FORMWORK & FALSEWORK MANUAL

Ministry
of
Transportation

Ontario

Prepared by
Head Office, Structural Office
Approvals Section

April 1997

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Preface

This manual is initiated by MTO to present general guidelines that reflect the current state of the practice for designing, constructing, and inspecting the falsework and formwork used to construct highway bridge structures.

Users of this manual are reminded that compliance with it does not confer immunity from relevant satutory and legal requirements. The applicability of all or part of this document to a given situation highly depends upon its specific circumstances, consequently, individual engineering judgement is, as always, called upon.

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1. INTRODUCTION

Formwork and falsework play an important role in the construction of bridge structures, both in terms of the function they perform and of their cost. They provide rigid support for the freshly cast concrete and sometimes they also provide temporary openings for the passage of vehicular or pedestrian traffic underneath bridges during their construction.

Formwork and falsework serve different functions. Falsework is intended to provide temporary vertical support for structures during their construction, alteration or repair. Formwork is intended to provide temporary containment of freshly placed concrete for structures during their construction, alteration, or repair.

Although formwork and falsework are classified as temporary structures, the same care must be taken in their design and construction as in any structure of a permanent nature. Faulty design and construction of formwork and falsework will reflect in the appearance of the finished structure, and could result in partial or total collapse with costly and sometimes tragic consequences.

The cost of formwork and falsework represents a substantial portion of the total cost of the bridge construction. It is to everybody's advantage to have them designed in the most economical way. At the same time, they should have adequate safety levels built into their design. Safety must be ensured during all construction stages including erection and dismantling.

This manual provides general guidelines for the design review and the inspection of falsework and formwork for bridge structures. Figure 1.1 illustrates the most common types of bridge structures built in Ontario.

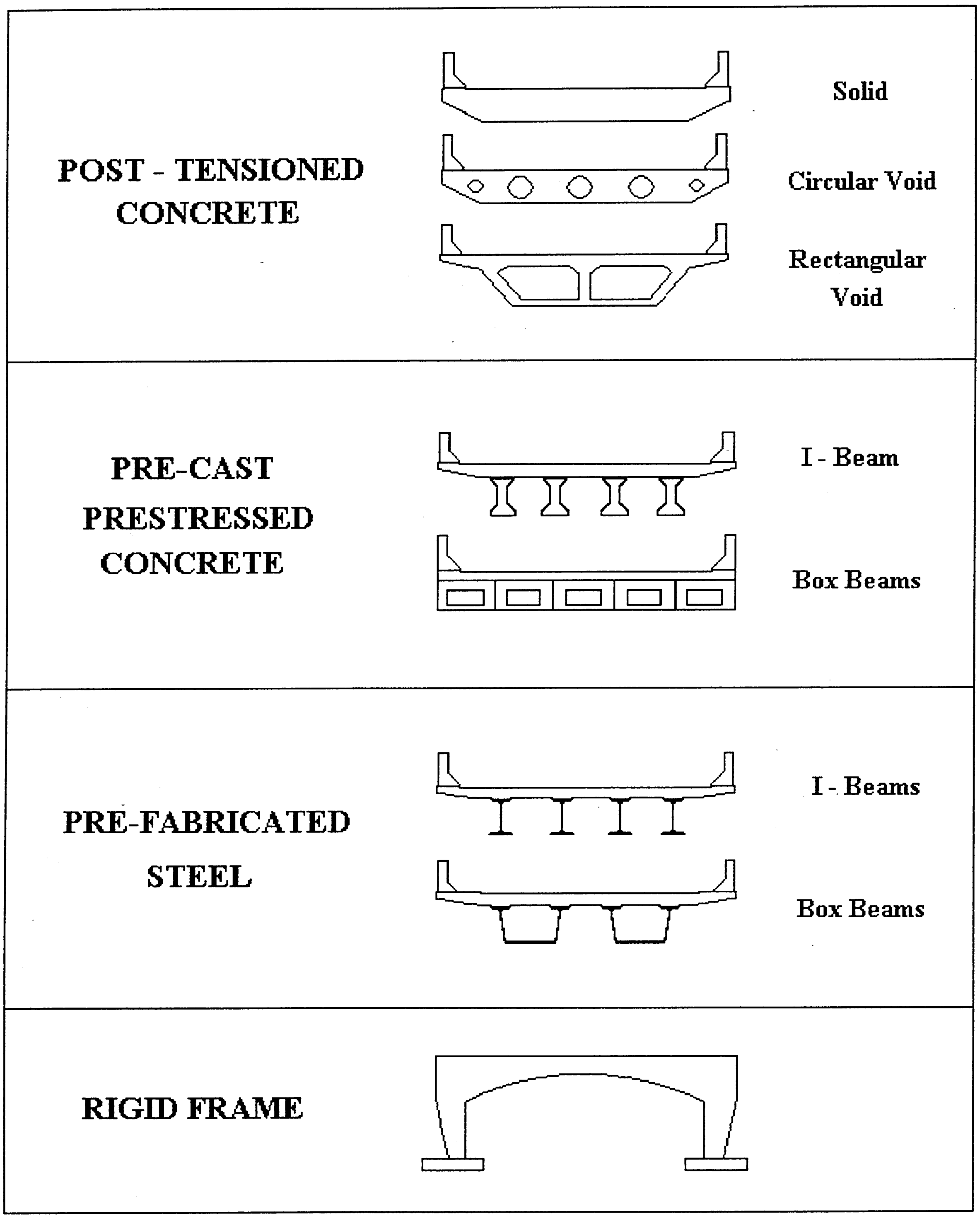


Figure 1.1 Types of Structures

2. FORMWORK MATERIALS AND CONSTRUCTION

2.1 General

Forms are the mould into which fresh concrete is placed until it hardens. They control the position, alignment, size and shape of concrete members. Formwork is designed and constructed to resist the internal pressure of freshly placed concrete. It can be stripped when the concrete hardens and the pressure is reduced to zero. Materials used for forms include wood, plywood (sanded and plastic-coated), steel and aluminum. Figure 2.1 shows the typical components of formwork.

2.2 Materials

2.2.1 Lumber

The general term lumber refers to both "Dimension lumber" and "Timber". Dimension lumber means a piece of lumber 38 to 102 mm inclusive in smaller dimension. Timber means a piece of lumber 114mm or more in smaller dimension.

Almost all formwork, regardless of its type, uses some wood. Although the wood species, grades and sizes vary with every supplier, the design of formwork can always be made to fit the material available. Any wood that is graded, straight and structurally sound can be used in the building of formwork.

Lumber is designated by its nominal dimensions that are the sizes of the cross-section prior to finishing. Lumber surfaced in a planing machine to attain smoothness of surface and uniformity of size is called Dressed Lumber. The finished dimension of the lumber cross section will be less than its nominal dimension, and it is the finished dimension that shall be used in the design.

The finished dimensions are sometimes referred to as "surfaced", "dressed" or "net" sizes. Lumber as supplied to the site comes in three categories; finished on all four sides designated as S4S, finished on two edges designated as S2E, or it may be used as it comes from the sawmill with no finish, designated as Rough.

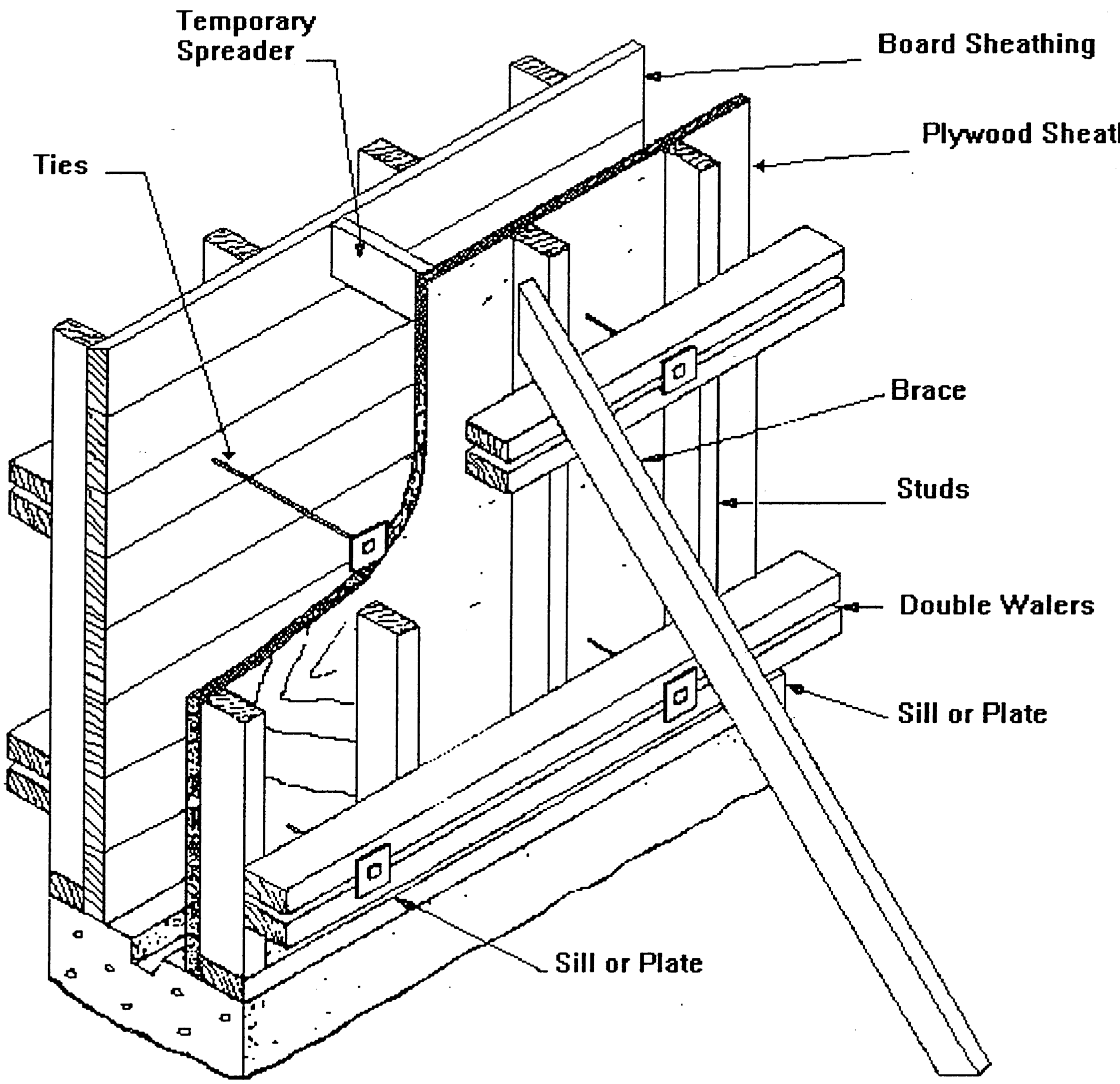


Figure 2.1 Typical Components of formwork

Formwork lumber members shall be assumed to be S4S, unless stated otherwise on the falsework drawings. If the use of rough-cut material is required by the falsework design, the actual member size must be verified prior to use.

Surfaced Dimension lumber can be either Surfaced Dry or Surfaced Green. Surfaced dry Dimension lumber (S-Dry) is dressed at a moisture content of 19 percent or less, and is designated according to its actual finished size.

Green Dimension lumber is defined as the lumber having a moisture content greater than 19%. Surfaced green Dimension lumber (S-Grn) is designated by its anticipated dry size at 19% moisture content, and will be approximately the same as S-Dry Dimension lumber.

Timbers are always surfaced green. Surfaced green Timber is designated by its actual green size. Tables 2.1 and 2.2 give standard sizes of Dimension lumber and Timber. Metric sizes are rounded to the nearest millimetre.

Table 2.1 : Dimension Lumber Sizes

Nominal Size (in)	Surfaced Green Size (S-Grn) (in)	Surfaced Dry Size (S-Dry) (in)	Metric Size (S-Dry) (mm)
2 x 2	1-9/16 x 1-9/16	1-1/2 x 1-1/2	38 x 38
3	2-9/16	2-1/2	64
4	3-9/16	3-1/2	89
6	5-5/8	5-1/2	140
8	7-1/2	7-1/4	184
10	9-1/2	9-1/4	235
12	11-1/2	11-1/4	286
3 x 3	2-9/16 x 2-9/16	2-1/2 x 2-1/2	64 x 64
4	3-9/16	3-1/2	89
6	5-5/8	5-1/2	140
8	7-1/2	7-1/4	184
10	9-1/2	9-1/4	235
12	11-1/2	11-1/4	286
4 x 4	3-9/16 x 3-9/16	3-1/2 x 3-1/2	89 x 89
6	5-5/8	5-1/2	140
8	7-1/2	7-1/4	184
10	9-1/2	9-1/4	235
12	11-1/2	11-1/4	286

Table 2.2 : Timber Sizes

Nominal Size (in.)	Surface Green Size (S-Grn) (in)	Metric Size (S-Grn) (mm)
6 x 6	5-1/2 x 5-1/2	140 x 140
8	7-1/2	191
10	9-1/2	241
12	11-1/2	292
14	13-1/2	343
16	15-1/2	394
18	17-1/2	445
8 x 8	7-1/2 x 7-1/2	191 x 191
10	9-1/2	241
12	11-1/2	292
14	13-1/2	343
16	15-1/2	394
18	17-1/2	445
20	19-1/2	495
10 x 10	9-1/2 x 9-1/2	241 x 241
12	11-1/2	292
14	13-1/2	343
16	15-1/2	394
18	17-1/2	445
20	19-1/2	495
12 x 12	11-1/2 x 11-1/2	292 x 292
14	13-1/2	343
16	15-1/2	394
18	17-1/2	445
20	19-1/2	495

2.2.1.1 Lumber Grading

Lumber is graded according to species and quality. Grading can be done visually or by machine. For bridge formwork construction, all lumber can be assumed to be visually stress-graded in accordance with the provisions of the National Lumber Grades Authority (NLGA).

