BE 21/5/022

CANCELLED
AMENDED 2/9/83

TECHNICAL MEMORANDUM (BRIDGES) BE 2/73
PRESTRESSED CONCRETE FOR HIGHWAY STRUCTURES

1. INTRODUCTION

The Department is at present assisting the British Standards Institution in drafting a document for bridge design and construction which in addition to bringing BS 153 up to date will deal with reinforced and prestressed concrete bridges. Until this document is published and adopted by the Department, the concrete grades and design criteria for prestressed concrete shall be as under.

CP 110, The Structural Use of Concrete, must not be used with the Department's current loading requirements for the design of highway structures.

This Memorandum supersedes Technical Memorandum BE 20 and Interim Memoranda IM23 and 8 and is intended to be used in conjunction with the 1969 Edition of the Specification for Road and Bridge Works as amended by Technical Memoranda BE 6/72, 8/72 and 9/72 with Technical Memorandum H 5/71, Metric Addendum to the Specification. It should also be read in conjunction with Technical Memorandum BE 5/73, Standard Highway Loadings.

This Memorandum, including the relevant clauses of CP 115: Part 2 and CP 116: Part 2 as listed in Appendix III, is mandatory for all prestressed concrete highway structures for motorway and trunk road projects. It is recommended for use where appropriate on other roads.

2. CLASSES OF CONCRETE

Prestressed concrete for Highway Structures should normally be Class 52.5 or Class 45. Higher grades should only be used where shown to be economically justifiable and account should be taken of the possible difficulty in maintaining the strength, the need to use high cement contents with consequent shrinkage problems and the possible extra cost of special aggregates which may be necessary.

3. PERMISSIBLE STRESSES IN PRESTRESSED CONCRETE

3.1 **Basic** permissible stresses in prestressed concrete shall be as follows:

Stress Type	Basic Permissible Stress	
	At Transfer	At Working Load
Uniform compression	$0.40\ u_t$	$0.25\ u_w$
Flexural compression	$0.50\ u_t$	$0.33\ u_w$ **
Uniform or flexural tension	1 N/mm^2	0, except that tension not exceeding 1 N/mm^2 due to prestress combined with dead load may be ignored

u_t is the spec. min. cube strength at transfer

u_w is the spec. min. works cube strength at 28 days

** see Clause 10 for composite instruction.

~~* Pending the issue of this Technical Memorandum relevant parts are given in Appendix IV~~

3.2 Increases in basic permissible stresses.

For the two combinations of forces given in Technical Memorandum BE 5/73 Standard Highway Loadings ~~(See temporary Appendix IV)~~, the basic permissible stresses in prestressed concrete may be increased by the appropriate percentage given below:

Combination of forces	Increase in basic permissible stresses	
	HA except the two 112 kN wheels percent	HB loading or the two 112 kN wheels of HA or accidental wheel loading on footways and verges, percent
1	0	25
2	15	30

4. PERMISSIBLE STRESS IN PRESTRESSING TENDONS

Immediately after anchoring, the stress in the prestressing tendons should not exceed 70% of the ultimate tensile strength. During stressing, this value may be exceeded at the discretion of the Engineer but it shall not exceed 80%.

5. PRESTRESS LOSSES

The assessment of prestress losses shall be based on the following criteria:-

5.1 Young's Modulus of tendons:

i. for wire and 7 wire strands: 200×10^3 N/mm^2 (Maximum diameter 18mm)

ii. for bars and 19 wire strands: 175×10^3 N/mm^2

iii. or the experimental values if these are available.

5.2 Relaxation of steel

The loss assumed shall be that established by the manufacturer for an initial load equivalent to 70% of the specified characteristic load and 1000 hours, at 20°C.

5.3 Young's Modulus of concrete may be taken from the following table:

Cube strength at stage considered N/mm^2	Young's Modulus for short-term loading kN/mm^2.
30	28.0
37.5	30.25
45	32.5
52.5	34.5
60	36.0

The table above gives, approximately, the value of elastic modulus which would be obtained from measurements of stress and strain in accordance with BS 1881 and will generally be correct within $\pm$ 6.0 kN/mm^2. If a more accurate figure is required for particular materials and a particular mix, tests should be made in accordance with BS 1881.

5.4 Creep of concrete:-

The loss of prestress in the tendons due to creep of the concrete should be calculated on the assumption that creep is proportional to the stress in the concrete. The loss of prestress is obtained from the product of the modulus of elasticity of the tendon (Clause 5.1) and the creep of the concrete adjacent to the tendons. Usually it is sufficient to assume, in calculating this loss, that the tendons are located at their centroid.

Where the maximum concrete stress at transfer anywhere in the cross section does not exceed $u_t/3$ the creep strain per N/mm^2 shall be taken as follows:-

for pretensioning : 48×10^{-6} or $48 \times 10^{-6} \times \frac{40}{u_t}$ whichever is greater

for post-tensioning : 36×10^{-6} or $36 \times 10^{-6} \times \frac{40}{u_t}$ whichever is greater

u_t is the min. spec. cube strength at transfer.

Where the maximum concrete stress at transfer anywhere in the cross section exceeds $u_t/3$ the strain calculated above shall be increased by an amount which varies linerly from zero at $u_t/3$ to 25% at $u_t/2$.

5.5 Reference should be made to the appropriate clause of CP 115: Part 2: 1969 for the assessment of prestress losses caused by the following factors:-

Factor	CP 115: Part 2: 1969 Clause
Shrinkage of the Concrete	304d
Anchoring	304f
Steam Curing	304g
Friction	305 a to 305 e

BE 21/5/022

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AMENDMENT LIST NO 3

CLAUSE 6 SPACING AND COVER

6.1 Spacing

6.1.1 Bonded tendons and other steel reinforcement

The distances shall be in accordance with Clauses 308 and 309 of CP 116 Part 2: The structural use of precast concrete.

6.1.2 Tendons in ducts

6.1.2.1 Clear distance between ducts or between ducts and other tendons shall be not less than the greatest of the following:-

(i) C + 5 mm, where C is the nominal maximum size of the coarse aggregate.

(ii) in the vertical direction: the vertical internal dimension of the duct.

(iii) in the horizontal direction: the horizontal internal dimension of the duct. Where internal vibrators are used, sufficient space shall be provided between ducts to enable the vibrator to be inserted.

6.1.2.2 Curved ducts. In order to prevent crushing of the concrete between ducts minimum spacing shall be:-

(i) in the plane of curvature: the values given in Table I or the value required by 6.1.2.1 if greater.

