high loads, or wide loads. Steel bridges are more susceptible to vehicular damage than concrete or timber. Although steel is strong under tensile and compressive loads, it can deform under loads which are perpendicular to the tension -compression axis. Impact points should be inspected for kinks, crimps, bends, and tears in the beams; and damage to connections. The extent of the distortion in the member itself as well as other portions of the bridge should be examined. When a steel member is deformed by vehicular impact, the mechanical properties of the steel may be altered as follows:

a. The yield point of the metal may be exceeded and the metal has been deformed.

b. The internal strain may be increased.

c. The stress lines may be altered.

d. The metal may become more brittle as a result of cold working.

3.5.7 OVERLOAD DAMAGE

Although bridge components have been designed with certain safety factors to account for various loading conditions, they can still be damaged by overloading. We know that from the stress-strain diagram, no permanent deformation occurs in the steel if the stress applied does not exceed the yield point. Therefore, the mechanical properties of steel obey Hooke's Law where the strain is directly proportional to the applied stress up to the elastic limit. Beyond the elastic limit, steel becomes plastic and deforms or elongates, and will remain in this condition even after the load has been removed, and will not return to its original state, resulting in permanent deformation.

In the case of overloaded bridge structures, plastic deformation can occur in both tension and compression members. Members subjected to plastic deformation in tension exhibit symptoms such as elongation and decrease in cross-section, commonly known as "necking". Members subjected to plastic deformation in compression show signs of buckling, looking like a single-bow or a double-bow. Double conditions occur in buckling when sections in compression are braced or pinned at the center point.

In the case of complete failure, the steel members have failed as a result of the tensile strength of the section being exceeded with a complete separation of the metal. The symptoms of complete failure due to overload conditions are characterized by a fibrous appearance at the point of separation, and at the point of failure we have necking or buckling.

3.6 NONDESTRUCTIVE METHODS OF CRACK DETECTION IN STEEL BRIDGES

Steel bridges that are in service for a number of years may experience fatigue damage as they are subjected to an increase in load and accumulation of loading cycles. A number of on-site non-destructive testing techniques have been developed for the detection of field fatigue cracks. The five basic methods of examination are radiography, ultrasonic, dye penetrant, magnetic particle, and eddy current. Although there are other methods such as acoustic emission, acoustic spectroscopy, acoustic holography, infrared, etc., they are not in general use because of their present state of development.

The Department uses radiography, ultrasonics, magnetic particle, and dye penetrants. In spite of the capabilities available to detect cracks and/or fatigue cracks, it must be remembered that no method is better than the operator, and that none of the methods are 100% reliable.

3.6.1 RADIOGRAPHIC EXAMINATION

Radiographic examination is one of the most widely used techniques for showing the presence and nature of macroscopic defects and other discontinuities in the interior of steel members and welds. This test is based on the ability of short wave radiation such as x-rays or gamma rays to penetrate metal and other opaque materials to produce an image on sensitized film or a fluorescent screen.

X-rays with a wavelength of 1/10,000 that of visible light are produced by high voltage generators. It is not very portable, and hence is not used as much in the field as gamma-rays, which involves less equipment. Gamma rays are produced by the atomic disintegration of radioisotopes or radium of which cobalt and iridium are the common sources. The wavelength of gamma rays are shorter than those of x-rays, and therefore the exposure time required to get an interpretable picture is usually many times longer than x-rays because of the lower intensity of the radiation. The radioactive source is usually housed in a small capsule and encased in lead to avoid danger of radiation when not in use. This method is portable and is adapted for field use.

All of the radiation emitted from an x-ray or gamma source and directed at the steel section tested may not get through the metal and to the film placed behind it. The amount of radiation getting through depends on the density and thickness of the section. Internal defects such as cracks or voids will have less metal for the radiation to pass through. Hence, there will be less absorption in the defective area and a greater amount of radiation striking the film. When the film is developed, the defects show up in its shape and size as black or dark areas on the film.

Radiographic examination of defects in steel is excellent in examining slag inclusions or porosity in welds. Planar defects such as cracks are detectable only if oriented approximately parallel to the axis of the source. Cracks or planar defects perpendicular to the source axis will not change the radiation absorption significantly, and thus will be undetected. Intermediate orientation will produce varying degrees of defect detectability.

The accuracy of crack detection is dependent on the size of the section examined, and the location of the crack. Under field conditions, fatigue cracks can be detected to a depth of as little as two per cent of the thickness of a member.