The NLGA publishes the Standard Grading Rules for Canadian lumber according to which, all Canadian lumber, regardless of species or source, is graded the same way and bears the same grade names. Graded lumber is identifiable by the grading stamp placed on every piece of new lumber produced at the sawmill.

There are many classifications of lumber, but for formwork, structural lumber is generally used. Structural lumber is one that is a minimum 38mm in thickness and has allowable stresses assigned to it for design purposes.

All lumbers intended for construction should be checked on delivery for the species, and grade specified. The grade stamping must correspond to that shown on the falsework or formwork drawings.

Used lumber of known history, where the grade and species are identifiable, may be used at the allowable stress level for new lumber of that grade and species, provided that the use has not damaged the lumber in such a way that the grade requirements are no longer met (CSA, S269.1-1975, Clause 4.4) [1].

Lumber that has been mechanically damaged or has deteriorated due to insects, decay or chemical attack should not be used unless it has been regraded by a qualified lumber grader. Lumber of an unknown species and grade, without any grading stamp, when intended to be used in formwork, should be graded to ensure its compliance with the required grade in design drawings.

There are many agencies and associations that issue grading stamps. While the form of the stamp is variable, the information contained is the same. The information on the grade stamp identifies the grading agency, the species, the grade and whether dry or wet.

Table 10 and Table 11, CSA, CAN3-086-M84 [2] (or Table 5.2.1.2 and Table 5.2.2.1, CAN/CSA-086.1-M94 [3]) summarizes the Species Combinations and the Grades and Their Dimensions for Visually Stress-Graded Lumber respectively.

2.2.2 Plywood

Plywood is used extensively in formwork construction as sheeting in direct contact with concrete. It is produced in two grades - interior and exterior. Plywood for formwork of bridge construction shall be exterior grade made with waterproof glue, 7 ply, 17mm minimum thickness Douglas Fir plywood in conformance with CSA 0121-M1978 [4].

The sheets are supplied as sanded both faces, one face, or overlaid with hard durable and impervious resin to produce a smooth concrete surface. Sanded surfaces are usually treated with an approved non-staining form oil to prevent sticking of the concrete to the forms to facilitate stripping.

Because of the ply orientation, plywood has different properties in the two perpendicular directions. The rigidity of the plywood in the direction of the face grain is much greater than that in the direction perpendicular to the face grain. Therefore, plywood sheets shall generally be so arranged that the face grain is perpendicular to the supporting studs or joists.

2.2.3 Metal forms

Steel or aluminum alloy forms are becoming more popular. The forms should conform to the appropriate specifications, drawings and CSA Standards. The forms are usually prefabricated into standard panel sizes and shapes. They have an advantage over the wood forms in that they provide better rigidity and strength, faster erection and dismantling, higher durability and they are fireproof. Typical application of metal forms is for forming of large abutments, piers, circular columns and permanent deck forms for steel box girder bridges. However, the use of permanent deck forms for steel box girder bridges has been prohibited since 1990 so that the deck concrete can be inspected later. Steel sections (e.g.][and I) are commonly used for form wales and studs.

2.2.4 Nails and Spikes

Nails and spikes are the most common mechanical fastenings used in construction of wood formwork. They are essential if the forms are to perform the function of a rigid and stable mould. Nails and spikes most frequently used are the common wire type and are manufactured in various sizes. Nails and spikes are usually specified by their type and their length in inches.

Nails are available in lengths from 1" to 6" and spikes from 4" to 12". A nail's length is the distance between the underside of the head to its tip. Common wire spikes are similar to nails but have larger diameters for the same length. Example: The diameter of a 4" nail is 4.88mm and that of a 4" spike is 6.4mm.

2.2.4.1 Types of Nails

Depending on the type of formwork, single-headed nails are generally used in the assemblies of form panels intended for multiple reuse, while double-headed nails are for installations where considerable holding power is needed and where they must be readily dismantled during stripping.

2.2.4.2 Holding Power of Nails and Spikes

Holding power of nails and spikes, as used in formwork construction, is based on their resistance to lateral forces. This resistance varies according to their smoothness, diameter, length of penetration into the main member and the density and moisture content of the wood, i.e. the holding power of nail or spike is greater if driven into the side grain rather than end grain; into the dry wood rather than wet wood; into hardwood rather than the softwood.

The length of penetration into the main member shall be at least 1/2 the length of the nail or spike. Nails driven into end grain should not be considered to carry load in withdrawal.

The characteristics of round wire nails and spikes can be found in Table 45 of CSA, CAN3-086-M84 [2] (or Table 10.9.4.1of CAN/CSA-086.1-M94 [3]).

2.2.5 Form Ties

Form ties are used in the construction of formwork such as those for walls or rectangular beams and columns to hold the two opposite sides of form panels against the pressure of concrete. In addition to resisting the pressure from concrete, some ties are designed to act as spreaders to keep the form sides apart.

The spacing of ties is governed by the magnitude of concrete pressure transferred to them. Form ties are produced of steel in a variety of types, shapes, diameters and lengths and are selected according to strength requirements. Manufacturers of ties specify the safe working load (SWL) for each size and type. Ties should be used in accordance with the manufacturer's recommendations.

It is required to have minimum 20mm concrete cover at the ends of the ties after removal of forms. Plastic cones are usually used at the ends of ties to prevent rusting of the ties and staining of the wall. Figure 2.1 shows some typical ties and their application in wall construction.

2.3 Construction

It is essential that formwork is built as designed. Formwork construction should be the subject of knowledgeable supervision and inspection to ensure that it is constructed safely according to the design drawings with materials of specified type and quality, and that only when all checks have proved satisfactory is the concrete placement allowed. Poor concrete placing practices could have a serious effect on a properly built formwork. Examples of good concreting practices may include:

- continuous inspection during the pour to ensure early detection of problems such as form displacement, deformation or even failure.
- Construction materials, equipment, demolition residue, etc. should not be dropped or be piled on formwork in such a way as to damage or overload all or part of it.
- concrete rate of pour, concrete admixtures, lift height, and concrete heaping must be controlled to match the design assumptions
- excessive vibration of new concrete or deep vibration into semi-hardened lifts may place higher than expected loads on formwork or may cause loosening effects on bolts, wedges and other friction connections

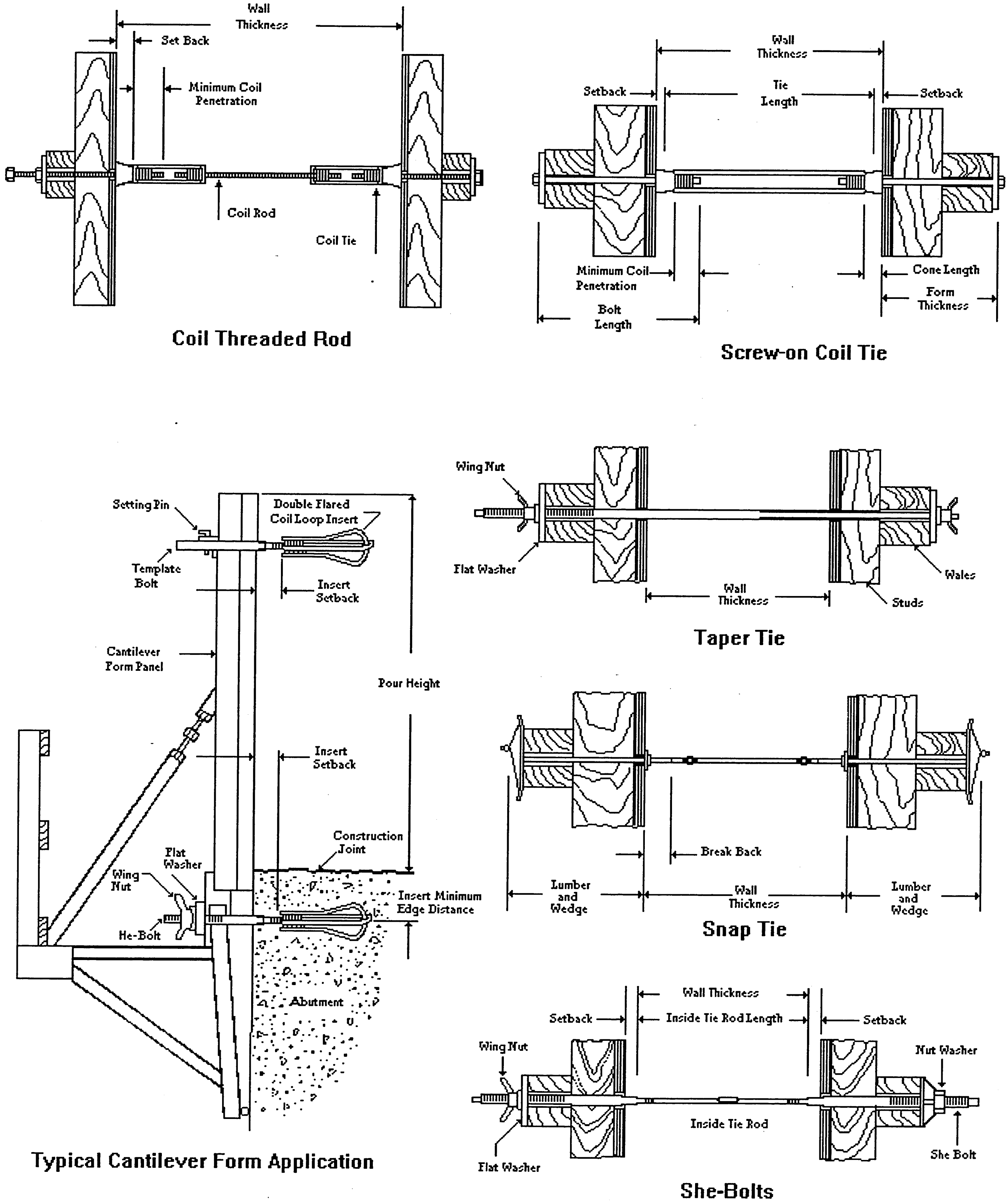


Figure 2.2 : Examples of Form Ties

3. FALSEWORK MATERIALS AND CONSTRUCTION

3.1 General

Falsework is a temporary structure designed to support all the vertical and lateral loads that may be applied during construction of a permanent structure until it becomes self supporting.

3.2 Materials

Falsework materials include manufactured shoring systems that generally consist of standard frames that can be stacked on top of each other vertically and cross-braced together horizontally. Other materials for falsework are basically the same as those for formwork (See Section 2.2).

3.3 Types of Falsework

There are mainly two types of falsework that commonly used for bridge construction; Hanger Type Falsework and Scaffold Type Falsework. These two types are widely used for the construction of the different types of bridge structures (Figure 1.1) in Ontario.

3.3.1 Hanger Type Falsework

In bridge structures where the concrete deck slab is supported by concrete or steel girders, the falsework for the slab is usually suspended from the girders by means of steel hangers (Figure 3.1).

For this type of falsework, the screed rails should be placed on the external girders, not on the cantilevered portion of falsework supported by the overhang brackets.

Many types of hangers are available. They are placed on the top flange of the girders and spaced according to their allowable safe working loads as specified by the manufacturer. Hangers should be checked for any obvious defects such as cracks, imperfect welds, etc. and defective ones should not be used.

The most common hanger is made-up of two chairs (end sections) connected with a single strut and two threaded hanger rods. Each hanger rod is attached to the chair with a nut at the top and has a steel plate washer at the bottom to carry the formwork ledgers (See Figure 3.2). At the time of formwork stripping, the two hanger rods can be unscrewed and removed. Any steel hardware that is left in place, either exposed or embedded in concrete within 20mm of its surface shall be hot dip galvanized. The advantage of the use of this type of hanger is that all vertical adjustments can be made from the top by turning the nut at the upper end of the hanger rod.

