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Assessing Alternative Details in Beam/Column Connections

Evaluation des détails constructifs d'assemblages poutres-colonnes

Bewertung verschiedener bewehrter Rahmenknoten

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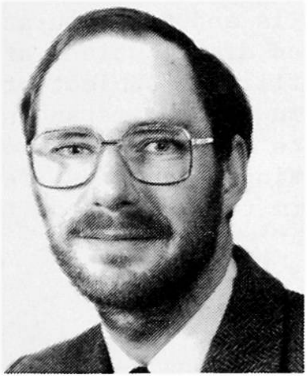

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SUMMARY

Test on three reinforced concrete beam/column connection specimens are described, each having a different reinforcement layout. Reinforcement strain distributions were measured by internally strain gauging the reinforcement; electric resistance strain gauges were installed in each specimen. The effects of the detailing arrangements on the overall structural behaviour are discussed, and an indication given of future tests in the programme.

RÉSUMÉ

Des essais ont été réalisés sur trois assemblages poutres-colonnes en béton armé, chacun ayant un renforcement de configuration différente. On a mesuré la répartition des tensions dans le renforcement en y introduisant des indicateurs de tension à résistance électrique. On discute les effets de la configuration des détails sur le fonctionnement de la structure en général et l'on esquisse les grandes lignes des essais envisagés pour la suite du programme.

ZUSAMMENFASSUNG

Es werden Tests mit drei verschiedenen Rahmenknoten beschrieben, jede mit einer anderen Bewehrungsführung. Die Verteilung der Bewehrungsspannungen wurde mit Dehnmessstreifen bestimmt. Bis zu 230 Dehnmessstreifen wurden in die Knoten einbetoniert. Die Wirkung der jeweiligen Anordnung auf das verhalten der Gesamtstruktur wird diskutiert und es wird auch auf zukünftige Tests in diesem Programm hingewiesen.

1. INTRODUCTION

The connections between beams and columns are often the most critical sections in a reinforced concrete structure. The connection zones are in a state of multi-axial stress due to the combined actions of axial load, bending moment and shear forces, and these effects can be particularly severe in the case of an external connection where the beam is present on one side of the joint only. It is well known that the reinforcement detailing in the connection zone has a profound effect on the joint behaviour; typically in external connections the beam tensile rods are bent either up or down into the column, or bent into a 'U' to form the beam compression reinforcement. Tests have been conducted in many countries to assess these details and to formulate guidelines for good detailing practice. However, the detailed distributions of strain along the reinforcement in the connection zone are still the subject of some speculation and here a significant area of ignorance in the understanding of connection behaviour still exists. The authors decided to address this problem by conducting a series of tests in the laboratory using specimens reinforced with strain gauged reinforcement. These tests form the subject of this paper.

2. SPECIMEN DETAILS AND TEST PROCEDURE

Three external beam/column connections have been tested to date. Each had a beam 850 mm long framing at mid-height into one side of a column 1700 mm high. The column cross-sections were all 150 mm × 150 mm and the beams 210 mm deep and 110 mm wide. Both the beam and the column were loaded, the former downwards at a point 100 mm from the free end; the tension steel was thus at the top of the beam's cross-section. The columns were each reinforced with four 16 mm diameter high yield rods (Torbar) and 6 mm diameter mild steel links at 150 mm centres; this included a link at the mid-height of the beam. The beams were reinforced with a pair of 12 mm diameter high yield rods top and bottom with 6 mm diameter mild steel links at 100 mm centres. In the connection zone the beam reinforcement fitted between the column reinforcement, but the two sets of rods touched where they became adjacent. The rods on one side of the specimen were specially machined to permit the installation of electric resistance strain gauges (gauge length 3 mm) for strain measurement. Three different detailing arrangements were studied. With Specimen 1, the beam tension reinforcement was bent down into the column, with Specimen 2 it was bent up into the column, and with Specimen 3 it was bent into a 'U' to form the beam compression reinforcement; with specimens 1 and 2 straight rods were used for the beam compression reinforcement.

The strain gauges were mounted in a duct 4 mm wide × 4 mm deep running longitudinally through the centre of the reinforcement, as described in reference 1. Up to 230 strain gauges were installed in the beam and column reinforcement, including the bent beam rods (which were machined after bending). The gauging layouts were designed to give both an overall picture of the specimen's behaviour plus very detailed information in the connection zone itself; the minimum gauge spacing was 12.5 mm.

