IRC:SP:71-2018

GUIDELINES FOR DESIGN AND CONSTRUCTION OF PRECAST PRE-TENSIONED GIRDERS FOR BRIDGES

(First Revision)

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CONTENTS

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GUIDELINES FOR DESIGN AND CONSTRUCTION OF PRECAST PRE-TENSIONED GIRDERS FOR BRIDGES

1 INTRODUCTION

1.1 IRC:SP:71 was first published in 2006, which was in line with IRC:18, IRC:21 and IS14268 with additional inputs from BS:5400, EURO and AASHTO Codes. In the year 2009, IRC decided to adopt Limit State Method (LSM) approach for bridge design standards in the country and gradually bring out new documents. In the year 2011, IRC:18 & IRC:21 have been withdrawn and replaced by IRC:112 covering Limit State design approach.

1.2 The B-4 Committee was re-constituted in the year 2015 for three years period and the committee in its first meeting decided to take up the task to align all existing Working Stress Method (WSM) based special publications of IRC with IRC:112. Accordingly, the task of revision of IRC:SP:71 was assigned to Shri Vinay Gupta and he carried out all requisite modifications in line with IRC:112, which were discussed in several meetings of B-4 Committee and finally approved in its meeting held on 11.10.2017. Thereafter, the draft document was approved by the Bridges Specifications and Standards Committee in its meeting held on 23.10.2017. Finally, the document was considered by the IRC Council in its 213th meeting held on 03.11.2017 during the Annual Session held at Bengaluru and was approved for publication.

1.3 The personnel of the Concrete (Plain, Reinforced and Pre-stressed) Structures Committee (B-4) are as under:

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2 SCOPE

2.1 These guidelines cover the specific design and construction requirements pertaining to precast pre-tensioned girders, which may constitute a superstructure system. Such structural systems may comprise precast girders in association with cast-in-situ/precast deck slab and diaphragms, spliced girder system, precast pre-tensioned open or closed box sections, precast pretensioned deck slab, integral bridge, etc. These superstructures may either be simply supported, continuous or integral. In case of continuous or integral superstructures, the continuity, integration may be achieved either through untensioned reinforcement at the intermediate supports/joints, through post-tensioning or any suitable method. In these type of construction, the decompression requirement as per Table 12.1 of IRC:112 for the precast, pre-tensioned or post-tensioned girder sections over the negative moment region need not be adhered to. However, the crack width requirement shall be satisfied.

2.2 In pre-tensioning, the tendons are prestressed before concreting and prestress transferred to the concrete, through bond, when it attains the requisite minimum strength and maturity. Whereas, in the case of post-tensioning, tendons are prestressed after concrete gains the requisite minimum strength and maturity. **Fig. 1** depicts examples of precast pretensioned girders made continuous over supports. **Figs. 2 & 3** depict an example of a pre-tensioned girder indicating bonded and debonded part of tendons which are specifically required for stress control in pre-tensioned girders. **Fig. 4** depicts a few possible shapes of stirrups of precast girders.

3 DESIGN REQUIREMENTS

The loads and load combinations shall be as per IRC:6.

Design shall be carried out in accordance with the provisions of IRC:112 except for the modifications and additional provisions specified below, which need to be followed.

3.1 Basis of Design

ULS (flexure and shear design) and SLS designs shall be carried out as per Sections 8, 10 and 12 of IRC:112, as relevant, with some modifications as specified below. Sections 1 to 7, 13 to 18, Normative Annexures and Informative Annexures of IRC:112 apply, releventl. Respective loads and load combinations shall be taken as per IRC:6.

