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GUIDELINES FOR FORMWORK, FALSEWORK AND TEMPORARY STRUCTURES FOR ROAD BRIDGES

(Second Revision)

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GUIDELINES FOR FORMWORK, FALSEWORK AND TEMPORARY STRUCTURES FOR ROAD BRIDGES

INTRODUCTION

The "Guidelines for Formwork, Falsework and Temporary Structures" was first published by IRC in year 1984 and thereafter it was first revised in 2011. The Formwork, Falsework and Temporary Structures Committee (B-7) during its tenure 2015-17 felt the necessity to revise this document again in order to keep pace with latest changes in technologies, machineries, workmanship etc. The initial draft was discussed in number of meetings of B-7 Committee and finally it was approved in its meeting held on 09.10.2017 for placing before the Bridges Specifications & Standards Committee (BSS). The BSS Committee in its meeting held on 23.10.2017 approved this document. The document was discussed in the 213th meeting of IRC Council held on 03.11.2017 during the 78th Annual Session of IRC held at Bengaluru and approved the document for publication.

The Formwork, Falsework and Temporary Structures Committee (B-7) of the Indian Roads Congress was re-constituted in 2015 for the tenure 2015-17 with the following personnel:

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Alam, Pervez	……	Co-Convenor
Jatkar, M.V.	……	Member-Secretary

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1 SCOPE

These guidelines apply to the design, fabrication, erection, and stripping of Formwork, Falsework and Temporary Structures built mostly from structural materials and used for supporting different types of permanent concrete bridge structures during construction till they become self supporting or built to provide access for doing concrete work or to support a plant/equipment or to support side slope of an excavation, etc.

Mechanised enabling structures (like launching girders, trolleys, etc.) used in bridge construction are excluded from the scope these guidelines. Working stress design, which was earlier a part of IRC:24, has now been added as **Annexure G** to this code.

The guidelines prescribe only the minimum requirements and are to be supplemented by design, engineering judgement and experience.

2 OBJECTIVES

The objective is to design and construct safe and economical formwork and falsework system that will support all loads imposed and provide the necessary rigidity to achieve the lines, grades and shapes shown in the working drawings. The basic parameters to be considered as under:

2.1 Quality

2.1.1 The forms and other structures are designed and built accurately so that the desired shape, size, alignment and finish of the cast-concrete is achieved in terms of dimension and strength as per approved working drawings.

The forms must be built to correct dimensions, must be sufficiently rigid under the construction loads to maintain the designed shape of the concrete within permissible deflections and tolerance limits, must be sturdy and strong enough to maintain large members in alignment, and must be constructed so they can withstand handling and reuse, without losing their dimensional integrity. The formwork must remain in place until the concrete is strong enough to carry its own weight.

2.1.2 The correct material should be chosen. The quality of surface finish of the concrete is affected by the material of the form. A correct combination of form material and oil or other parting compound can contribute in eliminating air holes or other surface imperfections in the cast concrete.

2.2 Safety

Safety should be included in the planning and management of the project and procedures that will assure safety for workmen and structure should be adopted. The following be ensured that:

2.2.1 Formworks, Falseworks and Temporary Structures are correctly designed after collection of required data and making sufficient investigations, by rational analysis with adequate safety margins and strong enough for the expected load.

These are supervised during erection and concreting by competent Supervisors who should see that these are constructed exactly as designed, following a safe erection procedure so that no members are temporarily overloaded.

2.2.2 No other loads are ever imposed on them if these have been designed with no allowance for unusual construction loads or eccentric loads due to placing sequence or any such load.

2.2.3 Adequate work area or work platforms with proper method of access have been provided.

2.2.4 Safety signs and barricades have been erected to keep unauthorized personnel clear of areas in which erection or stripping is underway.

2.3 Efficiency

The formwork, falsework and temporary works should be so planned and designed that these can be handled, erected and dismantled easily and used repeatedly to optimal limits.

2.4 Economy

Economy is one of the main concerns, since formwork cost may be more than 20-30 percent of the cost of concrete structure. No attempt, however, should be made to achieve economy at the cost of quality or safety.

2.4.1 The formwork falsework and temporary structures should be meticulously planned and designed to cater for all the parameters of quality, safety and efficiency and the provisions of codes and specifications such that these are time and cost effective.

2.4.2 Shortcut in design or construction of formwork may endanger quality and safety and should not be attempted.

2.4.3 The design and erection of formwork/falsework should, whereever possible, form an item of contract so that the cost of this item is correctly assessed, executed and supervised.

2.4.4 Coordinated efforts between Engineer/Designer and Contractor can also result in savings in the cost.

2.5 General Relationship and Responsibility

2.5.1 The responsibility of the designer, contractor, and the clients should be decided without ambiguity and the interests and views of all the three should be considered while deciding various parameters for design, specifications and erection with optimum utilization of the skills, knowledge and resources available at the site.

2.5.2 The system of designing, checking and approval of designs, erection systems and construction methodology should be clearly defined and agreed by all the involved parties.

2.5.3 The various parameters for design, its limitations and permissible tolerances should be finalized after mutual consultation between the involved parties and described in a design brief to be prepared and agreed before taking up the work.

3 DEFINITIONS

For the purposes of the guidelines, the following terms and definitions apply:

Adjustable Prop

Prop comprising of two tubes which are telescopically displaceable within each other so as to adjust its length

Base Plate

Metal plate for distributing the load from a standard, raker or other load bearing member.

Bay Length

Distance between the centers of two adjacent standards measured horizontally.

Blinding

Layer of lean concrete usually 50 mm to 100 mm thick, put down on soil such as clay to seal the ground and provide a clean level bed for construction work.

Brace

Tube or structural Member placed horizontally or diagonally with respect to the vertical or cross horizontal members of a scaffold and fixed to them to provide stability.

Camber

Vertical curvature of a beam or formwork, either formed initially to compensate for subsequent deflection under load, or produced as a permanent effect for aesthetic reasons.

Coupler

Component used to join members together.

Erection Drawing

Drawing prepared prior to erection showing the arrangement and details of the falsework structure.

Falsework

Temporary structure used to support a permanent structure until the structure becomes self supporting.

Formwork

Section of the temporary works used to give the required shape and support to poured concrete, which consists primarily of sheeting material (e.g. wood, plywood, metal sheet or plastic sheet) in direct contact with the concrete and other stiffening members that directly support the sheeting.

Hand Rail

Member incorporated in a temporary structure to prevent the fall of a person from a platform or access way.

Height of Lift

Height of concrete formed and cast in one pour.

Joint Pin

Adjustable fitting placed in the bore of a tube to connect one tube to another coaxially.

Joist

Horizontal or sloping beam.

Kentledge

Material placed on a structure to provide stability by counter-balancing through its dead weight.

Lacing

Members that connect together and reduce the unsupported length of compression members.

Permit to Load

Certificate issued to indicate that the falsework may safely be put to its designed use.

Permit to strike/dismantle

Certificate issued to indicate that permanent works have gained adequate strength to be self-supporting and that the temporary works can safely be removed or dismantled as per approved procedure.

Primary Member

Principal supporting member transferring load to the falsework.

Prop

Compression member used as a temporary support.

Re-Propping - Back Propping

System used during the construction operation in which the original props are removed and replaced in a sequence planned to avoid any damage to partially cured concrete.

Scaffold

Temporary structure that provides access or on which persons work or that is used to support material, plant or equipment.

Sole Plate Sill

Timber, concrete or metal spreader used to distribute the load from a standard or base plate to the ground/founding strata.

Soffit

Underside surface of a permanent concrete member like slab, beam, etc.

Spigot Pin

Pin placed transversely through the spigot and the scaffold tube or frame to prevent the two from coming apart.

Standard

Vertical or near vertical scaffold tube.

Stiff Length (of the bearing)

Length of the bearing that cannot deform appreciably in bending.

Strut

A member in compression.

Temporary Structures/works

Parts or the works that allow or enable construction of, to protect, support or provide access to, the permanent works and which may or may not remain in place at the completion of the works. They can also be used to support an item of plant/equipment or side-slopes of an excavation or provide access to work fronts during construction operations.

Temporary works co-ordinator

Competent person at project site with overall responsibility for co-ordination of all activities related to temporary works/structures.

Toe Board

Upstand at the edge of a platform intended to prevent operatives' feet from slipping off the platform.

Wedge

Two pieces of strong timber or metal that tapers along its length laid one above another with parallel outer faces.

Shim

A strong piece of timber or metal to adjust the level/length of the member in compression.

Tier

A unit or frame erected one above another in a vertical direction.

Top restraint

Mechanism/method through which falsework is stabilized by deriving support from surrounding permanent works or specifically designed temporary works.

Yoke

A vertical inverted U shape member generally used in slip form.

4 MATERIALS

4.1 General

The permitted materials for falsework in the context of these guidelines are timber, steel, plywood, concrete, masonry and fibre glass forms.

4.2 Specification for Materials

All the materials shall conform to the specified quality consistent with the intended purpose and actual site conditions as applicable. Where materials or component and their uses are covered by existing IS or IRC Standards as shown in **Table 4.1**, conformity with them subject to the satisfaction of supplementary requirements, if any, arising out of these guidelines shall be ensured.

Table 4.1 Specifications for Formork/Falsework Materials

Material	Principal Use	Minimum size	Specification and design data sources	Remarks
1	2	3	4	5
a) Timber	i) Form, shoring and scaffolding		IS 883	Softwoods of partially seasoned stock are recommended for formwork since fully dried timber swells excessively when it becomes wet and green timber will dry out and warp during hot weather.
	ii) Form for deck soffit, beam sides and other vertical surfaces	25 mm		-do-
	iii) Beam soffit columns side	50 mm 30 mm		-do-
	iv) Props	75 X 100 mm		-do-
	v) Bailies for Shore/ Bracing	75 mm dia Minm.		
b)	Ply-wood Forms and Form linings Sheeting and panels	6 mm	IS 4990	Plywood provides large area of joint free smooth concrete surface, easy in handling, light weight, flexibility of use, capacity to withstand hot and cold climates, no shrinkage cupping or twisting, high resistance to impact load and vibration, as of bonding, reusability.

Material	Principal Use	Minimum size	Specification and design data sources	Remarks
1	2	3	4	5
c)	i) steel	Forms and Form linings 3.15 mm with form vibrators	IS 2062	Steel forms can stand repetitive use. Note: Plate thickness may be increased if repetitive use is 500 or more
	ii) Rolled sections and tubes	Form supports shoring & framing, (i) Angles 50 X 50 X 6 mm (ii) Flats 50 X 6 mm (iii) Tubes 40 mm dia nominal bore with wall thickness 4.05 mm for main members and 25 mm dia for secondary members	IS 1161 IS 2062	Steel framing and bracing can be used in conjunction with timber and plywood panel system. Note: Sections may be increased up if repetitive use is 500 or more
	iij) Proprietary Systems	Forms can be obtained for round, square, rectangular or polygonal shapes Formwork components such as plates, prop, frames, accessories and trestles, etc.		Design data to be obtained from the manufacturer of the proprietary systems.
	iv) Clamps/ Couplers for tubular centering		IS 2750	
d) Aluminum Alloy		Light weight panels and forming systems shoring and falsework	Manufacturer's data	

Material	Principal Use	Minimum size	Specification and design data sources	Remarks
1	2	3	4	5
e) Fibre Glass	Precast concrete construction and architectural concrete		Manufacturer's data	This material is a glass fibre reinforced plastic product, excellent cast-concrete surfaces can be moulded to any shape without joints or seems.
f) Precast Concrete		37 mm		
g) Asbestos cement	Column forms and duct formers			Usually left in position and provides the finished surface.
h) Laminated pressed paper, tubes (Card Board)	Circular column forms, formers for small ducts		Manufacturer's data	
i) Hard board with lining	Form panels and G.I. lining.	Minimum 12 mm thick	-do-	
j) Plastic, Polyeterene, Polythe-Lene Polyvinyl chloride	Formliners for decorative concrete		-do-	
k) Rubber	Form lining and void forms		-do-	

Note : The sizes given in **Table 4.1** are only indicative of the minimum requirements and shall be derived from the actual detailed design.

4.3 New Materials

In case any new material is intended to be used that is not specifically covered in the Indian or International codes, but the use of which has been permitted elsewhere, it would be necessary to produce certification from the concerned authorities regarding the successful performance of such materials for 5 repeated uses. Such a certificate shall be supported with details of critical performance parameters and test results.

4.4 Formwork Accessories

For the design of form ties, form anchors and form hangers permissible stress shall conform to the relevant standards as well as design data based on test evidence published by the manufacturers.

4.4.1 *Form ties :* A form tie is a tensile unit adopted for holding concrete forms against the active pressure of freshly placed plastic concrete. Form ties, are also manufactured part of proprietary system.

4.4.2 *Form anchors :* Form anchors are devices used in the securing of formwork to previously placed concrete of adequate strength. The devices normally are embedded in the concrete during placement. Actual load carrying capacity of the anchors depends on the strength of concrete in which they are embedded, the area of contact between the concrete and anchor and the depth of embedment. Manufacturers also publish design data and test information to assist in the selection of proper form anchor devices.

4.4.3 *Form hangers :* Form hangers are often used to suspend formwork from a supporting structure.

4.5 Form Coatings or Release Agents and Sealants for Formwork

4.5.1 *Form coatings :* Form coatings or sealants are usually applied to contact surface either during manufacture or in the field to serve one or more of the following purposes:

a) To seal the contact surface and joints from intrusion of moisture or loss of moisture and cement slurry.
b) To alter the texture of the contact surface.
c) To improve the durability of the contact surface.
d) To facilitate release of form from concrete during stripping.

4.5.2 *Release agents :* Form release agents are applied to form contact surfaces to prevent bond and thus facilitate stripping. They may be applied permanently to form materials during manufacture or in the field or may be applied to the form before each use. The release agents shall be checked for compatibility with form surfaces, plastic concrete including admixtures and requirements for the application of further materials to the hardened concrete. They shall be kept off construction joints surfaces and reinforcing steel by applying before the reinforcement is laid. Care shall be taken to ensure that excessive application of release agent does not cause staining of concrete surface or retard curing. Where exposed aggregate work or other type of concrete surface finish is desired, release agents may be designed suitably.

4.5.3 *Form insulation :* These are usually used for protection of concrete in cold weather. These shall be used as per manufacturer's recommendations.

4.5.4 *Sealants :* In order to get smooth concrete surface finish and prevent escape of cement slurry, use of laminated tar paper or similar sealant can be permitted.

4.5.5 *Manufacturer's recommendations :* Manufacturer's recommendations shall be followed in the use of coatings, sealants and release agents, but independent investigation of their performance is recommended before use.

5 INVESTIGATIONS

The following investigations should be done before starting the design and all other data as made available should be verified with the site conditions.

5.1 All Topographical, Geographical and Climatic conditions should be investigated as relevant to design.

5.2 Sufficient Hydraulic and Hydrological investigations should be done to cover the river flow conditions, velocity of flow and discharge and water levels during different periods, any abnormal or sudden discharge which may be released from any Irrigation works in the upstream of construction site, any back flow conditions, tides or wave action, scour pattern during different seasons and flood conditions, any debris or trees flowing in the river.

This needs to be monitored regularly and whereever there are irrigation works upstream there should be continuous communication and alert system with them.

5.3 Adequate Geotechnical/sub soil investigations should be done at the locations of ground support to ascertain the allowable bearing capacity and to decide the type of foundation or support system after due consideration of the scours at those locations and the permissible settlements. Depth of sub-soil water should also be determined.

5.4 Adequate investigations should be done to locate any underground or overhead utility services which may foul with the foundation of the falsework/Temporary structures or the erection/launching or casting systems.

5.5 Detailed investigations should be done to find out the limitations at site because of space and movement restraints, headroom or clearances required, traffic regulation or diversion proposals, lighting and warning signs, regulations for noise control, vibrations or impact effects or environmental issues-pollution of air, soil or water etc.

5.6 Detailed investigations need to be done whenever there are any changes in any of the conditions which will affect the design or the systems of erection etc. being used. The designs/ systems could be reviewed and revised, if necessary, adopting the changed data/informations.

5.7 Falsework foundations in general are at a shallow depth. The subsoil investigations should be done keeping this factor in mind.

5.8 Necessary investigation should be done to assess the severity of the seismic effects to assess its implications on the design.

6 DESIGN

6.1 Procedural Control at Design Stage, Design Brief

The design, construction and supervision is needed to be ensured in respect of all aspects of formwork, falsework or temporary structures at site. These activities requires the same skill and attention to details as that of the permanent structure. These shall always be regarded as a structure in their own right, the stability of which at all stages of construction is paramount for safety of the permanent structure as well as for the personnel working at site.

Proper implementation of temporary works is largely dependent on management of various activities from concept to erection/dismantling as well as maintenance & storage. The procedures can be considered for controlling the three phases:

i) Design- Initially a design brief is to be prepared giving all data required for design of temporary works for the project. This includes drawings & specifications for permanent work, codes & contractual specifications as per which design of temporary works is to be carried out, soil investigation & environmental data, construction schedule & sequence of work, proposed methods of construction, access requirements, equipment & material available for temporary works and any other relevant data. If any deviations are proposed from the assumptions related to sequence or method of construction, loading or strength restrictions, etc. then the same have to be reviewed and approved by the designer of permanent works.

   It is to be ensured that a satisfactory design of temporary works is carried out. Depending on the complexity, the design & drawings are to be reviewed to check the concept, structural adequacy & compliance with the design brief.

ii) Communication & Documentation- After recording the design document & drawings, they are to be made available to all concerned.

iii) Site operations [Ref. **Clause 8.1**]

6.1.1 A design brief or design basis note should be prepared first in consultation with all concerned including the owner or the client and those involved in design, fabrication, construction and proof checking etc.

6.1.2 The brief should include all data relevant to the design, design philosophy and construction methodology etc. It is important that it is prepared early to allow sufficient time for all subsequent activities i.e. design, design check, procurement of equipment, construction and erection scheme etc.

6.1.3 The preparation of the brief might involve a large amount of information needed to be collected from various sources before design work can commence or a program for the construction or the temporary works can be drawn up.

6.1.4 Certain information might be of direct relevance to both the Permanent Works designer and the Temporary Works designers, such as site investigation information or where the Temporary Works affect or take support from the permanent works.

6.1.5 The following list indicates the type of information that might be required for the preparation of the brief.

a) Relevant drawings of the permanent works.

b) Relevant clauses from the Specification for the permanent works.

c) Statement of any requirement to design the temporary works in accordance witin a particular standard or guidance document.

d) Information on any significant risk associated with the design of the permanent works.

e) Program for the construction of the permanent works.

f) Methodology for construction including the different stages of construction for which design check may be required.

g) Program for the various phases of the design, design check, any external approvals, and procurement and erection of the Temporary Works.

h) The timing for the removal of the Temporary Works in relation to the ability of the Permanent works to be self-supporting.

i) Any requirements for access onto, under, or around the Permanent Works,

j) Any environmental constraints placed on the site by local authorities or other body, for example, a requirement by the local authority to limit noise to certain hours of the day.

k) Climatic and environmental conditions at site, hydraulic parameters, scour conditions, sub soil conditions, space restraints, wherever applicable.

l) Specific requirements for permissible stresses, tolerances, load combination, if in variance with the provisions of the standards being used for design.

m) Expected number of re-use.

n) Standards of safety and quality concerns.

6.1.6 The design brief should be provided to the designer or supplier to carry out the design of the temporary works.

6.1.7 When the design is completed the design brief should be provided to the organization/ individual who is to carry out the design check and also to the construction agency.

6.2 General Considerations

6.2.1 Formworks, Falsework and Temporary Structures shall be designed to meet the requirements of the permanent structure, taking into account the actual condition of materials, environment and site conditions in such a manner to facilitate easy erection and dismantling.

6.2.3 These may be designed in accordance with relevant IRC Codes for design of permanent structures except for loads, load combinations, allowable stresses and deflections which are dealt in this code. If, in case any item is not covered in this or other IRC codes, design may alternatively be based on other acceptable references or national/international codes.

6.2.4 Careful attention shall be paid to the detailing of the support/connections and their function so as to reflect and accommodate the behaviour of the structure. Wherever possible, the structure shall be designed in such a manner that any local failures will not lead to progressive failure of false work/temporary structure.

6.3 Loads

6.3.1 These structures shall be designed to cater for the vertical, horizontal and other loads as specified in the subsequent clauses.

6.3.2 *Vertical loads :* Vertical loads shall comprise of dead load, superimposed load, applicable live load and other loads as detailed below.

6.3.2.1 Dead loads

6.3.2.1.1 Dead load, generally static in nature, occur during the service life of these structures such as, Self-weight of the formwork and falsework, any ancillary temporary work connected to and supported by the falsework structure and permanent structure supported by the falsework.

6.3.2.1.2 Self-weight shall be determined according to IRC:6 except for the following items for which the unit weights given in the following clause shall apply.

6.3.2.1.3 The following unit weights shall be adopted in the absence of actual measurements:

a)	Wet concrete including reinforcement	26 kN/m^3
b)	Timber-soft wood	6 kN/m^3
c)	Timber-hardwood	7 to 10 kN/m^3
d)	Steel formwork, Aluminium formwork, Combination of steel and ply (sheeting, main and secondary bearers) and other materials.	Actual weight
e)	Scaffold tube (40 NB).	45 N/m

6.3.2.1.4 For falsework composed of scaffold tube fittings, the additional weight of fittings, in absence of actual data may be accounted for by increasing the self-weight of the vertical and horizontal members by 15 percent. Similarly, in the case of falsework built with fabricated frames, the additional weight of fittings may be estimated at 5 percent of the total weight of the frames and bracings.

6.3.2.2 *Impact :* In absence of data, to cater for impact in precast construction the dead load should be increased by minimum of 10 percent due to weight of precast concrete member. For cast-in-place concrete construction, impact forces are covered under superimposed loads.

6.3.2.3 *Up lift forces :* Reduction in self-weight due to submerged portions of structure should be considered in the calculations wherever applicable.

6.3.2.4 *Superimposed loads*

6.3.2.4.1 *Superimposed loads shall include the following :*

a) Construction personnel

b) Plant and equipment including the impact and surge - Special consideration shall be given to items of plant which cause vibration to formwork such as form vibrators and prestressing equipment.

c) The static load of the moving item should be increased by 25 percent for mechanically operated equipment, and by 10 percent when using manually operated equipment.

d) Stacking of materials - This normally occurs from storage of materials such as shutter plates, reinforcement and concrete making materials on the falsework prior to concreting. Stacking materials on falsework should be avoided. If it is unavoidable, then the maximum permissible load should be accounted for in the design and clearly indicated in the drawings.

e) Prestressing loads - The forces and deformation thereof, of the structure associated with prestressing are often transferred to the supporting falsework. Allowance shall be made in the falsework design to accommodate the force and/ or the movement involved as per the load transfer mechanism.

