**Seismic Behaviour of Soft Story RC Structures with Variable Infill Reductions Using Incremental Dynamic Analysis**

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**ABSTRACT**

Soft story RC buildings are increasingly common in urban areas, often designed to accommodate parking facilities on the ground floor. With the rapid development of mid and high-rise residential apartments in our country, the prevalence of these soft story structures is rising. Typically, these buildings include soft stories created for parking, open floors, or special spaces, resulting in varying infill placements and reductions. Such reductions often involve openings for doors and windows, as well as changes in the thickness of the infill walls, which are not always symmetrically placed within the building. Understanding the behavior of these structures under the influence of earthquake ground motions is crucial for ensuring their resilience. This study aims to evaluate the performance of soft story structures with different reductions in infill walls when exposed to seismic activity. The analysis includes the development of models with soft stories and varying infill reductions, followed by their evaluation. Two types of models, specifically three-story and five-story structures, are considered in this study. Each model is divided into four sub-models based on the extent of infill reduction: a bare frame, exterior walls with reductions, exterior and interior walls with reductions, and models without any reductions. A total of 11 ground motion data sets are used, and the models are analyzed using numerical software. The primary outcome of this study is the generation of fragility curves through Incremental Dynamic Analysis (IDA) for different infill reductions in all models and directions. These fragility curves provide estimates of the probability of collapse, allowing for conclusions regarding the impact of infill wall reductions on structural performance during earthquakes.

