AFDELINGEN FOR

BÆRENDE KONSTRUKTIONER

DANMARKS TEKNISKE HØJSKOLE

STRUCTURAL RESEARCH LABORATORY

TECHNICAL UNIVERSITY OF DENMARK

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EPOXY RESIN REPAIR OF CRACKED CONCRETE BEAMS

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EPOXY RESIN REPAIR OF CRACKED CONCRETE BEAMS

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CONTRIBUTION TO DISCUSSION

by

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EPOXY RESIN REPAIR OF CRACKED CONCRETE BEAMS

Severe shear cracks were observed in a number of reinforced concrete beams with circular web openings (Figure 1).

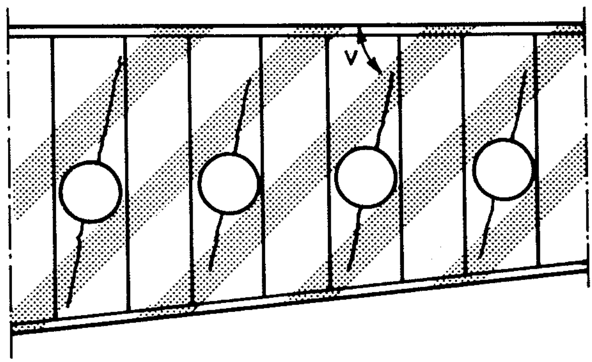

FIGURE 1

A structural analysis revealed that the shear reinforcement was inadequate and that strengthening was required. As there were about 900 damaged beams, careful planning of the repair was required. From a structural point of view a sound strengthening of the beams could be achieved by means of external post-tensioned stirrups, preferably placed in an inclined position. However, this solution was unattractive because the anchorages could hardly be placed invisibly in the ceilling.

Shear analysis on the Mörsch truss analogy indicated that with a 45° slope of the compressive concrete struts the existing shear reinforcement would be insufficient. This might have been overcome by adopting a smaller angle v (see Figure 1) between the compressive concrete struts and the top of the beam. However, the web openings prevented this possibility. As only very few of the web openings were actually used for their purpose - passage of pipes and other installations - it was possible to close most of the openings. If this were done simply by in-situ casting of concrete in the openings, this concrete would shrink , thus making the efficiency of the concrete plugs dubious. It was then suggested that precast concrete plugs be used and that they be allowed to shrink before being placed in the openings. A joint width of about 1 mm between web and plug was aimed at. This joint and the existing cracks could then be closed with a sealing agent on both sides of the web, and a two-component, low-viscosity epoxy resin could later be injected under high pressure whereby both the joint and the crack would be filled in one operation. Due to the magnitude of the repair job - comprising the closing of more than 3000 web openings - it was decided to test the efficiency of the proposed repair method. The experiments were carried out at the Structural Research Laboratory at the Technical University of Denmark.

From a structural point of view, the main requirement was that the web of the repaired beam should be able to transfer

