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# THE DESIGN OF EXPERIMENTAL CONCRETE CARRIAGEWAYS ON M180 (SANDTOFT TO TRENT SECTION)

by

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# THE DESIGN OF EXPERIMENTAL CONCRETE CARRIAGEWAYS ON M180 (SANDTOFT TO TRENT SECTION)

## ABSTRACT

The design of a major full-scale experimental concrete road investigating the construction, performance and cost of continuously reinforced concrete pavements (CRCP) is described. The performance of seven CRCP sections, each approximately 1.6 km long, will be compared with that of conventional jointed concrete pavements, both unreinforced and reinforced. The thicknesses of the CRCP sections are 250, 230 and 210 mm which are respectively 30, 50 and 70 mm less than the control sections. Two end treatments are being investigated; anchorages which restrain movement and wide flange beam joints which accommodate movement.

Also included in the experiment are lengths of jointed unreinforced concrete pavement with narrow unsealed transverse joint grooves; over one length of this type of construction the separation membrane has been omitted.

## 1. INTRODUCTION

Over the past twenty years continuously reinforced concrete pavements (CRCP) have been widely used for major roads in the USA and in Belgium. Other European countries have experimented with this form of construction but in Great Britain its use for roads has been very restricted. The Grantham full-scale experiment[1] incorporated four CRCP sections; the steel reinforcement in these sections was considerably underdesigned and early failures occurred.

A study group of British engineers visited the USA and Belgium in 1972 to assess the potential for CRCP in Great Britain. They recommended[2] that CRCP was a viable form of construction although not competitive with existing forms on first cost alone. The Study Group also concluded that, because of possible reduced maintenance, CRCP might be particularly suitable where traffic delays arising from maintenance operations were least acceptable; it was recommended that first hand experience with CRCP ought to be gained. In 1975 two relatively short lengths (840 and 540m long) were included in the Balkholme to Caves section of M62[3] over areas where differential settlement was anticipated. Two years later the Sandtoft to Trent section of M180 was selected for a major trial. The detailed design for the contract was undertaken by the West Yorkshire Metropolitan County Council Sub-Unit of the North Eastern Road Construction Unit in cooperation with TRRL.

## 2. BASIC CONCEPTS OF CRCP

Continuously reinforced concrete pavements contain continuous longitudinal reinforcement with no intermediate expansion or contraction joints. Stresses within the concrete slab are relieved by the occurrence of a random pattern of transverse cracks that are held tightly closed by the steel reinforcement, maintaining aggregate interlock to give good load transfer. Cracking may occur within a few days of construction and almost all the cracking will occur within the first three or four years. The desirable spacing of the cracks for optimum life is considered to be between 1.5 and 2.5m.

Many factors influence the crack spacing and hence the crack widths, which are directly related. The most important factor is considered to be the percentage of steel, ie the ratio of the cross-sectional area of longitudinal steel to the cross-sectional area of the concrete slab. Other factors influencing crack spacing are bond area of steel, depth of reinforcement, friction between slab and sub-base, concrete strength, environmental conditions at the time of construction and curing temperature.

Longitudinal movements occur at the ends of the pavements as the result of linear dimensional changes, caused principally by temperature variation; these movements occur only within 150m of the pavement ends, irrespective of the total length of the CRCP. The end movements are either controlled by the use of anchorages or accommodated by special joints.

## 3. DESIGN

The purpose of the M180 experiment was to compare the performance and overall costs, including maintenance, of different CRCP sections against those of normal jointed concrete sections designed to the recommendations of Road Note No. 29 (Third edition)[4].

### 3.1 *Description of the site*

The M180 Sandtoft to Trent section is a dual three-lane motorway between Sandtoft and the River Trent with only one grade separated junction; the length is 8.6 km as shown on Figure 1. There are two small underbridges and five overbridges. The Motorway is constructed on a shallow embankment except at the interchange, where the construction is at or near ground level, or in very shallow cutting. The soil types are wind-blown sand at the western end and alluvial clays and peats at the eastern end; Keuper Marl appears at formation level near the interchange and this is divided by a deposit of alluvial sands. The fill used for the embankments was mainly marl from local brickworks.

### 3.2 *Design of the experiment*

The layout of the experiment was designed to obtain the maximum results while keeping constructional changes to a minimum to reduce variability in production. Since 1970, all major roads in concrete had been of unreinforced construction and lengths of this design were included as control sections. Jointed reinforced slabs, a permitted alternative to unreinforced construction, were also included although they have not been used in the United Kingdom during the last decade because of their higher initial cost.