**KEYWORDS:** Soft Storey, Infill Walls, Infill Reductions, Incremental Dynamic Analysis, Fragility, Ground Motions.

**INTRODUCTION**

This study investigates the impact of various infill wall reductions in conjunction with the presence of a soft story in building models. The framework for this research includes an understanding of regional tectonic activity, prevailing construction practices, and the application of non-linear analysis methods. The Indian subcontinent, situated on the Indian tectonic plate, is moving towards the Eurasian plate at a rate of 26-36 mm per year. This tectonic movement results in significant activity along the collision zone, making the region highly prone to earthquakes. Approximately 60% of India's landmass is susceptible to seismic events. Over the past two decades, India has experienced several moderate to severe earthquakes, such as the 1988 Bihar-Nepal border earthquake (M6.4), the 1991 Uttarkashi earthquake (M6.6), the 1993 Latur earthquake (M6.3), the 1997 Jabalpur earthquake (M6.0), the 1999 Chamoli earthquake (M6.8), and the 2001 Bhuj earthquake (M6.9), which together resulted in over one lakh casualties due to structural collapses. These earthquakes had widespread effects beyond their epicenters, impacting entire states. The Hyderabad city is the capital of Telangana, India and It is located in the Deccan plateau region of south-central India along the river Musi. It is one of the largest cities in India. The construction activates increases manifold and initiates with mid-rise residential Apartment building for middle-income families and this apartment accommodate the number of population. The parking facilities are mandatory for every mid-rise residential buildings. The many mid-rise building more number in Hyderabad city as compared to low rise and high rise building Dr.B. Narender et.al (2020). However, after events like the 1967 Koyna, 1993 Latur, and 1997 Jabalpur earthquakes, the seismicity of these regions is now questioned. The safety of open ground storey RC buildings for a future event is questionable. In the other hand, The city had experienced seismic activity in the past. For the earthquake of 1876, few felt reports were available in the catalogues for the pre-instrumental period (Ramakrishna Rao, 1989). Seismic activity had also been experienced at Gundipet area was of 3.5 magnitude (June 30, 1983), Medchal event was of 4.0 magnitude, month of January and February 1982 (Rastogi et.al (1985), Kushaiguda event was 1.6 magnitude On August 25, 1984, Saroor Nagar, 2.2 in magnitude , November 29, 1984 and Juble Hills area was 2.0, whereas during the year 1994 (Ramakrishna Rao et.al (1996)). The above areas are in within city premises. The recent Latur Earthquake of 1993 and Jabalpur earthquake of 1997 has proven that the faults in the peninsular region are active and can cause earthquakes. Active zones in the state are the Eastern Ghat belt and Godavari Valley. Though not much of damage occurred due to these events, the earthquake in Killari (M6.3 1993) brought to the forefront the possibility of high risk to urban areas of Telangana state (Raju Sangam et.al (2011)). For this study, accelerograms from earthquakes occurring within the Indian subcontinent were exclusively used. In India, typical residential and commercial buildings often feature stilt or open stories at the ground level to accommodate parking. These stories lack infill walls, significantly reducing their stiffness compared to the upper stories, creating a "soft story" effect. When such structures are exposed to seismic forces, the columns in the soft story are particularly vulnerable, often leading to structural failure and collapse. India has witnessed several devastating earthquakes in the past, resulting in significant loss of life and property damage. Dr. Saraswati Setia et al. (2012) studied the seismic response of a six-story RCC building with a soft story using static non-linear analysis. They concluded that lateral displacements are larger in bare frames compared to structures with infill walls. Additionally, buildings with infill walls only on the upper floors show abrupt changes in displacement due to the sudden change in story stiffness, with maximum story shear occurring in structures with infill walls compared to bare frames. Similarly, Magdy Genidy et al. (2015) analyzed the seismic response of moment-resisting frames with soft stories at different levels and found that the presence of a soft story increases inter-story drifts, influencing the building's seismic behavior. S. Zubair Ahmed et al. (2014) examined the seismic response of building models using dynamic analysis performed with ETABS. The study evaluated building performance based on storey drifts, lateral displacements, lateral forces, storey stiffness, base shear, time period, and torsion. It was found that incorporating a steel braced system significantly enhanced structural stiffness and reduced maximum inter-storey drift and lateral displacement in RCC buildings. The paper discusses the results for bare frames, steel-braced systems, and open bottom storey frames, and draws conclusions based on these findings.F. Hejazi et al. (2011) investigated the impact of soft stories on the structural response of high-rise buildings. The study modeled twelve RC frame buildings in various configurations: (a) soft story at the bottom floor, (b) bracing at the bottom floor, (c) bracing at the center bay, (d) bracing at alternate bays, (e) fully braced bottom floor with an open upper structure, and (f) a completely braced structure. The results indicated that RC frame buildings with open first stories perform poorly during strong earthquakes due to significantly reduced stiffness at the lower floors compared to the floors above. The study concluded that bracing at strategic locations can mitigate the soft story effect and enhance structural performance during seismic events.Magdy Genidy et al. (2015) evaluated the seismic response of moment-resisting frame multi-story buildings with soft stories at various levels using the IDARC 2D program for nonlinear analysis. The study examined models with soft stories at the base, 3rd, 6th, 9th, and 12th levels, focusing on floor displacement, drift, and base shear. The results indicated that buildings with masonry infill walls perform significantly better compared to bare frame models. The presence of a soft story led to a sudden increase in drift at that specific level. Mohammad Reza Sheidaii et al. (2016) conducted Incremental Dynamic Analysis on four-story and eight-story structures with three bays in each direction. The analysis compared knee bracing and diagonal bracing under seismic forces using fourteen different earthquakes. The results showed that diagonal-braced frames experienced significant drift increase due to severe bracing buckling. In contrast, knee-braced frames allowed knee members to yield and absorb energy before buckling occurred, resulting in less drift compared to diagonal-braced frames.Lucia Tirca et al. (2013) performed Incremental Dynamic Analysis on two steel structures: a three-story and a six-story model, using ten ground motions. The study investigated various failure conditions, including connection failures, brace buckling, and overall building failure. The IDA results were used to generate fragility curves, which relate the probability of collapse to spectral intensity. The findings revealed that all brace-to-frame connections failed before the braces reached their maximum compressive strength. Low-rise buildings showed a maximum inter-story drift of 0.6%, while middle-rise buildings experienced up to 0.8% drift due to high-frequency seismic ground motions. Arton Dautaj et al. (2015) discuss the N2 method, highlighting its application for evaluating the seismic performance of both new and existing structures. They also describe its use in direct displacement-based design, where the design begins with a predetermined target displacement. The paper explains that the N2 method provides accurate results and is particularly effective for systems where the seismic response is primarily influenced by the first mode of vibration. Hiroshi Kuramoto et al. (2000) describe a method for converting complex structural systems into equivalent Single-Degree-of-Freedom (SDOF) models. They analyze four types of models: (a) a regular bare frame, (b) a soft first-story model with reduced stiffness at the ground floor, (c) a stiff first-story model with increased stiffness at the ground floor, and (d) a soft middle-story model with varying stiffness at the central story. The study compares the responses of these models as Multi-Degree-of-Freedom (MDOF) and SDOF systems. The results show that for regular-shaped buildings, SDOF models provide good agreement with MDOF responses across various heights. For irregular-shaped buildings, SDOF models effectively simulate the MDOF responses.

In this paper an attempt is made to study the effect of infill brick wall with and without opening on open ground RC framed building which are typical building are existed in Hyderabad city. The two types typical low to mid-rise RC building is selected and linear and nonlinear static analysis is carried out using numerical software and fragility analysis has been carried out.

