REPAIR OF STRUCTURES DAMAGED DURING EARTHQUAKES USING FIBROUS CONCRETE

M.LAKSHMIPATHY (I)
A.R.SANTHAKUMAR (II)
Presenting Author: M.LAKSHMIPATHY

SUMMARY

The structures located in earthquake prone zones will be subjected to large load reversals leading to the attainment of ultimate capacity besides undergoing large deformations. This leaves the structure in a damaged condition and warrants effective repair works. This paper describes an experimental investigation on damaged flexural members repaired with steel fibrous concrete. The results show that the repaired beam functions effectively as the original beam with respect to stiffness and load carrying capacity. The repaired beam has adequate code prescribed ductility. They are able to withstand more number of load cycles than the companion beam and absorb more energy.

INTRODUCTION

To overcome the brittle behaviour and to introduce desirable properties such as shatter resistance and damage control, the steel fibers are mixed in conventional concrete (Ref.1). The concrete thus obtained is referred to steel fibrous concrete (SFC). SFC exhibits ductile behaviour, better stiffness, larger energy absorption characteristics and better shear strength compared to conventional concrete (Ref.2). The use of steel fibrous concrete in the hinging zones of a flexural member along with conventional reinforcement makes it possess larger moment carrying capacity, increased stiffness and better resistance to cracking and disintegration compared to a conventional beam (Ref.3 & 4). The results of the present study reveal that SFC is a useful material for repairing the sick structures.

SCOPE OF THE INVESTIGATION

The SFC, having better ductile and energy absorption characteristics can be used for repairing the flexural RC member. This investigation deals with the behaviour of repaired flexural elements using SFC

(I) Lecturer, Structures Division, College of Engineering, Anna University, Madras 600 025.

(II) Professor, Structures Division, College of Engineering, Anna University, Madras 600 025.

with respect to stiffness, load carrying capacity, ductility, energy absorption characteristics under reversed cyclic loading.

TEST SPECIMEN AND TESTING SEQUENCE

Six beams of size 10x20x200 cm have been chosen for the study. All the six beams are identically reinforced, with 3 number of 10mm ø Tor steel bars both at top and bottom ($\rho = \rho' = 1.2\%$). 6mm ø M.S. two legged stirrups at 10 cm spacing has been used throughout the length of the beam (Fig.1). The stirrups are sufficient in number to suppress any shear failure. Out of the six beams, four beams (RC/SFC) have been prepared using conventional concrete of grade M20. The remaining two beams are termed as partial fibrous concrete beams (PFRC). The specimens were all cured under identical conditions. All the beams were designed to fail by flexure. Fig.2 shows the sequence of testing adopted. All the six beams have been tested as simply supported beams with central concentrated reversed static cyclic load. The intensity of load was such as to cause severe damage in the hinging zones due to flexure. Subsequently the damaged R.C. beams (4 Nos.) have been examined and the concrete in the damaged portions (limited to middle one third length of the beams) were removed. The main bars were strengthened. Using steel fibrous concrete the beams have been repaired and strengthened. The repair consisted of recasting the mid portion with SFC. Throughout the investigation steel fibers having 0.4mm dia, 40mm length giving an aspect ratio (l/d) of 100 and a quantity of 1% by volume of concrete have been used. The repaired beams were once again tested for assessing the behaviour. Loading sequence is shown in Fig.2.

DISCUSSIONS ON THE RESULTS OF TESTS

Load-Central Deflection and Stiffness

The load-central deflection curves for typical beams are shown in Fig.3. The broken lines indicate the behaviour before repair and full lines indicate the same after repair. It may be observed that the repairs carried out has in no way reduced the load carrying capacity or stiffness of the beam. (Tables I & II). The repaired beam exhibits slightly higher stiffness compared to its behaviour in the virgin stage during the first cycle after repair. The typical stiffness history of the specimens (W/Δ) were estimated from the load deflection curve and plotted against the load level (Fig.4) for first two cycles. The bar chart (Fig.4) shows that, at working load level the repaired beam has better stiffness. It is conclusively seen that the repairs have not in any way reduced the stiffness or load carrying capacity. The original beam was subjected to large deformations. After repair the test was carried out subjecting specimens to load reversals to reach a minimum code prescribed ductility factor of 4 to 6. The specimens could undergo more deformations without serious loss in load in the event of a higher ductility demand.

