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GUIDELINES FOR USE OF EXTERNAL AND UNBONDED PRESTRESSING TENDONS IN BRIDGE STRUCTURES

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GUIDELINES FOR USE OF EXTERNAL AND UNBONDED PRESTRESSING TENDONS IN BRIDGE STRUCTURES

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:

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Corresponding Members

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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 use of external and unbonded prestressing tendons in bridge structures 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 P.Y. Manjure and revised by Shri S.G. Joglekar. The draft was discussed by the B-6 Committee at several meetings and finalized in its meeting held on 5th November, 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 without modifications.

2. SCOPE

The guidelines contain the additional and/or alternative considerations covering the design aspects, prestressing systems, materials, protection of steel, durability aspects and also, describe few details of the applications. The Designer is advised to consult relevant specialist literature on the subject, if further information is needed.

3. UNBONDED PRESTRESSING - APPLICATION

There are three types of applications

(i) In the first type, the unbonded prestressing elements on their own comprise the total prestressing force. Segmentally constructed bridge superstructures using external cables is an example of this type.

(ii) In the second type, the unbonded elements act as part of total prestressing force, the other part being provided by bonded prestressing elements embedded in concrete. External prestressing provided for repair/rehabilitation/strengthening of existing prestressed concrete bridges is an example of this type. The external prestress may or may not contribute to the enhancement of ultimate strength.

(iii) In the third type, the external prestressing is used as a means of applying external load acting in the desired direction and quantum, and the deformation of the structure due to subsequent live load – both in service and under ultimate condition – do not affect the magnitude and direction significantly. The external prestressing is taken as equivalent load only without considering its contribution to the strength of the structure. Such is the method of strengthening of RCC structures by using prestressing elements to relieve part of the dead load effects.

In unbonded prestressing, no continuous bond is provided between the prestressing elements and concrete, by virtue of which concrete and prestressing steel can develop structural interaction. In these structures prestressing elements are outside the concrete section and are attached to it at discrete points of anchorages and deviators. The prestressing elements and the concrete elements behave as different component-structures of the overall structure, acting in unison by virtue of connection at anchorages and deviators, and thereby contribute to overall strength. The local strains in any part can be calculated by first calculating the overall deformations, i.e., relative displacements of common points of attachment and then analyzing the component-structures separately.

It is possible to use unbonded prestressing elements which lie within the ducts provided in concrete section, and thereby impose closely matching geometrical deflections on the two. Such solutions have been used where long term monitoring of prestressing force and/or possible replacement of cables, or augmentation of the force at a later date had been the design requirement. However, for these cases also, the local strains in concrete and the prestressing tendons are not identical.

4. MATERIALS

4.1. Prestressing Steel

Prestressing steels listed in Clause 3.5.1 of IRC:18-2000 are acceptable. In addition, factory produced protected steels, such as, galvanised, epoxy coated, lubricated and sheathed steel strands (in HDPE sheaths) are acceptable. For full specifications, relevant Indian Standards, or in absence of the same, International Standards should be referred to. However, steel material should pass the requirements of IRC:18-2000 Clause 3.5.1.

4.2. Sheathing

External tendons shall be housed in either High Density Poly-Ethylene (HDPE) sheaths or metallic steel sheaths (plain or with protective coatings), which have smooth internal surfaces. The sheathing ducts and connections should be fully leak-tight against water pressure equivalent to 1.1 × (maximum expected gravity head of grouting material + grouting pressure). The jointing specifications and details should also be leak-tight and pressure resisting as above.

The materials of sheaths shall meet requirements of respective Indian Standards/IRC Standards.

4.3. Deviators, Anchorage Brackets, Suspenders

These items can be in R.C.C./P.S.C. forming parts of the main structure or in steel which is embedded therein or fixed to the same by anchoring or by mechanical fixing arrangement (e.g., by bolting or welding).

The steel fasteners, welding materials, etc. used for fabrication of such parts shall be conforming to IRC:24-2001. The materials and reinforcing steels used in R.C.C. portion shall be as per the requirements of IRC:21-2000.

4.4. Anchorages, Guide-tubes and All Parts of Prestressing System

Anchorages should preferably be of replaceable/ or re-usable type for possible replacement of tendon.