**METHODOLOGY**

This study outlines a methodology for evaluating the effects of infill wall reductions in RC framed buildings through the following steps: (a) Structural Analysis and Design: Buildings were analyzed and designed using SAP2000 to ensure compliance with standard design requirements, (b) Model Analysis: Modal analysis was conducted to understand the dynamic properties of the structure, including its mode shapes and natural frequencies, (c) Pushover Analysis: Pushover analysis developed the backbone curve, illustrating the non-linear behavior of the structure under increasing lateral loads, (d) Fragility Analysis: Fragility curves were created using Incremental Dynamic Analysis (IDA) with the MATLAB-based II-DAP software by Ahmed Elkady and Dimitrios G. Lignos. Fragility curves plot peak ground acceleration against the probability of damage, estimating the structure's vulnerability. The IDA method, supported by studies such as those by Konstantinos Bakalis et al. (2018), is efficient for developing these curves. The conversion of MDOF models to SDOF models for IDA is guided by methods like the N2 method by Fajfar, as noted by Arton Dautaj et al. (2015) and Hiroshi Kuramoto et al. (2000), with additional insights from Dimitrios Vamvatsikos (2014).

**BUILDING MODELLING**

In this study, two structural models are considered: a three-story and a five-story building. These models are categorized into four distinct types based on the presence and configuration of walls: Model 1: Bare frames without any walls, Model 2: Soft story models with reductions in exterior walls, Model 3: Soft story models with reductions in both exterior and interior walls, Model 4: Models without any wall reductions and The configurations for these models are illustrated in fig.1. The effects of infill walls were modeled as equivalent struts per IS 1893-2016. Wall area reductions, due to door and window openings, follow typical sizes and wall thicknesses from general construction practices: main doors (1.2m x 2.0m), bedroom doors (1.0m x 2.0m), main hall windows (1.8m x 1.35m or 1.5m x 1.2m), bedroom windows (1.2m x 1.35m or 1.2m x 1.2m), and kitchen windows (0.9m x 1.05m or 0.6m x 1.35m), windows with various sizes, and wall thicknesses of 230mm for exterior and 150mm or 115mm for interior walls. The buildings' plot dimensions are 195 sqy and 693 sqy are consider in this study which is typical building in urban center. Loads were calculated using IS 875, with dead load densities from Part I and imposed loads from Part II and Dead loads for walls with thicknesses of nine inches and six inches (external and internal, respectively) were assigned to corresponding beams. Materials used include M25 and M30 concrete and Fe500 steel. Concrete design followed IS456-2000, with reinforcement details developed using SAP2000, as shown in Table.1 represents the buildings details of three and five story models, Fig.2 & 3 represents the typical plan column and strut placement, 3D frame view of the building model without infill walls and with infill walls represented as struts for three storey and five story models.

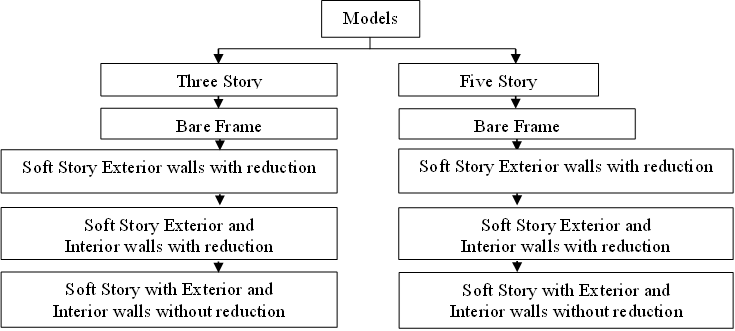
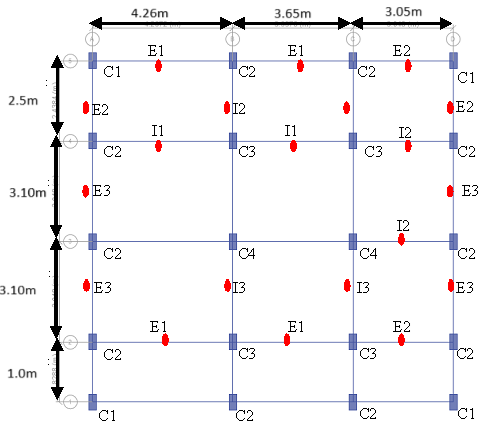
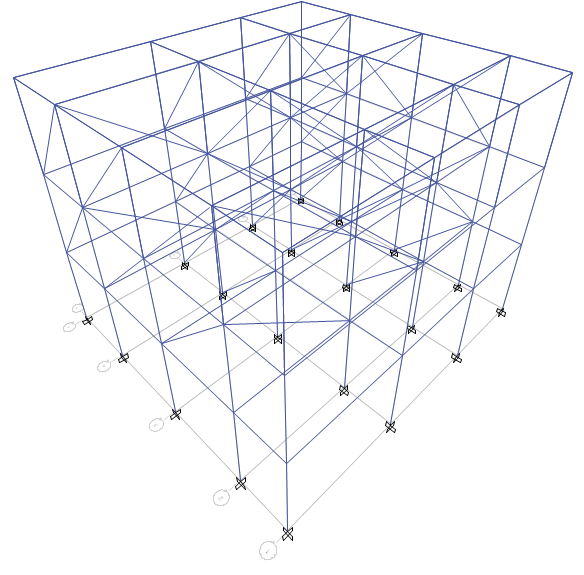
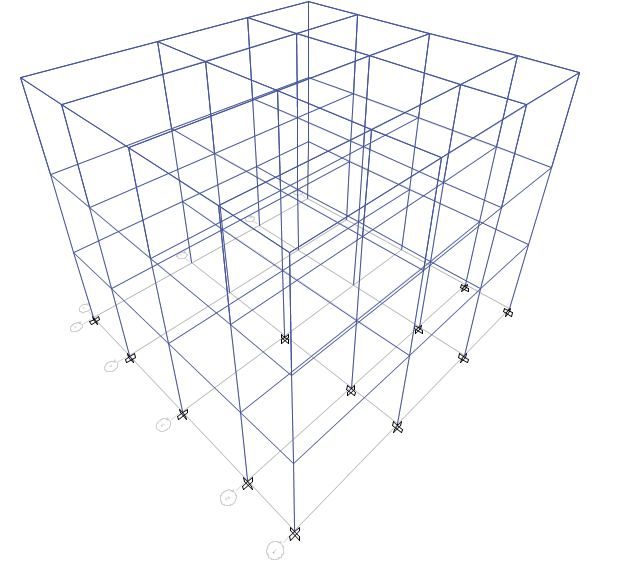