The column was loaded first to 275 kN in increments of 25 kN. This produced a compressive strain of around 500 microstrain in the column reinforcement which was considered to be a typical working load situation. The column load was then held whilst the beam was loaded in 1 kN increments until failure occurred. At each load stage a full set of strain gauge readings was recorded using a computer controlled data acquisition system. This also logged the applied loads, column shear forces and the load carried by a prop provided at the beam end to control sidesway. Where possible, increments of deflection were applied to the beam after joint failure had occurred.

3. RESULTS

The strain distributions along the beam tension reinforcement are shown in Figures 1, 2 and 3 for specimens 1, 2 and 3 respectively. The rods have been "straightened" for ease of interpretation with a key being provided with each figure to show its context within the specimen. The loads indicated are those applied to the beam; the column load is always 275 kN.

Loading the column to 275 kN produced compressive strains of about 500 microstrain both in the column reinforcement and in the vertical leg of the beam tension reinforcement, including the 'U' bar of specimen 3. The Poisson ratio effect caused by the column shortening led to small tensile strains being recorded in the bottom beam rods where they crossed the connection zone. Loading the beam soon eliminated these and caused a steady increase in tension of the top beam reinforcement and compression in the bottom beam reinforcement in all three specimens. The distribution of tension in the top beam reinforcement exhibited a series of peaks as cracks developed in the beam. A progressive movement into the connection zone of the point of zero strain was observed at each load stage as an increasing length of the top beam rod became tensile.

Diagonal cracking in the connection zone was first apparent at loads of 17.1, 18.9 and 19.9 kN for the three specimens respectively, at which time maximum strains in the beam tension rods, at the face of the column, were 1891, 2547 and 2442 microstrain. In specimens 1 and 2 the top beam rods were now in tension throughout the connection zone, whilst with specimen 3 tension had penetrated around both bends of the 'U' bar.

Up to this point in the tests - the onset of diagonal cracking - the behaviour of the three specimens had been broadly similar. However, marked differences were observed as the beam loads were increased further. With specimen 1, the effect was to cause an increasing length of the vertical leg of the top beam rod to become tensile at each load stage until, when failure occurred at 26.2 kN there were no compressive strains in the rod at all, even though its vertical leg abutted a column rod which was always in compression. This detail allowed the full moment of resistance of the beam to be developed and peak tensile strains at the column face were in excess of 20,000 microstrain; the reinforcement was either at, or near to, its yield stress well into the connection zone.

Specimen 2 was more brittle as it failed at 21.5 kN, only 2.6 kN above the load for the first diagonal crack. Failure was characterised by a sudden propogation of the tension zone along the vertical leg of the top beam rod when a vertical crack formed along the line of the adjacent column rod. The maximum strain was 5782 microstrain but there was little plasticity in the connection zone.

Specimen 3 exhibited behaviour similar to specimen 1 in that the advance of tension around the 'U' bar was progressive as the load was increased. Failure was at 25.9 kN, by which time the tension zone had extended back out into the bottom of the beam. The beam was able to develop its full moment of resistance but there was less ductility than with specimen 1 as the strains in the connection zone were lower. A small peak was discerned in the strains at the point where the rod re-entered the beam, believed to be caused by the effects of the diagonal cracking. A similar, but rather more marked, effect had previously been observed in the bottom beam rods of specimens 1 and 2, the strain distributions for the latter being shown in Figure 4. Peak tensile strains of 168 and 1207 microstrain were recorded for these two specimens respectively; with specimen 2, near to the column, both the top and the bottom rods in the beam were in tension at the end of the test.

