Evaluation of earthquake load resistance of masonry infilled RC frames using linear and non-linear dynamic analysis

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Abstract: The understanding of the dynamic behavior of structures is essential to design them to resist the lateral loads due to earthquakes. Recent past earthquakes have demonstrated the importance of proper designing of structural members to avoid damages in the buildings and loss of life. Generally the lateral load resistance of masonry infilled moment resisting frames is achieved by frame action and truss action. In this paper the seismic performance of a G+9 storeyed masonry infilled RC framed building is evaluated by linear and non-linear dynamic analysis. The analysis is carried out using the finite element software- ETABS. The response spectrum and time history pertaining to the specifications as given in the Indian Seismic Code IS 1893:2016 is considered for the analysis. Three different frame models are studied namely, bare frame, fully infilled frame and soft storey frame to understand the lateral load resistance of the frames. The dynamic characteristics of the frames such as time period, frequency, mode shapes, storey displacements, inter-storey drift, over-turning moments and energy dissipation capacity are evaluated and compared. The fully infilled frame shows better seismic behavior than that of other two frames though it attracts more forces.

1. Introduction

Multi-storey buildings are inevitable in Indian cities due to the demand of space for residential and commercial purposes. Most of these buildings are RC un-reinforced masonry infilled ordinary moment resisting framed structures with open ground storey for car parking, venue for family parties, etc. Many of them are designed and constructed only for gravity loading and their behavior during earthquake loading is uncertain. There are different methods to understand the buildings’ behavior during earthquake using experimental and analytical methods. Dynamic test on multi-storey buildings is a very good preference to know the actual behavior of structures under earthquake loading, but it is very costly and needs very high expertise. Analytical methods are equally as good as tests to predict the behavior of structures using highly sophisticated finite element tools. Static analysis is of less importance because the earthquake loads are dynamic in nature; therefore the structures’ response can be obtained by dynamic analysis [1, 2]. Dynamic analysis is mandatory for buildings with irregularities and buildings situated in high seismic zones.

The specifications given in IS 1893:2016 are very useful for regular buildings. The irregular and tall buildings are need to be analysed and checked for safety using response spectrum (RS) method or time history (TH) analysis method based on the actual or synthetic acceleration records [3,4,5].

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It is a usual practice of neglecting the role of masonry infills in the design of RCC framed buildings against earthquake loading. The masonry infills improve the strength and stiffness of the building and can be effectively utilized for the better design in the view of safety of the bounding frame to some extent and economy [6, 7, 8, 9, and 10]. In this paper, the seismic behavior of the multi-storey bare frame, fully infilled frame and soft-storey frame are analyzed using the linear (response spectrum) and non-linear (time history) dynamic analysis with the help of ETABS software.

2. Analytical investigation

2.1 Details of the building

The details of the building in this study are given below.

6 bay by 4 bay G+9 storeyed residential building
- Column Size - 350 mm x 350 mm
- Beam Size - 250 mm x 400 mm
- Slab Thickness - 120 mm
- Burnt Clay Brick Masonry Thickness - 230 mm
- Height of each storey - 3.0 m
- Grade of Concrete - M 20
- Grade of Steel - Fe 415
- Zone III, Soil type-Medium
- LL on floors - 3 kN/m²

2.2 Modeling and analysis of the building frames

The modeling of the G+9 storeyed building with and without masonry infill is done in ETABS and the material and section properties are assigned. The masonry infill is modeled as equivalent diagonal compression strut [11, 12]. Figure 1 shows the building models. The base is assumed to be fully fixed and the connectivity between the structural elements is considered as rigid. The dynamic responses of the frames are obtained by RS and TH methods. The response spectrum and time history data that are used in the analysis are given in figure 2(a) and (b), respectively. The modal characteristics such as mode shapes, frequencies and time periods are obtained for all the building models.

![Figure 1. 3-D Modeling of the frames.](image-url)
3. Results and Discussion

The fundamental frequency and mode shape of the building frames are shown in figure 3 and 4, respectively. The frequency of fully infilled frame is 2.28 times more than bare frame and soft-storey frame is 1.47 times more than bare frame. The mode shape explains the deflection pattern of the frames; the bare frame and fully infilled frame show the flexure mode whereas the soft-storey frame shows the shear mode.

