IRC:SP:65-2018

GUIDELINES FOR DESIGN AND CONSTRUCTION OF SEGMENTAL BRIDGES

(First Revision)

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GUIDELINES FOR DESIGN AND CONSTRUCTION OF SEGMENTAL BRIDGES

1 INTRODUCTION

1.1 IRC:SP:65 was first published in 2006, which was in line with IRC:18, IRC:21 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 In the year 2011, IRC:18 & IRC:21 have been withdrawn and replaced by IRC:112 covering Limit State design approach.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 bridges publication of IRC with IRC:112. Accordingly, the task of revision of IRC:SP:65 was assigned to Shri Vinay Gupta and he carried out all requisite modifications in line with IRC:112, which was improved after discussion 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:

Tandon, Prof Mahesh	……	Convenor
Kumar, Satander	……	Co-Convenor
Viswanathan, T	……	Member-Secretary

Members

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2 SCOPE

Segmental Construction is the one where entire span is not constructed in one go. Instead, parts are either cast (in-situ) in stages or precast concrete segments assembled by suitable means and prestressed. Some of the examples are cantilever construction bridge (precast or cast-in-situ), precast segmental span-by-span construction (simply supported or continuous resting on bearings or integral), spliced girder system etc. One of the other forms of Segmental Construction is assemblage of segments transversely as well longitudinally. Spine beam (segmental) with precast wing segments is one such example of this type. Girder slab bridges have been kept outside the preview of these guidelines, keeping in view the prevailing practices, all over the country. For such bridges, design as per IRC:112 is considered adequate.

These guidelines cover the specific design and construction requirements of precast and cast-in-situ RCC and prestressed concrete segmental superstructures of bridges. These provisions apply to the following types of superstructures :

i. Epoxy jointed precast segmental superstructure with internal bonded tendons as well as external unbonded tendons
ii. Cantilever construction superstructure (Precast or Cast-in-situ)
iii. Precast prestressed girder segments assembled using post tensioning (ie. spliced girder system) with cast-in-situ stitch as well as match cast jointed girder segments.

3 DESIGN

The main structural difference between segmental and non segmental structures is that the former has several joints, which is not the case with the latter. In the former, reinforcement may or may not continue across the joint, depending upon the type of segmental construction (cast-in-situ or precast). Strictly speaking, the specific requirements of these guidelines for segmental bridges are aimed at covering up the requirements of such joints. The designer may exercise the option of following the usual design requirements as per IRC:112 in the superstructures portions between the consecutive joints, if it is found feasible. However, at the joint locations, the specific requirements of these guidelines shall necessarily be followed.

Design of segmental bridges shall be carried out as per IRC:112 except for the additional provisions and for modifications indicated below, which need to be followed, at the segment joint locations:

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, respectively, with modifications as detailed below. Sections 1 to 7, 13 to 18, Normative Annexures and Informative Annexures apply, relevantly. Respective loads and load combinations shall be taken as per IRC:6. In transverse direction of the bridge, in case of no precast joints in that direction (i.e. no discontinuation of the reinforcement), all relevant provisions of IRC:112 apply, unaltered.

3.2 Allowable Stresses (SLS)

3.2.1 *Allowable Stresses in Concrete*

The maximum compressive stresses under Rare Combination of loads, shall be limited as per clause 12.2.1 of IRC:112 for all types of Segmental Bridges. The stresses at the least compressive face under Rare Combination of Loads shall be limited to minimum residual compression of 0.5 MPa in case of epoxy jointed precast segments. For cast-in-situ segmental structure and spliced girder structure with cast-in-situ stitch, where reinforcement is continuous over the segment joints, reference shall be made to clause 3.3.

3.2.2 *Allowable Tensile Stresses in Steel*

The limits specified in clause 12.2.2 of IRC:112 apply to all types of segmental bridges except longitudinal reinforcement of precast segmental bridges, where these stress checks have no relevance.

3.3 Check for Cracking (SLS)

The crack width limitations given in clause 12.3 of IRC:112 apply to all types of segmental bridges except at joints of precast segmental structure where minimum compressive stress limitations of para 3.2.1 above apply. The decompression limits of Table 12.1 of IRC:112 apply to Prestressed members with bonded tendons.

3.4 Check for Deflection

The provision of clause 12.4 of IRC:112 apply.

3.5 Design for Ultimate Shear

Provisions of Section 10 of IRC:112 shall apply except as modified by the provisions given below:

3.5.1 *Cast-in-Situ Segmental Superstructure and Spliced Girder Superstructure with Cast-in-Situ Stitch*

Provisions of Section 10 of IRC:112 apply, unaltered.

3.5.2 *Epoxy Jointed Precast Segmental Superstructure with Internal Bonded Tendons or External Unbonded Tendons*

Partial Safety factors shall be followed as per Table 3.2 of IRC:6. Any helping effect of bearing resistance developed through the shear keys shall be ignored.

3.5.2.1 For structures with internal bonded tendons the shear capacity calculated as per Section 10 of IRC:112 shall be multiplied by a factor of 0.90.

3.5.2.2 For structure with external unbonded tendons, the shear resistance shall be calculated as per clause 10.3.3.4 (2) of IRC:112.

For this purpose, the equation 10.18 of IRC:112 shall be modified as follows:

$V_{NS}/0.85 = V_{ED} < h_{redc}\ b_w v f_{ed} / (\cot\theta + \tan\theta)$

And equation 10.19 modified as follows:

$A_{SW}/S = V_{ED}/h_{redc} v_{fed} \cot\theta$

3.5.3 *Torsion in Segmental Construction*

The treatment of torsion shall be in line with the provisions of IRC:112 except for precast segmental construction. In precast segmental construction, it may not be possible to provide continuous longitudinal untensioned reinforcement across the joints. At any cross section, where the axial tension due to torsion and bending exceeds the compression due to prestressing and bending, supplementary tendons to counter the tension shall be added. The supplementary tendons shall be distributed around the perimeter of the precompressed tension zone inside the closed stirrups. At least one tendon shall be placed near each corner of the stirrups in the precompressed tension zone. For the purpose of calculation of torsional capacity, the reduction factors given in the respective clause 3.5.2 for shear capacity shall apply.

3.6 Design for Ultimate Flexure

Design shall be carried out as per Section 8 of IRC:112 except as modified below. Partial Safety factors shall be as per Table 3 B-2 of IRC:6. The untensioned reinforcement which are not continued between the precast segments shall not be assumed to contribute to the flexural strength.