6.3.2.4.2 Depending upon seasonal, geographic and construction factors, snow can accumulate and form into drifts on the permanent and temporary works causing additional loading, this loading shall generally be within 0.75 kN/m^2 and only in exceptional case will this loading be exceeded.

6.3.2.4.3 Impact due to deposition of Concrete - This can be due to the deposition of concrete of forms and secondary girders supporting the forms a design DDL of 3.6 KN/m^3 shall be considered.

6.3.3 *Lateral loads :* The lateral loads shall comprise of:

a) Lateral pressure of fresh concrete
b) Environmental loads - wind, water
c) Earth pressures
d) Earthquake forces
e) Any other load not covered in above

6.3.3.1 Lateral pressure of fresh concrete

6.3.3.1.1 The factors affecting lateral pressure on forms are:

a) Density of concrete
b) Rate of placing
c) Vibrating
d) Temperature of concrete
e) Concrete Slump
f) Method of discharge and compaction
g) Width, depth & shape of section
h) Vertical form height
i) Constituent material of concrete like admixtures, aggregate, cementitious material

6.3.3.1.2 The design pressures may be calculated on the basis of standard literature such as CIRIA report/ACI Manual SP-4

6.3.3.1.3 The design pressure for Self Compacting concrete will be different than for the other concretes. Special literature should be referred to for calculating the pressure from such concrete on the formworks.

6.3.3.1.4 In general a minimum value of 20 kN/m^2/m height shall be adopted in the design. This value is valid for the rate of rise of concrete of 1.0 m/h at 25 °C and slump 40 mm without admixtures.

6.3.3.2 Environmental loads

6.3.3.2.1 *Wind*- In view of temporary nature of falsework it may be designed for wind loads as per IS 875 (Part-3) but with a return period of 5 years.

6.3.3.2.2 *Water*- Where it is necessary for falsework supports to be placed in flowing water, the effect of the forces caused by the flow shall be considered. These will includes –

a) Water current forces with due consideration for scour, turbulent flow during the construction period

b) Flood level occurring during the period of erection and dismantling of temporary work 2 times the calculated scour will be considered.

c) Increased frontal area, and head of water due to trapped debris-

Where there are successive rows of falsework members exposed to flowing water it is possible that some shielding protection is provided to the downstream members by the upstream. The following factors will contribute to the total force being applied to the falsework in the water:

i) The area of obstruction to the water flow presented by the first line of falsework members.

ii) Any further decrease in the width available for the passage of the water as it passes through the falsework.

iii) The increase in obstruction to the flow that would result from the trapping of debris on the faces of the falsework.

6.3.3.2.3 Trapped debris effect

The accumulation of debris will produce a force on the falsework that may be calculated as for that on a rectangular cofferdam. This force is given by the expression :

$$F_d = 666\, A_d V_w^2$$

where,

A_d = Area of obstruction presented by the trapped debris and falsework (in m^2)

V_w = velocity of water flow (m/s)

Fd = force in N

This effect will be dependent up on the rate of flow, the amount and nature of the floating debris, the nature of the obstruction and the depth of water.

6.3.3.2.4 Wave action - When falsework is erected in or adjacent to water, it may be subjected to wave forces. In marine locations this is a probability, but elsewhere it is a possibility that should considered. For further information specialist literature may be referred to.

6.3.3.2.5 Earth pressure - Earth pressure shall be calculated as per IRC:6.

6.3.3.2.6 Earthquake forces

Earthquake forces shall be considered for structures in Zones IV and V Load combinations and permissible stresses shall be as per IRC:6. Response reduction factor R shall be as per IS:1893 (Part 1) and Importance factor (I) shall be taken as 1.0.

6.3.3.2.7 Any other load not covered in above. Other horizontal forces may result in from the following cases and shall be catered for wherever appropriate.

a) Movements of the permanent structures imposed on the falsework due to effects like prestressing operations.

b) External ties and anchorages.

c) Plant and equipment - Horizontal forces may result due to acceleration of plant moving on falsework. The design should allow for a horizontal force in any of the possible directions of movement equivalent to 10 percent of the static load of the moving item.

d) Horizontal forces may develop if the pumped concrete pipe is supported by falsework though surcharge will usually be smaller. The pipes shall be adequately anchored, specially at bends and the effect of blowing out the line pipe shall also be considered.

The additional force due to the concrete pipeline, Fx (in N), applied to the falsework shall be calculated from the expression:

$F = 0.25\ p\ A_x$

where,

p is the maximum pressure in the pipeline (in N/mm^2).

A_x is the cross sectional area of the pipeline (in mm^2)

The maximum pressure in the pipeline, P, is dependent up on a number of factors but the following pressures are not likely to be exceeded.

5 N/mm^2, for mechanical pumps

0.7 N/mm^2, for pneumatic placers

6.3.3.2.8 Design values of total lateral load : Certain horizontal forces are identifiable and can be calculated but there may be others which may not either be foreseen or estimated. As such, an amount equal to 1 percent of the total design vertical load of falsework in any direction shall be added to the calculated lateral loads to arrive at the design load.

The design value of the total lateral load however shall not be less than 3.0 percent of the total design vertical load. The point of application of the loading may be assumed at the soffit of the formwork.

6.3.4 *Load combinations*

Various combinations of forces which are likely to be applied on the falsework should be taken into account. An indicative typical arrangement of forces is illustrated in Figure below:

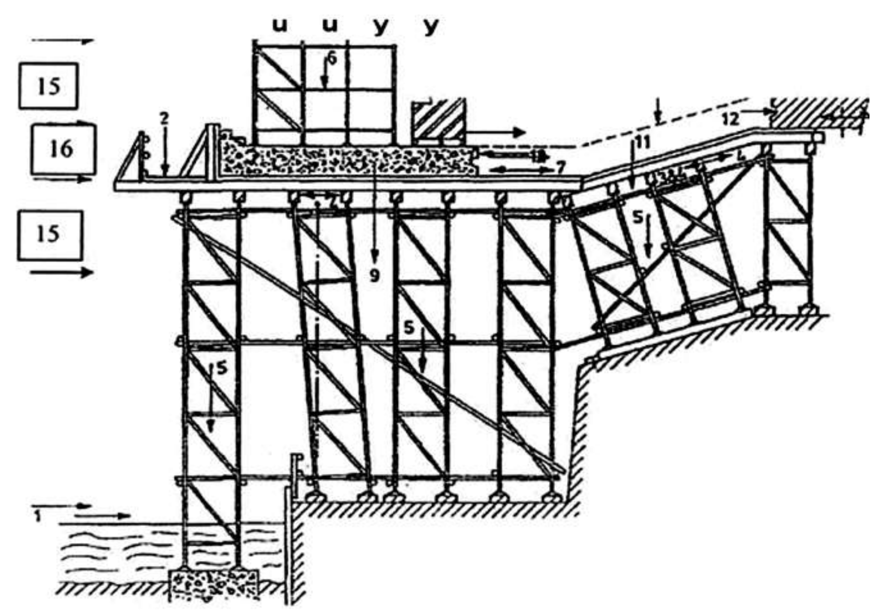

Fig. 1 Typical Forces on Falsework

Key

1) Water forces
2) Construction personnel
3) Out-of-vertical by design
4) Erection tolerances
5) Self weight of falsework
6) Self weight of later stage of falsework
7) Horizontal friction between concrete and soffit formwork
8) Impact due to motorized bogies/vehicles
9) Weight of already cast concrete
10) Mobile plant load
11) Weight of concrete to be cast
12) Reaction from active concrete pressure against completed work
13) Weight of stacked material
14) Thermal movement forces
15) Wind load on falsework
16) Wind load on formwork

6.3.5 *Permissible stresses*

Basic Permissible stresses shall be taken as below:

a) **Timber** - The permissible stresses in timber shall conform to IS 883 or IS 3629.
b) **Steel** - The permissible stresses shall be those as recommended in **Annexure G** as appropriate to the steel being used and the use to which it is put.
c) **Tubular sections** - Permissible stresses in tubular sections shall be those as recommended in IS 806.
d) **Masonry** - The permissible stresses shall be those as recommended in IRC:40.
e) **Concrete and Reinforcement** - Design shall be as per IRC:112
f) **Other materials** - Where material chosen is other than those mentioned above, the permissible stresses may be those as recommended by the manufacturer after tests based on relevant material codes. The permissible stresses chosen may also be related to the ultimate strength or to other physical characteristics, and it will be necessary to choose which criteria is critical in light of the form, extent and consequence of any possible failure.

6.3.5.1 Depending upon the condition of the material proposed to be used, suitable reduction factors in the above permissible stresses shall be applied.

6.3.6 *Over-turning*

Factor of safety against over-turning for load combinations other than wind or seismic shall be 1.33 min. For load combinations with wind or seismic or any other exceptional load, same shall be 1.1 min.

6.3.7 *Deflection limits*

In general, the deflection of members in formwork is limited by the tolerances specified for permanent works. In general, the calculated deflection of unsupported areas of form faces shall not exceed 3 mm.

The total deflection shall be such that the maximum dimensional tolerances specified for permanent works in specifications are not exceeded. Where the deflection of the falsework members is greater than permissible tolerances, suitable pre-camber arrangement shall be provided.

6.4 Analysis

6.4.1 *Load transfer systems:* The system which transfers the loads to the falsework shall be examined to ensure that all possible changes in the conditions of load transfer are provided for. Relative deflections between the permanent structure and the falsework including settlement of the foundations may cause high local concentrations of load.

Adjustable or non-adjustable distance pieces, including jacks and similar devices are often used to transfer loads. Capacity of such members shall be checked for a minimum of 3 percent of the vertical load acting horizontally at the load point.

6.4.2 *Special loading conditions:* The design or sequence of construction of the permanent structure may give rise to special or unusual loading conditions on the falsework. Where this is so, it shall be indicated clearly by the designer/user of such permanent works, so that it may be taken into account in the design of the falsework.

6.4.3 *Reversal of loading:* Reversal of moments and stresses may occur during erection and dismantling of the falsework and shall be accounted for in the design.

6.5 Lateral and Diagonal Bracings

6.5.1 Diagonal bracings in both the longitudinal and lateral directions shall connect the shores or props of the upper and lower bays of the scaffolding tubes at splice or joint as the case may be.

- i) The bottom horizontal bracing shall be within 600 mm of the bottom.
- ii) Top horizontal bracing shall be within 600 mm from top.
- iii) The intermediate horizontal bracings shall be designed to suit the design requirements.
- iv) The diagonal bracings shall be at slope between 30° and 60° to the horizontal.

6.5.2 The falsework system shall be designed to transfer all lateral loads to the ground or to completed construction of adequate strength and stiffness in such a manner as to ensure safety at all times. Diagonal bracing must be provided in vertical and horizontal planes for falsework tubes not designed as self standing to provide stiffness and to prevent buckling of individual members. A laterally braced system shall be anchored to ensure stability. Diagonal bracing must be capable of resisting the overturning moment.

6.6 Shores

6.6.1 All shores shall have a firm bearing. Inclined shores shall be braced securely against slipping or sliding. The bearing ends of shores shall be cut square and have a tight fit end splices. Splices shall be secure against bending and buckling. Connections of shore heads to other framing shall be adequate to prevent the shores from falling out when reverse bending causes upward deflection of the forms.

6.6.2 Timber shores, where used, shall meet the following requirements :

a) The number of splicing in any shore shall be kept to the minimum. The matching ends of shores to be spliced shall be cut square, for proper seating. Locations of splices should be staggered. The splicing members shall ensure concentric force transfer.
b) All splice fastening shall be adequate.
c) Metal splice pieces of adequate size may be used in place of timber.
d) Lap splice shall be prohibited.

6.7 Proprietary Items

When proprietary forms, shoring or components are used, the manufacturers recommendations for safe working loads shall be supported by data sheets and test reports for components by an approved testing organization. Necessary details required to be furnished by the manufacturer are given in **Appendix-1**.

6.8 Foundation of Falsework

6.8.1 Where the falsework rests directly on ground, or on permanent structure, it shall be ensured that load is transferred and distributed so as to ensure that total or differential settlements are within acceptable limits. The details of the actual site conditions and the safe bearing pressures for use in the design shall from part of design briefs. Safe bearing capacity of soil shall be arrived based on available data/sound engineering practices.

6.8.2 *Falsework supported on permanent structure* - Where it is intended to support the falsework on permanent construction, it is essential to determine limitations, if any, which the design of permanent works imposes on the incidence and distribution of load from the falsework. It is essential to determine the strength of the permanent works to receive loading based on the rate of gain of strength and maturity of concrete in the structure. Necessary checks shall be made to ensure the safety of the permanent structure.

6.8.3 *Falsework supported on the ground* - The loads from the falsework shall be applied to the ground through, distribution members which may be of timber, steel base plate or precast sleepers to ensure proper contact with the ground. Shores of the falsework system shall be centrally placed on the member. These distribution members shall be properly designed for all possible load combinations.

6.8.4 Foundation supports comprising piles or other deep ground insertions shall be designed and installed to specific designs and drawings. Where there is a likelihood of the foundation becoming flooded, foundations shall be designed to safely withstand the direct and indirect consequences of such flooding including scour, undermining or weakening of ground strata.

6.8.5 The slope of the ground can cause stability problems and it is recommended that the slope of the surface on which the falsework rests should not exceed 1 in 6 unless approved by a suitably qualified engineer specializing in geotechnics. The stability of the ground above and below the falsework site should also be considered.

6.8.6 Falsework foundations in general are set at a very shallow depth, compared with those of permanent structures, which brings them within the zone affected by seasonal moisture content changes, frost action, scour, etc. These effects should be duly considered in making investigations as well as in the design.

6.9 Special Requirements for Prestressed Concrete

6.9.1 The structural designer shall indicate special requirements, if any, for prestressed construction. Where required, it may be necessary to provide appropriate means of lowering or removing the formwork before full prestress is applied to prevent damage due to upward deflection of resilient formwork and possible redistribution of loads to falsework supports nearer the permanent supports.

6.9.2 The restraint to shrinkage of concrete shall be kept to a minimum and the hogging of members due to prestressing force and the elastic deformation of formwork or falsework shall be considered in the design and removal of the formwork.

6.10 Common Deficiencies in Design

Some avoidable common design deficiencies leading or contributing to failure, are

a) Lack of sufficient allowance in design for special loads as mentioned above.
b) Inadequate/improper shoring.
c) Improper positioning of shores at different levels where high/tall falsework is involved. This may create reversal of stresses.
d) Inadequate provisions (especially where beam hangers are used) to prevent rotation or twisting of beam forms, particularly when slabs frame into them on only one side or slabs of unequal spans frame into beams.
e) Inadequate provision against uplift.
f) Insufficient allowance for unsymmetrical or eccentric loading due to placement sequence.
g) Inadequate design of form ties or clamps.
h) Inadequate protection against scour and effect of Buoyancy where applicable.
i) Poor foundation conditions of sites not accounted for in design.
j) Lack of proper adjustment of shims and wedges during concreting.
k) Neglecting horizontal and inclined pressures of concrete on inclined formwork.
l) Neglecting concrete buoyancy.
m) Not accounting the continuity of the members.
n) Omitting dead weight of void forms and Buoyancy effect.
o) incorrectly assessing the effective length of support towers or struts, or neglecting the possibility of torsion failure.
p) Deformation/extensions of tension components such as ropes, strands, etc. to enable adequate load transfer.

q) Forgetting that the effective weight of anchorages may be reduced by buoyancy when they are set below water table & buoyancy effect. Buoyancy effects on counterweights placed below water table/flood level.

7 SPECIFICATIONS

7.1 The specifications for different materials used and the item of work shall be the same as given in MORT&H Specifications or relevant IS publication.

7.2 If the specification of a particular item are not available in the above documents then specification provided elsewhere, if applicable or suitable, may be followed.

7.3 If no specifications are available for a particular item then proper specifications shall be drafted and got approved by the competent authority before starting the work of that item.

7.4 For patented items the specifications as prescribed by the manufacturer shall be followed after verification of test reports and other details.

8 SITE OPERATIONS, PROCEDURAL CONTROLS, PRECAUTIONS AND INSPECTIONS

8.1 Procedural Controls – Site Operations

Multiplicity of actions normally is required when Temporary Works are being erected and put into service. Such activities may be widely separated in time and place and it is, therefore, essential that lines of communication and responsibility are explicit and clearly defined and known to all those involved in the activity. A methodical approach should be adopted and adequate records should be maintained. Care should be taken that latest versions of approved drawings are available at site with all concerned.

Before being put to use for every construction cycle, the erected temporary structure is to be inspected to ensure that it is as per the final drawings. If any change in specifications or detail are noticed at any stage, the same are to be got approved from the designer. After the permanent structure gains required strength, the temporary structure can be permitted to be dismantled as per the specified sequence.

When not in use, components of the temporary structure are to be stored properly after necessary repairs and maintenance.

8.2 Responsibilities

8.2.1 *Allocation of responsibilities*

For proper planning, implementation, monitoring, coordination and supervision of this activity on major bridge projects a separate person should be identified/appointed as Temporary Work Coordinator. Wherever necessary, he should be supplemented by appointment of Temporary Work Supervisors.

These designated individuals shall be competent and experienced appropriate to the complexity of the project and shall be responsible for establishing and implementing all procedures for the control of all functions related to temporary structures. It is essential that the persons to whom these responsibilities are allocated to, are given adequate and defined authority to take and enforce decisions.

8.2.2 *Key Issues*

a) Responsibility for each of the actions set down in this code should be specifically allocated.

b) The responsibilities should be clearly defined.

c) All instructions should be clear and complete.

d) Documented records of responsibilities allocated, instructions given and actions taken should be maintained.

8.2.3 *Responsibilities of Temporary Works Coordinator*

The basic activities which need to be coordinated and monitored are:

i) He should be the point of contact between the designer of temporary structures and site office for all design issues including:
   - The preparation of an adequate design brief including wherever appropriate, establishing of the scheme/concept.
   - The designs including calculations, sketches, drawings, specifications, risk assessment and where necessary, a designer's method statement for the temporary works scheme.
   - The independent checking of the design. This should include the definition of the degree of check to be carried out on any design.
   - The issue of a design/design-check certificate, where appropriate.

ii) Management of coordination and monitoring of interfaces between different organizations involved in the related activities and retain an overview of the whole scheme to ensure each step of the procedure is completed and does not adversely affect the scheme. Details of the interfaces should be included in the construction phase plan.

iii) Preparation of Method statements and Check lists for different activities.

iv) The procurement of materials for temporary structures in accordance with the designer's specifications.

v) The checking of erection, safe use, sequence of loading, dismantling in stages, if required, maintenance and storage in stages where necessary, to ensure compliance with the design and any hold points.

vi) Wherever necessary, the issue of a formal "permit to load" and a "permit to dismantle" the temporary works.

vii) Ensuring that any proposed changes in materials, method statements or sequence of construction are checked with the designer of temporary structures and appropriate action taken.

viii) Ensuring that the agreed changes are correctly carried out at site.

8.3 Site Operations

The site operations are broadly divided into the operations of erection of falsework & formwork/ other temporary work, concreting/applications of loads and dismantling of formwork & falsework/ other temporary work.

Work on site should be subject to the careful direction, supervision and checks to ensure that the temporary structures are erected safely in accordance with the agreed design with materials of agreed quality, and the structure is first loaded only when all checks have proved satisfactory and then dismantled in accordance with an agreed sequence and procedure.

The required standards of workmanship shall be explained to all involved and specifically to the less experienced workmen who should also be made to realize the importance of this activity to achieve the required Quality. To ensure appropriate safety standards, an assessment of the risks Job Safety Analysis (JSA) shall be carried out by the contractor in conjunction with health and safety representatives of and/or workers of all agencies involved in the work.

Before starting any activity a comprehensive method statement should invariably be prepared and got approved. The entire team should be briefed about this statement. Constant emphasis should be laid upon attention to details.

8.3.1 *Erection of falsework/formwork/other temporary work*

Following points require particular attention during erection and before loading:

i) Whether the assumed design loads and sequences are compatible with the actual conditions at site.

ii) The field practice follows the working drawings/instructions from the designer. Any changes found necessary shall be effected in consultation with all concerned.

iii) Whether the formwork has not deteriorated and is still in accordance with the design.

iv) The foundations for the formwork are adequate in respect of scour conditions, bearing capacity and settlement characteristics.

v) Suitable precautions as necessary to guard against excessive storage of materials on a recently formed deck before it starts acting as self-supporting structure.

vi) Partially erected formwork is not left in place without proper support.

vii) Whether the wedges are of sufficient height to allow raising the forms to the required position. Wedges shall be used only at one end of a prop.

viii) For night construction, adequate, lighting facilities shall be provided. If electric wires are used these should be duly protected and insulated.

ix) All Construction equipments like cranes, hoists etc. shall only be operated by trained and experienced staff.

x) No distribution members (i.e. footing) shall be founded over ground (either partially or fully) which has previously been excavated locally and backfilled without proper precautions.

xi) Edges subject to erosion such as the edges of slopes and terraces shall be protected against eroding forces.

xii) Any rock outcrops, buried rocks or obstructions which are uncovered and not indicated on the drawings shall be reported to the designer as they can result in differential settlements.

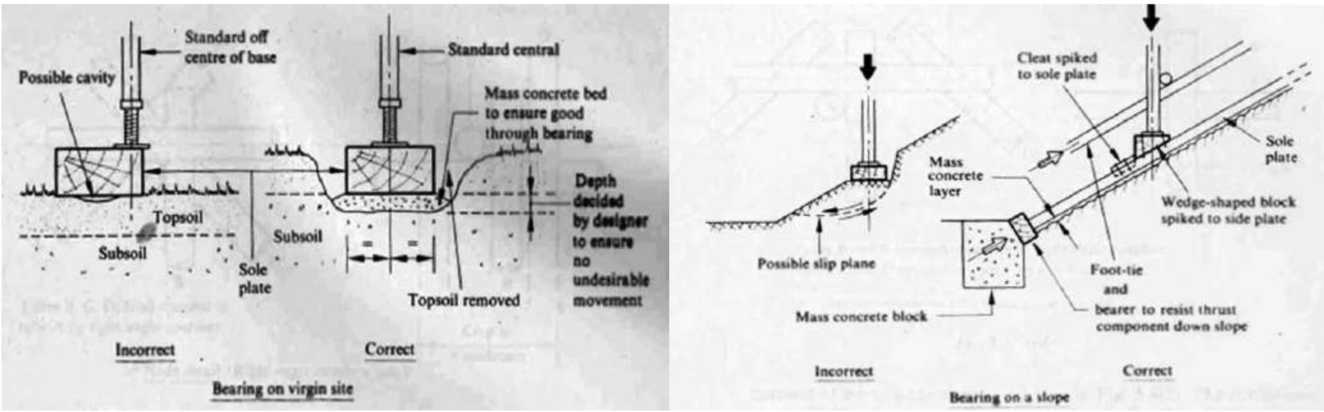

Fig. 2 Foundation for falsework: Dos & Donts

xiii) All foundation members shall be set level.

xiv) Splicing of timber shall be done with the help of MS bolts and nuts.

xv) In respect of proprietary components, the manufacturer's recommendations shall be rigidly adhered to.

xvi) All the minor details, even of the smallest connections have been examined to be properly fastened. The thorough checking of work has been done and all precaution to achieve desired workmanship have been taken. It is possible that the omission of a bolt or ineffective fixing of securing devices or the failure to tighten up an item properly, may lead to local instability which might place the whole structure in jeopardy.

xvii) All bearing points and lifting points are identified.

xviii) Inserts, void formers and cast-in fixings are properly positioned and secured. Props supporting formwork having out of plumb alignment and runners located eccentrically in prop heads seriously reduce their load carrying capacity even in proprietary systems.