(ii) perpendicular to the plane of curvature: the requirements of 6.1.2.1

Where tendon profilers or spacers are provided in the ducts, and these are of a type which will concentrate the radial force, the values given in Table I will need to be increased because of the higher local stresses induced by the point - load effect. If necessary additional reinforcement should be provided between the ducts.

For a given combination of duct internal diameter and radius of curvature the distance between ducts shown in Table I may be reduced pro rata with the tendon force when this is less than the value tabulated, subject to the requirements of 6.1.2.1.

Exceptionally to achieve minimum spacing it may be possible to tension and grout first the tendon having the least radius of curvature, and to allow an interval of 48 hours to elapse before tensioning the next tendon. In this case the spacing requirements given in 6.1.2.1 apply.

6.1.2.3 Two or more rows of ducts. The horizontal gaps between the ducts should be vertically in line wherever possible, for ease of construction.

6.2 Cover

6.2.1 Bonded tendons and other steel reinforcement

6.2.1.1 Minimum cover. The cover shall be in accordance with Clause 2.4 of Technical Memorandum BE 1/73 (1st Revision) Reinforced Concrete for Highway Structures. The ends of individual pre-tensioned tendons do not normally require concrete cover and should be cut off flush with the end of the concrete member.

6.2.2 Tendons in ducts

6.2.2.1 Minimum cover. The cover to any duct shall be not less than 50 mm. Precautions should be taken to ensure a dense concrete cover, particularly with large or wide ducts.

6.2.2.2 Curved ducts. In order to prevent bursting of the cover:-

(i) perpendicular to the plane of curvature,

(ii) in the plane of curvature eg, where the tendons run close to and approximately parallel to the surface of a member,

the cover shall be in accordance with the values given in Table II.

Where tendon profilers or spacers are provided in the ducts, and these are of a type which will concentrate the radial force, the values given in Table II will need to be increased because of the higher local stresses induced by the point-load effect.

The cover for a given combination of duct internal diameter and radius of curvature shown in Table II may be reduced pro rata with the square root of the tendon force when this is less than the value tabulated, subject to the requirements of 6.2.2.1.

6.2.2.3 Additional reinforcement. Where 6.2.2.2 (ii) applies and the tendon develops radial forces perpendicular to the exposed surface of the concrete, the duct shall be restrained by stirrup reinforcement anchored into the member.

6.2.3 External tendons

A tendon is considered to be external when, immediately after stressing, it is outside the concrete section. Where protection is provided by dense concrete added subsequently the thickness of cover to these tendons shall be not less than that required for tendons inside the structural concrete under similar conditions.

The protective concrete shall be anchored by reinforcement to the prestressed member and shall be checked for the control of cracks in accordance with Clause 2.3 of Technical Memorandum BE 1/73 (1st Revision) Reinforced Concrete for Highway Structures.

TABLE I

MINIMUM DISTANCE BETWEEN CENTRE LINES OF DUCTS IN PLANE OF CURVATURE mm.

DUCT INTERNAL DIA. mm =	19	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
TENDON FORCE kN. =	296	387	960	1337	1920	2640	3360	4320	5183	6019	7200	8640	9424	10336	11248	13200
RADIUS OF CURVATURE OF DUCT 2 m.	110	140	350	485	700	960										
4 m.	55	70	175	245	350	480	610	785	940							
6 m.	38	60	120	165	235	320	410	525	630	730	870	1045				
8 m.			90	125	175	240	305	395	470	545	655	785	855	940		
10 m.			80	100	140	195	245	315	375	440	525	630	685	750	815	
12 m.					120	160	205	265	315	365	435	525	570	625	680	900
14 m.						140	175	225	270	315	375	450	490	535	585	785
16 m.							160	195	235	275	330	395	430	470	510	600
18 m.								180	210	245	290	350	380	420	455	535
20 m.									200	220	265	315	345	375	410	480
22 m.											240	285	310	340	370	435
24 m.												265	285	315	340	400
26 m.												260	280	300	320	370
28 m.																345
30 m.																340
32 m.																
34 m.																
36 m.																
38 m.																
40 m.	38	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340

RADII NOT NORMALLY USED

NOTES: (1) The tendon force shown is the maximum normally available for the given size of duct (taken as 80% of the characteristic strength of the tendon).

(2) Values less than 2 x Duct Int. Dia are not included.

TABLE II

		MINIMUM COVER TO DUCTS: (SEE CL. 6.2.2)															
DUCT INTERNAL DIA. mm =		19	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
TENDON FORCE kN. =		296	387	960	1337	1920	2640	3360	4320	5183	5019	7200	8640	9424	10336	11248	13200
RADIUS OF CURVATURE OF DUCT	2 m.	50	55	155	220	320	445								RADII NOT NORMALLY USED		
	4 m.		50	70	100	145	205	265	350	420							
	6 m.			50	65	90	125	165	220	265	310	375	460				
	8 m.				55	75	95	115	150	185	220	270	330	360	395		
	10 m.				50	65	85	100	120	140	165	205	250	275	300	330	
	12 m.					60	75	90	110	125	145	165	200	215	240	260	315
	14 m.					55	70	85	100	115	130	150	170	185	200	215	260
	16 m.					55	65	80	95	110	125	140	160	175	190	205	225
	18 m.					50	65	75	90	105	115	135	150	165	180	190	215
	20 m.						60	70	85	100	110	125	145	155	170	180	205
	22 m.						55	70	80	95	105	120	140	150	160	175	195
	24 m.						55	65	80	90	100	115	130	145	155	165	185
	26 m.						50	65	75	85	100	110	125	135	150	160	160
	28 m.							60	75	85	95	105	120	130	145	155	170
	30 m.							60	70	80	90	105	120	130	140	150	165
	32 m.							55	70	80	90	100	115	125	135	145	160
	34 m.							55	65	75	85	100	110	120	130	140	155
	36 m.							55	65	75	85	95	110	115	125	140	150
	38 m.							50	60	70	80	90	105	115	125	135	150
	40 m.	50	50	50	50	50	50	50	60	70	80	90	100	110	120	130	145

NOTES: (1) The tendon force shown is the maximum normally available for the given size of duct (taken as 80% of the characteristic strength of the tendon.)