3.6.1 *Cast-in-Situ Segmental and Spliced Girder Superstructures with Cast-In-Situ Stitch*

Provisions of Section 8 of IRC:112 shall apply.

3.6.2 *Epoxy Jointed Precast Segmental Superstructure with Internal Bonded Tendons or External Unbonded Tendons*

The ultimate flexural capacity calculated as per Section 8 of IRC:112 shall be multiplied by a factor of 0.95 for internal bonded tendons and 0.90 for external unbonded tendons. In the case of external unbonded tendons where the tendons are only connected to the structure at the anchorages, any strain will be distributed equally through out the length of the tendons. Available prestressing force after all losses is used for working out ultimate moment carrying capacity. In such cases failure takes place due to crushing of concrete. Generally, it is considered adequately accurate to assume that deflected geometry of superstructure will not cause any additional strain in the tendons. It must be specifically noted that strains in unbonded tendons are not the same as those in the concrete. In the case of internal bonded tendons, ultimate flexural capacity of the structure may be calculated by principles of strain compatibility or any other appropriate method. **Figs. 1** and **2** illustrate sample arrangements of external and internal prestressing tendons respectively. **Fig. 3** illustrates analogus model of externally prestressed superstructure.

While calculating joint capacity of sections with internal bonded tendons, depth of the section actually in compression under the relevant ULS load combination shall be considered and the prestressing taken at its relevant CG.

3.7 Types of joints in precast segmental bridges shall either be cast-in-situ stich or match cast epoxied joints.

3.8 Stagewise Construction of Segmental Bridges

Most segmental bridge spans are constructed in stages. The design check shall be made appropriately at all such stages of construction including the relevant temporary construction loads.

4 CONSTRUCTION REQUIREMENTS

Minimum grades of concrete, minimum cement content, maximum water-cement ratio and other durability requirements shall be same as indicated in Section 14 of IRC:112.

There are several specific requirements relating to construction which need to be adhered to. These are as follows:

4.1 Precasting

All sides, bottom, inside, and header forms shall be of steel. 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. Compaction of concrete may be achieved through needle vibrators or form vibrators along with needle vibrators. For casting of precast segmental superstructure any of the two commonly known techniques of precasting (i) Long Line method and (ii) Short Bench method may be used. After the first segment of each unit is cast, succeeding segments shall be match cast against the previous ones and shall be given a unique identification mark so as to be placed at the intended location in the superstructure. A bond breaking material such as flax soap, talc, wax or any other approved material shall be used between previously cast segment and newly cast segment, as well as the end headers when required.

4.1.1 Segments shall not be moved from the casting yard until stipulated strength requirements have been attained and shall be supported in a manner that will minimize warping. Under any circumstances the concrete shall have attained a minimum compressive strength of 20 MPa at the time of removal of forms. At the time of lifting and assembly of precast segments in to the structure, the concrete shall have attained sufficient strength to withstand the handling stresses. Curing of segments may be achieved through water or steam followed by water curing. Approved curing compound may be used.

4.1.2 In case of spliced girder system, usually match casting is not necessary because the gap between the girder segments is filled with concrete or epoxy material at the locations of splices. The faces, which are required to receive the cast-in-situ stitch concrete shall be adequately roughened and prepared as construction joint before pouring the stitch concrete. In case of epoxy jointed spliced girder system (with no gap between the girder segments), match casting shall be resorted to, and all provisions of epoxy jointed segmental structure as per this document shall apply.

4.1.3 A full scale mock-up of the lifting and holding equipment (including assembly truss, cantilevering formwork etc) shall be performed to demonstrate their adequacy and eficacy prior to beginning any erection/assembly of the segments.

4.1.4 *Tolerances in Precasting*

Finished segment tolerances should not exceed the following:

Length of match-cast segment (not cumulative)	± 5 mm
Overall span length between bearings	±10 mm
Web thickness, depths of top and bottom flanges, Width of top and bottom flanges, overall depth of segment, thickness of diaphragm	± 5 mm

Grade of form edge and soffit	± 1.0 mm/m
Tendon hole location	± 3.0 mm
Position of shear keys	± 5.0 mm

4.2 Shear Keys

Precast segments shall be provided with shear keys at match cast joints. These shear keys shall cover as much area of the cross section as possible. Shear keys in the webs shall be smaller in size and more in number whereas those in top flange and bottom flange may have larger sizes with lesser number. Shear keys shall be dimensioned in the form of trapezium. Shear keys shall be avoided at the tendon hole locations. Refer **Fig. 4** for general details of shear keys. An example of shear keys in a box girder segment is also enumerated in **Fig. 5**.

However, in case of spliced girder superstructure, not using match casting, large amplitude shear keys may be used.

4.3 Geometry Control

Since, segmental superstructure has several joints and in certain cases, several stages of construction, geometry control in design and during construction needs to be specifically taken care of. In case of stagewise construction (cast-in-situ or precast), initial designs should take care of varying concrete properties at various time stages of construction. Subsequently, during construction, actual deformation of the structure should be compared with the theoretical ones and necessary adjustments made in case of differences between the two, during construction stages. In case of span by span type of precast construction, a stricter control of precasting is required to maintain the desired geometry of the final structure.

4.4 Epoxy Jointing of Segments

In case of epoxy jointed superstructure, mating surfaces of both adjoining segments shall be effectively prepared by wire brushing, water jetting and /or any other approved means to ensure that the bond breaking material is completely removed. Epoxy of about 1mm thickness on each of the mating surfaces shall be applied (usually by hand application) within 70% of its pot life. Subsequently, the segment shall be brought closer to hug each other and an axial temporary compression of at least 0.3 MPa shall be applied by approved means for a minimum of 24 hrs. Refer **Fig. 6** for a sample arrangement of temporary prestressing. The Epoxy shall essentially have properties as indicated in para 4.5.1. The contractor shall plan his erection system in such a way that the time elapsed between mixing of components of epoxy applied to the mating surfaces of precast concrete segments and application of temporary axial force does not exceed 60 minutes. No epoxy from a batch for which the time since combining the components has exceeded 20 minutes shall be used.

4.5 The broad sequence of operations shall generally comprise placing of all segments of a portion intended to be assembled and prestressed in one stage, touching each other and then visually examining the matching of mating surfaces. Subsequently each segment shall be separated from adjoining segment by a distance just sufficient to apply the epoxy. After applying epoxy, temporary axial compression shall be imparted and maintained for minimum 24 h. Thereafter intended permanent prestress shall be imparted prior to demobilizing the temporary axial prestress.

