Theme Meeting and Round Robin Exercise on Pushover Test on Prototype RCC Structure: a report

Earlier, the Reactor Safety Division (RSD), BARC along with Central Power Research Institute (CPRI) Bangalore conducted a round robin exercise and theme meeting on pushover test on prototype Reinforced Concrete structure on 01/05/2008 and 02/05/2008 at CPRI Bangalore. The structure tested was a replica of a substructure of an existing office building at BARC. At the outset, Dr. G.R. Reddy, BARC introduced all the participants about the requirement and objectives behind the exercise. Mr. Akanshu Sharma, BARC provided the details of designs and was followed by Dr. Ramesh Babu and Mr. M.N. Gundu Rao of CPRI to give information on construction and instrumentation aspects. This was followed by presentations by participants of the theme meeting namely BARC, NPCIL, DCS&EM, AERB, IIT Bombay, IIT Delhi, IIT Madras, IIT Roorkee, IIT Guwahati, NITK Surathkal, CPRI Bangalore, SERC Chennai, Thapar Institute of Technology Patiyala and Tyagarajar College of Engineering.

The theme meeting was followed by the experiment, which was inaugurated by Chairman, Atomic Energy Commission along with Director, BARC and Director-General, CPRI. The structure was tested till failure. Fig. 1 shows the structure being tested at the tower testing facility at CPRI Bangalore.

This structure was then repaired and retrofitted using Fiber Reinforced Polymer Composites (FRPC). Again, a two-day theme meeting on 24-25 March, 2010 was conducted where Dr. Ramesh Babu, CPRI gave the welcome address and Dr. G.R. Reddy, BARC briefed all the participants about the exercise. Researchers, working in the field of pushover analysis and repairs and retrofitting of RCC structures participated in the exercise. The institutes/ organizations who participated in the second phase of the exercise included, BARC, NPCIL, DCS&EM, IIT Bombay, IISc Bangalore, CPRI Bangalore, SERC Chennai, Thapar Institute of Technology Patiyala, UVCE Bangalore, IIIT Hyderabad, SIT Tumkur and PSN College of Engineering Tirunelveli, Sardar Patel College of Engineering, Mumbai. Binyas Contech Pvt. Ltd., Bangalore and R&M International, Mumbai provided the necessary support for repair and retrofitting of the structure. On the next day, the structure was tested till failure. Fig. 2 shows the retrofitted structure being tested at CPRI Bangalore. Fig. 3 shows the theme meeting in progress and the participants taking part in the experiment.

Fig. 1: Testing of original structure

Fig. 2: Testing of retrofitted structure

In-Situ Free Vibration Test

In order to evaluate the fundamental frequency of the structure in the two directions, before commencing the pushover test, a free vibration test was conducted for the retrofitted structure. Highly sensitive accelerometers were placed at different floors to pick up the vibration signal generated by the blow of a hammer. Fast Fourier Transform (FFT) of the signal gave the information on the fundamental frequency of the structure.

Experimental Results

The pushover curves as obtained for as built and retrofitted structure are shown in Figs. 4 and 5 respectively. The curves were plotted till large damage occurred at various locations and no significant lateral load resistance remained in the structure.

Fig. 3: Theme meeting and experiment under progress

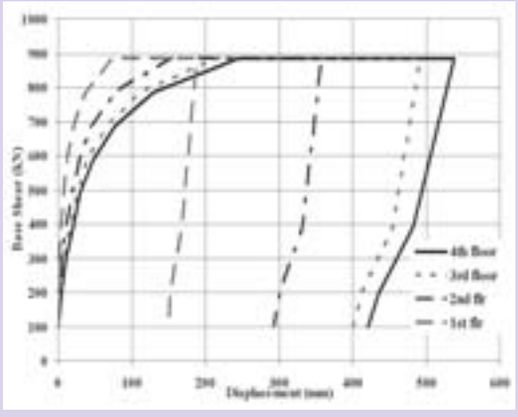

Fig. 4: Pushover curve for original structure

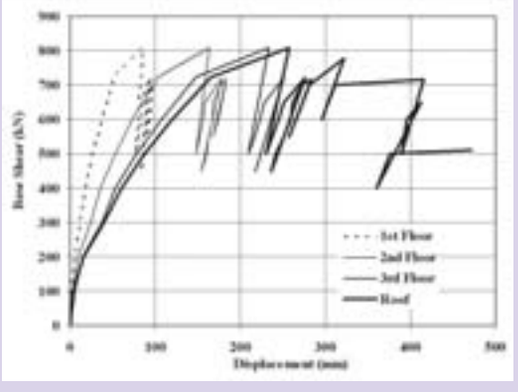

Fig. 5: Pushover curve for retrofitted structure

As seen from the plots, the original structure could resist a peak base shear of around 900 kN. During the test, the structure displayed various failure modes and at the end of the test, the structure could not resist any significant lateral load. However, the structure after being repaired and retrofitted with the FRPC could be restored up to almost 90% of its original state and the retrofitted structure could resist a peak base shear of around 800 kN. Till date, almost all the tests on FRPC retrofitting have been conducted at component level or small scale structural level. The results of this test could therefore very well prove the efficacy of the retrofit system using FRPC.

Failure Patterns

A few failure patterns of the as built and retrofitted structure are shown in Figures below. Fig. 6 shows typical beam failures observed in the test. The beams displayed various flexural and flexural-shear cracks. Spalling of concrete can be observed on the tension face of the beams.

Fig. 7 show typical joint failures observed in the structure.

Fig. 6: Failure of beams of as built and retrofitted structure

Fig. 7: Joint failures of as built and retrofitted structure

Observations and Discussions

Pushover test on a full scale prototype structure was conducted as round robin exercise where participants from various institutes from India participated in the theme meeting and the experiment. The failure patterns observed clearly displayed the vulnerability of RC buildings with non-conforming detailing to fail in undesirable failure mechanisms such as joint shear failures, bond failures etc. In addition to that, many failures like beam flexure, column compression-flexure, column tension-flexure, beam torsion etc. were displayed in the experiment.

The structure could successfully pushed back to original geometric position, repaired and retrofitted with FRPC to get the original capacity of the structure. After retrofitting, the failures were modified, first in terms of non-spalling of concrete due to good confinement provided by FRPC and second, the failure modes and locations also got shifted from joints to the beams and columns.

Comparing the experimental results with pre- and post- test analysis provided vital information regarding the modeling aspects. It was observed that considering only flexural failure modes for beams and columns, as is generally done in analysis and design, may not be sufficient to provide correct picture, and the results may be on unconservative side. In order to make predictions in close agreement with the real behavior, it is required to incorporate all the possible failure modes in the analysis such as flexural, shear, axial and torsion modes along with suitable interactions. Also, nonlinear modeling of the joints has to be considered to obtain the true behavior of the structure.

Failure modes and test results of retrofitted structure revealed that while performing retrofitting design, one needs to understand the behavior of the structure in both linear as well as nonlinear range by analysis. Identify the change in the failure modes and locations and if required the retrofitting scheme has to be appropriately modified. Thus, the retrofitting design is an iterative procedure. Another very important aspect of repair and retrofitting is the workmanship. Surface preparation by removal of old loose concrete, pouring of new concrete and its bonding with old concrete, rounding off sharp corners etc are few important aspects. Also, proper care should be taken to bond the FRP sheets and laminates to the original structure