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Reinforcement Strains in Reinforced Concrete Tension Members

Allongement de l'acier d'armature dans des tirants

Stahldehnungen in Zuggliedern aus Stahlbeton

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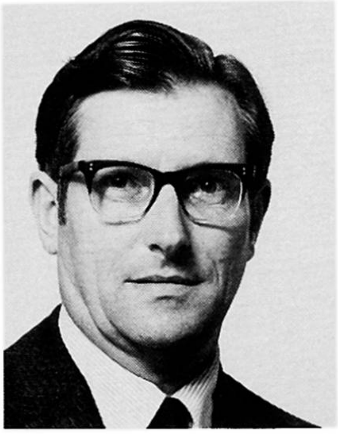

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SUMMARY
This paper describes the technique which has been developed to measure longitudinal reinforcement strains in reinforced concrete tension members. A programme of short-term tests has been completed to date. The testing procedure is described and preliminary results presented.

RESUME
Cette contribution décrit les techniques développées pour mesurer les allongements relatifs de l'acier d'armature dans des tirants en béton armé. Un programme d'essais de courte durée a été réalisé. Le procédé d'essais et les premiers résultats sont présentés.

ZUSAMMENFASSUNG
Der Beitrag beschreibt eine eigensentwickelte Technik der Dehnungsmessung in der Längsbewehrung von Zuggliedern aus Stahlbeton. Eine Serie von Kurzzeitversuchen ist bis heute durchgeführt worden. Die Versuchsdurchführung wird beschrieben und die ersten Ergebnisse werden vorgestellt.

1. INTRODUCTION

Calculation of the deflection of reinforced concrete structures requires an accurate assessment of the stiffnesses of the constituent members. With beams, in particular this is influenced considerably by the behaviour of the concrete in tension below the neutral axis.

Previous experimental work in this field has involved surface strain measurements on beams or tension specimens tested in the laboratory. The authors believed that useful further advances would result from a detailed study of the reinforcement strains themselves, particularly as modern strain measuring technology and data acquisition systems would permit this to be undertaken in a far more detailed manner than had been attempted previously [1, 2].

This is being achieved through a series of tests on tension specimens using internally strain-gauged reinforcing rods. Three series of tests are being undertaken covering short-term incremental, long-term sustained and long-term cyclic loadings. The short-term testing programme is now complete and long-term sustained load tests are currently in progress. Cyclic loading tests will commence later this year.

This paper describes the strain-gauging technique which has been developed to measure the longitudinal reinforcement strains. Details of the testing procedure and preliminary results for the short-term tests are presented.

2. MEASUREMENT OF LONGITUDINAL REINFORCEMENT STRAINS

A prime consideration when selecting a technique for measuring reinforcement strains is to avoid altering the bond characteristic through degradation of the steel/concrete interface. This effectively precludes bonding electric resistance strain gauges to the surface of the rod since the gauges and their associated lead wires disturb the stress fields around the reinforcement and the concrete. Consequently a solution was sought which would involve mounting strain gauges inside the reinforcement and thus leave the interface undisturbed.

The technique which was tried out and subsequently adopted involved milling two reinforcing rods down to a half round and then machining a longitudinal groove in each to accommodate the strain gauges and their wiring. After installation of the gauges the two halves were then glued together so that outwardly they had the appearance of a normal reinforcing rod, but with the lead wires coming out at the ends.

Early results using comparatively short rods were extremely promising [3] and have led to the development of the technique to the stage where eighty four strain gauges, each connected with three lead wires, can be installed in a 5 mm x 5 mm duct inside a rod 2.6 m long.

The space available in the duct is severely limited and has necessitated using very small diameter lead wires. A two wire, common dummy, installation was tried at first but gave problems with stability since the small lead wires were necessarily about four metres long. This was largely cured by changing to a three wire, common dummy situation, despite requiring even smaller lead wires.

3. DATA COLLECTION

An automated data collection system was obviously essential in order to handle the large quantities of data that the tests would generate. The chosen system, which has been described in detail elsewhere [4, 5] consists of two units; a data logger and a supervising microcomputer.

The logger handles 208 input channels using constant current energisation which is switched to each channel in turn by reed-relay scanners.

The microcomputer controls the logger using purpose-written interfacing software and handles data storage on twin floppy disks. Software data transfer to a mainframe computer is also available which makes the power of a large machine available for subsequent data analysis.

