COLOUMN-BEAM JOINTS FAILED UNDER SEISMIC LOADING, REPAIRED AND RE-TESTED UNDER SEISMIC LOADING

by

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SYNOPSIS

Half-scale coloumn-beam joints of several R.C. frames and one beam have been tested under static and, subsequently, under seismic loading, up to failure. The mechanical behaviour of these joints has been reported elsewhere. The same failed joints have been repaired by means of conventional techniques. The new loading of the frames followed almost the same procedure as their previous loading.
Stresses of constituent materials, both the new and the old ones, were continuously measured, by means of a Lightbeam Oscillograph. Several conlcusions practical and theoretical are drawn concerning the dynamic behaviour of these simply repaired elements.

1.-I n t r o d u c t i o n

Repair-work of simple poorly detailed R.C. structures after earthquakes is becoming an urgent social need, especially for remote areas where sophisticated technology is not available (like e.g. welding of new reinforcements and high-quality shotcreting). (1).

Thus, simpler techniques have been selected for the purposes of this paper in order to repair R.C. elements damaged (Fig. 1) after dynamic and/or static loading.

Type "I" damage, of corner joints under opening loads, has been repaired by a) removing and recasting loose and spalled concrete (Fig. 2a), b) adding three external collar-stirrups (Fig.2b).

Type "II", flexural, damage (Fig. 3a) has been repaired by means of a steel sheet glued to the bottom of the beam, with commercial epoxy resin (Fig.3b), after removing and recasting heavily damaged concrete.

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2.-C o r n e r   j o i n t s   r e p a i r e d

Two series (A_1 and A_2) of knee joints of R.C. frames were previously tested up to failure, as shown in Fig. 4, (2). The absence of diagonal stirrups within the joint was the main reason for a rather premature failure, at a loading level of approx. 75% (for static loading) or 65% (for dynamic loading), as compared to the expected static load capacity of the cantilever beam[(i)].

Two frames of each of the series A_1 and A_2 were subsequently repaired, as described in §1 and Fig.2. The total section of the additional collar-stirrups was purposely lower than the necessary value (Fig.5). Nevertheless, an initial axial prestressing of $250\,^{N}/_{mm^2}$ was given to these collars, by means of a commercial screwing device. The frames were then retested under repetitive opening loads. A dynamic hydraulic jack was connected to a low-cycling mashine. Strain-gauges' and inducers' measurements were read on a oscillograph recorder.

Some of these results are shown in Fig.6 and 7, as well as in Table I. The following conclusions may be drawn, based on the detailed results of this project, as compared to the initial behaviour of the frames (2):

a.-Carefull removing and recasting of loose and spalled concrete is a basic repair operation "per se"[(ii)].

b.-Additional steel has to be provided where redesign or crack formation deems it necessary. Welded steel seems preferable. External collar-stirrups have shown satisfactory behaviour, although their strains at failure of the corner-joints were relatively small

(i) Somehow similar results were found by Swann (3), Wilson (4), Bertero et al. (5) and others.

(ii) Compare to the findings of Barda et al. (6), having succeeded to restore 80%of dynamic strength in R.C. shear walls,by means of simple concrete packed by hand.

(0,1 to 1,3‰) and scattered. (Observe the absence of diagonal crack on concrete, Fig.6). The lack of steel in repaired areas may lead to very brittle behaviour, as shown by McCafferty et al. (7), even in cases where epoxy mortars are used.

c.-Under the conditions of this investigation, the rigidity of the repaired element was not practically affected.

d.-Ductility was increased, as it may be seen from Table I (comparison of number of cycles up to failure). Comparison of steel strains and total deflections lead to the same conclusion.

e.-Strength under cyclic loading was not affected (Table I, frames A_2). A strength decrease of only 10% was observed when a frame statically failed, was dynamically tested after its repair (frames A_1).

3.-F l e x u r a l   b e n d i n g   r e p a i r e d

Type II (flexural) failure (Fig.1) produced by static loading has been repaired as shown in Fig.3, and retested under cyclic loading. Complete measurements of strains were taken, by means of a oscillograph recorder, both on concrete and the steels (initial bar reinforcements and glued steel sheet). Deflections are shown in Fig.8, compared to those of the initial beam. The final upper limit of cyclic load 154,0 kN was equal to the static strength reached before repair. Five hundred and ten cycles up to this level have created cracks starting from the ends of the glued sheet and the sheet started to slip. At that moment, its stress was equal to 140 N/mm^2, while the initial bar reinforcements were restrained slightly over their yield limit. Nevertheless, the beam continued to bear load. In order to produce its failure, a monotonic static load was applied up to 175 kN.

