THE HIGHWAYS AGENCY BA 58/94

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND

The Design of Concrete Highway Bridges and Structures with External and Unbonded Prestressing

Summary: This Advice Note provides guidance on the design of bridges with external and unbonded prestressing.

This Advice Note provides advice on specification requirements for use in public purchasing contracts. It does not lay down legislative requirements for products and materials used in highway construction in the United Kingdom.

REGISTRATION OF AMENDMENTS

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SECTION 3	GENERAL DESIGN

PART 10

BA 58/94

THE DESIGN OF CONCRETE HIGHWAY BRIDGES AND STRUCTURES WITH EXTERNAL AND UNBONDED PRESTRESSING

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1. INTRODUCTION

General

1.1 The Design of prestressed concrete structures with external or unbonded prestressing is not covered in the current Code of Practice for the design of concrete bridges, BS 5400 Part 4. This coupled with durability problems experienced by some structures with external prestressing has resulted in this type of construction being seldom used in this country.

1.2 Tendon corrosion associated with the ingress of de-icing salts through inadequately grouted ducts, has been encountered in a number of structures of bonded post-tensioned construction. Recent sudden collapses of bridges with bonded tendons is a cause for concern, especially as there are no satisfactory means available to monitor the condition of tendons. As a result, the Overseeing Organisations wish to encourage the use of external and unbonded tendons as a form of construction which can be easily inspected, monitored and maintained.

1.3 This Advice Note should be used in conjunction with BD 57 (DMRB 1.3.7) and BA 57 (DMRB 1.3.8) Design for Durability, particularly as regards access to enclosed spaces and the quality of protection from environmental effects (including leakage) within enclosed spaces.

Implementation

1.4 This Advice Note may be used forthwith for schemes currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress. Design Organisations should confirm its application to particular schemes with the Overseeing Organisation.

1.5 Where this Document is applied for products which are procured through a contract incorporating the Specification for Highway Works (MCHW 1), products conforming to equivalent standards and specifications of other states of the European Economic Area will be acceptable in accordance with the terms of the 104 and 105 Series of Clauses of that Specification. Any contract for the procurement of products which do not include these Clauses must contain a suitable clause of mutual recognition having the same effect regarding which advice should be sought.

Scope

1.6 This Advice Note provides guidance on the use of unbonded prestressing and some background information on the design requirements set out in BD 58, the Design of Concrete Highway Bridges and Structures with External and Unbonded Prestressing.

Definition

1.7 Unbonded prestressing is prestressing where, in the finished structure, no continuous bond is provided between the prestressing elements and the concrete section, either by the provision of grout or by any other means. The term, external prestressing is applied to that class of unbonded prestressed structures where some or all of the prestressing is unbonded and outside the concrete section, and where the load is transferred to the concrete through end anchorages and deviators. It is, in theory, possible to use unbonded prestressing elements in ducts which lie within the concrete section. This is unbonded internal prestressing.

2. CONCEPTUAL DESIGN

Factors affecting choice

2.1 The choice of whether to use external or unbonded prestressing should be made at the conceptual design stage as it is likely to affect a structure's form and dimensions. Although external prestressing is unlikely to be economical in structures spanning less than 40m, when whole life costs are considered its use may be justified.

2.2 Advantages

The following is a list of advantages associated with the use of unbonded prestressing:

i. Facilities for inspection, monitoring and re-stressing or replacing of tendons can be easily incorporated.

ii. The lack of ducts within concrete when using external prestressing makes steel fixing easier and facilitates the use of thinner webs, thereby resulting in a reduction in dead load.

iii. External tendons afford simpler cable layouts.

iv. Prestress loss due to both friction and creep is lower.

v. Flexural failures will always be preceded by extensive cracking and excessive deflection, thus giving prior warning of collapse.

vi. Since the opening and closing of cracks does not affect the tendon stress, as in the case of bonded construction, and as corrosion protection to the tendons is not dependent on the encasing concrete, the serviceability requirement for crack widths can be relaxed for external prestressing.