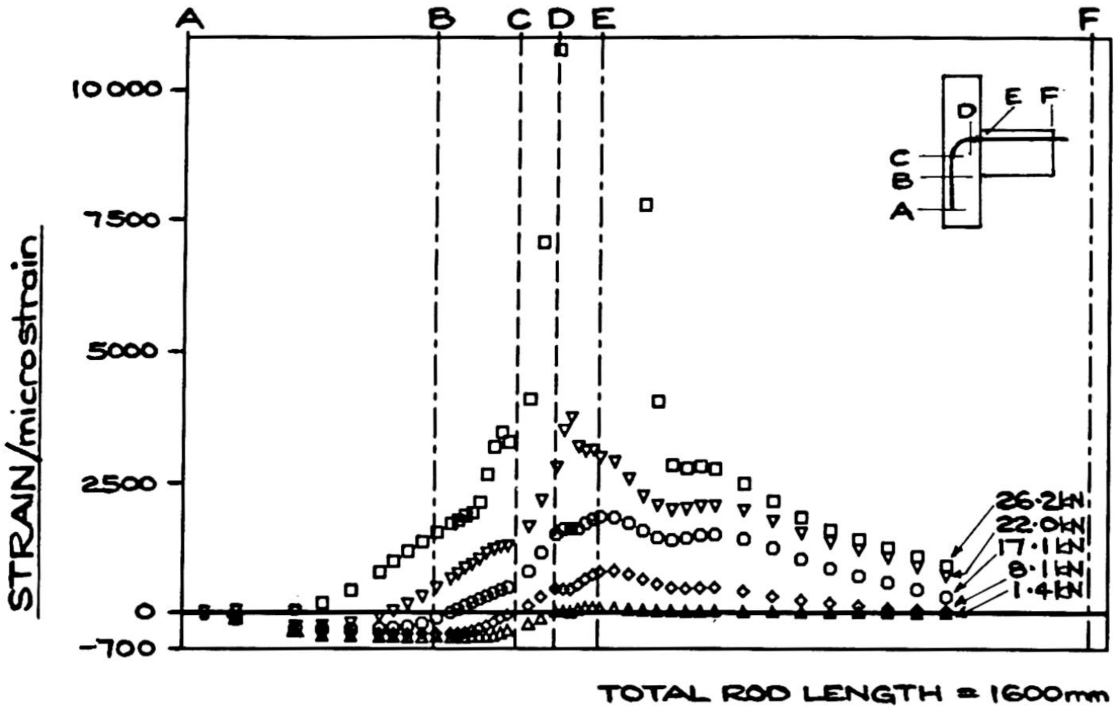

Fig.1: SPECIMEN 1 – TOP BEAM ROD

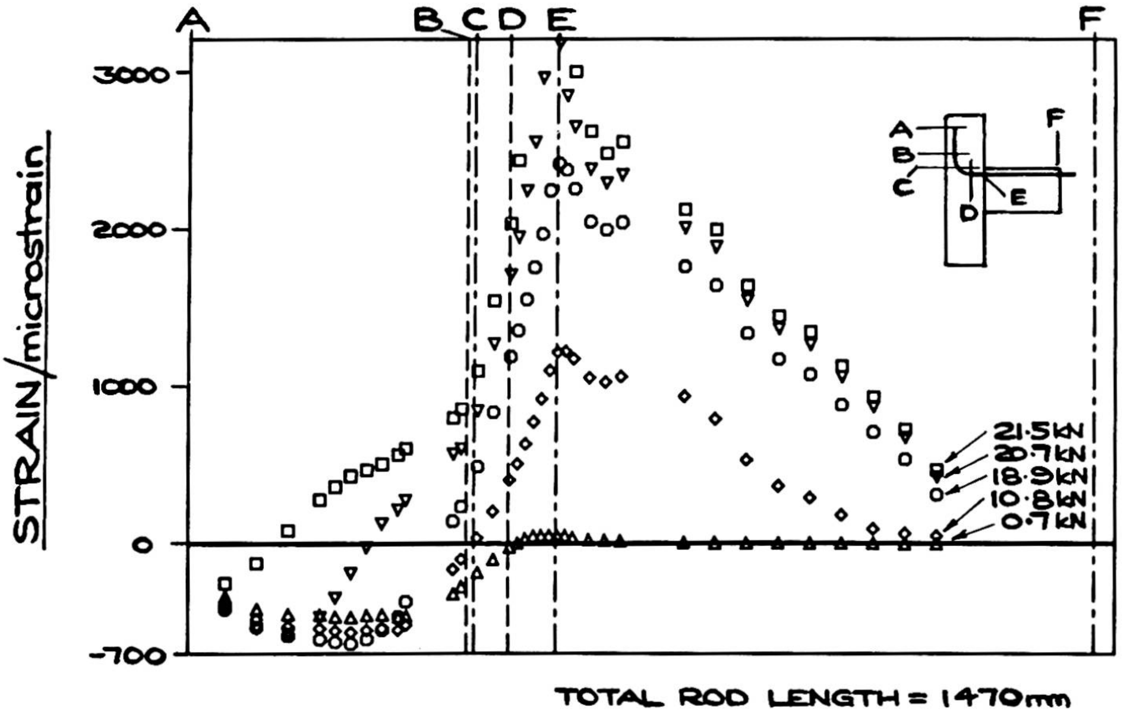

Fig2: SPECIMEN 2 – TOP BEAM ROD

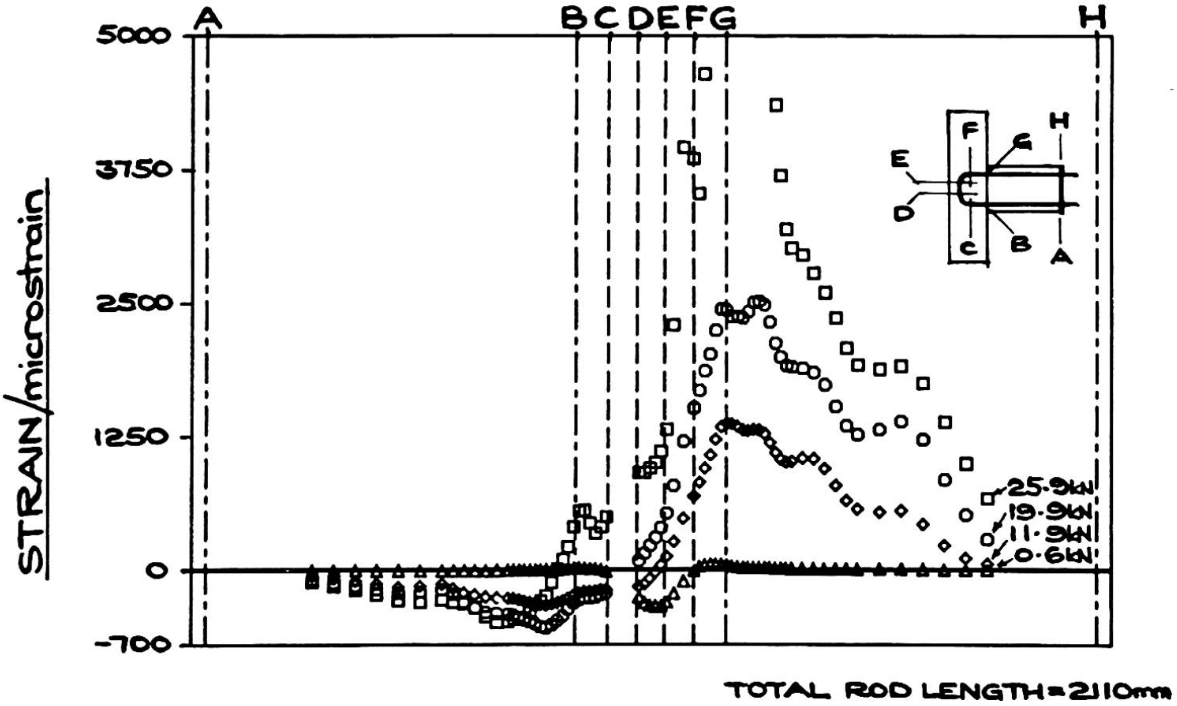

Fig3: SPECIMEN 3 – 'U'-BAR

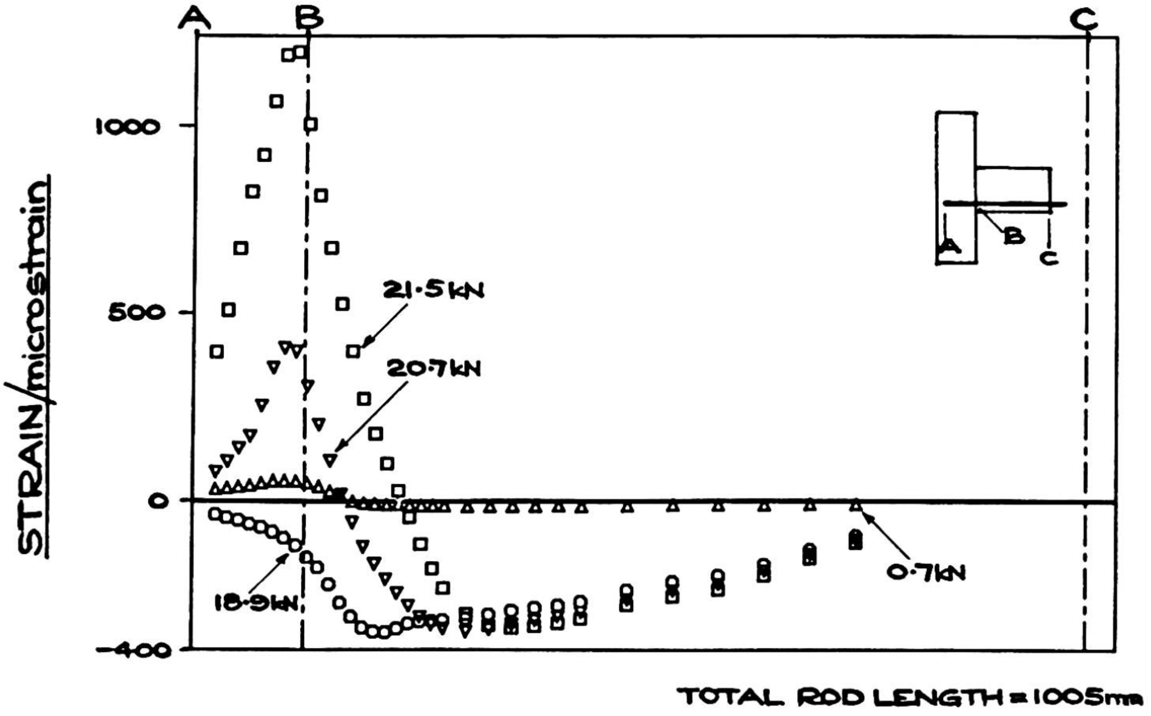

Fig4: SPECIMEN 2 – BOTTOM BEAM ROD

4. DESIGN IMPLICATIONS

Some preliminary implications regarding overall structural behaviour may be drawn from these tests. The detailing system of specimen 1 - beam reinforcement bent down into the column - is capable of developing considerable ductility and thus would permit a considerable redistribution of moments throughout a structure at the ultimate limit state. However, as the beam tension steel is at or near to its yield stress throughout much of the connection zone under these conditions, then consideration should be given to increasing its anchorage length in the column since bond stresses in the connection zone will be very low. The 'U' bar detail of specimen 3 also performed well but