



THE HIGHWAYS AGENCY

BD 28/87



THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

**Incorporating
Amendment No.1,
1989**



**THE WELSH OFFICE
Y SWYDDFA GYMREIG**



**THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND**

Early Thermal Cracking of Concrete

Summary:

VOLUME 1	HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN
SECTION 3	GENERAL DESIGN

BD 28/87

**EARLY THERMAL CRACKING OF
CONCRETE**

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1. INTRODUCTION

1.1 Early thermal cracking is the cracking that occurs due to restraint of a member as the heat of hydration dissipates and while the concrete is immature. It can occur in a number of places in a structure such as the parapet edge beam, when it is cast separately from the deck, in the web of a hollow box type deck cast in stages, and in retaining walls and abutments. It is important that the extent and size of such cracking should not be such as to impair the serviceability and durability of the structure or its appearance.

1.2 Experience has shown that in many instances the requirements of BS 5400: Part 4: 1984+, are not sufficiently detailed to accurately assess the area of reinforcement necessary to control early thermal cracking. The prediction method and advice on arrangement of reinforcement given in this Standard shall therefore be used instead of the simplified rules of Clause 5.8.9, BS 5400: Part 4: 1984.

+ All references to BS 5400: Part 4: 1984 shall be taken as reference to that Part as implemented by Departmental Standard BD 24/84.

2. SCOPE

2.1 This Departmental Standard gives requirements supplementary to BS 5400: Part 4 for the control of thermal cracking of concrete by means of additional distribution reinforcement. It applies to both reinforced concrete members and to post-tensioned members prior to prestressing, but not where an accelerated curing process or lightweight aggregates are used. The associated Advice Note BA 24/87 gives background information on thermal and shrinkage movements, forms of restraint, factors influencing temperature differences and discusses the various means of controlling cracking.

2.2 The requirements of this document are based on the behaviour of concrete in new construction and are therefore not applicable to the repair of existing concrete elements.

3. EARLY THERMAL MOVEMENT

3.1 Early thermal movement is inevitable in all concrete sections as a result of the heat of hydration as the concrete hardens. At first the concrete expands as the heat of hydration exceeds the rate at which heat is dissipated, but then the section contracts as the concrete cools down to the ambient temperature. If any part of the section is restrained from contraction as the section cools then cracking of the immature concrete may occur. In the past this has often been referred to as 'shrinkage cracking', which has led to confusion.

3.2 Although cracking due to restraint of early thermal movement is the dominant effect for UK conditions, allowance has also to be made for the restraint of the subsequent thermal and shrinkage movement in the mature concrete. Factored terms to include for these longer-term movements are therefore included in the prediction method given in this Departmental Standard. The prediction method does not allow for the effects of any subsequent loading, but crack widths produced by such loading need not be added to the thermal crack widths when checking against permissible values.

4. CONTROL OF THERMAL CRACKING

4.1 Thermal cracking can be controlled by reducing the thermal movement, by reducing the restraint, by prestressing or by provision of distribution reinforcement. In most cases the use of distribution reinforcement parallel to each face of the member is the most economical and convenient method of crack control. Other methods of crack control are considered in the associated Advice Note BA 24/87.

4.2 Distribution reinforcement shall be placed as close to the surface as is consistent with cover requirements, have the full required anchorage length and be distributed evenly around the perimeter of the section. A greater number of small diameter bars at close centres is more effective in the control of cracking than a lesser number of larger diameter bars at greater centres. It is not necessary to provide such reinforcement in the faces of construction joints.

5. REINFORCEMENT REQUIREMENTS - PREDICTION METHOD

5.1 To control crack spacing there must be sufficient reinforcement so that the reinforcement will not yield before the tensile strength of the immature concrete is exceeded. This is achieved by satisfying the equation,

$$A_s f_y \geq f_{ct}^* A_c \quad \dots\dots\dots (1)$$

Thus minimum reinforcement area $A_s = \left(\frac{f_{ct}^*}{f_y} \right) A_c \quad \dots\dots\dots (2)$

- Where:-
- A_s = area of reinforcement in a given direction to prevent early thermal cracking. This reinforcement should be distributed evenly around the perimeter of the section.
 - A_c = area of effective concrete (see 5.2)
 - f_y = characteristic tensile strength of reinforcement. (N/mm²)
 - f_{ct}^* = tensile strength of immature concrete which may be taken as $0.12 (f_{cu})^{0.7}$ (N/mm²)
 - f_{cu} = characteristic cube strength of concrete (N/mm²)

5.2 The area of effective concrete, A_c , from which the value of A_s is determined is normally the gross cross sectional area. In sections thicker than 500mm, A_c is that area of concrete which lies within 250mm of the surface.

5.3 In addition to controlling the spacing of cracks, the reinforcement must be adequate to ensure that crack widths do not exceed the permissible values. For most cases this will require more than the minimum needed to satisfy the requirements of 5.1.