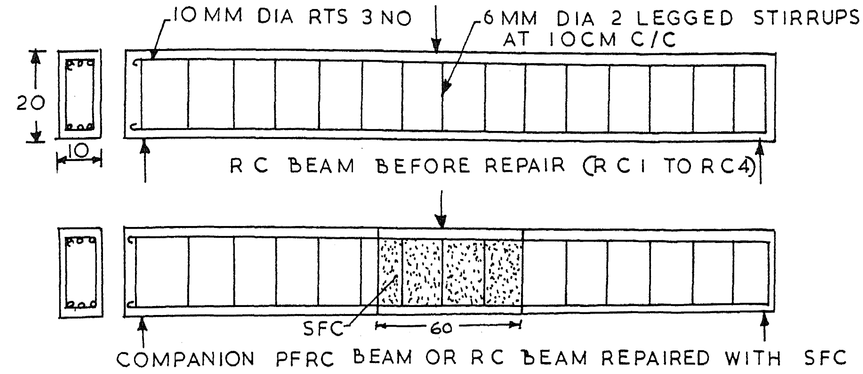

FIG.1. DETAILS OF REINFORCEMENTS USED IN THE SIX SPECIMENS

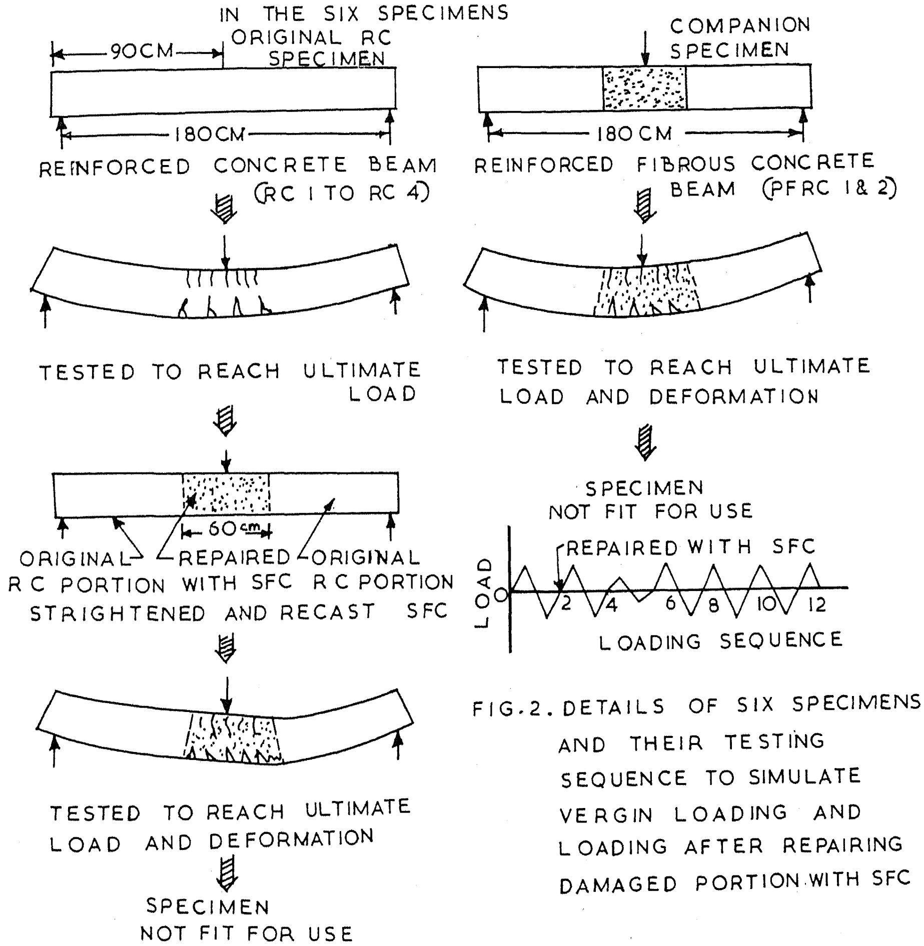

FIG.2. DETAILS OF SIX SPECIMENS AND THEIR TESTING SEQUENCE TO SIMULATE VERGIN LOADING AND LOADING AFTER REPAIRING DAMAGED PORTION WITH SFC