The advantage of radiographic examination of defects is that it provides a permanent record on film and the ability to determine the size and shape of internal defects. It is therefore widely used in industry. The main disadvantages of this method are that it cannot locate the depth of cracks or poorly oriented planar defects, and the need to use hazardous equipment which is subject to government licensing.

3.6.2 ULTRASONIC TESTING

Ultrasonic testing uses high frequency sound waves to detect internal flaws in steel, and is based on the factor that a discontinuity or density change will act as a reflector for high frequency vibrations propagated through the metal. The sound waves are produced by a wave generator and are picked-up by the receiver. Depending on the system used, the sender and receiver units can be one unit. The initial and reflected pulse are displayed on an oscilloscope, which permits the determination of the depth, nature, and size of a defect. The sensitivity of the test is influenced by the sound frequency, design of the search unit, instrumentation, electronic processing of the return signal, and operator skill.

The major advantages of ultrasonic testing are its portability, sensitivity, and the ability to detect the locations and depths of cracks or defects. The disadvantage of this type of nondestructive testing is that it is strongly influenced by the ability of the operator, does not provide a permanent record without taking a photographic record of the display, can not detect surface defects very well, and is sometimes too sensitive (i.e. too much information such as grain size in metals, boundaries, and minor defects are detected).

3.6.3 DYE PENETRANT

The dye penetrant inspection of defects in steel is limited to defects which penetrate the surface of the structure only. It is inexpensive, easily applied and interpreted, and can be used both in the field and shop. This method requires a minimum of equipment. The process consists of the following:

a. The surface to be examined is mechanically or chemically cleaned.

b. A low viscosity, high capillarity fluid containing a red dye is applied to the surface by brushing or spraying, and allowed to penetrate the cracks or surface defects.

c. After the penetration time, excess penetrant is removed.

d. The surface is then sprayed and/or brushed with a second solution called a developer.

e. The developer will show by capillary attraction the red penetrant from locations where cracks are present, and regions not affected will remain a chalky white. Other modification of this system of examining cracks is to use penetrants that flouresce under ultraviolet light.

The major advantages of this method of examination are that it is low in cost, requires minimal skills, is not time consuming, and is very portable. The disadvantages of this system are that it can only detect surface cracks, and does not reveal the depth of a crack.

3.6.4 MAGNETIC PARTICLE

This method of testing is limited to the detection of surface or near surface defects, and applicable only to materials which can be magnetized. The method works on the principle that when a magnetic field is induced in steel, and this field encounters any surface or subsurface discontinuities, the field will become distorted at that point, causing concentrations of magnetic lines. When a fine iron powder is sprayed on the test surface, the discontinuity (cracks) will cause a build-up of iron powder. In order to detect cracks for visual inspection, it must be aligned transverse or nearly transverse to the magnetic field and therefore, the test rods must be moved about the structure so that defects can be identified at any orientation.

The advantages of this method are that it is portable, requires minimal skill, and detects fine cracks. Its disadvantages are that it requires the removal of paint from the testing surface, leaves the test section magnetized, and does not determine the depth of the crack.

3.6.5 EDDY CURRENT

This method of detecting defects is similar to the magnetic particle inspection except that the defect is detected by a perturbation in the electrical field in the material tested. The technique involves the use of a coil carrying alternating current which produces eddy current in the examined part. The examined part eddy current in turn creates impedance in the exciting coil. The impedance produced depends on the nature of the part tested and the exciting coil, magnitude and frequency of the current, and the presence of discontinuities in the part examined. The equipment needs calibration so that when the coil is used to scan the surface of the defect area, any defects present will result in a change in the impedance, which is read directly from a meter.

This method has limited use but has potential. It can detect defects in depth, estimate defect size, and is not affected by surface conditions such as paints. However, it is influenced greatly by geometry, that is, only simple geometries can be examined because more complex geometries change the impedance readings by themselves.

3.6.6 COMPARISON OF NONDESTRUCTIVE EXAMINATION METHODS

Table 3.2 summarizes the overall capabilities of each method of testing. Of the five methods discussed, there is not one process that is good for all kinds of defects, and each has its limitations. The intent of the table is to give a rapid assessment of the strengths and weaknesses of each technique available, and to enable the user to select the methods most suitable for a particular application.

Radiography has been widely used in the detection of internal voids and defects in welds, but is not satisfactory for detection of surface cracks. It is also poor in the detection of fatigue cracks in structures already in service.