Anchorage systems should be factory manufactured under strict quality assurance/quality control, and supplied in appropriately protective packing. These items being of proprietary nature, their manufacturers should be got approved from competent authorities. The supplied product itself should be subjected to acceptance testing for satisfactory performance of the same. Guidelines for acceptance testing may be taken from ‡FIB guidelines or from British Standards §BS:4447-1973 (Reprinted in 1990).

Attention is specially brought to the requirement of passing dynamic test for two million cycles for the cable/anchorage assembly when tested in accordance with FIB or BS test procedure. Certificate of testing by independent testing laboratory using the assemblies similar to those proposed for the work in hand is a minimum level of acceptance for all applications. These should be supplemented by testing of not less than three samples from the materials supplied to site.

5. DESIGN

5.1. General

The provisions of IRC:6-2000, IRC:18-2000 and IRC:21-2000, for design are also applicable for bridges with unbonded prestressing steel except as discussed hereinafter. Although not explicitly stated in codes, the prestressing is treated partly as load and partly as a component of load-resisting mechanism (i.e., adding to the strength of section). When treated as load, it is treated as a permanent load varying between prestress level before losses and after long-term losses, with further provision that losses themselves can vary ±20 per cent from the mean design value. This method of design is used in "working load" or "allowable stress" method of design. When this method is supplemented (as is done in IRC:18-2000) by additionally stipulating minimum required ultimate strength equal to or greater than that required by "factored load combinations" the contribution of prestressing steel in ultimate resistance of section needs to be considered.

Note: *In Limit State Design method, both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) need to be checked for which detailed rules are given in codes using Limit State Philosophy for design. The requirements of IRC:18-2000 for ULS checking, need to be supplemented by suitable strength models to cover the case of external and unbonded prestress. - Refer Section 4.4.3. &* ***Appendix****.*

5.2. Load, Load Combinations and Factored Loads For Ultimate Strength Requirements

Provisions of IRC:5-1998, IRC:18-2000 and IRC:21-2000 are applicable.

The prestressing load is taken to vary between limits as described in 5.1 above. By implication the load factor for ultimate load on prestress is taken as 1.0 in IRC:18-2000. However, IRC:18 does not cover indeterminate structures. For such structures, a load factor of 1.2 for unfavourable combinations and 0.9 in favourable combinations is recommended for analysing the response of indeterminate structures and establishing required ultimate load resistance at different sections.

5.3. Ultimate Strength in Flexure

5.3.1. Principles : The contribution of the prestressing tendons to the resistance of

‡Recommendations for the Acceptance of Post-Tensioning Systems : 1993

§Specification for the Performance of Prestressing Anchorages for Post-Tensioned Construction.

the sections should be limited to their additional strength beyond prestressing. This may be calculated assuming that the origin of the stress/strain relationship of the tendon is displaced by the effects of prestressing (Refer Fig.1 and Fig. 2).

5.3.2. Section analysis : In absence of detailed rules (in IRC:18) for estimating the ultimate resistance in bending of sections with unbonded prestress, set of rules consistent with principles of 5.3.1 above are given in ***Appendix*** for ready reference.

5.3.3. Resistance to shear : Calculations for shear are required only for ultimate strength.

Sections with full prestressing provided by unbonded or external tendons shall be checked for shear by considering them as reinforced concrete sections subject to externally applied axial load (such as columns).

In members where partial prestress is provided by bonded tendons, the shear resistance should be checked as prestressed member (with bonded prestress), treating the unbonded prestress to provide only the external axial force as stated above. Where shear capacity itself is directly provided by - or augmented by - external unbonded prestress, the partial load-factor for prestressing load in total shear in ultimate load combination should be taken as 0.9. Its contribution to strength by further elongation should be neglected since additional strains by shear deformations are small.

5.3.4. Design of Anchorages/Deviator/Local Zone

(i) For external cables, the anchorages are normally external and the tendons may be required to be re-stressed or replaced. Also, anchorages have to be able to hold cables in stressed condition for the design life. Hence, the anchorages and all its components should be suitable to meet these requirements.