Figure 2. Input for the analysis.
Figure 3. Fundamental frequency of the building frames.

Figure 4. Fundamental mode shape of the building frames.

Storey stiffness is very significant in infilled frames than the bare frame; however the stiffness in the soft-storey frame between first and second floor is about 88.6% (figure 5). This kind of behavior should be avoided in order to make the buildings safe against earthquake loads.

Figure 5. Storey stiffness of the building frames.
Tables 1, 2 and 3 represents the dynamic response of bare frame, fully infilled frame and soft-storey frame, respectively obtained from response spectrum analysis and time history analysis. The base shear of bare frame and fully infilled frame from RS and TH analyses is almost same but for the case of soft-storey frame the TH value is 35 % lower than that of RS approach.

The storey displacement for the bare frame is found to be more when compared to other two frames and observed that both RS and TH analyses produced nearly equal magnitude of displacement. The fully infilled and soft-storey frames have lower deflection from TH analysis than RS analysis.

The storey drift of all the three frames is within the limit as per the IS 1893 codal provisions. However, inter-storey drift between first and second floor in the case of soft-storey frame is found to be 89%.

Overturning moments are very high in frames with masonry infills when compared to bare frame. It is found that the values of overturning moments of frames with masonry infills from TH analysis are much lower than that of RS analysis.

The weight of the bare frame, fully infilled frame and soft-storey frame is 24142.24 kN, 62544.37 kN and 58704.15 kN, respectively. Due to more inertia the infilled frames attract more forces and becomes stiffer thereby reduction in the lateral displacement than the bare frame.

The dynamic responses of the bare frame are well simulated by RS and TH analyses whereas RS analysis resulted high values for frames with masonry infills. This may be due to the material non-linearity of masonry infill due to cracking and crushing.

| Storey Level | Storey Shear (kN) | Storey Displacement (mm) | Storey Drift | Overturning Moment (kN-m) |
|--------------|-------------------|----------------------------|--------------|--------------------------|
|              | RS | TH | RS | TH | RS | TH | RS | TH | RS | TH |
| Story10      | 187.18 | 144.62 | 23.12 | 22.17 | 0.000301 | 0.000233 | 0 | 0 |
| Story9       | 349.43 | 241.16 | 22.34 | 21.47 | 0.000483 | 0.000387 | 545.88 | 368.92 |
| Story8       | 479.55 | 361.93 | 21.08 | 20.32 | 0.000639 | 0.000528 | 1553.95 | 1170.31 |
| Story7       | 584.78 | 487.83 | 19.37 | 18.74 | 0.000764 | 0.00067 | 2923.39 | 2304.26 |
| Story6       | 672.85 | 561.86 | 17.27 | 16.79 | 0.000866 | 0.000796 | 4575.58 | 3764.02 |
| Story5       | 750.52 | 622.46 | 14.81 | 14.41 | 0.000952 | 0.000924 | 6452.90 | 5598.15 |
| Story4       | 821.81 | 698.08 | 12.06 | 11.68 | 0.001027 | 0.001002 | 8518.11 | 7786.06 |
| Story3       | 886.29 | 800.45 | 9.03 | 8.78 | 0.001088 | 0.001052 | 10749.93 | 10187.58 |
| Story2       | 938.43 | 853.49 | 5.79 | 5.69 | 0.001111 | 0.001079 | 13134.41 | 12751.29 |
| Story1       | 967.97 | 842.78 | 2.46 | 2.45 | 0.000822 | 0.000818 | 15653.50 | 15429.31 |
| Base         | 0 | 0 | 0 | 0 | 0 | 0 | 18272.62 | 18136.90 |
Table 2. Response of fully infilled frame.