Props shall be checked for verticality.

xix) Proprietary formwork support system shall specify safe working loads and factors of safety at specified tolerances. They shall indicate whether the information given is based on the yield or on the collapse value of the unit and whether the values given are based on calculations or actual tests. The recommended safe working loads shall not apply to any prop in defective condition or to any prop erected outside the specified tolerances. Factor of safety for the first use shall not be less than 2 (with capacity calculated based on yield stress) and may be increased suitably for subsequent use.

xx) Normal tolerances shall be such that no runner shall be placed with its centerline more than 25 mm eccentric to the center of the prop head or no prop shall be erected more than (1 in 40) out of plumb. In case any of the following defects, prop may be set aside, discarded or returned to workshops or deport for attention or scrap.

xxi) The following or similar types of defective parts shall not be used:
  a) Members with a bend, crease, dents or any noticeable lack of straightness.
  b) Members with more than superficial corrosion.
  c) A bent head or base plate.
  d) An incorrect or damaged connecting pin.

xxii) Where a shutter vibrator is used, a step down transformer shall be provided to lower the voltage for the safety of the workers.

8.3.2 *Placement of concrete/application of load*

Points to be seen before and during concreting operations and the application of loads are as follows :

i) Whether proper permission to commence the placement of concrete has been accorded?

ii) Whether the reinforcement and falsework have been checked?

iii) Whether the forms are clean and free from wood-shavings, grit etc.?

iv) Whether release agent to form surface has been applied? This should be avoided for concrete surfaces to be plastered. On such surfaces whitewash is desirable. If release agent is applied it should be checked that this is not applied or splashed carelessly on the reinforcement or pre stressing tendon and anchorages.

v) Where camber has been provided, the free (top) surface of the concrete should never be finished flat but should also be cambered to the same extent as the form i.e. the thickness for any element shall be maintained.

vi) Whether all forms are water/slurry tight?

vii) Whether the sequence and rate of concreting, that is of placement is as per the design brief?

viii) Whether all precautions have been taken to prevent accidental impact and possibility of scouring/flooding of falsework foundations in case of river bridges?

ix) Whether adequate precautions have been taken to keep unnecessary materials away from the falsework?

x) Whether adequate access ramps etc. in the correct positions have been provided for the smooth flow of men, materials and machines?

xi) Whether the forms are in the correct position in space and adequately braced to remain there and the forms are dimensionally accurate to produce finished concrete of the required dimensions?

xii) The props and bracing shall be watched during the placement of concrete and the vibrations. Any members which may tend to get loose or wedges which get shifted should be attended to.

xiii) System of communication between the man in charge of formwork and the man in charge of concreting operations should be established so that concreting can be stopped instantly if at all it becomes necessary to do so.

xiv) Platforms for the movement of workers and mechanized concrete buggies (used in large works) shall be separated. It should not place load upon the reinforcing steel. If this is unavoidable, steel chairs shall be placed under the reinforcement at adequate spacing to prevent deformation of the reinforcement.

xv) Arrangements for field adjustments and constant inspections of forms, shores and foundations during placing of concrete both by supervising as well as construction agency to be ensured (to stop leaks, tightening wedges and clamps, to adjust shores and for timely action against disturbances,etc).

xvi) Adequate stand by equipment should be available.

xvii) During concreting operation some skilled/trained worker or supervisor should watch and observe centering to notice if there is any warning or indication of likely failures. In the event of such signs of distress prompt action should be taken to bring to the notice of Temporary Works Coordinator or Supervisor to address and rectify the causes immediately to prevent collapse.

8.3.3 *Removal/dismantling of formwork/falsework/other temporary work*

i) The timing of formwork removal is a very important. For efficient use of formwork, it is important to have options that allow them to be removed as soon as possible without jeopardizing the structure's safety or damaging the edge of concrete surfaces. But not before the concrete has reached strength at least twice the strength to which the concrete may be subjected at the time of removal of formwork or as decided from design considerations. The strength referred to shall be that of concrete using the same cement and aggregates with the same proportions and cured under conditions of temperature and moisture similar to those existing on the work where possible. Proper precautions shall be taken to allow for the decrease in the rate of hardening of concrete occurring during cold weather.

ii) The dismantling plan prepared at the time of design or before the start of construction should be strictly followed.

iii) The procedure for Formwork removal for concrete wall, sides of beams and columns will also be controlled by the possibility of damaging the concrete while removing the forms and not simply by the concrete's capacity to withstands its own weight.

iv) All the factors, like temperature, age and admixtures used, that can affect concrete strength shall be considered for calculation of stripping time. For the formwork removal the stripping time can be determined by the use of any reasonable method. The number of props to be left under, their sizes and disposition shall be such as to be able to safely carry the full dead load of the slab, beam or arch, as the case may be, together with any live load likely to occur during curing or further construction.

v) Falsework shall be gradually and uniformly lowered in such a manner so as to avoid any shock or vibration or injurious stresses in any part of the structure.

vi) Immediately after removal of the formwork, the concrete shall be carefully inspected. Defects if any, shall be made good as soon as practicable.

vii) Where the side shutter also support the flange of the T-Beam, such shutter shall be removed only after the flange concrete attains sufficient maturity.

viii) For pre-stressed units, the vertical side forms shall be released as early as possible and the soffit forms shall permit without restraint deformation/ shortening of the member when pre-stress is applied. Form supports and soffit forms for cast-in-situ members shall not be removed until sufficient pre-stress has been applied to carry the dead load, any formwork supported by the member and anticipated construction loads.

8.4 Inspections/Checks

All the activities related to the Formworks, Falsework or Temporary structures shall be properly inspected by the Temporary Works Coordinator or supervisory staff authorized by him, at different stages of work to insure that the work is being done properly and safely with all due precautions as enumerated above after checking the compliances with the help of Checklists.

The Temporary Works Coordinator should establish a plan to carry out inspection & checks of the temporary works from the drawings & information given by the designer. Generally formal inspections are required at following stages :

a) Before the start of work to check or confirm the site conditions, hydraulic and geotechnical conditions and other data related to erection of formwork.
b) Preparation of founding level for falsework.
c) When Falsework attains a height of 10 m or height equal to 1.5 times the minimum of plan dimensions.
d) When Falsework reaches its highest level.
e) At Intermediate stages, when the strength or stability of the falsework may have adverse effects by environmental or other loading conditions.
f) Immediately prior to loads being transferred.
g) After the concreting is completed.
h) During dismantling and immediately after removal of formworks.
i) Before storing and before reuse.
j) Immediately after any failure is reported.

Check list shall be prepared for different stages and operations as described above, in a tabular form and adopted for verification of erected/assembled temporary structures in the field. Typical format for a sample checklist is given in **Appendix-2**.

8.5 Common Fault, Causes & Precautions

The following faults are generally noticed during construction. The possible reasons are indicated against each so that these points may be checked, investigated and corrective measures taken promptly-

Table 1 Common Faults during Erection of Falsework

Fault	Possible design Deficiency	Possible Construction Deficiency
Dimensional Inaccuracy	Excessive deflection	Metal locking devices not tight enough in column or beam clamps
Joints opening and deflection of forms	Supports too far apart or section of support members too small	Forms filled too rapidly

Fault	Possible design Deficiency	Possible Construction Deficiency
	Incorrect or insufficient ties	Vibration from adjacent loads
	Bearing area of plate washers or prop heads/base plates too small	Insufficient allowance for live loads and shock loads
	Insufficient column or beam clamps. Failure to provide adequately for lateral pressures on formwork	Void formers and top forms floating due to insufficient fixing/anchoring
	Insufficient allowance for incidental loadings due to placing sequences	Plywood not spanning in the directions of its greater strength
	On cantilever soffits, rotational movement and elastic deformation of system	Use of lower strength class members than designed
		Change of concrete pressure by use of retarders etc;
Lifting of single faced forms	Forms not adequately tied down to foundations to resist uplift forces generated by raking props	Ties not tight enough. Ties omitted. Forms filled too rapidly. Vertical forms not bolted to bottom shuttering
	During Placement of Concrete	Wedging and strutting not adequately fixed
General	Props inadequate. Failure to provide adequately for lateral pressures on formwork	Failure to regulate the rate of sequence of placing concrete
	Lack of allowance in design for Various factors/eccentricities	Failure to inspect formwork during and after placing concrete
	Inadequate provision of support To prevent failure rotation of beam forms	Insufficient nailing, Screwing/Boltings
		Inadequately tightened forms or wedges
		Premature removal of supports, especially under cantilever sections
		Use of defective materials

8.5.1 *Precaution to be taken*

Precautions to be taken at various stages are given below for normal type of projects. Additional precautions shall be taken for complex projects as per requirements.

Table 2 Precautions during Erection & Dismantling of Formwork

S.No	Stage	Precautions
1)	Design of Permanent Structure	• Design assumption shall be realistic and commensurate with field conditions • Design assumptions, design constraints, sequences to be followed etc, shall be clearly spelt out in the notes on drawings • Effect of loads of the temporary structures as well as effect of sequence/stages of construction on the design of permanent structure shall be taken into account
2)	Design of Temporary Structure	• Design for all the components shall be done as per design brief • Mixture of different systems shall be avoided • Mixture of old and new parts shall be avoided • Constraints, assumptions etc. from the design of permanent structure shall be taken into account • Necessary field investigation to assess foundation conditions, ground profile etc. shall be carried out and data used in design • Likely eccentricities in loading provided for
3)	Fabrication	• Designs shall be prepared using commercially available sections • Detailing of the structural members must take into account fabrication sequence and practices • Thick rolled sections, generally more than 20 mm, may be avoided if possible to eliminate failures due to possibilities of lamination in the sections • Wherever falsework have been made into various pieces then these should be properly match numbered on both sides so as to facilitate their erection at the time of use • Date of the fabrication/manufacture be marked on each components
4)	Erection	• The scheme of erection of temporary structures must be made to suit the site conditions and availability of equipment
5)	Dismantling and Shifting	• Dismantling scheme shall be specified • Scheme of dismantling shall be taken care of in the design detailing • Dismantling sequence shall be specified whereever critical

6)	Storage for Reuse	• Various systems and their parts shall be suitably marked/ numbered and stored in a proper manner for easy identification at later stage. • Appropriate register shall be maintained for purpose of reference • Steel structures shall be stored above ground level • Protective coatings shall be applied to steel members to prevent corrosion All the parts and systems which have been stored shall be properly maintained. These shall be thoroughly inspected and checked before these are re-used

9 CAUSES OF FORMWORK FAILURES AND POST FAILURE INVESTIGATIONS

Some of the causes for failures have been observed as follows:

9.1 Inadequate Bracing Leading to Instability

a) The more frequent causes of formwork failure are the effects that induce lateral force components or displacement of supporting members.

Inadequate cross bracing/diagonal bracing and horizontal bracing of shores is one of the factors most frequently involved in formwork accidents.

b) High shoring with heavy load at the top is vulnerable to eccentric or lateral loading. Diagonal bracing improves the stability of such a structure.

c) When a failure occurs at one part, inadequate bracing may permit the collapse to extend to a large portion of the structure and multiply the damage.Adequate bracing will prevent a minor accident or failure from becoming a disaster.

9.2 Vibrations

Forms sometimes collapse when their supporting shores, wedges or jacks are displaced by vibration caused by:

- Passing traffic
- Movement of workers and equipment on the formwork
- The effect of vibrating concrete to consolidate it
- Diagonal bracing can help prevent failure due to vibration

9.3 Vertical Members Not in Plumb

Vertical members must be set plumb to avoid eccentric loading which may lead to failure.

9.4 Unstable Soil Under Mudsills, Undermining or Scouring Under Supports

Formwork should be safe if it is adequately braced and constructed so that all loads are carried to solid ground through vertical members. The ground must be able to carry the load without permissible settlements.

Shores and mudsills must not rest on uncompacted ground; moisture and heat from the concreting operations, or changing air temperatures, may thaw the soil and allow settlement that overloads or shifts the formwork.

Site drainage must be adequate to prevent a washout of soil supporting the mudsills.

9.5 Inadequate Control of Concrete Placement

The temperature and rate of increase in height of concrete are factors influencing the development of lateral pressures that act on the forms.

If temperature drops during construction operations, rate of concreting often has to be slowed down to prevent a build up of lateral pressure overloading the forms. If this is not done, formwork failure may result.

Failure to regulate properly the rate and order of placing concrete on horizontal surfaces may produce unbalanced loadings and consequent failures of formwork.

9.6 Lack of Attention to Formwork Details

9.7 Improper Stripping and Shore Removal

Premature stripping of forms, premature removal of shores, and careless practices in re-shoring can cause failures.

9.8 There are some other Causes which can Cause Failure :

i) External causes like earthquake tremor, untimely floods and hailstorm etc.
ii) Defective centering structures and joints
iii) Unsuitable foundation support like earthen embankment
iv) Subsoil flow in sandy bed
v) Wrong sequence of construction or unbalanced horizontal forces as in arches

9.9 Post-Failure Investigations

The purpose of the false work failure investigation is to determine the reasons for failure and to collect data and carryout analysis to provide suggestions on preventing its recurrence. The following steps may be followed :

i) The failure site should be inspected immediately by the Temporary Works Coordinator or his authorized representative to ascertain by visual methods the probable cause of failure, such as, hydraulic, geotechnical, improper materials, design deficiency, erection or construction faults or supervision negligence etc.
ii) The area should be cordoned off and all safety precautions be taken immediately, so that, no further damage is done.
iii) An investigating team should be constituted to look into the matter which should preferably consist of a representative from design, supervision staff for the work and from the overall project management staff.

iv) The team should collect all the relevant data, consult records and drawings etc., take photographs, collect samples, test and investigate as may be necessary for the purpose and prepare the report giving detailed findings, lessons learnt, further precautions to be taken and preventive or remedial measures to be adopted.

10 SPECIAL FORMWORKS

10.1 Slipforms

10.1.1 *General*

Slipforms can be used for vertical structures, such as tall piers and wells etc. These forms are usually moved by jacks riding on steel rods or pipes embedded in or attached to the hardened concrete. The movement of forms may be continuous process until the structure is completed or in a phased sequence of finite placements.

Slipforms shall be designed, constructed and the sliding operations carried out under the supervision of persons experienced in slipform work.

Jacking rods or pipes may be left in place or withdrawn as conditions permit.

The design of the yokes must provide for adequate clearance to install horizontal reinforcing bars and embedments.

Forms shall be of about one meter height and may be of timber, plywood or steel. Special care must be taken in building the forms and arranging the jacks so that the forms will draw straight without twist.

Forms shall be constructed with a slight batter so that they will be self-clearing as they slide. A range of 6 mm to 8 mm in a height of 1 m of form is indicative of current practice.

10.1.2 *Sliding operations*

The sliding speed is determined by the rate of setting and hardening of the freshly placed concrete, the rate at which the concrete can be supplied, placed and compacted, and the rate at which reinforcement steel can be supplied and fixed. When using ordinary Portland cement, the average sliding speed is in the range of 150 mm - 300 mm per hour.

Alignment and plumbness of the structure shall be checked at the beginning and at least once in eight hours of operation.

10.2 Travelling Forms

10.2.1 Travelling forms consist of formwork mounted on moveable frames or scaffolding called travellers. After the purpose of the formwork is served at one section of the structure, the forms are released and moved along the structure to the next section to be concreted.

10.2.2 Travelling forms are suitable for many types of bridges particularly where a number of repetitions are involved. These forms can be used both for members of constant cross-section and variable cross-section.

10.2.3 Each set of forms and travellers shall be designed for the particular job. Forms are attached to the traveller mounted on wheels, skids, etc. Jacks are generally used for deshuttering and for adjustment to profile at the next section.

10.2.4 Travelling cantilever formwork for cantilever bridges is a particular example of use of travelling forms for bridge deck construction. Such formworks, because of their importance and large loads involved, are designed with the same care as that for a permanent structure.

10.2.5 Cantilever formwork eliminates falsework all together. The deck is constructed as a series of segments progressively cantilevering out of the pier. The forms are suspended from a structural frame anchored to the already concreted segment of the deck and cantilevering out to sustain the forms for the next segment.

10.2.6 The cantilever forms shall be so arranged as to facilitate continuous concreting of the entire segment in one operation. Necessary provision shall be made to enable adjustments in profile to cater to the camber requirements of the bridge deck.

10.3 Caissons

10.3.1 *General*

The terminology "Caisson" used here is purely for the temporary enabling structure required for constructing the permanent foundation.

Caisson is a hollow structure generally fabricated of structural steel but can also be constructed in concrete or a combination of both. It has dimensions of the permanent foundation like well and it remains in position. The dimensions may be suitably increased for open foundation. Though, it often forms part of permanent structure but is not accounted for in strength evaluation of the structure. It is a hollow watertight retaining structure used for under water construction work. It also facilitates construction of foundations in or near a body of water. Use of caisson facilitates construction at sites with either site constraints or poor soil conditions.

It is generally circular but may be rectangular, elliptical or any other shape. Large caissons are generally cellular. Sketch of typical circular cellular caisson is shown in **Fig. 1**.

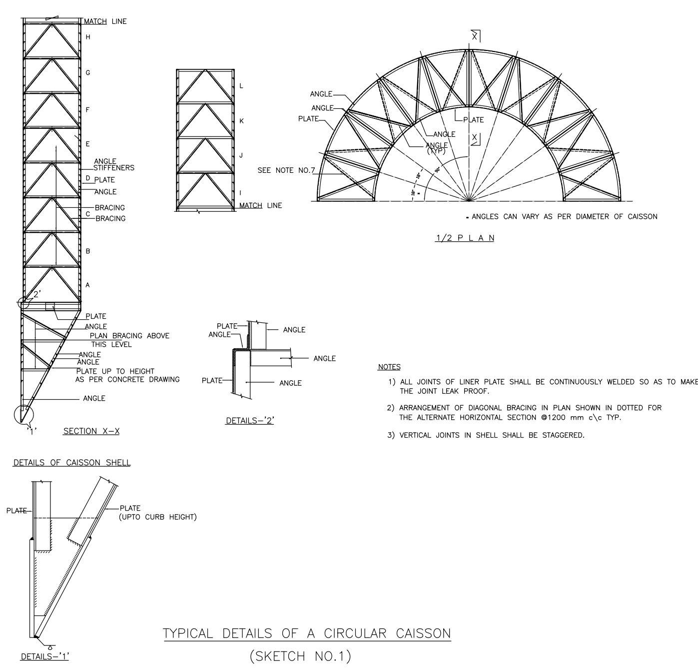

Fig. 3 Typical details of a Circular Caisson

The purpose of using a caisson in construction is to provide a temporary structure from which earth, water and other materials can be removed and into which concrete or some other fill material can be placed as per the design requirements.

It is fabricated on the shore or bank or on floating barge, and then lowered in water either by sliding (see typical details in **Fig. 2**) or by lifting (**Fig. 3**). It is then towed to the location of foundation and sunk with ballast added at its final location. Ballast can be part of permanent concrete in part or full depending on requirements of final stability. For temporary ballasting, water can also be used.

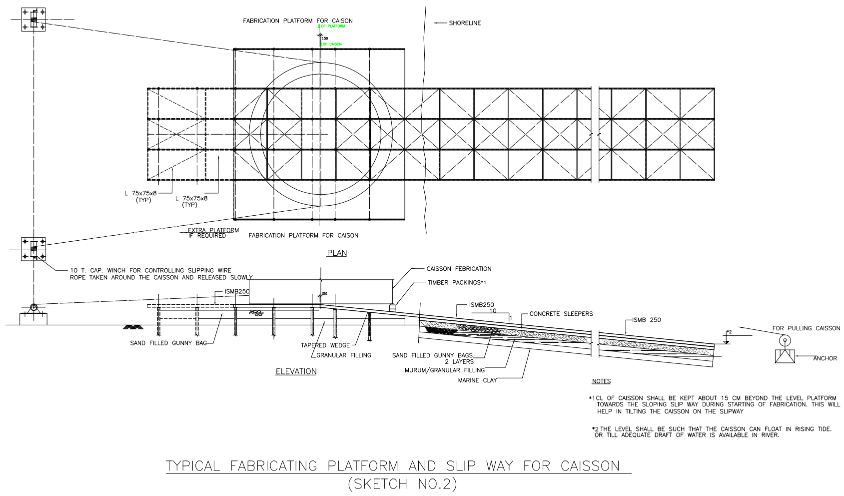

Fig. 4 Typical fabrication platform & slipway for caisson

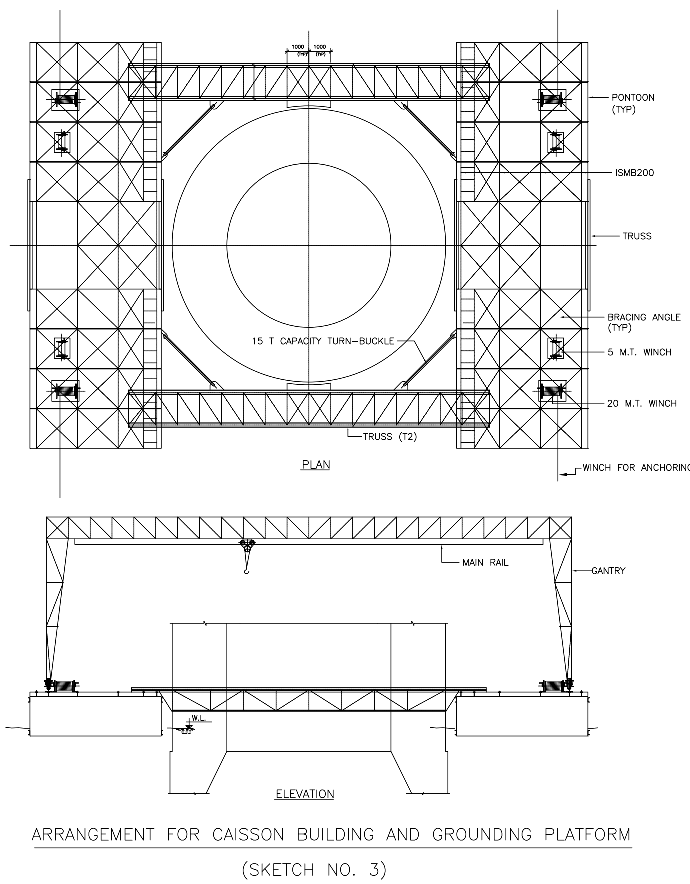

Fig. 5 Arrangement for Caisson Lowering

10.3.2 *Types of Caisson:*

There are three types of caissons such as: a) Open Caisson b) Pneumatic or Compressed-air Caisson c) Box Caisson. For bridges only type `a' and type `b' are used. Description of the said types of Caisson is given below:

a) **Open Caisson:**

It is open both at top and bottom, of size and shape to suit the foundation and fitted with a cutting edge around the bottom which facilitates sinking through soil while excavation is carried out inside the caisson by excavators or grab buckets or water jet pumps. As excavation proceeds, the caisson sinks and additional sections are added to the shaft above. This process is continued until the caisson has sunk to the required depth. Then bottom is plugged by generally pouring concrete below the water by using `tremie'/skip buckets. After plugging the bottom, further construction work inside can be carried out in conventional manner as per requirement.

b) **Pneumatic or Compressed-air Caisson:**

It is similar to an open caisson except that it is provided with airtight bulkhead so that the inner cavity formed can be made dry by filling it with compressed air. Pneumatic caisson is usually employed in riverbed work to aid sinking in rocky stratum or removing obstructions or where quicksand condition is present. The steining joints shall be airtight and steel liners on inner face may be provided to make Caisson airtight.