~~6. COVER~~

~~The cover to tendons and to all steel reinforcement, including stirrups, links, etc shall be in accordance with Clause 2.4 of Tech. Memo. BE 1/73, Reinforced Concrete for Highway Structures. For post-tensioning systems, particularly with large or wide ducts, special consideration should be given to ensure a dense concrete cover.~~

7. ULTIMATE LOAD FACTORS

Factors for calculating ultimate loads shall be taken as follows:

7.1 Dead Load and Live Load

HA Loading except the two 112kN wheels	1.5 (dead load) + 2.5 (Live load) or 2 (dead load + live load) whichever is the lesser.
HB Loading or the two 112kN wheels of HA or the accidental wheel loading on footways and verges **	1.5 (dead load) + 2.0 (live load)

Note 1: The global factors tabulated above contain partial safety factors for both loads and materials.

2: Where the effects of dead and live loads are of opposite sign the case of a dead load factor of unity should be considered. In most cases it should be sufficient to apply Dead Load factors of 1.0 and 1.5 alternately to the whole structure to obtain the worst effects. Consideration should also be given to dead load factors of 1.0 and 1.3 applied simultaneously to adjacent spans of a continuous structure.

** described in Tech. Memo. BE 5/73, Standard Highway Loadings.

7.2 Prestress

A load factor of unity should be applied to the secondary (parasitic) effects of prestress (after losses) unless these effects are reduced by the formation of plastic hinges in which case this should be considered. Further information is given in Appendix II.

8. SHEAR IN PRESTRESSED CONCRETE

The requirements shall be based on the ultimate load using the factors specified in Clause 7.

8.1 Reinforcement for monolithic construction:

Reinforcement shall be provided in accordance with the equations given in the flow chart, Figure 1. For further background information reference should be made to Appendix I. Requirements for composite construction are given in Clause 10.

8.2 Requirements for Stirrups

i. A stirrup should extend as close to the tension and compression faces as possible, with due regard to cover. The stirrups provided at a cross section must between them enclose all the tendons and additional tensile reinforcement and must be adequately anchored.

ii. At all corners a stirrup must either pass round a longitudinal bar, a tendon or group of tendons* having a diameter not less than the stirrup diameter. Where it passes round a duct a stirrup should not be considered as fully effective until the duct has been grouted.

iii. The spacing of stirrups along a member shall not exceed $0.75d_2$ nor four times the web thickness for flanged members. When Q exceeds $1.8Q_c$ the maximum spacing shall be reduced to $0.5\ d_2$. The lateral spacing of the individual legs of stirrups provided at a cross section shall not exceed $0.75\ d_2$.

9. ULTIMATE MOMENT OF RESISTANCE

The ultimate moment of resistance calculated as below shall be not less than the moment due to the loads prescribed in Clause 7.

when analysing sections under ultimate loads the following assumptions should be made:

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

ii. The stresses in the concrete in compression are either derived from the stress - strain curve given in figure 2, or, where the compression zone is of rectangular section above the neutral axis at failure, may be taken to be $0.4u_w$ over the whole zone with the resultant acting at a depth of 0.4 [illegible] of the neutral axis. In both [illegible] the [illegible] or the

$$f = 0.44\ U_w \left[1-\left(1-\frac{5000\ \varepsilon}{\sqrt{U_w}}\right)^2\right] \text{ for } 0 \leqslant \varepsilon \leqslant \frac{\sqrt{U_w}}{5000}$$

where f = Stress and ε = Strain

The two tangent points to the parabola therefore occur at the origin and at $\varepsilon = \frac{\sqrt{U_w}}{5000}$ respectively.

[illegible] ly tensioned or untensioned, and in additional reinforcement are derived from the appropriate stress-strain curves supplied by the manufacturer. In the case of a rectangular compression zone above the neutral axis at failure stresses in bonded prestressing tendons may be obtained from Table 7, Clause 313 of CP 115.

vi. In post-tensioned members, where the tendons are unbonded, the stress in the tendons is based on Table 8, Clause 313 of CP 115 unless a higher stress can be justified by tests.

* See Appendix II for further information.

FIGURE 1

FLOW CHART FOR SHEAR REINFORCEMENT IN PRESTRESSED CONCRETE BEAMS

AT SECTION UNDER CONSIDERATION

CALCULATE: Q_{max}

↓

IS $Q_{max} > 0.92\, bd_2 \sqrt{u_w}$?

YES → SHEAR RESISTANCE OF THE CONCRETE IS INADEQUATE: ADOPT NEW SECTION

NO ↓

CALCULATE **Q AND M**

$$Qcw = 0.67\, bd \sqrt{f_t^2 + f_p f_t} + Qp$$

$$Qcm = 0.045\, bd_1 \sqrt{u_w} + \frac{Q}{M} Mc$$

$$\text{BUT } Qcm \nless 0.12\, bd_1 \sqrt{u_w}$$

$$Mc = (0.45 \sqrt{u_w} + f_{ep}) \frac{I}{y}$$

SEVERAL LOADING CONFIGURATIONS MAY HAVE TO BE CONSIDERED IN ORDER TO FIND THE VALUE OF $\frac{Q}{M}$ IN THE EXPRESSION FOR Qcm SUCH THAT (Q-0.8 Qcm) IS A MAXIMUM.

↓

Qc = LESSER OF Qcw AND Qcm

↓

IS $Q < 0.5\, Qc$?

YES → PROVIDE NOMINAL SHEAR REINFORCEMENT

NO ↓

IS $0.5\, Qc < Q < 0.8Qc$?

YES → PROVIDE MINIMUM SHEAR REINFORCEMENT IN THE FORM OF STIRRUPS SUCH THAT $f_{yq}.A_{sq} \geqslant 0.4\, bs.\sin\alpha$ EXCEPT THAT SHEAR REINFORCEMENT NEED NOT BE PROVIDED IN SLABS, FOOTINGS, PILE CAPS, WALLS AND MEMBERS OF MINOR IMPORTANCE

NO ↓

PROVIDE SHEAR REINFORCEMENT IN THE FORM OF STIRRUPS SUCH THAT:-

$$0.4\, bs \sin\alpha \leqslant f_{yq}.A_{sq} \geqslant (Q-0.8Qc)\frac{s_v \sin\alpha}{d_2}$$

NOTATION FOR FIGURE 1

Q_{max} the maximum shear force due to the loads prescribed in Clause 7 (N)

Q the shear force due to the loads prescribed in Clause 7 where Q may be less than Q_{max} (see flow chart: calculation of Qcm).

M the bending moment corresponding to Q (N.mm)

Q_{cw} the shear capacity of the plain concrete section uncracked in flexure (N). The expression given in the flow chart is based on the shear capacity of a rectangular section bxd and applies to all cross sectional shapes in which the centroidal axis occurs within the web. In flanged members in which the centroidal axis occurs within the flange, the principal tensile stress should be limited to $0.294\sqrt{u_w}$ at the intersection of the flange and the web using expressions based on elastic theory.