Ultrasonic is not completely ideal for detection of fatigue cracks in all its operating modes. However, it has the advantage over other methods in that it is capable of detecting the size and position of hidden and surface flaws. The minimum crack length that can be detected with ultrasonics is about 2.5 mm (0.1 in) long, but crack detection in the field in the order of 25 mm (1 in) is practical.

The best methods for surface crack detection are magnetic particle and dye penetrant. Of these two, magnetic particle inspection is probably better because it can detect tight cracks and surface preparation is not an important factor. The real limitation in the two methods is their inability to reveal the depth or the length of cracks progressing below the surface.

DEFECTS	TECHNIQUES					
	RADIATION	MAGNETIC CURRENT		EDDY CURRENT	DYE PENETRANTS	ULTRASONICS
		WET	DRY			
Minute Surface Cracks	N	G	F	F	F	P
Deep Surface Cracks	F-	G	G	G	G	G
Internal Cracks	F-	N	N	N	N	G
Fatigue Cracks	P	G	G	N	G	G
Internal Voids	G	N	N	N	N	G
Porosity and Slag in Welds	G	N	N	P	N	F
Thickness	F	N	N	P	N	G
Stress Corrosion	F	G	F	N	G	F
Blistering	P	N	N	N	N	F
Corrosion Pits	G	N	P	N	F	P

Note:

1) G= Good; F=Fair; P=Poor; N=Not Suitable
2) *If radiation beam is parallel to crack
3) **Capability varies with equipment and operating mode

Table 3.2 Nondestructive Examination Methods

3.7 STEEL BEAMS AND GIRDERS

3.7.1 GENERAL

Beams and girders are generally classified as primary support members. A member that spans two supports is generally called a girder, while members supported by girders are called beams. This definition is not rigidly adhered to when referring to bridge structures as the terms beam and girder are generally used interchangeably. In bridge structures it is the function of beams/girders to transmit the deck loads to the piers and abutments. There are three distinctive types of steel beams and girders for bridge structures: Rolled Sections (wide flange), Built-up Sections (plate girders), and Steel Box Girders.

The simplest steel girders consist of rolled I beams or wide flanges. These sections are generally one piece units which are mill-rolled in a steel fabrication mill. It has no seams, welds, bolts, or rivets. The horizontal portions of the cross-section are called flanges and the vertical section is called a web.

The term plate girders refers to built-up beams of I-shaped cross-section which are larger than rolled sections in depth to meet design requirements. They are comprised of the web and flanges which are either riveted or bolted together from plates, angles, and channels or welded from plates alone. Girder webs are protected against buckling by transverse stiffeners, and in the case of deep webs, by longitudinal stiffeners. These vertical stiffeners act like bearing posts over load concentration points and serve as short compression members. The longitudinal or horizontal stiffeners found in some deep girders are located about one-third of the depth from the compression flange which help to prevent the web from buckling due to high compressive flexural stresses. The stiffeners can be made from plain plates, angles, or T sections, which are riveted, bolted, or welded on the web.

Steel box girders in cross-section are usually rectangular or trapezoidal in shape. They are often used in highway bridges because of their rigidity, economy, and appearance. They have an advantage over plate girder and rolled beam bridges in that they have high torsional rigidity. Manholes or openings are usually provided to gain access to the interior of the box for inspection, maintenance, drainage, or access to utilities.

3.7.2 INSPECTION OF BEAMS AND GIRDERS

The following areas should be checked when inspecting beams and girders:

3.7.2.1 Cover Plate

Cover plates are plain steel plates which are bolted, welded, or riveted to the flanges of steel beams to provide additional section. Check for the following:

1) The gap or space between the two plates should be examined for rust, trapped dirt and moisture. Expansion forces created by corrosion maybe enough to spread the plates apart.

2) Check for cracks at welds, missing bolts, or rivets.

3) Check cover plates that are welded on the bottom of flanges for tension and fatigue cracks. Fatigue cracks are likely to occur when there is a change in flange cross-section at the ends of welded cover plates. There may be severe stress concentrations at the fillet weld and the crack may form at the toe of the weld and grow through the flange.

3.7.2.2 Flange

Flanges are the top and bottom parts of an I beam or built-up girder that carry the compressive and tensile forces generated by the internal resisting moments of the beam. Check for the following:

1) Check the general alignment of the member by sighting along the member. Any misalignment or distortion maybe the result of overstressing, collision, or fire.