The air in the space beneath the bulkhead called the working chamber is kept under pressure to the extent necessary to control the inflow of soil and water and keep the bed dry. The shafts/openings through the bulkhead permit the passage of men, equipment and excavated material between the bottom and the surface. Thus, the excavation can be performed by workmen operating in the working chamber at the bottom of the caisson under water-free condition.

c) **Box Caisson:** It is similar to Open Caisson except that it is closed at bottom.

10.3.3 *Potential Difficulties:*

Potential difficulties include:

a) Keeping the structure vertical as it sinks into place. In case of deviations from verticality, corrective measures are taken such as removing the soil from underneath on one side or applying extra loading from top eccentrically.

b) The ability to advance the structure to its desired elevation and stop it once the correct elevation is achieved

c) Ability to provide a watertight structure

d) In case of Pneumatic Caisson, `decompression sickness' (also called bends or caisson disease) which is a physiological effect of the formation of gas bubbles in the body because of rapid transition from a high-pressure environment to one of lower pressure. Generally the workers work in shifts of one hour. Services of a doctor shall be always available at site when pneumatic sinking is done.

Relief from `decompression sickness' can usually be achieved only by recompression in a hyperbaric chamber followed by gradual decompression. But this process is not always able to reverse damage to tissues.

Caisson workers are highly susceptible to the sickness because their activities subject them to pressures different from the normal atmospheric pressure experienced on land. At atmospheric pressure, the body tissues contain, in solution, small amounts of gases that are present in the air. In case of pneumatic caisson the workers in working chamber are subject to breathing compressed air with the possibility of problems similar to sudden decompression. (see Note *1)

10.3.4 *Design Considerations:*

a) While designing the caissons a detailed study for the various stages of construction shall be carried out (see details of stages in **Fig. 4 & Table 1**).

The height of caisson and concrete inside the caisson at any given time shall be such that the metacenter (M) is above the centre of gravity (G) by about 1 meter.

b) The first stage construction for open caisson is very critical as the triangular shaped curb reduces the stability as CG is at a higher level and hence this stage shall be planned for required height with appropriate stability measures till the time the centre of gravity is lowered by concreting of the structure. additional safety measures for maintaining stability against overturning shall be provided during initial stages.

c) Height of caisson shall also be planned to ensure that at any given time, at least one meter of the shell shall be above water level/high tide level while floating as well as after initial grounding.

d) In sandy/soft stratum especially with strong water current, the bed is likely to scour locally when the caisson nears the bed and even after grounding has taken place. Proper investigation shall be made before design to assess appropriate additional height of caissons necessary for this condition.

Simultaneous sinking and concreting may be required to keep the centre of gravity close to the bed to prevent caisson from tilting.

e) The caisson shell shall be designed for water pressure from differential head, water current forces, wet concrete pressure etc. to which it is likely to be subjected to (see **Fig. 5**). The minimum thickness of plate used shall be 4 mm for external face and 3 mm for internal face. The plates shall be stiffened using suitable structural elements. Bracings both in transverse and vertical directions shall be provided between outer and inner shells. Diagonal bracings shall be provided as necessary. Adequate rigidity of the framing structure shall be ensured by providing bracings with due consideration to slenderness ratio. Generally slenderness ratio shall not be more than 100. For framing, a minimum element of 50 x 50 x 6 mm angle or equivalent is recommended. In case of severe corrosion, the adequacy of structure shall be rechecked.

f) Anchorage points and any other locations where concentrated loads are expected, shall be locally strengthened suitably by providing a thicker plate or increased bearing area or like measures.

g) All joints shall be continuously welded and shall be leak proof. The joints of shell shall preferably be located at the face of stiffeners so that proper welding is achieved. In critical locations where no stiffener support is available, providing and welding of 75 mm wide, 3 mm thick cover plate along the length of joint is recommended.

h) The anchorage of caisson shall be designed for the maximum water current and wave effects expected with minimum factor of safety of 3. Minimum water current of 1m/sec shall be considered. In rivers where water flow is unidirectional, designed anchorage shall be provided on upstream side and lower capacity anchors to keep the caisson just in position can be provided on downstream side. In tidal rivers/creeks, anchors in both directions shall be of designed capacity.

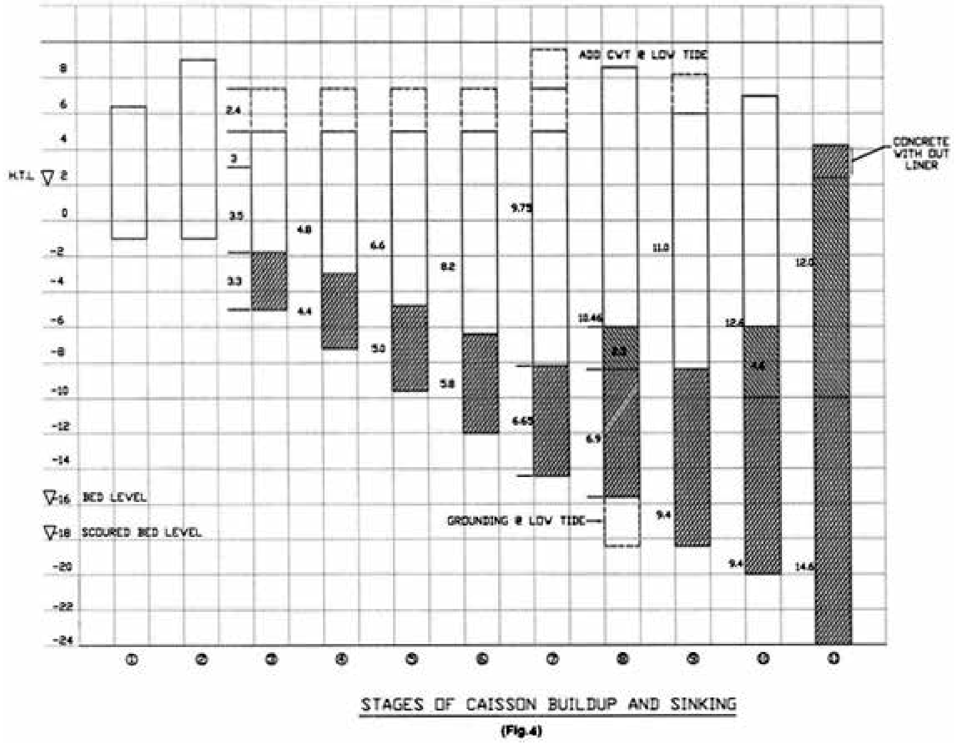

Fig. 6 Stages of Caisson Build-up & Sinking

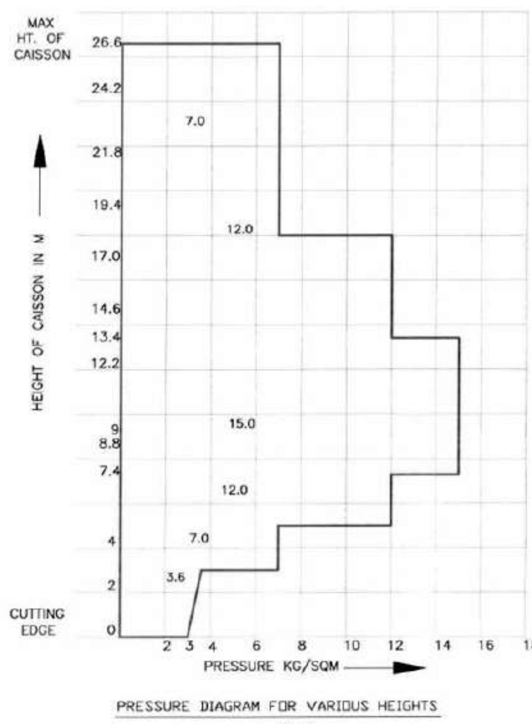

Fig. 7 Pressure diagram for various stages of Caisson

Table 3 Typical format for calculation of Water Head on Caisson at various stages

TYPICAL FORMAT FOR CALCULATION OF WATER HEAD

Sr. no	Ht	Self Wt.	Vol	Draft with 3.0 m Free Board	Vol Displaced	Wt. of Concrete	Vol of Concrete	Ht of Concrete	Head of Water	Remarks
	m	MT	Cum		Cum	MT	Cum	m	m	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
					Vol @ ht (5)	(6) - (3)	(7) / 2.5		(5) - (9)	
1	0		0							
2	1.0		11							
3	2.0		41							
4	3.0		88							Well Kerb
5	4.0		151							
6	5.0	62.0	240							
7	6.2	80.2	335							Steining lift of 1.2m
8	7.4	92.4	429	3.1	80.00	-	-		3.1	4.3m free board
9	8.6	104.6	523							
10	9.8	116.8	617	6.8	381.40	264.6	105.8	3.3	3.5	
11	11.0	129.0	712							
12	12.2	141.2	806	9.2	570.00	428.8	171.5	4.4	4.8	
13	13.4	153.4	900							
14	14.6	165.5	994	11.6	758.40	592.9	237.2	5.0	6.6	
15	15.8	177.6	1,089	12.8						
16	17.0	189.7	1,183	14.0	947.00	757.3	302.9	5.8	8.2	
17	18.2	201.8	1,277	15.2						
18	19.4	213.9	1,371	16.4	1135.40	921.5	368.6	6.7	9.8	
19	20.6	226.0	1,466	17.6						
20	21.8	238.1	1,560	18.8	1324.00	1085.90	434.4	7.5	11.3	
21	23.0	250.2	1,654	20.0						
22	24.2	262.3	1,748	21.2	1512.40	1250.10	500.0	8.3	12.9	
23	25.4	274.4	1,843	22.4						
24	26.6	286.5	1,937	23.6	1701.00	1414.50	565.8	9.2	14.5	

10.3.5 *Precautions:*

a) The fabricated caisson structure shall be checked against leakage at joint locations before floating.

b) Stability of caissons shall be ensured for all operational conditions such as during sliding into water, in floating condition, transportation and lowering in position. The centre of gravity shall always be close to the bed after grounding.

c) The structure shall be held in position against untoward movement by wire ropes/chains etc, using winches mounted on stationary suitable platforms/buoys or similar anchoring systems. Anchoring in minimum three directions shall be provided to prevent non-acceptable longitudinal and lateral movement.

d) The system shall permit a small movement until the stage when the foundation is just getting grounded. Special care is necessary where variation in water level is frequent such as in tidal zones to prevent re-floatation of the grounded caisson during subsequent high tide.

e) A dewatering pump of adequate capacity shall be provided at caisson location for dewatering due to any leakage.

f) The anchorage ropes shall have adequate slackness to allow vertical movement of shell in tidal zones till grounding operations.

g) Delay in grounding when very close to bed can lead to heavy local scour. This will require additional heights of caisson shell to be added.

NOTE *1:

It is generally said that the air compression limit permissible for man's safe operation is at around 0.392 MPa or 4kgf/cm^2. Physical disorders like nitrogen narcosis, oxygen toxics, respiratory distress etc. appear as air compression increases. The bends or caisson disease tends to occur at the stage when human body undergoes change from decompression to atmospheric pressure. In an effort to prevent occurrence of such a physical disorder, a helium gas mixed air respiratory system has been developed. This system provides the worker with safe working environment even in higher compressed air when Caisson is sunk to deeper position. In this system, excessive amount of nitrogen and oxygen causing physical disorder are replaced as much with helium gas. This theory was adopted in the Pneumatic Caisson for the first time in Japan.

10.4 Construction Barges

10.4.1 *General*

This clause is limited to dumb barges used in construction of bridges. Barge is a flat bottom single deck floating vessel rectangular in plan with generally vertical sides and its bow and stern may or may not be raked. Its flat bottom shape permits its use in low water depth conditions. Construction barges are generally dumb barges and towed by tugboats for their movement. Barges may also be formed by assembling modular barge units which can be transported by road from one site to another.

10.4.2 *Barge Types and Applications*

a) Deck Barge

Deck barges carry cargo on their deck. They differ in size and structural design depending on their intending use. They are generally used for construction activities in rivers, lakes, inland water bodies, shallow sea-bed etc. and used for transporting men, materials and equipment to work sites in water. Cargos can be pipes, piles, fabricated structures, construction materials, construction equipment, cranes, transit mixers, batching plants, welding machines, DG sets, compressors etc.

b) Spud Barge

Spud barge is a deck barge which can be moored by providing through-deck pilings known as spuds to anchor it in place to provide a stable and fixed work platform in water. Spud barges are used for specific applications like pile driving, drilling for geotechnical investigations, mounting cranes to enhance their lifting capacity etc.

c) Other Types of Barges

Other types of barges are crane barges which carry floating cranes, clamshells or draglines, hopper barges with openable bottom for transporting and dumping dredged material, pontoon barges for supporting temporary floating bridges, etc. Catamaran barges having two or more connected hulls to increase its base width are generally used to support heavy lift floating cranes.

10.4.3 *Barges Supporting Cranes/Lifting Devices*

Barges used for mounting crane/derrick etc. should have structurally sound deck members designed to withstand the static and dynamic loads of the crane operating at its maximum rated capacity with all other co-existent loads. It should be ensured that the rated capacity of the crane including load charts etc. applicable for use on land is reduced to account for actions when using the same under floating conditions and that the entire deck surface of barge remains above water and entire bottom area of the barge remains submerged. For cranes secured to barge deck and having rated capacity up to 50 tons, angle of list (longitudinal tilt) and trim (transverse tilt) should generally be not more than 5 degrees or as specified by the crane manufacturer or by a qualified Naval Architect. When using load charts designed or corrected for barge mounted cranes, assumed dynamic and environmental parameters considered in their design shall be specified for use by crane operator. The rated capacity of such cranes shall be decided by a qualified person having expertise with respect to crane/derrick capacity operating on land and the stability of floating vessels. Permitted area for positioning, travel, and operation of the crane should be marked on barge deck for identification by the user and crane should be secured by suitable means to prevent its movement during operation.

10.4.4 *Barge Registration*

Construction barges used in channels where inland transporartion takes place and those used in open sea are required to be certified by Indian Register of Shipping (IRS).

10.4.5 *Safety Requirements*

Barges, whether newly constructed or used shall be inspected for any leakage or structural soundness before they are put to use. Barges shall be fitted with lights, sound signaling appliances, signage etc. in accordance with the regulations for preventing collisions in navigation waterways. They shall be equipped with life-saving appliances such as fire extinguishers, ring life-buoys, life-jackets for the crew, rescue boats, walkie-talkie etc. To prevent fall from the barge deck, railing shall be installed along the edge of the barge if it does not affect its functioning. Alternately, edge of the barge along perimeter should be painted with contrasting color. All walkways, gangways and access ladders should be kept clean, dry, free of equipment and obstructing materials. Any oil spills must be cleaned immediately. Access ramps should be secured during loading and offloading operations.

For barges having winches operating at deck level, winch drum may be enclosed in a cage if possible. Workmen should be instructed not to stand over, on or in line with winch cables when they are under tension. The danger zone lies within 15 degrees of either side of a cable under tension. Winch system should be inspected regularly for general deterioration and structural, mechanical, or electrical deficiencies.

Barges shall have a main towing arrangement and a spare towing arrangement of sufficient strength ready for use at all times. The spare towing arrangement shall be such that it is possible to establish a new towing connection quickly.

10.5 Precasting Arrangements for Precast Segmental Construction

10.5.1 *Casting Yards:*

The main requirements for a casting yard set up for precast segmental construction include:

i) Storage and handling arrangements for materials like cement, aggregates, sand, reinforcement, inserts for post-tensioning systems, etc.

ii) Batching plant for concrete production.

iii) Reinforcement cage assembly areas, jigs and templates.

iv) Shortline/longline casting beds for various types of segments.

v) Inspection/repair bay for precast segments.

vi) Control stations for survey towers for geometry control.

vii) Curing arrangements (steam /sprinklers, etc.).

viii) Segment lifting and handling equipment like goliath gantries/straddle carriers, etc.

ix) Stacking arrangements for precast segments including loading arrangements on to trailers for transporting to actual site.

x) Quality control laboratory, offices, etc.

The size and layout of casting yard largely depends on access/egress points, number and types of casting beds, number of segments required to be stacked as per construction plan, etc.

10.5.2 *Types of casting beds*

Casting beds for segments are basically of two types: Shortline & longline.

10.5.2.1 Longline casting bed

In this method all the segments in a span are cast on a fixed bed in their correct relative position as per design geometrical alignment with formwork moving along the bed for successive casting operations. The profile of the bed replicates the final bridge deck profile with allowance for camber. (Figs. 8 & 10).

Fig. 9 shows formwork positions for successive operations. Pier segments can be cast in a separate bed and brought to the bed for remaining span.

The main advantage of this method is that the entire span is set out in the bed and it is easy to control the deck geometry. Disadvantage is that it takes large space. For a curved deck with super-elevation, the soffit formwork must have necessary arrangements to adjust the geometry. (Fig. 10).

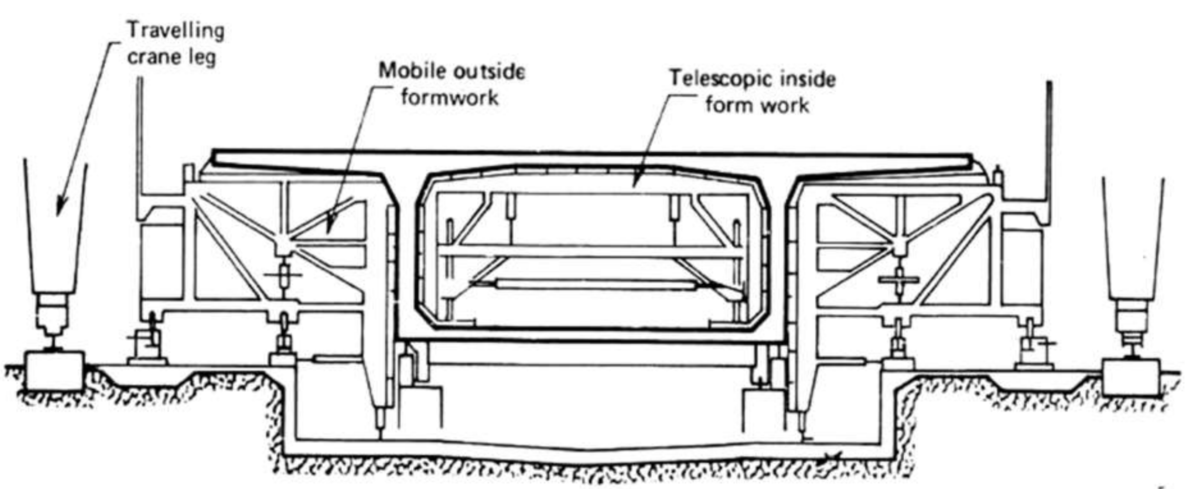

Fig. 8 Schematic Cross-Section of a Longline Bed (Straight Span)

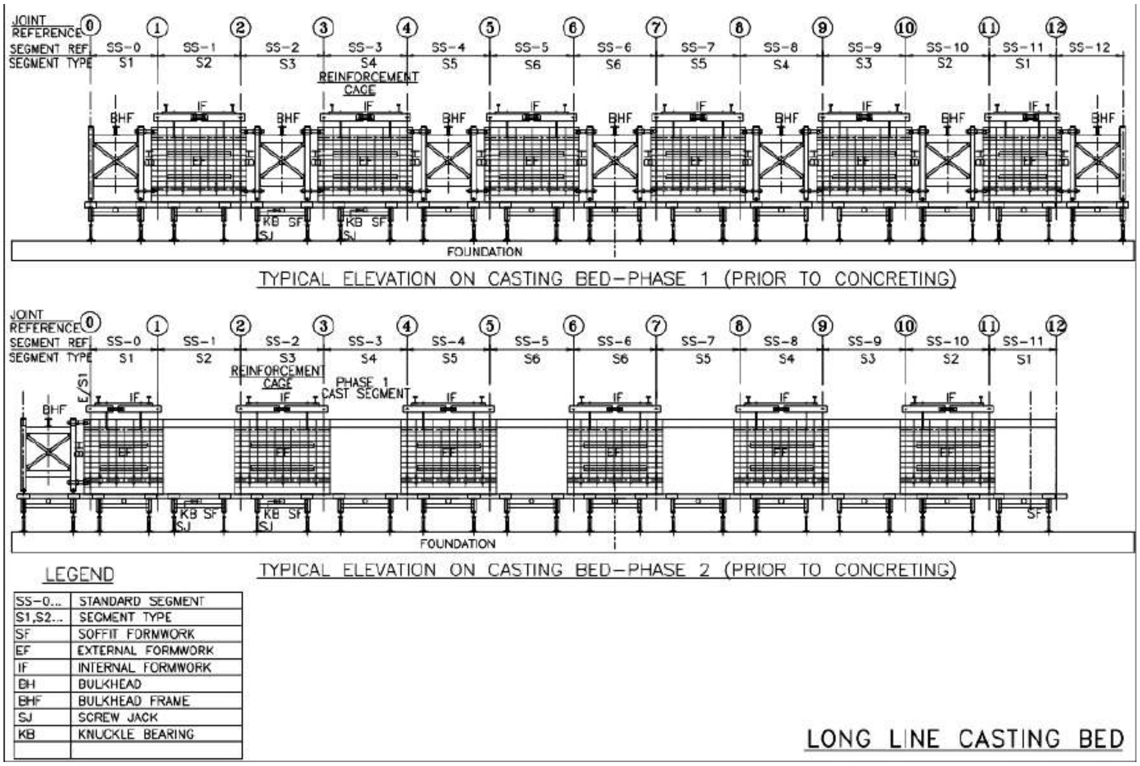

Fig. 9 Schematic Longitudinal Section of a Longline Bed

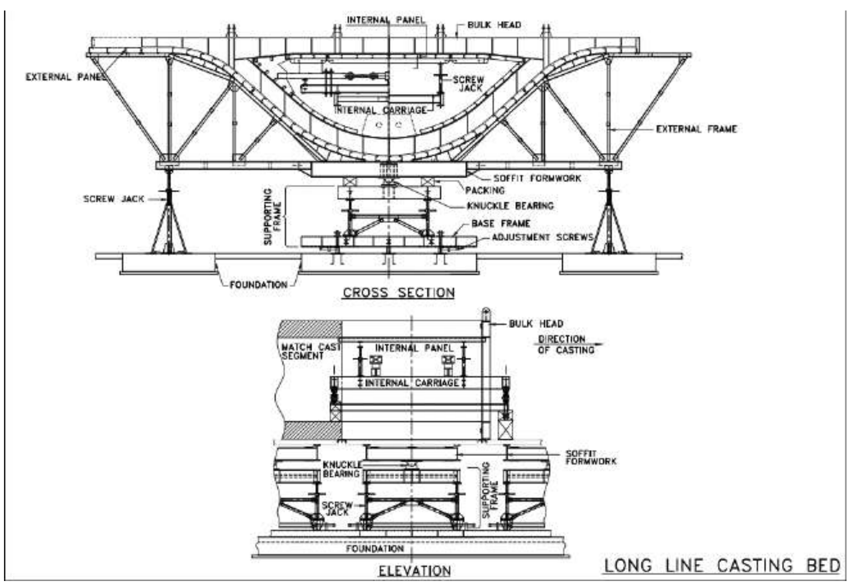

Fig. 10 Schematic Cross-Section of a Longline Bed (Curved Span with Superelevation)

10.5.2.2 Shortline casting bed

In this method, all segments in a span are cast in the same place using stationary formwork. The previously cast segment is positioned so as to obtain a match-cast joint. After initial curing, the previously cast segment is moved to stacking area and the freshly cast segment is moved in its place for casting the next segment.