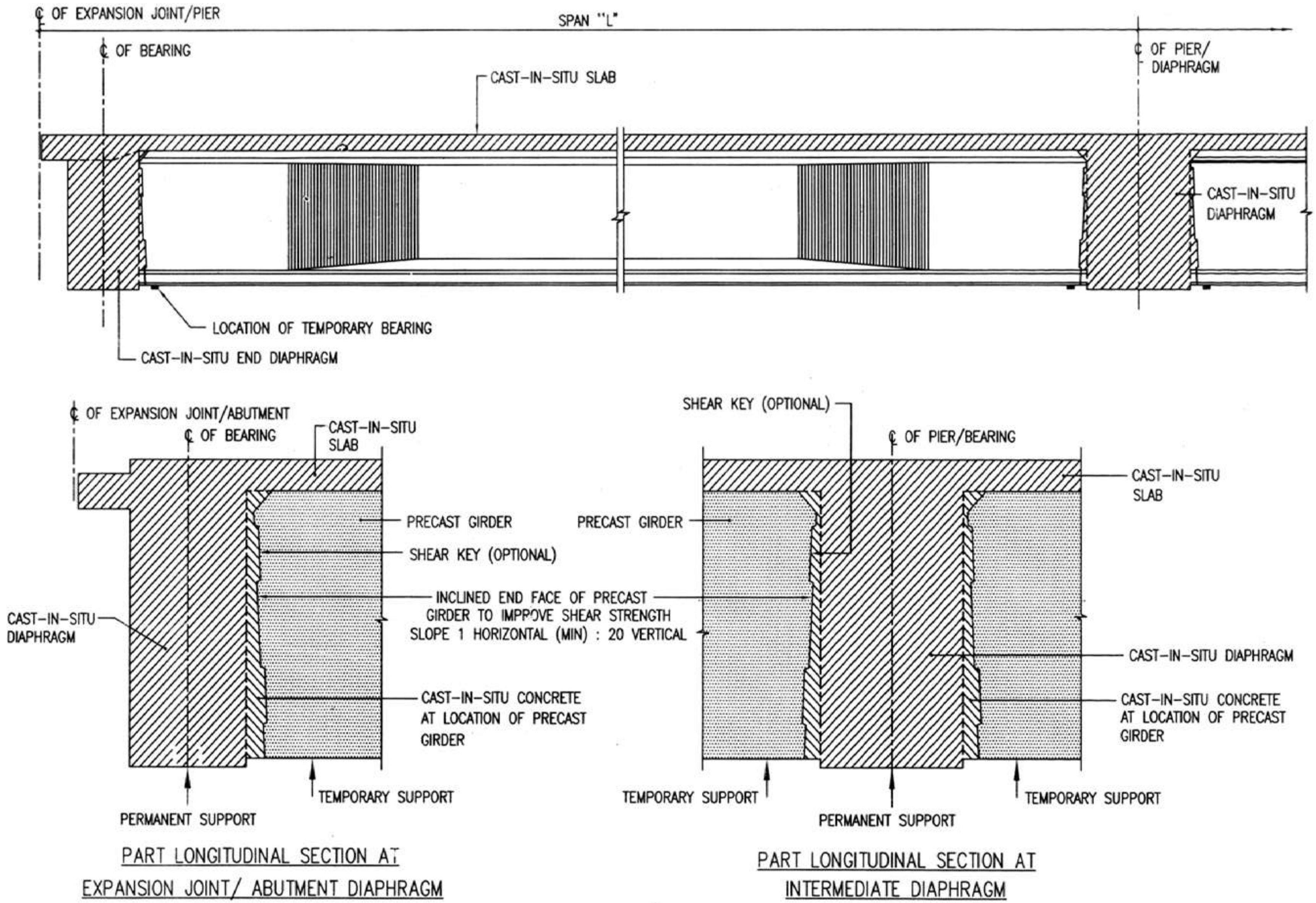

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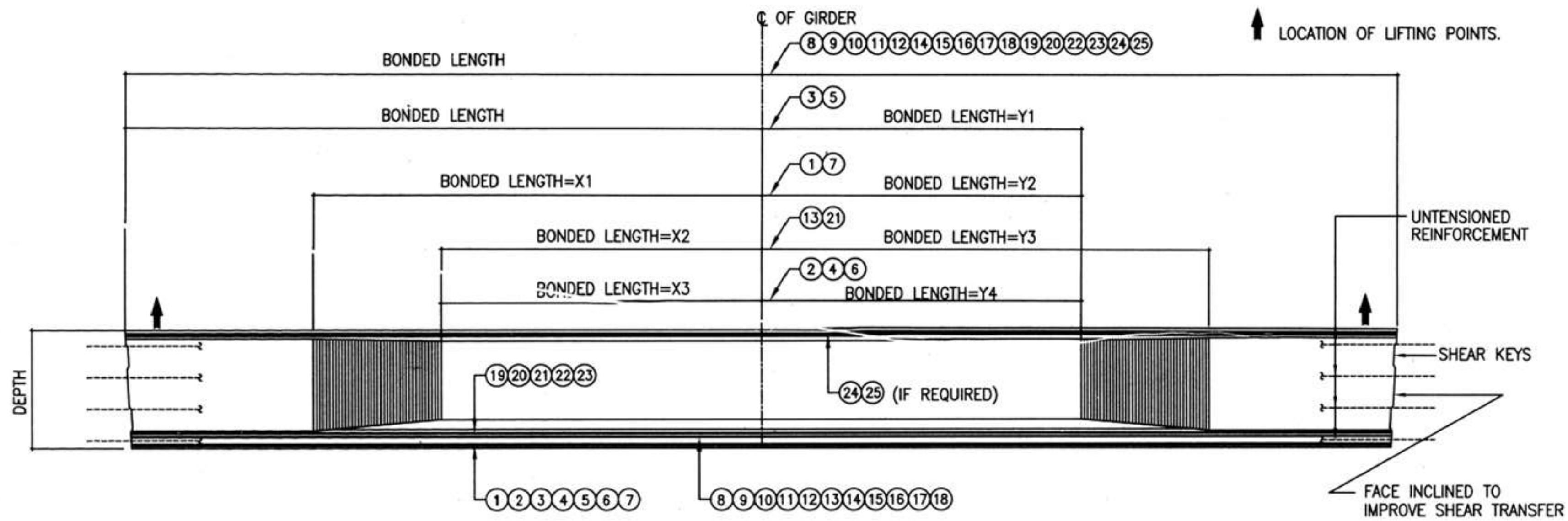
Fig. 1 Typical Arrangement of Precast Girder, Made Continuous