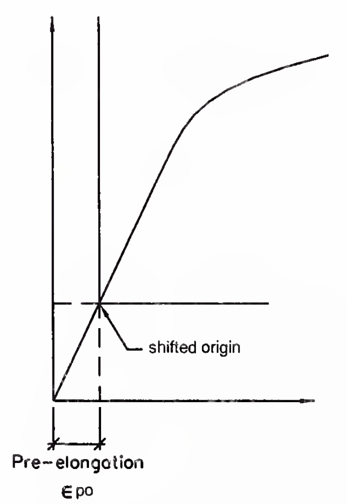

Fig. 1. Stress-strain of Prestressing Steel

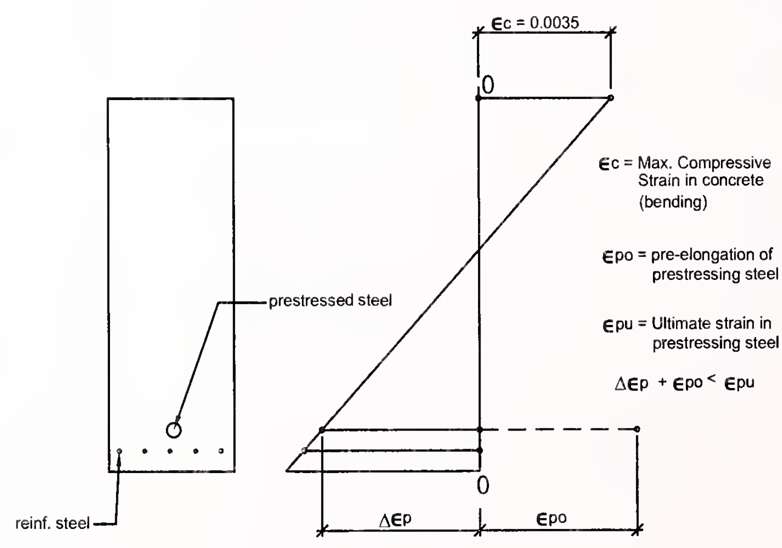

Fig. 2. Strain Diagram of Typical Section

(ii) Anchorages, deviators, the supporting brackets, projecting concrete blisters, etc. should be designed for carrying full nominal ultimate capacity of tendon as a design load.

(iii) The load transmitted to concrete section by these elements should be resisted by appropriately designed and reinforced local zone of the main structure to which they are affixed. The spalling and bursting reinforcement shall not be less than that recommended by the manufacturer of anchorages. The zones immediately behind the anchorage (and zone in front and sides of it in case of intermediate anchorages) should be properly reinforced taking into account the effects of dispersal of load in the concrete section.

(iv) The design of the deviators, in steel or in concrete, shall meet the requirements of IRC:18, IRC:21 and IRC:24 as applicable.

6. DETAILING

6.1. Alignment of External Cables

The tendons can be straight or draped using deviators depending on the particular requirements. Various profiles can be adopted to suit the required combination of axial load and bending. Careful consideration should be given to the overall stress distribution at critical sections and the local stresses at points of anchorages and deviators.

Some of the commonly adopted shapes for alignment are shown in Fig. 3 and Fig. 4. Typical arrangements of deviators are shown in Fig. 5 and Fig. 6. Typical details of anchorages often adopted in repair/rehabilitation works are shown in Fig. 7. For new works, normal embedded types of anchors or specially manufactured anchors for external application are used.

6.2. Straight Lengths Between Deviators

Only in case of embedded ducts, non-linear geometrical shapes can be provided for unbonded tendons. Otherwise, alignment of external cables will be in straight segments between points of attachment to the structure, such as, anchorages, deviators, etc.

For straight cables, the spacing of deviators and anchorages shall be such that the straight segments of cable are not longer than 12 times the depth of the beam or 12 m whichever is less. An intermediately placed deviator intended to break the long straight length shall project outwards beyond theoretical straight line joining the deviators on two sides to ensure that the tension in the tendon will keep it fully pressed against the intermediate deviator and keep the tendon in place by friction. Also at all deviators tendons should be restrained against lateral movement. In all cases, the natural frequency of tendons with lengths held between the points of fixing should not be in range of 0.8 to 1.2 times the natural frequency of bridge element to which external cables are fixed. The natural frequency of tendon is a function of its effective mass per unit length rigidly attached to the tendon, it's stress level and the distance between the points of attachment. It is given by :

$$f = \frac{1}{2L}\sqrt{\frac{F}{m}}$$

f : Frequency in cycles/sec.