Mc the moment just sufficient to cause a flexural crack. (N.mm)

Qcm the shear capacity of the plain concrete section cracked in flexure. (N)

Qp the vertical component of the prestressing force after losses. The sign of this term is positive where the shear capacity of the section is increased. (N)

b the breadth of the member at the centroid of the section i.e. for flanged and box beams and for infilled inverted Tee-beam construction the breadth of the precast web (mm) (3).

d the overall depth of the member. (mm)

u_w the 28 day cube strength (N/mm^2)

f_t the maximum principal tensile stress at the centroid of the section. It is to be taken as $0.294\sqrt{u_w}$ and positive in evaluating Qcw. (N/mm^2)

f_p the compressive stress taken as positive, due to prestress, at the centroid of the section. (N/mm^2) (1) (2)

f_{ep} the compressive stress taken as positive, due solely to prestress, at the extreme fibre at which applied loading causes tensile cracks, this fibre being at a distance y from the centroid of the section. (N/mm^2) (1) (2)

I the second moment of area of the section (mm^4)

d_1 the effective depth, for calculating Q_{cm}, is the distance from the extreme compression fibre to the centroid of all tendons. (mm)

d_2 the effective depth in the expressions $0.92\ bd_2\sqrt{u_w}$ and $(Q - 0.8Q_c)\ \frac{s.\sin\alpha}{d_2}$ and in Clause 8.2.iii. shall be taken as the depth from the extreme compression fibre either to the centroid of the longitudinal bars or tendons enclosed by the stirrups referred to in Clause 8.2 ii. or to the centroid of all tendons, whichever is the greater. (mm)

f_{yq} the specified characterisitic strength of the stirrup reinforcement, but not greater than 425 N/mm^2.

A_{sq} the cross sectional area of the two legs of a stirrup. (mm^2)

s the stirrup spacing along the length of the member. (mm)

α the inclination of the stirrup to the longitudinal axis of the member, to be not less than 45^o.

Note 1 Refer to Appendix II for further details.

Note 2 In a pretensioned prestressed member the reduced prestress in the concrete at sections falling within the transmission zone should be considered when calculating the shear capacity of the plain concrete. See Clause 12.

Note 3 b should be reduced if ducts (grouted or ungrouted) or tendons have diameter ϕ greater than $\frac{1}{10}$ actual web thickness. The reduction should be $\frac{2}{3}\,\Sigma\phi$ (as proposed by F Leonhardt, FIP, Prague, 1970) unless evidence is available to show this is unnecessary.

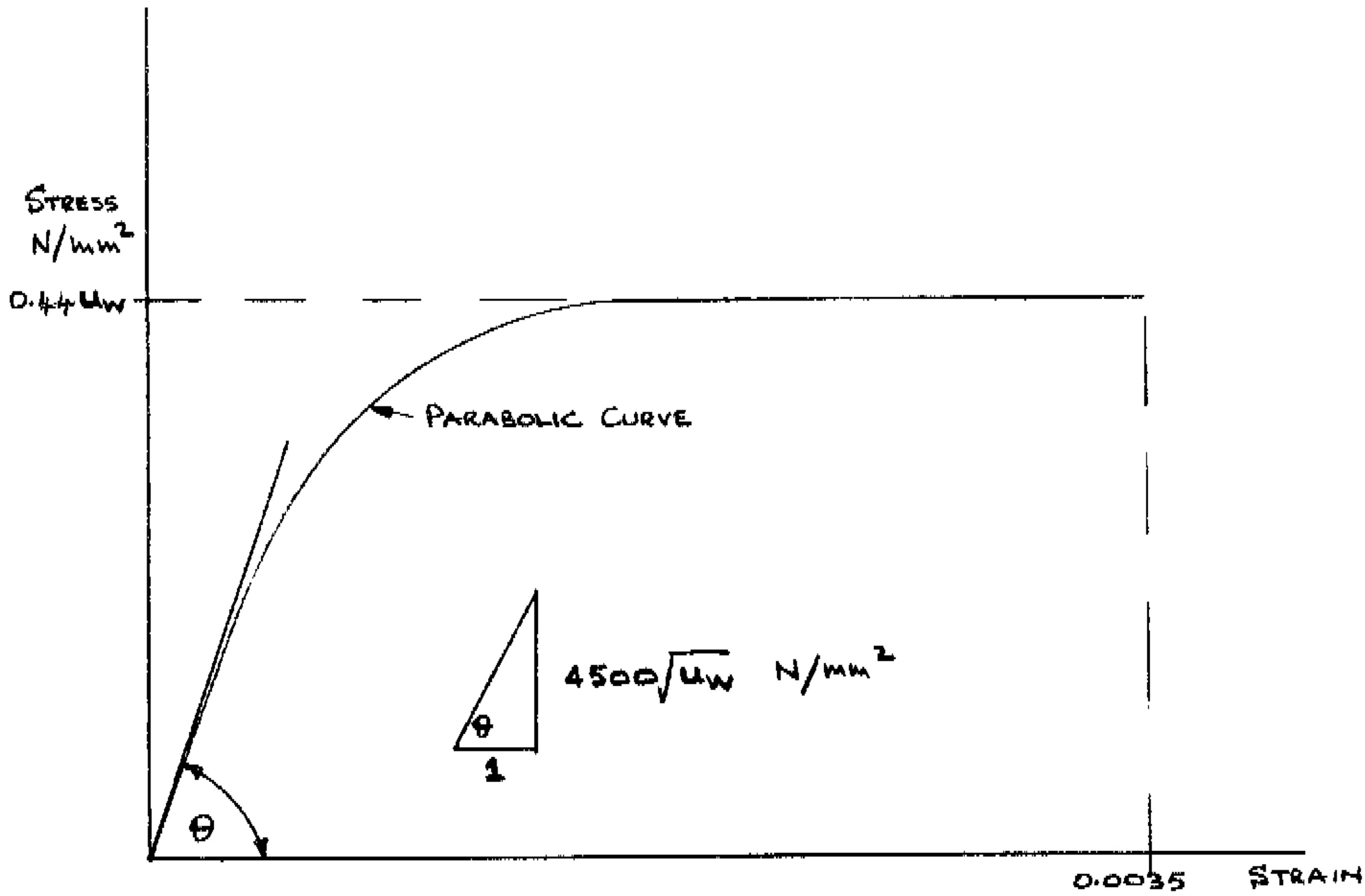

FIGURE 2. SHORT TERM DESIGN STRESS-STRAIN CURVE FOR CONCRETE

SEE CLAUSE 9

10 COMPOSITE CONSTRUCTION

10.1 Definition

A composite section consists of two parts effectively* joined together:

i. The precast element taken to be the primary concrete member; it is generally prestressed and forms the sole support for the infill concrete.

ii. the insitu concrete cast at a later stage of construction and after the prestressing operation. Where second-stage prestressing is applied to the composite section further consideration will be required.