Fig.1Flow chart of model development

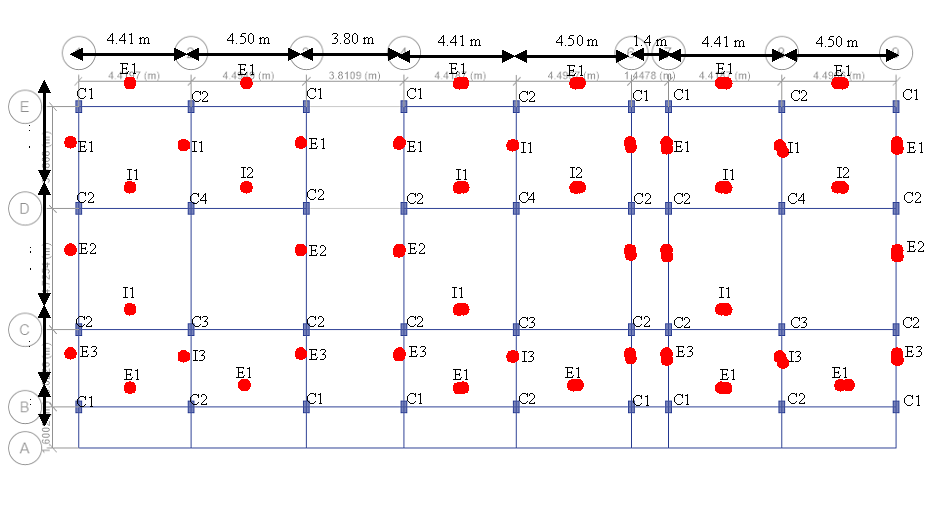
**Table 1 Buildings details**

|  |  |  |
| --- | --- | --- |
|  | **Three story** | **Five story** |
| Plot Dimensions | 12.19m x 12.80m | 36.85m x 16.0m |
| Built Up Dimensions | 10.97m x 10.36m | 32.27m x 13.56m |
| Plot Area | 156.03Sqm | 589.6Sqm |
| Built Up Area | 113Sqm | 437.58Sqm |
| No of stories | 3 | 5 |
| Ground story height | 3m | 3m |
| Typical Story height | 3m | 3m |

