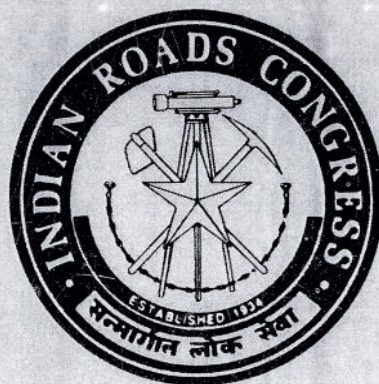


26-78

Library

IRC:SP:65-2005

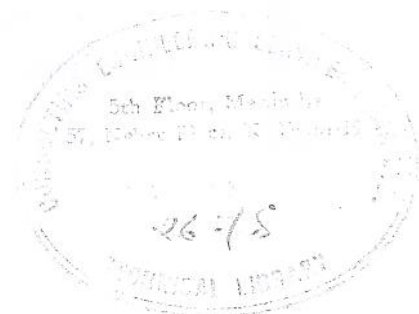
GUIDELINES FOR DESIGN AND CONSTRUCTION OF SEGMENTAL BRIDGES



**THE INDIAN ROADS CONGRESS
2005**

IRC:SP:65-2005

GUIDELINES FOR DESIGN AND CONSTRUCTION OF SEGMENTAL BRIDGES



Published by

THE INDIAN ROADS CONGRESS

Kama Koti Marg,
Sector 6, R.K. Puram,
New Delhi – 110 022
2005

Price Rs 100.00
(Plus Packing & Postage)

IRC:SP:65-2005

First Published : July, 2005

(The Rights of Publication and of Translation are reserved)

(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)

Printed at Aravali Printers & Publishers (P) Ltd., New Delhi-110 020
(1000 copies)

CONTENTS

	Personnel of the Bridges Specifications and Standards Committee	(i) & (ii)
1.	Introduction	1
2.	Scope	1
3.	Construction Requirements	2
4.	Epoxy Jointing of Segments	3
5.	Dry Jointed Precast Segmental Construction	11
6.	References	19

**PERSONNEL OF THE BRIDGES SPECIFICATIONS AND
STANDARDS COMMITTEE**

(As on 20-12-2004)

- | | | |
|----|---|--|
| 1. | V. Velayutham
(<i>Convenor</i>) | Addl. Director General, Ministry of Shipping, Road Transport & Highways, New Delhi |
| 2. | V.K. Sinha
(<i>Co-Convenor</i>) | Chief Engineer, Ministry of Shipping, Road Transport & Highway, New Delhi |
| 3. | Chief Engineer (B) S&R
(<i>Member-Secretary</i>)

(A.N. Dhodapkar) | Ministry of Shipping, Road Transport & Highways, New Delhi |

Members

- | | | |
|-----|-------------------|--|
| 4. | K.N. Agrawal | C-33, Chandra Nagar, Ghaziabad-201 011 |
| 5. | S. Ahmed | Secretary to the Govt. of Meghalaya PWD, Shillong |
| 6. | C.R. Alimchandani | Chairman & Managing Director, STUP Consultants Ltd., Mumbai |
| 7. | A.K. Banerjee | B-210, (SF), Chitranjan Park, New Delhi |
| 8. | Ashok Basa | Director (Tech.) B. Engineers & Builders Ltd., Bhubaneswar |
| 9. | P.C. Bhasin | ADG (B), MOST (Retd.) 324, Mandakini Enclave, New Delhi |
| 10. | S.S. Chakraborty | Managing Director, Consulting Engg. Services (I) Pvt. Ltd., New Delhi |
| 11. | K.K. Gupta | House No.1149, Sector 19, Faridabad |
| 12. | A.R. Jambekar | Chief Engineer & General Manager (Tech.) CIDCO, NAVI Mumbai |
| 13. | S.K. Jain | Director & Head, Civil Engg. Department, Bureau of Indian Standards, New Delhi |
| 14. | S.K. Kaushik | Chairman, Estate & Works & Coordinator (TIFAC-CORE) IIT, Roorkee |
| 15. | C.V. Kand | Consultant, Bhopal |
| 16. | Ninan Koshi | DG (RD) & Addl. Secy., MOST (Retd.), H-54, Residency Green, Gurgaon |
| 17. | Prafulla Kumar | DG (RD) & AS, MORT&H (Retd.) D-86, Sector-56, Noida |
| 18. | P.Y. Manjure | Director, Freyssinet Prestressed Concrete Co. Ltd., Mumbai |
| 19. | N.V. Merani | Principal Secy., Maharashtra PWD (Retd.), Mumbai |
| 20. | M.K. Mukherjee | 40/182, Chitranjan Park, New Delhi |
| 21. | A.D. Narain | Director General (Road Dev.) & Addl. Secretary, MOST (Retd.) B-186, Sector-26, NOIDA |
| 22. | S.K. Puri | Chief Engineer, Ministry of Shipping, Road Transport and Highway |
| 23. | N. Rajagopalan | Chief Technical Advisor, L&T-Ramboll Consulting Engg. Ltd., Chennai |

IRC:SP:65-2005

- | | |
|--|---|
| 24. M.V.B. Rao | A-181, Sarita Vihar, New Delhi |
| 25. Dr. T.N. Subba Rao | Chairman, Construma Consultancy (P) Ltd., Mumbai |
| 26. S.A. Reddi | Dy. Managing Director, Gammon India Ltd., Mumbai |
| 27. Director | Highway Research Station, Chennai |
| 28. G. Sharan | Member (T), National Highways Authority of India, New Delhi |
| 29. N.K. Sinha | DG (RD) & SS, MORT&H (Retd.) G-1365, Ground Floor, Chitranjan Park, New Delhi |
| 30. Dr. M.G. Tamhankar | BH-1/44, Kendriya Vihar Kharghar, Navi Mumbai |
| 31. Mahesh Tandon | Managing Director, Tandon Consultants (P) Ltd., New Delhi |
| 32. P.B. Vijay | A-39/B, DDA Flats, Munirka, New Delhi |
| 33. Chief Engineer (NH)
Planning & Budget | (Shri S.K. De) M.P. PWD, Bhopal |
| 34. Addl. Director General | HQ DGBR, Seema Sadak Bhavan, New Delhi |
| 35. Chief Engineer (NH) | U.P. PWD, Lucknow |
| 36. Chief Engineer (NH) | Chepauk, Chennai |
| 37. R. Subramanian | Engineer-in-Chief, PWD, New Delhi |
| 38. Rep. of RDSO | (R.K. Gupta) Executive Director (B&S) Bidges & Structures Directt., RDSO, Lucknow |

Ex-Officio Members

- | | |
|--|--|
| 39. President, IRC | (S.S. Momin), Secretary (R), Maharashtra PWD, Mumbai |
| 40. Director General
(Road Development) | (Indu Prakash), Ministry of Shipping, Road Transport & Highways, New Delhi |
| 41. Secretary, IRC | (R.S. Sharma), Indian Roads Congress, RK. Puram, Kama Koti Marg, Sector-6, New Delhi |

Corresponding Members

- | | |
|-------------------|---|
| 1. M.K. Agarwal | Engineer-in-Chief, Haryana PWD (Retd.), Panchkula |
| 2. M.K. Bhagwagar | Executive Director, Engg. Consultant Pvt. Ltd., New Delhi |
| 3. A. Chakraborti | Addl. Director General (TD), CPWD, New Delhi |
| 4. Dr. V.K. Raina | B-13, Sector-14, Noida |

GUIDELINES FOR DESIGN AND CONSTRUCTION OF SEGMENTAL BRIDGES

1. INTRODUCTION

1.1. The Reinforced, Prestressed and Composite Concrete Committee (B-6) of the Indian Roads Congress was reconstituted in 2003 with the following personnel:

Ninan Koshi	...	Convenor
Addl. DGBR	...	Co-Convenor
T. Viswanathan	...	Member-Secretary

Members

A.K. Banerjee
Alok Bhowmick
A.N. Dhodapkar
Vinay Gupta
G.R. Haridas
S.G. Joglekar
Jose Kurian
S.D. Limaye
M.K. Mukherjee
Dr. A.K. Mullick
Dr. N. Rajagopalan
Dr. G.P. Saha
R.S. Sharma
N.K. Sinha
K.B. Thandavan
C.E. (B) S&R, MOSRT&H

Ex-Officio Members

President, IRC
(S.S. Momin)
DG(RD), MOSRT&H
(Indu Prakash)
Secretary, IRC
(R.S. Sharma)

Corresponding Members

Ashok Basa
C.V. Kand

1.2. At its first meeting on 29th April, 2003, the Committee felt that in the light of the massive construction programme that was under execution in the highway sector, it was necessary to bring out guidelines on certain topics which were not adequately covered in the existing IRC Codes and Standards. The design and construction of segmental bridges was one of the topics selected. It was decided that while highlighting the special design and detailing requirements in each case, the guidelines would be generally in line with IRC:18 and IRC:21 with additional inputs from BS:5400, EURO and AASHTO codes, wherever necessary.