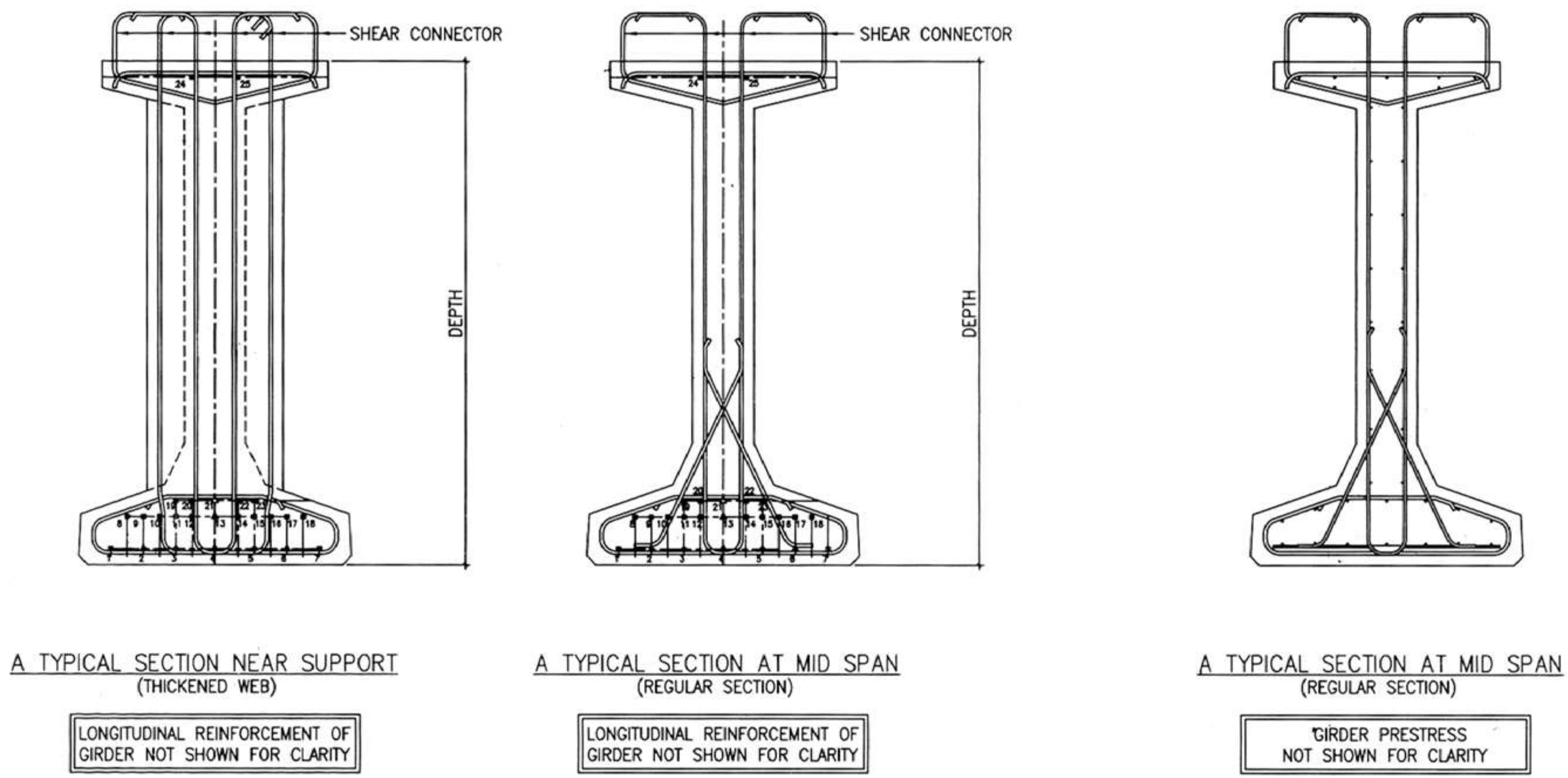
ELEVATION (SHOWING TENDONS ONLY)

TYPICAL BONDING/DEBONDING SCHEDULE

SYMBOL	STRAND NOS.	BONDING LENGTH (mm)	SCHEDULE OF BONDING & DEBONDING
■	8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24 & 25	NO DEBONDING	FACE OF THE BEAM — BONDED LENGTH — ℄ OF BEAM/SYMM. — FACE OF THE BEAM
◓	3 & 5	VARIES	FACE OF THE BEAM — BONDED LENGTH — Y1 (BONDING) — DEBONDED — FACE OF THE BEAM
◪	1 & 7	X1+Y2	FACE OF THE BEAM — DEBONDED — X1 (BONDING) — Y2 (BONDING) — DEBONDED — FACE OF THE BEAM
△	13 & 21	X2+Y3	FACE OF THE BEAM — DEBONDED — X2 (BONDING) — Y3 (BONDING) — DEBONDED — FACE OF THE BEAM
▲	2, 4 & 6	X3+Y4	FACE OF THE BEAM — DEBONDED — X3 (BONDING) — Y4 (BONDING) — DEBONDED — FACE OF THE BEAM

Reference Para : 2

Fig. 2 Typical Detail of Pretensioned Girder



BONDED STRANDS SUCH AS 8 TO 12, 14 TO 20 & 22 TO 25, CAN BE EMBEDDED IN CAST–IN–SITU CONCRETE OF DIAPHRAGM TO CONSTITUTE BOTTOM REINFORCEMENT OF THE GIRDER IN ADDITION TO THE HYSD REINFORCEMENT.

