Seismic Fragility Analysis of FRP Retrofitted Soft Story Buildings
Danish Khan1 Ram Kishor Yadav2
1Rajiv Gandhi Proudyogiki Vishwavidyalaya 2Indian Technocrats Limited

Abstract—This study gives fragility analysis of masonry infill soft storey frames retrofitted with various types of fibre reinforced polymer (FRP) sheets. Soft storey buildings with first storey free from infill are common choice of multi storey building in India. These type of buildings, due to their abrupt discontinuity in first storey, are known to perform poorly during earthquake. In particular, the columns of soft storey buildings undergo large inelastic deformations under earthquake hence leading to collapse of whole building. The first storey columns of soft storey buildings are retrofitted by confining columns with FRP sheets. Various types of FRP sheets are used for confining column and building models are analyzed using nonlinear static analysis. The confining effect of FRP leads to increased stiffness, strength as well as ductility which results in better performance under earthquake loads. The assessment of performance is done using fragility analysis which is a probability based method of analysis. The result shows that confinement of columns with FRP effectively reduces the probability of collapse of soft storey buildings.

Key words: Fragility Curves, Masonry Infill, Nonlinear Static Analysis, Soft Storey Buildings

I. INTRODUCTION

BUILDING with first storey free from masonry infill while rest of storey having continuous masonry infill are termed as soft storey buildings due to the increased flexibility in first storey. These type of buildings are preferred in India and other developing countries for construction of multi-storey buildings.

The soft storey buildings have performed poorly in recent earthquakes in Indian and world like Mexico earthquake of 1985 [1], Northridge earthquake of 1994 [2], Jabalpur earthquake of 1997 [3], Bhuj earthquake of 2001 [4], [5] and recent Nepal earthquake of 2015 [6], [7]. In all these earthquake, several concrete frame buildings having soft storey characteristic suffered large scale structural damage or collapsed entirely.

In present study, a soft storey frame is retrofitted with GFRP and CFRP sheets of different thickness and is analysed using nonlinear static procedure nonlinear in SeismoStruct software [8]. The effect of partial confinement is studied parametrically by increasing amount of confinement by 20%, 40%, 50%, 60%, 80% and 100% of FRP sheets with respect to column area of soft storey columns.

II. MODELLING CONSIDERATIONS

The building model for present study is taken from [9]. The geometry of model is shown in Fig. 1. The model is a 7 storey, 3 bay frame, the height and width of each bay is 3 m. More details of building model can be found in [9].

A. Properties of Materials

The various building models will consist of material - concrete, steel reinforcement bars, masonry infill and FRP sheets.

The design compressive strength of concrete is taken as 35 MPa and yield strength of reinforcement steel is 415 MPa. The loading and weight on all frames is kept same and weight of masonry acts as uniformly distributed load.

The properties of FRP sheets used for retrofitting of columns of soft storey buildings are shown in Table I which is similar to the properties mentioned in [10], [11].

Table 1: Mechanical Properties of GFRP Sheets

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Type of FRP</th>
<th>Thickness (mm)</th>
<th>E (MPa)</th>
<th>f_c (MPa)</th>
<th>(\varepsilon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFRP1</td>
<td>GFRP</td>
<td>1</td>
<td>70000</td>
<td>400</td>
<td>3.0</td>
</tr>
<tr>
<td>GFRP2</td>
<td>GFRP</td>
<td>2</td>
<td>70000</td>
<td>400</td>
<td>3.0</td>
</tr>
<tr>
<td>CFRP11</td>
<td>CFRP</td>
<td>1</td>
<td>150000</td>
<td>900</td>
<td>1.2</td>
</tr>
<tr>
<td>CFRP12</td>
<td>CFRP</td>
<td>1</td>
<td>215000</td>
<td>900</td>
<td>1.2</td>
</tr>
<tr>
<td>CFRP22</td>
<td>CFRP</td>
<td>2</td>
<td>215000</td>
<td>900</td>
<td>1.2</td>
</tr>
</tbody>
</table>

B. Details of Building Models

Various building models used in study are tabulated in Table II. The concept of wrapping of FRP sheets is shown in Fig. 2 and schemes for wrapping for confinement of concrete is shown in Fig. 3. The distance x in Fig. 3 (a) is expressed in terms of percentage of confinement and studied for varying values.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Detail of model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare frame</td>
<td>Model without infill walls</td>
</tr>
<tr>
<td>Soft storey</td>
<td>Model with infill wall in all storeys except at first storey</td>
</tr>
<tr>
<td>GFRP1</td>
<td>Soft storey model retrofitted with GFRP1 sheet</td>
</tr>
<tr>
<td>GFRP2</td>
<td>Soft storey model retrofitted with</td>
</tr>
</tbody>
</table>