1.3. The initial draft of the guidelines was prepared by Shri Vinay Gupta. The draft was discussed by the B-6 Committee at several meetings and finalized in its meeting held on 3rd September, 2004. The draft document was approved by Bridges Specifications and Standards Committee in its meeting held on 20th December, 2004. The document was considered by IRC Council in its 173rd meeting held on 8th January, 2005 in Bangalore and approved with certain modifications. The required modifications were accordingly carried out by the Convenor, B-6 Committee before sending the document for publication.

2. SCOPE

The guidelines cover the specific design and construction requirements of precast and cast-in-situ prestressed concrete segmental superstructures of bridges. The 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) Dry jointed precast segmental superstructure with external unbonded tendons,
- (iii) Precast as well as cast-in-situ cantilever construction superstructure, and
- (iv) Precast prestressed girder segments assembled using post tensioning (i.e., spliced girder system) with cast-in-situ stitch as well as match cast epoxy jointed girder segments.

2.1. Applicability in High Seismic Areas

Dry jointed precast segmental superstructures monolithic with piers shall not be permitted in the seismic Zones IV and V defined in IRC:6-2000.

3. CONSTRUCTION REQUIREMENTS

Minimum grades of concrete, minimum cement content, maximum water-cement ratio and other durability requirements shall be same as indicated in Table 5 of IRC:21-2000.

There are several specific requirements relating to construction which need to be adhered to. These are specified hereinafter.

3.1. 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, viz, Long Line method or 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.

3.1.1. 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 into 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.

3.1.2. 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.

3.1.3. 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 efficacy prior to beginning any erection/assembly of the segments.

3.1.4. Tolerances in Precasting: Finished segment tolerances should not exceed the following:

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

of segment, thickness of diaphragm	$\pm 5\text{mm}$
Grade of edge and soffit	$\pm 1\text{mm/m}$
Tendon hole location	$\pm 3\text{mm}$
Position of shear keys	$\pm 5\text{mm}$

3.2. 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. 1 for general details of shear keys in precast box girder segments. An example of shear keys in a box girder segment is also enumerated in Fig. 2.

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

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 per cent 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 hours. Refer Fig. 3 for a sample arrangement of temporary prestressing. The Epoxy shall essentially have properties as indicated in para 4.2.1.