4.6 Epoxy

Depending upon the ambient temperature range, following types of epoxies are recommended for use:

5 to 20º Celsius	:	Fast reacting
15 to 30º Celsius	:	Medium fast reacting
25 to 40º Celsius	:	Slow reacting

Epoxy comprises two components, namely resin and hardener. Resin must be stirred by a mixer in its container for about 10 seconds or until homogeneity is reached. Thereafter hardener must be added and mixing continued. For a mix of 5 kg batch, a mixing rotor attached to a 350 W, 400 rpm electric hand drilling machine is recommended. The speed of 400 rpm should not be exceeded because higher revolutions will entrap air in the mix, cause excessive frictional heat and therefore shorten the pot life. The mixing time should not exceed 3 minutes and the temperature not allowed to rise above 40ºC for fast reacting and medium fast reacting formulations and 60ºC for slow reacting formulations. It must be ensured that mixing paddles scrape the bottom and sides of the container, so as to ensure complete mixing of the two components. The mixing should be carried out as close as possible to the place where the epoxy will be applied, so as to avoid loss of time, and therefore wasting of pot life in transport.

4.6.1 Epoxy shall be tested for its conformance to the FIP-1978 “Proposal for Standard Tests and Verification of Epoxy Bonding Agents for Segmental Construction”. Some of the important properties (minimum values) of epoxy are as follows:

Pot life	:	20 minutes (at 40ºC for fast and medium reacting epoxies and at 60ºC for slow reacting epoxy)
Open time	:	60 minutes (at upper temperature limit)
Compressive strength	:	60 MPa at 24 hrs and 75 MPa at 168 hrs on 50x50x50 mm cube (at lower temperature limit)
Tensile bonding strength	:	after 24 hrs at 100% humidity, should have concrete failure, no joint failure with M40 concrete (at lower temperature limit)
Shear strength	:	12 MPa (at lower temperature limit)
Curing rate	:	compressive strength on 50x50x50 mm cube shall be 20 MPa at 12 hrs, 40 MPa at 24 hrs and 75 MPa at 168 hrs (at lower temperature limit)

4.7 Cast-in-situ Concrete Pour

In every continuous precast segmental unit of superstructure, there shall be suitable numbers (at least one) of cast-in-situ concrete pour/stitch, which is essential to ensure longitudinal geometry and alignment of the spans.

4.7.1 *Segment Dimensioning*

The segment lengths must be dimensioned keeping adequate allowance of the epoxy thickness applicable after the imparting temporary prestressing. This is to ensure correct placement/ alignment of bearings.

4.8 Spliced Girder System

A spliced girder system is provided to obtain large girder spans, given the limitations of weight and length of individual girder segments, which could be on account of limitations of handling or transportation of the same. In this system smaller girder segments, usually pretensioned at precasting yard, are assembled together using cast-in-situ concrete or epoxy and post tensioning. For this purpose the girder segments are temporarily supported over centering/ steel tower or assembled at ground level and then post tensioned after jointing. In case of superstructures curved in plan, straight girder segments are placed along the chord line of the curvature to obtain the required geometry. In such cases it is necessary to provide a cast-in-situ cross diaphragm at each such kink in plan coinciding with the splice. The splicing can either be done before casting the deck or along with the deck. In the former, post tensioning is imparted to the girder section alone whereas in the latter the post tensioning is imparted to the composite section, (refer **Fig. 7** for one such arrangement). Other methods of splicing such as structural steel splicing and RCC splicing are not in the purview of these guidelines. Similarly, RCC girder segments spliced using post tensioning are also not in the purview of these guidelines.

4.8.1 A preferred location of splice will be the points of minimum stress such as 1/3rd span points. At each cast-in-situ splice location, adequately designed untensioned reinforcement shall be provided by lapping, welding or with the use of mechanical reinforcement couplers subject to the limitations of the relevant codes. However, in the case of epoxy jointed splice such reinforcement is not provided.

4.9 Placement of Bearings

Bearings under precast segments shall be placed by sandwiching shrinkage compensated high strength prepackaged cement mortar in order to ensure homogeneous contact between top surface of the bearing and bottom surface of the superstructure.

4.10 Prestressing Ducts

In the case of epoxy jointed segments, either metallic or HDPE duct may be used for internal prestressing and only HDPE duct for external prestressing. The ducts shall be corrugated for internal prestressing and plain for external prestressing. Material specifications of corrugated metallic and corrugated HDPE ducts used for internal prestressing shall be as per clause 13.4.2 and 13.4.3, respectively of IRC:112. In case of external prestressing, wall thickness of the HDPE ducts shall be at least 1/21 of the outside diameter of the duct and internal diameter as per the provisions of Clause 13.4.3 of IRC:112. Adequate precaution shall be taken to ensure that epoxy material does not leak into joints of the ducts.

4.11 External Prestressing

External prestressing, if used, shall employ specialized external anchorages (replaceable type), suitably protected against corrosion. In the replaceable system of prestressing, the bearing plate is outside the concrete, which is provided with grease filled cap for protection against corrosion. Usually a sliding layer is provided between trumpet and duct in such a way that the duct along with bearing plate and wedges can be removed for replacement after detensioning of the cables. In some systems of prestressing the anchorage cone/trumpet remains connected to a small piece of duct, which is connected to the remaining duct, through a duct coupler, which is decoupled for replacement. For the purpose of detensioning, the cables remain sufficiently projected beyond anchorages, which are encompassed in long grease filled caps. Refer **Figs. 8, 9** and **10** for general system of replaceable anchorages. The tendons may be protected against corrosion using grouting with approved grease, wax, cement or any other approved material. Refer **Fig. 11** for some of the systems of corrosion protection of external prestressing tendons. Design of end block for external anchorages shall be in conformity with Section 13 of IRC:112.

4.11.1 In the case of external prestressing, the minimum web thickness shall be 200 mm.

4.11.2 The loss of prestress in unbonded tendons shall be calculated from the average creep movement between anchors. The creep loss in the unbonded tendons is not directly proportional to the local creep strain in the concrete at center of gravity of tendons.

4.11.3 The structure shall be designed for snapping of any cable, one at a time, which will cater for the condition of replacement of cables.