10.2 Section properties

Where the strength of the subsequent infill concrete differs from that of the precast element, the section properties of the former shall be multiplied by the modular ratio.

In-situ concrete in which the flexural tensile stress under any loading exceeds the following values shall be ignored:

Cube strength N/mm^2	Limiting flexural tensile stress N/mm^2
22.5	3.0
30	3.6
37.5	4.2
45 and over	4.7

Where the in-situ concrete is not included in the composite section the flexural tensile stress in it need not be calculated.

10.3 Permissible flexural compressive stress in precast element

When the compression flange of the precast element is completely encased in in-situ concrete the compressive stresses under working load may be increased by 25% above the values given in clause 3.1. This increase shall not apply where the in-situ concrete is only in contact with the compression face and does not encase the whole flange.

* "Effectively joined" means that provision is made for transfer of shear across the surface of contact by the use of adequate shear connectors (See Clause 10.5) or as otherwise established by tests to failure.

10.4 Vertical shear

Reinforcement shall be provided in accordance with the equations and notation given in the flow chart, Figure 1 with the following exceptions:

i. Equations

$$Qcw = Q_1 + Q_2 + Q_p$$
$$Qcm = 0.045\ bd_1 \sqrt{u_w} + Q_1 + \left[\frac{Q - Q_1}{M - M_1}\right] M_2$$
$$\text{but } Qcm \not< 0.12\ bd_1 \sqrt{u_w}$$

ii. Notation

Q_1 the initial shear force due to loading, excluding the vertical component of the prestressing force Q_p, carried by the precast element prior to any composite action. (N) *

Q_2 the shear force due to additional loading which may be applied to the composite section such that the principal tensile stress f_t at the centroid of the composite section does not exceed $0.294\sqrt{u_w}$. Q_2 may have to be reduced in certain cases so that for example, the principal tensile stress at the junction of the flange and the web of the precast element does not exceed $0.294\sqrt{u_{lw}}$. (N) *

When calculating the value of Q_2 using an elastic analysis areas of plain in situ concrete which develop principal tensile stresses in excess of $0.294\sqrt{u_{lw}}$ shall be ignored where u_{lw} is the min. spec. 28 day cube strength of the insitu concrete.

b the breadth of the composite section at its centroid, but for flanged members and box beams, the breadth of the web. See also Clause 10.2 and Note 3 of notation for figure 1. (mm).

d_1 the effective depth, for calculating Q_{cm}, is the distance from the extreme compression fibre of the composite section to the centroid of all tendons. (mm).

d_2 the effective depth in the expressions $0.92\ bd_2\sqrt{u_w}$ and $(Q - 0.8Q_c)\frac{s.\sin\alpha}{d_2}$ and in Clause 8.2.iii shall be taken as the depth from the extreme compression fibre of the composite section either to the centroid of the longitudinal bars or tendons enclosed by the stirrups referred to in Clause 8.2.ii or to the centroid of all tendons, whichever is the greater. (mm).

u_w the min. spec. works cube strength at 28 days of the precast element. (N/mm^2)

M_1 the initial bending moment corresponding to Q_1. (N.mm)

M_2 the bending moment due to superimposed loading which may be applied to the composite section such that the tensile stress in the extreme fibre of the precast element is raised from the value attained under M_1 to a limiting value of $0.45\sqrt{u_w}$ (N.mm)

Symbols d, f_p, I, M_c not used

Section properties are those of the precast element or the composite section as appropriate.*

* See Appendix II

10.5 Longitudinal shear

This problem is dealt with in Clause 345 of CP 116 but the solution given does not specifically cover the case of repeated and dynamic loading, nor was the work on which it was based much concerned with the case of the concrete being in tension (eg the case of a continuous concrete/concrete composite beam over a support). Clause 10 of CP 117 Part 2 contains recommendations which relate specifically to steel/concrete composite bridge construction and it has been decided to adapt these rules. They are based on working loads and provide an interim solution until the new Bridge Code becomes available.

Notation

Q the longitudinal shear force at working load on any shear plane through the concrete of the composite beam, eg at the interface of the precast and in-situ concrete. (N/mm run of beam)

L_s length of the shear plane under consideration, eg the interface between precast and in-situ concrete. (mm)

u_w the lesser of the cube strengths of the precast and in-situ concrete and not more than 37.5 N/mm^2

a_s the total cross sectional area of reinforcement transverse to the beam intersected by the shear plane under consideration excluding the area of reinforcement required to resist moments in the deck slab. (mm^2/mm run of beam)

f_s the permissible tensile stress in shear reinforcement ie:

175 for high yield bars
140 for mild steel bars not exceeding 40 mm diameter
125 for mild steel bars exceeding 40 mm diameter (N/mm^2)

a_t the cross sectional area of bottom reinforcement transverse to the beam excluding the area of reinforcement required to resist moments in the deck slab. (mm^2/mm run of beam)

f_y the specified characteristic strength of the steel reinforcement, but not more than $425 N/mm^2$

f_{tc} the maximum tensile stress at the top surface of the slab in the longitudinal direction of the beam calculated on the assumption that the concrete is uncracked. (N/mm^2)

Rules

Q shall not exceed any of the following by more than the appropriate percentage given in Table 1 of CP 117 part 2 :-

i. $\frac{5}{12} Ls \sqrt{u_w}$ (for concrete alone)

ii. $2a_t f_y$ (for strength of in-situ slab reinforcement)

iii. in the region of longitudinal sagging moment

$$\frac{Ls}{12} \sqrt{u_w} + a_s f_s \quad \text{(for uncracked section)}$$

iv. in the region of longitudinal hogging moment, the first term being ignored if negative.

$$\left[1 - \frac{10 \; f_{tc}}{U_w} \right] \cdot \frac{Ls}{12} \sqrt{u_w} + a_s f_s \quad \text{(for cracked section)}$$

10.6 Differential Shrinkage

The effects of differential shrinkage need not be considered in the case of pretensioned beams with solid insitu infilling. In other cases, the strains given in Clause 304d of CP 115 should be used.