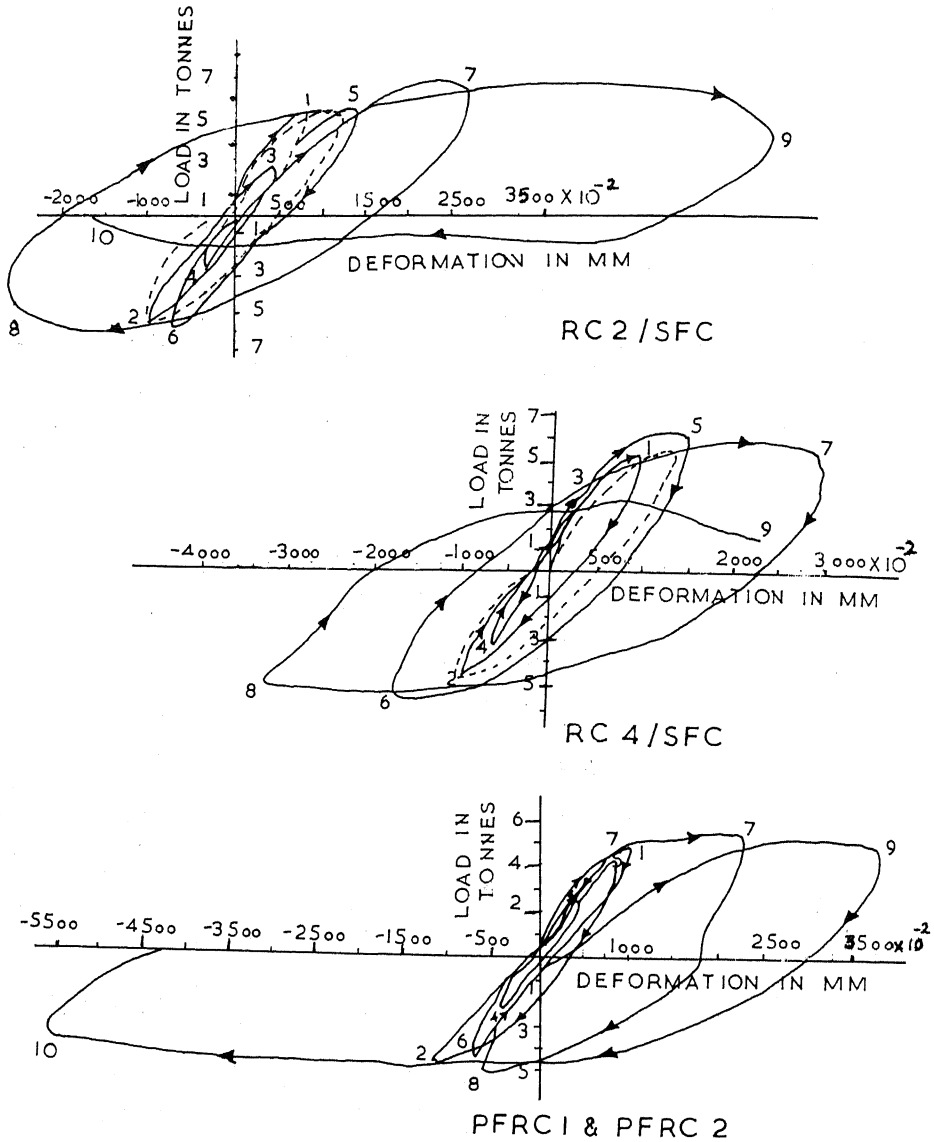

FIG. 3. LOAD Vs CENTRAL DEFLECTION

Table I. Ultimate Load Capacity of the Six Specimen

Beam Designation	Forward loading	Reserved loading	Repaired Forward	Repaired Reversed load
RC1/SFC	2.75	4.0	5.0	5.0
RC2/SFC	5.0	5.0	5.0	5.0
RC3/SFC	5.0	5.0	5.0	5.0
RC4/SFC	5.2	5.0	5.2	5.0
PFRC 1	5.0	5.0	-	-
PFRC 2	5.0	5.0	-	-