The brackets that support the bridge deck overhanging slab are also suspended from the hangers as shown in Figure 3.1. Care should be taken when suspending falsework with the two component hangers so that the ends of chairs will not be exposed after stripping. Chairs that might be exposed should be raised by means of concrete blocks or by using another type of hanger with high haunches. The ends of hanger rods protruding into the concrete slab should be well greased or oiled to facilitate removal.

The stability of the exterior girders need to be checked and bracing should be used to resist the unbalanced moment, caused by the cantilevered slab load transferred through the brackets at the exterior side of the girder. If the girders were supported on elastomeric bearings, the possible horizontal movement should also be checked and bracing or retention devices should be used to limit the deformation of the bearings.

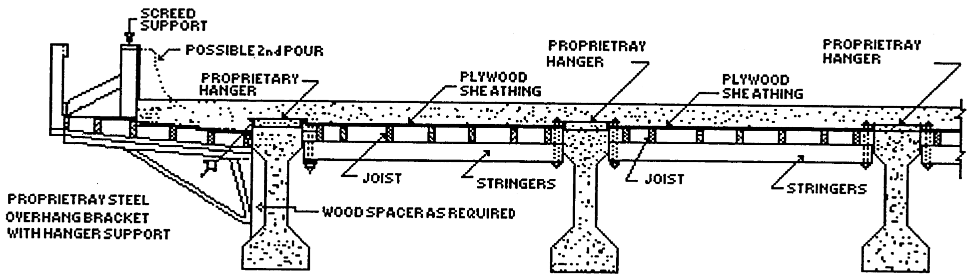


Figure 3.1 Hanger Type Falsework for Deck Slab

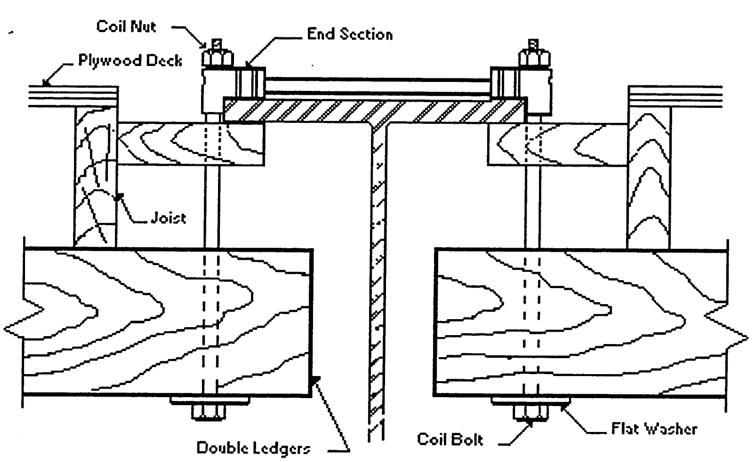


Figure 3.2 Typical Hanger

3.3.2 Scaffold Type Falsework

The scaffold type falsework (Figure 3.3) is the most commonly used shoring system in bridge construction for post-tensioned concrete and rigid frame structures. Originally designed to carry light loads, scaffolding has been developed for heavier load carrying capacities by increasing the thickness and the diameter of the tubular sections used. Heavy duty aluminum/steel tubular scaffolding is capable of carrying loads up to 133 kN per leg or even higher.

The main component of scaffolding is the frame that consists of two legs braced together with horizontal tubular members. Frames can be equipped with an adjustable base at the bottom of each leg and an adjustable top called U-head. Scaffolding towers are formed by pairs of end frames connected together with diagonal cross bracing.

Frames are available in various widths. They are stacked on top of one another to form a scaffold tower to the required height. Horizontal and/or diagonal tube-and-clamp bracing may be required to tie the different towers together depending upon towers total height and the slope of the deck they support.

The use of modular scaffolding in falsework for bridge construction is gaining wide popularity due to the following:

1. Components are uniform, standardized, factory produced and available in the market. They are composed of a complete integrated system, virtually without the need for other products or materials. This results in saving time and reducing cost through speedy erection & dismantling and easy storage & maintenance.

2. The availability of frames in various sizes allows the construction of scaffolding to suit the required height and to cover the required area.

3. The frames are supplied with adjustable screw jack extension that enables fine adjustments in total height to be made quickly and easily.

4. Flexibility in spacing the scaffold frames due to variety of diagonal bracing lengths available. This enables the optimum use of frames capacities.

5. The use of steel/aluminum scaffolding reduces the fire hazard.

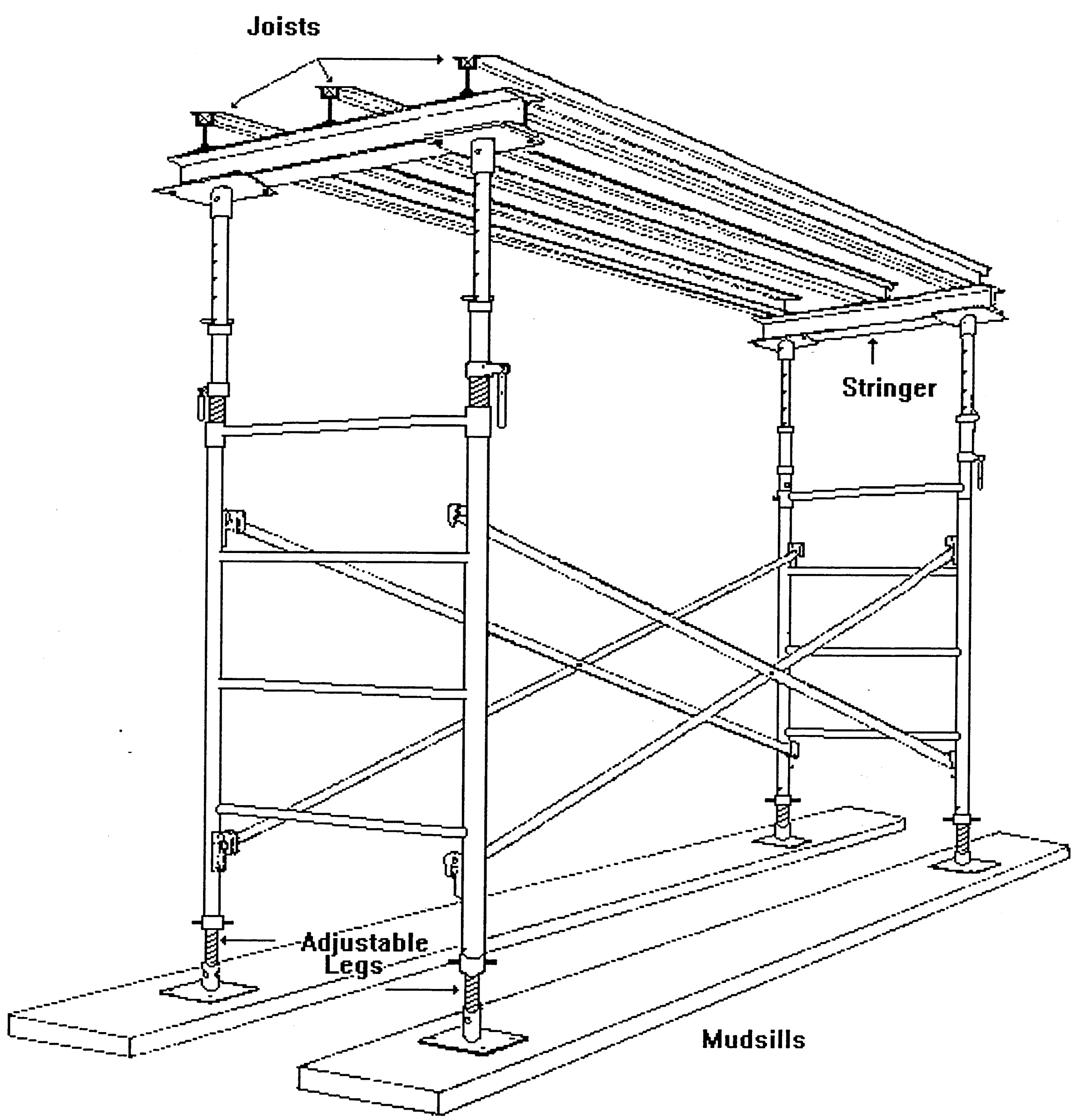


Figure 3.3 Typical Scaffold Type Falsework

Ledgers/stringers supported by modular scaffolding need to be positioned centrally in the U-head over the vertical leg. If U-heads of wider size than the ledgers they support are to be used, ledgers should be blocked in U-heads from both sides with filler blocking of equal thickness to ensure that they sit centrally over frame legs. It is also important that ledgers' joints are centrally positioned inside an U-head. Generally, the joint is spliced with a plate and bolts in accordance with the manufacturer's instructions. These requirements are necessary to avoid eccentric loading of the tubular legs and the U-heads beside the benefit of restraining the scaffold frames. If ledgers are sloping to produce a required deck slope, hardwood wedges are to be driven between the bottom of the ledgers and the U-heads of the frames that support them to achieve full bearing (Figure 3.4).

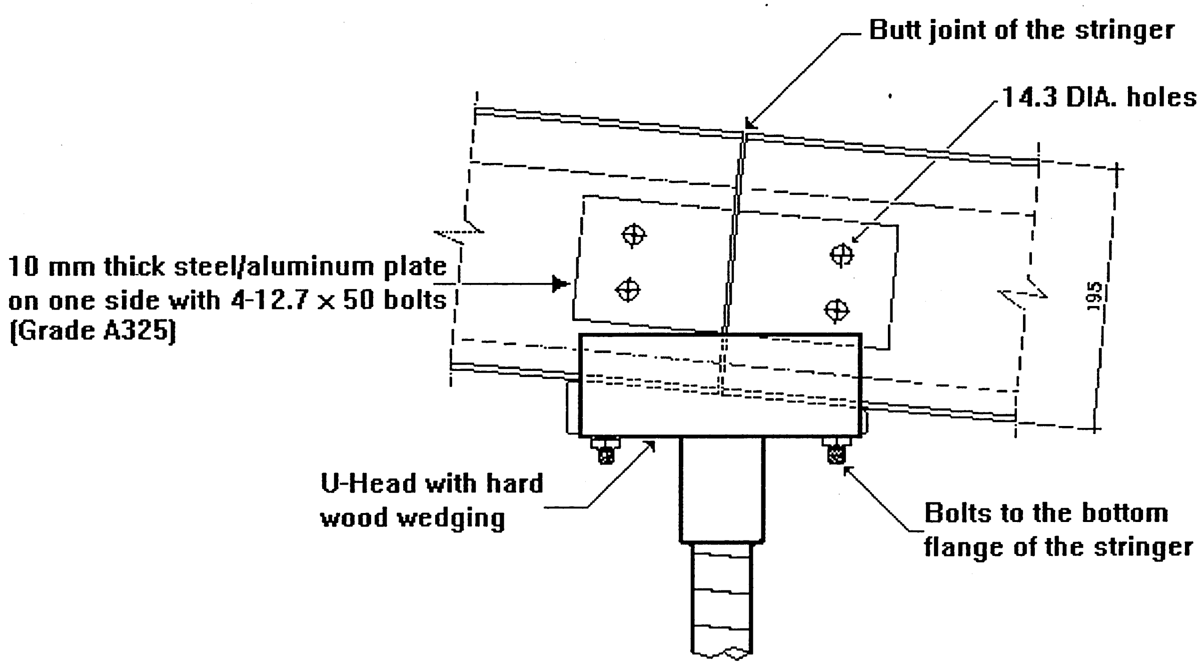


Figure 3.4 Stringer Splice inside U-Head

Generally, for cross-falls less than or equal to 2%, no wedges are required. Since the length of the U-head is generally 200mm, the maximum theoretical gap between the U-head and the ledger would be 4 mm. This will not hinder the provision of full bearing under the load due to the flexibility of the scaffolding system as a whole. In cases where the slope is greater than 2% or a gap greater than 4mm is evident, wedges are required.

For load-bearing wedges, pieces of metal or hardwood that taper to fit in the surfaces they support are to be used. Hardwood whose density exceeds 650 kg/m^3 is generally acceptable. Some commonly available hardwood species are maple, beech, birch, and oak.

3.4 Falsework Foundations

Falsework shall be designed so that all vertical and horizontal loads are safely transmitted to the supporting ground without excessive settlements. To properly distribute these loads, foundations are used in a variety of forms to suit the existing soil conditions.

The falsework drawing shall show the minimum required soil bearing capacity of the supporting soil. A Falsework Foundation Design Report, signed and sealed by an Engineer shall be submitted indicating the soil bearing capacity, the site preparation requirements, if any, and the expected mudsills settlement. Generally, the minimum soil bearing capacity required to support tubular scaffolding leg load of 44 kN (10 kips) on 4" x 12" mudsills (as long as it is justified by calculations) is about 195 kN/m^2 (4000 psf). Suitable drainage shall be provided to protect the ground from water flows or freezing.
Organic and soft clay materials shall be removed and replaced with well compacted granular materials. A layer of well-compacted granular shall be placed on top of bedrock to achieve the required elevation and to provide an even supporting surface.