11. END BLOCK DESIGN FOR POST-TENSIONED MEMBERS

End blocks may be designed by the method described in Research Reports No. 9 and 13 published by the Cement and Concrete Association or in accordance with the provisions of the British Standard Code of Practice CP110 The Structural Use of Concrete.

In the absence of more exact information the cylinder splitting tensile strength of the concrete may be taken from the following table:

GRADE (28 day cube strength) N/mm^2	CYLINDER SPLITTING TENSILE STRENGTH (at 28 days) N/mm^2
22.5	1.7
30	2.1
37.5	2.4
45	2.6
52.5	2.9
60	3.1
67.5	3.2

Note 1: The above values are for concrete made with smooth gravel aggregate. Other aggregates may give higher values.

Note 2: The cylinder splitting tensile strength shall not exceed 3.2 N/mm^2 for 28 day cube strengths exceeding 67.5 N/mm^2.

Note 3: The permissible tensile stress in the concrete is to be taken as the cylinder splitting tensile strength divided by a factor of 1.25

12. TRANSMISSION LENGTH IN PRE-TENSIONED MEMBERS

The transmission length is defined as being the length of bonded tendon, required to transmit the initial prestressing force in the tendon to the concrete.

Due to the large number of variables, the transmission length should be based on experimental evidence for known factory or site conditions. However in the absence of more exact information the following general recommendations, based on research work carried out on factory produced units, may be used where the concrete cube strength at transfer is not less than 35 N/mm^2.

Type	Tendon details	Typical crimping details		Tendon force	Transmission length
		offset mm	pitch mm	%	
Wire	plain			100	160 diameters
	indented or plain	0.3	40	80	70 diameters
				100	100 diameters
	indented	1.0	40	80	54 diameters
				100	65 diameters
Strand	9.3mm dia.			100	200 ± 25 mm
	12.5			100	330 ± 25 mm
	15.2			100	420 ± 35 mm
	17.8			100	500 ± 50 mm

Note: the transmission lengths are likely to be greater where

(a) the concrete strength at transfer is less than 35N/mm^2

(b) the tendons lie at the top of the beam as cast

(c) the tendon force is released suddenly (see Clause 1714 of Specification)

(d) compacted strand is used.

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30 January 1973

APPENDIX I

The design for shear in prestressed beams, which has until now been based on the provisions of CP 115 has been changed to take account of the work reported in TRA 432 published by the Cement & Concrete Association. It has been decided for the present to maintain the global factors given in Clause 7 and because these already contain partial safety factors for steel and concrete the design equations in this memorandum omit these factors and therefore do not correspond numerically with those given in the TRA.

If a beam is cracked in flexure, the parameter $\frac{M}{Q}$ or shear span is of considerable significance in estimating its shear resistance at ultimate load. Numerous tests have shown that before the flexural crack develops into an inclined shear crack, the lower bound solution for the shear which the unreinforced section will carry is given by:

$$Q_{cm} = 0.045 \ bd_1 \sqrt{u_w} + \frac{M_cQ}{M}$$

It will be noticed that the first term represents the capacity of the section regardless of the loading while the second term takes account of the relative magnitude of the shear force and bending moment.

If the concrete does not crack flexurally, diagonal shear cracks will occur in the web when the principal tensile stress exceeds that which the concrete can carry. The lower bound formula, based on elastic theory and proved by tests, for the shear resistance of a simplified rectangular section is:

$$Q_{cw} = 0.67 \ bd \sqrt{f_t^2 + f_p f_t}$$

The shear capacity of the concrete at any section is therefore the lesser value of Q_{cm} and Q_{cw}.

Provided that the applied shear does not exceed 0.92 $bd_2 \sqrt{u_w}$, the limit for web crushing, the shear capacity of the concrete may be augmented by the capacity of shear reinforcement. From the review of experimental results given in the TRA the vertical component of the prestressing force in beams with inclined tendons can be added to Q_{cw} but not to Q_{cm}. This applies even if the applied ultimate moment M is less than the critical moment M_c at the section considered.

APPENDIX II

1. Note on Prestressing Effects

a. Regardless of the method of supporting a prestressed member the tendon force is able to create axial, vertical and transverse direct stresses, and also longitudinal and transverse bending and shear stresses depending on the position and orientation of the tendon. These effects influence directly the capacity of the member to support dead, live and secondary (or parasitic) moments and shears. The tendon force after all losses therefore, provides values for Qp, fp, fep which are defined in the text above. Because prestressing is a closely controlled operation and losses can be estimated with some confidence, a factor of unity is applied to these quantities.

b. Secondary (or parasitic) moments and shears arise where a continuous structure is stressed and the tendon profile is non-concordant. Support reactions are changed and so shears, moments and in some cases axial forces are developed in the member. These effects are considered to be part of the loading applied to the structure, a factor of unity being applied to them.

2. The diameter of a group of tendons.

For the purposes of Clause 8.2 ii the group of tendons (wires or strands) local to the bend in the stirrup means those tendons within the circle of the bending mandrel for the stirrup. If their total cross sectional area is A, the diameter of this group of tendons is $d=\sqrt{\frac{4A}{\pi}}$

3. Shear capacity of the concrete alone in a composite section assuming that it is uncracked in flexure

$$Q_{cw} = Q_1 + Q_2 + Q_p$$

a. Consider the first term Q_1. The shear stress in the precast element, f_{s_1}, should be calculated at the level of the centroid of the composite section. Elastic theory gives:

$$f_{s_1} = \frac{Q_1 A_1 \bar{y}_1}{I_1 B_1} \qquad (N/mm^2)$$

where $A_1 \bar{y}_1$ is the first moment of area of that part of the precast element above the level being considered (mm^3)

B_1 is the breadth of the precast web at this level (mm)

I_1 is the second moment of area of the precast element (mm^4)

Also the longitudinal stress, f_{x_1} (compression positive) should be calculated at the level of the centroid of the composite section. (N/mm^2)
f_{x_1} will consist of:-

(i) bending stress due to loads supported solely by the precast beam

(ii) axial and bending stresses due to the prestressing force.

In addition, at this stage, check that the principal tensile stress at critical points in the section caused by the loads supported solely by the precast element and prestress, does not exceed $0.294\sqrt{u_w}$.

b. Now consider the composite section. Q_2 may be obtained from the following expression which is based on elastic theory:

$$Q_2 = \frac{I_2 \; B_2}{A_2 \; \bar{y}_2}\left[\sqrt{f_{t_2} \; (f_{t_2} + f_{x_1})} - f_{s_1}\right] \qquad (N)$$

where $A_2 \; \bar{y}_2$ is the first moment of area of the part of the composite section above its centroid

B_2 is the breadth of the composite section at the centroid (mm)

I_2 is the second moment of area of the composite section (mm^4)

f_{t_2} the maximum principal tensile stress at the centroid of the composite section. It is to be taken as $0.294\sqrt{u_w}$ and positive.