was rather less ductile than specimen 1, whilst the marked lack of ductility in specimen 2 - beam reinforcement bent up into the column - would be a severe hindrance should moment redistribution be found necessary due, say, to an accidental overload. The presence of surprisingly large tensile strains in the bottom beam reinforcement suggests that the column link in the connection zone may be quite highly stressed under ultimate conditions and so have an important role in tying the connection zone together.

5. FURTHER WORK

This paper has described the first phase of a comprehensive programme of tests. Currently, an examination of the effects of a higher reinforcement percentage is in progress by using two 16 mm diameter rods for the beam tension steel. Further tests will induce more bending in the column by using a lower column load, and an attempt will be made to measure directly the strains in the beam and column links. Associated with the experimental work is a comprehensive programme of data analysis using purpose-written inter-active colour graphics software.

6. CONCLUSIONS

A detailed picture of the reinforcement strain distributions in three reinforced concrete beam/column connections has been established using internally strain gauged reinforcement. The style of the reinforcement detailing had a profound effect on the behaviour of the specimen by controlling the degree to which ductility could be developed in the connection; this has implications for the redistribution of moments around a structure at the ultimate limit state. Consideration should be given to increasing anchorage lengths in some instances.

7. ACKNOWLEDGEMENTS

The technical support of Mr. S.P. Wilkinson and the financial support of the Science and Engineering Research Council are both gratefully acknowledged.

8. REFERENCE

1. SCOTT R.H. and GILL P.A.T., Short-Term Distributions of Strain and Bond Stress Along Tension Reinforcement. The Structural Engineer, Vol. 65B, No. 2, June 1987, pp. 39-43.