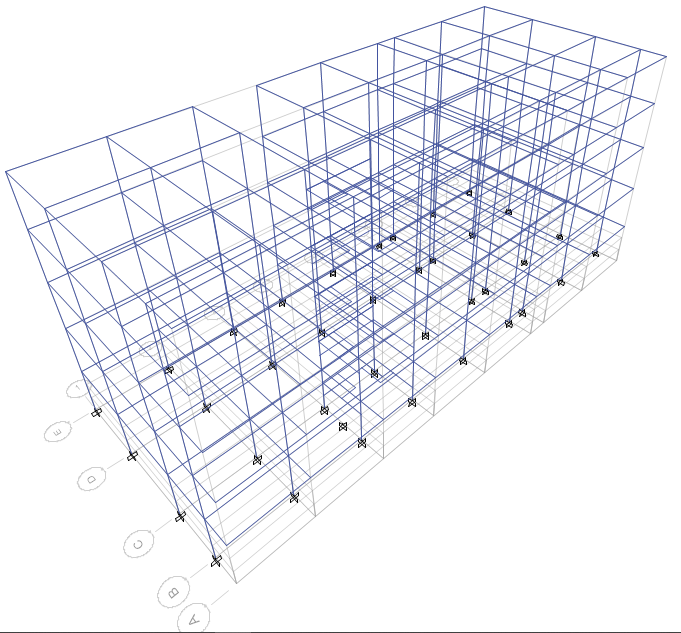
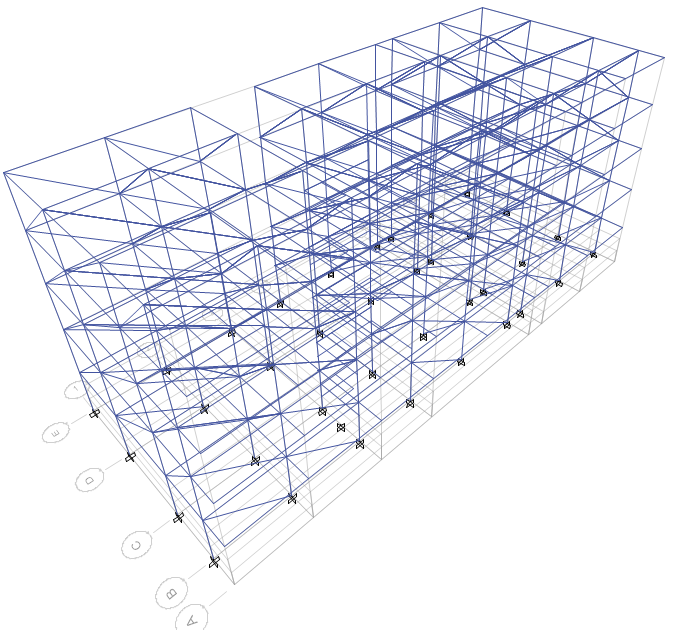
 

(a) (b) (c)

Fig.2 (a) Column and strut placement, (b) Three story bare frame and (c) Three Story with infill walls as struts.



(a)

(b) (c)

Fig.3(a) Column and strut placement, (b) Five story bare frame, (c) Five Story with infill walls as struts

**INFILLWALL REDUCTION**

In the structural model, the infill walls are represented as equivalent diagonal struts in accordance with the IS 1893-2016 provisions. The development of these struts is based on the standard formula provided for equivalent strut modelling. The struts are designed using the Section Designer tool and are modeled as pin-jointed frames, which effectively capture the behavior of infill walls during seismic events. To account for the presence of openings such as doors and windows, the area of these openings is subtracted from the total area of the wall. This reduction in area is crucial for accurately representing the structural capacity of the infill walls. Specifically, a 12% reduction in the infill area is applied to both internal and external walls that contain such openings. This adjusted area ensures that the model realistically reflects the reduced stiffness and strength of the walls. The axial load carried by each strut is calculated based on the density of the masonry material used in the infill walls. The width of the equivalent diagonal strut is also considered in the development of axial hinges during the pushover analysis. The axial load for each strut is determined by calculating the total weight of the wall and dividing it by the area of the strut, providing a realistic representation of the forces the wall would experience. This method of modeling ensures that the impact of infill walls on the overall seismic performance of the structure is accurately captured, taking into account the reduced area due to openings and the material properties of the masonry. The details of struts located in the Fig.2 and Fig.3 their dimensions and axial loads are represented in the Table 2. Table 3 outlines the details of the sections utilized in the three-story and five-story buildings. The specific locations of these sections within the structures are depicted in Fig.2 and 3. Additionally, Table 4 presents the moment-curvature relationships and axial load values corresponding to the sections listed in Table 3.

**Table 2** Strut details

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Location | Type |  | Three story | | | Five story | | |
| Reduction Percentage | Width (mm) | Breadth  (mm) | Axial load(Kn) | Width (mm) | Breadth  (mm) | Axial load(Kn) |
| Exterior 1 | without reduction | 0 | 230 | 502 | 615 | 230 | 552 | 682 |
| with reduction | 12.08% | 230 | 502 | 535 | 230 | 552 | 593 |
| Exterior 2 | without reduction | 0 | 230 | 458 | 561 | 230 | 522 | 645 |
| with reduction | 12.08% | 230 | 458 | 488 | 230 | 522 | 561 |
| Exterior 3 | without reduction | 0 | 230 | 414 | 507 | 230 | 482 | 596 |
| with reduction | 12.08% | 230 | 414 | 441 | 230 | 482 | 518 |
| Interior 1 | without reduction | 0 | 150 | 532 | 422 | 150 | 576 | 464 |
| with reduction | 12.08% | 150 | 532 | 367 | 150 | 576 | 403 |
| Interior 2 | without reduction | 0 | 150 | 478 | 385 | 150 | 545 | 439 |
| with reduction | 12.08% | 150 | 478 | 334 | 150 | 545 | 381 |
| Interior 3 | without reduction | 0 | 150 | 432 | 348 | 150 | 503 | 405 |
| with reduction | 12.08% | 150 | 432 | 302 | 150 | 503 | 352 |