Where the ground is sloping and it is required to step it, the slope is usually terraced for the placing of mudsills. The slopes should be terraced so that the steps will remain stable throughout the construction period. Slopes between the horizontal steps shall not be steeper than 1:1. A minimum horizontal width of 300mm shall be provided between the mudsill and the top edge of slope. (Figure 3.5)

Different types of foundations are used for transmitting falsework loads to the supporting soil. Mudsills are the most common type of falsework foundation. They are lumber planks placed under a group of vertical shores to distribute evenly and safely the load of each scaffold leg to the underlying supporting soil. Preferably, sills shall be continuous under at least three consecutive vertical shores. Size of mudsills depend upon the vertical loads from the shores they support and the bearing capacity of the supporting soil.

Mudsill can be single member or multiple members placed side by side to provide a bigger bearing area. The shore load is distributed to the multiple member sill by a spreader that must be rigid enough to safely distribute the leg load to all members of the sill.

The joint location of a continuous mudsill in relation to the vertical shore is important. It must be placed far enough from the vertical shore so that enough bearing area is provided to distribute its load to the underlying soil safely and without higher settlement than that at other locations. In cases where joints are located within sill projection, a splice with same size shall be placed over the joint to distribute the load evenly. Minimum sill projection is determined by the shore load, size of sill and soil bearing capacity. Uneven settlement of mudsills can change the shores' reactions, resulting in unexpected overloading of some shores and underloading of others. The minimum sill projection required shall be shown on the falsework drawing. Typical arrangement of joints in continuous mudsills is shown in Figure 3.6.

Concrete pads may be used instead of timber sills. They shall be designed considering the load, soil bearing capacity and the strength of concrete required.

Generally mudsills or concrete pads are used where the soil conditions are reasonably good and suitable for spread footings. When the soil bearing capacity is very low, pile bents (steel or timber) may be used to provide adequate supporting platform for the falsework.
Excavation around the piers and abutments is usually backfilled with granular material and compacted. This may result in areas with variable degrees of bearing capacities and consequently these areas may settle more than the adjacent undisturbed areas. The experience has shown that areas around piers and at abutments exhibit higher settlements than other areas due to the excavation and backfilling operations for these substructures. It is sometimes recommended to use double mudsills with spreader on top or to consider lower soil bearing capacity in the design calculations of sills for these areas.

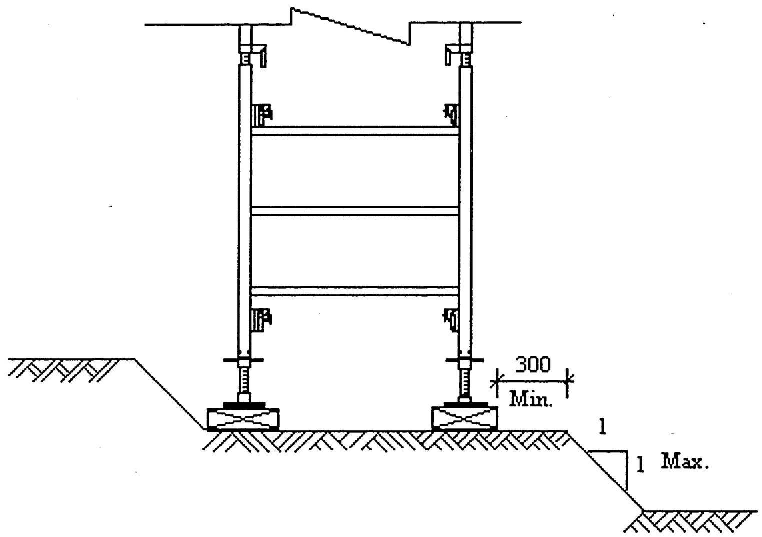


Figure 3.5 Ground Terrace Detail

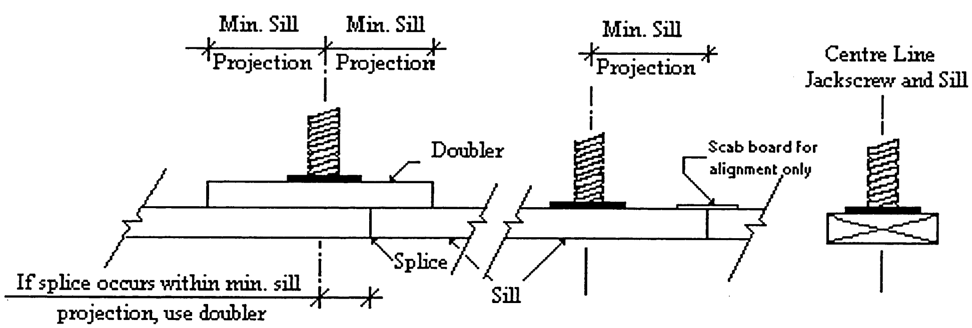


Figure 3.6 Sill Splicing Detail

4. LOADS ON FALSEWORK AND FORMWORK

4.1 General

Falsework and formwork shall be designed to carry all the loads that they will be subjected to till the time when the permanent structure they support gains sufficient strength to be self-supporting. Examples of these loads are dead loads (e.g. fresh concrete(*), scaffolds, forms, etc.), live loads (e.g. workmen, equipment, tools, etc.) and environmental loads (e.g. wind, temperature effects, etc.).

(*) When Limit States Design procedures are used, concrete loads must be taken as specified live loads and factored accordingly (CAN/CSA-S269.3-M92, Clause 5) [6]

4.2 Vertical Loads

These include the following:

(a) Dead Loads

These include the weight of concrete, reinforcing steel, tendons, and weight of the falsework and formwork. Table 4.2 provides information for unit material weights for calculating the dead loads.

Material	Unit Weight KN/m³
Aluminum Alloy	27.0
Plain Concrete	23.5
Prestressed Concrete	24.5
Reinforced Concrete	24.0
Granular soil/Crushed stones	22.0
Steel	77.0
Hardwood	9.5
Softwood	6.0
Water	9.8

Table 4.2 Material Unit Weights

Minimum loads to be assumed in design are as follows (CSA, S269.1-1975, Clause 5.2) [1]:

- (i) The greater of the weight of concrete being supported, or 2.5 kN/m^2 on the horizontal projected area of the formwork.
- (ii) The greater of the weight of the formwork supported by the falsework or 0.5 kN/m^2 on the horizontal projected area.

(b) Live Loads

These include the weight of workmen, equipment and tools that will be supported during construction, concrete placing and finishing operations or 3.1 kN/m^2 of the horizontal projected area of formwork, whichever is greater. Live loads caused by any special conditions of construction likely to occur (e.g. unsymmetrical placement of concrete, impact, uplift, concentrated loads and the additional pressure due to placing concrete pneumatically or by pump in confined locations) has to be considered and clearly specified on the drawings. Falsework and formwork should not be subjected to any loads that were not considered in their design such as stacked construction materials or demolition debris, heaping of concrete during the pour, etc.

4.3 Horizontal Loads

These include the following:

(a) The greater of (OPSS 919, Cl. 919.04.02.04)[5]:

- (i) The calculated lateral wind forces according to the National Buildind Code of Canada [10] using 1/30 probability for falsework and 1/10 probability for formwork with a gust factor of two or a minimum wind pressure of 0.8 kPa .
- (ii) A horizontal force of not less than 2% of the total vertical loads or 1.5 kN per linear meter of deck edge applied at the mid-depth of the deck, whichever is greater.

(b) Lateral force components that would develop from loads applied on sloping members,

(c) Lateral forces due to the placement of fresh concrete against formwork surfaces, (Section4.4),

(d) Any other reasonably anticipated lateral forces (e.g. post tensioning, inclined supports, impact from dumping of concrete or moving equipment, etc.).

4.4 Concrete Pressures

When concrete is placed into forms, at first it behaves like a fluid and exerts full hydrostatic pressure on the forms. It then goes through a series of chemical changes and with the passage of time it becomes plastic and finally solid. Different layers of concrete will be in different stages of hardness. In the same concrete pour, the change from fluid to plastic and finally to solid state starts at the lower layers and progresses upward to upper layers.

The gradual change in the state of concrete results in a gradual change in the amount of the lateral pressure exerted on the containing forms.

4.4.1 Factors affecting lateral pressure on forms:

The magnitude of lateral pressure of freshly placed concrete on forms has been found to be influenced by the following factors:

1. Rate of concrete placement
2. Concrete temperature at the time of placing
3. Proportions of mix components
4. Consistency
5. Method of vibrating the concrete
6. Impact during depositing
7. Size and shape of forms
8. Amount and arrangement of reinforcing steel
9. Density of concrete
10. Depth of placement
11. Type of cement and additives used in the concrete
12. Air temperature, humidity and wind speed.

The lateral pressure on concrete forms may be calculated as outlined by **ACI Committee 347, ACI 347R-94** [7] for concrete made with Type I cement, weighing 23.5 kN/m^3, containing no pozzolans or admixture, maximum slump 100 mm, and internal vibration to a depth of 1.2 m or less (See subsection 4.4.2).

It should be noted here that the concrete pressures recommended by CAN/CSA-S269.3-M92 [6] are based on ACI 347-78 Report by ACI Committee 347, **and not** on the later Reports ACI 347R-88 and ACI 347R-94 of the same Committee, which give lower pressures. With good on-site control of concreting practices, the use of the concrete pressures recommended by ACI 347R-94 in bridges construction has proved to be satisfactory, otherwise, CSA pressures have to be used.

The load information in the following subsections is intended for use with Working Stress Design standards. When Limit States Design standards are used, these loads must be considered as **live loads** and factored in accordance with the requirements of the applicable standards (CAN/CSA-S269.3-M92, Clause 5) [6].

4.4.2 Lateral Concrete Pressure on Wall Formwork { ACI Committee 347, ACI 347R-94 [7] }

(a) For forms up to 1.3 m in height, wall formwork shall be designed for the full hydrostatic pressure.

(b) For forms higher than 1.3 m, wall formwork shall be designed for pressures derived from the formulae as given in Table 4.4.2 .

Table 4.4.2: Lateral Concrete Pressure on Wall Formwork

For the rate of pour (R) of 7 to 10 ft/hr (2.1 to 3.0 m/hr)	
Imperial Formula (psf)	Metric Formula (kPa)
The lesser of: (i) p = 150 + 43400/T + 2800 (R/T) {Max. 2000 and Min. 600 psf} (ii) p = 150 x H	The lesser of: (i) p = 7.2 + 1156/(T+17.8) + 244 R/(T+17.8) {Max. 95.8 and Min. 28.7 kPa} (ii) p = 23.5 x H

For rate of pour (R) of less than 7 ft/hr (2.1 m/hr)	
Imperial Formula (psf)	Metric Formula (kPa)
The lesser of: (i) p = 150 + 9000 (R/T) {Max. 2000 and Min. 600 psf} (ii) p = 150 x H	The lesser of: (i) p = 7.2 + 785 R/(T+17.8) {Max. 95.8 and Min. 28.7 kPa} (ii) p = 23.5 x H

Where:

p - lateral pressure of concrete in (psf) for imperial formula, (kPa) for metric.

R - rate of placement of concrete in (ft/hr) for imperial formula, (m/hr) for metric.

T - Concrete temperature in the forms in (deg. F) for imperial formula, (deg. C) for metric.

H - maximum height of fresh concrete in the forms in (ft) for imperial formula, (m) for metric.

4.5 Other Forces

4.5.1 Prestressing Forces

When post-tensioned structures are stressed, they tend to deflect upward. For continuous structures, stressing will cause the midspan areas to deflect upward while areas around intermediate supports will tend to deflect downward. This will reduce the leg load of the frames at the mid-span and increase the leg load of the ones near piers and abutments. The forces involved in this redistribution of loading are of a considerable magnitude in case where there is a traffic opening directly next to a pier. The leg loads of falsework towers carrying the traffic opening beams should be calculated carefully and an allowance for the additional load due to prestressing should be considered { State of California, Department of Transportation, Falsework Manual [8] and AASHTO: Guide Design Specifications for Bridge Temporary Works [9] recommend increasing the actual leg load by 50% }. OPSS 919 [5] and CSA S269.1 [1] did not quantify an allowance factor to be applied to leg loads to account for these forces, however OPSS 919 requires the provision of supplementary bracing to traffic opening shoring towers (Cl. 919.04.02.06) [5].

4.5.2 Deck Shrinkage Forces

As newly-placed deck concrete shrinks during the curing period, it exerts a downward force on the falsework. The increased force due to shrinkage is greatest near the centre of the span, and it reaches its maximum four to seven days after deck concrete is placed. Trying to quantify shrinkage forces is a sophisticated exercise. For small span bridges, the effect of the shrinkage forces on the leg loads of traffic openings frames can be neglected given that the supplementary bracing requirements of OPSS919, Cl. 919.04.02.06 [5] are provided.