L : Length between two supports consisting of anchorages or deviator.

F : Tension in the cable (force units).

m : Vibrating mass per unit length (inclusive of duct and grout).

6.3. Curvature at Deviators

In the absence of test results or other investigation justifying smaller values, the radius of curvature of tendons in the deviators should not be less than the values as specified in Table 1.

TABLE-1

Tendon (Strand Number-Size)	Minimum Radius (m)
19-13 mm and 12-15 mm	2.5
31-13 mm and 19-15 mm	3.0
53-13 mm and 37-15 mm	5.0
13 mm, 15 mm, or 18 mm dia. Single strands	40 times nominal dia. of stand

(The above values of radii may be adopted for wire cables with equivalent ultimate strength)

7. PROTECTION OF PRESTRESSING STEEL/ANCHORAGES/DEVIATORS

Prestressing steel shall be protected during temporarily exposed stages by coating with water soluble oils, grease or other suitable means. The

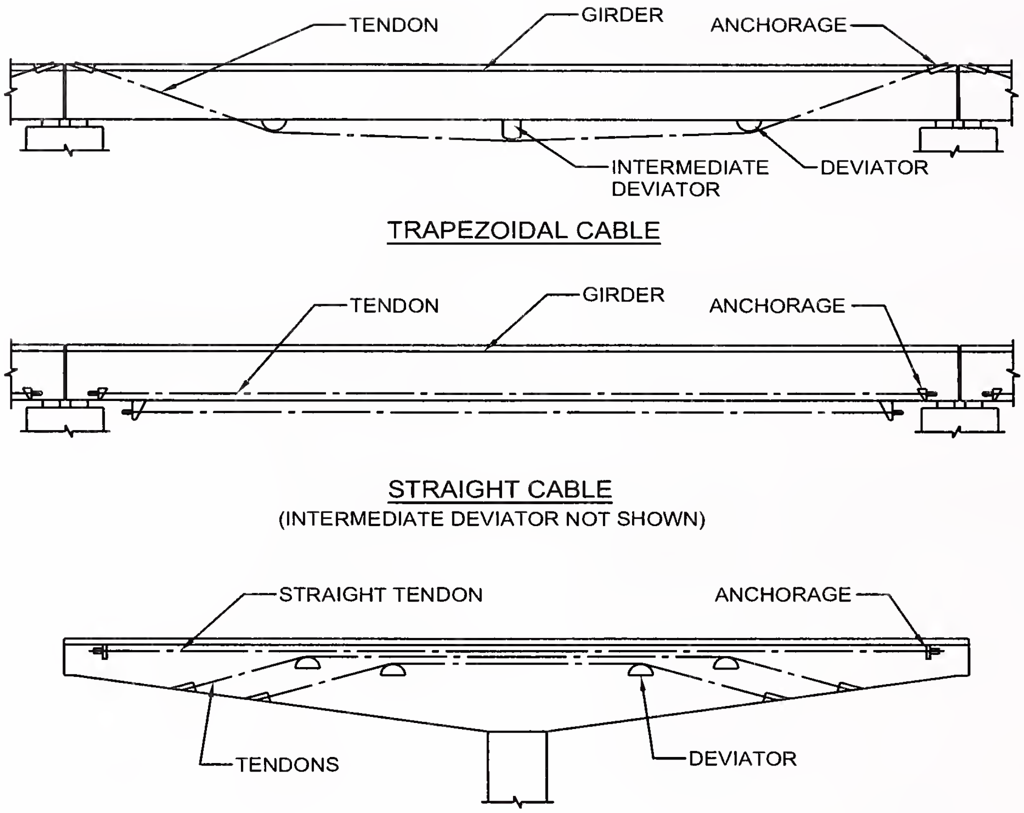

Fig. 3. Typical Alignment of Tendons in Repair/Rehabilitation Works

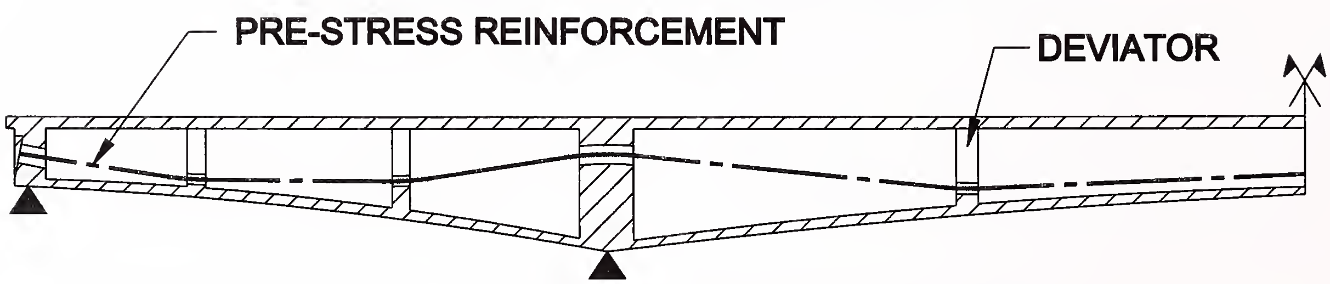

Fig. 4. Typical Alignment of Tendons for New Constructions

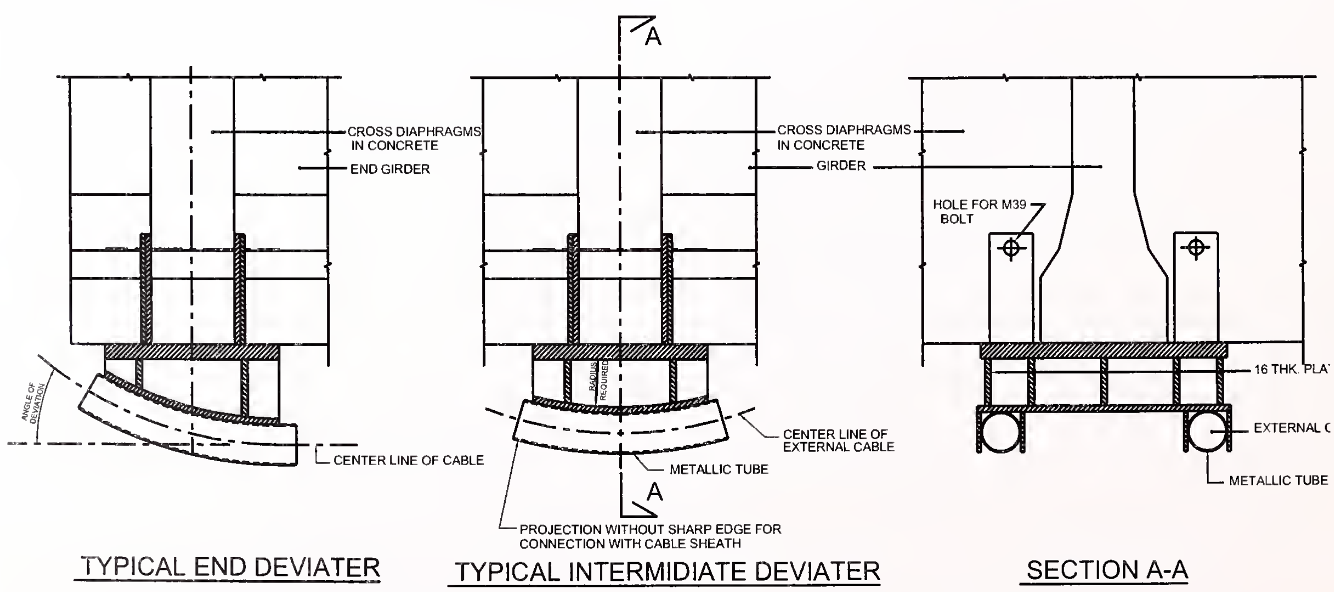

Fig. 5. Typical External Deviators in Steel in Repair/Rehabilitation Works

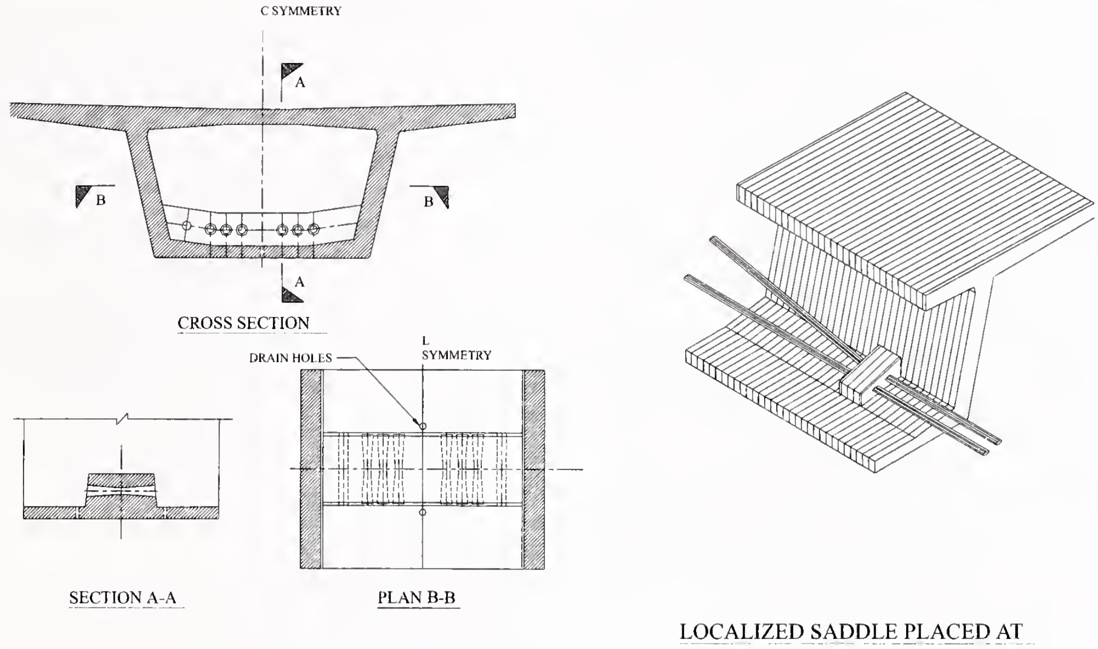

Fig. 6. Arrangement of Deviator Blocks for New Constructions

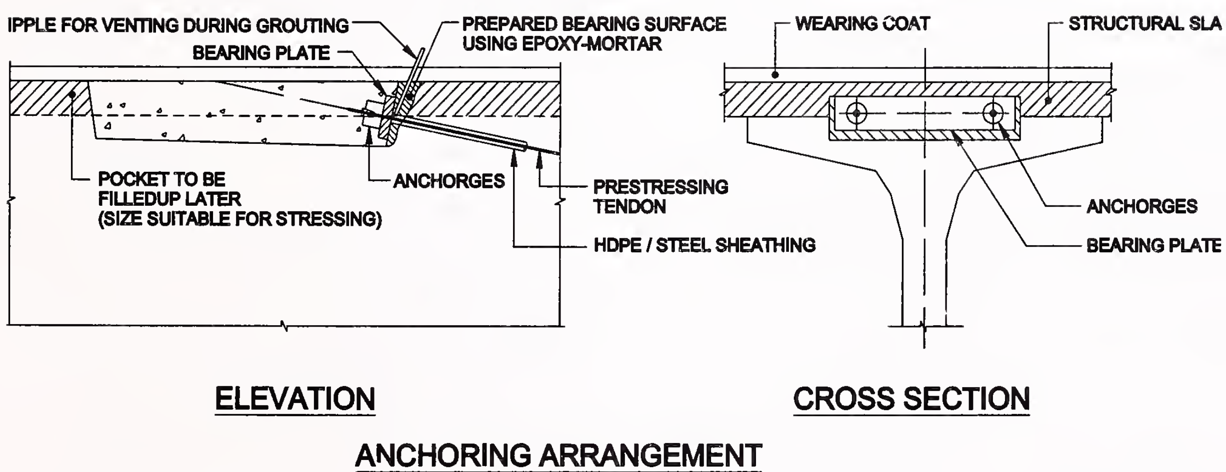

Fig. 7. Typical Repair/Rehabilitation Scenario