Table II. Stiffness of the specimen at working load

Beam Designation	Forward loading	Reversed loading	Stiffness at working load kg/mm	
			Repaired forward	Repaired reversed
RC1/SFC	450	475	750	500
RC2/SFC	525	400	612	450
RC3/SFC	525	400	625	500
RC4/SFC	537	470	700	500
PFRC 1	600	500	-	-
PFRC 2	600	500	-	-

In general the stiffness of the repaired beams were found to vary between 0.6t/mm and 0.8t/mm during the first cycle of loading after repair. This value compares favourably with that of the companion PFRC beam with a value of 0.7t/mm. As the load cycle increase the general trend for stiffness is found to be decreasing. After 10 cycles of loading the repaired beam exhibits a stiffness variation of 0.29t/mm to 0.21t/mm as against 0.21t/mm for PFRC companion beam.

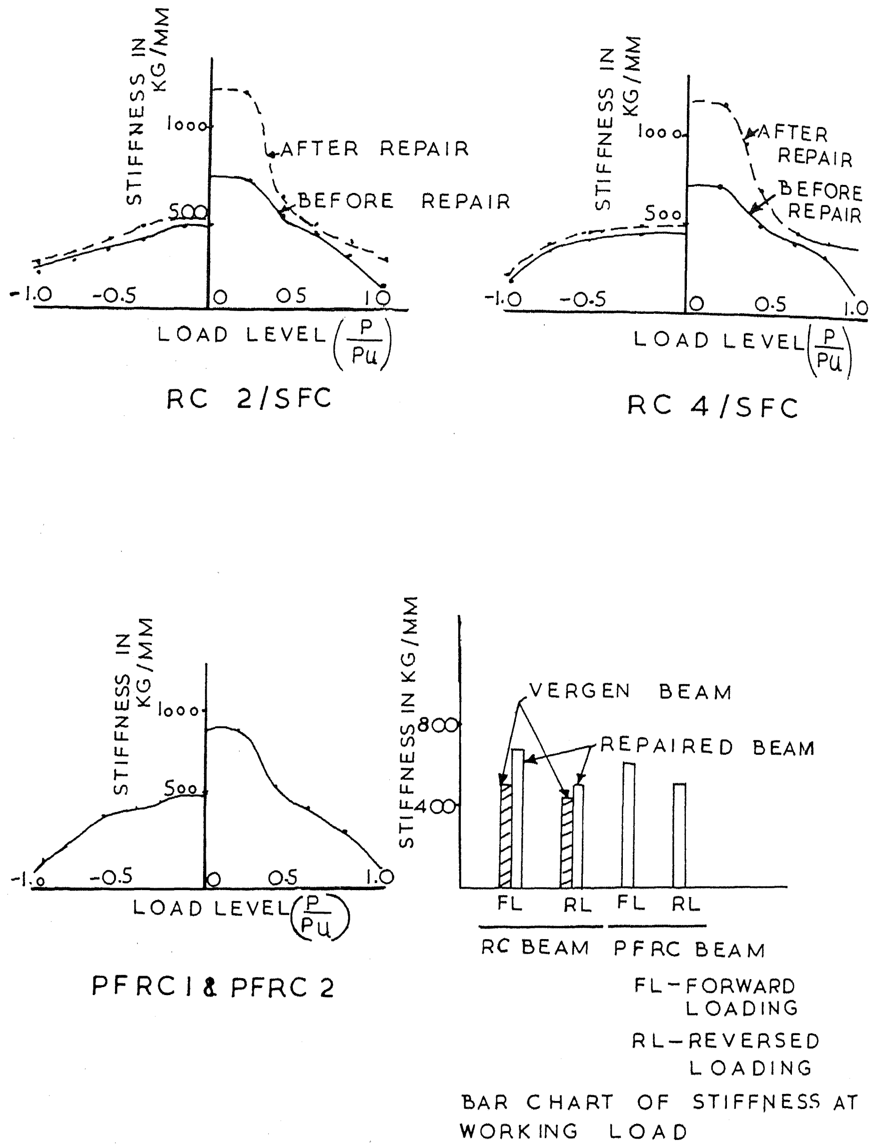

FIG. 4. STIFFNESS Vs LOAD LEVEL

Strain Variation along the length

The measurement for the strain variation along the length of the specimens both for virgin loading and loading after repairs clearly showed that a distinct flexural hinge at the maximum moment section (Central section) during first cycle. The strain distribution for the virgin beam showed a distinct peak whereas the repaired beam exhibited the length of the plastic hinge on either side of the maximum moment section. This is to be expected since the virgin beam has a single large flexural crack. But the repaired beam has many distributed cracks. This increases the length of the plastic hinge. Such a type of behaviour is considered advantageous as it reduces the demand for section ductility for the same overall member ductility. The maximum strains reached at critical locations are also of the same order. This type of behaviour is considered favourable since the repaired portion is seen to participate in the load transfer better than the original segment of the beam .

Ductility

The ductility (μ) is defined as the ratio of the deflection at any load level to yield deflection. The ductility of the repaired beams are found to increase as the number of cycles increase. The ductility for the repaired beam during the first cycle is found to vary between 1.8 and 2.7 and during 10th cycle the same is found to vary between 14.2 and 16.25 which compares well with the values of 16.28 obtained for companion PFRC beams during respective load cycles.