2) Check the tops and bottoms of flanges of steel beams and girders for wrinkles, waves, cracks, or damages of any kind.

3) Check the tops of the flange and top side of the bottom flange for accumulation of debris.

4) Check bottom flange for tension cracks as a result of fatigue.

5) Check top and bottom of flanges for rust, deterioration, and measure the cross-section for possible loss in sectional area.

3.7.2.3 Web

The web is that portion of a beam or girder located between the two flanges. It serves to resist shear stresses.

1) Check for web crippling, buckling, and shear.

2) Check the connections of floor beam and diaphragms to girder or stringers for cracks in the web of the girder. This is an example of a detail that has sharp re-entrant and coped corners.

3) Check for wrinkles or waves.

3.7.2.4 Stiffeners

Stiffeners are angles, tees, channels, plates, or other rolled sections that are welded, bolted, or riveted to the web of girders. They are used to transfer stress and prevent buckling or other deformation in the web.

1) Check welds of longitudinal or transverse stiffeners for cracks.

2) Check stiffeners for straightness and sound connections.

3.7.2.5 Splices

A splice is the joining of two structural members by splice plates. Fastening may be achieved by rivets or bolts. The splices are designed to transmit stresses.

1) Check riveted, bolted, and welded connections for completeness, and ensure that there is no looseness, sign of movement, or cracking.

2) Check splice plates for cracks, rust, or deterioration.

3.7.2.6 Weld, Bolts, and Rivets

Riveting, bolting, or welding are the connection methods used for girder and beam construction. In the case of riveted or bolted sections, their total available cross-section is reduced by the number and size of fastener holes required. The strength of welded connections depends on the type of weld and the length and type of weld material used. In most cases, the weld is stronger than the member being welded. Check to ensure that all welds, bolts, and rivets are complete and that they are not rusted or deteriorated.

3.8 TRUSS BRIDGES

3.8.1 GENERAL

Another structural system for transmitting deck loads to piers and abutments is called a truss. A truss is a structural system made up of individual members connected in a triangular pattern. The properties of a truss are the following: 1) the members are generally straight with the exception that the top chord could be of a bow shape depending on the type of truss (Bow Truss), 2) connections between members are considered as frictionless hinges, and 3) all loads act at the joints. Based on the above assumptions, truss members can be subjected to either tension or compression forces which act axially on the member.

Bridge trusses are always constructed in pairs. The flooring system used in trusses consists of floor beams which are connected at truss joints or panel joints perpendicular to the direction of flow of traffic. Stringers which frame into the floor beams or placed on top of the beam run in a longitudinal direction with respect to the flow of traffic. These stringers carry the deck load to the floor beams which transfer these loads to the truss at the panel points. The bridge trusses are designed to carry their own weight, the weight of the floor system, and the live loads which include vehicular traffic, impact, and wind.

3.8.2 STRESSES

Forces in truss members can be analyzed by the Method of Sections, Method of Joints, and Graphic Statics. Depending on the method used, the basic principles which are common to all the methods is that forces acting at each joint can be evaluated by the law of equilibrium. Therefore, the stresses and loads at the joint must be in equilibrium, and the sum of the horizontal components and the sum of the vertical components must be equal to zero. In general, stresses in truss members are either in tension or compression. The upper chord of a single span truss is placed in compression and is called the compression member. The lower chord is placed in tension and is called the tension member. Web members, which are verticals and diagonals, can be either in compression or tension, depending on the type of truss and its location within the truss.

The loads which act on trusses are similar to those acting on beams and girders. For each truss, the dead load consists of the weight of the truss and one-half the weight of the deck and floor system acting uniformly along the span of the truss. This load is divided evenly among the panel points between the supports. Live loads are vehicular axle loads which traverse the bridge and also include the impact loads. In the analysis of trusses, the moving live load produces maximum stress in each member and the truss member is designed to accommodate these anticipated loading conditions. These loads act vertically only at the panel points to which the floor system is attached.

The trusses are supported by end bearings which transmit reactions from trusses to substructure elements such as abutments or piers. Roller type bearings are usually used at one end so as to accommodate vertical, horizontal, and rotational forces.