5. ANALYSIS AND DESIGN

5.1 Design Capacity

The load-carrying capacities of the falsework and formwork systems and their individual members, connections, fittings, components and assemblies can be determined by either:

(a) Structural analysis in accordance with the appropriate standards, codes and references, or

(b) Test results values obtained using acceptable test procedures and factors of safety as outlined in CSA, S269.1-1975 [1] and CAN/CSA-S269.3-M92 [6].

5.1.1 Design Using Analytical Methods

The falsework and formwork designs may be checked and member capacities determined by using the appropriate engineering standards. Generally, in the analysis of continuous beams, the adverse effect of continuity must be investigated to prevent overstressing of any falsework member. The equal area method can generally be used to calculate the load distribution to supporting structural members.

Falsework and formwork designs based on Working Stress Design (WSD) standards require the calculation of stresses due to all unfactored applied loads and compare them with the allowable stresses.

Limit State Design (LSD) standards separate the factor of safety, commonly used in working stress design standards, into two parts: a load factor component and a resistance factor component. Falsework and formwork designs, based on limit states design standards, require that the factored resistance of members should be greater than or equal to the effects of all factored loads.

Falsework and formwork, compared with other types of structures, incorporate repeatedly used materials and components. The condition and identification of used materials are always questionable and present a level of uncertainty that should be considered at design and review stages. The actual condition of the materials to be used should always be considered in the design and should be specified in the drawings.

5.1.2 Design Using Test Results

As an alternative to using analytical methods, safe load-carrying capacities of members, connections, fittings, components and assemblies, etc. may be established based on their ultimate strengths when tested divided by the appropriate factors of safety set in CSA, S269.1-1979[1] and CAN/CSA-S269.3-M92 [6]. The testing shall be carried out by a recognized, independent testing authority; or witnessed by an independent professional engineer (CSA, S269.1-1979, Cl. 10.2.1.6) [1]. All test results shall be properly recorded in a test report that shall be signed and sealed by a professional engineer. Test reports shall be made available to the Owner when requested.

The safe load-carrying capacities of proprietary products and devices, such as beam hangers, deck overhang brackets, scaffold frames, form ties, etc. are usually established based on testing. Manufacturers usually issue Product Data Sheets which specify the recommended applications, method of installation, safe load-carring capacities, safety factors used in establishing safe working loads for recommended applications, etc.

5.2 Wood Design

Used lumber of known history where the grade and species are identifiable may be used at the stress level for new lumber of that grade and species provided that the use has not damaged it in such a way that the grade requirements are no longer met. Lumber with mechanical damage, deterioration or decay shall not be used unless it is regraded by a qualified lumber grader. (CSA, S269.1, Cl. 4.4)

The design of wood can be carried out according to: either the Working Stress Design (WSD) Standard **CAN3-086-M84** [2], or the Limit State Design (LSD) Standard **CAN/CSA-086.1-M94** [3].

Normally, a load duration factor corresponding to seven days loading shall be used in the design and the service condition shall be considered to be dry.

For simple beams, the span length should be taken as the clear distance from face-to-face of supports, plus one-half the required length of bearing at each end. For continuous beams, the span length is the centre-to-centre distance between supports. For end spans of continuous beams, the span length should be taken as the distance between the centre-of-bearing at the continuous support and the face of the end support plus the required length of bearing at end supports.

For analysis, falsework posts (timber) may be considered as pinned at both ends, regardless of the actual end condition. For timber piles, the effective length shall be governed by the fixity conditions imposed on it by the structure it supports and by the nature of the ground into which it is driven (CSA, CAN3-086-M84, Clause 8) [2].

In the calculation of shear resistance, the effect of all loads acting within a distance from a support equal to the depth of the member need not be taken into account { CAN3-086-M84, Cl. 4.5.2.1.2 [2] or CAN/CSA-086.1-M94, Cl. 5.5.5.2 [4] }.

5.2.1 Working Stress Design

The maximum allowable capacities of sawn members shall be calculated in accordance with **CSA-CAN3-086-M84, Engineering Design in Wood, Working Stress Design [2]**. The relevant clauses are as follows:

(a) Bending Moment capacity: **Clause 4.5.1.2**

(b) Shear Resistance: **Clause 4.5.2.2**

(c) Compressive Resistance perpendicular to grain: **Clause 4.5.4**

(d) Compressive Resistance parallel to grain: **Clause 4.5.3.3.5**

5.2.2 Limit States Design

The factored capacities of sawn members shall be calculated in accordance with **CAN/CSA-086.1-M94, Engineering Design in Wood, Limit States Design [3]**. The relevant clauses are as follows:

(a) Load Factors for the ultimate limit states shall be taken as specified in **Clause 4.2.4.2.**

(b) Factored Bending Moment Resistance M_r : **Clause 5.5.4**

(c) Shear Resistance V_r : **Clause 5.5.5**

(d) Compressive Resistance perpendicular to grain Q_r : **Clause 5.5.7**

(e) Compressive Resistance parallel to grain P_r : **Clause 5.5.6**

5.3 Structural Steel Design

Falsework drawings shall state the steel grade of the different steel members of the falsework. If steel grade information is unavailable or uncertain, and coupon tests have not been taken, the values shown in Table 11-5.2.1.1 of OHBDC [10] can be used.

5.3.1 Working Stress Design

The maximum allowable stresses for steel listed in **CSA Standard S16-1969, Steel Structures for Buildings [11]** shall be used for design except that the stresses allowed may be increased by 15% for temporary loading (OPSS 919, Cl. 919.04.02.02) [5].

(a) Allowable Bending stresses in tension and in compression: **Clause 16.2.4**

(b) Allowable Shear stresses: **Clause 16.2.3**

(c) Bearing Stiffeners: **Clause 19.5**

(d) Web Crippling: **Clause 19.8**

(e) Stability of Thin Webs: **Clause 19.9**

(f) Axial Compression: **Clause 16.2.2**

5.3.2 Limit States Design

Limit states design of structural components and connections shall be in accordance with CSA Standard **CAN/CSA-S16.1-M89, Limit States Design of Steel Structures [12]**. The relevant clauses are as follows:

(a) Bending Resistance - Laterally supported members: **Clause 13.5**
Laterally unsupported members: **Clause 13.6**

(b) Shear Resistance: **Clause 13.4**

(c) Bearing Stiffeners: **Clause 15.6**

(d) Web Crippling: **Clause 15.9**

(e) Axial Compression: **Clause 13.3**

5.4 Manufactured Modular Shoring Systems

In Ontario, proprietary or manufactured shoring systems are more commonly used in bridge construction than wood shoring systems. A modular (Steel/aluminum) shoring system consists of individual components that can be assembled and erected in place to form a series of internally-braced scaffold towers to any desired height.

From a design standpoint, shoring "towers" are indeterminate space frames; they cannot be analyzed by the general formulas applicable to statically determinate framed structures. Instead, empirical criteria, developed by considering the effect of such factors as tower height, differential leg loading, sidesway, method of external support, etc. are used to determine their safe load carrying capacity. Ultimate capacities are established by load tests using the appropriate test procedures and then, Safe Working Loads (S.W.L) are determined using the appropriate factors of safety (CSA, S269.1-1975, Clause 6.5 and 10) [1].

5.4.1 Safe Working Loads

The maximum load to be carried shall not exceed the safe working load recommended by the manufacturer. Shoring capacity as given by the manufacturer should be considered as the maximum load that the shoring can safely support under normal loading conditions.

Overstressing or reduction of specified factors of safety is not permitted especially as a variety of adverse loading conditions (e.g. excess in horizontal loads, eccentricity due to unbalanced span
or pouring sequence, uneven foundation settlement, shoring components not in good condition, etc.) are often encountered in bridge falsework,

5.4.2 Tower Leg Loads

Loads on tubular scaffold frame legs may be based on simple span assumptions; i.e. the loads supported by a frame leg may be assumed to be those loads applied to the area immediately above the frame leg which is bounded by the centre lines of the bays around the leg under consideration (OPSS 919, Cl. 919.04.02.05) [5].

In order to minimize the unbalanced load on legs within the same tower, the following criteria shall be considered:

(i) The maximum load on one leg of a frame should not exceed four times the load on the other leg under all loading conditions.

(ii) The maximum load on one of the two frames making up a tower should not exceed four times the load on the opposite frame under all loading conditions.

5.4.3 Minimum Bracing Requirements

The minimum bracing requirements (OPSS 919, Cl. 919.04.02.06) [5] in the transverse and longitudinal directions will be in accordance with the conditions illustrated in 5.4.3.1 and 5.4.3.2 below.

5.4.3.1 Transverse Direction

Every fourth joist shall be connected to a ledger. Ledgers/joists on top of frames must be continuous across the full width of the shoring system so that horizontal force can be distributed evenly to individual scaffold towers below. Ledgers may be considered continuous if spliced properly (Figure 3.4).

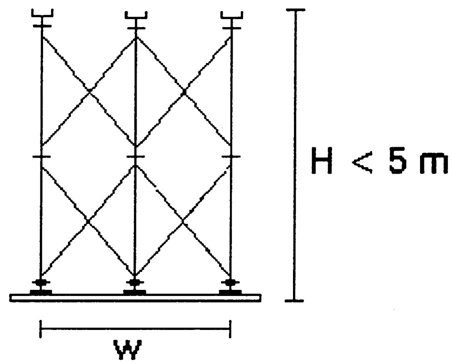
No supplemental bracing is required for shoring height up to two frames if total height is 5.0 m (including extensions) or less. However, maximum height to width ratio of individual scaffold towers in transverse direction should exceed 3:1 except that, to the satisfaction of the engineer, towers are braced against the existing structure or tied to adjacent towers with sufficient supplemental bracing (e.g. Tube & Clamp).

One continuous horizontal brace is required on one face of every tower when the shoring height reaches three frames or total height is more than 5.0 m. The brace shall be located at the mid height of a two-frame tower and at the top of the second frame for a three-frame tower (Figures 5.1, 5.2, 5.3 and 5.4).

When the shoring height is composed of more than three frames, at least one continuous horizontal brace and one continuous diagonal brace shall be attached to one transverse face of every tower, for every three frames of shoring height. The lowest horizontal brace should be located near the top of the third frame, and an additional horizontal braces for every extra three frames. Diagonal braces shall be located on the opposite tower faces, and shall run in opposite directions (Figure 5.5).

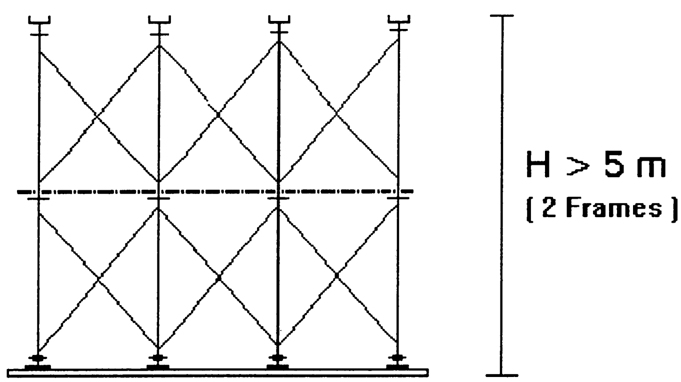
When the shoring height is greater than 20.0 m, guy wires shall be used. The spacing of the guy wires shall not be greater than 15.0 m in the longitudinal direction (Figure 5.6).

When the deck superelevation is 4% or greater, a transverse brace parallel to the slope shall be attached to one tower face at its top frame in addition to the bracing specified in the preceding paragraphs (Figure 5.7).



Condition: H < 5 m , W > $\frac{H}{3}$, 2 frame tower, transverse.
Bracing: Not required

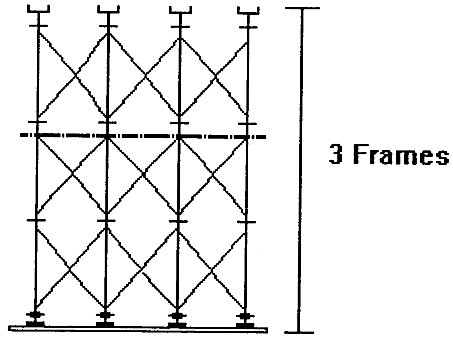
Figure 5.1



Condition: H > 5 m , 2 frame tower , transverse.
Bracing: Horizontal tubing placed at mid height.