On the basis of this limited part of the investigation, the following conclusions may be drawn:

a) Strength is easily and fully restored, even under high level dynamic loading.

b) Rigidity seems to decrease considerably. Nevertheless, if the steel sheet were considerably longer, a substantial improvement of rigidity could be possible.

4.-Acknowledgement

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Table I

Comparison of mechanical behaviour of corner joints before and after repair, under repetitive opening loading

frame		number of cycles to failure	failure load P_f	P_f after / P_f before	static load capacity of cantilever beam (computed) P_u	P_{req}
(a)		(b)	(c)	(d)	(e)	(f)
A_1,(1)	before	1	29,0 kN	95%	33,0 kN ($\varepsilon_{c,u}$=1,2‰ $\varepsilon_{s,u}$=5,0‰)	≈36,5 kN
	after	537	27,5			
A_1,(2)	before	4	28,0	90%		
	after	322	25,0			
A_2,(1)	before	137	22,5	100%	31,5 kN ($\varepsilon_{c,u}$=1,6‰ $\varepsilon_{s,u}$=5,0‰)	≈35,0 kN
	after	263	22,5			
A_2,(2)	before	67	25,0			
	after	85	25,0			

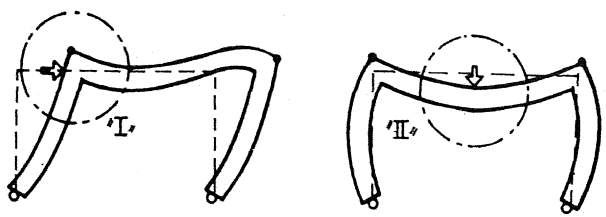

Fig. 1: Types of damage repaired

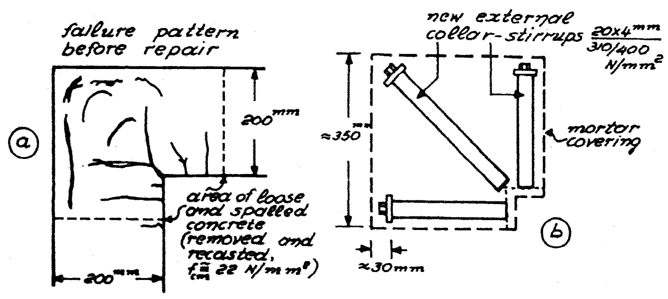

Fig. 2: Repair of corner joints (type "I")

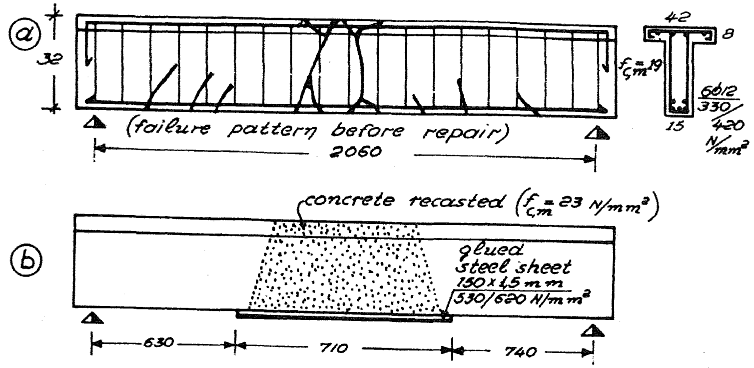

Fig. 3: Repair of beams (type "II")