4. SPECIMEN DETAILS

The twelve specimens for the short-term tests were all 1500 mm long with cross-sections ranging from 70 x 70 mm up to 200 x 200 mm. They were reinforced with either 12 mm or 20 mm diameter strain gauged rods, positioned centrally. Both plain mild steel and ribbed high yield steel reinforcement was used. Details of the specimens are given in Table 1.

A number of different strain gauge layouts were tried with the early specimens but eventually a standard layout having 80 gauges each of 3 mm gauge length, spaced at 12.5 mm intervals along alternate halves of the central metre of each rod was adopted.

All specimens carried sets of Demec gauge points (200 mm gauge length) to allow measurement of average surface strains. Some specimens also contained embedment strain gauges (12 mm gauge length, overall size 30 mm x 9 mm x 2.5 mm). These were always restricted to one half of the specimens as it was considered that they might act as crack inducers. Depending on the specimen cross-section one, two or three rows of embedment gauges have been used to investigate the strain gradients from the reinforcing rod to the surface of the concrete.

Concrete for the specimens had a maximum aggregate size of 10 mm (determined by the spacing of the embedment gauges), a water:cement ratio of 0.6 and an aggregate:cement ratio of 5.5. Test cubes and cylinders were cast along with each specimen for determination of compressive strength and indirect tensile strength respectively.

Before concreting the rods were mounted in the test rig and load cycled in order to check fully the installation, and minimise any hysteresis. The results from this procedure were also used to calculate a Young's modulus value for each rod.

5. TESTING EQUIPMENT AND PROCEDURES

The short-term tests were conducted in a purpose-built test rig and were each completed within one day. A manual hydraulic loading system was employed with the jack being located at the bottom of the specimen. Loading was measured by a flat load cell at the top of the specimen and displayed on a meter giving a direct digital read-out. The voltage output from the load cell was also connected directly into the data logger via an output from the meter.

The specimens were loaded incrementally with the increment sizes adjusted as the tests proceeded to reflect the rates at which changes were occurring within the specimen. In particular very detailed information was sought immediately before and after the formation of cracks and this often demanded load increments as fine as 0.5 kN.

The applied load and a full set of strain gauge readings were read and stored at every load stage. Time constraints precluded Demec readings being taken at all load stages, so a selective procedure was adopted with emphasis being given to the period during which the cracks formed. Crack widths were measured, when appropriate, at the same time as the Demecs, using an Ultra-Lomara 250 b microscope.

Loading of the specimens was halted when the reinforcement had fully yielded. With mild steel rods this often resulted in very high strain readings.

Cross-Section (mm x mm)	Bar Type & Dia (mm) R-Mild T-Torbar	% Reinforcement	Embedment Gauges Yes/No	Age At Test (days)	Cube Strength At Test (N/mm^2)	Indirect Tensile Strength At Test (N/mm^2)	No. of Cracks	Applied Load At First Crack (kN)	Reinforcement Strain At First Crack (microstrain)	Applied Load At Last Crack (kN)	Reinforcement Strain At Last Crack (microstrain)
70 x 70*	R12	1.80	No	28	45.5	3.1	5	12.0	134	15.5	161
70 x 70	R12	1.80	No	29	46.7	2.8	5	12.0	85	14.5	117
70 x 70	T12	1.80	No	28	47.3	3.0	8	12.5	120	18.5	177
100 x 100	R12	0.88	No	29	41.5	3.0	3	20.0	109	28.0	171
100 x 100	T12	0.88	Yes	29	45.0	2.7	4	18.0	98	30.0	162
100 x 100	R20	2.65	No	28	38.7	2.8	4	25.0	80	45.0	375
100 x 100	T20	2.65	Yes	28	46.7	3.1	7	12.5	52	40.0	281
140 x 140	T12	0.45	No	28	54.0	3.1	2	47.5	99	47.5	99
140 x 140	R20	1.35	No	29	42.0	3.1	2	47.5	165	55.0	223
140 x 140	T20	1.35	Yes	28	54.7	2.8	4	35.0	103	80.0	568
200 x 200	T20	0.66	Yes	28	60.3	3.1	1	65.0	83	-	-

* No gross yield of reinforcement

Table 1: Specimen Details and Test Results

Two tests had to be repeated. In the case of a 100 mm x 100 mm specimen having a 12 mm diameter high yield rod this was due to strain gauge stability problems and failure of the load measuring instrumentation during the test. It does not appear in Table 1. The 70 mm x 70 mm specimen having a 12 mm diameter mild steel rod was repeated because the expected gross yield of the reinforcement was not observed. Subsequent hardness measurements revealed that the rod was unusually hard, thus having an atypically high yield strength.