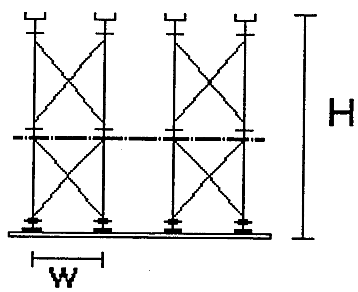
–·–·–·– Tube & Clamp

Figure 5.2



Condition: 3 frame tower, trnsverse.
Bracing: Horizontal tubing placed at the top of the second frame.
-·-·- Tube & Clamp

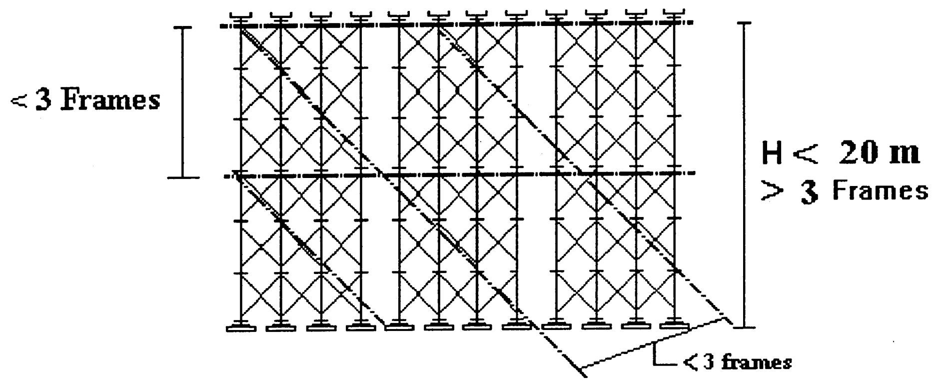
Figure 5.3



Condition: $W < \frac{H}{3}$, transverse.
Bracing: Horizontal tubing placed at mid height.

-·-·- Tube & Clamp

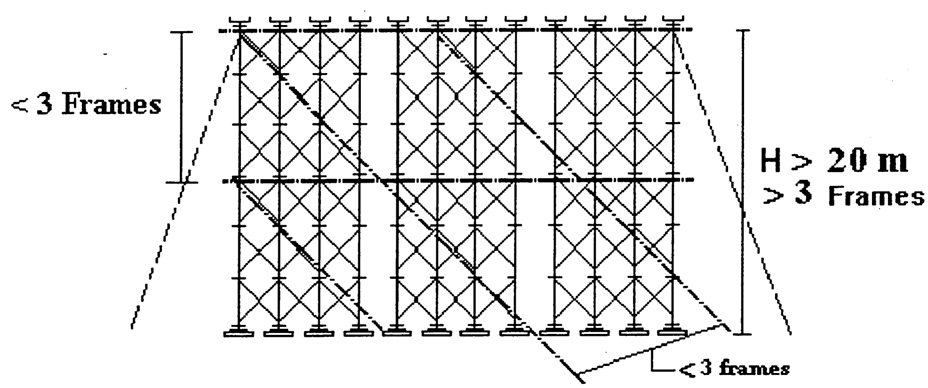
Figure 5.4



Condition: H < 20 m, > 3 frames, transverse.
Bracing: At least one horizontal and one diagonal every 3 frames, all made continous.

—·—·— Tube & Clamp

Figure 5.5



Condition: H > 20 m, > 3 frames, transverse.
Bracing: At least one horizontal and one diagonal every 3 frames, all made continous.
Guy wire maximum spacing 15 m longitudinal.

------------ Guy wire
—·—·— Tube & Clamp

Figure 5.6

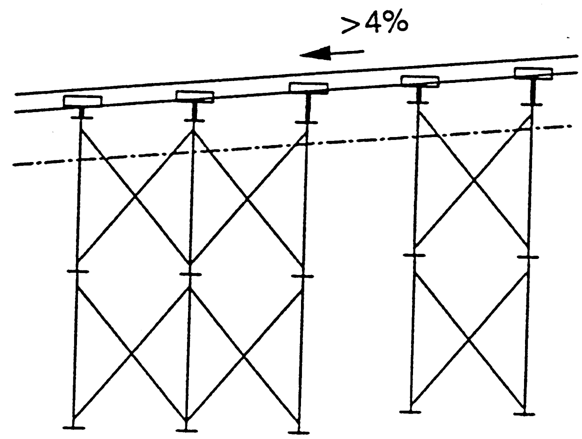


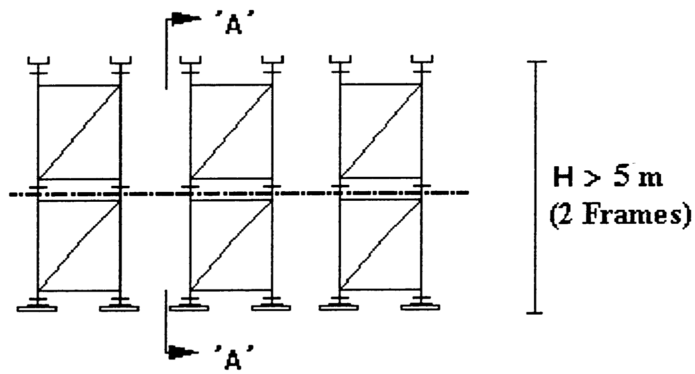
Figure 5.7 Superelevation ≥ 4%

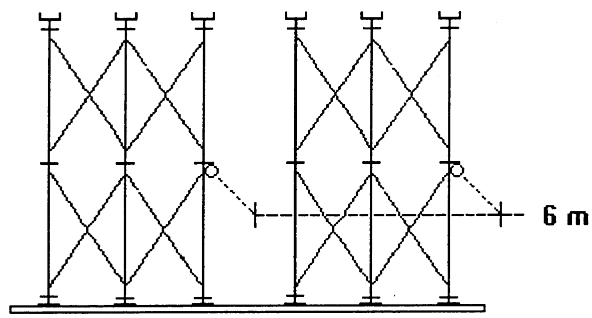
5.4.3.2 Longitudinal Direction

When the shoring height is composed of three frames or the total height is more than 5.0 m (including extensions), one horizontal brace made continuous shall be installed spaced in the transverse direction not more than 6m apart. The brace shall be located at the top of the first frame of a two-frame tower and the top of the second frame of a three-frame tower (Figure 5.8 and Figure 5.9).

When the shoring height is composed of four frames or more, horizontal braces and diagonal braces made continuous shall be attached to opposite sides of a line of towers and spaced horizontally not more than 6m apart. The lowest brace shall be located at no higher than the top of the third frame and any additional braces should be spaced (vertically) no further than three frames (Figure 5.10).

When the bridge is on a longitudinal grade of 4% or greater, a brace parallel to the grade shall be attached to one tower face of the top frame and spaced not more than 6.0 m apart in the transverse direction.



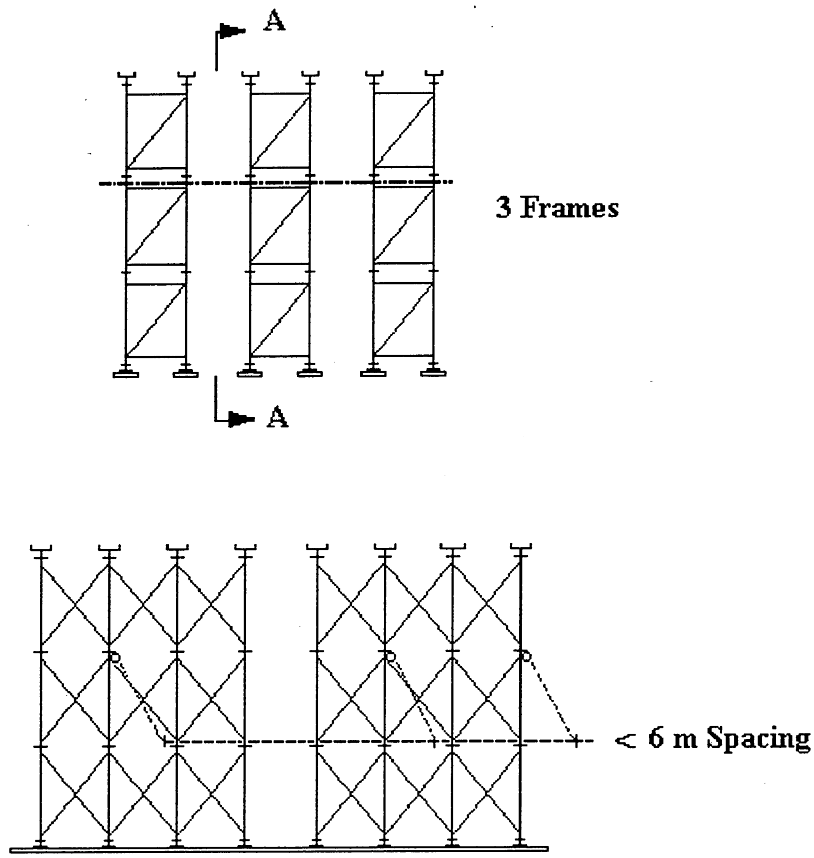


Section A-A

Condition: H > 5 m, 2 frame tower, longitudinal.
Bracing: Horizontal tube placed at mid height, made continuous, at no more than 6 m spacing

○ Tube & Clamp
-------- Tube & Clamp

Figure 5.8

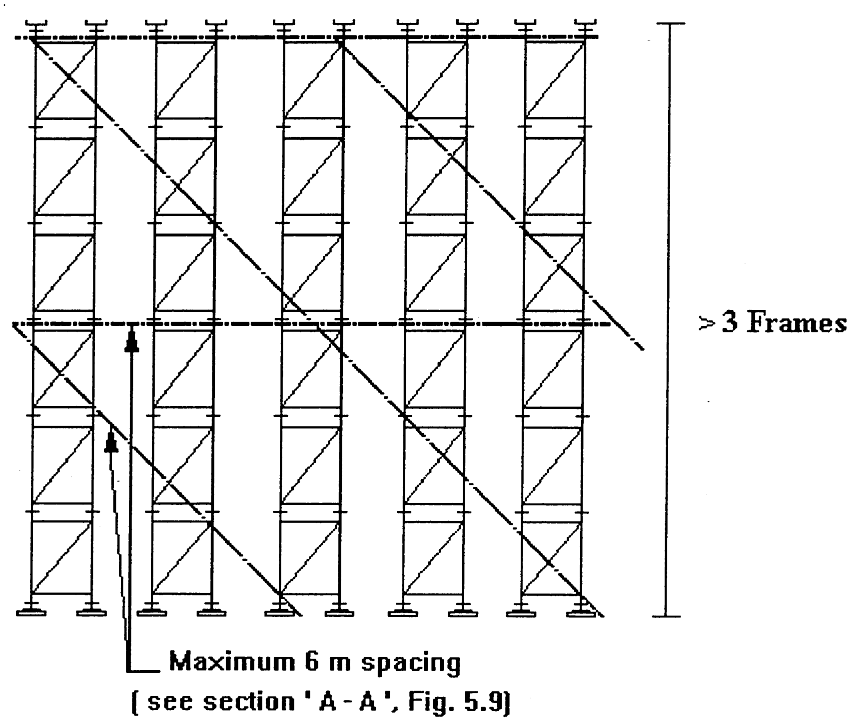


Section A-A

Condition: 3 frame tower, longitudinal.
Bracing: Horizontal tube placed at the top of 2nd frame, made continuous, at no more than 6 m spacing.

○ Tube & Clamp
-·-·-·- Tube & Clamp

Figure 5.9



Condition: more than 3 frames, longitudinal.
Bracing: At least one horizontal and one diagonal every 3 frames, all made continuous.

-·-·-·-·- Tube & Clamps

Figure 5.10

5.4.4 System Stability

The factor of safety against overturning or sliding (unfactored loads) of falsework or formwork systems, for all possible loading conditions, prior to, during, and after concrete placement, shall not be less than 2:1.

Generally, a shoring system of a height-to-width ratio of 1.0 or less where the ledgers/stringers made continuous on tubular (steel/aluminum) scaffold frames that are properly braced is considered stable against overturning. In special cases such as very deep decks with high sideforms vulnerable to wind, high longitudinal/transverse deck slope, high ratio of height-to-width (slender) scaffold towers, etc., the global stability of the falsework and formwork structures should be checked.

5.5 Traffic Opening

A traffic opening is generally required in the falsework for bridge structures that are passing over existing highways, so that traffic is not interrupted during their construction period. The basic traffic opening's falsework components normally consist of steel I-beams spanning over the traffic lanes with scaffold towers providing the end supports.

The required vertical minimum clearance at the lowest point is 4.5m (OHBDC, Clause 1-5.2.2) [10]. The horizontal clearance varies according to the number of traffic lanes that need to be in operation. Falsework clearances requirements shall be in accordance with OPSD - 4602.00 [13].

The falsework opening towers shall be longitudinally braced to two rows of scafold towers behind them in conformance with 5.4.3.2 above, regardless of the height, and shall be continuously braced transversely (OPSS 919, Cl. 919.04.02.06) [5].

5.6 Falsework Foundation

At the point of contact of the falsework with the ground or with the permanent construction, it is necessary to distribute the loading from the falsework into the ground or works below in a safe manner and to limit deformations and settlements to acceptable levels. Proper foundation detailing is very important to ensure the safety of the falsework. Many catastrophic falsework failures were due to poor foundation construction. The basic components that make up the falsework foundation are mudsills and the supporting ground.