4.12 Deviator Blocks

In the case of external prestressing it is a usual practice to provide concrete protrusions inside the box girder in order to pass the prestressing ducts so as to maintain the intended alignment. Refer **Figs. 12** and **13** for some suggested details of deviator blocks. These deviator blocks also help control the vibrations of the cables. The deviator blocks shall be located at a spacing not exceeding 12 m. In case it not possible to adhere to this maximum spacing criteria, check shall be made to ensure that the first natural frequency of the tendons vibrating between the fixing points (deviator blocks or anchorage points) is not in the range 0.8 to 1.2 times that of the bridge. Deviator blocks shall be so detailed as to avoid damage to tendon/sheathing/deviator blocks during stressing operation. In case a permanently embedded duct in concrete deviator block is provided, it shall be of galvanized steel (at least 150 micron coating thickness).

4.13 Prestressing Couplers

In case prestressing couplers are used, not more than 50% of the prestressing cables passing through a section shall, in general, be coupled at that section. Longitudinally, the couplers shall be staggered by at least a distance equal to each segment length or twice the overall depth of the girder, whichever is more. Usual practice is to couple half the cables in one span and the other half in the next span and so on. Two immediately adjacent cables shall not be provided with couplers at one section. Void areas around the coupler shall be deducted from the gross concrete section area and other section properties when computing stresses at the stages before grouting.

4.14 Deck Waterproofing

Approved flexible membrane waterproofing shall be provided over the deck slab, preferably Polyurethane based. The waterproofing may be a single component one or two component one. It shall have at least 400% elongation at break, adequate UV resistance, adhesion to substrate as well as bituminous/concrete wearing course (minimum pull out strength of 2.5 MPa), adequate tensile strength (at least 2 MPa). A suitable primer may be necessary. Complete procedure of laying the waterproofing shall be as per the supplier's recommendations layed under the supervision of its qualified representative.

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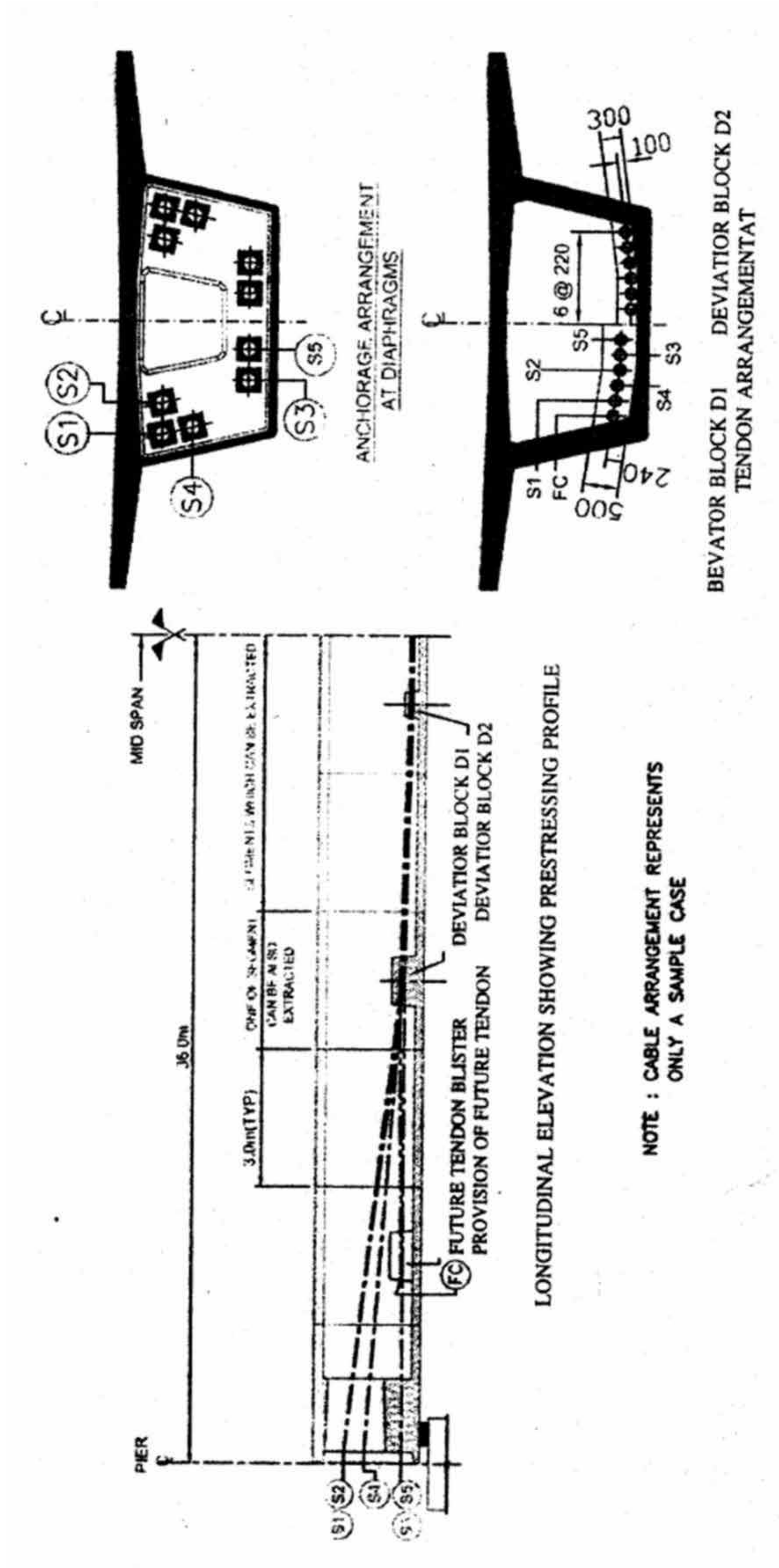

Fig.1 Tendon Profile of Simply Supported Span Constructed by Precast Segmental Technique using External Unbonded Tendons