Reference Para : 2

Fig. 3 Typical Sections of Pretensioned Girder

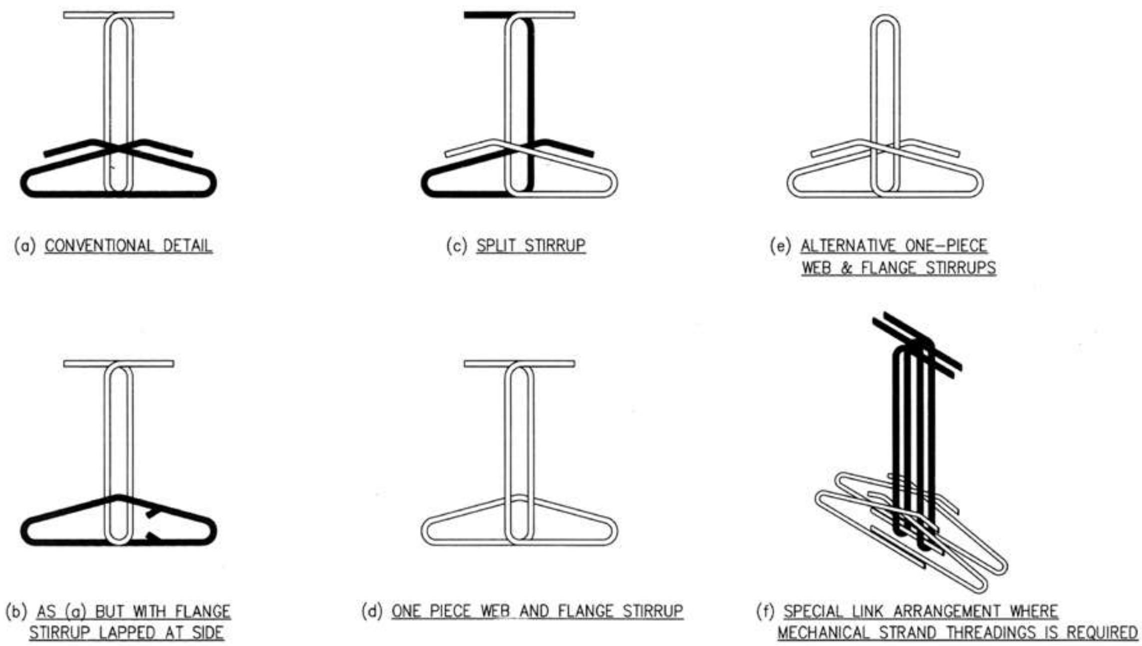


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Fig. 4 Suggested Shapes of Stirrups in Girders

3.2 Allowable Stresses (SLS)

3.2.1 *Allowable Stresses in Concrete*

The maximum compressive stresses, in different load combinations shall be limited as per clause 12.2.1 of IRC:112 for precast pre-tensioned superstructures.

3.2.2 *Allowable Stresses in Steel*

The limits given in clause 12.2.2 of IRC:112 shall apply.

3.3 Minimum Dimensions

The minimum dimensions of all components of pre-tensioned girders shall satisfy various requirements of IRC:112, such as cover, spacing of bar/prestressing strand etc.

The following minimum limitations relating to various structural components shall be followed:

Thickness of top flange	: 100 mm
Thickness of bottom flange	: 150 mm
Thickness of web	: 150 mm
Thickness of deck slab where top flanges are contiguous	: 150 mm

Note:

The minimum web thickness indicated above applies to 'T' and 'I' shaped girders. In case of other special types of sections, minimum web thickness may be decided on the basis of appropriate specialist literature.

3.4 Minimum Reinforcement

The minimum longitudinal reinforcement (as far as possible, evenly spaced over periphery) in precast girder-slab superstructure shall be as follows:

a) Fully prestressed superstructure where no tension is occurring: 0.15% of HYSD bars for upto M45 grade concrete and 0.18% for higher concrete grades.

b) In partially prestressed superstructure: In tension zone it shall not be less than that calculated as per Sections 12 and/or 16 (whichever is higher) of IRC:112. And, in compression zone, same as in (a) above.

In order to meet the requirement of minimum untensioned steel as per Sections 12 and 16 of IRC:112, the available high tensile steel (bonded only) may be assumed to constitute this requirement, considering it at same strength as the untensioned steel.

3.5 Losses in Prestress

The losses due to creep and shrinkage of concrete shall be calculated in the manner stipulated in Section 7 of IRC:112, taking due account of various stages of loading. Non-linear creep can often occur in precast girders, where stressing is often carried out at an early age and initially there is small dead load. In such cases, compressive stress as per clause 12.2.1(2) has a greater chance of exceeding 0.36 $f_{cm(t).}$ under quasi-permanent load combination. In such case, reference may be made to Annexure A-2, clause A.2.5 of IRC:112, specific to non-linear creep effects. Losses due to seating and friction are not applicable to pre-tensioning. Losses due to elastic shortening and relaxation of tendons differ from those in the case of posttensioning. These can be calculated as follows:

3.5.1 *Elastic Shortening of Concrete*

The loss of stress (f_{PES} in MPa) in the prestressig steel in pre-tensioned girder shall be calculated as:

$$f_{PES} = \frac{E_p}{E_{ci}} f_{cgp} \qquad \textbf{Eq. 3.1}$$

Where,

f_{cgp} = sum of concrete stresses at the centre of gravity of prestressing tendons due to the prestressing force at transfer and the self-weight of the member at the sections of maximum moment (MPa)

E_p = modulus of elasticity of prestressng steel (MPa)

E_{ci} = modulus of elasticity of concrete at transfer (MPa)

Note :

The above method is different from that used for post-tensioning as all the strands are stressed at the same time and the forces transferred to the concrete simultaneously.