6. RESULTS

Results for the short-term specimens are summarized in Table 1.

The cracks generally formed on the cast face of the specimens possibly due to the concrete being less completely compacted adjacent to the free surface and so having a lower Young's modulus. Once formed they usually extend around three faces of the specimen with compressive strains being recorded on the back face. Only occasionally would a crack propogate right round the specimen, and then usually only at high load levels.

More cracks formed in specimens reinforced with Torbar than in those reinforced with the plain mild steel rods, all other things being equal. Typical longitudinal strain distributions for R12 and T12 100 mm x 100 mm specimens are shown in Figures 1 and 2 and it can be seen that the changing strain profiles as the cracks developed have been clearly recorded.

Often quite considerable bending was recorded at the cracks, but away from the cracks the strain distributions were remarkably linear indicating near constant bond stresses along the specimens. These were higher in the case of the Torbar specimens, as would be expected.

It was common for peak reinforcement strains at the cracks to be higher than the rod strains outside the concrete, due to bending initiated by the cracking, and consequently gross yield in the mild steel rods always occured at a crack. There is some evidence to suggest that slipping between the reinforcement and the concrete, again at the cracks, was occurring with the mild steel rods but not with the Torbar. Debonding at the ends of the specimens was also observed when it extended into the strain-gauged section of the rods.

Reinforcement strains just prior to the formation of the final cracks could be surprisingly high (see Table 1), while in contrast there were strong indications that with specimens containing embedment gauges the first cracks formed at strains which were atypically low. With these specimens the first crack always formed in the region of an embedment gauge.

However, the embedment gauges have yielded useful information regarding strain profiles across the concrete and are giving an interesting indication of how load is shared between the reinforcement and the concrete particularly prior to cracking.

The above observations are based on an initial assessment of the large amount of numerical data generated by an investigation of this type. Much more detailed discussion will be possible when the data has been fully analysed using computer software which is currently being developed.

7. CONCLUSIONS

The technique of internally strain gauging reinforcing rods has been developed to the stage where reliable detailed strain distributions can be obtained, even over long time periods.

The programme of tests already completed is enabling an improved understanding of tension stiffening and bond behaviour to be obtained for short-term loading