3.8.3 NOTATION FOR SPAN & TRUSS COMPONENTS

The following notations are used for truss spans and components by the Department:

a. Looking downstream, the spans are numbered from left to right.

b. All spans, including approach spans such as timber, must be included.

c. For the bottom chord, the truss notation should start with L0 to the left when looking downstream and increase by one with each panel point i.e. L0, L1, L2, L3, etc.

d. For the top chord, the truss notation starts with U1 at the first panel point when looking downstream and increase by one with each panel point.

This notation is contrary to the span notation system used for other bridge types (i.e. increasing chainage, south to north and west to east). This notation system is used for trusses because there are numerous historical records of trusses using this system and it would be too difficult to change all of these records.

3.8.4 INSPECTION OF TRUSS COMPONENTS

The principal components of a truss bridge are top chords, batter posts, sway bracing, diagonals, verticals, portals, connections, floor beams, bottom chord, and stringers. A brief explanation on the function of each part as well as inspection items to look for are presented below.

3.8.4.1 Top Chord

Functions similar to the top flange of a beam, the top chord is a longitudinal structural member extending the full length of the structure. The top flange of a truss is generally in compression. When inspecting the top chord, one should sight along the individual members for proper alignment. Any conditions of misalignment may be the result of overstressing or buckling of the compression members. The overstressed members exhibit signs of wrinkles or waves in the flanges, webs, or cover plates. The load carrying capacity of the bridge is reduced by buckled, torn, or misaligned members.

3.8.4.2 Batter Post

Batter posts (End Posts) are compression-chord members which are located at each end of a single-span truss. They are usually inclined or sloped to meet the bottom chords just above the bearings. Examine the batter posts for collision damage as a result of high or wide loads.

3.8.4.3 Sway Bracing

Bracing between corresponding vertical posts of a pair of main trusses is called sway bracing. The purpose of these frames is to stiffen the structure and resist the sway and torsional effects of windloads and other lateral forces. These members should be visually inspected as follows:

1) Check fasteners for rust at bolts or rivet heads. Look for loose or broken connections which could lead to further damage as a result of vibration, impact, or abrasion of parts wearing against each other.

2) Check all bracing members, especially those which lie horizontally, for accumulation of debris such as salts, dirt, water, etc. which could lead to rust and deterioration.

3) Since these bracing members could be designed for tension or compression, check for bent or twisted members. Any bends or kinks will distort the cross-sectional area and shape as well as reduce its load carrying capacity.

4) Where the bracing is welded to truss members, the weld should be examined for cracks.

5) Observe excessive vibration or movement under traffic to see if bracing system is adequate as this vibration or movement could lead to fatigue stresses.

3.8.4.4 Lateral Bracing

Lateral bracings are bracings in the horizontal plane that span between the two chords of the truss. It is found either at the top or bottom and serves the purpose of stiffening the structure against lateral vibrations due to wind loads. Like sway bracings, they are considered as the secondary system of members to the main load carrying frame. When inspecting bracings, visually inspect for the following:

1) Check horizontal bracings for rust, deterioration, and debris. This includes lateral gusset plates which lie on a flat surface which can collect salts, dirt, and moisture.

2) Check for loose, missing, rusted or broken fasteners. Loose connections lead to abrasion wear between parts as a result of vibration and movement.

3) Check lateral bracing for weld cracks when welded to flanges.

4) Check for excessive vibration or movement under traffic. Excessive vibration could lead to fatigue cracks at the connections.

5) Check for distorted, bent, or twisted members.

3.8.4.5 Diagonals

Diagonals are cross web members which frame into the top and bottom chords. They can be either in tension or compression, depending on the truss shape and design. The diagonals provide for shear capacity. The member should be examined as follows:

1) Check all tension members for localized contraction in the cross-section area which is usually shown by flaking of the painted surface. Diagonal members that are subjected to cyclic stresses may develop fatigue cracks long before other members do in the structure.

2) Check to see that members are not distorted, twisted, or bent.

3.8.4.6 Verticals

Verticals are web members that are framed between top and bottom chords. They provide additional points for the introduction of loads and reduce the span of the chords under dead load bending. Verticals which are subjected to compression are called posts and those which are subjected to tension are called hangers. Examine the truss as follows:

1) Check tension members for localized failures where we have evidence of flaking of the painted surface.

2) Check compression members for kinks, bents, or buckling.