3.5.2 *Calculations of Losses due to Relaxation of Prestressing Steel*

In the case of pre-tensioned concrete, relaxation losses start as soon the pre-tensioning is carried out, whereas, the effect of the same on the concrete begins only after the prestressing force is transferred to the concrete. In this regard, relaxation losses shall be calculated as per Tables 6.2 and 6.3 of IRC:112 for assessment of actually available prestressing force at transfer. In case of steam curing, variation of pattern of relaxation loss with temperature and time shall be assessed as per clause 7.9.3 and Annexure A-2 of IRC:112.

3.6 Cover and Spacing of Prestressing Steel

Requirements of clauses 15.3.1.2 and 15.3.1.3 of IRC:112 shall be relevantly applied. Precautions should be taken to locate prestressing strands in such a way that cutting of projecting strands at the ends of girders does not affect the projecting untensioned reinforcement, which is required to be bonded into the adjoining cast-in-situ concrete. In case the designs cater for utilization of bonded strands as passive reinforcement extending from precast girder into the adjoining cast-in-situ concrete, stress in the strands shall be limited to that in the adjoining reinforcing steel, in order to maintain strain compatibility. In such case, these strands shall not be cut at face of the girder, but, shall have adequate development length beyond face of the girder.

3.7 Anchorages of Pre-tensioned Tendons, Transfer of Prestress and Deviators

Provisions of clause 15.3.2.2 of IRC:112 shall apply.

3.8 Coated Steels

Provisions of clause 15.4 of IRC:112 shall apply.

3.9 Secondary Effects

These may be estimated as per clause 7.7.2 of IRC:112.

3.10 Establishing Continuity of Girders

Continuity of girders can be achieved in many ways. Where continuity is achieved using post tensioning, the prestress may be imparted to girder section alone, in which case loads of deck slab, diaphragm, SIDL, live loads etc. act on continuous girders. Alternatively, prestress may be imparted after casting of deck slab and diaphragms, where the loads of deck slab and diaphragms will act on simply supported structure and SIDL, live loads etc. will act on the continuous structure. Another common way of establishing continuity is by incorporating cast-in-situ diaphragm (RCC or PSC) at support locations, along with deck slab to provide RCC continuity of girders.

3.11 Additional, Treatment at Girder-Diaphragm Interface

The girder- diaphragm interface is usually located at a crucial location where shear forces are high and in case of continuous spans, bending moments are also high. At these interfaces, apart from adequate preparation of the construction joint, as specified in clause 4.7, a suitably designed longitudinal reinforcement (as per clause 10.3.4. of IRC:112) extending into the precast girder and the cast-in-situ concrete, adequate to withstand the shear force across the interface shall be provided. This reinforcement shall be in addition to the design shear reinforcement. This reinforcement across the interface shall have adequate development length, both in precast girder as well as in the cast-in-situ diaphragm.

3.12 Shear Connectors

Shear connectors between the mating surfaces of precast pretensioned girder and cast-in-situ deck slab shall be designed as per the relevant provisions of clause 10.3.4 of IRC:112.

3.13 Reinforcement to cater for Indirect Support

Provisions of clause 16.13 of IRC:112 shall apply.

3.14 Handling Stresses

Precast girders should be designed to resist, without permanent damage, all stresses induced by handling, storage, transportation and erection. The position of lifting and supporting points should be specified. The design should take account of the effect of lifting and placing on to supports. All locations of high concentration of stresses in precast members as well as the concrete members, over which the precast members are supported temporarily or permanently, should be provided with closely spaced reinforcement mesh, close to the surface of contact to prevent local crushing of concrete.

4 CONSTRUCTION REQUIREMENTS

Minimum cement content, maximum water-cement ratio and other durability requirements shall be as indicated in relevant sections of IRC:112 except minimum grade of concrete, which shall be M40 for pre-tensioned girders. And, the minimum strength at transfer of prestressing shall be 80% of f_{ck}.

4.1 Precasting

All sides, bottoms and header forms shall be of steel or any other suitable material. Forms shall be of sufficient thickness, with adequate external bracing and shall be stiffened and adequately anchored to withstand the forces due to placement and vibration of concrete. All joints of formwork shall be leak proof. The bottom shutter shall have arrangement to permit longitudinal movement of girder concrete, which happens while imparting prestress. Identifying marks shall be placed on the girders to indicate the correct orientation to ensure correct debonding locations, which may not be symmetrical, longitudinally.

Compaction of concrete may be achieved through needle vibrators or form vibrators along with needle vibrators. For casting of precast beams, any of the two commonly known techniques of precasting *viz*. (i) Long Line method with 2 to 6 girders in a line or (ii) Short Bench method with only one girder in a line may be used. It shall be ensured that tolerances mentioned in para. 4.10 are strictly adhered to.

The girders shall not be moved from the casting location until stipulated strength requirements have been attained. The concrete shall have attained a minimum compressive strength of 20 MPa at the time of removal of forms. Curing of concrete may be achieved through water or steam followed by water curing. Approved curing compound may also be used.