Narrow unsealed transverse joint grooves, which have been used experimentally at a number of sites, were included in a length of the unreinforced construction. Half of this length is laid on a separation membrane, which is the normal requirement, in the other half the membrane was omitted; omission of the membrane is now finding favour on the continent.

For the CRCP, which is the greater portion of the experimental length, the variables were a) three different slab thicknesses, b) two positions of reinforcement, c) two types of end treatment; the layout of the experiment is shown in Figure 2.

### 3.3 *Pavement design*

3.3.1 Jointed pavement: The control sections of unreinforced slabs and the jointed reinforced slabs were designed in accordance with the recommendations of the Notes for Guidance on the Specification for Road and Bridge Works[5] for an estimated life of 70 million standard axles. The slab thickness is 280 mm with a sub-base thickness of 180 mm. The total construction depth of 460 mm was maintained throughout the contract.

As a limestone aggregate was used, the spacing of construction joints in the unreinforced sections is 6m. In the reinforced slabs, steel reinforcement weighing 5.55 kg/m$^2$ is included and the contraction joint spacing is 42m. The construction of the pavement took place during the summer and expansion joints were therefore not used except in transition lengths.

3.3.2 CRCP design: As there are no design recommendations in Great Britain for CRCP, the designs current in the USA and in Belgium were examined and adapted to British practice.

3.3.2.1 Slab thickness: The Study Group recommended in their report[2] that, for roads designed to carry more than 11 msa during their design life, the reduction in thickness below that of normal slabs should be 30 mm, for a minimum steel percentage of 0.6. The most common reduction in thickness in the USA is 50 mm (200 mm thick CRCP is considered as the equivalent of 250 mm thick jointed pavement); some highway authorities in the USA, however, reduce slab thickness by 25 per cent from that required for a jointed pavement. In Belgium, the design thicknesses on autoroutes are 230 mm for jointed pavements and 200 mm for CRCP[6], irrespective of traffic.

In the M180 experiment, CRCP slab thicknesses of 250 mm, 230 mm and 210 mm were used, giving reductions in thickness of 30 mm, 50 mm and 70 mm respectively (11 per cent, 18 per cent and 25 per cent) from the normal slab thickness. It was considered that these thicknesses would cover the range likely to be used in practice with the prospect that early information might be obtained from the thinner slabs to enable assessments to be made of the eventual performance of CRCP.

3.3.2.2 Reinforcement: The steel content is known to be critical for good performance of CRCP; theoretical studies[7,8] have shown that the correct percentage of longitudinal steel is directly related to the tensile strength of the concrete. The greater the tensile strength, the greater the percentage of steel required and vice versa. Thus, in examining the designs used by different authorities, the strengths of concrete associated with the steel contents are important. In the USA, concrete strengths do not differ significantly from those used in Britain and steel contents range from 0.5 to 0.7 per cent. The concrete used in Belgium is approximately 50 per cent stronger than that used in the UK and the percentage of longitudinal steel specified in Belgium is between 0.85 and 0.9. After consideration of these designs and the fact that most of the American CRCP with a steel content of 0.6 per cent in climatic zones with no great extremes of temperature has given a satisfactory performance, a nominal percentage of 0.6 was adopted for M180. Deformed steel reinforcement was specified as all authorities agree that plain round steel is unsatisfactory for use in CRCP.

The requirement for steel percentage can be met either by a few large diameter wires or bars at wide spacings or by many small diameter wires at close spacings. In addition, the bond area of the steel must be sufficient to develop the yield strength of the steel; minimum ratios of bond area per unit volume of concrete (1180 mm$^2$/m$^3$)

have been specified in the USA. The design of the steel reinforcement is also influenced by the spacing between wires or bars, which should be large enough to permit easy placement of the concrete. For these reasons two alternative sizes of deformed longitudinal bars were allowed, 14 and 16 mm; the latter size was adopted as it is a British Standard size bar. For one 210 mm thick CRCP section, a fabric reinforcement was also specified; this consisted of standard 12 mm diameter wires at 90 mm spacing. The longitudinal steel was specified as Type 2 deformed ribbed wires or bars to British Standards BS 4449[9] and BS 4461[10].