4. Shear capacity of the concrete alone in a composite section assuming that it is cracked in flexure

$$Qcm = 0.045b \; d_t\sqrt{u_w} \quad + \quad Q_1 \quad + \left(\frac{Q-Q_1}{M-M_1}\right) M_2$$

a. If we consider the second term Q_1; this is derived from the expression:-

$$\frac{M_1}{\quad} \qquad \text{ie. } \frac{M_1}{M_1 / Q_1}$$

Shear span for this type of loading

The longitudinal bending stress should be calculated at the extreme fibre at which loads first cause tensile cracks to appear in the precast element. Taking the stress to be tensile and positive

$$f_{e_1} = \frac{M_1 \; y_1}{I_1} - f_{ep}$$

where y_1 is the distance of the extreme fibre from the centroid of the precast element. (mm)

b. We now consider the third term involving M_2. After the member has become a composite section superimposed loading is applied. This produces a bending moment M_2. Let the extreme fibre stress due solely to this loading be f_{e_2}

(tensile positive).

The maximum flexural tensile stress which plain concrete can sustain prior to cracking is assumed to be $0.45 \sqrt{u_w}$ N/mm^2

$$\therefore \; f_{e_2} \leqslant 0.45 \sqrt{u_w} - f_{e_1}$$

leading to an expression for the limiting value of:-

$$M_2 = \left[0.45\sqrt{u_w} - M_1\left(\frac{y_1}{I_1}\right) + f_{ep}\right]\frac{I_2}{y_2}$$

where y_2 is the distance of the extreme fibre of the precast element from the centroid of the composite section. (mm)

c. In the third term the maximum value of the shear span for the superimposed loading is derived by considering the various loading configurations at the limit state of collapse. Values of M_1 and Q_1 are deducted from M and Q respectively since their effects have already been accounted for in the second term.

APPENDIX III

The following clauses of BSCPs 115 and 116 are particularly relevant to the design of prestressed concrete highway structures.

CP 115: PART 2: THE STRUCTURAL USE OF PRESTRESSED CONCRETE IN BUILDINGS

GENERAL

301 Basic assumptions.

302 Loadings;

2nd and 3rd paragraphs only,

303 Permissible stresses;

(a) General;
2nd paragraph only.

(c) Permissible stresses in Prestressing steel;
(ii) Alloy steel bars;
first sentence only.

(d) Sequence of prestressing;
Omit the words "by this clause" in first sentence.

304 Loss of prestress;

(c) Elastic deformation of the Concrete;
last 3 paragraphs only.

(d) Shrinkage of the concrete;
for Clause 304c substitute Clause 5.1 of this Memorandum.

(e) Creep of the concrete;
last paragraph only;
omitting the words "in the preceeding paragraphs" in first sentence.

(f) Anchoring.

(g) Steam curing;
omit the reference to Clause 501 g.

305 Losses due to friction.

306 Spacing of tendons;
see also Clause 6 of this Memorandum.

307 Bond;
the recommendations given in Clause 701 have been incorporated in Clause 12 of this Memorandum

BEAMS (AND OTHER MEMBERS) IN BENDING

310 Effective span.

312 Design for working loads except:-

1. read Clause 304 with Clause 5 of this Memorandum

2. for Clause 303 substitute Clauses 3, 8 and 10 of this Memorandum.

3. for Clause 309 (i) substitute Clauses 3, 8 and 10 of this Memorandum.

313 Ultimate strength of beams;

(a) General.

(b) Assumptions in beam design;
superseded by Clause 9 of this Memorandum

(c) Stresses in tendons at failure;
use where appropriate and only in the absence of special test results.

(d) Allowance for steel reinforcement.
where f_y is the yield or proof stress of the reinforcement in accordance with B.S 4449 or B.S 4461.

(e) Strength of beams with steel in tensile zone only;
but the general method described in Clause 9 of this Memorandum is preferred.

314 Proportion of prestressing steel in beams.

315 Reinforcement in beams;
omit last paragraph.
Also read in conjunction with this Memorandum and BE 1/73, Reinforced Concrete for Highway Structures which prevail over CP 114.

316 Slender Beams;
for Clause 303 substitute Clauses 3,8 and 10 of this Memorandum.

317 Beam and slab construction.

318 Composite beams;
4th paragraph only. See also Clause 10 of this Memorandum.

320 Deflection;
for Table 3 substitute Clause 5.3 of this Memorandum
for Clause 304e. substitute Clause 5.4 of this Memorandum.
omit last two sentences.

COMPRESSION MEMBERS

321 General.

322 Basis of design of compression members;
for Clause 303 substitute Clauses 3, 8 and 10 of this Memorandum.

323 Reinforcement in compression members.

OTHER STRUCTURES

324 Statically indeterminate structures.

GENERAL

301 General considerations in the design of precast structures;
Paras. a. and b. omitting the reference to Clause 413.

305 Permissible stresses in prestressing steel;

(c) Alloy steel bars; first sentence only.

(d) Sequence of prestressing.

306 Loss of prestress;
Use Clause 5 of this Memorandum which invokes parts of Clause 304 and also Clause 305 of CP 115.

308 Minimum distance between bars, including tendons.

309 Maximum distance between bars, including tendons, in slabs.

PRESTRESSED MEMBERS IN BENDING

327 Effective span.
The same as Clause 310 of CP 115.

329 Design for working load;
The same as Clause 312 of CP 115.

330 Calculation of ultimate strength of beams;
The same as Clause 313 of CP 115.

331 Proportion of prestressing steel in beams;
The same as Clause 314 of CP 115.

332 Reinforcement in beams;
Substantially the same as Clause 315 of CP 115.

333 Slender Beams;
The same as Clause 316 of CP 115.

334 Deflection;
The same as Clause 320 of CP 115.

PRESTRESSED COMPRESSION MEMBERS

335 Basis of Design;
The same as Clauses 321 and 322 of CP 115.

336 Reinforcement in compression members;
The same as Clause 323 of CP 115.

OTHER PRESTRESSED STRUCTURES

337 Statically indeterminate structures;
The same as Clause 324 of CP 115.

TRIMMINGS AND BEARINGS FOR PRESTRESSED SLABS

339 Trimmings to openings;
omit the reference to floors or roofs.

340 Bearings for precast units;
substitute the following: Precast units should have a bearing of at least 75mm.

COMPOSITE PRECAST AND IN-SITU CONSTRUCTION

341 Composite beams;
The same as Clause 318 of CP 115.

342 Beam and slab construction;
The same as Clause 317 of CP 115.

344 Special design considerations.

345 Shear Connections;
Substitute Clause 10 of this Memorandum.

CONNECTIONS

346 Connections;
except:

1. Substitute "structure" for "building"

2. Substitute the following for all after the first sentence of: a (iii):-
These details should allow for deviations from correct dimensions and clearances during erection.