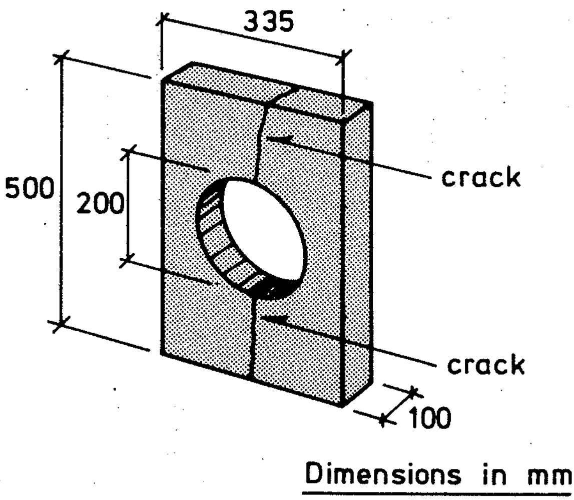

FIGURE 2

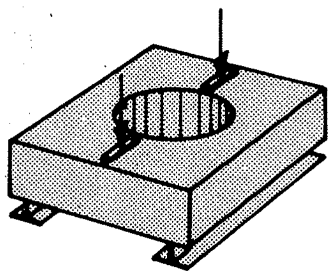

FIGURE 3

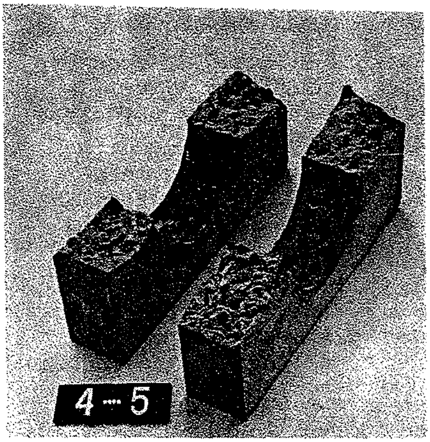

FIGURE 4

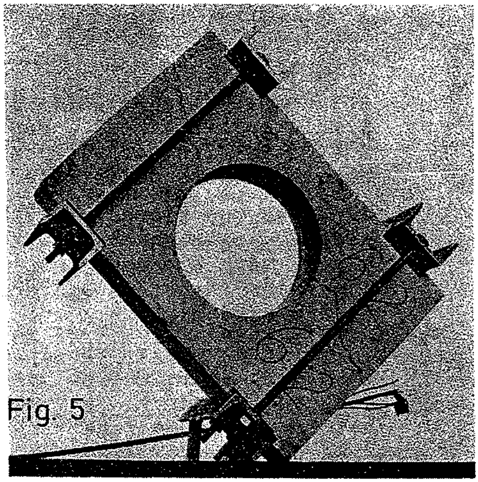

FIGURE 5

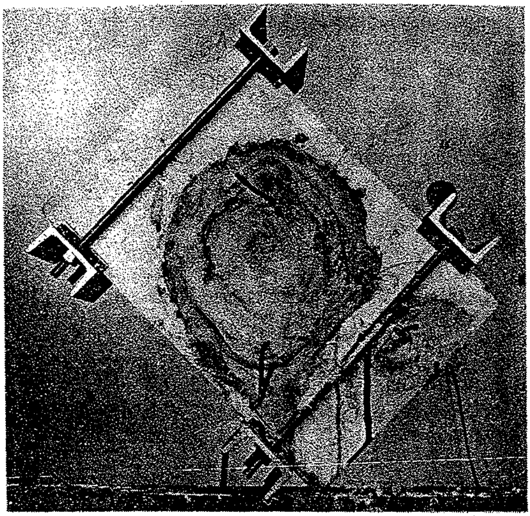

FIGURE 6

FIGURE 7

the compressive stresses in the concrete struts. In order to simulate this effect a number of specimens of the type illustrated in Figure 2 were cast. After hardening, the specimens were broken as illustrated in Figures 3 and 4.

The two pieces were then reassembled and placed in a sloping position as illustrated in Figure 5. A variation in crack width from zero to 1 mm was aimed at. In some of the specimens the crack width incrased downwards, and in others it incrased upwards.

For a repair job of this type the quality of the repair is highly dependent on both workmanship and details of the working procedure. For this reason it was decided to let three interested firms repair three specimens each.

One of the repaired specimens is illustrated in Figure 6. The firm repairing this specimen adopted a method in which the two components of epoxy resin were mixed in the nozzle, i.e. at the injection point.

In order to obtain a reference level, some of the specimens were not provided with a web opening. Other specimens with web opening were not broken and were tested without closing the web opening. Some specimens with web opening were broken and tested without being repaired. The specimens were tested in compression in the laboratory's hydraulic 2 MNMFL testing machine. The specimens were provided with electric resistance strain gauges in order to investigate how the repair influenced the non-uniformity of the strain distribution (see Figure 7).

The acoustic emission produced by the cracking and microcracking was registered by means of transducers fixed to the specimens, and the signals were plotted so that the cumulative acoustic emission up to the current load levels could be followed.

The results of the compressive tests are given in Table N° 1, where the strength of the specimens without web opening is adopted as reference level so that their average compression strength is taken as equal to 1,00.

There was no significant diference in the strength of the non-repaired specimens with web opening regardless whether they had been broken before the test or not. This is obviously because the unbroken specimens developed a central crack at a very low load level anyway. This is also apparent from the acoustic emission plots (see Figure 8).

Whereas the relative strength of the specimens repaired according to methods A and B was almost the same, the standard deviation of method A was so large that the characteristic strength according to the Danish Code of Practice - i.e. with a 10 % fractile and a 75 % confidence level - was negative (see Table 1). The characteristic strength is considered to be the best indication of the quality of the repair. There were significant differences between the strengths achieved with the three repair methods.

TABLE 1

Results of Compression tests

Specimen				Relative average compressive strength	Characteristic compressive strength
Without web opening				1.00	
With web opening	Uncracked, not repaired			0.30	
	Cracked	not repaired		0.32	
		Repair methods	A	0.62	< 0
			B	0.63	0.55
			C	1.29	1.05

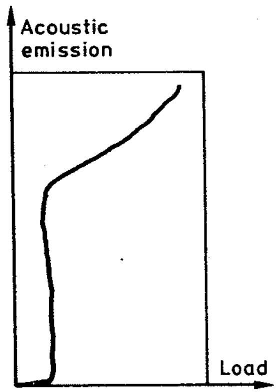

FIGURE 8

The strength of the specimens repaired according to method C is significantly higher than that of the specimens without web opening. This may be ascribed to two concurrent causes. One cause may be that the concrete plugs had a higher strength than the specimen and acted as transverse reinforcement. Another cause may be that the low-viscosity epoxy resin impregnated pores in the specimen in the vicinity of the crack and the joint and thus increased the strength of the specimen.

The latter explanation is supported by the fact that epoxy resin was observed to bleed out through small pores at some distance from the cracks. Similar cases, where the strength of broken and epoxy-repaired specimens was found to be higher than the strength of the specimens before the first rupture, have been found by other laboratories.

ACKNOWLEDGEMENTS

Dr. techn. H. Krenchel participated in the planning of the tests. Søren Traberg and Peter Mossing conducted the tests. The recording of the acoustic emission was carried out by Henrik Schmidt, who also developed the equipment used for this purpose.

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