5.6.1 Mudsills

Mudsills are used to evenly distribute the loads from the falsework to the supporting ground without exceeding the allowable soil bearing capacity or the allowable stresses of sills material. Most sills are made of wood. Where leg loads of 44 kN (10 kips) or more occur, sills shall be not smaller than 4" x 12" wide (Solid section) laid flat to transfer load to the soil subgrade (CSA, S269.1-1975, Clause 6.6.3.3) [1].

Joints in continuous sills do not need scabbing; however, the minimum sill projection "L" (the minimum distance from the centre of support to the end of sill) shall be calculated as follows:

$$L = \frac{P}{2\,W\,S}$$

where:

P = vertical load
W = width of sill
S = allowable bearing pressure of soil

If the sill projection that can be provided is less than "L", then the sill with the small projection shall butt onto the adjacent sill and the joint shall be overlaid with a second sill (usually called spreader) of the same cross section. The spreader shall be of a length equal to 2 "L" and shall be centred in position under the vertical load as shown in figure 3.6.

Structural adequacy of mudsills section shall be checked. Bending moment, shear and bearing capacities of the sill section are usually calculated and compared with the corresponding effects of the applied loads on the sill.

5.6.2 Supporting Ground

The minimum required soil bearing capacity of the falsework supporting soil shall be shown on the falsework drawings. This value shall be used to check the proposed mudsills details of the falsework. A Falsework Foundation Design Report, signed and sealed by a professional engineer, shall be provided stating the available soil bearing capacity, the site preparation requirements, if any, and the expected mudsills settlement which shall not exceed 12mm. Special attention shall be given to the areas around abutments and piers as the soil there was disturbed by the excavation and backfilling for the construction of these substructures.

6. INSPECTION

6.1 Introduction

Falsework and formwork inspection is important to ensure that the requirements of the design drawings are implemented. Many accidents and failures that occur during construction, are falsework/formwork related failures, which usually happen at the time of concrete placement. Falsework, as a structure, becomes most vulnerable in terms of stability when the forms they support are filled with wet concrete. If some unexpected effect causes failure of one member, then others become overloaded or misaligned and the whole system can collapse.

Nevertheless, good construction practices and thorough inspection can ensure safety and efficiency of properly designed falsework and formwork structures. Competent in-progress supervision and inspection are important to verify that:

- Design drawings are followed,
- Satisfactory workmanship according to good construction practices and customs of - trade is achieved,
- Quality materials of the specified type are used, and
- Acceptable remedial action is taken to rectify any observed deficiencies

6.2 Drawings

Inspection of falsework and formwork is normally based on design drawings and details that are checked and released for construction. The layout, dimensions and materials must be in accordance with these drawings so that they will safely support the load imposed on them.

It is clearly in the interest of all parties concerned to have the falsework and formwork drawings prepared, checked and released for construction in time before proceeding with their construction as it is often very difficult, impractical and costly to correct details after the fact.

Some activities such as ground preparations can commence (based on the recommendations of the Falsework Foundation Report) even before the drawings are available. Copies of drawings released for construction shall be made available before the placing of mudsills, and shall be used for in-progress inspection.

Minor deviations (e.g. $\pm$ 300 mm in elevation of falsework supporting ground, stronger beams or frames used, etc.) to suit field conditions or due to availability of other materials are permissible if it is evident that the change will not adversely affect any individual member or the falsework system as a whole. If any doubt arises from certain changes, the design engineer and the checking engineer should be consulted and a proper documentation of the changes must be made.

If substantial deviations are necessary because of field conditions, the falsework drawings shall be revised, checked and released for construction in the same manner as the original drawings. Work shown on revised falsework drawings may not begin until these drawings have been checked and released for construction. Typical examples of substantial changes are:

- Change in the size, spacing or material of any primary load-carrying member
- Change in the method of providing lateral or longitudinal stability

6.3 Ground Preparation Work

Foundation condition should be inspected before the mudsills are set in place to ensure that the soil can adequately support the anticipated loads to be placed on it. The purpose of ground preparation is to produce a firm, even surface for bearing and to achieve a soil bearing capacity that meets the requirements of the approved drawings. The key to achieve this goal depends largely on the foundation soil type and characteristics and on the variations in its composition, compaction and strength. Good foundation material should be compact and free draining. Any soft clay, organic soil or unsuitable materials must be removed and replaced with well compacted granular fill.

When the shoring system is placed on fill or on ground where disturbance to the native soil layers has occurred (e.g. areas around abutments and piers), close supervision of the compaction and reworking of these areas is necessary to insure proper foundations.

The prepared ground for falsework sills should be a level surface free from bumps or depressions within the bearing areas. Depending on the situation, a thin layer of sand may be used to fill in surface irregularities. When constructing falsework on sloping ground, the slope is usually terraced for the placement of mudsills. Terraces in either fill or natural slopes should be cut into firm material with the sill set well back from the edge of the terrace so that the steps will remain stable throughout the construction period.

Figure 6.1 Site Preparation and placement of mudsills

Figure 6.2 Terrace

In addition to checking the load-carrying capacity of the foundation material, it is also important to check for any precautions that need to be taken so that environmental conditions do not reduce the assumed capacity of soil. Attention should be drawn to the drainage facilities behind abutments and around mudsills. If water is allowed to pond in these areas, it will eventually cause softening, scour or undermining of the soil strata on which the sills are placed. Where there is a likelihood of the foundation soil becoming frozen, attention shall be given to probable thawing effects and appropriate measures shall be considered.

Figure 6.3 Drainage

6.4 Mudsills

Sills are used to distribute the falsework loads to the supporting soil evenly and safely. They shall be sound, rigid and capable of resisting the maximum forces they will be subjected to without undue settlements or deformations.

Mudsills material, usually used lumber, shall be inspected for type, grade, size and condition before they are set in place. If there is any doubt about the identification or condition of used lumber, a verification by a qualified lumber grader shall be required. Deteriorated or defective lumber shall not be used (Figure 6.4).

All mudsills under shores must be placed on firm and even ground so that full bearing is achieved. Any void under the sill must be filled with compacted sand or other suitable material (Figure 6.5).

Scaffold legs shall be positioned centrally on mudsills to avoid overstressing or overturning of the falsework or the mudsill. Mudsills joints shall be inspected to ensure that they do not fall within the minimum sill projection distance, and if in practice the minimum sill projection cannot be achieved, a spreader of the same cross section as the sill, is used to butt the joint as specified on the drawings (Figure 6.6).

To ensure proper load distribution, the sill shall be continuous under at least two consecutive vertical members except under single post shores where the mudsill shall extend continuously under three vertical members.

Figure 6.4 Rotten Wood

Figure 6.5 Void Under Sill

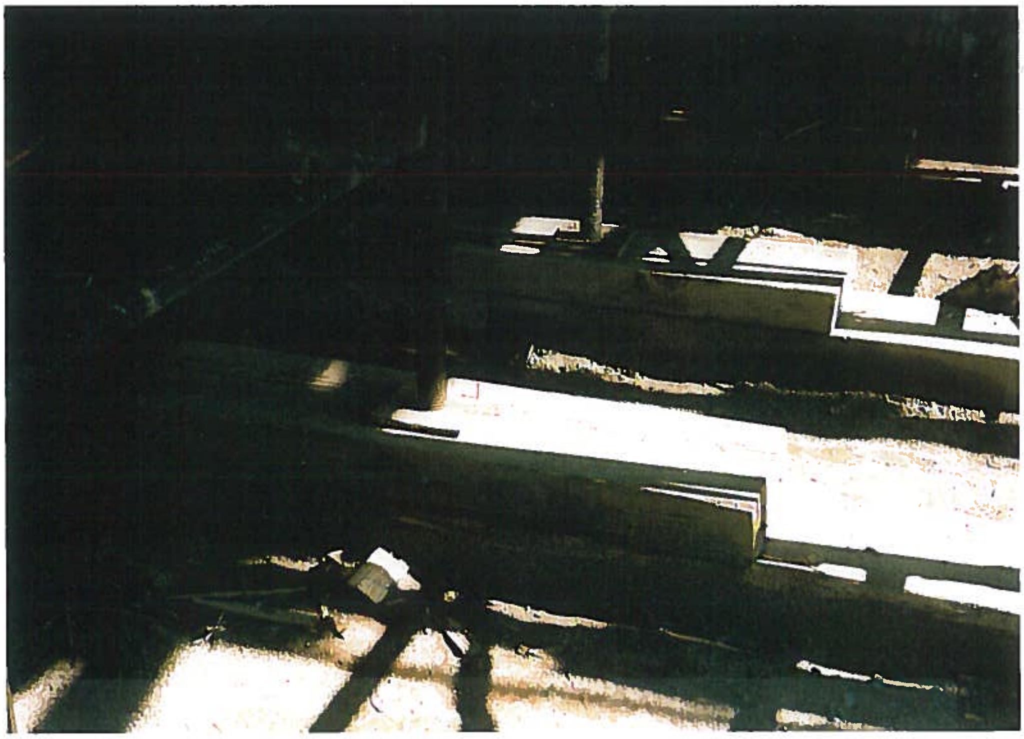


Figure 6.6 Mudsill Splice

6.5 Scaffold Frames

All shoring frames and components shall be identified and inspected before and during their erection to ensure that they meet the requirements of the drawings and that they are in a good condition. Any frame or component that is heavily rusted, bent, dented or damaged should not be used (Figures 6.7 and 6.8).

When checking the erected shoring frames against the shoring layouts, spacing between towers, cross brace spacing and number of tiers shall not exceed that shown on the layout, and all locking devices shall be in the closed position. The completed shoring set up as a whole constitutes an integrated stable load carrying system.

Vertical shores shall be plumb and braced in two directions. Variations from plumb shall be in accordance with CSA, S269.1 Clause 7.2.6 [1]. Shore heads, screw jacks and similar components shall be axially loaded; eccentric loads are not allowed on shoring components. Screw jacks' extensions should be checked for compliance with the maximum allowable.

All Shoring components that are supported on each other as joists, stringers, U-heads, frame legs, screw jacks, base plates and mudsills shall have full bearing, without voids or gaps, between their bearing surfaces. Frames stacked on top of one another shall have firm and full bearing of their ends.

Cross braces shall be tight and snug when locked and of correct lengths. If tube-and-clamp bracing is used, it shall be placed at locations specified on drawings and securely fastened to every frame leg.

Normally, shoring can be removed/released after the post-tensioning cables are stressed and grouted. The method of releasing the load on the falsework shall be carefully considered. Loaded shoring shall not be released or removed without the approval of the engineer.

Figure 6.7 Typical Frames

Figure 6.8 Unacceptable Frames

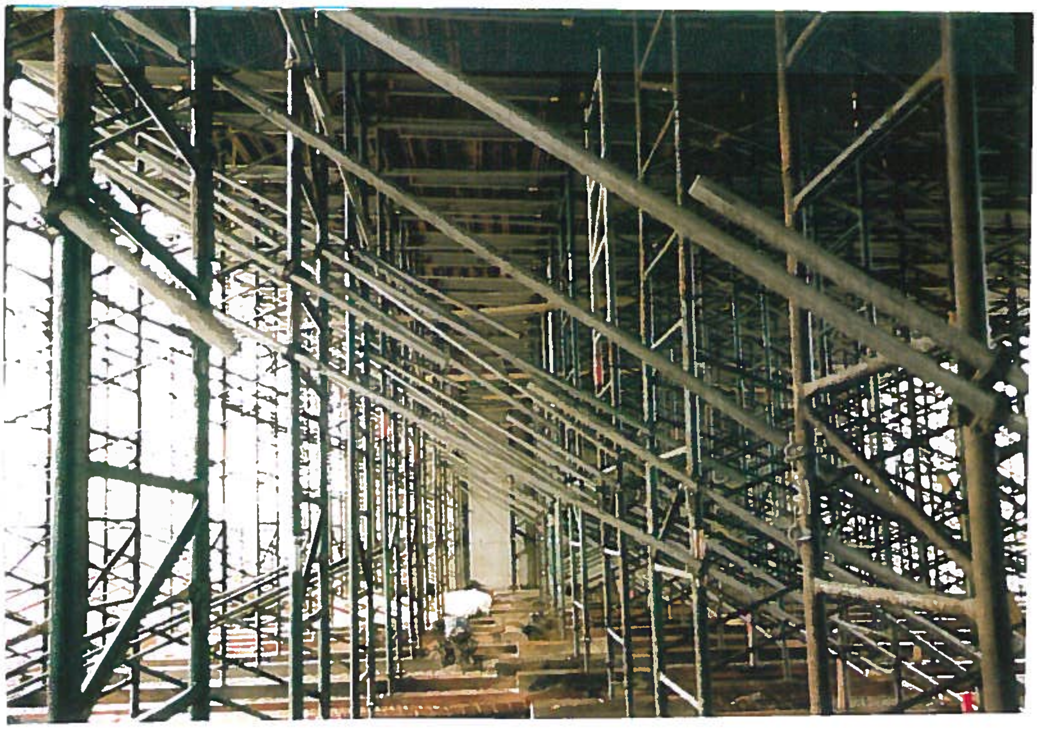


Figure 6.9 Tube & Clamp Cross Brace

6.6 Ledgers and Joists

Check ledgers and joists for being in good condition and for compliance with the drawings in terms of type, size, grade, spacing, splicing, clamping, etc.