Longitudinal movement of the girders that takes place while transferring/releasing the prestress shall be suitably catered for in the gap between the girders. In case of long line method of precasting, adequate longitudinal gap shall be provided between girder ends during precasting to accommodate projecting reinforcement and required length of the projecting strands.

4.2 Pre-tensioning Operation

Pre-tensioning of strands may be carried out either using single pull jack or multi pull jack. In case of the former, it shall be ensured, at each stage, that the strands are stressed symmetrically. This may be achieved through suitably designed moving trolley engaging the strands or any other suitable arrangement. Prestressing force shall be transferred to metallic spacer, trolley or to high tensile bars, as the case may be, so that the force does not remain on the hydraulic system for long.

It is necessary to apply a small prestressing force, through hydraulic jacks to remove slackness of the strands. After removal of the slackness, the strands must be thoroughly examined to ensure correct alignment, including that of the debonding tubes. Reference marks for measuring elongation shall then be established and the full strand load is applied thereafter. Loads indicated by gauging system shall control the tensioning, with elongation checked on every strand. After completion of pretressing and before concreting, all the debonding tubes must be brought back to their intended locations, as the same may have moved during prestressing operation.

It shall be ensured that the entire length of each strand between the grips is free of any defects. This is of particular importance while precasting girders using long line method entailing, long length of strands between the grips.

4.3 Detensioning of Strands

In order to transfer the prestress, detensioning shall be effected gradually, so that there is no significant loss of bond due to slippage of strands and consequent increase in the transmission length. For detensioning, the trolley or high tensile bars are pulled outward by a small distance, in order to release the metallic spacers, before releasing the prestressing force or locking nuts of bars. Even when the pre-tensioning is carried out through single pull jack, the release of the force in all the strands, while imparting the prestress to the concrete, shall be simultaneous. It shall be ensured that, during this process, prestressing forces at any stage does not exceed 90% of 0.1% proof stress.

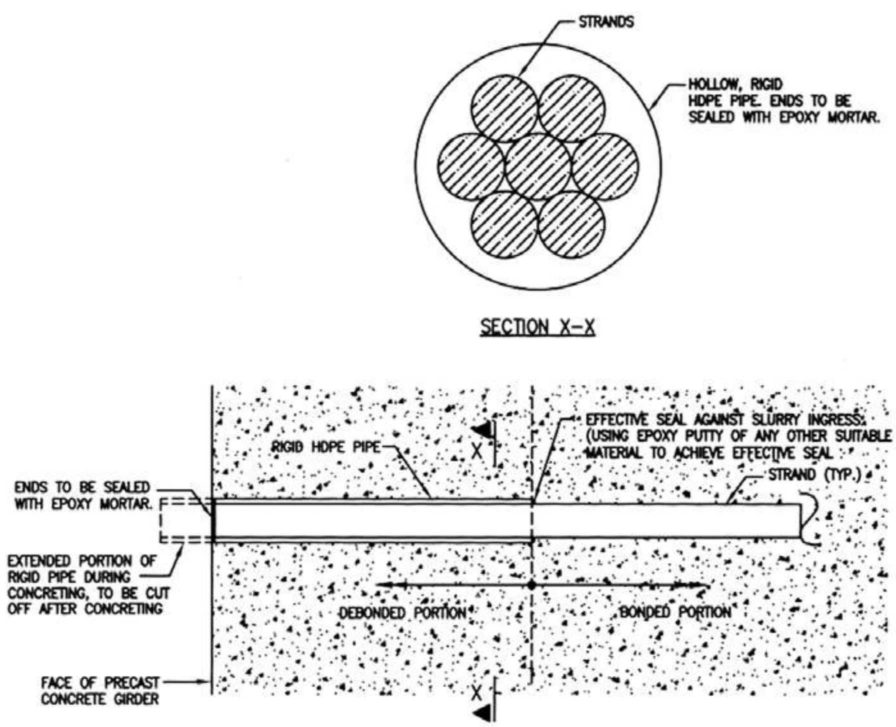
4.4 Cutting of Strands

Cutting of strands is an important operation in case of pre-tensioned girders because they are in close proximity with the untensioned reinforcement which is required to be extended into the adjoining cast-in-situ concrete. Diamond bit saw or grinder with cutting wheel shall be used to cut the strands. Strands and untensioned reinforcement shall be so arranged that the untensioned reinforcement and those strands which are required to be extended into the adjoining cast-in-situ concrete, do not get affected during cutting operation.

Under factory conditions, flame cutting may be resorted to. Yellow flame should be used first to heat the strand without introducing undue stresses and then blue flame for the actual cutting. Heat cutting of strands shall be carried out symmetrically about the vertical axis of the members. One strand at a time on each side of the vertical axis for all girders in a long line shall be cut. The next two strands of all the girders shall be cut in the same manner. The above process shall be repeated till all the strands are cut. This will ensure gradual uniform transfer of prestress to girders.

4.5 Debonding of Strands

Debonding of strands, wherever required, shall be carried out using HDPE debonding tubes. PVC tubes shall not be permitted for this purpose. After pretensioning the strands and before concreting, a recheck shall be made to ensure that the debonding tubes are placed at the intended locations. Both ends of the debonding tubes shall be effectively sealed against ingress of any cement slurry using epoxy putty or any other suitable material. **Fig. 5** depicts a possible arrangement of debonding. The number of partially debonded strands at any section shall be limited to 33% of the total number of strands in the girder and the number of debonded strands in any horizontal row shall be limited to 50% of the strands in that row.



