Seismic Fragility Analysis of FRP Retrofitted Soft Story Buildings

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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].

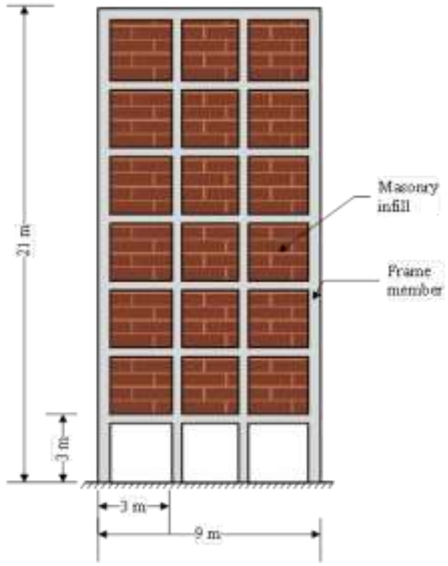

Fig. 1: Building model for study from [8]. The model is showing masonry infill at all storeys except at first storey which is termed as soft storey.

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].

Specimen	Type of FRP	Thickness (mm)	E (MPa)	f_u	ε_u
GFRP1	GFRP	1	70000	400	3.0
GFRP2	GFRP	2	70000	400	3
CFRP11	CFRP	1	150000	900	1.2
CFRP12	CFRP	1	215000	900	1.2
CFRP22	CFRP	2	215000	900	1.2

Table 1: Mechanical Properties of GFRP Sheets

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.

Designation	Detail of model
Bare frame	Model without infill walls
Soft storey	Model with infill wall in all storeys except at first storey
GFRP1	Soft storey model retrofitted with GFRP1 sheet
GFRP2	Soft storey model retrofitted with

	GFRP2 sheet
CFRP11	Soft storey model retrofitted with CFRP11 sheet
CFRP12	Soft storey model retrofitted with CFRP12 sheet
CFRP22	Soft storey model retrofitted with CFRP22 sheet
GFRP20%	Soft storey model retrofitted with GFRP1 sheet and confining 10% of concrete
GFRP40%	Soft storey model retrofitted with GFRP1 sheet and confining 20% of concrete
GFRP50%	Soft storey model retrofitted with GFRP1 sheet and confining 50% of concrete
GFRP60%	Soft storey model retrofitted with GFRP1 sheet and confining 60% of concrete
GFRP80%	Soft storey model retrofitted with GFRP1 sheet and confining 80% of concrete

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

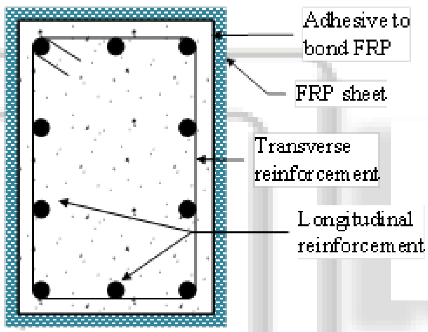

Fig. 2: Conceptual model of column wrapped with FRP sheets.

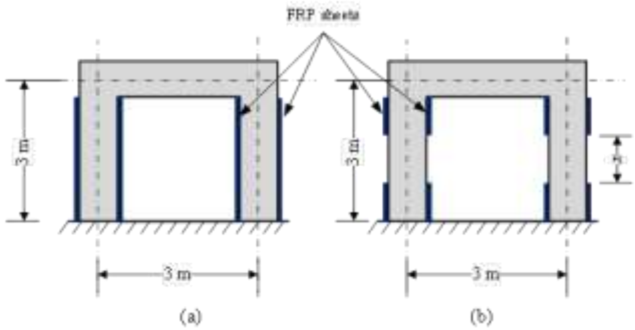

Fig. 3: Schemes of wrapping columns with FRP sheets (a) full FRP confinement, (b) partial FRP confinement, x is the length of unconfined column

C. Nonlinear Modelling of Frame Members

The nonlinear stress-strain relationship of frame member is based on Mander's model [12] and are modelled as inelastic force based plastic hinge elements in SeismoStruct software.

D. Nonlinear Modelling of Infill Walls

The use of equivalent struts to model effect of infill wall in analysis is recommended in literature [13]–[17]. In present study, the model proposed by Crisafulli [17] is used for nonlinear modelling of infill walls.

III. Methodology for Analysis

The nonlinear analysis procedure is used to analyses various models. The nonlinear analysis is chosen due to the fact that soft storey frames undergo displacement of high magnitude under earthquake loads. The analysis is done in SeismoStruct software [8].