Energy Absorption Capacity

The specimens were subjected to load reversals upto the distruction and the energy absorbed in each cycle is calculated from the area under load deflection curves. The total energy absorption capacity of the beams are obtained by adding the energies absorbed during each cycle. The energy absorption during first cycle for the repaired beams is found to vary 2000 kg.cm to 2900 kg.cm and during 10th cycle 28000 kg.cm to 29000 kg.cm which compare well with the value of 32000 kg.cm for the companion PFRC beam.

Crack Pattern

The crack width in the repaired beam is less compared with the original beam because of the use of fibrous concrete. The crack with at working load level in the repaired beam is less than 0.1mm.

CONCLUSIONS

1. The repaired beam is found to have approximately same ultimate load carrying capacity as the virgin beam.

2. The stiffness of the repaired beams during first cycle is found 10% more than that of the original beam.

3. The repaired beam has adequate code prescribed ductility (4 to 6).

4. It is observed that the energy absorption capacity of the repaired beam is nearly same as that for the companion beam.

This provides evidence that the use of steel fibrous concrete becomes a handy method for repair works of the structure damaged due to earthquake.

ACKNOWLEDGEMENT

This work has been carried out as a part of the UGC project and the financial assistance received is gratefully acknowledged.

REFERENCES

1. Doherty T.J. and Henager C.H. (1976) 'Analysis of Reinforced Fibrous Concrete Beams' - Journal of Structural Division, ASCE, Vol. 102.

2. Lakshmipathy M. and Santhakumar A.R. (1980) 'Use of Reinforced Fibrous Concrete for Disaster Prone Areas' proceedings of the International Conference on Engineering for Protection from Natural Disasters, Asian Institute of Technology Bangkok, Thailand.

3. Lakshmipathy M. and Santhakumar A.R. (1980) 'Reinforced Fibrous Concrete for Structures in Earthquake prone zones' Proceedings of the VII world Conference on Earthquake Engineering, Istanbul, Turkey.

4. Lakshmipathy M. and Santhakumar A.R. (1981) 'Rehabilitation of Structural Elements with Fibrous Concrete' Proceedings of the International Symposium on Rehabilitation of Structures by Maharastra India Chapter of American Concrete Institute, Bombay during December.