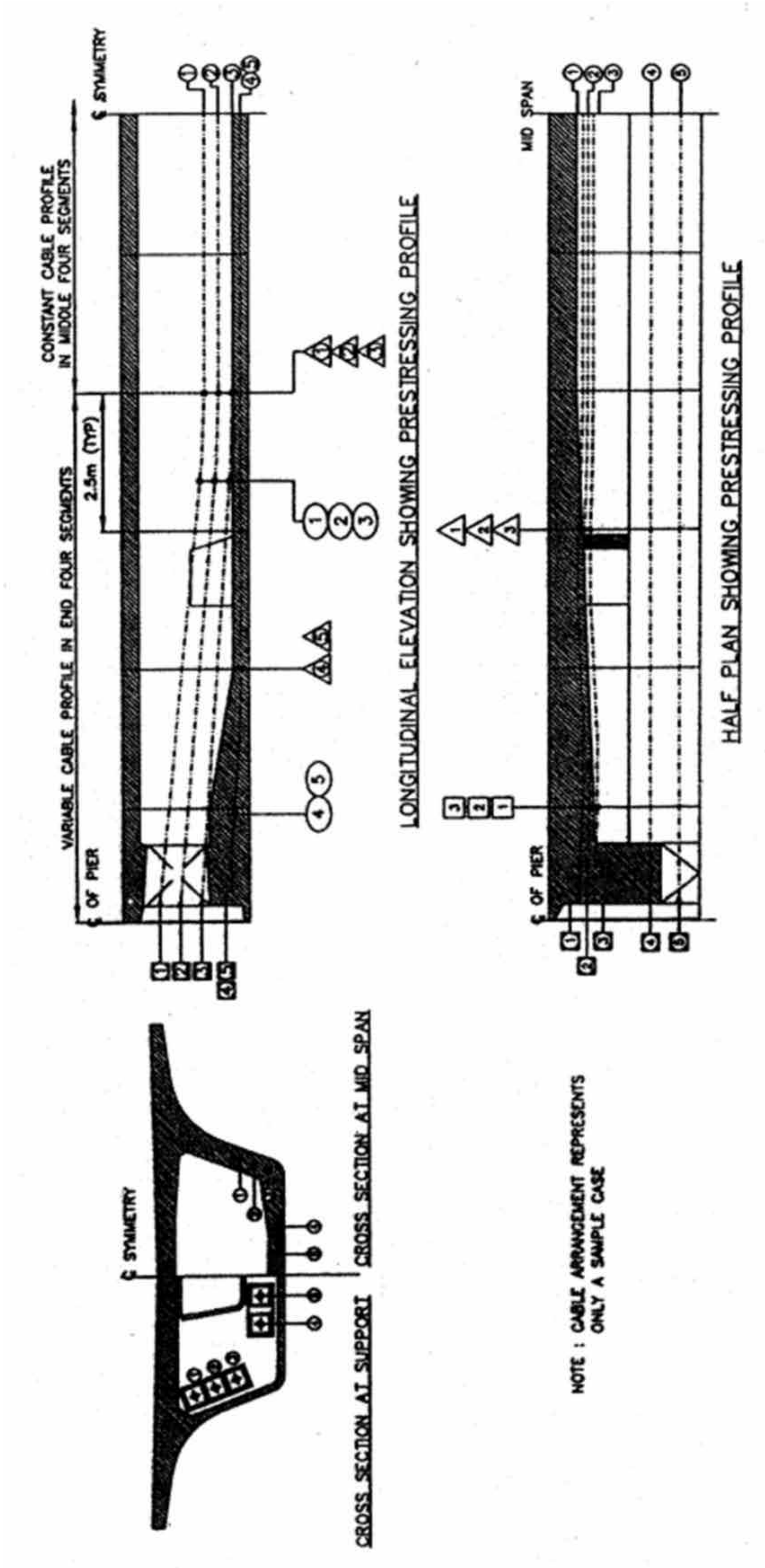

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Fig. 2 Tendon Profile of Simply Supported Span Constructed by Precast Segmental Technique using Internal Bonded Tendons