A. 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.

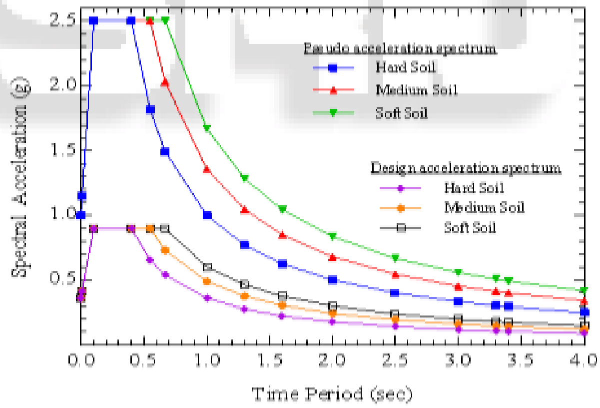

Fig. 4: Response spectrum data from IS 1893:2002 [19]

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[ds|S_d] for given value of spectral displacement S_d and is given by following lognormal standard cumulative probability distribution equation.

$$P[ds \mid S_d] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] \qquad (1)$$

Where,

$\bar{S}_{d,ds}$ is spectral displacement for given damage state

β_{ds} is the standard deviation of log of spectral displacement

Φ 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

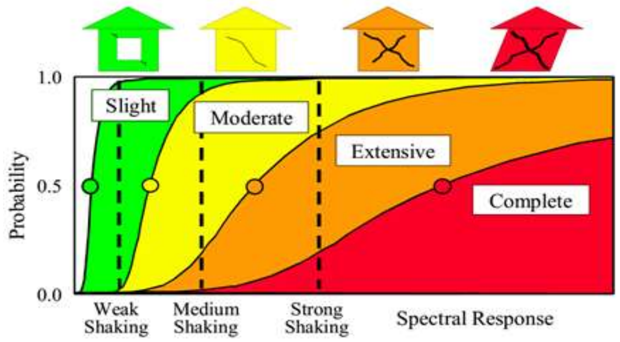

Fig. 5: Example of fragility curves for different damage levels [20]

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.

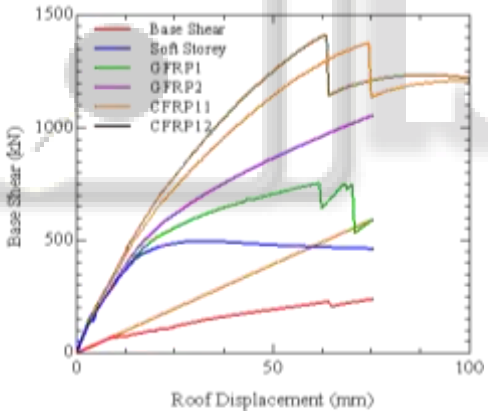

Fig. 6: Pushover curves for frames retrofitted with different FRP sheets

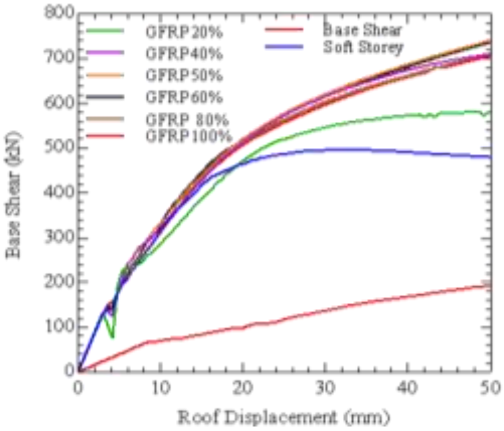

Fig. 7: Pushover curves for frames with different percentage of confinement of soft storey columns by FRP sheets.

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.

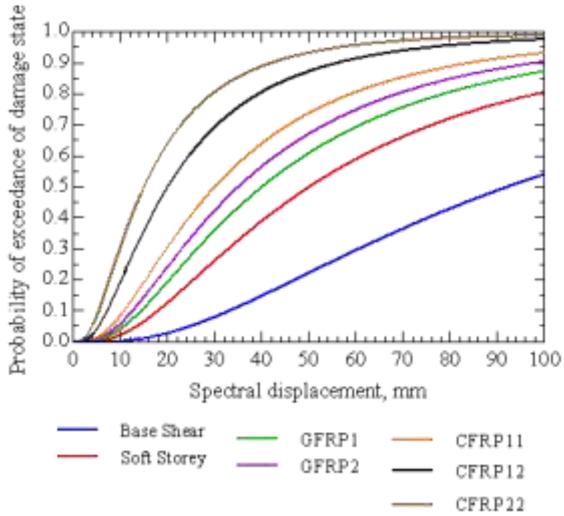

Fig. 8 Fragility curves for frames retrofit with different FRP sheets

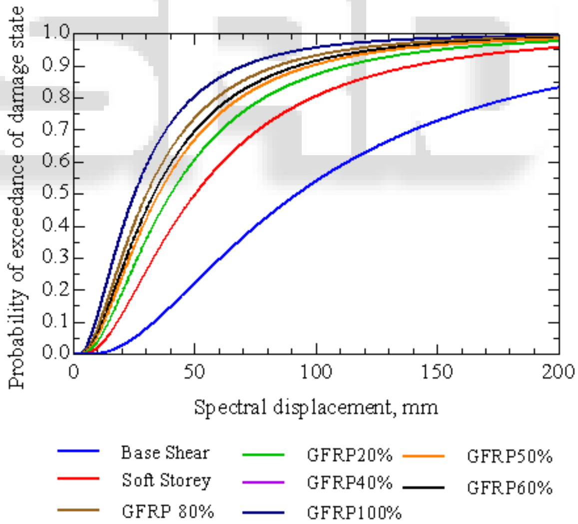

Fig. 9 Fragility curves for frames with different percentage of confinement of soft storey columns by FRP sheets.

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.

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