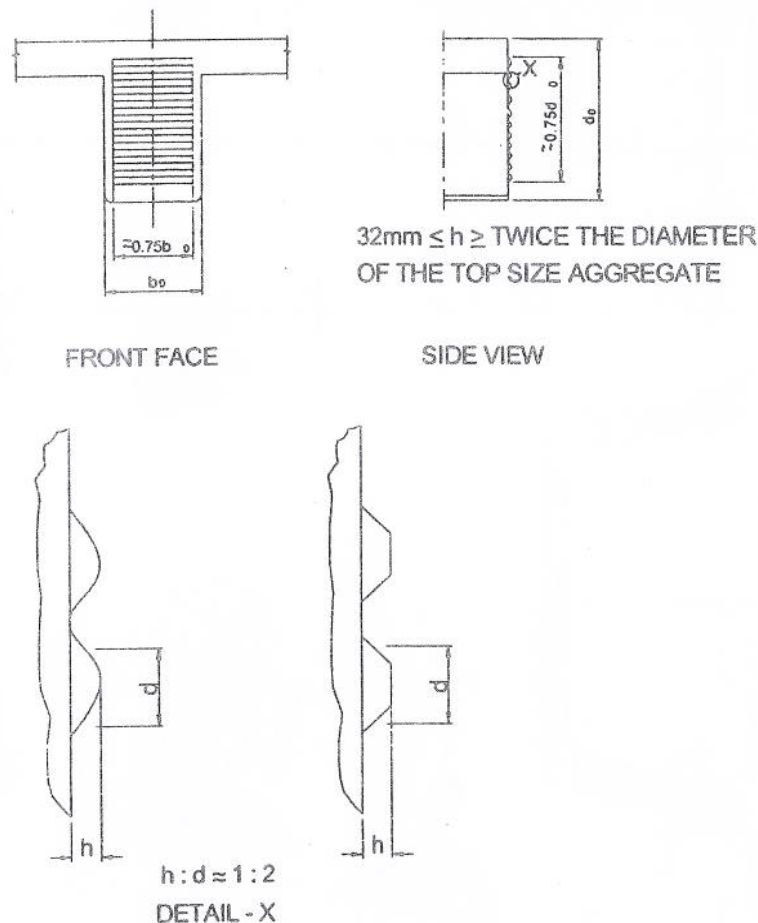


Fig. 1. Examples of Shear keys in Box Segments

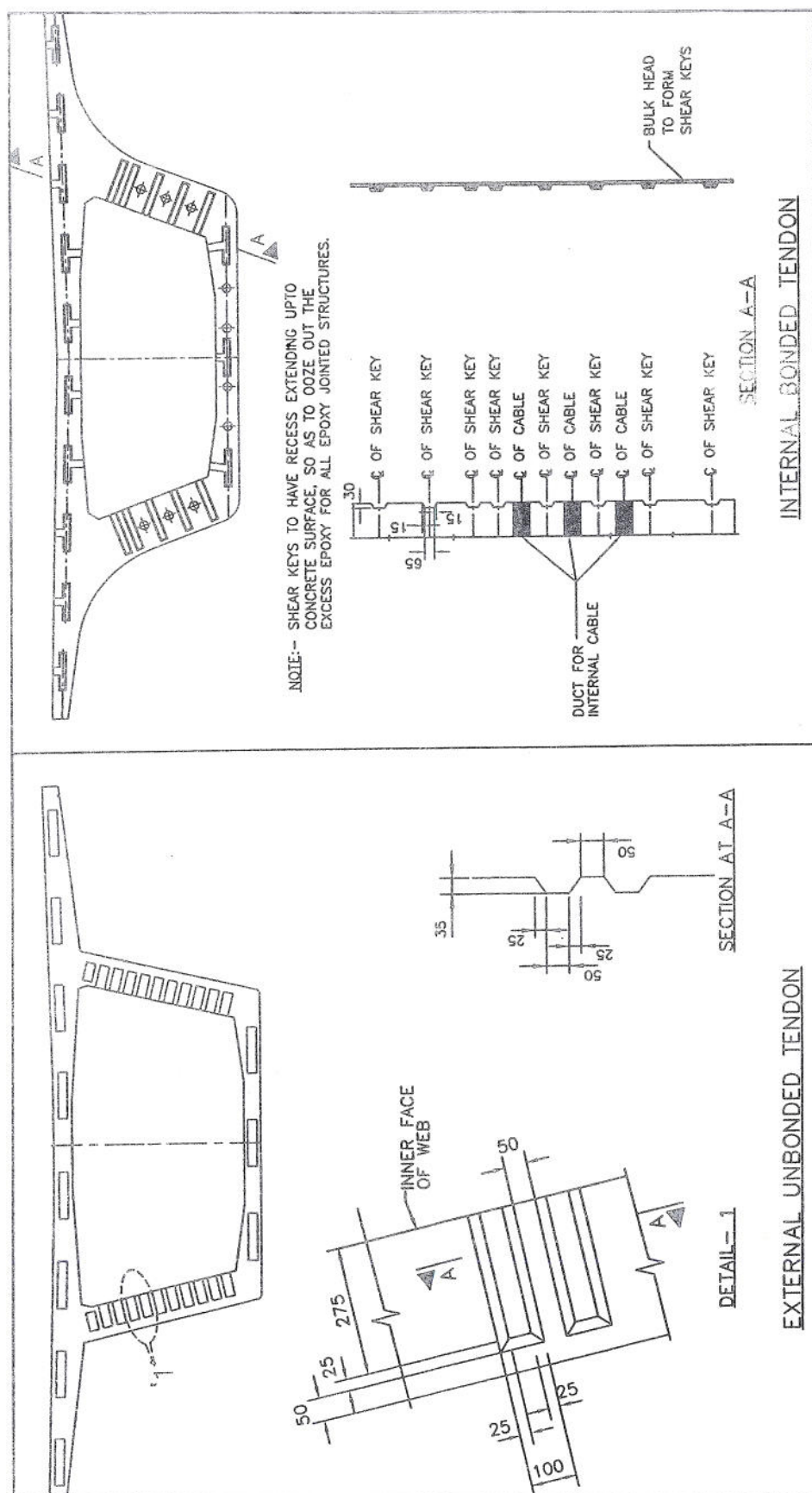


Fig. 2. Organisation of Shear Keys in Precast Box Girder Segment

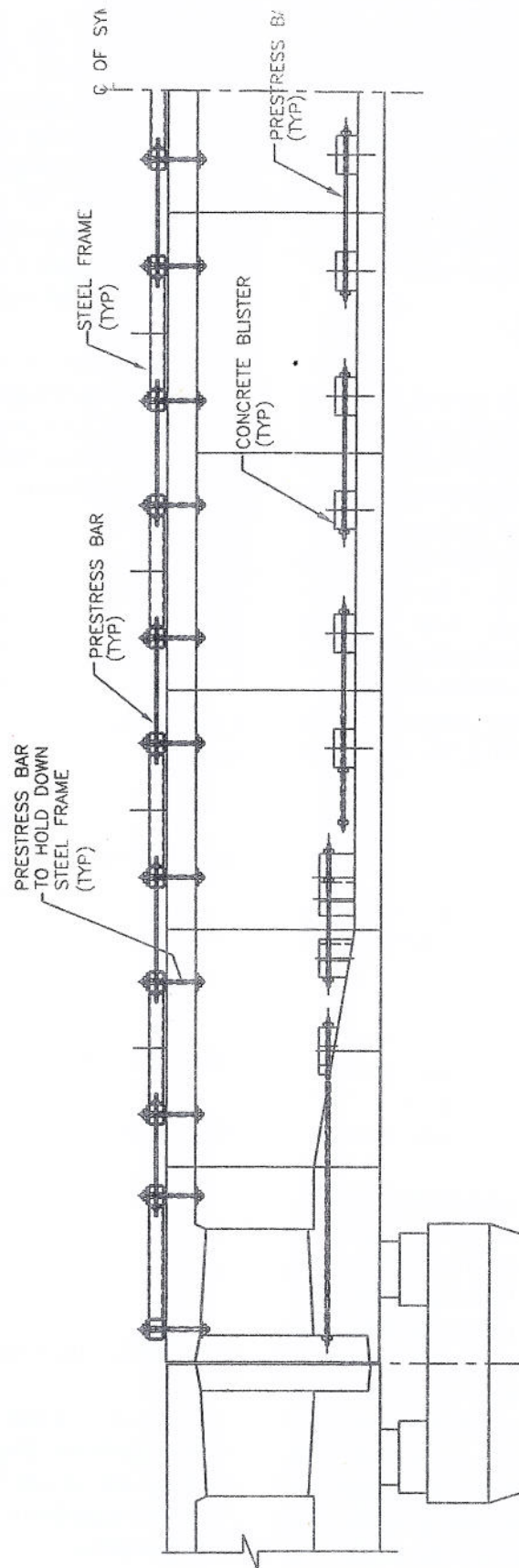


Fig. 3. Longitudinal Section showing Arrangement of Temporary Prestressing



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.

4.1. Sequence of Operation

The broad sequence of operation 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 hours. Thereafter, intended permanent prestress shall be imparted prior to demobilizing the temporary axial prestress.

4.2. Epoxy

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

5 to 20° Celsius	:	Fast reacting
15 to 30° Celsius	:	Medium fast reacting
25 to 40° 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 350W, 400rpm electric hand drilling machine is recommended. The speed of 400rpm 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 40°C for

fast reacting and medium fast reacting formulations and 60°C 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.

4.2.1. 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 upper temperature limit)
Open time	:	60 minutes (at upper temperature limit)
Compressive strength	:	60 MPa at 24 hours and 75 MPa at 168 hours on 50x50x50mm cube (at lower temperature limit)
Tensile bonding	:	after 24 hours at 100 percent strength 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 50x50x50mm cube shall be 20 MPa at 12 hours, 40 MPa at 24 hours and 75 MPa at 168 hours (at lower temperature limit)

4.3. 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 alignment of the segment.

4.4. 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. 4 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.

4.4.1. A preferred location of splice will be the points of minimum stress, such as, $1/3^{\text{rd}}$ 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.

4.5. 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.

4.6. Prestressing Ducts

In the case of dry jointed segments, prestressing duct shall necessarily be of HDPE material. 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. 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 diameter as per the provisions of IRC:18-2000. In case of internal prestressing, duct size and thickness shall be as per the provisions of IRC:18-2000. Adequate precaution shall be taken to ensure that epoxy material does not leak into joints of the ducts.

4.7. 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. 5, 6 and 7 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. 8 for some of the systems of corrosion protection of external prestressing tendons. Design of end block for external anchorages shall be in conformity with Clause 17 (along with Foot Note (ii) below Table 8) of IRC:18-2000.