APPENDIX C MOVEMENT JOINTS

To be used in conjunction with Technical Memorandum BE 3/72; Expansion Joints for Use in Highway Bridge Decks.

C1. General.

C2. Need for movement joints;
First paragraph only.

C3. Types of movement joints.

TEMPORARY APPENDIX IV

1. FORCES TO BE TAKEN INTO ACCOUNT

For the purpose of calculating stresses the following items shall, where applicable, be taken into account:

1. Dead load
2. Live load
6. Centrifugal force
7. Longitudinal force
8. Wind pressure effect
9. Temperature effect
10. Resistance of expansion bearings to movement
11. Forces on parapets
12. Erection forces and effects
13. Forces and effects due to subsidence and other similar causes
14. Shrinkage and creep effects

Note: the numbering 1 to 13 inclusive has been taken from B.S.153: Part 3A: 1972

2. COMBINATION OF FORCES

2.1 Steel girder bridges: as Clause 16 of B.S. 153: Part 3A: 1972

2.2 Steel box girder bridges: in accordance with the Interim Design and Workmanship Rules for steel Box Girder Bridges

2.3 Composite construction in Structural steel and concrete: as Clause 5 of B.S.C.P. 117: Part 2: 1967

2.4 Reinforced, prestressed and composite concrete bridges

The following combinations of forces at working load shall be considered:

1. The worst combination possible of dead load and live load.
2. The worst combination of any or all of items (1) to (14) in Clause 1.

In addition the effects of factored values of dead load and live load shall be combined as described in Clause 7 of Tech. Memo. BE 2/73, Prestressed Concrete for Highway Structures, to check the adequacy of the ultimate moment of resistance and the shear capacity of prestressed concrete superstructures.

3. ACCIDENTAL WHEEL LOADING ON FOOTWAYS AND VERGES

3.1 The single 40 kN wheel load specified in Clause 4 of BS 153: 1972 is less severe than loading that can occur in practice.

3.2 Pending revision of the Standard, footways and verges on highway bridges shall be checked for the wheel load arrangement shown in Figure 1 of this Appendix. This applies to local effects and shall not be taken into account in determining global effects on the deck.

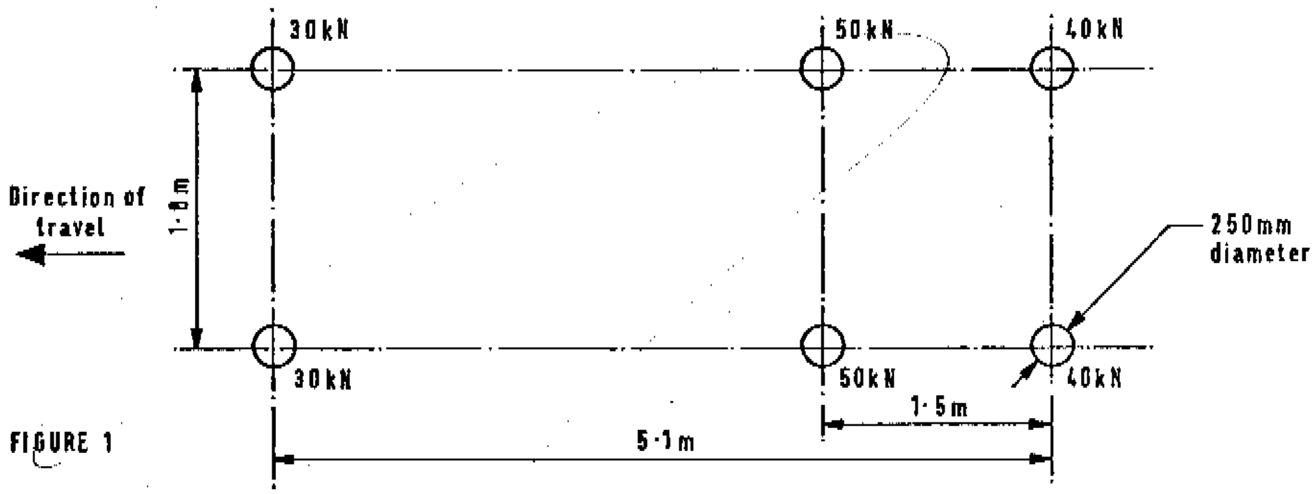

FIGURE 1

3.3 Each wheel load shall be deemed to include impact and to be distributed over a contact area 250mm diameter. Stresses may be increased by 25 per cent when accidental loading is considered in combination with parapet forces and other loading.

4. CONTACT AREA OF HA OR HB WHEEL LOADS

HA or HB wheel loads shall be assumed to be uniformly distributed over a circular or square area assuming an effective pressure of 1.4 N/mm^2.

EBB

BE 21/5/022

TECHNICAL MEMORANDUM (BRIDGES) BE 2/73
PRESTRESSED CONCRETE FOR HIGHWAY STRUCTURES

AMENDMENT LIST NO 1

Figure 2. Short term design stress-strain curve for concrete; peak value of stress.

"Substitute 0.44 u_w for $0.67u_w$ "

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BE 21/5/022

TECHNICAL MEMORANDUM (BRIDGES) BE 2/73
PRESTRESSED CONCRETE FOR HIGHWAY STRUCTURES
AMENDMENT LIST NO. 2.

Page 1. Amend footnote to read:
"**See Clause 10 for composite construction."

Page 5. Clause 8.1 Delete the reference to "Clause 9" and substitute "Clause 10".

Page 8. Note 2. Delete the reference to "Clause 11" and substitute "Clause 12".

Page 10. Clause 10.4 ii. Notation.
Q_2 last sentence. Delete "0.294 u_{1w}"
and substitute "$0.294\sqrt{u_{1w}}$ "
d_2 Delete "7.2.ii" and substitute "8.2.ii".

Page 12. Note 3. Delete "1.5" and substitute "1.25".

Page 19. APPENDIX III. Clause 313 (d)
Delete "BS 785 or BS 1144"
and substitute "BS 4449 or BS 4461".

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15 June 1973

Amended