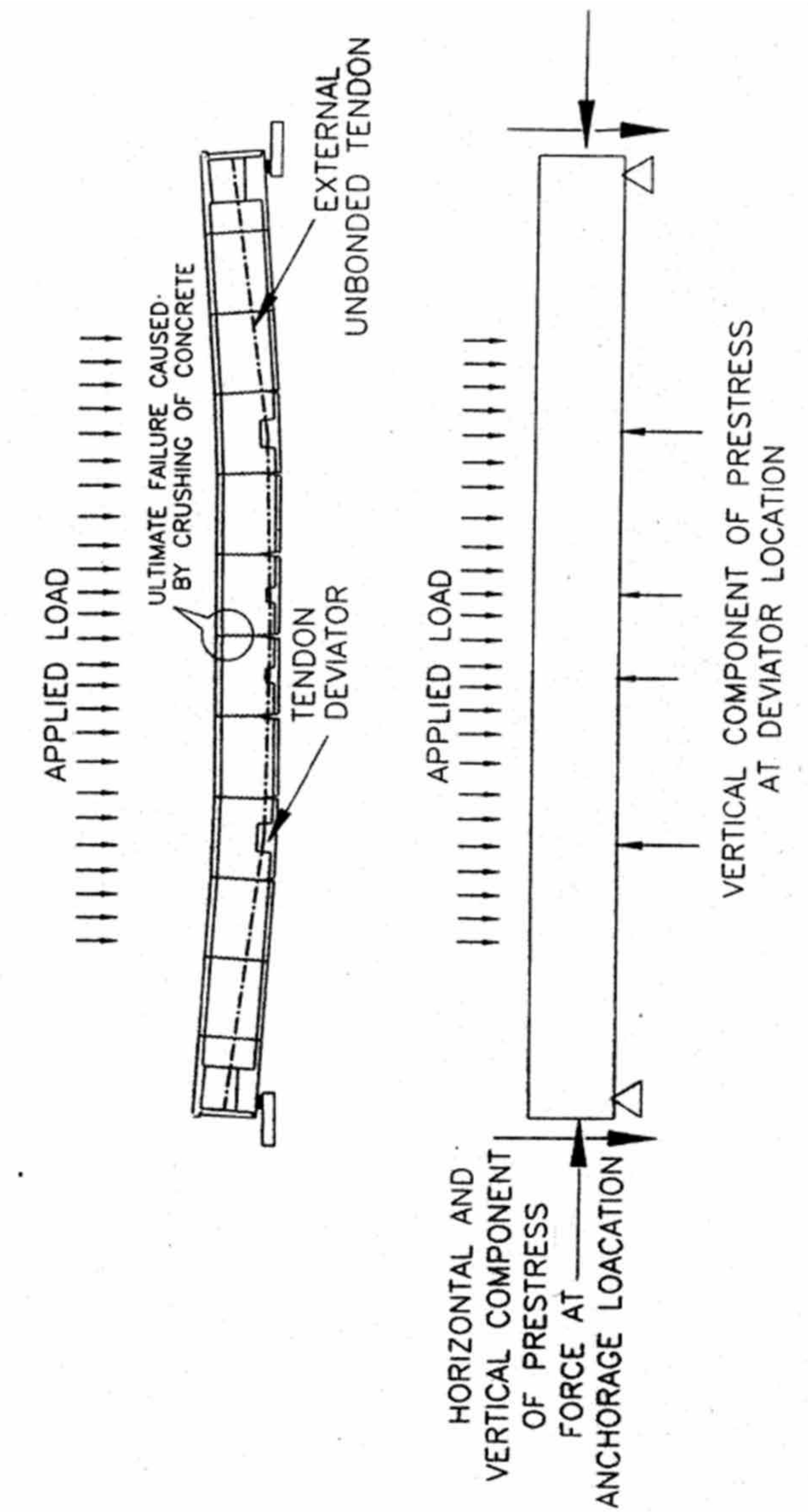

Fig. 3 Analogus Model of Externally Prestressed Structure

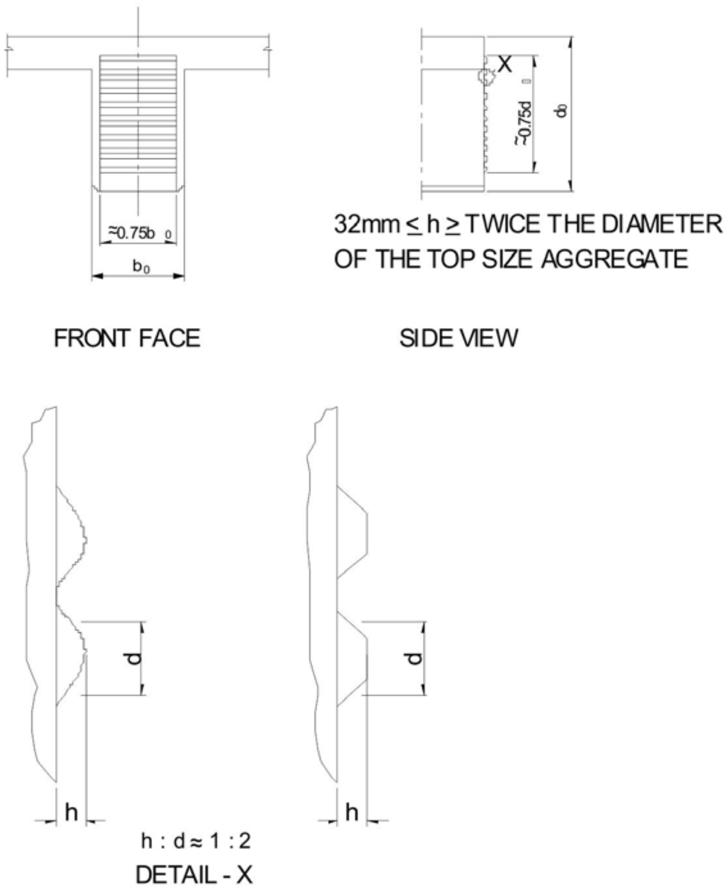

Fig. 4 Example of Shear Keys in Box Segments

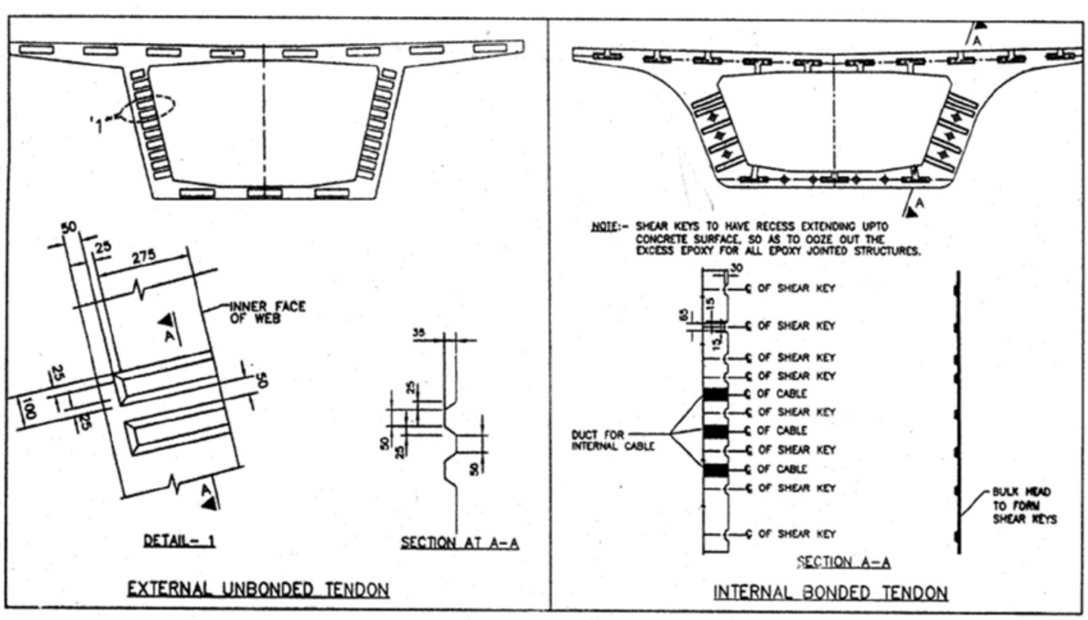

Fig. 5 Organisation of Shear Keys in Precast Box Girder Segment

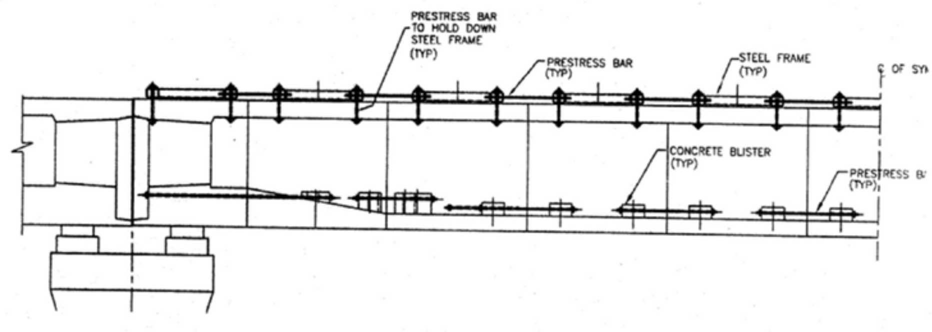

Fig. 6 Longitudinal Section Showing Arrangement of Temporary Prestressing