Check that ledgers' splices are done in accordance with Manufacturer's instructions. Butt splices shall be located centrally inside the U-heads of the scaffold frames (or at most within the perimeter of the jack screw stem underneath the U-head) to avoid eccentric loading of the U-head section and the frame leg. Some manufacturers recommend using aluminum/steel splice plate from one side (bolted to both ledgers) while others ask for hardwood wedges from both sides (clinched nails to the U-Head). If lumber ledgers are used, plywood scabs from both sides (nailed to both ledgers) are usually provided.

When a bridge deck has a superelevation/cross falls of more than 2% slope, check that wedges are provided between sloped ledgers and the U-heads that carry them. Wedges shall be hardwood and in full contact with U-heads and ledgers.

Check that joists are properly spaced and in full contact with the ledgers. Joists shall be overlapped over the ledgers. Butt joints over ledgers are not recommended. For deck slopes greater than 2%, joists shall be clipped to ledgers for stability and alignment purposes. Normally, every fourth joist is to be clipped to the ledger.

Cantilevered part of joists/ledgers, if any, shall not exceed the specified length due to strength and deflection constraints. Always check for obvious mistakes like omitting joists, using the wrong size ledger, or wrong slopes direction.

Figure 6.10 Ledger Splice Off Centre

Figure 6.11 Hardwood Wedge

Figure 6.12 Lap Joints and Clipping

6.7 Formwork

Prior to permitting concrete placement to go on, final inspection of the formwork shall be performed to verify that it is properly built according to the design drawings.

Check sizes, grades and quality of all materials and components to ensure that they are sound and they match the requirements of the design drawings.

Check that formwork plywood "Formply" (OPSS 919, Cl. 919.05.03) [5] is 7 ply, 17 mm minimum thickness and exterior grade Douglas Fir plywood in conformance with CSA 0121. Plywood with approved plastic surface coating shall be used for exposed surfaces, except in the following circumstances:

(a) the underside of a deck between girders;
(b) the end faces of decks;
(c) the face of ballast walls;

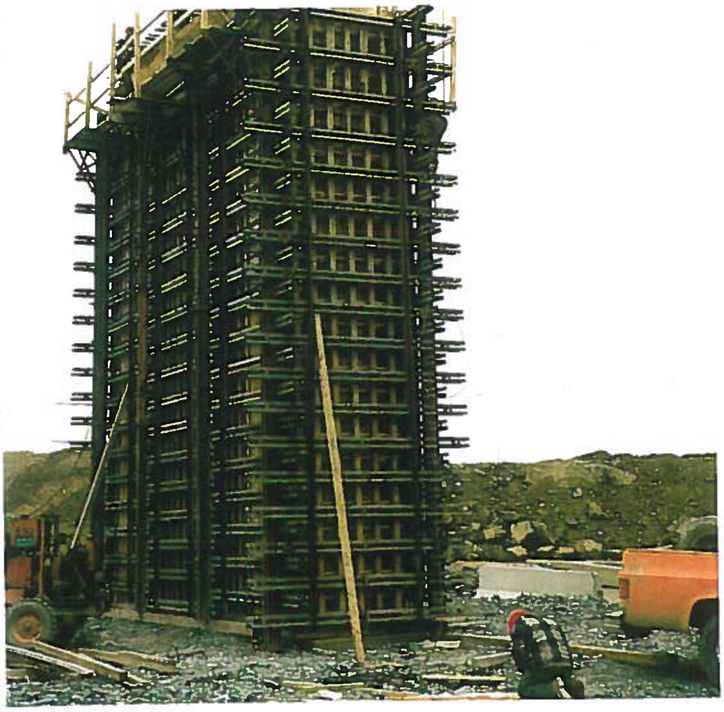


Figure 6.13 Form

As a rule of thumb, plastic coated plywood is required for all post-tensioned deck structures. Form oil or other coatings should be applied to surfaces in contact with concrete to facilitate stripping. It should be applied before reinforcing steel is placed.

Bracing and tying of formwork shall be adequate and in proper locations as shown on the approved drawings. Incorrectly built forms may distort or even fail under the loads of the freshly poured wet concrete and then it will be impossible to force them back into position.

Plywood sheets shall be arranged so that the face grain is perpendicular to the studs or joists. Edges of abutting sheets shall be nailed to the same stud or joist with 2" nails at not more than 200 mm centres. The joints between sheets abutting over joists shall be staggering a minimum of 400 mm (OPSS 919, Cl. 919.07.01) [5].

Joints and seams in the forms shall be checked for tightness to prevent accumulation of dirt before concreting, or loss of mortar of the wet concrete when placed.

6.8 Sideforms and End Bulkhead

These are forms for the sides and ends of the bridge deck where internal form ties cannot be used and therefore inspection of the external braces that resist the lateral pressure of the fresh concrete is of critical importance.

Trapezoidal or triangular wooden frames are commonly used to hold sideforms in place against lateral concrete pressure. Insure that kickers are provided and adequately nailed to main members to prevent lateral movement of the sideforms when concrete is placed. Check that all nails are driven home and bent over if possible. Lumber members shall be checked for the right species, grade, size and of good condition.

Bulkhead forms at both ends of the bridge deck are subjected to the full depth of fresh concrete. Stronger members and additional vertical studs or strongbacks are usually used to provide greater rigidity to bulkhead forms. External bracing set at an angle to the form shall butt against kickers securely driven into the ground. Size and quality of material for the bracing are to be checked.

Figure 6.14 Side Form

Figure 6.15 Bulkhead form

6.9 Traffic Opening

The checklist for shoring details for traffic opening is similar to the checklists previously discussed. Usually, steel beams are used to support the deck slab over comparatively long spans. This results in heavier loads to be supported by the vertical shores. Consequently, greater care must be taken in checking the bracing of the vertical shores and inspecting the foundation and mudsills that support them.

Steel beams size, grade, condition and spacing must be according to the drawings. Used beams, and particularly those beams salvaged from different type of use, should be examined carefully for distortion, loss of section, damage due to welding, bolt holes, web openings, corrosion, or partial splices/connections that may adversely affect their structural behaviour and their load carrying capacities.

Figure 6.16 Traffic Opening

Check for the provision of the additional bracing in accordance with Section 5.5 before to assure stability of traffic opening falsework towers. Special attention should be given to ensure that the bracing is properly connected and positioned.

Where the deflection of the beams is 10 mm or more, check for the provision of blockings to compensate for the expected deflections in accordance with the camber diagram shown on the drawings. Wood packing of different heights placed on the top flanges of the beams are usually used to do this job.

The horizontal and vertical clearance provided at the falsework opening should be checked as soon as the shoring towers are erected and the beams are set in place.

6.10 Installation of Telltales

After the final adjustments and checking of the falsework and formwork, telltale devices shall be installed to facilitate the detection and measurement of vertical movements during concreting. Telltales should be installed at intervals of 10m to 12m longitudinally and 2 to 3 rows transversely. Regular checking of elevations and camber may be necessary during the pour.

Depending on the situation and the volume of the pour, at least one mark is made before the pour, a second mark shall be made when concrete is approximately at half depth, and a third mark shall be made just after concreting.

If excessive settlement (20mm or more) is detected during the pour, either due to yielding of the foundation soil or deflection of the shoring system, the rate of concreting should be slowed to allow investigation of the problem so that satisfactory corrective measures can be taken.

If any serious weakness develops during concreting which would endanger the structure or the workmen or cause undue settlement or distortion, work must be halted to allow strengthening of the falsework/formwork. Concrete placing should not be resumed until all parties concerned are satisfied that it is safe to do so.

Figure 6.17 Telltale

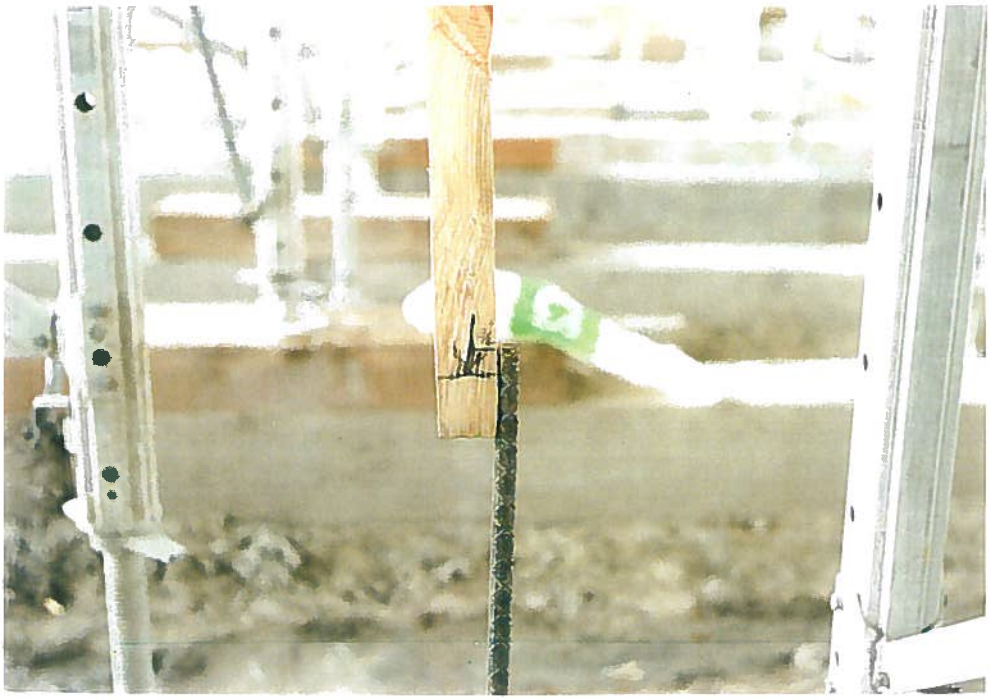


Figure 6.18 Telltale Mark

References:

[1] CSA Standard S269.1- 1975, *Falsework for Construction Purposes*, Canadian Standards Association, Rexdale, Ontario, Canada.

[2] CSA Standard CAN3-086-M84, *Engineering Design in Wood (Working Stress Design)*, Canadian Standards Association, Rexdale, Ontario, Canada.

[3] CSA Standard CAN/CSA-086.1-M94, *Engineering Design in Wood (Limit States Design)*, Canadian Standards Association, Rexdale, Ontario, Canada.

[4] CSA Standard CAN/CSA-0121-M1978, *Douglas Fir plywood*, Canadian Standards Association, Rexdale, Ontario, Canada.

[5] Ontario Provincial Standards, OPSS 919, *Construction Specification for Formwork and Falsework*, St. Catharines, Ontario, Canada.

[6] CSA Standard CAN/CSA-S269.3-M92, *Concrete Formwork*, Canadian Standards Association, Rexdale, Ontario, Canada.

[7] ACI Committee 347, *Guide to Formwork for Concrete*, American Concrete Institute, Detroit, Michigan, U.S.A, 1994.

[8] Falsework Manual, State of California, Department of Transportation, Office of Structure Construction, Sacramento, California, U.S.A, 1988.

[9] *Guide Design Specifications for Bridge Temporary Works*, AASHTO, Washington, D.C., U.S.A, 1995.

[10] *National Building Code of Canada*, Ottawa, Ontario, Canada, 1990.

[11] CSA Standard S16-1969, *Steel Structures for Buildings (Working Stress Design)*, Canadian Standards Association, Rexdale, Ontario, Canada.

[12] CSA Standard CAN/CSA-S16.1-M89, *Steel Structures for Buildings (Limit States Design)*, Canadian Standards Association, Rexdale, Ontario, Canada.

[13] Ontario Provincial Standard Drawing, OPSD 4602.00, *Falsework Clearances*, St. Catharaines, Ontario, Canada.

[14] CSA Standard CAN/CSA-G40.20-M92, *General Requirements for Rolled or Welded Structural Quality Steel*, Canadian Standards Association, Rexdale, Ontario, Canada.

[15] CSA Standard CAN/CSA- G40.21-M92, *Structural Quality Steels*, Canadian Standards Association, Rexdale, Ontario, Canada.

[16] CSA Standard CAN/CSA-S157-M92, *The Structural Use of Aluminum in Buildings*, Canadian Standards Association, Rexdale, Ontario, Canada.

[17] National Lumber Grades Authority (NLGA), *Standard Grading Rules for Canadian Lumber*, 1980.

[18] *Construction Handbook for Bridge Temporary Works*, AASHTO, Washington, D.C., U.S.A, 1995.

[19] BS 5975: *Code of practice for Falsework*, British Standards Institution, London, U.K., 1982.

[20] *Ontario Highway Bridge Design Code* (OHBDC), 3rd edition, Ontario Ministry of Transportation (MTO), Downsview, Ontario, Canada, 1991.