SUGGESTED DETAIL OF DEBONDED STRAND

Reference Para : 4

Fig. 5 Typical Detail of Debonded Strand

4.6 Concreting

A fully automated, computer-controlled batching plant shall be used. The batching plant shall be provided with moisture measuring and compensating devices and automatic pump for dispensing admixtures.

Sampling and testing of concrete shall be as per the relevant provisions of IRC:112. Additional cubes shall be prepared to determine the concrete strength at the time of removal of forms and transfer of prestress. Adequate number of samples shall be taken for this purpose, which shall be cured in identical conditions to those of the concrete of respective girders.

4.7 Surface Preparation

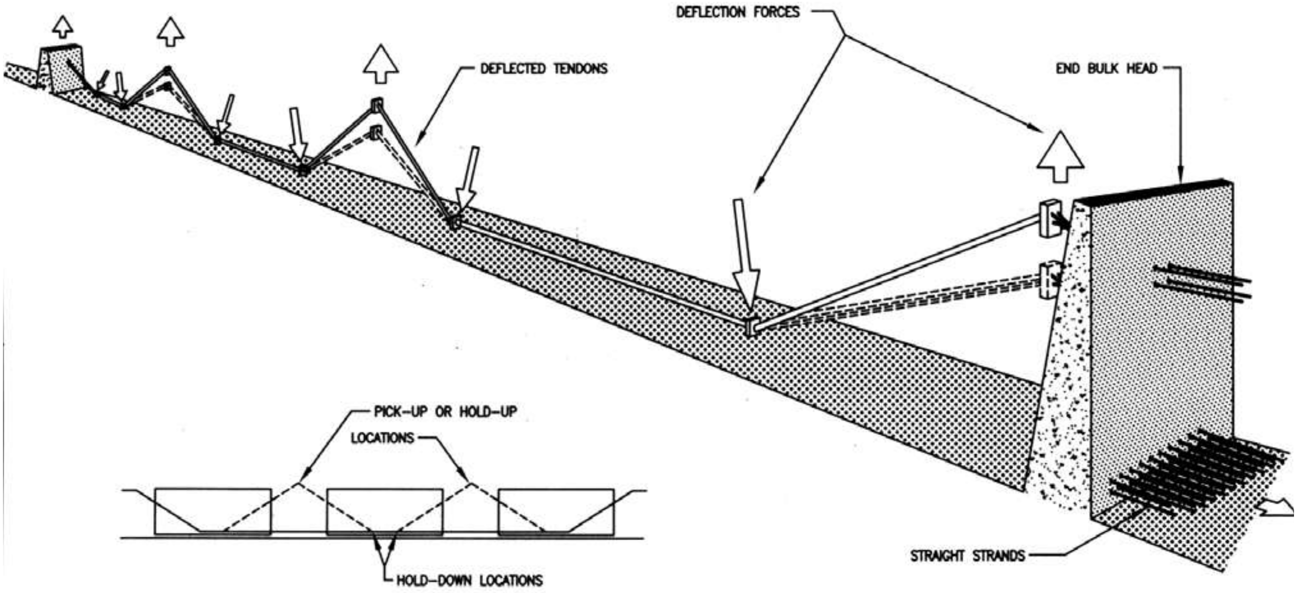
All surfaces, coming in contact with deck slab/diaphragm shall be adequately prepared by green cutting, using surface retarders, or by mechanical means to remove the laitance and just expose the aggregates. Usually, precast girders join the cast-in-situ concrete of end diaphragms at the points of high shear stress and also high bending moment in case of continuous superstructure. Therefore, it is extremely important to adequately prepare the end faces of the girders for effective bonding with the new concrete. This shall be done using suitable mechanical means (such as 100% hacking) to ensure that the course aggregates are just exposed. Surface retarders, may also be used for this purpose.

4.8 Deflected Tendons

An effective way of making long span pre-tensioned girder feasible is to use deflected tendons instead of the conventional straight tendons. This requires the use of hold-up/ hold-down devices at each deflection location, in order to hold the tendons in the desired profile and location. A hold-down device normally consists of rollers attached to a vertical rod, which passes through the bottom form and is anchored to the form substructure or foundation to resist the vertical component of the prestress force. The force which must be resisted by the hold-up/ hold-down device, and therefore its size, depends on the number of deflected strands and the trajectory angle of the strands.

One method of producing deflected tendon profile is to use hold-up/hold-down devices to raise the profile of the strand at the ends of beams and then tension the strands in their already deflected profile. Other method is to hold-up/hold-down the strand to the proper elevation after tensioning the strands. Again, the number of deflected strands and their angle directly influence the size and cost of the hold-up/pick-up device. **Fig. 6** shows a typical deflected strand profile in a prestressing bed.

For single tendons, the deflector in contact with the tendon, should produce a radius of not less than 5 times the tendon diameter for wire or 10 times the tendon diameter for strand and total angle of deflection should not exceed 15^{o}.