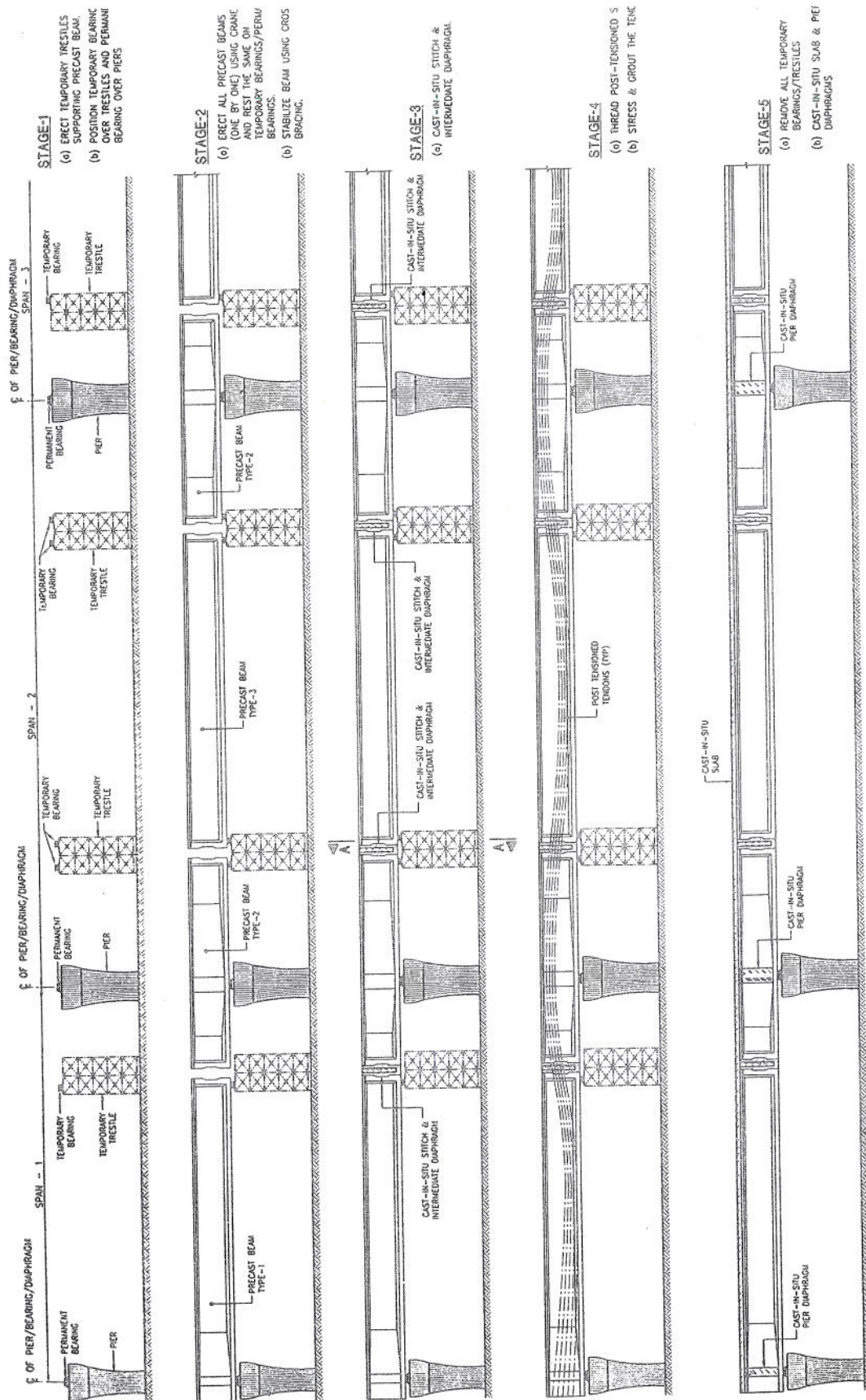


Fig. 4. Spliced Girder Superstructure

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

4.7.2. 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.

4.7.3. The structure shall be designed for snapping of any cable, one at a time, which will cater for the condition of replacement of cables. In this condition, load factors and permissible stresses corresponding to erection condition in Table 1 of IRC:6-2000 shall be considered.

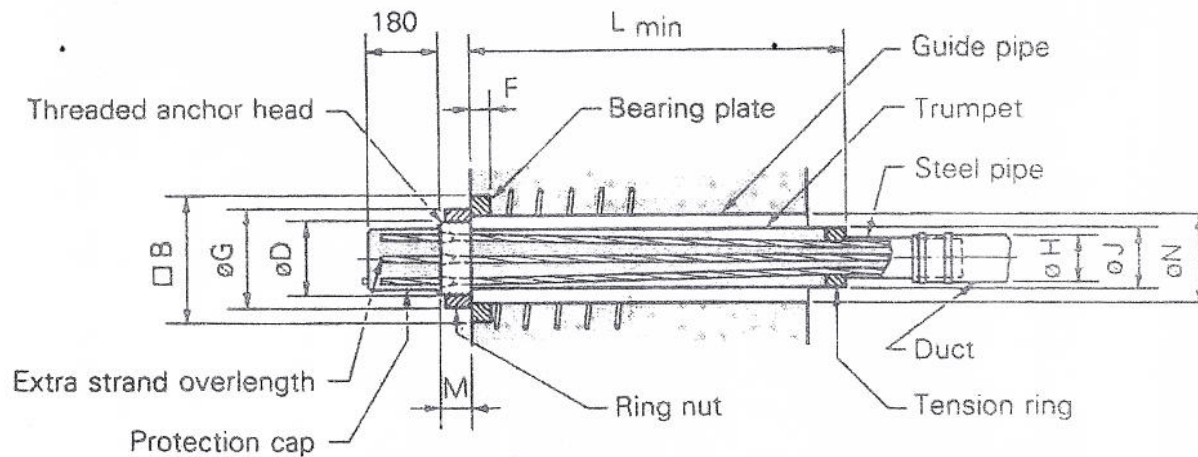


Fig. 5. Replaceable Anchorages for External Prestressing

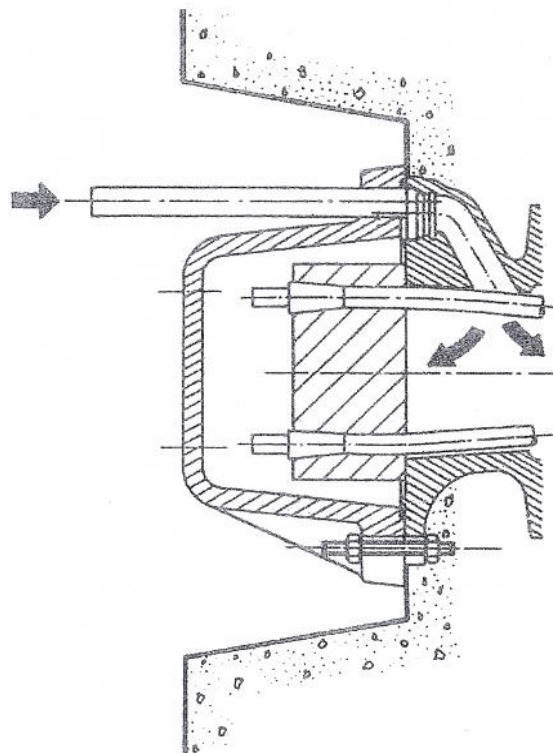


Fig. 6. Protection Cap over Permanently Sealed Anchorage

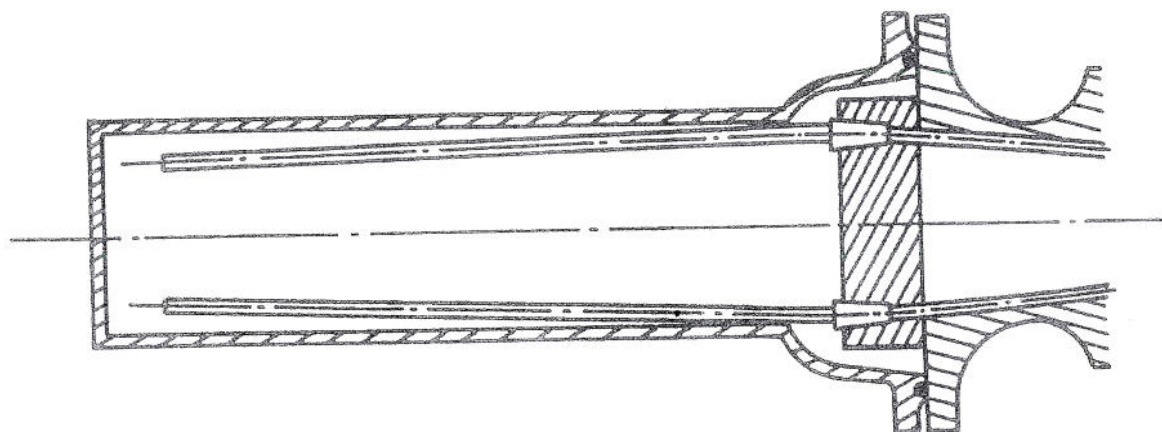


Fig. 7. Protection Cap over Anchorages to be Handled in Future

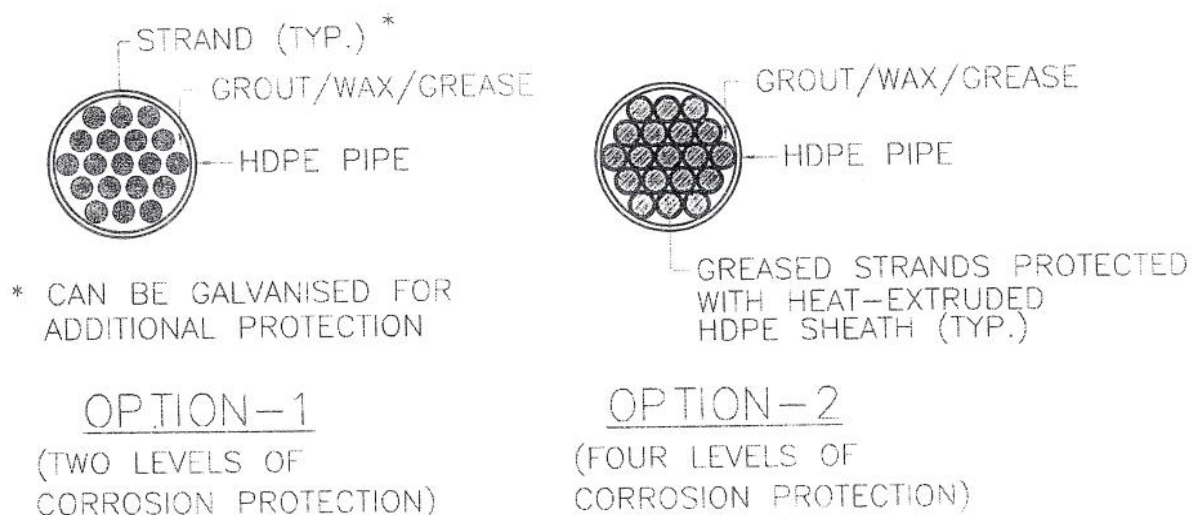


Fig. 8. Options for Corrosion Protection of External Tendons

4.8. 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. 9 and 10 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).