2.3 Disadvantages

The following is a list of disadvantages associated with the use of unbonded prestressing:

i. In external prestressing the maximum cable eccentricity is likely to be less than for bonded post-tensioning.

ii. The increase in cable force at ultimate is less than that with bonded tendons, and hence the ultimate flexural capacity of a section is usually reduced. Slightly deeper structures may be required to compensate for this.

iii. In external prestressing, the cables are not protected by concrete and hence are more vulnerable to terrorist attack or fire.

iv. In the event of a tendon failure, tendons do not have the capability to rebond.

v. The strength of the structure is dependent on the anchorages.

Maintenance and Replacement

2.4 Concrete boxes housing external tendons should ideally have a reasonable working space and means of access; see Design for Durability, BD 57 (DMRB 1.3.7) and BA 57. (DMRB 1.3.8). This requirement would result in a practical minimum span for externally prestressed structures of about 40m. Where external prestressing is used on shorter spans, a reduced headroom may be used with the agreement of the Overseeing Organisation provided that the full requirements of Health and Safety legislation are met.

2.5 Provision should be made for the replacement and re-stressing of tendons. The structure should be capable of accommodating a range of prestressing force resulting from future tendon replacement, and galleries should be incorporated at abutments with sufficient room to manoeuvre prestressing jacks. The provision of runway beams, which may also be used to facilitate construction, would be desirable. For further information on the design of abutment galleries see The Design for Durability, BD 57 (DMRB 1.3.7) and BA 57 (DMRB 1.3.8).

Robustness

2.6 The local failure of tendons in a bonded post-tensioned structure would not normally have a significant effect on its ultimate load capacity as the tendons rebond with the concrete. However, in the case of unbonded prestressing, failure in any position makes a tendon ineffective over its entire length. Hence structures with unbonded prestressing may be vulnerable to a disproportionate collapse. This is particularly true for continuous bridge decks where localised failure in one span could result in a progressive collapse of adjacent spans.

2.8 The design criteria in BD 58 (DMRB 1.3) introduce a check to ensure that structures with unbonded prestressing will not collapse as a result of a local tendon failure. This requirement may have a significant influence on a structure's form. For instance, the position of anchorages in continuous structures may need to be staggered or box girder decks may require transverse stiffening to prevent collapse following a loss of tendons in an external web.

Demolition

2.9 In practice, when cut or broken, conventional grouted or pretensioned tendons will re-anchor and hence the energy stored in the tendon is not released. However, cutting unbonded tendons will release much greater amounts of energy. It should therefore be avoided in demolishing structures with unbonded pre-stressing.

2.10 As re-stressable tendons can be de-stressed individually, demolition of structures with unbonded prestressing is usually quite straightforward. However the effect on adjacent spans of de-stressing multi-span cables should be carefully considered.

2.11 In short span bridges where the provision of abutment galleries is not feasible, anchorages should nevertheless be detailed to facilitate future de-tensioning for demolition.

3. DETAILED DESIGN

General

3.1 This Chapter deals with the detailed design of post-tensioned concrete with external and unbonded prestressing. It includes some information on the background to the design requirements contained in BD 58 (DMRB 1.3.9. The Design of Concrete Highway Bridges and Structures with External and Unbonded Prestressing).

3.2 References to Clause numbers in this chapter refer to BS 5400 as modified by BD 58 (DMRB 1.3.9).

Flexure

3.3 As the ultimate strength of structures with unbonded prestressing is dependent on the prestress force, allowance must be made for the actual prestress force present being less than that which is assumed in design. This may be, for instance, as a result of the jacking force being less than intended or the prestress loss being greater than calculated. A partial safety factor γ_{FL} of 0.87 is therefore applied to the prestress force. (See Clause 6.3.3.1(d)).