Transverse reinforcement is omitted by some American states where the possibility of longitudinal cracking is considered minimal. However, transverse reinforcement has other roles; these are (1) to maintain the correct spacing of the longitudinal steel, (2) to assist in supporting the longitudinal steel at its correct depth, (3) to serve where necessary as tie-bars across longitudinal joints, and (4) to hold any longitudinal cracks tightly closed. For these reasons and because the special placing equipment necessary to place longitudinal steel on its own is not available in the UK, transverse reinforcement was specified in a sufficient quantity to act as tie-bars across the longitudinal joints where more than one lane width was constructed in a single operation.

The details of the reinforcement used for the CRCP lengths are given in Table 1.

TABLE 1

Details of reinforcement in CRCP sections

| Slab thickness (mm) | Longitudinal reinforcement | | | Transverse reinforcement | | |
|---|---|---|---|---|---|---|
| | Diameter (mm) | Spacing (mm) | Percentage | Diameter (mm) | Spacing (mm) | Percentage |
| 250 | 16 | 135 | 0.61 | 12 | 500 | 0.09 |
| 230 | 16 | 144 | 0.62 | 12 | 500 | 0.10 |
| 210 | 16 | 160 | 0.61 | 12 | 500 | 0.11 |
| 210* | 12 | 90 | 0.60 | 8 | 200 | 0.12 |

* fabric reinforcement

Originally, both hot-rolled and cold-worked steel reinforcements were to be used because their different tensile properties would have influenced the crack spacing. However the future British Standard specifications were to require that there be no difference in the tensile properties of the two types of steel; the experimental layout was therefore amended. Reinforcement depth was selected as the alternative variable because accommodating this in the experiment would cause least disruption to the contractor and because American data have shown that the depth of longitudinal steel is a major factor influencing the final crack spacing. Two positions for the reinforcement were selected, at mid-slab depth and at approximately one-third slab depth. The specified depths are given in Table 2.

TABLE 2

Specified positions of longitudinal steel

| Slab thickness (mm) | Position of longitudinal steel | Depth of steel from surface (mm) |
|---|---|---|
| 250 | Mid-depth | 125 |
| 250 | Third-depth | 90 |
| 230 | Mid-depth | 115 |
| 230 | Third-depth | 80 |
| 210 | Mid-depth | 105 |
| 210 | Third-depth | 75 |
| 210* | Mid-depth | 105 |

* fabric reinforcement

In all the CRCP sections the specified tolerances for the position of the longitudinal steel were ± 10 mm. The methods of fabricating and positioning the reinforcement were the responsibility of the contractor and subject to approval by the engineer.

3.3.2.3 Sub-base: Experience in the USA[11] suggests that for good performance CRCP should be constructed on a stabilised sub-base placed on top of a well-compacted sub-grade. In Belgium[6] CRCP is laid on a 60 mm thick bituminous layer placed upon a 200 mm thick layer of lean concrete. For the M180, stabilised sub-bases were specified for the CRCP sections and three alternatives were offered to the contractor. These were:—

(1) 60 mm thickness of dense bitumen macadam laid on granular sub-base material to Clause 803 (Type 1) of the Department of Transport Specification for Road and Bridgeworks[12].

(2) Lean concrete or cement-bound granular material to Clauses 807 and 806 of the above specification.

(3) 150 mm thickness of lean concrete or cement-bound granular material, as above, laid on granular sub-base material (Type 1).

In all cases the thickness of the sub-base was such that the total construction depth of slab and sub-base remained constant at 460 mm throughout the contract, for ease of construction. The alternative selected by the successful contractor was (3) and Table 3 shows the types and thicknesses of the sub-base.

TABLE 3

Sub-base types and thicknesses under CRCP sections

| Slab thickness (mm) | Sub-base type and thickness | | | |
|---|---|---|---|---|
| | Upper layer | | Lower layer | |
| | Type | Thickness (mm) | Type | Thickness (mm) |
| 250 | Cement-bound granular | 150 | Granular Type 1 | 60 |
| 230 | Cement-bound granular | 150 | Granular Type 1 | 80 |
| 210 | Cement-bound granular | 150 | Granular Type 1 | 100 |

3.3.2.4 Terminal treatments: At the ends of CRCP sections creep may exceed 50 mm and annual movements of 25 to 50 mm have also been recorded; these movements must either be restrained by the use of anchorages or be accommodated by an expansion system.