4.9. Prestressing Couplers

In case, prestressing couplers are used, not more than 50 per cent 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.

4.10. Deck Waterproofing

Bituminous or any other approved flexible membrane waterproofing shall be provided over the deck slab.

5. DRY JOINTED PRECAST SEGMENTAL CONSTRUCTION

Dry jointed construction shall not be used with internal tendons. Dry jointed precast segmental externally prestressed superstructures have advantage of speed of construction over the epoxy jointed precast segmental externally prestressed superstructures. However, adequate caution needs to be exercised while adopting the former. Generally, these structures have been found to exhibit lower ductility level, lower shear strength and larger deflections compared to epoxy jointed superstructures under the ultimate loading conditions. It is also apprehended that a small order warping is caused after precasting of segments due to non-uniform exposure to the sun and other

weather conditions. Since, dry-jointed segments do not have filler material, like, epoxy, there could be a likelihood of stress concentrations. Precautions may be exercised to avoid such warping. The possibility of water leakage through the dry joints cannot be ruled out and hence in climates where freeze-thaw conditions exist, dry-jointed construction shall be avoided.

5.1. Design

Design shall, in principle, be done in the same way as for cast-in-situ structure as per IRC:18-2000 except for the additional provisions and/or deviations indicated below, which need to be followed.

5.2. Basis of Design

Permissible stresses in concrete and prestressing steel shall be applicable as per Clauses 7 and 8 of IRC:18-2000 respectively except as modified below. Similarly, section properties and modulus of elasticity shall be applicable as per clauses 9 and 10 of IRC:18-2000 respectively. Losses in the prestressing shall be calculated in the manner given in Clause 11 of IRC:18-2000. Ultimate flexural strength shall be calculated as per Clauses 12 and 13 of IRC:18-2000 except as modified below. Shear design shall be done as per Clause 14 of IRC:18-2000 except as modified below. Other Clauses 15 to 25 of IRC:18-2000 shall be applicable unaltered.

5.3. Permissible Stresses in Concrete

5.3.1. Permissible temporary stresses in concrete: Temporary maximum compressive stresses in concrete shall be as per Clauses 7.1.2 and 7.1.3 of IRC:18-2000. The stresses on the tensile face shall be limited to no tension in case of epoxy jointed precast segments, minimum residual compression of 0.7 MPa in case of dry jointed precast segments and as per Clause 7.1.4 of IRC:18-2000 for cast-in-situ segmental structure and spliced girder structure with cast-in-situ stitch.

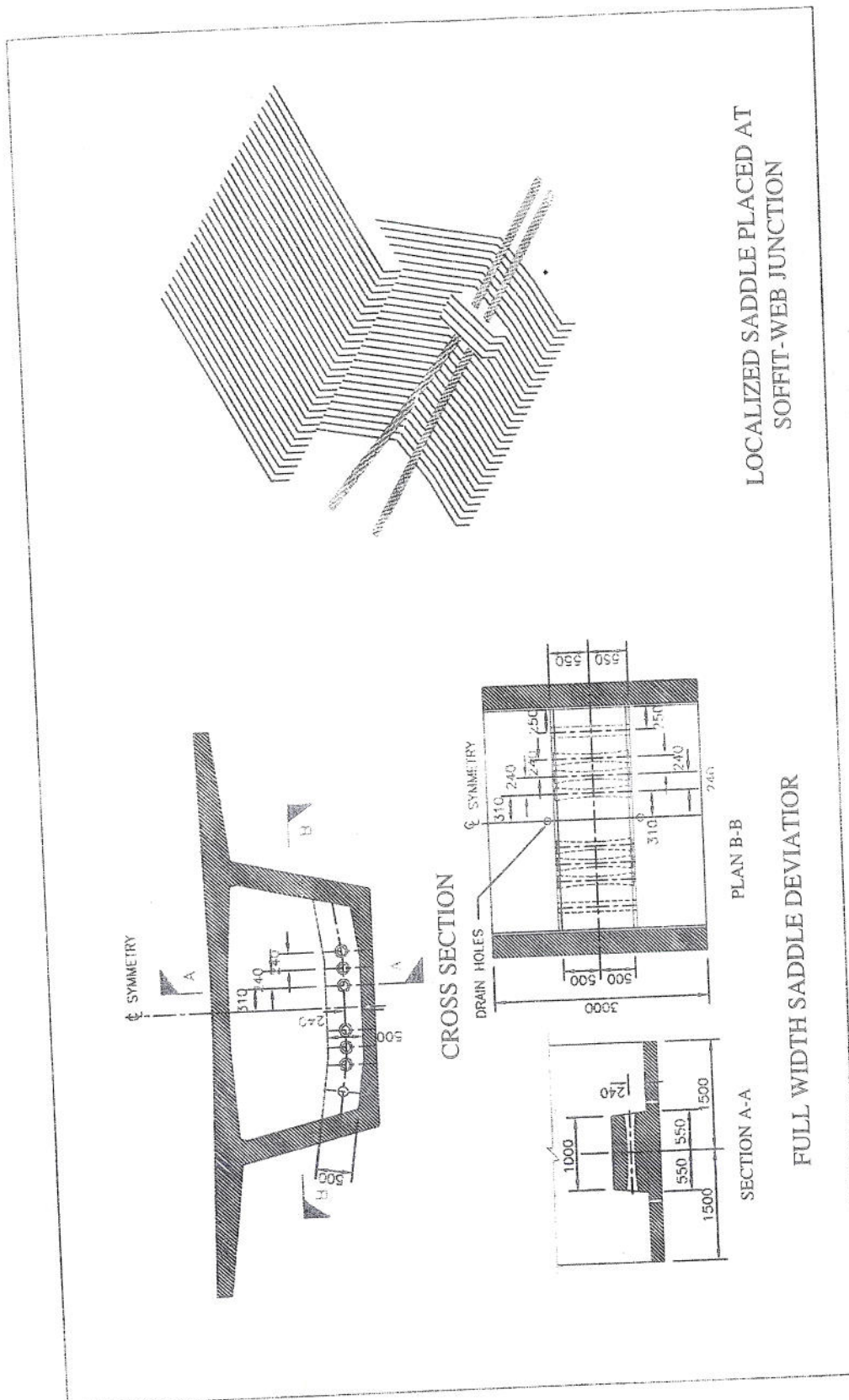
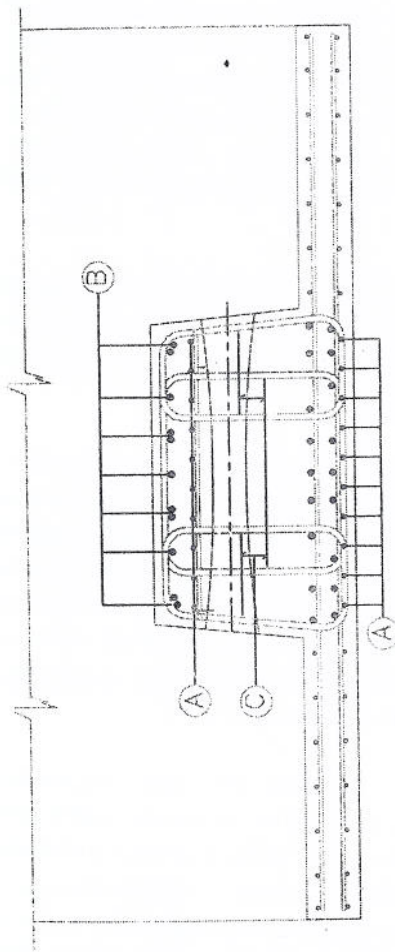
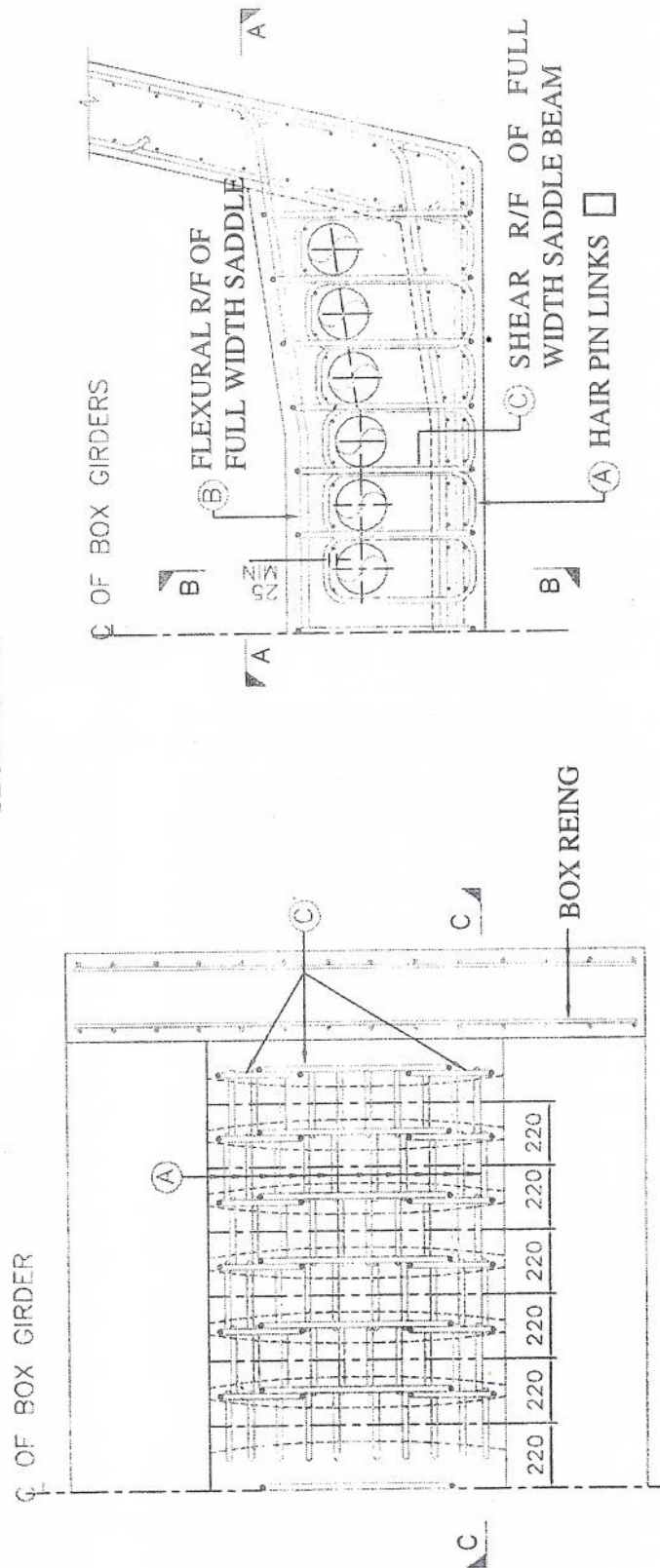