3.4 Since the strain in unbonded tendons at the ultimate limit state is unlikely to be sufficient to cause yield, failure is likely to be through crushing of the concrete. However, the overall behaviour of the structure should remain ductile with extensive cracking and excessive deflections being apparent before yield. It is, therefore, not felt necessary to impose the 15% over strength requirement that is prescribed for over-reinforced bonded prestressed sections.

3.5 In bonded prestressed construction plane sections, including their prestressing tendons, are assumed to remain plane. This assumption depends on the tendons remaining bonded to the concrete and is therefore not valid with unbonded prestressing. The increase in steel strain in unbonded prestressing at failure is less than for bonded tendons and usually not sufficient to reach yield. Clause 6.3.3.1(f) introduces a simple but conservative rule to estimate the increase in steel strain, and hence stress at failure. As an alternative a more rigorous non-linear analysis may be used.

Shear

3.6 The design rules for shear in beams given in BS 5400 Part 4 are empirical and based on test results on bonded tendons. They are therefore not considered appropriate for unbonded prestressing. The approach adopted for determining shear resistance is to treat unbonded prestressing as reinforced sections with an externally applied load (See Clause 6.3.4.1).

3.7 The design for shear is based on a form of truss analogy and thus implies a greater force in the tension cord than would be expected by simple bending theory. This has been reflected in BS 5400: Part 4: 1990. However, in the case of unbonded prestressing it is necessary to check that the requisite tendon force rather than tendon strength, is available. This has been addressed in BD 58 (DMRB 1.3.9) by adding a requirement to extend tendons beyond the section at which they are required. (See Clause 6.3.3.1(g)).

Torsion

3.8 As the torsion rules for bonded tendons in BS 5400 Part 4 make no allowance for the beneficial effects of prestress, they do not require modification for the use of unbonded tendons.

Prestress Loss

3.9 The use of unducted systems or ducts with greased or waxed strands means that prestressing systems used in external and unbonded prestressing have lower coefficients of friction than bonded systems. In addition, with external prestressing wobble losses are eliminated.

3.10 Although the lack of bond will not alter the average loss due to creep, as the creep losses are constant over the length of a beam, losses at critical sections are likely to be smaller than with bonded construction. This may be significant in shorter spans where the permanent compressive stresses for live loads are high.

Anchors and Deviators

3.11 The strength of structures with unbonded prestressing is dependent on the anchors and, where they are used, the deviators. This is particularly significant as the failure mode of anchors and deviators may be brittle.

3.12 The design of members with unbonded prestressing for flexure and shear is based on a lower bound estimate of tendon force. However, anchors and deviators should be designed for the unfactored tendon strength. (See Clauses 6.7.5, 6.7.6).

3.13 If tendons are not adequately restrained within the concrete section, the deformation of the concrete between deviators can have a significant effect on the moment applied by the tendon to the concrete section. In addition, inadequately restrained tendons may vibrate excessively and be susceptible to fatigue failure. Compliance with the requirements of Clause 6.8.8 will ensure that tendons are adequately restrained.

Radius of Curvature

3.14 Clause 6.8.8 sets out the minimum radius of curvature of tendons in deviators. If a specific tendon and duct or shoe type is tested or investigated and found to be satisfactory for smaller radii, the resulting values can be used.

3.15 Smaller radii may be used in positions where there is no significant movement of the cable relative to the duct or shoe in the bend; for example loop anchors at the centre of cable length.

Serviceability

3.16 In the design of bridges with bonded prestressing to BS 5400 Part 4, for the serviceability limit state, the force in the tendons due to deformation resulting from the applied load is normally ignored. As this is analogous to unbonded tendons, the BS 5400: Part 4 design approach for serviceability can be adopted for unbonded prestressing.