permanent protection to the steel shall be provided by cement grout, nuclear-grade grease (low sulphur contents) or other suitable means. The external exposed steel components of deviators, supporting brackets, etc. shall be protected by clear epoxy paint coating.

The anchorages and exposed free lengths of cables (left for de-tensioning) shall be properly housed in steel boxes and filled with protective agents, such as, nuclear grade-grease or other suitable material.

A periodic inspection and maintenance of these components should be carried out.

8. OTHER STRUCTURES

Additional provisions for special constructions, like, segmentally assembled bridge sections are given in the respective Chapters of the guidelines. Reference is also made to the specialist literature.

9. REFERENCES

In this publication, reference to the following IRC, BS and FIB Standards has been made. At the time to publications, the editions indicated were vaild. All Standards are subject to revision and parties to agreements based on these guidelines are encouraged to investigate the possibility of applying the most recent editions of the Standards.

9.1. Codes and Specifications

1. IRC:5-1998 — Standard Specifications & Code of Practice for Road Bridges, Section I - General Features of Design (Seventh Revision)
2. IRC:6-2000 — Standard Specifications & Code of Practice for Road Bridges, Section II - General Features of Design (Fourth Revision)
3. IRC:18-2000 — Design Criteria for Prestressed Concrete Road Bridges (Post - Tensioned Concrete) (Third Revision)
4. IRC:21-2000 — Standard Specifications and Code of Practice for Road Bridges, Section III Cement Concrete (Plain and Reinforced) (Third Revision)
5. IRC:24-2001 — Standard Specifications and Code of Practice for Road Bridges, Section IV Steel Road Bridges (Second Revision)
6. BS 4447-1973 (Reprinted 1990) — Specification for the Performance of Prestressing Anchorages for Post - Tensioned Construction
7. FIB — Recommendation for the Acceptance of Post-Tensioned System 1993.

Appendix

CALCULATION OF ULTIMATE MOMENT OF RESISTANCE

A-1(1) When analysing a cross-section to determine its ultimate strength, the following assumptions should be made:

a) The strain distribution in the concrete in compression is derived from the assumption that plane sections remain plane.

b) The stresses in the concrete in compression are derived either from the stress-strain curve with design strength equal to 2/3 of f_{ck} value. This is further reduced dividing by $\gamma_m = 1.5$, where γ_m is material strength reduction factor for concrete. The strain at the outermost compression fibre is taken as 0.0035.

c) The tensile strength of the concrete is ignored.

d) The strains in bonded prestressing tendons and in any additional reinforcement, whether in tension or compression, are derived from the assumption that plane sections remain plane. In addition, the tendon will have an initial strain due to prestress after all losses.

e) The stresses in bonded prestressing tendons, whether initially tensioned or untensioned, and in additional reinforcement, are derived from the appropriate stress-strain curves, with $\gamma_m = 1.15$, where γ_m is material strength reduction factor for steel.

f) The strain in unbonded tendons shall be assumed not to increase above the initial value due to prestress after all losses including γ_m except that either.

   i) In slabs and beams, the strain in the mid- span region of cables which are within 0.1d of the soffit at mid-span and which do not extend beyond the supports may be taken to increase by 0.0005, with no additional calculation.

   ii) The strain in the tendons at failure may be calculated from a non-linear analysis ot the structure. If this is done, checks shall be made to ensure that conventional "conservative" assumptions, such as, ignoring the tensile strength of concrete, do not have the effect of increasing the tendon strain and hence the ultimate strength.

g) Tendons and reinforcing bars which are anchored within a distance equal to h/2 of the section being considered shall be ignored. However, within h/2 of a simply supported end, all prestress which is anchored beyond the centre-line of the support may be considered effective.

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