Fig. 9. Arrangement of Deviator Blocks



SECTION B-B



PLAN A-A

SECTION C-C

Fig. 10. Reinforcement details of Typical Full Width Saddle Deviator

5.3.2. Permissible Stresses in concrete During Service: During service condition, after all losses of prestressing, the maximum compressive stresses, in normal condition, shall be limited to $0.33 f_{ck}$ as per Clause 7.2.1 of IRC:18-2000 for all types of segmental structures. The stresses on the tensile face shall be limited to minimum residual compression of five per cent of maximum permanent compressive stress that may be developed in the same section in case of epoxy jointed precast segments. In case of dry jointed precast segments, minimum residual compression of 0.7 MPa or five per cent of maximum permanent compressive stress that may be developed in the same section, whichever is more, shall be ensured on the tensile face. For cast-in-situ segmental structure and spliced girder structure with cast-in-situ stitch, no tensile stresses shall be permitted on the tension face as per Clause 7.2.2 of IRC:18-2000.

5.3.2.1. In the load combinations involving temperature effects (over all temperature variation as well as differential temperature gradient), minimum residual compression of upto zero (no tension) shall be ensured through prestressing in all types of precast segmental structures where untensioned reinforcement can not continue across the segments. The permissible compressive stresses in concrete may be enhanced by 15 per cent. Tension, upto a maximum of two third of the modulus of rupture may be permitted in case of cast-in-situ segmental structures and spliced girder structures with cast-in-situ stitch where adequately designed untensioned reinforcement, continuing across the segments, can be provided as per the provisions of Clause 5.2(iv) of IRC:18-2000. In this case, permissible stresses in concrete and steel may be increased by 15 per cent. In all load combinations involving differential temperature, gradient maximum 50 per cent live load shall be considered.

5.3.2.2. The structure shall also be checked for 20 per cent higher time dependant losses, like, creep, shrinkage, relaxation, etc. for normal load combination for the above mentioned limits of stresses as per Clause 7.2.4 of IRC:18-2000.

5.4. Design for Ultimate Shear

Provisions of Clause 14 of IRC:18-2000 shall apply except as modified by the provisions given below.

5.4.1. Cast-in-Situ segmental super structures and spliced girder super structures with cast-in-situ stitch: Provisions of Clause 14 of IRC:18-2000 apply.

5.4.2. Epoxy jointed precast segmental superstructures with internal bonded tendons or external unbonded tendons: Ultimate load factors shall be followed as per Clause 12 of IRC:18-2000. Any helping effect of bearing resistance developed through the shear keys shall be ignored.

5.4.2.1. For structures with internal bonded tendons, the ultimate shear capacity calculated as per Clause 14 of IRC:18-2000 shall be multiplied by a factor of 0.90.

5.4.2.2. Structure with external unbonded tendons shall be considered as reinforced concrete column subject to externally applied loads for the purpose of shear design. For this purpose, the limit of maximum shear stress shall be as per Table 6 of IRC:18-2000. For structures with external unbonded tendons, calculated shear capacity shall be multiplied by a factor of 0.85.

5.4.3. Dry jointed precast segmental superstructures with external unbonded tendons: Structure with external unbonded tendons shall be considered as reinforced concrete column subject to externally applied loads for the purpose of shear design. For this purpose, limit of maximum shear stress shall be as per Table 6 of IRC:18-2000. The ultimate shear capacity so calculated shall be multiplied by a factor of 0.85. In the case of dry jointed segmental superstructure associated with external unbonded tendons, under any load combination, the design shear resistance of mating surfaces of precast segments shall be more than the net applied shear at any dry joint in order to prevent joint slippage. For calculating shear capacity of joints of segments, add $a + b$, where 'a' is the capacity of shear key acting as

corbel (designed by shear friction theory) with frictional coefficient $\mu_1 = 1.4$ and axial force derived from prestressing after all losses and 'b' is equal to the capacity of the remaining web area using friction coefficient $\mu_2 = 0.6$ and axial force derived from prestressing after all losses. In other terms, $a = \mu_1 \times (0.87 \times \text{prestressing force after all losses} / \text{cross-sectional area of superstructure}) \times \text{shear key area}$. And $b = \mu_2 \times (0.87 \times \text{prestressing force after all losses} / \text{cross-sectional area of superstructure}) \times (\text{web area} - \text{shear key area})$. The ultimate shear capacity of the shear keys so calculated shall be multiplied by a factor of 0.75. Ultimate load factors shall be followed as per Clause 12 of IRC:18-2000.