In the USA, both methods have been used with apparent success, but in Belgium, following the unsuccessful performance of some expansion systems, only anchorage systems are now used. The CRCP lengths on M62[3] have anchorages at each end which have so far performed satisfactorily. To assess the relative merits of the two methods, both were included in the M180 experiment. Where the CRCP abuts underbridges, anchorages only were used; as a result the 210 mm thick slab with the fabric reinforcement has anchorages at either end. All the other CRCP sections have an anchorage at one end and a wide-flange beam joint (Burdell type) at the other. The design details of the anchorages and the wide-flange beam joint are shown in Figures 3 and 4 respectively. Each anchorage is associated with three short slabs (up to 12m long) containing two normal expansion joints and each wide-flange beam joint is associated with four short slabs containing three normal expansion joints.

3.3.3 Hardshoulder: The hardshoulder was designed in concrete, thus anticipating the requirements of the current specification[13]. The thickness of the hardshoulder was to be the same as that of the adjoining carriageway. Two alternative designs were offered in the contract. These were:—

(1) The hardshoulder to be of the same type of construction as the adjoining carriageway (ie either CRCP, jointed unreinforced concrete or jointed reinforced construction), or

(2) The hardshoulder to be of unreinforced construction throughout with transverse contraction joints or expansion joints, where these occurred in the carriageway; the joints were to be spaced appropriately for the type of aggregate used in the concrete. Where this type of hardshoulder abutted CRCP in the carriageway it was to be tied only over the middle third of the individual hardshoulder slabs.

These alternatives allowed for construction either as the complete three-lane width carriageway, with an added hardshoulder, or as two passes each of two-lane width; the successful contractor paved by the former method and elected to construct the hardshoulder in unreinforced construction.

## 4. SPECIFICATION AND CONTRACT

Design work on the contract started in 1976. The specification was therefore based on the Ministry of Transport Specification for Road and Bridgeworks (Fourth edition)[12], as amended by the then current Technical Memoranda. Special clauses relevant to the construction of CRCP were inserted.

Work commenced in November 1976. Adverse weather conditions delayed the work during the early stages of the 24-month contract and an extension of three months to the contract period was granted.

## 5. FUTURE WORK

Further reports will be prepared on the construction of the experiment and on its performance with the aim of developing design recommendations for CRCP in the United Kingdom.

## 6. ACKNOWLEDGEMENTS

The work described in this report was carried out in the Construction and Maintenance Division (Division Head: Mr P D Thompson) of the Highways Department of TRRL.

The whole-hearted cooperation of the staff of the West Yorkshire Metropolitan County Council Sub-Unit (Chief Engineer: Mr J A Gaffney) and the North Eastern Road Construction Unit (Director: Mr K C Westhorp) is gratefully acknowledged.

## 7. REFERENCES

1. NOWAK, J R. The full-scale reinforced concrete experiment on the Grantham By-pass. Performance during the first six years. *Ministry of Transport, RRL Report* LR 345. Crowthorne, 1970 (Road Research Laboratory).

2. GREGORY, J M, A E BURKS and V A PINK. Continuously reinforced concrete pavements: a report of the study group. *Department of the Environment, TRRL Report* LR 612. Crowthorne, 1974 (Transport and Road Research Laboratory).

3. WALKER, M J. CRCP takes a fast train down the M62. *New civ. eng.*, Aug 21–28, 1975.

4. ROAD RESEARCH LABORATORY. A guide to the structural design of pavements for new roads. *Department of the Environment, Road Note* No. 29. London, 1970 (H M Stationery Office).

5. DEPARTMENT OF TRANSPORT. Notes for guidance on the specification for road and bridge works. London, 1976 (H M Stationery Office).

6. L'ADMINISTRATION DES ROUTES, LE CENTRE DE RECHERCHES METALLURGIQUES and LE CENTRE NATIONAL DE RECHERCHES SCIENTIFIQUES ET TECHNIQUES POUR L'INDUSTRIE CIMENTIERE. Continuously reinforced concrete roads (La route en béton armé continu) Vade-Mecum. Administration des Routes, Brussels, 1972.

7. VETTER, C P. Stresses in reinforced concrete due to volume changes. *Transactions Am. Soc. Civ. Engineers* (98), 1039–80. 1933.

8. FRIBERG, B F. Frictional restraint under concrete pavements and restraint stresses in long reinforced slabs. *Proc. Highway Research Board* 33. 167–182 Washington DC, 1954.

9. BRITISH STANDARDS INSTITUTION. Hot rolled steel bars for the reinforcement of concrete. *British Standard* 4449: 1969. London, 1969 (British Standards Institution).