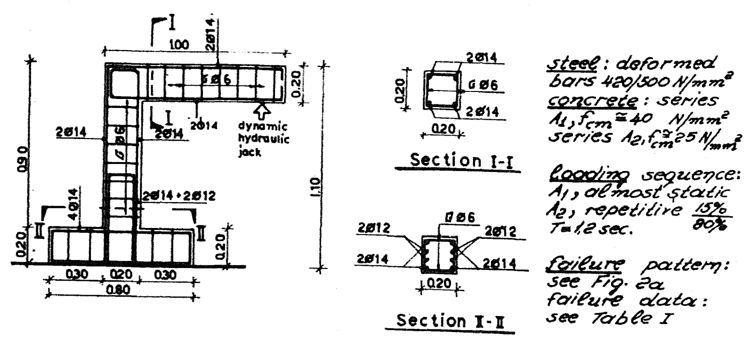

Fig. 4: Corner joints brought to failure before repair and retesting

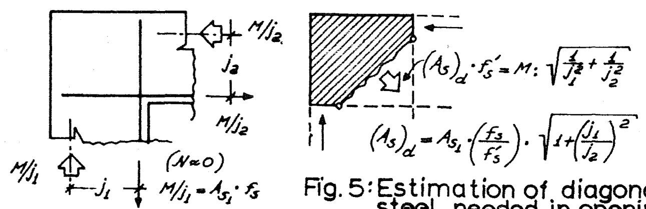

Fig. 5: Estimation of diagonal steel needed in opening loaded joints

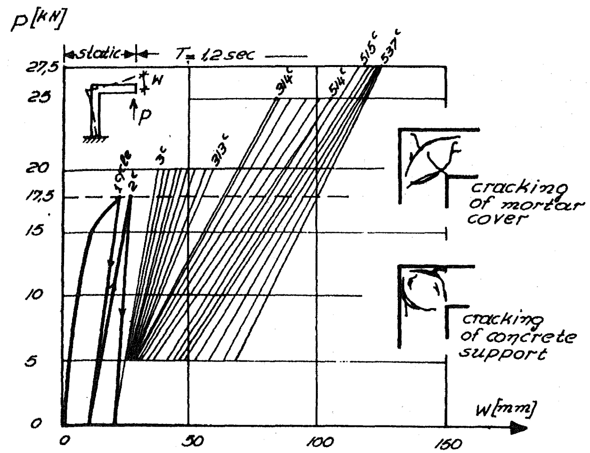

Fig. 6: Deflections during loading of frame A1,(1) after its repair

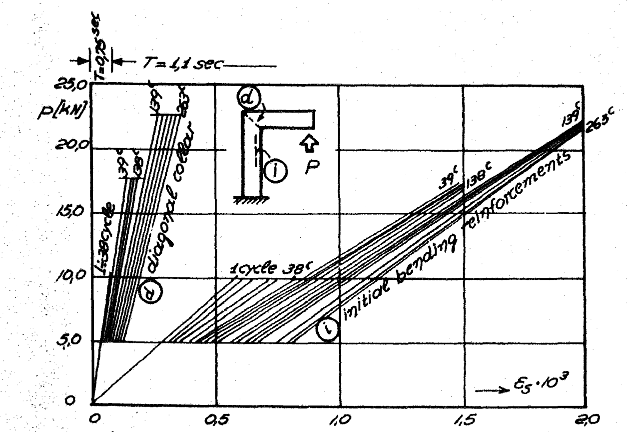

Fig. 7: Steel strains during cyclic loading of frame A2 (1) after its repair

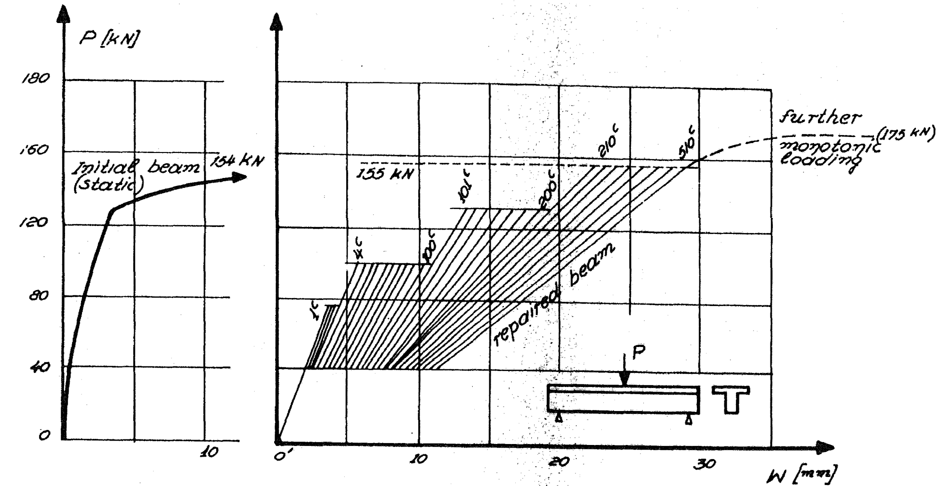

Fig. 8: Deflections of the beam of Fig. 3b retested under cyclic loading

DISCUSSION

D.B. Naik (India)

Could you please throw light on the effectiveness of using externally prestressed hoops for strengthening the transverse and inclined cracks ? What would be the effect on the strength capacity and ductility ? How does this method compare with the method of strengthening by using plate attached by epoxy adhesive and concrete for the central portion of the beam, as suggested in your paper ?

B.R. Seth (India)

As the authors have reported there is fall in rigidity, it can be improved as follows:

1. By keeping the inclination of end planes of recasted concrete in opposite direction than employed.

2. By making part of these planes vertical in the portion of compression zone.

3. By making grooves across in the old concrete surface.

4. By casting two straps on each side in recasted concrete which shall be bolted tight after full setting of recasted concrete under the glued plate and located as well over the old concrete.