5.5. Design for Ultimate Flexure

Design shall, in general, be carried out as per Clause 13 of IRC:18-2000 except as modified below. Ultimate load factors shall be followed as per Clause 12 of IRC:18-2000. The untensioned reinforcement not continuing between the precast segments shall not be assumed to contribute to the flexural strength.

5.5.1. For Cast-in-situ segmental and spliced girder superstructures with cast-in-situ stitch: The provisions of Clause 13 of IRC:18-2000 shall apply.

5.5.2. For Epoxy jointed precast segmental superstructure with internal bonded tendons or external unbonded tendons: The ultimate flexural capacity calculated as per Clause 13 of IRC:18-2000 shall be multiplied by a factor of 0.95 for internal bonded tendons and 0.90 for external unbonded tendons. In the case of 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 tendon's length. 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 deflection 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. 11 and 12 illustrate sample arrangements of external and internal prestressing tendons respectively. Fig. 13 illustrates analogous model of externally prestressed superstructure.

5.5.3. For Dry jointed precast segmental superstructure with external unbonded tendons: The ultimate flexural capacity calculated as per Clause 13 of IRC:18-2000 shall be multiplied by a factor of 0.85. In the case of 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 tendon's length. 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 deflection 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.

5.6. Tension Behind Intermediate Anchorages

At the intermediate anchorage locations, concentrated tensile stresses develop behind the anchorages. Adequately designed reinforcement shall be provided for the same. Appropriate specialist literature may be followed for design of this reinforcement. In the case of precast segmental superstructure, the design needs additional precautions because the reinforcement cannot continue between the adjoining segments. In such cases, appropriate specialist literature may be followed for catering to such tensions behind the intermediate anchorages.

5.7. Correction for Centre of Gravity of Tendons

Draped tendons shall be assumed to be below the duct CG in hogging ducts and above the duct

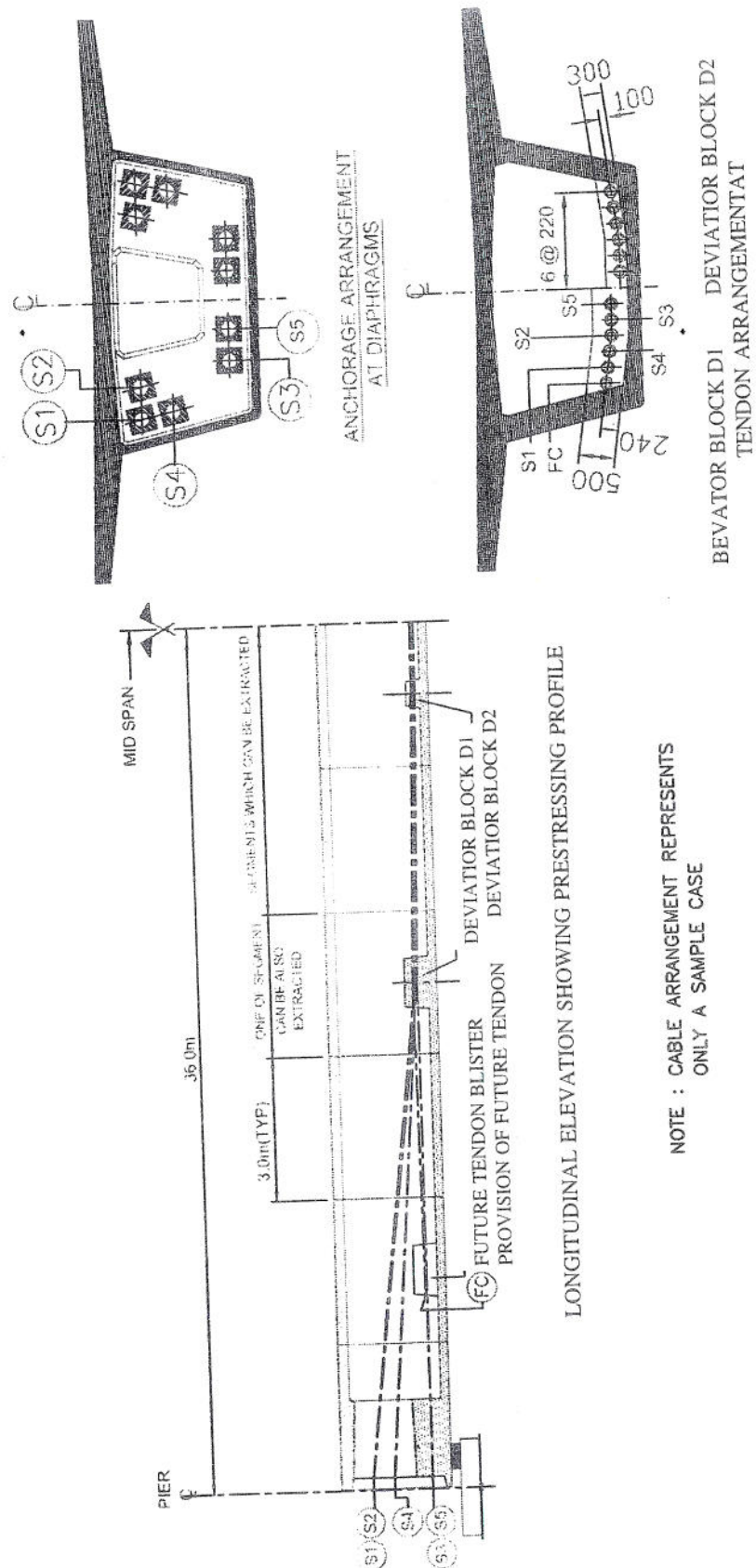


Fig. 11. Tendon Profile of Simply supported Span Constructed by Precast Segmental Technique using External Bonded Tendons