Required reinforcement area $A_s = \left(\frac{f_{ct}^*}{f_b} \right) A_c \frac{\phi}{2w} [R (\epsilon_{sh} + \epsilon_{th}) - 0.5\epsilon_{ult}] \quad \dots\dots\dots (3)$

- where:-
- f_b = average bond strength between the reinforcement and the immature concrete. (N/mm²)
 - ϕ = bar size (nominal diameter) (mm)
 - w = permissible crack width. (See 5.5) (mm)
 - ϵ_{sh} = shrinkage strain (See 5.6)
 - ϵ_{th} = thermal strain (See 5.7)
 - ϵ_{ult} = ultimate tensile strain capacity of concrete which may be taken as 200 microstrain.
 - R = restraint factor (see 5.11)

In all cases the greater of the requirements given by equations (2) and (3) shall be provided.

5.4 The ratio of the tensile strength of the immature concrete to the average bond strength between the reinforcement and the immature concrete, f_{ct}^*/f_b may be taken as,

1.00 for plain round bars

0.80 for Type 1 deformed bars
0.67 for Type 2 deformed bars

The classification of bars as Type 1 or Type 2 shall be in accordance with BS 5400, Part 4, Clause 5.8.6.1.

5.5 The permissible crack width w shall be taken from the values in Table 1 of BS 5400: Part 4: 1984 for the appropriate environmental condition for the element under consideration.

5.6 The shrinkage strain ϵ_{sh} shall be taken as the free shrinkage strain modified by the effects of creep. An estimate of the free shrinkage strain and the creep reduction factor can be made using BS 5400: Part 4, Appendix C. For normal UK conditions the shrinkage is usually not more than $0.5 \epsilon_{ult}$.

5.7 The thermal strain ϵ_{th} is given by:

$$\epsilon_{th} = 0.8\alpha (T_1 + T_2) \quad \dots (4)$$

where:-

- α = coefficient of thermal expansion of concrete, 12×10^{-6} per °C for normal weight concrete.
- T_1 = Short-term fall in temperature from hydration peak to ambient conditions. (See 5.8)
- T_2 = Long-term fall in temperature from ambient to the seasonal minimum. (See 5.9)

5.8 Typical values of T_1 for ordinary Portland cement (OPC) concrete members up to 500mm thick shall be taken from Table 1. For sections thicker than 500mm the values in Table 1 shall be increased by 10°C. If a sulphate resisting Portland cement (SRPC) is specified, the values from Table 1 shall be reduced by 20%. The use of a rapid hardening Portland cement (RHPC) or an accelerating admixture shall be avoided where possible except when concreting takes place in very cold weather. In such circumstances the value of T_1 may be assumed to be as for OPC in summer conditions.

Cement Content (Kg/m ³)	Steel Formwork		18mm Plywood Formwork	
	Winter	Summer	Winter	Summer
300	12	18	20	28
350	15	23	27	35
400	17	27	32	43

Table 1 - Typical Values of T_1 (°C)

5.9 Typical values of T_2 shall be taken as 20°C for summer concreting and 10°C for winter concreting. However, if full movement joints are provided at no more than 15m spacings the effects of T_2 can be ignored. Similarly, if the restraint is being provided by a section subject to the same climatic exposure as that being restrained, the effects of T_2 can also be ignored.

5.10 Reinforcement that is present in the section for other purposes may be included as part of the area of reinforcement necessary to satisfy the requirements for the control of early thermal cracking.

5.11 The restraint factor R represents the amount of restraint to lateral and shrinkage movement which is actually provided, normally by the previously cast elements of the structure. The value of the factor depends on the nature of the structural elements concerned and typical values of R for different examples of restraint are listed in Table 2.

Restraint Condition	Restraint Factor R
External:	Base cast onto blinding. 0.2
	Edge restraint in box type 0.5
	deck cast in stages 0.6
	Wall cast onto base. 0.8
	Edge element cast onto slab. 1.0
	Infill bays.
Internal:	0.5

Table 2 - Restraint Factors

6. ARRANGEMENT OF REINFORCEMENT FOR DIFFERENT TYPES OF RESTRAINT

6.1 External End Restraint

For a section in which the cracking is caused by external end restraint, as shown in Figure 1, the reinforcement shall be provided throughout the member perpendicular to the restraining edge as indicated. The area of reinforcement, A_s , necessary to satisfy the requirements of 5.1 to 5.3 shall be provided in the faces of the section.