| Storey Level | Storey Shear (kN) | Storey Displacement (mm) | Storey Drift | Overturning Moment (kN-m) |
|--------------|-------------------|--------------------------|--------------|--------------------------|
|              | RS                | TH                       | RS           | TH                       | RS | TH |
| Story10      | 790.59            | 1134.19                  | 12.10        | 4.80                     | 0  | 0  |
| Story9       | 1820.70           | 2136.47                  | 11.02        | 4.29                     | 2215.91 | 3495.68 |
| Story8       | 2684.76           | 2245.35                  | 9.82         | 3.71                     | 7460.77 | 10329.16 |
| Story7       | 3403.92           | 1767.12                  | 8.52         | 3.22                     | 15354.93 | 18058.58 |
| Story6       | 4001.60           | 1858.18                  | 7.15         | 2.85                     | 25524.59 | 24632.37 |
| Story5       | 4497.05           | 1807.11                  | 5.77         | 2.48                     | 37625.08 | 28971.64 |
| Story4       | 4902.19           | 2410.21                  | 4.40         | 2.11                     | 51338.13 | 30964.87 |
| Story3       | 5218.77           | 3304.52                  | 3.08         | 1.70                     | 66366.28 | 31065.78 |
| Story2       | 5441.54           | 4614.79                  | 1.88         | 1.20                     | 82419.78 | 31689.25 |
| Story1       | 5556.26           | 5556.12                  | 0.83         | 0.60                     | 99203.96 | 36379.74 |
| Base         | 0                 | 0                        | 0            | 0                        | 116406.60 | 46623.87 |

Table 3. Response of soft-storey frame.

| Storey Level | Storey Shear (kN) | Storey Displacement (mm) | Storey Drift | Overturning Moment (kN-m) |
|--------------|-------------------|--------------------------|--------------|--------------------------|
|              | RS                | TH                       | RS           | TH                       | RS | TH |
| Story10      | 349.3441          | 195.397                  | 13.382       | 9.24                     | 0  | 0  |
| Story9       | 841.2211          | 480.106                  | 12.791       | 8.86                     | 988.239 | 586.191 |
| Story8       | 1297.29           | 761.509                  | 12.14        | 8.445                    | 3423.904 | 2021.712 |
| Story7       | 1717.795          | 1042.02                  | 11.438       | 7.997                    | 7257.965 | 4306.24 |
| Story6       | 2104.763          | 1325.627                 | 10.698       | 7.521                    | 12435.03 | 7432.315 |
| Story5       | 2461.31           | 1611.612                 | 9.933        | 7.025                    | 18896.08 | 11409.20 |
| Story4       | 2791.047          | 1893.324                 | 9.163        | 6.516                    | 26580.39 | 16244.03 |
| Story3       | 3097.425          | 2161.511                 | 8.405        | 6.006                    | 35426.87 | 21924.00 |
| Story2       | 3383.981          | 2410.397                 | 7.697        | 5.521                    | 45374.44 | 28408.54 |
| Story1       | 3566.333          | 2566.406                 | 6.947        | 4.995                    | 56364.92 | 35639.73 |
| Base         | 0                 | 0                        | 0            | 0                        | 68029.31 | 43338.95 |

The base shear versus top displacement of the different frames describes the global behavior of the frames as shown in figure 6. The strength and initial stiffness of the fully infilled frame is higher than that of other two frames. The energy dissipation capacity of the fully infilled frame is nearly 2.84 times and 2.2 times higher than that of bare and soft-storey frames, respectively. Though the strength and initial stiffness of the soft-storey frame is better than the bare frame, the energy dissipation capacity is reduced by 20% because of the absence of masonry infill in the ground storey.
4. Conclusion
The RS and TH analyses of bare frame, fully infilled frame and soft-storey frame are compared for their seismic resistance. Considerable increase in base shear is obtained for frames with masonry infills and the infills reduced the lateral displacement significantly. Storey drifts of all the frames are lesser than the limit as given in the IS code; however the inter-storey drift in soft-storey frame in the bottom storey is relatively higher and this will lead to a concentration of heavy damage in the columns in that particular storey. The energy dissipation capacity of fully infilled frame is superior to that of other two frames. The dynamic responses of fully infilled and soft-storey frames from RS analysis are highly magnified when compared to TH analysis.

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