3.17 As the tendons in externally prestressed, structures do not rely on the concrete for corrosion protection, and as the problem of high stress fluctuations in tendon associated with cracks in bonded construction, are not relevant to unbonded prestressing, the serviceability cracking criteria have been relaxed in the case of external prestressing (see Clause 4.2.2).

3.18 In the case of internal unbonded tendons, as the tendons are not easily inspected and as durability problems associated with tendon corrosion are less easy to detect, the serviceability requirements have not been relaxed.

Untensioned Reinforcement

3.19 In order to control thermal and shrinkage cracking and facilitate construction, a requirement for nominal untensioned reinforcement has been introduced in Clause 6.8.4.

Segmental Construction

3.20 The "dry jointing" technique, where joints between segments are constructed without the use of epoxy or other suitable materials, has been used on several long span bridges, especially in the USA. However, with this method of jointing, a watertight seal cannot be achieved at the segment joints. This would therefore reduce the corrosion protection of internal grouted tendons. For this reason dry jointing may only be used in segmental construction in association with external tendons.

4. CORROSION PROTECTION

General

4.1 Corrosion protection systems for unbonded prestressing should be considered in relation to the overall design of the structure. As tendon corrosion would only take place in a damp environment, every effort should be made by good design, detailing and specification of materials, to ensure that water is excluded from ducts and concrete box enclosures. See the Design for Durability, BD 57 (DMRB 1.3.7) and BA 57 (DMRB 1.3.8).

External Prestress

4.2 For maintenance reasons it is advisable that external tendons can be inspected easily and are replaceable. External tendons enclosed within a concrete box are subject to an environment in which corrosion rates are negligible. It is therefore considered sufficient to provide corrosion protection by galvanising tendons in accordance with BS 2763. Other forms of corrosion protection may also be considered. Designers should be aware of the possibility of hydrogen embrittlement and galvanic corrosion associated with galvanising and take the necessary precautions to ensure against them.

4.3 Unducted galvanised tendons have the advantage of being easily inspected throughout their length.

4.4 In detailing deviators, the use of open shoe-type deviators may be preferable to the use of closed duct-type deviators since they allow more complete inspection of the condition of the tendons at deviator positions.

Unbonded Tendons

4.5 Ducts for unbonded tendons within the concrete section should be made from High Density Polyethylene (HDPE) with a minimum wall thickness of 2mm, or other suitable materials. Ducts should be waterproof with drainage holes at low points along their profile to release any water that may be trapped and to facilitate inspection by means of an endoscope.

4.6 Unbonded tendons within ducts may be corrosion protected with galvanising, painted in a light colour to aid inspection, or with a suitable system which allows for tendon replacement and restressing.

Anchorages

4.7 As the prestressing force in unbonded prestressing is transferred to the concrete solely through the anchorages, care should be taken to exclude water from the vicinity of anchorages. Anchorage ends should be open and inspectable, and anchorage pockets should be sealed by means of removable cover plates. Projecting tendons and anchor plates should be protected with a suitable water excluding wrapping tape.

4.8 The position at which tendons are gripped at the anchorage is a potential location of bi-metallic corrosion. Anchorage plates and wedges should therefore be of the same type of steel as the tendon.

4.9 Care should be taken to ensure that anchorage systems and the detailing of tendons at the anchorages can facilitate the de-tensioning and re-stressing of tendons.

5. REFERENCES

1. Design Manual for Roads and Bridges

Volume 1: Section 3 General Design

BD 58 The Design of Concrete Highway Bridges and Structures with External and Unbonded Prestressing (DMRB 1.3.9)

BD 57 Design for Durability (DMRB 1.3.7)

BA 57 Design for Durability (DMRB 1.3.8)

2. British Standards

BS 5400: Part 4: 1990: Code of Practice for the Design of Concrete Highway Structures.

BS 2763: 1982: Specification for Round Carbon Steel Wire for Wire Rope.

6. ENQUIRIES

All technical enquiries or comments on this Advice Note should be sent in writing as appropriate to:

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