10. BRITISH STANDARDS INSTITUTION. Cold worked steel bars for the reinforcement of concrete. *British Standard* 4461: 1969. London, 1969 (British Standards Institution).

11. HIGHWAY RESEARCH BOARD. Continuously reinforced concrete pavement. *National Cooperative Highway Research Programme Synthesis of Highway Practice* 16. Washington DC, 1973 (Highway Research Board).

12. MINISTRY OF TRANSPORT. Specification for road and bridge works. Fourth edition. London, 1969 (H M Stationery Office).

13. DEPARTMENT OF TRANSPORT. Specification for road and bridge works. Fifth edition. London, 1976 (H M Stationery Office).

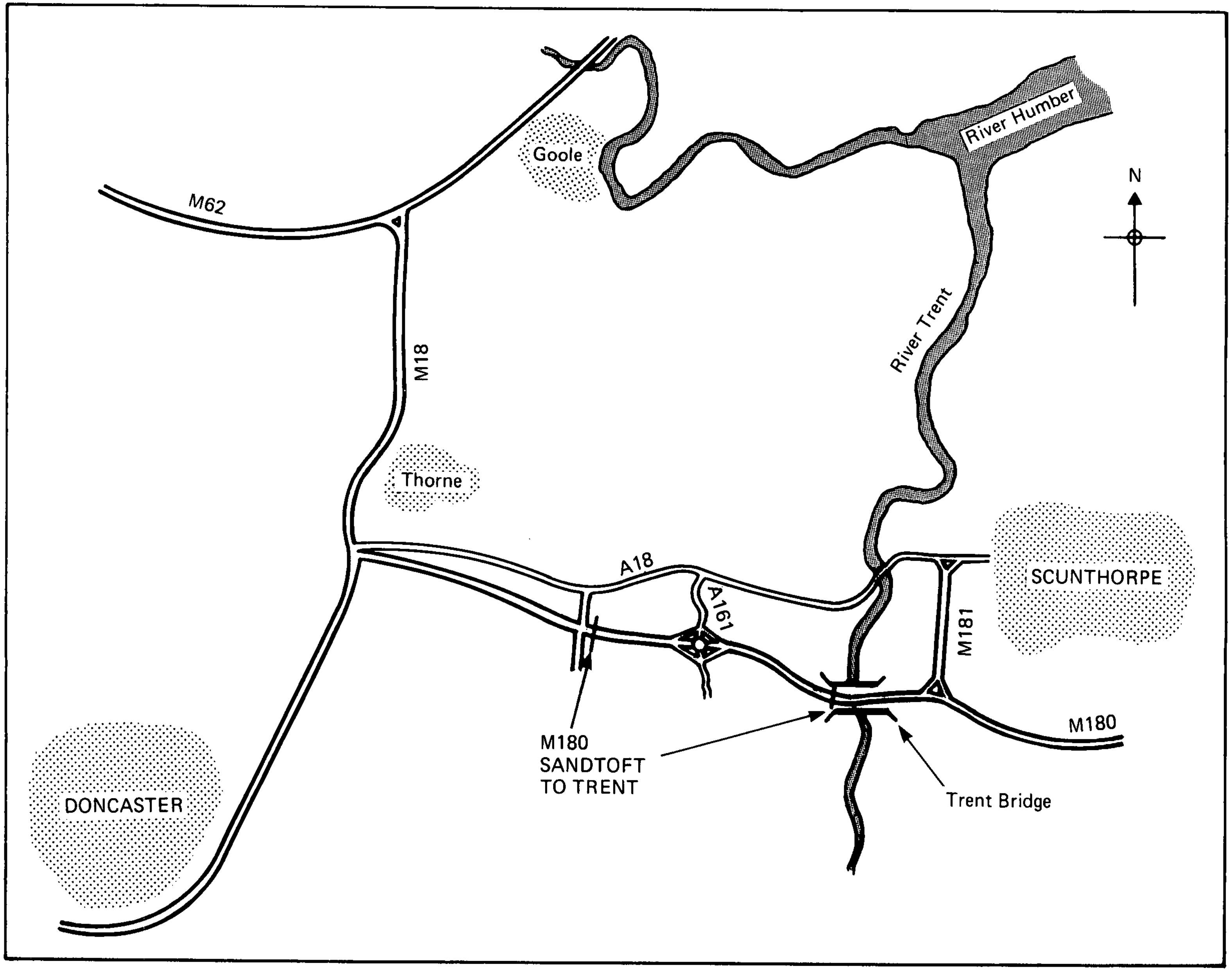


Fig. 1 Location of experimental site

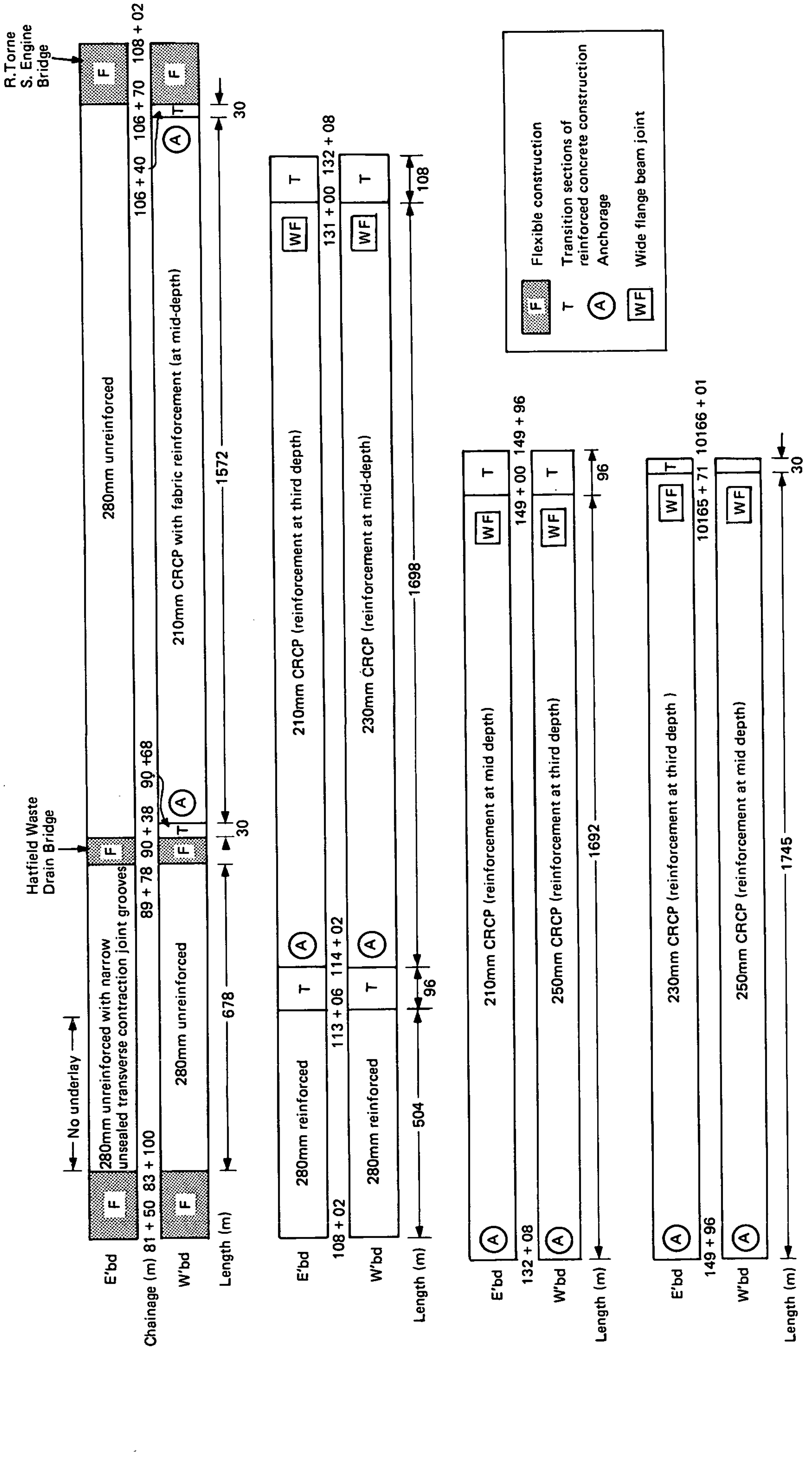
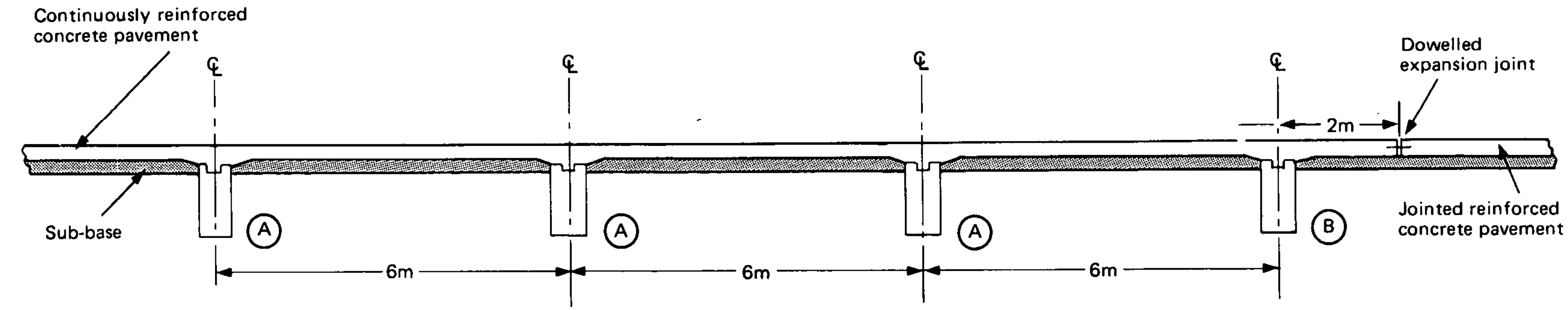
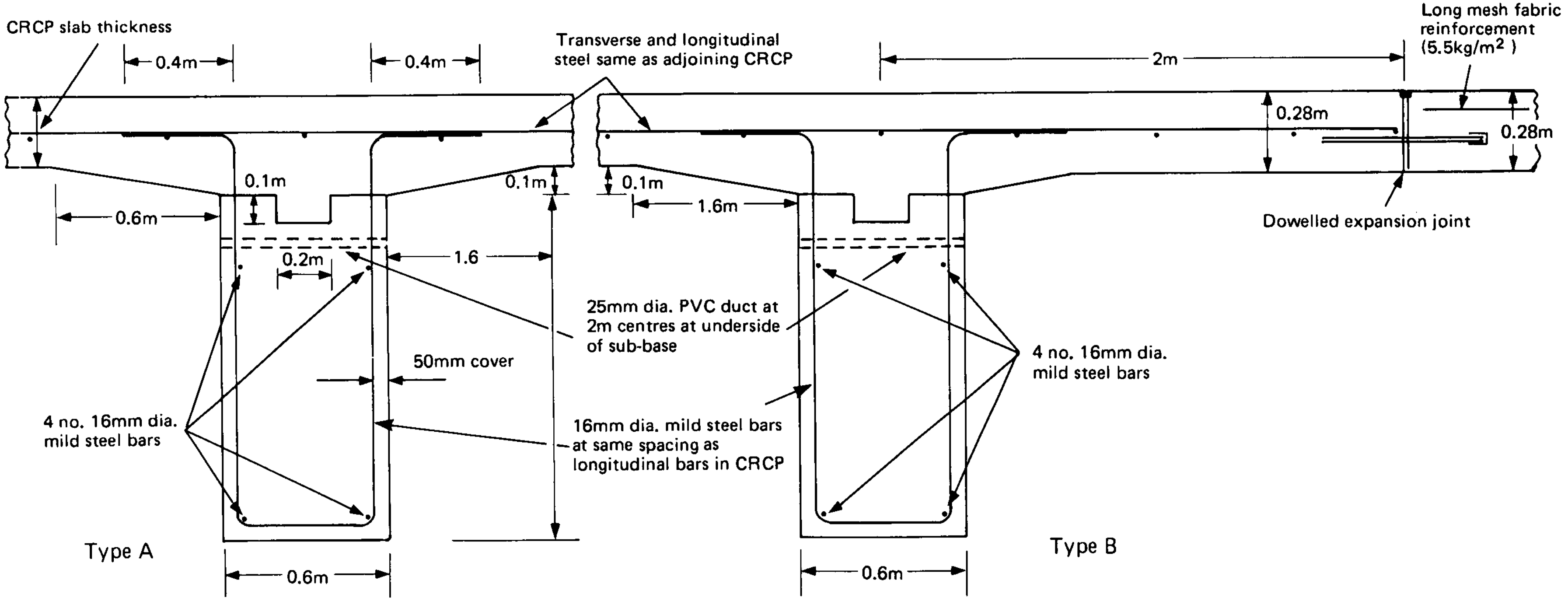