Fig. 1: Building model for study from [8]. The model is showing masonry infill at all storeys except at first storey which is termed as soft storey.
Seismic Fragility Analysis of FRP Retrofitted Soft Story Buildings
(IJSRD/Vol. 4/Issue 03/2016/370)

Table 2: Designation and Details of Various Building Models Used In Study

<table>
<thead>
<tr>
<th>Designation</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFRP11</td>
<td>Soft storey model retrofitted with CFRP11 sheet</td>
</tr>
<tr>
<td>CFRP12</td>
<td>Soft storey model retrofitted with CFRP12 sheet</td>
</tr>
<tr>
<td>CFRP22</td>
<td>Soft storey model retrofitted with CFRP22 sheet</td>
</tr>
<tr>
<td>GFRP20%</td>
<td>Soft storey model retrofitted with GFRP1 sheet and confining 10% of concrete</td>
</tr>
<tr>
<td>GFRP40%</td>
<td>Soft storey model retrofitted with GFRP1 sheet and confining 20% of concrete</td>
</tr>
<tr>
<td>GFRP50%</td>
<td>Soft storey model retrofitted with GFRP1 sheet and confining 50% of concrete</td>
</tr>
<tr>
<td>GFRP60%</td>
<td>Soft storey model retrofitted with GFRP1 sheet and confining 60% of concrete</td>
</tr>
<tr>
<td>GFRP80%</td>
<td>Soft storey model retrofitted with GFRP1 sheet and confining 80% of concrete</td>
</tr>
</tbody>
</table>

Nonlinear Static Analysis

The nonlinear static analysis, also known as pushover analysis, is displacement controlled in which point at top storey is displaced up to a certain target displacement in finite number of steps.

The result of pushover analysis is so called pushover curve which is the plot between roof displacement and base shear. The pushover gives the behavior of building under load.

To calculate response of building under given earthquake, capacity spectrum method of ATC-40 [18] is used. In this, the pushover curve is first converted into acceleration displacement response spectrum (ADRS) format, named capacity curve. The capacity curve is then plotted with response spectrum curve on same graph. The response spectrum curve is then modified according to building characteristic to give modified acceleration displacement spectrum (MADRS). The intersection of capacity curve with MADRS gives the point which corresponds to the performance of building in given earthquake.

The response spectrum data to calculate response of buildings of present study is taken from IS 1893:2002 [19] and is given in Fig. 4.

B. Fragility Analysis

The fragility analysis is done according to methodology of HAZUS [20]. The fragility is defined as probability of exceeding a damage state $P[d_s|S_d]$ for given value of spectral displacement $S_d$ and is given by following lognormal standard cumulative probability distribution equation.

$$P[d_s|S_d] = \Phi \left( \frac{1}{\beta_{ds}} \ln \left( \frac{S_d}{S_d,ds} \right) \right)$$  \hspace{1cm} (1)

Where,

- $S_d,ds$ is spectral displacement for given damage state
- $\beta_{ds}$ is the standard deviation of log of spectral displacement
- $\Phi$ is normal cumulative distribution function

The plot between $S_d$ and probability of exceedance gives the required fragility curve. An example curve taken from HAZUS [20] is shown in Fig. 5.
Seismic Fragility Analysis of FRP Retrofitted Soft Story Buildings
(IJSRD/Vol. 4/Issue 03/2016/370)

IV. RESULTS AND DISCUSSIONS

The results of analysis are given in terms of pushover curves and fragility curves. The results are categorized in two ways. Firstly, the frames.

A. Pushover Curves

The pushover curves of frames retrofitted by different types of FRP is shown in Fig. 6 and it clearly shows that post elastic stiffness is increased when FRP is used to confine concrete. CFRP confined frames performed better than GFRP frames. Fig. 7 gives results for frames having various percentage of confinement of concrete by GFRP1 and is observed that for more than 40% confined concrete, the results are similar and 50% confinement is more or less similar to 100% confinement.

B. Fragility Curves

The fragility curves of frames having different FRP material are shown in Fig. 8 and different percentage of confinement of concrete by GFRP1 are shown in Fig. 9.

The fragility curves visually show that when FRP material is used damage is reduced considerably. Moreover amount of confinement of soft storey column by FRP sheets has an effect on fragility curve and it is observed that as amount of confinement is increased, the probability of damage is decreased.

V. CONCLUSION

The fragility analysis of soft storey frame retrofitted by various types of FRP sheets and for various amount of confinement is carried out using nonlinear static analysis procedure. The results are given in terms of pushover curves and fragility curves.

The results show that frames strengthened with CFRP sheets performed better, compared to GFRP sheets.

Another conclusion drawn is that pushover curve is very similar for 50% confined frames and 100% confined which suggests that 50% confined frames can be used which will be economical as well as effective.
REFERENCES