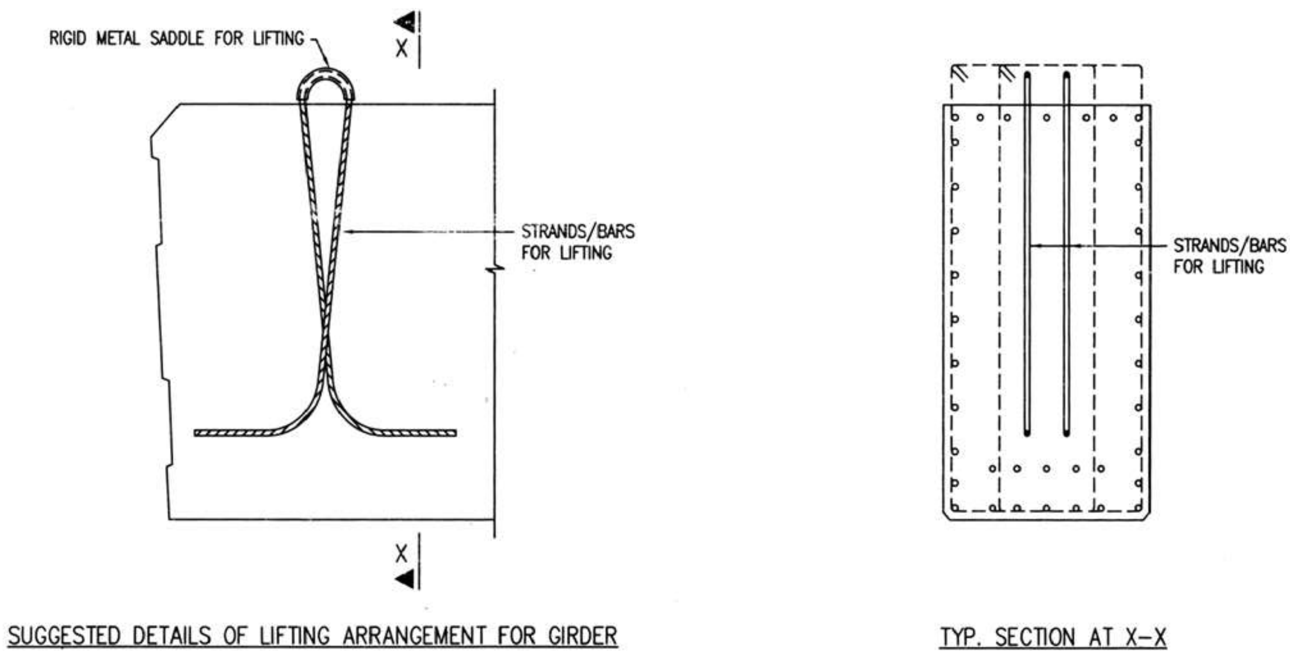


Reference Para : 4

Fig. 6 Arrangement for Deflected of Tendons

4.9 Handling and Transportation of Precast Girders

Handling of precast girders from precasting location to the stacking/ bridge site requires careful operation. Lifting locations shall be strictly as indicated on the construction drawings. **Fig. 7** depicts typical details of lifting hook.



Reference Para : 4

Fig. 7 Typical Lifting Arrangement of Girder

Lifting devices generally consist of loops of prestressing strand or mild steel bars or any other suitable arrangement. The lifting device shall develop the required strength within lower one third of the girder (e.g. web) to avoid in-direct loading during handling. If it is anticipated that embedded material for lifting devices will be cast into the face of a member that will be exposed to view or to corrosive materials in the completed structure, the depth of removal of the embedded material and method of filling the cavities after removal shall be as shown on the construction drawings. The depth of removal shall not be less than the clear cover required to the reinforcing steel. The cavity so formed shall be suitably grouted for protecting the embedded metal. Also, the projecting reinforcement shall be suitably protected against corrosion.

Method of transportation should be planned in such a way that the vehicle employed to transport the long girders can successfully negotiate the available road geometry. Adequate care shall be taken to ensure that the girder being transported does not topple due to unstable arrangement. For this purpose, height of vehicle shall be kept as low as possible. This will also help in controlling height of the system in such a way that during transportation below existing bridges or through any other constraints the same is feasible. Girders should be transported only after 28 day concrete strength is achieved.

4.10 Recommended Dimensional Tolerances for Precast Girders

Length	± 10 mm
Flange width & thickness	± 5 mm
Depth	± 5 mm
Web thickness	± 3 mm
Position of tendons	± 3 mm
Maximum surface roughness	= 1.5 mm on 3.0 m template

4.11 Quality Control

To ensure that the drawings and specifications are truly followed, inspection personnel and a regular programme of inspecting all aspects of production should be provided. Although production personnel should be responsible for quality of products, a system of checks and balances should be in place to ensure review of all materials and processes. Complete record of inspection and testing shall be maintained. Periodical calibration of relevant equipments shall be carried out. Load test, to destruction, of precast girder may be carried out, if specifically provided for in the contract.

REFERENCES

1. AASHTO LRFD Bridge Design Specifications-2010.
2. BCA: Detailed Design of Composite Concrete Bridge Superstructures - 1988.
3. PCI: Precast Prestressed Concrete: Short Span Bridges - 1991.
4. Euro Code 2: Design of Concrete Structures BS EN 1992-2-2005 (E)
5. IRC:112-2011 (Reprinted November, 2016)- Code of Practice for Concrete Road Bridges.
6. IRC:6-2017: Loads and Load Combinations

(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)