**Table 3** Reinforcement details

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Three story** | | | | **Five story** | | | |
|  | **Breadth** | **Depth** | **Rebar** | **Grade** | **Breadth** | **Depth** | **Rebar** | **Grade** |
| C1 | 230 | 410 | #12@16mmØ | Fe500, M30 | 230 | 460 | #12@18mmØ | Fe500, M30 |
| C2 | 230 | 410 | #12@18mmØ | Fe500, M30 | 230 | 460 | #12@20mmØ | Fe500, M30 |
| C3 | 230 | 410 | #12@20mmØ | Fe500, M30 | 230 | 460 | #12@22mmØ | Fe500, M30 |
| C4 | 230 | 410 | #8@18mmØ  #4@20mmØ | Fe500, M30 | 230 | 460 | #8@22mmØ  #4@25mmØ | Fe500, M30 |
| B1 | 230 | 360 | #6@14mmØ | Fe500, M25 | 230 | 370 | #6@14mmØ | Fe500, M25 |
| B2 | 230 | 360 | #6@14mmØ | Fe500, M25 | 230 | 370 | #6@16mmØ | Fe500, M25 |

**Table 4** Moment-curvature and axial load values for columns and beams

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Three story** | | | | | **Five story** | | | | |
| **Member** | **My** | **Mu** | **Øy** | **Øu** | **P** | **My** | **Mu** | **Øy** | **Øu** | **P** |
| C1 | 132.7 | 152 | 0.007 | 0.70 | 1846 | 157.0 | 198 | 0.006 | 0.38 | 1998 |
| C2 | 145 | 172.15 | 0.01 | 0.70 | 2069 | 196 | 243 | 0.009 | 0.6 | 2333 |
| C3 | 170 | 209 | 0.01 | 0.72 | 2180 | 239 | 308 | 0.01 | 0.6 | 2507 |
| C4 | 207 | 264 | 0.001 | 0.70 | 2355 | 292 | 371 | 0.01 | 0.6 | 2857 |
| B1 | 48.98 | 78.0 | 0.008 | 0.49 | - | 50.98 | 78.21 | 0.008 | 0.50 | - |
| B2 | 58.6 | 82.7 | 0.008 | 0.87 | - | 60.1 | 81.6 | 0.009 | 0.60 | - |

**PUSHOVER ANALYSIS**

The pushover analysis was conducted for the structural model in both the X and Y directions. To capture the nonlinear behavior of the structure, hinges were strategically assigned along the members. Specifically, hinges were placed at 0.1% and 0.95% of the relative distance along the length of the members. For columns, P-M2-M3 hinges were used, while M2-M3 hinges were assigned to the beams. The analysis utilized a monitored displacement control approach, where the displacement was controlled up to 4% of the building's height. This method allows for a detailed understanding of the structure's performance under increasing lateral loads, simulating seismic forces. The load case pattern for this pushover analysis included an acceleration load pattern, which was applied in combination with 100% of the dead load and 25% of the live load, in accordance with IS 875 Part I & Part II. This combination ensures that the structural model accurately represents the expected load conditions during a seismic event. Additionally, lateral loads were introduced in the form of earthquake ground motions through Incremental Dynamic Analysis Procedures (II-DAP). The following Table 5 summarizes the load intensities and load cases used in the pushover analysis, providing a comprehensive overview of the applied forces and conditions.The analysis is performed twice, initially for the pushover analysis and then again from the outputs obtained from the pushover analysis the analysis is again performed using the Incremental Dynamic analysis using the Scaled set of ground motions as represented in Table 6, for the pushover analysis the results obtained are converted into equivalent SDOF parameters using the N2 method and they are further used in the II-DAP for performing IDA from the same II-DAP collapse fragility curves are obtained from the IDA curves by using the Lognormal Distribution Function all the ground motions are scaled from 0.1g to 2.0g with an increment of 0.1g Intensity measure this ground motions are scaled on the basis of peak acceleration values in each of the ground motion file and are divided with all the acceleration points to get a accelerogram of 1.0g and then it is multiplied with 0.1g increments to get the complete set of ground motions for each earthquake.