The main advantage of this method is that it requires relatively small space. The formwork and mobility of equipment associated with casting is limited to a smaller area. The main disadvantage is that achieving the correct deck geometry depends on accurate adjustment of the match-casting segment. This requires precise survey and control procedure. A geometry control software is used for computing the position of match-casting segment required based on the survey data for previous segments.

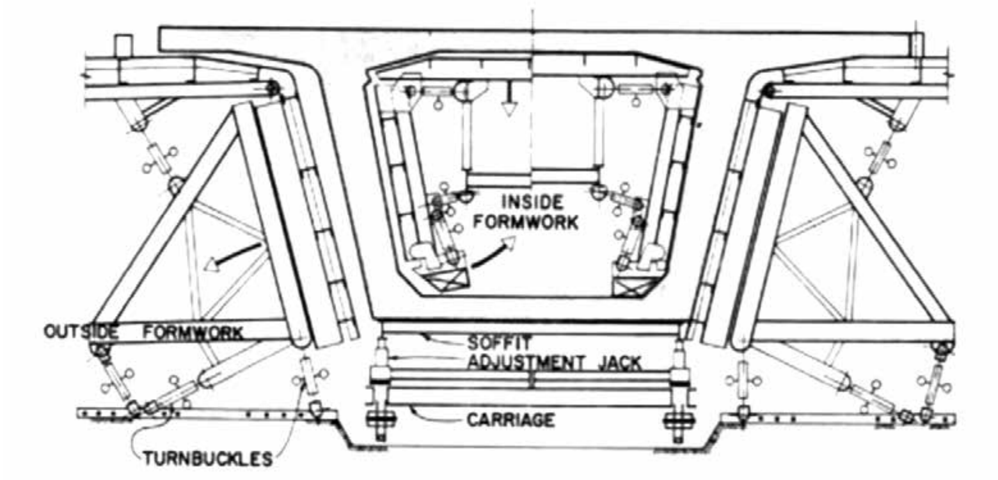

Fig. 11 Schematic Cross-Section of a Shortline Bed

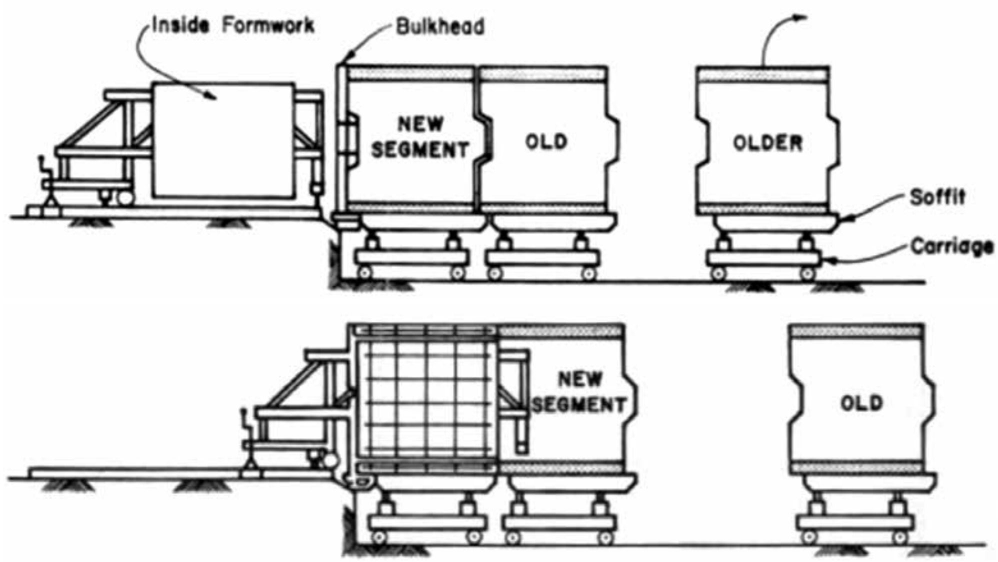

Fig. 12 Schematic Longitudinal Section of a Shortline Bed

10.5.2.3 Requirements for formwork & casting bed

i) Foundation for the casting bed should be designed to carry all the expected loads safely without undesirable settlement. Soil stabilization may be necessary in case of weak soils.

ii) Formwork for the casting bed should be rigid enough to achieve the close dimensional tolerances necessary for precast segmental construction as specified in IRC:SP 65 “Guidelines for Design & Construction of segmental bridges”. There should be no undesirable deformations of the formwork during various operations. The dimensional tolerances directly affect the alignment and shape of deck and any deviations can lead to serious problems during erection at site.

iii) As the forms are expected to reuse multiple times, the should be sturdy, easy to strip and handle.

iv) Formwork joints, particularly junctions of sheathing, should be properly sealed using a flexible sealing material to prevent cement slurry leakage.

v) Forms should be designed so as accommodate slight differences in dimensions due to camber, curvature and rotation for super-elevation, etc.

vi) It should be possible to fix inserts like anchorages, sheathing, block-outs so that their position is not disturbed during concreting. The fixing arrangements used for inserts should not interfere with stripping of forms.

vii) If external vibrators are expected to be used, their positions should be finalized and provisions made in the form for attachment & replacement.

viii) If flexible sheathing is being used, it is necessary to use suitable arrangement like inflatable rubber tubes placed inside the sheathing during concreting operations.

11 SAFETY, HEALTH AND ENVIRONMENT REGULATIONS AND LEGISLATION

11.1 A comprehensive Safety, Health and Environment Management Guide/Manual should be prepared at all construction sites and be a part of the Contract Documents.

This should define the principal requirements of the Safety, Health and Environment.

Management associated with the Employer, Contractor/Sub-Contractor and any other agency to be practiced at construction worksites at all time to ensure that adequate precautions are taken to avoid accidents, occupational illness and harmful effects on environment during construction.

11.2 The document should cover all the requirements and compliance of the Local and National Acts and Regulations on these aspects and ensure conformity to the guidelines given in OHSAS1 8001 - Occupational Health and Safety Management System and ISO 14001 - Environmental Management Systems.

11.3 Major part of safety concerns at any construction site is related to the preparation, erection, dismantling, launching, lifting, floating equipments etc. for formwork, false work and also the temporary structures. The Safety, Health and Environment Guide/Manual should adequately address all the issues related to them.

11.4 All and adequate measures should be taken for safe and sound construction. To ensure safety sufficient precautions should be taken, all investigations be done thoroughly, design and erection and dismantling should be as per design brief, all systems and procedures should be tested and calibrated, and all regulations should be strictly followed.

11.5 A system of conducting Safety, Health and Environment inspections and other risk management analysis on a periodical basis will be evolved and administered. All required Safety Inspection Check lists for all activities, operations and equipment conforming to Indian Standards, Rules and Regulations and Employer's requirements, shall be prepared and implemented.

11.6 In India Safety and Health aspects at work or during construction are not adequately regulated by any Rules or Acts as in some other Countries. There is need to identify the scope of such acts to cover all the Safety and Health aspects by regulatory Acts through legislation so that the careless and negligent attitude and approach of construction agencies towards this important issue is curbed and lots of accidents and failures occurring on almost all the construction sites could be avoided.

11.7 The Regulations and Acts need to cover the following aspects during construction:

1) Safety and Health in Construction
2) Work at Height
3) Lifting Operations and Lifting Equipments
4) Personal Protective Equipment at Work
    i) Head Protection (Safety Helmets)
    ii) Foot Protection (Safety footwear, Gumboot. etc.)
    iii) Body protection (High visibility clothing (waistcoat/jacket). Apron, etc.)
    iv) Personal fall protection (Full body harness. Rope-grap fall arrester, etc.)
    v) Eye Protection (Goggles, Welders glasses, etc.)
    vi) Hand Protection (Gloves. Finger coats, etc.)
    vii) Respiratory Protection. (Nose mask, SCBAs. etc.)
    viii) Hearing Protection (Ear plugs. Ear muffs, etc.)
5) Provision and use of Work Equipment
6) Construction (Design and Management)
7) Risk Assessment
8) Failures and Accidents Management
9) Environmental Management
10) Other controls for the specific requirements of the project

11.8 If the above aspects are not covered by the existing available Rules, Regulations and Acts, these shall be prepared and included in the Safety, Health and Environment Guide/ Manual.

11.9 Adequate number of trained and experienced personnel to be headed by a Safety, Health and Environment Supervisor/Manager/Coordinator, shall be identified and made responsible and accountable for ensuring compliances of all the Rules, Regulations, Acts and Manual and implementation of all the systems, procedures, inspections, checking and reporting etc.

11.10 The Safety, Health and Environment Supervisor will keep constant liaison with the Temporary Structures Coordinator and Supervisors to ensure that all activities related to Formwork, Falsework and Temporary Structures are carried properly and safely.

Appendix-1

(Clause 6.7)

Information to be Supplied by Manufacturers of Proprietary System

A-1 General

A-1.1 The information which the manufacturer is required to supply shall be in such detail as to obviate unsafe use of the equipment due to the intention of the manufacturer not having been made clear due to wrong assumptions on the part of the user.

A-1.2 The user shall refer unusual problems of erection/assembly not in keeping with the intended use of the equipment, to the manufacturer of the equipment.

A-2 Information Required

A-2.1 The manufacturers of proprietary systems shall supply the following information:

a) Description of basic functions of equipment.
b) List of items of equipment available, giving range of sizes, spans and such like, with manufacturer's identification numbers or other references.
c) The basis on which the safe working loads have been determined and whether the factor of safety given applies to collapse or yield.
d) Whether the supplier's data are based on calculations or tests. This shall be clearly stated as there may be wide variations between results obtained by either method.
e) Instructions for use and maintenance, including any points which require special attention during erection, especially where safety is concerned.
f) Detailed dimensional information, as follows:
   i) Overall dimensions and depths and widths of members.
   ii) Line drawings including perspectives and photographs showing normal uses,
   iii) Self weight.
   iv) Full dimensions of connections and any special positioning arrangements.
   v) Sizes of members, including tube diameters and- thicknesses of material.
   vi) Any permanent camber built in to the equipment,
   vii) Sizes of holes and dimensions giving their positions,
g) Data relating to strength of equipment as follows:
   i) Average failure loads as determined by tests.
   ii) Recommended maximum working loads for various conditions of use.
   iii) Working resistance moments derived from design calculations and tests.
   iv) Working shear capacities derived from design calculations and tests.
   v) Recommended factors of safety used in assessing recommended loads and deflections based on design calculations and test results.
   vi) Deflections under load together with recommended pre-camber and limiting deflections.
   vii) If working loads depend on calculations, working stresses should be stated. If deflections depend on theoretical moments of inertia or equivalent moments of inertia rather than tests, this should be noted,
   viii) Information on the design of sway bracing against wind and other horizontal loadings.
   ix) Allowable loading relating to maximum extension of bases.

Appendix-2

Sample Checklist for Falsework

Typical format for the checklist given below provides the basic requirements for formwork & falsework related activities & is for general guidance only. It is not exhaustive. In case of system formwork, manufacturers should be consulted on all safety requirements for preparation of the checklist. The checklist should be prepared specifically to meet the requirements of a project to suit work methods and conditions.

Job Name : ______________________

Portion to be Checked ______________________

Name of Engineer/Supervisor carrying out check ______________________

Drawing Ref. No ______________________

Date and Time ______________________

Sr. No	Item	Compliance			Remarks/corrective action
		Yes	No	NA	
(A)	**Basic requirements**				
	Is final version good for construction design drawing for the falsework available with all concerned?				
	Is any modification proposed to be done at site? Is it referred to the temporary works designer & approved by him in writing?				
	Are the formwork supervisors & workers adequately trained according to erection and dismantling sequence for the falsework?				
	Safety: • Has Hazard Identification & Risk Analysis been done? • Is proper access arrangement for supervisors and workmen provided ? • Is proper lighting arrangement during night shift works provided? • Are PPEs for workers available? • Is the work area neat and tidy, free of tripping hazards like materials with projecting nails etc.? • Are warning notices placed at appropriate locations near work-fronts?				
(B)	**Falsework materials**				
	• Are all falsework materials as per GFC drawing are available in good condition? • Are members like scaffolding pipes/trestles, bracings, etc. straight and cleaned, are free from defects ?				
(C)	**Foundation preparation**				

Sr. No	Item	Compliance			Remarks/corrective action
		Yes	No	NA	
	• Is the ground below supporting system is adequately prepared and having the required S.B.C? • Are the supporting sleepers/blocks properly spaced, centrally placed below verticals and fully bedded? • Are the sleepers/blocks laid on slope prevented from sliding by proper arrangements? • Are adequate precautions taken to prevent scouring / flooding of foundations for falsework?				
(D)	**Erection of falsework**				
	Are the verticals of falsework erected plumb or at their intended angle? Arte the bracings and ties provided as per the drawing and properly connected? Are the jack extensions of adjustable props within specified limit?				
	Restraint against horizontal forces: • Is the falsework system having adequate restraint against any horizontal forces/movement that may occur due to uneven loading during concreting/workers & equipment movement/sloping structure, etc.? • Is the permanent structure having adequate restraint?				
(E)	**Inspection before loading and during concreting**				
	• Is the formwork structure erected according to the approved design and drawing? • Are the structural dimensions within agreed tolerances? • Is the require camber, if any, provided?				
	Are there adequate guardrails, handrails, walkways, signs, lighting, etc in position?				
	Cleanliness • Are the form faces cleaned? • Is any damage correctly repaired? • Is the correct release agent in use? • Is it being correctly applied? • Has all debris been removed from within the form?				
	Water-tightness • Are all form panel joints properly sealed? • Are the construction joints sealed?				
	Work at Heights • Is a Fall Prevention Plan developed & implemented? • Are every open sides or openings covered or guarded by effective means to prevent falls? • Are visual checks conducted to ensure that anchorage for the formwork is fully engaged? • Have all persons using the fall arrest systems undergone training to understand the safe and correct use of the system?				

Sr. No	Item	Compliance			Remarks/corrective action
		Yes	No	NA	
	• **Is permit to load certificate issued before start of concreting?**				
	During concreting • Is a trained supervisor available to observe the formwork/falsework & report any signs of distress to TWC immediately? • Is the maximum rate of placement and pour sequence followed as specified? • Is the formwork/falsework maintaining line, level, plumb, shape, etc. during concreting?				
(F)	**Dismantling of falsework**				
	• Is there a documented formwork erection, dismantling and shifting sequence? • Is the permanent structure stable with adequate restraint against sliding/overturning after removal of temporary bearings/falsework ? • What are the minimum stripping times?(The dismantling start only after the concrete gets adequate strength as per the cube test result.) • What curing methods are to be used once the formwork is removed? • Is the stability of the partly dismantled falsework checked ? • Is the storage area for the formwork organised? • Is the falsework & accessories cleaned and the materials stacked properly ?				

For Contractor

Name :
Designation :
Signature :
Date :

For Department

Name :
Designation :
Signature :
Date :

BIBLIOGRAPHY

Indian Standard (IS) Codes:

- IS:806 -1968 (reaffirmed 2013) - "Code of Practice for Use of Steel Tubes in General Building Construction"
- IS: 883 – 2016 Design of Structural Timber in Buildings - Code of Practice (Fifth Revision)
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- IS: 1161- 2014 Steel Tubes for Structural Purposes"
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- IRC:24-2010 "Standard Specifications and Code of Practice for Road Bridges, Steel Road Bridges (Limit State Method) (Third Revision)"
- IRC:40-2002 –"Standard Specifications and Code of Practice for Road Bridges, Section IV – Brick, Stone and Block Masonry (Second Revision)"
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- Bragg S.L. (Dept. of Employment, Dept. of Environment, U.K.) – "Final report of the Advisory Committee on Falsework, London, HMSO, June 1975
- BS:5975: 2008 – "Code of Practice for temporary works procedures and the permissible design of falsework"
- CIRIA report no. 108 – " Concrete Pressure on Formwork"
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- ISO14001:2015 – "Environmental management systems"

Annexure – G

Working Stress Design

(Based on IRC:24-2010)

G1 GENERAL

In this method structural members are designed so that the unit stress caused by the design loads does not exceed a pre-defined permissible stress. The permissible stress is defined as the yield stress multiplied by a factor of safety. This factor of safety caters for the uncertainties in loads, material strength, behaviour of the structure, corrosion, fatigue etc.

In the working stress method, apart from structural strength, serviceability requirements such as deflection, etc. also need to be considered and properly checked.

G2 LOADS AND STRESSES

G2.1 Combinations

G2.1.1 *Main effects*

For the purpose of computing stresses, the classifications (column 1) and combinations (column 2) as given in **Table G.1** will be followed. For legend of symbols under Combination (column 2) refer to **Clause 202.1** of IRC:6.

G2.1.2 *Other effects*

G2.1..2.1 Secondary Effects (F_s) shall include, where applicable, the effects due to creep and shrinkage of concrete for composite deck and warping for box girder sections.

G2.1.2.2 Erection effects shall include the loads and forces arising out of construction equipment and the effects of wind/seismic.

G2.2 Permissible Increase in Stress

G2.2.1 *Increase*

The permissible increase (percent) in stress in the various members covered by this code due to combination stated in **Clause G2.1** shall be as given under Increase (column 3) of **Table G.1**.

G2.2.2 *Limitation*

The above permissible increase in stress, shall however be limited to 90 percent of yield stress.

Table G.1

Classification (1)	**Combination (2)**	**Increase' (3)**
I	$G + Q$ *or* $G_s + Q_{im} + F_{wc} + F_f + G_b + F_{cf} + F_{ep} + G_c$	Nil
II	(I) + $F_s + F_d + F_{te}$	15 percent
III	(II) + $W + Fwp$	25 percent
IV	(II) + $F_{eq} + F_{wp}$	40 percent
V	(II) + $F_{im} + W$	25 percent
VI	$G + F_{wc} + G_b + F_{ep} + F_{er} + F_f + W + G_c$	30 percent
VII	(VI) + $F_{eq} - W$	40 percent

G2.3 Worst effect

Subject to the provision of other clauses, all forces shall be considered as applied and all loaded lengths chosen in such a manner that the worst adverse effect is caused on the member under consideration.

G2.4 Working Stresses

G2.4.1 *Basic Permissible Stresses*

The basic permissible stresses for steelwork are given in **Table G.2**.

Table G.2 Basic Permissible Stresses

1)	Axial tension on net area	$0.6\ f_y$
2)	Axial compression on effective section	$0.6\ f_y$
3)	Bending In plates, flats, tubes & similar sections In girders and rolled sections	 $0.66\ f_y$ $0.62 f_y$
4)	Shear Stress Maximum Average For yield stress $f_y \leq 250$ MPa For $f_y > 250$ MPa	 $0.43 f_y$ $0.38 f_y$ $0.35 f_y$
5)	Bearing stress on flat surface	$0.8 f_y$

However, the permissible stresses in axial or flexural compression shall not exceed those as per relevant clauses considering the effect of buckling.

G2.4.2 *Equivalent Stress*

G2.4.2.1 When a member is subjected to a combination of stresses, the equivalent stress $\sigma_{e,cal}$ due to combination of shear stress $\tau_{v,\,cal}$ bearing stress $\sigma_{p,cal}$ and bending stress $\sigma_{bt,cal}$ (tensile) or $\sigma_{bc,\,cal}$ (compressive) is calculated from

$$\sigma_{e,\,cal} = \sqrt{(\sigma_{bt,cal})^2 + (\sigma_{p,cal})^2 + (\sigma_{bt,cal})(\sigma_{p,cal}) + 3(\tau_{v,cal})^2}$$

$$\text{or } \sigma_{e,\,cal} = \sqrt{(\sigma_{bc,cal})^2 + (\sigma_{p,cal})^2 - (\sigma_{bc,cal})(\sigma_{p,cal}) + 3(\tau_{v,cal})^2}$$

$\sigma_{e,\,cal}$ shall not exceed the permissible stresses as indicated in relevant sections under different combination of stresses.

G2.4.2.2 Irrespective of the permissible increase of stress in other clauses, the equivalent Stress $\sigma_{e,cal}$ calculated in **Clause G2.4.2.1** above shall not exceed 92 percent of yield stress.

G2.5 Permissible Stresses in Bolts, Rivets & Tension Rods

G2.5.1 *Fasteners*

All fasteners would be in accordance with Indian Standards. For bolts, the yield stress used for calculating the permissible stress would be derived from the property class chosen as per relevant Indian Standards. The nut should be of matching property class. For hot rolled and high tensile rivets, the yield stress would be in accordance with the relevant Indian Standards.

G2.5.2 *Calculations of Stresses*

In calculating shear and bearing stresses, the effective diameter of a rivet shall be taken as the hole diameter and that of bolt shall be taken as its nominal diameter. In calculating the axial tensile stress in a rivet, the gross area shall be used and in calculating the axial tensile stress in a bolt or screwed tension rod, the net area shall be used.