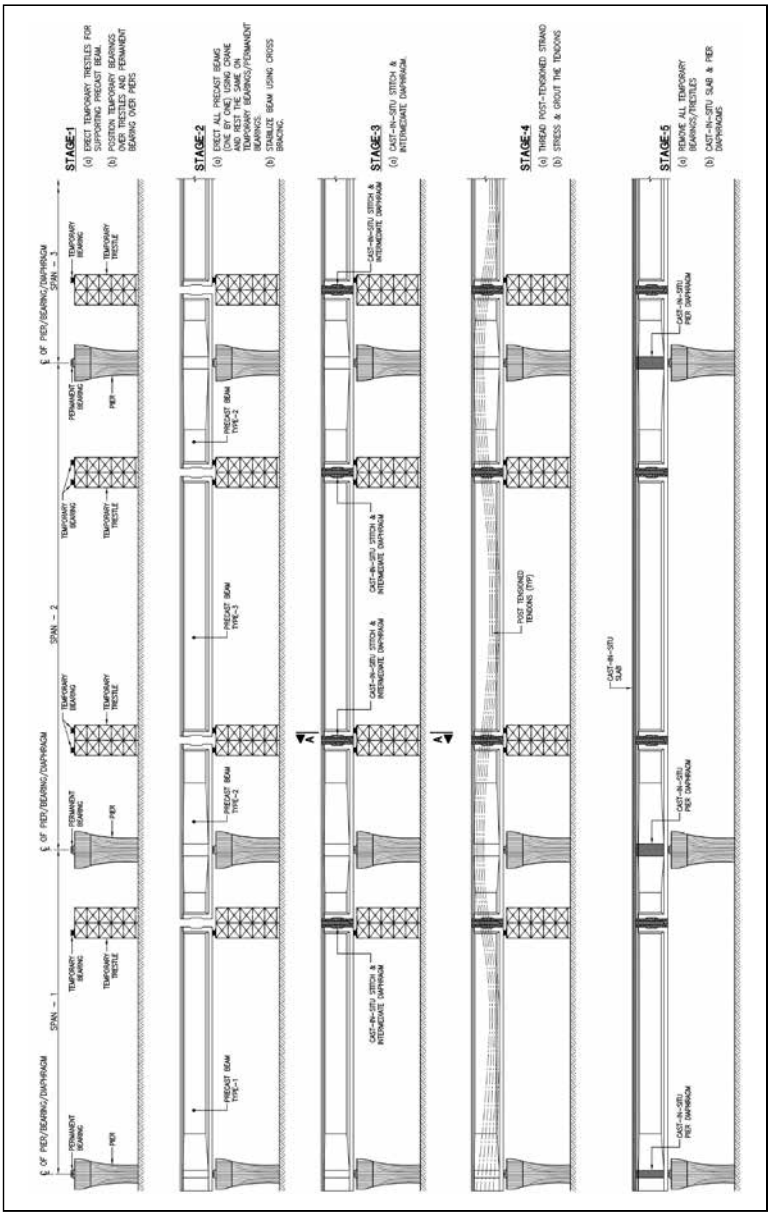

Fig. 7 Spliced Girder Superstructure

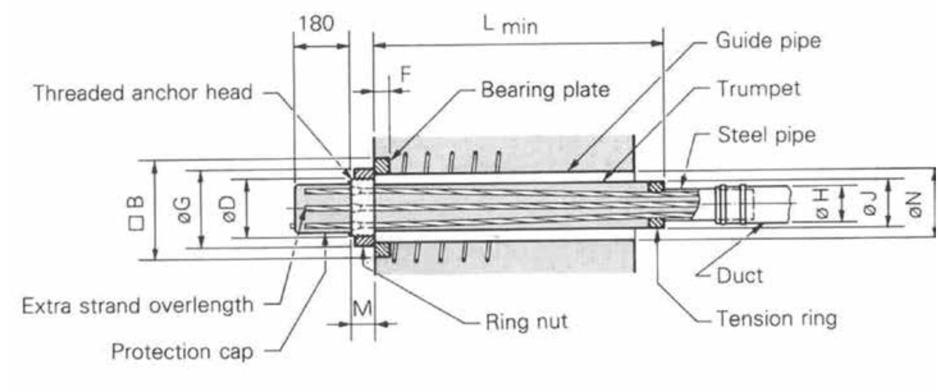

Fig. 8 Replaceable Anchorages for External Prestressing

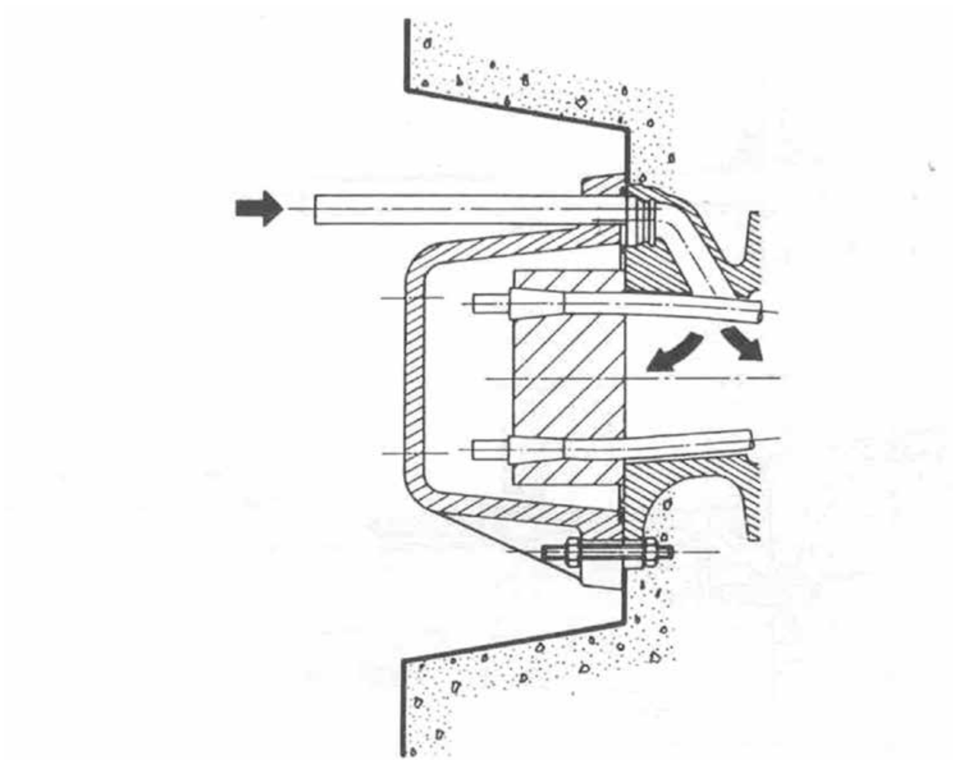

Fig. 9 Protection Cap Over Permanently Sealed Anchorage

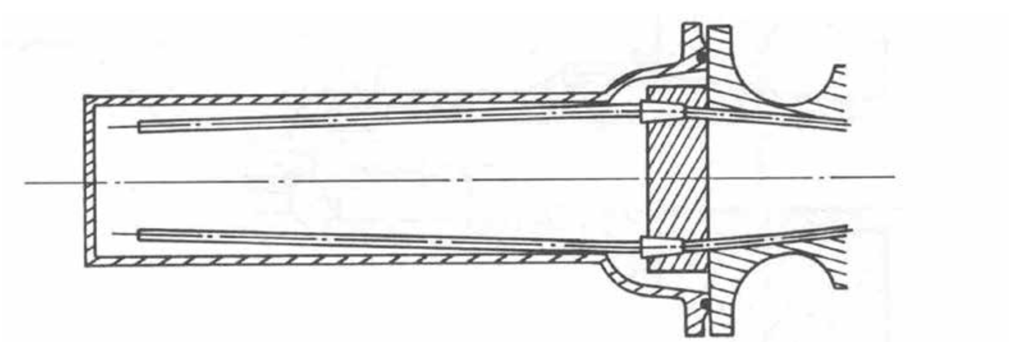

Fig. 10 Protection Cap Over Anchorages to be Handled in Future