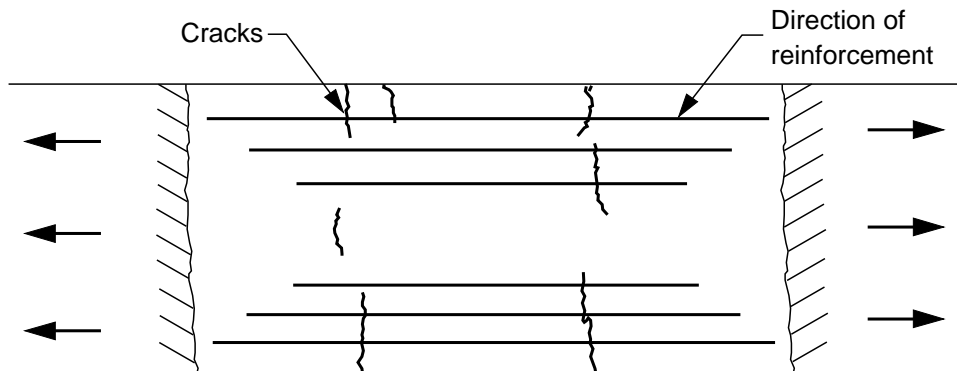


Figure 1 - End Restraint

6.2 External Edge Restraint

For a section in which the cracking is caused by external edge restraint as shown in Figure 2, the reinforcement shall be provided parallel to the restraint as indicated. Where the length to height ratio exceeds 2:1 this reinforcement shall be placed over the full height of the section. When the length to height ratio is 2:1 or less, and there is no end restraint, reinforcement to control early thermal cracking need only be placed in the half of the section adjacent to the restraint.

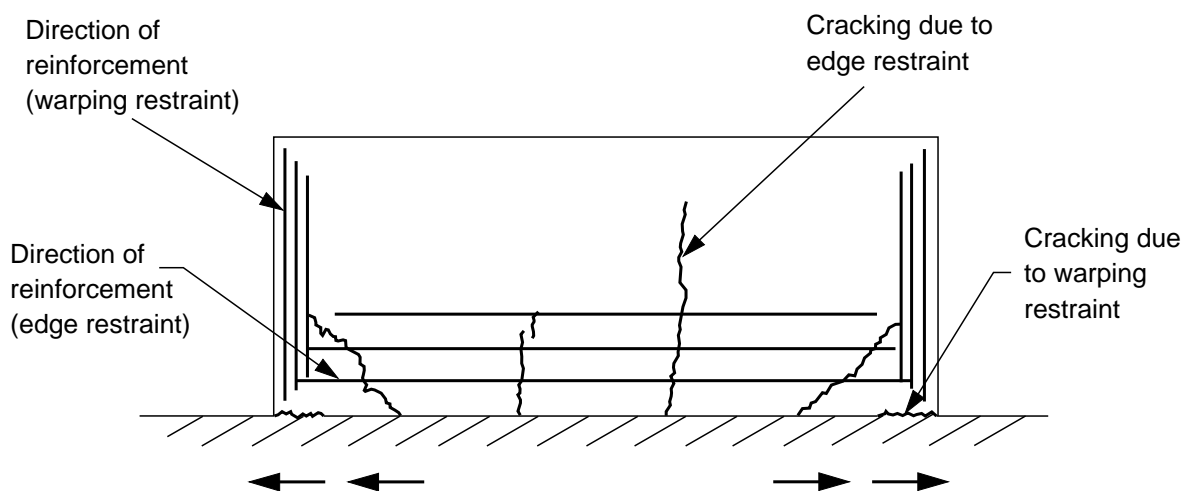


Figure 2 - Edge Restraint and Warping Restraint at End

The area of reinforcement, A_s , necessary to satisfy the requirements of 5.1 to 5.3 shall be provided in the faces of the section.

In addition to the reinforcement parallel to the edge restraint in such a section, reinforcement of the same unit area shall also be provided to control the effects of warping restraint at the ends. This reinforcement shall be perpendicular to the edge restraint and be provided over a length at the end equivalent to the lesser of the height of the section, or 0.2 times the overall length.

6.3 Internal Restraint

Where the least dimension of a member exceeds 1 m and the sum of the two smallest dimensions exceeds 4 m, the member shall be considered as being subject to internal restraint due to the temperature gradient changes between the core and the surface. The area of reinforcement, A_s , necessary to satisfy the requirements of 5.1 to 5.3 shall be provided in each of two directions in all surfaces of the member, (but see 4.2).

6.4 External and Internal Restraint

Where there is combined internal and external restraint the appearance of cracking is similar to that for a thin section. As the cracking progresses from the surface, economies in reinforcement can be made based on an effective surface zone as discussed in 5.2. However, as the temperature rise of the core is greater than that of the surface zones, the typical values of temperature rise T_1 given in Table 1 shall be increased by 10°C. The area of reinforcement, A_s , necessary to satisfy the requirements of 5.1 to 5.3 shall be provided in each of two directions in all surfaces of the member.

7. REFERENCES

The following documents are referred to in this Departmental Standard.

- (1) BS 5400. Steel, Concrete and Composite Bridges. Part 4: 1984: Code of Practice for Design of Concrete Bridges.
- (2) Departmental Standard BD 24/84: Use of BS 5400: Part 4: 1984.
- (3) Departmental Advice Note BA 24/87: Early Thermal Cracking of Concrete.

8. ENQUIRIES

Technical enquiries arising from the application of this Departmental Standard to a particular design should be addressed to the appropriate Technical Approval Authority, for that scheme.

All other technical enquiries or comments should be addressed to:-

Head of Bridges Engineering Division
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