**Table 5 Details of Loadings**

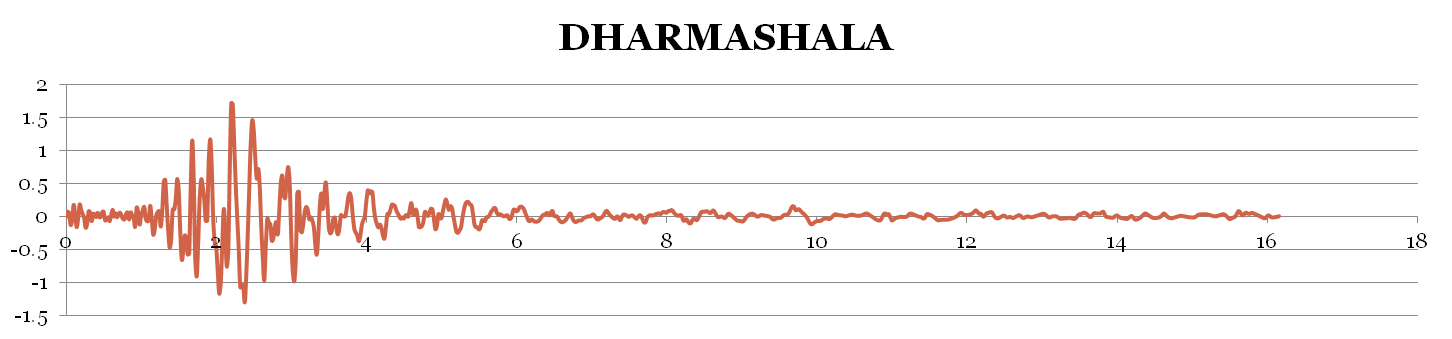
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No** | **Load Case** | **Component** | **Load Type** | **Application** | **Intensity** |
| 1 | Dead Load | External Walls | UDL | External Beams | 13kN/m |
| 2 | Internal Walls | UDL | Internal Beams | 9kN/m |
| 3 | Parapet Walls | UDL | Roof beams | 6kN/m |
| 4 | Floors-Floor finish | UDL | All slabs | 1.5kN/m2 |
| 5 | Live Load | Hall, kitchen, bedroom, toilet | UDL | Slabs | 2kN/m2 |
| 6 | Corridors, balconies | UDL | Slabs | 3kN/m2 |

**INCREMENTAL DYNAMIC ANALYSIS**

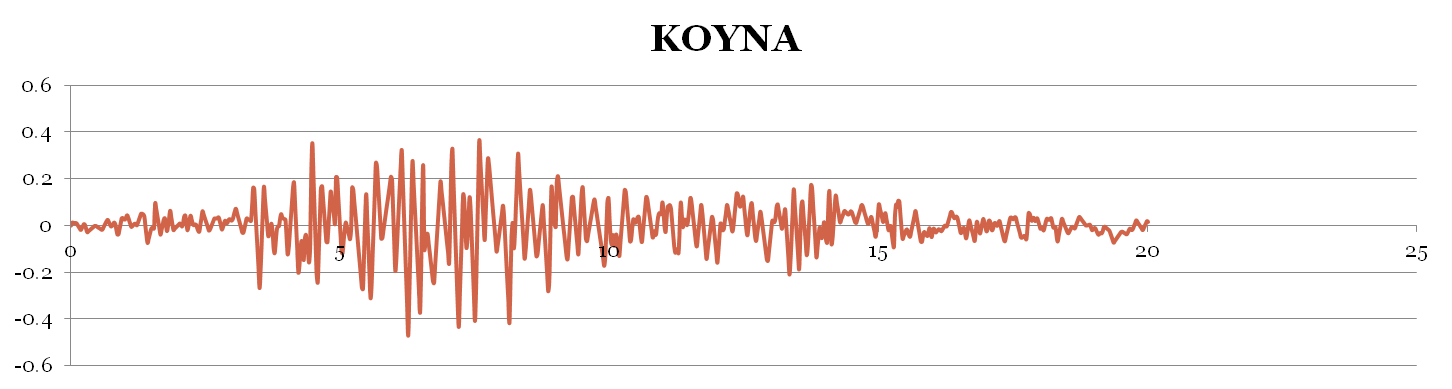
Incremental Dynamic Analysis (IDA) involves performing a series of time history analyses on a structure subjected to multiple ground motions, with incremental increases in the intensity measure of the given ground motion. IDA curves are plotted with the intensity measure against the displacement of the structure, providing an estimate of the structure's capacity to withstand increasing ground motion intensity without collapsing. To develop these curves, a set of scaled ground motions from 11 earthquakes that occurred in the Indian subcontinent, as represented in Table 6, were used and typical ground acceleration as shown in fig.4. These ground motions were initially scaled to 1.0g and then incrementally increased by 0.1g, resulting in a range of scaled ground motions from 0.1g to 2.0g.The outputs from the pushover curve were converted into a Single-Degree-of-Freedom (SDOF) system using the N2 method. These outputs were then used in the II-DAP software to perform the incremental dynamic analysis. Figure 5 shows sample accelerograms from a couple of the earthquakes used in the study.