G2.5.3 *Gross and net area*

G2.5.3.1 The gross area of a rivet shall be taken as the cross sectional area of the rivet hole. The nominal diameter of rivet shall be the diameter (cold) before driving. The nominal area of a rivet shall be based on the nominal diameter.

G2.5.3.2 The net sectional area of a bolt or a screwed tension rod shall be taken as the area of the root of the threaded part or cross sectional area of the unthreaded part whichever is lesser. The nominal diameter of a bolt shall be the diameter of the shank of the bolt. The nominal area of a bolt shall be based on the nominal diameter.

G2.5.4 *Basic Permissible Stresses*

The basic permissible Stresses for rivets, bolts, tension rods are given in **Table G.3**.

G2.5.5 *Combined tensile & Shear Stresses*

Rivets and bolts subject to shear and externally applied tensile forces shall be so proportioned that the quantity.-

$$\left[(\sigma_{tf,cal}/\sigma_{tf})^2+(\tau_{vf,cal}/\tau_{vf})^2\right]\leq 1$$

Where

$\sigma_{tf,cal}$ = actual tensile stress in the rivet or bolt

σ_{tf} = permissible tensile stress in the rivet or bolt as given in **Table G.3**

$\tau_{vf,cal}$ = actual shear stress in the rivet or bolt,

τ_{vf} = permissible shear stress in the rivet or bolt as given in **Table G.3**

G2.5.6 *HSFG bolts*

High strength friction grip bolts shall be used in conformity with IS 4000-1992.

G2.6 Permissible Stresses in Welds

G2.6.1 *Basic Permissible Stresses*

The basic permissible stresses in weld shall be as per Indian Standards, namely IS 816-1969 and as modified in IS 1024-1979.

G2.6.2 *Shop Welds*

G2.6.2.1 Butt Welds

Butt weld shall be treated as parent metal with a thickness equal to the throat thickness, and the stress shall not exceed those permitted in the parent metal.

Table G.3 Basic Permissible Stresses for Rivets, Bolts and Tension Rods

1)	**In Tension** Axial stress on nominal area of rivet and on net area of bolts and tension rods :	
	Power driven shop rivets	$0.33\,f_y$
	Power driven field rivets	$0.27\,f_y$
	Bolts over 38 mm dia	$0.53\,f_y$
	Bolts 20 mm up to 38 mm dia	$0.40\,f_y$
	Bolts less than 20 mm dia	$0.33\,f_y$
	Tension Rods	$0.53\,f_y$

2)	**In Shear** Shear stress on gross area of rivets and nominal area of bolts :	
	Power driven shop rivets	0.43 f_y
	Power driven field rivets	0.40 f_y
	Hand driven rivets	0.33 f_y
	Turned and fitted bolts (IS 3640)	0.43 f_y
	Black bolts (IS 1363)	0.37 f_y
3)	**In Bearing** Bearing stress on gross diameter of rivets and nominal diameter bolts	
	Power driven shop rivets	1.00 f_y
	Power driven field rivets	0.90 f_y
	Hand driven rivets	0.67 f_y
	Turned and fitted bolts (IS 3640)	1.00 f_y
	Black bolts (IS 1363)	0.87 f_y

G2.6.2.2 Fillet welds

The basic permissible stress in fillet welds shall not exceed the permissible shear stress as follows :

Steel Conforming to	**Electrode Designation as per IS 815-1974**	**Shear Stress MPa**
IS 2062 upto Grade E250	EXXX-43X	108
IS 2062 Grade E300 and above	EXXX-51X	131

G2.6.2.3 Plug Welds

The permissible shear stress in plug welds will not exceed those given for fillet welds as above.

G2.6.3 *Site welds*

The permissible stresses for shear and tension for site welds made during erection of structural members shall be reduced to 80 percent of those given in **Clause G2.6.2** above. Site welding should be proposed only if quality welds can be ensured at site including facilities for testing the welds as per codal requirements. The percentage of site welds to be tested should be 100 percent as given under **Clauses 513.6.12.7.2 to 4** of IRC:24.

G2.6.4 *Combined stresses in a weld*

G2.6.4.1 When a weld is subjected to a combination of stresses, the equivalent stress $\sigma_{e,\,cal}$ due to Combination of shear stress $\tau_{v,cal}$ bearing stress $\sigma_{p\,cal}$ and bending stress $\sigma_{bt,cal}$ (tensile) or $\sigma_{bc,cal}$ (compressive) is calculated from

$$\sigma_{e,\,cal} = \sqrt{(\sigma_{bt,cal})^2 + (\sigma_{p,cal})^2 + (\sigma_{bt,cal})(\sigma_{p,cal}) + 3(\tau_{v,cal})^2}$$

$$\text{or } \sigma_{e,\,cal} = \sqrt{(\sigma_{bc,cal})^2 + (\sigma_{p,cal})^2 - (\sigma_{bc,cal})(\sigma_{p,cal}) + 3(\tau_{v,cal})^2}$$

$\boldsymbol{\sigma}_{e,cal}$ shall not exceed the permissible stresses as indicated in relevant sections under different combination of stresses.

G2.6.4.2 Irrespective of the permissible increase of stress in other clauses, the equivalent stress $\boldsymbol{\sigma}_{e,cal}$ calculated in **Clause G2.6.4.1** above shall not exceed 92 percent of yield stress f_y.

G2.7 Stress Analysis

G2.7.1 *General*

The global analysis of the structure should be done using an elastic method. For structures in which the load effects are not proportional to the loads and/or the secondary effects due to deformation are significant, the method of analysis should be suitable for treatment of non-linear behaviour.

G2.7.2 *Sectional Properties*

The sectional properties to be used in global analysis should generally be calculated for the gross section assuming the specified sizes. For beams or trusses on flexible supports, account should however be taken of its influence of shear lag on their stiffenesses. The effect of shear lag should also be taken into account in analysis of conditions during erection of continuous girders of box construction or with integral decks.

G2.7.3 *Longitudinal Stresses in beams*

The distribution of longitudinal stress between the flanges and web or webs of a beam may be calculated on the assumption that plane section remains plane, but using effective widths of the flanges and the effective thickness of a deep web in accordance with the provisions of **Clause G4**, no further account need be taken of deformation of the plate out of its plane.

G2.7.4 *Shear Stress*

The design values of shear stress in webs of rolled or fabricated I, box or channel sections may be calculated in accordance with the provisions of **Clause G4**. Shear stresses in other sections should be computed from the whole cross-section having regard to the distribution of flexural stress across the section.

G2.8 Stresses

G2.8.1 *Primary Stresses*

In the design of triangulated structures, axial stresses in members are usually calculated on the assumption that:

- all members are straight and free to rotate at the joints;
- all joints lie at the intersection of the centroidal axes of the members
- all loads, including the weight of the members, are applied at the joints.

These stresses are defined as primary stresses.

G2.8.2 *Secondery Stresses*

In practice these assumptions are not realised and consequently members are subjected not only to axial stress but also to bending and shear stresses. These stresses are defined as secondary stresses and fall into two groups:

i) Stresses which are the result of eccentricity of connections and off-joint loading generally (i.e. loads rolling directly on chords, self weight of member and wind loads on member).

ii) Stresses which are the result of the elastic deformation of the structure and the rigidity of the joints. These are known as deformation stresses.

G2.8.2.1 Structures shall be designed, fabricated and erected in such a manner as to minimize, as far as possible, secondary stresses.

G2.8.2.2 Secondary stresses which are the result of eccentricity of connections and of off-joint loading [under **Clause G2.8.2 (i)** above], shall be computed and combined with the coexistent axial stresses in accordance with appropriate clause, but secondary stress due to the self weight and wind on the member shall be ignored in this case.

NOTE: *In computing the secondary stress due to loads being carried direct by a chord, the chord may be assumed to be a continuous girder supported at the panel points, the resulting bending moments, both at the centre and at the supports being taken as equal to 3/4 of the maximum bending moment in a simply supported beam of span equal to the panel length. Where desired, calculations may be made and the calculated bending moments may be taken. In computing such bending moments, the impact allowances shall be based on a loaded length equal to one panel length.*

G2.8.2.3 Secondary stresses which are the result of the elastic deformation of the structure (under **Clause G2.8.2 (ii)** above) shall be either computed or assumed in accordance with **Clause G2.8.3** below and combined with the coexistent axial stresses.

G2.8.3 *Deformation stresses*

In order to minimize the deformation stresses in girder, the ratio of the width of the members in the plane of distortion to their length between centre of intersections shall preferably be not greater than 1/12 of the chord members and 1/24 of web members. In the absence of calculations the deformation stresses shall be assumed to be not less than $16\frac{2}{3}$ percent of the dead load and live load stresses including impact.

G2.8.3.1 All open web girders of effective spans greater than 50 m may properly be cambered. Recommended procedure for cambering such girders is given in **Annex-B** of IRC:24. For such girders, deformation stresses (under **Clause G2.8.3**) above may be ignored.

G3 GENERAL DESIGN CONSIDERATIONS

G3.1 **Effective Spans**

Refer to **Clause 504.1** of IRC:24

G3.2 **Effective Depths**

Refer to **Clause 504.2** of IRC:24

G3.3 Spacing of Girders

Refer to **Clause 504.3** of IRC:24

G3.4 Depth of Girders

Refer to **Clause 504.4** of IRC:24

G3.5 Deflection of Girders

Refer to **Clause 504.5** of IRC:24

G3.6 Camber

Refer to **Clause 504.6** of IRC:24

G3.7 Minimum Sections

Refer to **Clause 504.7** of IRC:24

G3.8 Sectional Area

G3.8.1 *Gross Sectional area*

The gross sectional area shall be the area of the cross section as calculated from the specified sizes.

G3.8.2 *Effective Sectional area*

G3.8.2.1 Tension members - The effective sectional area of the member shall be the gross sectional area with the following deductions as appropriate.

G3.8.2.1.1 Except as required in **Clause G3.8.2.1.2**, the areas to be deducted shall be the sum of the sectional areas of the maximum number of holes in any cross-section at right angles to the direction of stress in the member.

G3.8.2.1.2 In the case of :

a) all axially loaded tension members
b) beams of structural steel conforming to IS 2062 upto Grade E250 and with d/t greater than 85
c) beams of structural steel conforming to IS 2062 Grade 300 and above and with d/t greater than 75

Where

t = thickness of web, and

d = depth of beams to be taken as the clear distance between flanges ignoring fillets.

and where bolt or rivet holes are staggered, the area to be deducted shall be the greater of the following :

i) The maximum number of the holes in any cross-section at right angles to the direction of stress in the member.

ii) The sum of the sectional areas of all holes in a chain of lines extending progressively across the member, less s^2 t/4g for each line extending between holes at other than right angles to the direction of stress, where, s,g and t are respectively the staggered pitch, gauge, and thickness associated with the line under consideration. The chain of lines shall be chosen to produce the maximum such deduction. For non-planer sections, such as angles with holes in both legs, the gauge, g, shall be the distance along the centre of the thickness of the section between hole centres.

NOTE : *In a built-up member where the chains of holes considered in individual parts do not correspond with the critical chain of holes for the members as a whole, the value of any rivets or bolts joining the parts between such chains of holes shall be taken into account in determining the strength of the member.*

G3.8.2.1.3 Angles and tees in tension

a) In the case of single angle connected through one leg, the net effective sectional area shall be taken as :

$A_1 + A_2 \text{ x } k$

Where,

A_1 = effective cross-sectional area of the connected leg

A_2 = the gross cross-sectional area of the unconnected leg, and

k = $3A_1 \div (3A_1 + A_2)$

Where lug angles are used, the effective sectional area of the whole of the angle member shall be considered.

b) In the case of pair of angles back-to-:back (or a single tee) connected by one leg of the angle (or by the flange of the tee) to the same side of a gusset, the net effective area shall be taken as:

$A_1 + A_2 \text{ x } k$

Where,

A_l and A_2 are as defined in **G3.8.2.1.3 (a)** and

$k = 5A_1 \div (5A_l + A_2)$

The angles shall be connected together along their length in accordance with the requirements as given in **Clause 506.2.6.1** of IRC:24.

G3.8.2.2. Compression members

The gross sectional area shall be taken for all compression members subject to relevant clauses.

G3.8.2.3 Parts in shear

The effective sectional area for calculating average shear stress for parts in shear shall be as follows:

a) *Rolled beams and channels* - The product of the thickness of the web and the overall depth of the section.

b) *Plate girder* - The product of the thickness of the web and the full depth of the web plate.

NOTES:

1) *Where webs are varied in thickness in the depth of the section by the use of tongue plates or the like and in the case of other sections, the maximum shear stress shall be computed from the whole area of cross-section having regard to the distribution of flexural stresses.*

2) *Webs which have openings larger than those used for rivets, bolts or other fastenings require special consideration and the provisions of this clause are not applicable.*

G3.9 Skew Bridges

Refer to **Clause 504.8** of IRC:24.

G4 DESIGN OF BEAMS

G4.1 General

G4.1.1 Beams shall be proportioned on the basis of the moment of inertia of the gross cross-section with the neutral axis taken at the centroid of that section. In computing the maximum stresses, the stresses calculated on this basis shall be increased in the ratio of the gross to the effective area of the flange section. For this purpose the flange sectional area in riveted or bolted construction shall be taken-to be that of the flange plates, flange angles and the portion of the web and side plates, if any, between the flange angles. In welded construction, the flange sectional area shall be taken to be that of flange plates and of the tongue plates (i.e. the thick vertical plates connecting flange to web) if any, upto a depth of the tongue plate equal to eight times its thickness, which shall not be less than twice that of the web.

G4.2 Web Plates

G4.2.1 *Minimum thickness*

Refer to **Clause 509.6** of IRC:24

G4.3 Flanges

G4.3.1 The effective sectional area of compression flanges shall be the gross area with the specified deduction for excessive width of plates (**Clause G4.3.3, G4.3.4**) and maximum deduction for open holes and holes for bolts occurring in section perpendicular to the axis of the member.

G4.3.2 The effective sectional area of tension flanges shall be the gross sectional, area with specified deduction for excessive width or projection of plates (**Clause G4.3.5**) and deduction of all holes as specified for rivet or bolt holes in tension members in **Clause G3.8.2.1**.

G4.3.3 In riveted or bolted construction, flange angles shall form as large a part of the area of the flange as practicable (preferably not less than 1/3) and the number of flange plates shall be kept to a minimum. Where flange plates are used, they shall preferably of equal thickness and at least one plate of the top flange shall extend the full length of the girder, unless the top edge of the web is finished flush with the flange angles.

Compression flange plates unstiffened at their edges shall not project beyond the outer lines of connections to the flange angles by more than 16t' for steel conforming to IS 2062 upto Grade E250 or 14t' for steel conforming to IS 2062 Grade E300 and above where t' is the thickness of the thinnest flange plate or the aggregate thickness of the two or more plates when projecting portions of these plates are adequately tacked together.

G4.3.4 In welded construction, compression flange plates unstiffened at their edges shall not project beyond the line of connection to the web or tongue plates by more than 12t'.

G4.3.5 In all cases, tension flange plates, stiffened or unstiffened at their edges, shall not project beyond the outer line of connections to the flange angles (or where there are no flange angles, to the web or tongue plates) by more than 20t'.

G4.3.6 For the flanges of beams with vertical stiffeners only (see **Clause G4.11.2.2**), where d_1/ t is greater than 130 in the case of steel conforming to IS 2062 upto Grade E250 or 110 in the case of steel conforming to IS 2062 Grade E300 and above and when the average shear stress in the web is greater than 0.6 of the permissible stress given for mild steel in **Clause G2.4.1**, the quantity I /(b^3t) shall not be less than 2.5 x 10^{-4} in the case of steel conforming to IS 2062 upto Grade E250 and 3 x 10^{-4} in the case of steel conforming to IS 2062 Grade E300 and above.

Where

I = the moment of inertia of the compression flange about its axis normal to the web, taken as that of the flange angles and plates and the enclosed portion of the web in the case of riveted construction and in the case of welded construction, as the flange plate together with a depth of web (adjacent to the flange plate) equal to 16 times the web thickness.

d_1 = effective depth of the girder as defined in **Clause 509.6** of IRC:24.

b = spacing of stiffeners

t = thickness of web

G4.4 Effective Length of Compression Flanges

The effective length of the compression flange for buckling normal to the plane of the girder shall be as given below.

G4.4.1 Simply supported beams with no intermediate lateral support to compression flange, but with each end restrained against torsion.

G4.4.1.1 When there is no intermediate lateral restraint to a compression flange, effective length l should be taken as

$$l = k_1 L$$

L = Span of the beam (i.e between restraint at supports)

k_1 = 1.0 if the compression flange is free to rotate in plan at the points of support, or

= 0.85 if the compression flange is partially restrained against rotation in plan at one support and free to rotate in plan at the other, or

= 0.7 if the compression flange is fully restrained against rotation in plan at the points of support.

G4.4.1.2 Restraint against torsion at the supports can be provided by web or flange cleats, by bearing stiffeners, by end frames or by lateral supports to the compression flange. The restraint element shall be designed to resist, in addition to the effects of wind and other applied lateral forces, the effects of a horizontal force acting normal to the compression flange of the girder at the level of the centroid of this flange where:

$$F = \frac{1.4\times10^{-3}\times l}{\delta(f_{cb}/f_{bc}-1.7)}$$

In the above formula

l = has the value given in **Clause G4.4.1.1**

f_{cb} = the critical stress in the flange as defined in **Clause G4.6.2**

f_{bc} = the calculated working stress in flange

δ = the deflection of the flange under the action of unit horizontal force as defined in **Clause G4.4.2**

G4.4.2 Simply supported beams with compression flange laterally supported by U-Frames.

For simply supported girders where there is no lateral bracing of the compression flanges but where cross members and stiffeners forming U-Frames provide lateral restraint.

$$l = 2.5 \times \sqrt[4]{EI_c a\delta} \qquad \text{but not less than "}a\text{"}$$

Where

E = Young's Modulus

I_c = Maximum moment of inertia of compression flange about its centroidal axis parallel to the web of the girder.

a = distance between frames

δ = the lateral deflection which would occur in the U-Frame at the level of the centroid of the flange being considered when a unit force acts laterally to the U-Frame only at this point and simultaneously at each corresponding point on the other flange or flanges connecting to the same U-Frame. The direction of each unit force should be such as to produce the maximum aggregate value of δ. The U-Frame should be taken as fixed in position at each point or intersection between the cross member and a vertical as free and unconnected at all other points.

when δ is not greater than $a^3/(40\ E\ I_c)$

$l = a$

In cases of symmetrical U-Frames where cross members and stiffeners are each of constant moment of inertia throughout their own length.

$$\delta = \frac{(d_1)^3}{3EI_1} + \frac{(d_2)^2 b}{EI_2}$$

Where

d_1 =	distance of the centroid of the compression flange from the top of the cross member
d_2=	distance. of the centroid of the compression flange from the neutral axis of the cross member
b =	half the distance between centres of the main girders.
I_1 =	the moment of inertia of a pair of stiffeners about the centre of the web, or a single stiffener about the face of the web. A width of web plate upto 16 times the web thickness may be included on each side of centre lines of connection.
I_2 =	Moment of inertia of the cross member in its plane of bending

G4.4.3 *Beams with laterally supported compression flanges*

When a compression flange is provided with effective discrete lateral restraints effective length l should be taken as the greatest distance centre-to-centre of restraint members between a restraint and a support. Where such restraint is provided by interconnecting bracing, consideration should be given to the possibility of lateral instability of the combined cross-section.

G4.4.4 *Cantilever beams without intermediate lateral support*

When a cantilever beam is not provided with lateral support between its support and tip, l may be taken from **Table G.4**, where L is the length of cantilever.

Table G.4 Effective Length *l* for A Cantilever Beam without Intermediate Lateral Restraint (Clause G4.4.4)

Restraint Conditions		Position of Load	
At support	**At tip**	**On tension flange where there is no lateral restraint to load or flange**	**All other position**
1) Built in	a) Free	1.4 L	0.8 L
	b) Tension flange held against displacement	1.4 L	0.7 L
	c) Both flanges held against lateral displacement	0.6 L	0.6 L

Restraint Conditions		Position of Load	
At support	**At tip**	**On tension flange where there is no lateral restraint to load or flange**	**All other position**
2) Continuous and both flanges held against lateral displacement	a) Free b) Tension flange held against displacement c) Both flanges held against lateral displacement	2.5 L 2.5 L 1.5 L	1.0 L 0.9 L 0.8 L
3) Continuous with tension flange held against lateral displacement	a) Free b) Tension flange held against displacement c) Both flanges held against lateral displacement	7.5 L 7.5 L 4.5 L	3.0 L 2.7 L 2.4 L

NOTE: L is the length of the cantilever

G4.4.5 *Beams continuously restrained by deck at compression flange level*

A compression flange continuously supporting a reinforced concrete or steel deck shall be deemed to be effectively restrained laterally throughout its length (i.e. l =0) if the frictional or positive connection of the deck to the flange is capable of resisting a lateral force of 2.5 percent of the force in the flange at the point of maximum bending moment, distributed uniformly along length.

G4.5 Slenderness Ratio

The slenderness ratio λ (i.e. l/r_{yy}) of a beam shall not exceed 300 and it shall not exceed 150 for cantilevers.

l = effective length of the compression flange as specified in **Clause G4.4**

r_{yy} = the radius of gyration of the whole beam about its y-y axis based on the gross moment of inertia and the gross sectional area.

G4.6 Permissible Bending Stresses

G4.6.1 The tensile and compressive bending stresses calculated according to **Clause G4.1.2** shall not exceed the appropriate permissible stresses in **Table G.2**.

G4.6.2 For beams and plate girders with I_y smaller than I_x.