Author's Closure

Related to Mr. Naik's questions the authors have some experience on external hoops as a repair method for shear inclined cracks of beams, but only under static loading. On Fig. 9 is shown a R.C. beam failed under shear. Repair has been effectuated by means of external hoops, lightly prestressed, subsequently covered by shotcrete (Fig. 10). The effectiveness of this simple method prooved to be quite satisfactory: Both bending stiffness and ductility are not affected and the new cracks were due mainly to bending, in contrast to the initial beam. Besides, crack widths were smaller after repair for the same load. It has to be noted, however, that steel strain of the external hoops was rather low (of the order of 0,5 to 1,0%, just before collapse load of the beam).

As per the comparison of this technique to the steel plates glued on the web, as a repair method against shear, there is also a promising experience.

Related to Mr. Seth's comments on how to counterbalance fall of rigidity in case of steel sheet glued for repair against flexural failure, the authors agree in principle but they would like to remind that unsufficient anchorage length of the steel plate was the main handicap in this case.

Fig. 9: Beam before repair

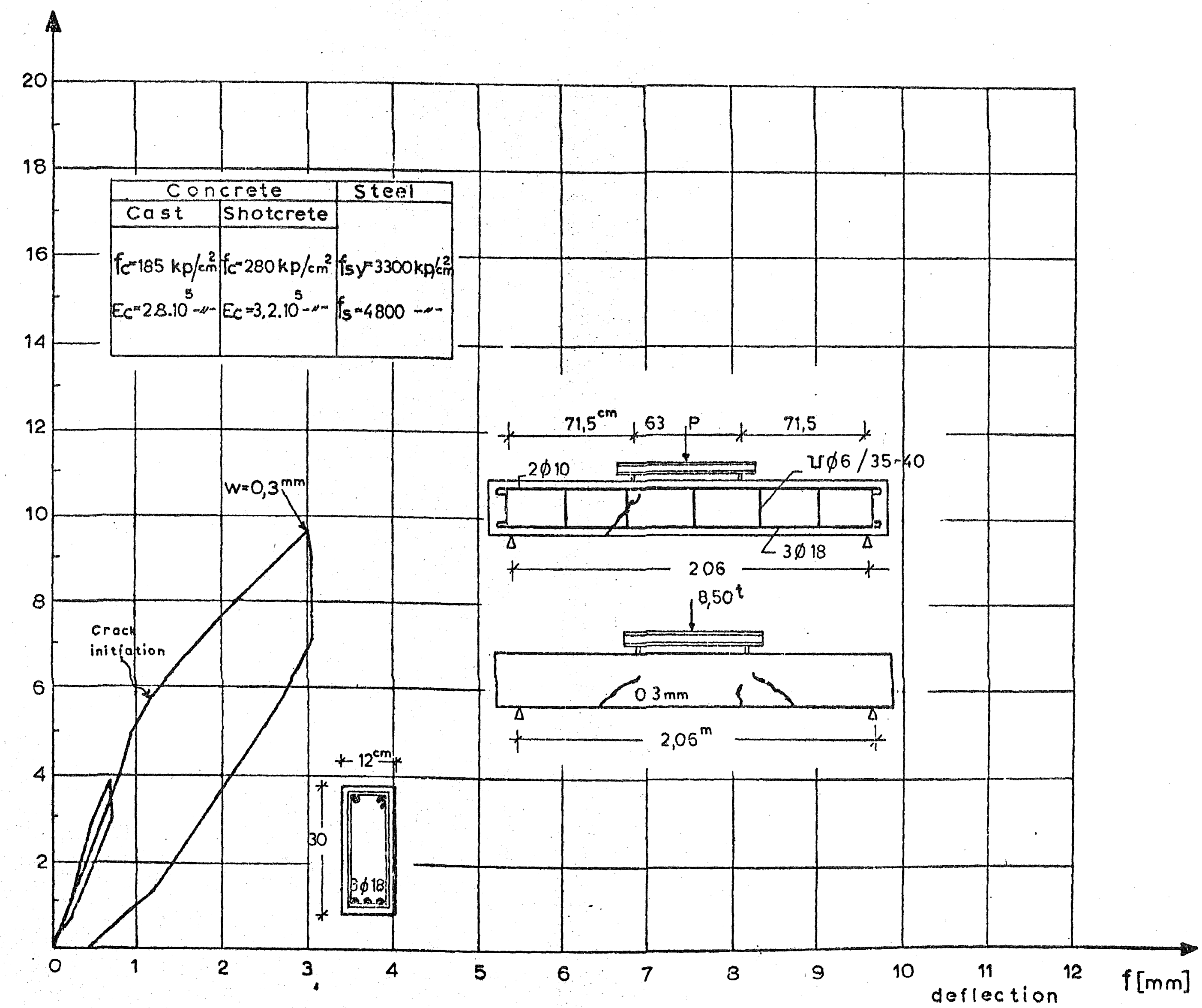

Fig. 10: Beam after repair