**Fig. 2 Layout of experimental sections**

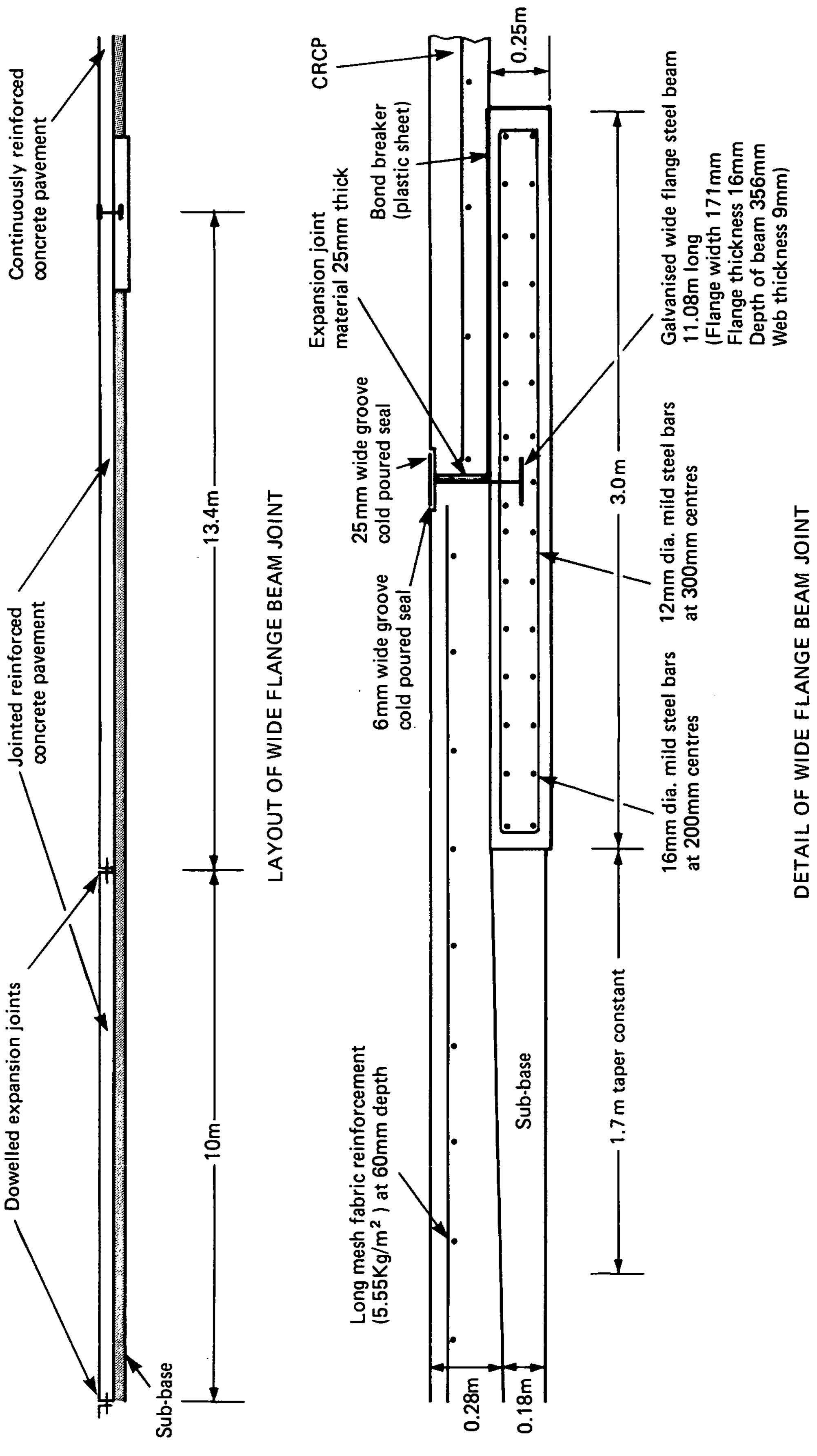


LAYOUT OF ANCHORAGE



DETAILS OF ANCHORAGE BEAMS

Fig. 3 Layout and detail of anchorage



LAYOUT OF WIDE FLANGE BEAM JOINT

DETAIL OF WIDE FLANGE BEAM JOINT

**Fig. 4 Layout and detail of wide flange beam joint**

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