Where

I_y = moment of inertia of the whole section about the axis lying in the plane of bending (y-y axis)

I_x. = moment of inertia of the whole section about the axis normal to the plane of bending (x-x axis)

The bending compression stress calculated according to **Clause G4.1** shall not exceed the permissible bending compressive stress σ_{bc} given in **Table G.5** corresponding to f_{cb}, (elastic critical stress),calculated as follows :

Table G.5 Value of σ_{bc} Calculated from f_{cb} for Different Values of f_y
(Clause G4.6.2)
All Units in MPa

$f_y \rightarrow$ $f_{cb} \downarrow$	**250**	**340**	**400**
20	13	13	13
30	19	19	19
40	25	26	26
50	31	31	32
60	36	37	38
70	41	43	44
80	46	48	49
90	51	54	55
100	55	59	60
110	60	64	65
120	64	68	70
130	67	73	75
140	71	77	80
150	74	81	84
160	78	85	89
170	81	89	93
180	84	93	97
190	87	97	102
200	89	100	105
210	92	103	109
220	94	106	112
230	93	110	116
240	99	113	119
250	101	115	122
260	103	118	126
270	104	121	129
280	106	123	132
290	108	126	135
300	110	128	137
310	111	130	140
320	113	133	143
330	114	135	145

$f_y \rightarrow$ $f_{cb} \downarrow$	**250**	**340**	**400**
340	115	137	148
350	117	139	150
360	118	141	152
370	119	143	155
380	120	144	157
390	121	146	159
400	122	148	161
420	124	151	165
440	126	154	169
460	128	157	172
480	130	159	175
500	131	162	178
520	133	164	181
540	134	166	184
560	135	168	187
580	136	170	189
600	137	172	192
620	138	174	194
640	139	175	196
660	140	177	198
680	141	178	200
700	142	180	202
720	143	181	204
740	143	182	205
760	144	184	207
780	145	185	208
800	145	186	210
850	147	188	213
900	148	191	216
950	149	193	219
1000	150	195	222
1050	151	196	224
1100	152	198	226
1150	152	199	228
1200	153	200	230
1300	154	203	233
1400	155	205	236
1500	156	206	238

$f_y \rightarrow$ $f_{cb} \downarrow$	**250**	**340**	**400**
1600	157	208	240
1700	157	209	242
1800	158	210	243
1900	158	211	245
2000	159	212	246
2200	160	213	248
2400	160	215	250
2600	161	216	251
2800	161	216	252
3000	161	217	253
3500	162	218	255
4000	163	219	257
4500	163	220	258
5000	163	221	259
5500	163	221	259
6000	164	222	260

Elastic Critical Stress

The elastic critical stress f_{cb} for beams and plate girders with I_Y smaller than I_x shall be calculated - using the following formula:

$$f_{cb} = k_1 (X + k_2 Y)(c_2 / c_1)$$

Where

$$X = Y \sqrt{1 + (1/20)\left[(lT)/(r_y D)\right]^2} \text{ MPa}$$

$$Y = 26.5 \times 10^5 / (l / r_y)^2 \text{ MPa}$$

c_1, c_2 = respectively the lesser and greater distances from the section neutral axis to the extreme fibres.

D = overall depth of the beam

T = mean thickness of the compression flange

l = effective length of-compression flange

r_y = radius of gyration of the section about its axis of minimum strength (y-y axis)

k_1 = a coefficient to allow for reduction in thickness or breadth of flanges between the points of effective lateral restraint and depends on Ψ the ratio of total area of both flanges at the point of least bending moment to the corresponding area at the point of greatest bending moment between such points of restraint. Values of k_1 for different values of Ψ are given in **Table G.6**.

k_2 = a coefficient to allow for the inequality of flanges and depends on ω, the ratio of the moment of inertia of the compression flange alone to that of the sum of the moments of inertia of the flanges each calculated about its own axis parallel to the yy axis of the girder, at the point of maximum bending moment. The values of k_2, for different values of ω are given in **Table G.7** Values of X and Y for appropriate values of *D/T* and l/r_y are given in **Table G.8**.

Table G.6 Value of k_1 for Beams with Curtailed Flanges
(Clause G4.6.2)

Ψ	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
k_1	1.0	1.0	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2

NOTE : Flanges should not be reduced in breadth to give a value of Ψ lower than 0.25

Table G.7 Value of k_2 for Beams with Unequal Flanges
(Clause G4.6.2)

ω	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
k_2	0.5	0.4	0.3	0.2	0.1	0	-0.2	-0.4	-0.6	-0.8	-1.0

G4.6.2.1 Values of f_{cb} shall be increased by 20 percent when *T/t* is not greater than 2.0 and d_1/t is not greater than $1344/\sqrt{f_y}$ where d_1 is as defined in **Clause 509.6** of IRC:24 and t the thickness of the web and the value of f_y is expressed in MPa.

G4.6.3 *Beam bent about the axis of minimum strength (y-y axis)*

The maximum permissible bending stress in tension or in compression in beams bent about the axis of minimum strength shall not exceed the appropriate permissible stresses in **Table G.2**.

G4.6.4 *Angle and tee shapes*

The bending stress in the leg when loaded with the flange or table in compression shall not exceed the appropriate permissible stresses in **Table G.2**. When loaded with the leg in compression, the permissible bending stress shall be calculated from **Clause G4.6.2** with k_2= -1.0 and T = thickness of leg.

G4.7 Permissible Shear Stress

G4.7.1 *Maximum Shear Stress*

The maximum shear stress in a member having regard to the distribution of stresses in conformity with the elastic behaviour of the member in flexure, shall not exceed the appropriate permissible stress in **Table G.2**.

Table G.8 Values of X and Y for Calculating f_{cb}
(Clause G4.6.2)

D/T → l/ry↓	X															Y
	8	10	12	14	16	18	20	25	30	35	40	50	60	80	100	
40	2484	2222	2066	1965	1897	1849	1814	1759	1728	1709	1697	1683	1675	1667	1663	1656
45	2103	1856	1709	1612	1546	1499	1465	1411	1380	1362	1349	1335	1327	1319	1315	1309
50	1822	1590	1449	1357	1293	1248	1214	1161	1131	1113	1101	1086	1078	1070	1067	1060
55	1607	1389	1254	1166	1105	1061	1028	976	947	929	917	902	894	886	883	876
60	1437	1232	1104	1020	961	918	886	835	806	788	776	762	754	746	743	736
65	1301	1107	985	904	847	806	775	726	697	679	667	653	645	637	634	627
70	1188	1005	889	811	757	717	687	638	610	592	581	567	559	551	547	541
75	1094	920	810	735	682	644	615	567	540	522	511	497	489	481	478	471
80	1014	849	743	672	621	584	556	509	482	465	454	440	432	424	421	414
85	945	788	687	618	570	533	506	461	434	417	406	392	385	377	373	367
90	886	735	639	573	526	491	464	420	394	377	366	353	345	337	334	327
95	833	689	597	534	488	454	428	385	360	343	332	319	311	304	300	294
100	787	649	560	499	455	423	398	356	331	314	304	290	283	275	272	265
110	708	582	499	443	402	371	347	307	283	268	257	244	237	229	226	219
120	644	527	451	398	359	330	308	270	247	232	222	209	202	194	191	184
130	591	482	411	361	325	298	277	240	218	204	194	181	174	167	163	157
140	546	444	378	331	297	271	251	217	195	181	172	160	153	145	142	135
150	508	412	350	306	274	249	230	197	177	163	154	142	135	128	124	118
160	474	385	326	284	254	230	212	181	161	148	139	127	121	113	110	104
170	445	360	305	265	236	214	197	167	148	135	126	115	109	102	98	92
180	420	339	286	249	221	200	184	155	137	125	116	105	98	92	88	82
190	397	320	270	235	208	188	172	145	127	115	107	96	90	83	80	73
200	376	304	256	222	197	177	162	136	119	107	99	89	83	76	73	66
210	358	288	243	210	186	168	153	128	112	101	93	82	76	70	66	60
220	341	275	231	200	177	159	145	121	105	94	87	77	71	64	61	55
230	326	262	220	191	169	152	138	115	99	89	82	72	66	60	56	50
240	312	251	211	182	161	145	132	109	94	84	77	67	62	55	52	46
250	299	241	202	175	154	138	126	104	90	80	73	64	58	52	49	42
260	288	231	194	167	148	133	121	99	85	76	69	60	55	48	45	39
270	277	222	186	161	142	127	116	95	82	72	66	57	52	46	42	36
280	267	214	180	155	137	122	111	91	78	69	63	54	49	43	40	34
290	257	207	173	149	132	118	107	88	75	66	60	52	46	41	38	32
300	249	200	167	144	127	114	103	84	72	64	57	49	44	38	35	29

G4.7.2 *Average Shear Stress*

The average shear stress in a member calculated on the cross section of the web shall not exceed the maximum permissible average shear stress τ_{va} as follows:-

a) *For unstiffened webs: appropriate permissible stress in* ***Table G.2***

b) *For stiffened webs: the values given in* ***Tables G.9, G.10*** *and* ***G.11*** *as appropriate yield stress values 250, 340 and 400 MPa respectively.*

NOTE :The allowable stresses given in **Tables G.9, G.10** and **G.11** apply provided any reduction of the web cross-section is due only to rivet/bolt holes etc. where large apertures are cut in the web, a special analysis shall be made to ensure that the maximum permissible average shear stresses laid down in this standard are not exceeded.

G4.8 Curtailment of Flange Plates

Each flange plate shall be extended beyond its theoretical cut-off point adequately. The extension shall contain sufficient rivets, bolts and welds to withstand the forces developed at the theoretical cut off point.

In welded construction, the use of curtailed flange plates shall be avoided as far as possible, local strengthening being provided by other means such as inserting by butt welding a thicker and or wider plate. The heavier section plate shall be suitably tapered to the lighter plate. If, in welded construction the use of curtailed flange plates cannot be avoided, the end of the plate shall be tapered in plan to a rounded end and all welds shall be continuous round the ends.

G4.9 Connection of Flanges to Web

The flanges of plate girders shall be connected to the web by sufficient rivets, bolts or welds to transmit the horizontal shear force combined with any vertical loads which are directly applied to the flange. In welded construction, where the web is in close contact with the flange before welding, vertical loads causing compression may be deemed to be resisted by the bearing between the flange and the web.

G4.10 Dispersion of Load through Flange to Web

Where a load is directly applied to a flange, it shall be considered as dispersed uniformly through the flange and the web at an angle of 45º.

Table G.9 Permissible Average Shear Stress τ_{va} in Stiffened Webs of steel with f_y =250 MPA (Clause G4.7.2)

Stress τ_{va} (MPa) for different distances between stiffeners

d/t ↓	0.3d	0.4d	0.5d	0.6d	0.7d	0.8d	0.9d	1.0d	1.1d	1.2d	1.3d	1.4d	1.5d
90	100	100	100	100	100	100	100	100	100	100	100	100	100
95	100	100	100	100	100	100	100	100	100	100	100	100	99
100	100	100	100	100	100	100	100	100	100	100	99	99	98
105	100	100	100	100	100	100	100	100	100	99	98	97	96
110	100	100	100	100	100	100	100	100	99	98	96	95	94
115	100	100	100	100	100	100	100	100	98	96	95	94	93
120	100	100	100	100	100	100	100	98	96	95	93	92	91
125	100	100	100	100	100	100	98	97	95	93	92	91	90
130	100	100	100	100	100	99	97	96	94	92	90	89	88
135	100	100	100	100	100	98	96	94	92	90	89	87	86
140	100	100	100	100	99	96	95	93	91	89	87	86	85
150	100	100	100	100	97	94	92	90	88	85	84	83	81
160	100	100	100	97	94	92	89	88	85	83	81	80	78
170	100	100	100	96	92	89	87	85	82	80	78	76	75
180	100	100	98	94	90	87	84	82	80	77	75	73	72
190	100	100	97	92	88	84	82						
200	100	100	95	90	86	82	81						
210	100	99	93	88	83	81							
220	100	98	91	86	81	80							
230	100	96	90	84	79								
240	100	95	88	83	77								
250	100	93	86	82	74								
260	100	92	85	81									
270	100	90	84	81									

Non-applicable zone.

NOTE : Intermediate values may be obtained by linear interpolitan.

Table G.10 Permissible Average Shear Stress τ_{va} in Stiffened Webs of steel with f_y =340 MPA (Clause G4.7.2)

Stress τ_{va} (MPa) for different distance between stiffeners

d/t	0.3d	0.4d	0.5d	0.6d	0.7d	0.8d	0.9d	1.0d	1.1d	1.2d	1.3d	1.4d	1.5d
75	136	136	136	136	136	136	136	136	136	136	136	136	136
80	136	136	136	136	136	136	136	136	136	136	136	136	136
85	136	136	136	136	136	136	136	136	136	136	136	134	133
90	136	136	136	136	136	136	136	136	136	135	133	132	131
95	136	136	136	136	136	136	136	136	135	133	131	129	128
100	136	136	136	136	136	136	136	136	132	130	128	127	126
105	136	136	136	136	136	136	135	133	130	128	126	124	123
110	136	136	136	136	136	135	133	131	128	126	124	122	120
115	136	136	136	136	136	133	131	129	126	123	121	119	118
120	136	136	136	136	135	131	129	127	124	121	119	117	115
125	136	136	136	136	133	129	127	125	121	119	116	114	113
130	136	136	136	135	131	127	125	122	119	116	114	112	110
135	136	136	136	134	129	126	123	120	117	114	111	109	108
140	136	136	136	132	127	124	121	118	115	112	109	107	105
150	136	136	136	129	124	120	117	114	110	107	104	102	100
160	136	136	132	126	120	116	113	110	106	102	99	97	95
170	136	136	129	123	117	112	109	106	101	98	95	92	90
180	136	135	127	119	113	108	105	102	97	93	90	87	84
190	136	133	124	116	110	105	100						
200	136	130	121	113	106	101	96						
210	136	128	118	110	103	97							
220	136	126	116	107	99	93							
230	136	123	113	103	96								
240	134	121	110	100	92								
250	132	119	107	97	89				(Non-applicable zone)				
260	130	116	104	94									
270	128	114	102	91									

NOTE: Intermediate values may be obtained by linear interpolation.

Table G.11 Permissible Average Shear Stress τ_{va} in Stiffened Webs of steel with f_y =400 MPA (Clause G4.7.2)

Stress τ_{va} (MPa) for different distance between stiffeners

d/t	0.3d	0.4d	0.5d	0.6d	0.7d	0.8d	0.9d	1.0d	1.1d	1.2d	1.3d	1.4d	1.5d
70	160	160	160	160	160	160	160	160	160	160	160	160	160
75	160	160	160	160	160	160	160	160	160	160	160	160	159
80	160	160	160	160	160	160	160	160	160	160	159	157	156
85	160	160	160	160	160	160	160	160	160	158	156	154	152
90	160	160	160	160	160	160	160	160	157	155	152	151	149
95	160	160	160	160	160	160	159	157	154	152	149	147	146
100	160	160	160	160	160	160	157	155	151	149	146	144	143
105	160	160	160	160	160	157	154	152	149	146	143	141	139
110	160	160	160	160	159	155	152	149	146	143	140	138	136
115	160	160	160	160	156	152	149	147	143	140	137	135	133
120	160	160	160	159	154	150	147	144	140	137	134	132	129
125	160	160	160	157	152	147	144	141	137	134	131	128	126
130	160	160	160	155	150	145	141	139	131	131	128	125	123
135	160	160	160	153	147	143	139	136	130	128	125	122	120
140	160	160	158	151	145	140	136	133	129	125	122	119	116
150	160	160	155	147	141	135	131	128	123	119	115	112	110
160	160	160	151	143	136	130	126	123	117	113	109	106	103
170	160	155	148	139	132	126	121	117	112	107	103	100	97
180	160	153	144	135	127	121	116	112	106	101	97	93	90
190	160	152	140	131	123	116	111						
200	160	149	137	127	118	111	106						
210	160	146	133	123	114	106							
220	157	143	130	119	109	101							
230	155	140	126	114	105								
240	153	137	123	110	100								
250	151	134	119	106	96			(Non-applicablezone)					
260	148	131	116	102									
270	146	128	112	98									

NOTE: Intermediate values may be obtained by linear interpolation.

G4.11 Web stiffeners

Web stiffeners shall be provided as follows:

G4.11.1 *Load bearings stiffeners*

G4.11.1.1 General

Webs of plate girders and rolled beams shall be provided with load bearing stiffeners at points of supports and at points of concentrated load where reaction or concentrated load exceeds the value of

$\sigma_{ac}.t.B$

where,

σ_{ac} = maximum permissible axial stress for struts as given in **Clause G2.4.2.1** for a slenderness ratio of $(d_3\sqrt{3})/t$

t = web thickness

d_3 = clear depth of web between root fillets

B = the length of the stiff portion of the bearing plus the additional length given by dispersion at 45° to the level of the neutral axis. The stiff portion of a bearing is that length which cannot deform appreciably in bending and shall not be taken as greater than half the depth of the beam continuous over a bearing.

G4.11.1.2 Details and design

a) Load bearing stiffeners should be in pairs (i.e, two legs of plates, angles etc.) placed symmetrically at both sides of the web. When the condition is not met the effect of the resulting eccentricity should be considered.

b) The ends of the load bearing stiffener should be closely fitted or adequately connected to both flanges. They should be shaped to allow space for any root fillet or weld connecting the web to the flange, with a clearance not exceeding five times the thickness of the web.

c) Load bearing stiffeners shall not be joggled and shall be solidly packed throughout.

d) Outstanding legs or each pair of load bearing stiffeners shall.be so proportioned that the bearing stress on that part of their area in contact with the flange and clear of the root of the flange or flange angles or clear of the flange welds, does not exceed the bearing stress specified in **Clause G2.4.1**.

e) Load bearing stiffeners consisting of two legs shall be designed as struts assuming the section to consist of the pair of stiffeners together with a length of web on each side of the centre line of the stiffeners equal to twenty times the web thickness (but limited to the edge distance of the web and half the distance of the adjacent stiffener).

   In case of bearing stiffeners consisting of four or more legs, the effective stiffener section should be taken to comprise the stiffeners, the web plate between the two outer legs and a portion of web plate not exceeding the length of the web as specified for single leg stiffeners on the outer sides of the outer legs.

f) The radius of gyration shall be taken about the axis parallel to the web of the beam or girder, and the working stress shall be in accordance with appropriate allowable value for a strut, assuming the effective length equal to 0.7 times the length of the stiffener.

g) The load bearing stiffeners shall be provided with sufficient rivets, bolts or welds to transmit to the web the whole of the load in the stiffeners.

h) When load bearing stiffeners at supports are the sole means of providing restraint against torsion (see **Clause G4.4.1.2**) the moment of inertia I of the stiffener shall not be less than

$$(D^3 \, T_m/250) \times (R/W)$$

where

I = moment of inertia of the pair of stiffeners about the centre line of the web plate

D = overall depth of the girder

T_m = maximum thickness of compression flange

R = reaction of the bearing

W = total load on girder

i) In addition, the base of the stiffeners in conjunction with the bearing of the girder shall be capable of resisting a moment due to horizontal force specified in **Clause G4.4.1.2**.

G4.11. 2 *Intermediate stiffeners*

G4.11.2.1 General

When the thickness of the web is less than the limits specified in **Clause 509.6(a)** of IRC:24, transverse stiffeners shall be provided throughout the length of the girder. When the thickness of the web is less than the limits specified in **Clause 509.6(b)** of IRC:24, longitudinal stiffeners shall be provided in addition to the transverse stiffeners.

In no case shall the greater unsupported clear dimension of a web panel exceed 270 t nor the lesser unsupported clear dimension of the same panel exceed 180 t where t is the thickness of the web plate.

G4.11.2.2 Transverse stiffeners

Where transverse stiffeners are required, they shall be provided throughout the length of the girder at a distance apart not greater than 1.5 d_1 and not less than 0.33 d_1, where d_1 is the depth as defined in **Clause 509.6** of IRC:24. Where horizontal stiffeners are provided d_1 shall be taken as the clear distance between the horizontal stiffener and the farthest flange ignoring fillets.

Transverse stiffeners shall be designed so that I is not less than :

$$1.5 \times (d_1^3 \times t^3)/s^2$$

Where

I = the moment of inertia of a pair of stiffeners about the centre of the web or a single stiffener about the face of the web,

t = minimum required thickness of the web

s = the maximum permitted clear distance between stiffener for thickness t

NOTE: *If the thickness of the web is made greater, or the spacing of stiffener made smaller than that required by the standard, the moment of inertia of the stiffener need not be correspondingly increased.*

Intermediate transverse stiffeners, when not acting as load bearing stiffeners, may be joggled and may be single or in pairs placed one on each side of the web. Where single stiffeners are used they should preferably be placed alternatively on opposite sides of the web. The stiffeners shall extend from flange to flange. They can be connected or fitted to, or kept well clear of the flanges.

G4.11.2.3 Longitudinal Stiffeners

Where longitudinal stiffeners are used in addition to vertical stiffeners they shall be as follows:

One longitudinal stiffener, on one or both sides of the web, shall be placed at a distance from the compression flange equal to two fifths of the distance from the compression flange to the neutral axis, when the thickness of the web is less than $d_2/200$ for steel conforming to IS 2062 upto Grade E250 and $d_2/180$ for steel conforming to IS 2062 Grade E300 and above where d_2 is the depth of web as defined in **Clause 509.6** of IRC:24. This stiffener shall have a moment of inertia **I** not less than 4 S_1 t^3 where I and t are as defined in **Clause G4.11.2.2** and S_1 is the actual distance between stiffeners.

A second longitudinal, on one or both sides of the web shall be placed on the neutral axis of the girder when the thickness. of the web is less than $d_2/250$ for steel conforming to IS 2062 upto Grade E250 or $d_2/225$ for steel conforming to IS 2062 Grade E300 and above. The stiffener shall have a moment of inertia **I** not less than d_2 t^3 where I and t are as defined in **Clause G4.11.2.2** and d_2 in **Clause 509.8** of IRC:24.

Longitudinal stiffeners shall extend between vertical stiffeners but need not be continuous over them or connected to them.

G4.11.2.4 External forces on intermediate stiffeners

When vertical intermediate stiffeners are subject to bending moments and shears due to the eccentricity of vertical loads, or the action of transverse forces, the moment of inertia I of the stiffeners specified in **Clause G4.11.2.2** shall be increased as follows :

a) Bending moment on stiffener due to eccentricity of vertical loading with respect to the vertical axis of the web :

   Increase of I = $(1.5\ M\ D^2)/(E\ t)$

b) Lateral loading on stiffener

   Increase of I = $(3\ P\ D^3)/(E\ t)$

Where

M = the applied bending moment

D = overall depth of girder

E = Young's modulus

t = thickness of web

P = lateral force to be taken by the stiffener and deemed to be applied at the compression flange of the girder.

G4.11.2.5 Connection of intermediate stiffeners to web

Intermediate transverse and longitudinal stiffeners not subjected to external loads shall be connected to the web by welds or rivets, in order to withstand a shearing force in kilograms per millimeter run between each component of stiffener and the web, of not less than $12.6.t^2/h$, where *t* equals web thickness in mm and h equals the projection in mm, of the stiffener component from the web.

G4.11.2.6 Outstand of all stiffeners

Unless the outer edge of each stiffener is continuously stiffened, the outstand from the web shall be not more than the following:

For sections	:	16*t* for steel conforming to IS 2062 upto Grade E250
		14*t* for steel conforming to IS 2062 Grade E300 and above
For flats	:	12*t* for all steels

Where *t* is the thickness of the section or flat

G4.12 Flange Splices

Flange joints should preferably not be located at points of maximum stress. Where splice plates are used, their area shall not be less than 5 percent in excess of the area of the flange element spliced, their centre of gravity shall coincide, as nearly as possible, with that of the element spliced. There shall be enough rivets or welds on each side of the splice to develop the load in the element spliced plus 5 percent, but in no case should the strength developed be less than 50 percent of the effective strength of the material spliced.