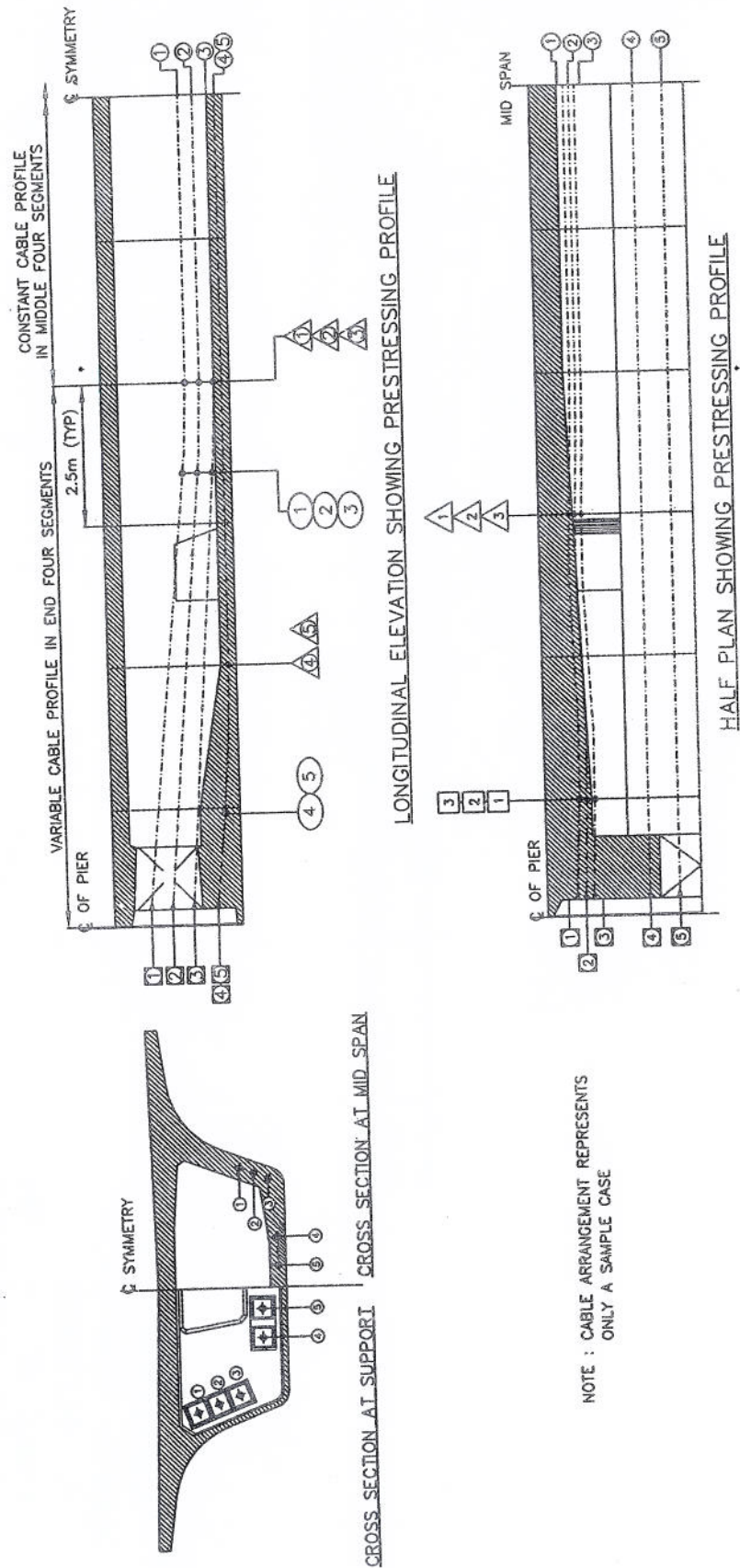


Fig. 12. Tendon Profile of Simply Supported Span constructed by Precast Segmental Technique using Internal Bonded Tendons

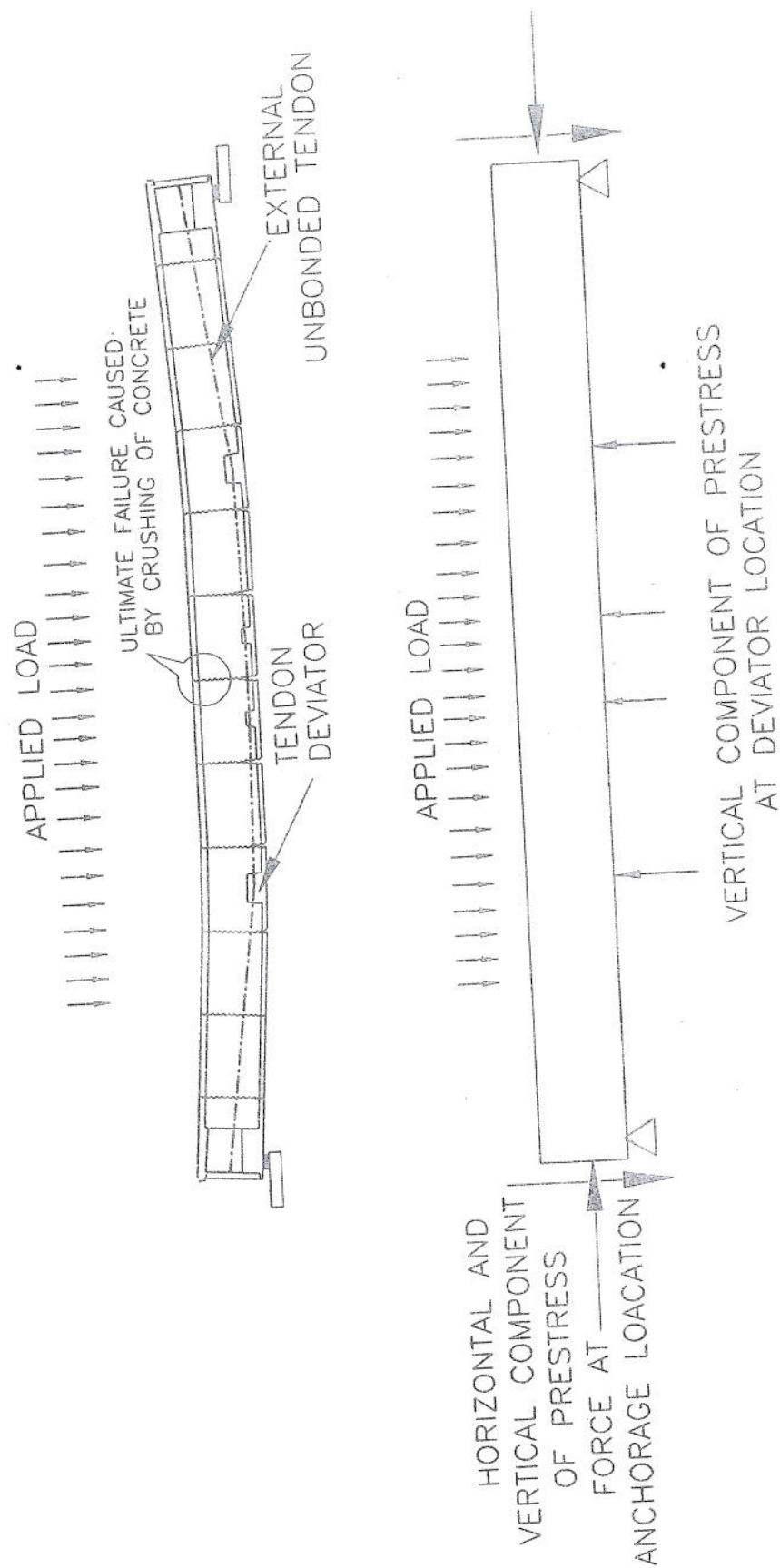


Fig. 13. Analogus Model of Externally Prestressed Structure

CG in sagging ducts by 6 mm, 12 mm, 18 mm and 25 mm for duct ID of 50 mm, 51 mm to 75 mm, 76 mm to 100 mm and above 101 mm respectively. For portions of transitions between hogging and sagging ducts, intermediate values may be used appropriately.

5.8. Axial Tensions

Design shall adequately take account of the axial tensions occurring in the superstructure on account of bearing restraints against creep, shrinkage, thermal movements, breaking/tractive forces and longitudinal seismic forces. This effect is, more importantly, required to be taken care of in precast segmental structure due to the absence of continuing reinforcement.

5.9. Local Effects of Blisters

It is a common practice to provide concrete protrusions called blisters inside the box girder to accommodate tendon anchorages. These blisters associated with prestressing force cause significant local bending moments. Therefore, every possible attempt shall be made to locate these blisters at web-bottom slab or web-top slab junctions so as to minimize additional local bending moments. If it is inevitable to provide blisters over the mid width of top/bottom slab or mid-height of webs, they shall be extended till the adjoining top/bottom slabs or the webs, as the case may be. In any case local bending moments from such blisters shall be accounted for appropriately in the design of the adjoining structure for which appropriate specialist literature may be consulted.

6. REFERENCES

In this publication, reference to the following IRC, BS, AASHTO Standards has been made. At

the time of publication, the edition indicated were valid. All standards are subject to revision and the parties to agreements based on these guidelines are encouraged to investigate the possibility of applying the most recent editions of standards.

6.1. Codes and specifications

1. IRC:6-2000, Standard Specifications and Code of Practice for Road Bridges, Section II-Loads and Stresses (Fourth Revision)
2. IRC:18-2000, Design Criteria for Prestressed Concrete Road Bridges (Post Tensioned Concrete) (Third Revision)
3. IRC:21-2000, Standard Specifications and Code of Practice for Road Bridges, Section III-Cement Concrete (Plain Reinforced) (Third Revision)
4. BS 5400: Part 4: 1984 Code of Practice for Design of Concrete Bridges
5. BS 58/94, The Design of Concrete Highway Bridges and Structures with External and Unbonded Prestressing
6. AASHTO LRFD Bridge Design Specifications: 1999 Interim
7. American Segmental Bridge Institute July 1998 Guide Specifications for Design and Construction of Segmental Concrete Bridges (Second Edition)
8. FIP-1978 Proposal for standard tests and verification of Epoxy bonding agents for segmental construction.

6.2. Papers & Publications

1. 'External prestressing' by Service D' Etudes Techniques des et Autoroutes, France.
2. Ahmed M, Abdel Karim and Mahen K Tadros-'Splicing Increases Span Capabilities of Precast Bridge I Girders' (Technical Paper).