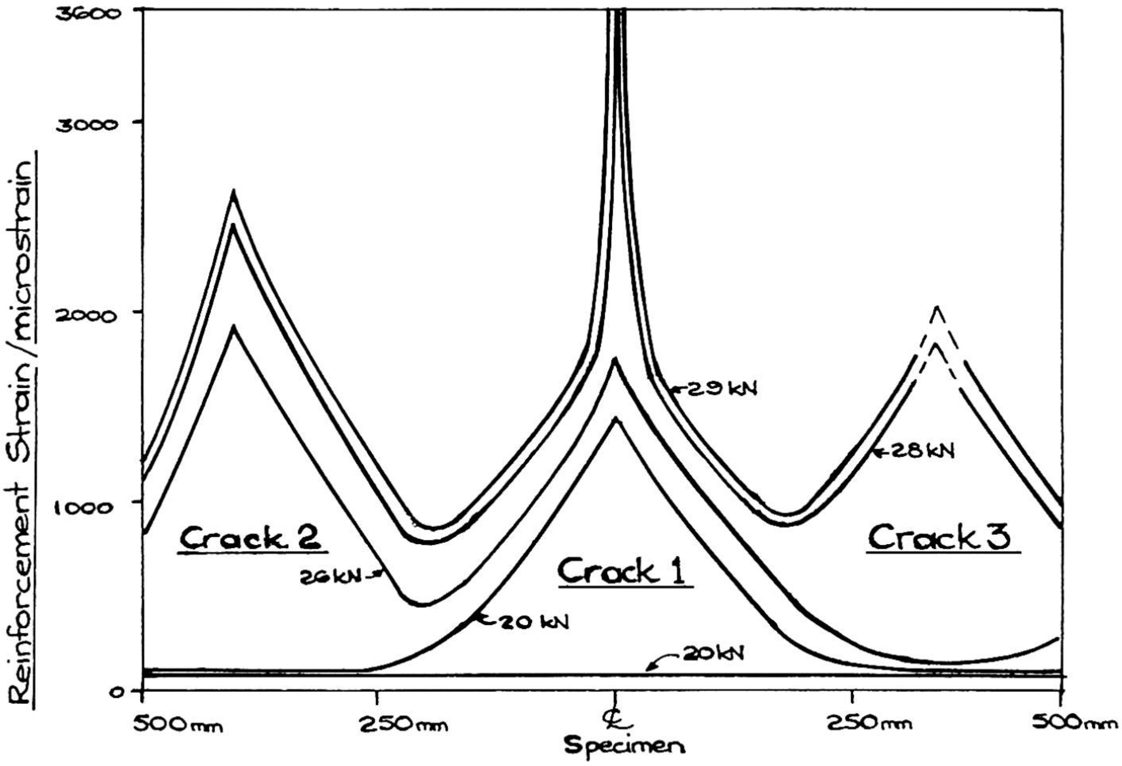

Fig 1: STRAIN DISTRIBUTIONS FOR R12 100x100x1500 mm

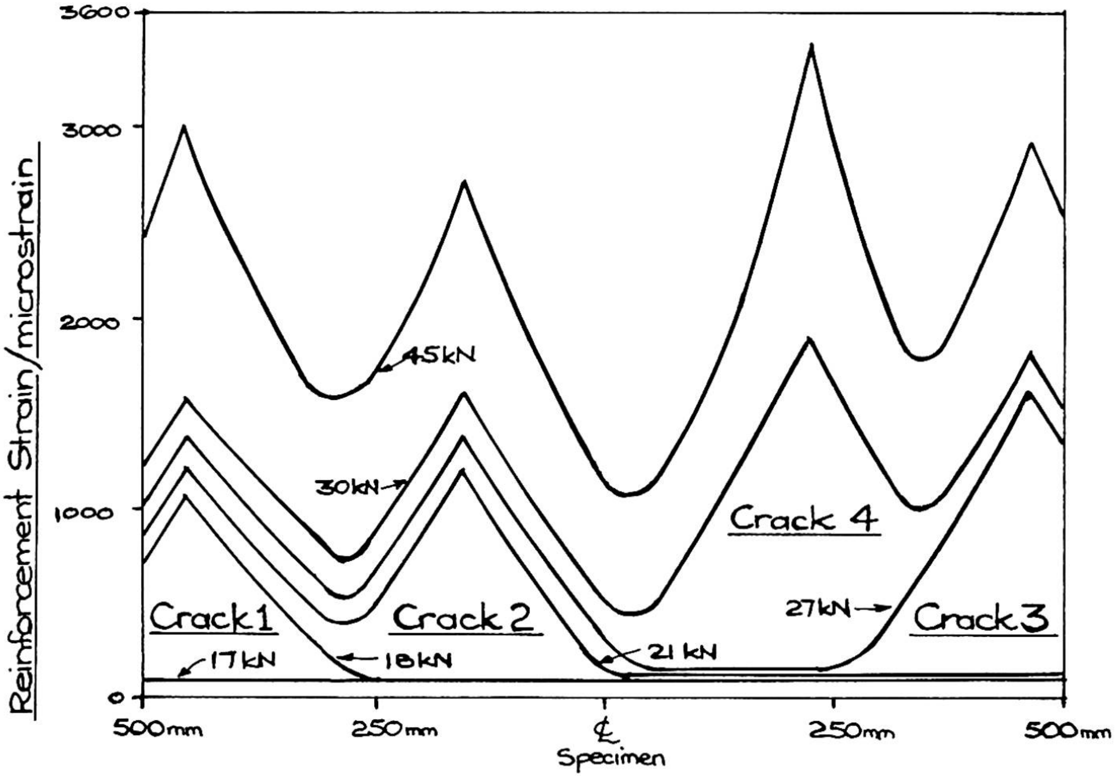

Fig2: STRAIN DISTRIBUTIONS FOR T12 100x100x 1500 mm

conditions, and long-term tests are currently in progress which are enabling time-dependent effects to be studied.

Results to date are most encouraging and a full programme of analysis is currently being undertaken.

8. ACKNOWLEDGEMENTS

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