In welded construction, flange plates or angles shall be joined by full penetration buttwelds wherever possible. These butt welds shall develop the full strengths of plates or angles. Where this is not possible, splice plate should be used.

G4.13 Splices in Webs

Splices in the webs of plate girders and rolled sections shall be designed to resist the shears and moments at the spliced section.

In riveted construction, splice plates shall be provided on each side of the web. In welded construction web plates shall be joined by full penetration buttwelds wherever possible. Where this is not possible, splice plate may be used on both sides.

G4.14 End Connections

Connections at the ends of all beams designed as simply supported beams shall have flexibility.

G4.15 Lateral Bracing

All spans shall be provided with a lateral bracing system extending from end to end of sufficient strength to transmit to the bearings all lateral forces due to wind, seismic effect etc. as applicable.

G4.16 Expansion and Contraction

In all bridges, provision shall be made in the design to resist thermal stresses induced, or means shall be provided for movement caused by temperature changes. Provision shall also be made for changes in length of span resulting from live loads.

G5 DESIGN OF COMPRESSION MEMBERS

G5.1 General

Design of compression members should generally follow the considerations under **Clause G7.2** under "Trusses or open web Girders" of this Annexure.

G5.2 Base Plate

G5.2.1 Base Plate is a structural part which serves as medium for uniformly transferring load from member/stanchion/column to foundation.

G5.2.2 Area of base plate should be such that at any point reactive pressure acting on it is less than allowable stress of concrete in compression.

$$A_F = N/\sigma_{cc}$$

Where,

A_F = Area of base plate
N = Load in the member
σ_{cc} = Allowable compressive stress of concrete
For Crushing value of concrete, IS 456 may be referred for guidance.

G5.2.2.1 Width of base plate should be $B=b(\text{or } h) + 2t_s+2c$

Where
b and *h* = Size of member/stanchion/column
t_s = Thickness of saddle plate, 8 mm - 10 mm
c = Cantilever portion restricted to 100 mm – 120 mm, but not less than 20 mm from outside member, stiffener to the edge of base plate.
Length of base plate $L = A_F / B$
A_F= Area of base plate

G5.2.2.2 Thickness of base plate should not be less than 20 mm

G5.2.2.3 Thickness of plate is determined from its bending consideration due to reactive pressure of foundation on base plate.

$$P_F=N/A_F$$

Where
P_F= Reactive pressure on base plate

Base plate area in general can be divided in four types depending upon boundary conditions of support (stiffeners).

i) Cantilever
ii) Supported on two sides perpendicular to each other
iii) Supported on three sides
iv) Supported on four sides

G5.2.2.3.1 Bending moment in case of cantilever for 1 cm width of base plate (case-1):

$$M_1 = P_F c^2/2$$

G5.2.2.3.2 Maximum bending moment in centre of free B-side in case of plate having support at three sides and also at two perpendicular sides.

$$M_2 = \alpha P_F b^2$$

Where

α = Coefficient as per table below depending on a/b

a = Length in the other perpendicular direction

b = Length of free shorter side of plate

a/b	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	2.0	More than 2
α	0.06	0.074	0.088	0.097	0.107	0.112	0.120	0.126	0.132	0.133

If $a/b \leq 0.5$, the support of plate on a-side does not have any effect, as such for bending moment on base plate formula for cantilever type should be used with c =*a*.

G5.2.2.3.3 Maximum Bending Moment in case of plate having support at four sides

$$M_3 = \beta P_F (b_1)^2$$

Where

β = Coefficient as per table below, depending on a_1/b_1

a_1= longer side length

b_1= Short side length

a_1/b_1	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	More than 2
β	0.048	0.055	0.063	0.069	0.075	0.081	0.086	0.091	0.094	0.098	0.1	0.125

In case $a_1/b_1>2$, plate works as single span simply supported beam and bending moment,

$$M_3 = P_F (b_1)^2/8$$

G5.2.2.3.4 Thickness of the base plate

$$t_B = \sqrt{\frac{6M}{\sigma_{bc}}}$$

Where

M = Maximum bending moment considering all areas in which base plate is divided

σ_{bc} = Maximum permissible bending stress in slab base

G5.2.2.4 Section of stiffeners saddle element of base plate and its connections are designed for loads coming on them. Main stiffeners are designed as simply supported over hanging beam loaded with uniformly distributed load equal to $qs_1 = P_F * l_1$ and checked for bending and shear stresses.

G5.2.2.4.1 Secondary stiffeners (considering cantilever) are designed for load equal to $qs_2 = P_F * l_2$ and checked for bending and shear stress.

G5.2.2.5 Welded and riveted connections are designed to transfer the loads coming on stiffeners to main member and also to connect base plate with stiffeners.

G5.2.2.6 In case of heavy load transfer from member to the base plate, machining of contact surface between base plate and member is recommended and the area of the base plate shall be sufficient to limit the stress in bearing for whole of the load. In such cases the weld or rivet connecting base plate with stiffeners and main member should be designed for 25 percent of total load coming on base plate (for resisting the unforeseen bending and shear) which should be resisted by total weld length or all rivets.

G5.2.2.7 Base plate for eccentrically loaded members - Action due to bending moment in base plate along with compression causes non uniform pressure on the foundation and value of max. and min. pressure can be computed as under:

$$P_{FMAX,\,Min} = \frac{N}{BL} \pm \frac{6Mx}{BL^2} \pm \frac{6My}{LB^2}$$

Where B&L are width and length of base plate. M_x and M_y are moments in the length and width direction of base plate respectively.

G5.2.2.8 Thickness of base plate is computed as per **Clauses G5.2.2.3.1** to **G5.2.2.3.4** and bending moment is calculated based on maximum pressure acting on each area in which base plate is divided, neglecting non-uniform pressure from foundation on base plate on conservative side.

G5.2.2.9 Elements of base plate main and secondary stiffeners are designed as per **Clauses G5.2.2.4** and **G5.2.2.4.1**.

G5.3 Cap Plate

Cap plate serves as medium for transferring the axial load from structure above (beam, girder) uniformly to the member/stanchion.

G5.3.1 The thickness of cap plate should be preferably 16-25 mm and stiffener's thickness should not be less than

$\frac{I}{15}\sqrt{\frac{2600}{F_y}}$ times width of stiffener, where F_y is the yield stress of stiffener in kg/cm²

G5.3.1.2 When the load from beam is transferred to stanchion member through bearing stiffeners extended beyond the beam, the cap plate serves as media to transmit this load to the stiffeners connected to web of stanchion/member, or to tie beam for lattice member by rivet or weld. The cap plate is designed for specified load.

G5.3.1.2.1 If the beam/girder is supported on stanchion in such a manner that loads are directly transmitted to the flange of stanchion or main element or lattice member, cap plate should be provided as per **Clause G5.3.1** without calculation.

G5.3.1.3 The width of cap stiffeners is determined from bearing criteria

$$bsc = \frac{N}{\sigma_{bg} . t_c}$$

and also shear stress should not exceed specified stress

$$\frac{N}{l_{sc}.t_c} \le \sigma_s$$

Where

l_{sc} = Length of stiffener to be sufficient for transmitting the load to web of stanchion by rivet or weld.

σ_{bg} = Basic permissible bearing stress

N = Load to be transmitted from girder/beam

b_{SC} = Width of stiffener.

t_c = Thickness of the stiffener

G6 DESIGN OF TENSION MEMBERS

G6.1 Design of tension member should generally follow the considerations under **Clause G7.3** under "Trusses or open web Girders" of this **Annexure**.

G7 DESIGN OF TRUSSES OR OPEN-WEB GIRDERS

G7.1 General

G7.1.1 *Analysis*

Refer to **Clause 508.2** of IRC:24

G7.1.2 Intersection at joints

Refer to **Clause 508.3** of IRC:24

G7.2 Compression Member

G7.2.1 *General requirements*

This clause covers the design of straight members of uniform cross section subjected to axial compression or to combined compression and bending.

G7.2.2 *Effective sections*

G7.2.2.1 The properties of the cross section should be computed from the effective sectional area. Where plates are provided solely for the purposes of lacing or battening these shall be ignored in computing the radius of gyration of the section.

G7.2.2.2 The effective sectional area shall be the gross area less the specified deduction for excessive widths of plate, (see **Clauses G7.2.2.3 & G7.2.2.4**) and the maximum deduction for open holes, including holes for pins and black bolts occurring in a section perpendicular to the axis of the member within the critical zone of the compression member.

G7.2.2.3 For members other than circular hollow section, for calculating the effective cross sectional area of a member in compression, the effective width be of a plate, in terms of its width b measured between adjacent lines of rivets, bolts or welds connecting it to other parts of the section, unless effectively stiffened shall be taken as :

i) For riveted, bolted or stress relieved welded members in steel conforming to IS 2062 upto Grade E250.

   For b/t not above 45, $b_e = b$

   For b/t above 45, $b_e = 45t$

   With a maximum value of b/t = 90

ii) For riveted or bolted members in steel conforming to IS 2062 Grade E300 and above

   For b/t not above 45, $b_e = b$

   For b/t above 45, $b_e = 40\,t$

   With a maximum value of b/t = 80

iii) For welded members (not stress relieved) in steel conforming to IS 2062 (all Grades)

   For b/t not above 30, $b_e = b$

   For b/t above 30, $b_e = 40\,t \times [(b/t - 18)/(b/t - 14)]$

   With a maximum value of b/t = 80

In the above, "t" is the thickness of a single plate or the aggregate thickness of two or more plates; provided these are adequately tacked together considering maximum allowable pitch and edge distance of rivets or bolts.

G7.2.2.4 The unsupported projection of any plate, measured from its edge to the line of rivets, bolts or weld connecting the plate to other parts of the section shall not exceed :

i) *l6t* for Steel conforming to IS 2062 upto Grade E250

ii) *l4t* for Steel conforming to IS 2062 Grade E300 and above

where *'t'* is as defined above. However in case of compression flanges *'t'* is the thickness of the thinnest flange plate or the aggregate thickness of two or more plates when the projecting portions of these plates are adequately tacked together.

G7.2.3 *Permissible stresses and slenderness ratio*

G7.2.3.1 Permissible stress

Values of axial compression in MPa for some of the structural steels corresponding to various slenderness ratios are given in **Table G.12**.

G7.2.3.2 The ratio of the effective length to the least radius of gyration shall not exceed:

120 for main members, and

140 for wind bracings and subsidiary members

G7.2.3.3 All values of permissible stress in axial compression in MPa for structural steel with Yield stress other than those shown in **Table G.12** may be calculated by using the following formula subject to the condition that σ_{ac} shall not exceed $0.6f_y$.

$$\sigma_{ac} = 0.6\frac{f_{cc}{}^{*}f_y}{\left[(f_{cc})^n + (f_y)^n\right]^{1/n}}$$

Where

σ_{ac} = Permissible stress in axial compression, in MPa

f_y = yield stress of steel, in MPa

f_{cc} = elastic critical stress in compression

$$= \frac{\pi^2.E}{\lambda^2}$$

E = modulus of elasticity of steel; 2 x 10^5 MPa

$\lambda=(l/r)$ Slenderness ratio of the member, ratio of the effective length to appropriate radius of gyration; and

n = a factor assumed as 1.4

Table G.12 Permissible Stress σ_{ac} (MPa) in Axial Compression for Steels with Various Yield Stresses (Clause G7.2.3.1)

Yield stress (f_y) MPa			
λ=*l*/r ↓	**250**	**340**	**400**
10	150	204	239
20	148	201	235
30	145	194	225
40	139	183	210
50	132	168	190
60	122	152	168
70	112	135	147
80	101	118	127
90	90	103	109
100	80	90	94
110	72	79	82
120	64	69	71
130	57	61	62
140	51	54	55
150	45	48	49
160	41	43	43
170	37	38	39
180	33	34	35
190	30	31	31

Yield stress (f_y) MPa			
λ=*l*/r ↓	**250**	**340**	**400**
200	28	28	28
210	25	26	26
220	23	24	24
230	21	22	22
240	20	20	20
250	18	18	19

Where l = effective length of the member & r = radius of gyration

G7.2.4 *Effective length of compression members other than lacings*

G7.2.4.1 In riveted, bolted or welded trusses, the compression members act in a complex manner and the effective length to be used in computing allowable working stresses for compression members shall be taken as given in **Table G.13** except that, for battened struts, all values given in table shall be increased by 10 percent.

Table G.13 Effective Length of Compression Members
(Clause G7.2.4.1)

Member		Effective length *l* of member		
			For bucking normal to the plane of the truss	
		For buckling in the plane of the truss	Compression chord or (compression) member effectively braced by lateral system	Compression chord or (compression) member unbraced
Chords		0.85 x distance between centres of intersection with the web members	0.85 x distance between centres of intersection with the lateral bracing members or rigidly connected cross girders	See Clause G7.2.4.1
Web	Single triangulated system	0.70 x distance between centres of Intersection with the main chords	0.85 x distance between centres of intersections	Distance between centres of intersection
	Multiple intersection system where adequate connections are provided at all points of intersection	0.85 x greatest distance between centres of any two adjacent intersections	0.70 x distance between centres of intersection with the main chords	0.85 x distance between centres of intersection with the main chords

NOTE: *The intersection referred to are those of the centroidal axis of the members*

G7.2.4.2 For single angle discontinuous struts connected to gussets or to a section either by riveting or bolting by not less than two rivets or bolts in line along the angle at each end, or by their equivalent in welding, the eccentricity of the connection with respect to the centroid of the strut may be ignored and the strut designed as an axially loaded member provided that the calculated average stress does not exceed the allowable stresses given in **Table G.12** in which *"l"* is the length of the strut, centre to centre of fastenings at each end and *'r'* is the minimum radius of gyration.

G7.2.4.3 For single angle discontinuous struts intersected by, and effectively connected to another angle in cross bracing, the effective length in the plane of bracings shall be taken as in **Table G.13** and normal to the plane of bracing the effective lengths shall be taken as the distance along the bracing members between the points of intersection and the centroids of the main member. In calculating the ratio of slenderness, the radius of gyration about the appropriate rectangular axis shall be taken for buckling normal to the plane of the bracing and the least radius of gyration for buckling in the plane of the bracing.

G7.2.4.4 Effective length of unbraced compression chords

For simply supported trusses with ends restrained at the bearings against torsion, the effective length I of the compression chord for buckling normal to the plane of the truss shall be taken as follows:

a) With no lateral support to compression chord; where there is no lateral bracing between compression chords and no cross frames:

$$l = \text{span}$$

b) With compression chords supported by U frames, where there is no lateral bracing of the compression chord but where cross members and verticals forming U frames provide lateral restraints:

$$l = 2.5 * \sqrt[4]{EIa\delta} \text{ but not less than "a"}$$

Where

E = Young's modulus

I = maximum moment of inertia of compression chord about the axis lying in the plane of the truss

a = distance between frames, and

δ = the virtual lateral displacement of the compression chord at the frame nearest mid span of the truss, taken as the horizontal deflection. This deflection shall be computed assuming that the cross member is free to deflect vertically and that the tangent to the deflection curve at the centre of its span remains parallel to the neutral axis of the unrestrained cross member

When δ is not greater than $a^3/(40EI)$

I = a

In case of symmetrical U frames, where cross member and verticals are each of constant moment of inertia throughout their own length; it may be assumed that :

$$\delta = \frac{(d_1)^3}{3EI_1} + \frac{(d_2)^2 C}{EI_2}$$

Where,

d_1 =	distance of the centroid of the compression chord from the top of the cross member,
d_2 =	distance of the centroid of the compression chord from the neutral axis of the cross member,
C =	half the distance between centres of the main trusses;
E =	Young's Modulus
I_1 =	moment of inertia of the vertical in its plane of bending and
I_2 =	moment of inertia of the cross member in its plane of bending
f	flexibility of the joint between the cross member and the stiffeners of U frame expressed in radian per unit moment

U frames shall have rigid connections and shall be designed to resist, in addition to the effects of wind and other applied forces, the effects of a horizontal force F acting normal to the compression chord of the truss at the level of the centroid of this chord where:

$$F = \frac{1.4 x 10^{-3} l}{\delta \left\{ \frac{C_0}{f_a} - 1.7 \right\}}$$

In the above formula:

$$l = 2.5\, x \sqrt[4]{EIa\delta}$$

δ =	the deflection of the chord under the action of unit horizontal force F
C_0 =	Euler critical stress in chord = $\pi^2 E/(l/r)^2$

Where,

E =	Young's modulus
r =	radius of gyration
f_a =	calculated working stress in the chord

c) With compression chord supporting continuous deck, a compression chord continuously supporting a reinforced concrete or steel deck shall be deemed to be effectively restrained laterally throughout its length (e.g., *l* = 0) if the friction or positive connection of the deck to the chord is capable of resisting a lateral force, distributed uniformly along its length of 2.5 percent of the maximum force in the chord, in addition to other lateral forces.

G7.2.5 *Lacing and battening*

For general design and detailing aspect refer to **Clauses 507.6, 507.7, 507.8** and **507.9** of IRC:24.

G7.3 Tension Members

G7.3.1 *General requirements*

Tension members should preferably be of solid cross section. However, when composed of two or more components these shall be connected as described in **Clauses 506.2.6, 506.2.7** and **506.2.8** of IRC:24.

G7.3.2 *Effective sectional area*

The properties of the cross-section shall be computed from the effective sectional areas as given in **Clause G3.8.2**. When plates are provided solely for the purposes of lacing or battening, they shall be ignored in computing the radius of gyration of the section.

G7.3.3 *Slenderness ratio*

Refer to **Clause 506.2.1** of IRC:24

G7.3.4 *Lacing and battening*

For design and detailing refer to **Clauses 506.2.4, 506.2.5, 506.2.7** and **506.2.8** of IRC:24.

G7.3.4.2 Where battens are attached by welds, the length of welds connecting each longitudinal edge of the batten plate to the component shall, in the aggregate, be not less than half the length of the batten plate, and at least 1/3 of the weld shall be placed at each end of the longitudinal edge. In addition, welding shall be returned along the ends of the plate for a length at least four times the thickness of the plate.

G7.3.4.3 Where the tie or batten plates are fitted between main components they shall be connected to each member either by fillet welds on each side of the plate, at least equal in length to that specified in the preceding paragraph or by full penetration butt weld.

G7.4 Splices

G7.4.1 *For compression member*

G7.4.1.1 Splices in compression members located at or near effectively braced panel points shall be designed to transmit the full design load in the member. All other splices in compression members shall have a sectional area 5 percent more than that required to develop the load in the member at the average working stress of the member. All cover material shall, as far as practical, be so disposed with respect to the cross-section of the member so as to transmit the proportional load of the respective parts of the section.

G7.4.1.2 Wherever possible both surfaces of the parts spliced shall be covered or other means taken to maintain the alignment of the abutting ends.

G7.4.1.3 Where flexural tension may occur in the member, the cover material shall be designed to resist such tension.

G7.4.1.4 Rivets, bolts or welds shall develop the full load in the cover material as defined above calculated on the cover area.

G7.4.2 *For tension members*

G7.4.2.1 Splices in tension members shall have a sectional area 5 percent more than that required to develop the load in the member and, whenever practicable, the cover material shall be disposed to suit the distribution of stress in the various parts of the cross section of the member. Both surfaces of the parts splices shall be covered wherever possible.

G7.4.2.2 Rivets, bolts or welds shall develop the full load in the cover material as defined above, calculated on the cover area.

G7.5 *Connections at intersection- refer to Clause 508.6 of IRC:24*

G7.6 *Lug angles- refer to Clause 508.7 of IRC:24*

G7.7 *Section at pin holes in tension members- refer to Clause 508.8 of IRC:24*

G7.8 *Pin plates- refer to Clause 508.9 of IRC:24*

G7.9 *Diaphragms in members-refer to Clause 508.10 of IRC:24*

G7.10 *Lateral bracings- refer to Clause 508.11 of IRC:24*

G.8 CONNECTIONS

G8.1 Composite Connections

In any connection which takes a force directly communicated to it and which is made with more than one type of fastening, only rivets and turned and fitted bolts may be considered as acting together to share the load. In all other connections sufficient number of one type of fastening shall be provided to communicate the entire load for which the connection is designed.

G8.2 Welded Connections

G8.2.1 *Welds shall conform to IS 816 and IS 9595 as appropriate*

G8.2.2 *Types of welds: Refer to **Clause 512.4.2** of IRC:24*

G8.2.3 *Strength of weld: Refer to **Clause 512.4.3** of IRC:24*

G8.2.4 *General requirements of welds: Refer to **Clause 512.4.4** of IRC:24*

G8.3 Connections made with Bearing type Bolts, Rivets or Pins

G8.3.1 *General*

Refer to **Clause 512.5.1** of IRC:24

G8.3.2 *Connections and splices in flexural members:* Refer to **Clause 512.5.2** of IRC:24

G8.3.3 *Connections in triangulated structures:* Refer to **Clause 512.5.3** of IRC:24

G8.3.4 *Rivets and bolts*

a) Gross and Net Areas of Rivets and Bolts-

The gross area of a rivet shall be taken as the cross sections area of the rivet hole.

The net sectional area of a bolt or screwed tension rod shall be taken as the tension area for the particular diameter of bolt as given in the table below :

Nominal Thread Dia (mm)	12	14	16	18	20	22	24	27	30	33
Nominal Stress Area (mm²)	84	115	157	192	245	303	353	459	561	694

b) Calculation of stresses

Calculation of stresses in rivets and bolts shall be as per **Clause G2.5.2**

C) Diameter of Rivet and Bolt Holes

Refer to **Clause 512.5.4(a)** of IRC:24

d) Edge Distance

Refer to **Clause 512.5.4(b)** of IRC:24

e) Pitch of rivets or bolts

Refer to **Clause 512.5.4(c)** of IRC:24

f) Long Rivets

The grip of rivets carrying calculated loads shall not exceed 8 times the diameter of the holes. Where the grip exceeds 6 times the diameter of the hole, the number of rivets required by normal calculation shall be increased by not less than half a per cent for each additional millimeter of length of grip above 6 times the hole diameter.

g) Rivets with counter Sunk Head

Refer to **Clause 512.5.4 (d)** of IRC:24

h) Rivets or bolts through packing

Number of rivets or bolts carrying calculated shear through a packing shall be increased above the number required by normal calculations by 2.5 percent for each 2.0 mrn thickness of packing except that, for packing having a thickness of upto 6 mm, no increase need be made. For double shear connections packed on both sides, the number of additional rivets or bolts required shall be determined from the thickness of the thicker packing. The additional rivets or bolts shall be placed in an extension of the packing.

i) Staggered Pitch –

When rivets and bolts are staggered at equal intervals and the gauge does not exceed 75 mm, the distances between centres of rivets and bolts as specified earlier may be increased by 50 percent.

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/Manual, etc. from the date specified therein)