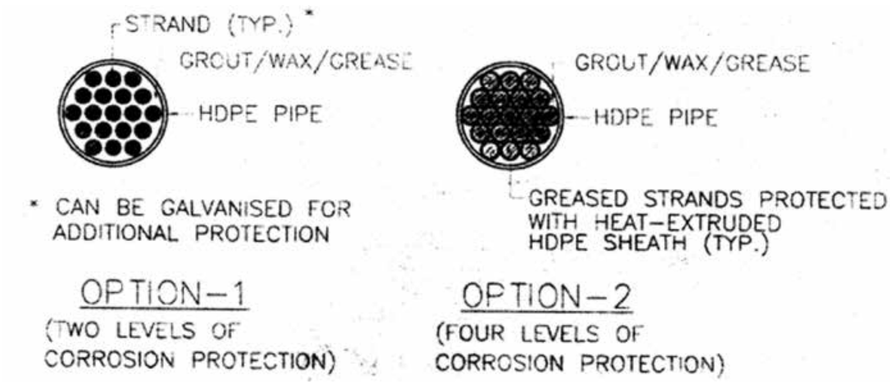

Fig. 11 Options for Corrosion Protection of External Tendons

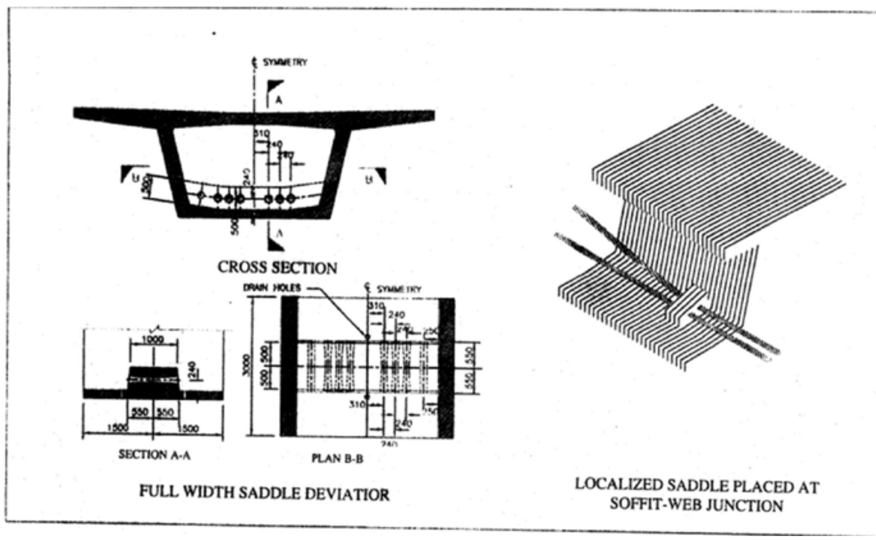

Fig. 12 Arrangement of Deviator Blocks

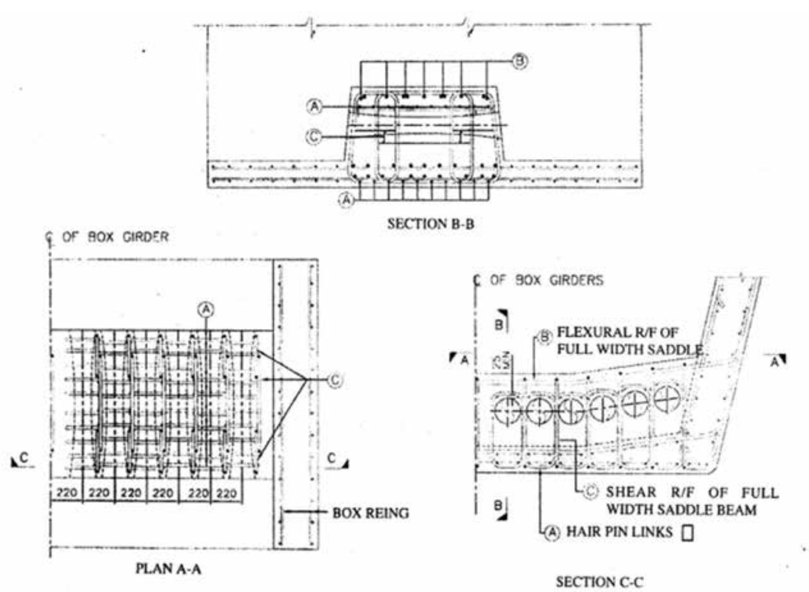

Fig. 13 Reinforcement Details of Typical Full Width Saddle Deviator

(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)