3.8.4.7 Portals

Portals are bracing members between sloping chords of a pair of main through trusses located at the end posts. It helps to maintain the shape of the end cross-section of the bridge. The portal is normally a sway frame whose purpose is to transfer lateral and shear forces to the end post. Overhead portals generally restrict the height of vehicles that can go over the bridge. Because of this clearance, these members are frequently hit by high loads which can cause members to break or bend. This would result in a transfer of stresses to other members which can add more stresses than what they were designed for. It is therefore important not to just inspect the damaged areas, but also to examine other truss members in close proximity for hidden damage as well.

3.8.4.8 Connections

Truss members are joined at the panel points which are located along the upper or lower chords between panels. The connections at the panel points are fastened by either welding, rivets, or high strength bolts. The main members are connected by plates or angles except in the case of pin-connections. Depending on the type of members intersecting at the joints, gusset plates are paired to avoid eccentricity. The gusset plates are usually designed to meet shear, direct stress, and flexure, and does not permit rotation of the truss members around the joints or panel points. At connections the following items should be examined:

1) Check fasteners for loose, missing, or rusted bolts, rivets, or nuts. Cracks in the paint may indicate the presence of movement at the joints.

2) Check gusset plate for possible failure in the material as a result of fasteners exerting a bearing stress on the material through which they pass. They have a tendency to tear through the material which they hold together or crush the bearing material.

3.8.4.9 Floor Beams

Floor beams are members which run perpendicular to the direction of traffic flow. They are connected at the panel points between the trusses and are designed to transmit the deck load to trusses. Their main purpose is to support the stringers and transfer their loads. When examining the floor beams, the following areas should be examined:

1) Check corrosion at the connection points at the ends of floor beams. This is critical when end connections are exposed to moisture, deicing salts, dirt, and debris which collect at connections and promote rapid deterioration.

2) Check for cracks in the web, along the top and bottom flanges, connections, and at the bearing ends over supports. Excessive vibration and movement of floor beams by vehicular loads could induce fatigue failures.

3) Check the floor beam for sagging, buckling, twisting, or canting. The stresses that should be considered are compression along the top flange, tension along the bottom flange, and stresses that produce crippling of the web or transverse buckling between the end supports. In cases where the floor beams are supported by other members, check for crushing or vertical shear at the bearing points.

4) Check end connections for tightness, missing or loose rivets or bolts, and also for any movement of plates or angles used in the connection.

5) Examine welded connections for cracks.

6) In the case of built-up sections, check along the top flange underneath the deck slab for corrosion, and check welds for corrosion or rusting between the individual parts such as angles used in joining of the web plates.

3.8.4.10 Bottom Chord

The bottom chord is considered as the main lower longitudinal structural member which extends the full length. It is in tension and resists forces induced by bending. When inspecting the bottom chord, the following items should be examined:

1) On a through truss, the lower chord members and members adjacent to the web should be examined for rust, deterioration, accumulation of debris and soils. Salts, debris, sand, and dirt tend to hold moisture that results in rapid deterioration of fasteners and connections.

2) Check for overstressing resulting in reduction of cross-sectional area.

3) Check for excessive vibration, noise, and movement with passage of vehicles.

4) Check fasteners for loose, missing, or rusted rivets, bolts, or nuts. At the connections, cracks in the paint may indicate that there is movement in the joint.

5) Sight along the length of the chord to check for misalignment.

3.8.4.11 Stringers

Stringers are longitudinal beams that are set parallel to the direction of traffic flow, connecting floor beams. They are used to transmit the deck load to the floor beams and are usually framed into the floor beams by angles. If the stringers are supported on the top flanges of the floor beams, they may or may not be continuous over two or more panels. If stringers are not present, then the deck slab which is structurally reinforced is cast on top of floor beams and the main reinforcing connects the floor beams. Stringers should be inspected as follows:

1) Check stringer web and flanges at end connections for fatigue cracks. This condition occurs when the end connections are rigid.

2) Check for sagging, twisting, or canting of stringers. Excessive deflection of stringers usually produce transverse bending, resulting in lateral buckling of the beam at its connections.

3) In the case of continuous stringers, the riveted or bolted splices, joints, and plates should be examined for rust, corrosion, missing or loose bolts, or rivets.

3.8.4.12 Pins

Rigid joints such as gusset plate connections do not allow movement and can induce secondary stresses. To eliminate secondary stresses at panel points on the truss members, pin connections are used. These pinned connections have the same strength as the cover plate/rivet or bolted connections. They are held in place by nuts or rollers or both. Since these pinned connections permit rotation of the truss member or the pin itself, they should be checked to ensure that the pin is not worn, and that spacers, nuts, retaining caps and keys are in place.