**Table 6** Ground Motion Data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.no** | **Name of Earthquake** | **Location** | **Date** | **Magnitude** |
| 1 | Bhuj | Kutch-Gujarat | 26-01-2001 | 7.7 |
| 2 | Chamba | Chamba-Himachal | 24-03-1995 | 5.1 |
| 3 | Chamoli(Main Shock) | Chamoli | 29-03-1999 | 6.8 |
| 4 | Dharmashala | Kangra-Himacal | 26-04-1986 | 5.5 |
| 5 | India Shillong | Meghalaya-Assam | 10-09-1986 | 5.2 |
| 6 | Uttarkashi | Uttarakshi | 20-10-1991 | 6.8 |
| 7 | India-Burma Border | Shilong | 06-08-1988 | 7.3 |
| 8 | Koyna | Koynanagar Maharashtra | 11-12-1967 | 6.6 |
| 9 | Nepal-Gorkha | Ghokra Nepal | 25-04-2015 | 7.8 |
| 10 | Sikkim | Kanchenjunga | 11-09-2011 | 6.9 |
| 11 | India-Nepal | Northeast India | 06-08-1988 | 6.5 |



(a)



(b)

Legend: - X-Axis Time (Sec) Y-Axis Acceleration (g)

Fig.4 (a) Dharamshala accelerogram (b) Koyna accelerogram

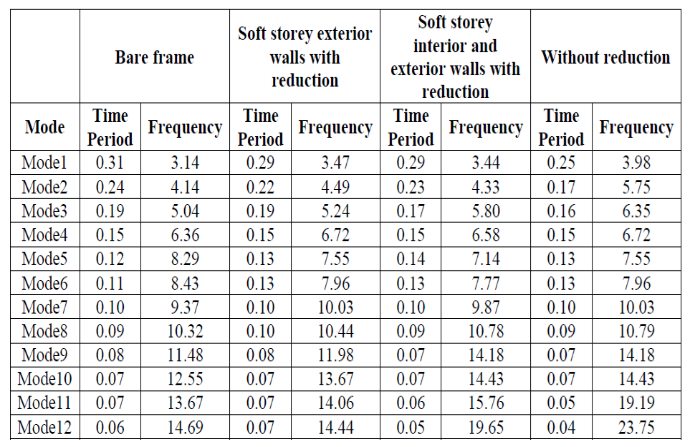
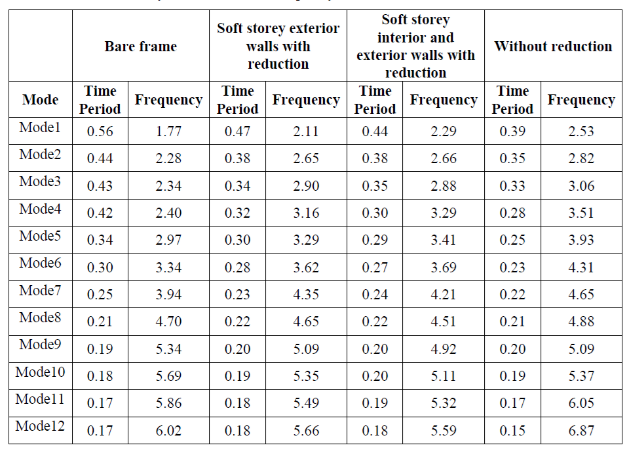
**RESULTS AND DISCUSSION**

**MODEL ANALYSIS**

Table 7(a) indicates that for the three-story structure, adding struts significantly reduces the time period. The model with no reduction shows the shortest time period due to higher stiffness and increased mass, while the bare frame, with the lowest stiffness, has the longest time period. Time period decreases by 9% from the bare frame to the soft story with exterior walls. No change in the first mode time period between the soft story with exterior walls and the model with both exterior and interior walls. Time period decreases by 14% from the soft story with interior and exterior walls to the no-reduction model. Time period decreases by 20% from the bare frame to the no-reduction model. Table 7(b) shows that for the five-story structure, increasing mass by adding struts also reduces the time period. The no-reduction model has the shortest time period. Time period decreases by 17% from the bare frame to the soft story with exterior walls. Time period decreases by 7% between the soft story with exterior walls and the model with both exterior and interior walls. Time period decreases by 12% from the soft story with interior and exterior walls to the no-reduction model. Time period decreases by 31% from the bare frame to the no-reduction model. In both structures, the time period increases with building height. As walls are added, the increased mass reduces the time period. The order of observed time periods is: Bare Frame, Soft Story without Interior Walls, Soft Story with Interior Walls, and No Reduction. Models with larger lateral dimensions show a higher time period.Top of Form

**Table 7(a)** Time period of three storey buildings **Table 7(b)** Time period of five storey buildings

Bottom of Form

**PUSHOVER ANALYSIS**

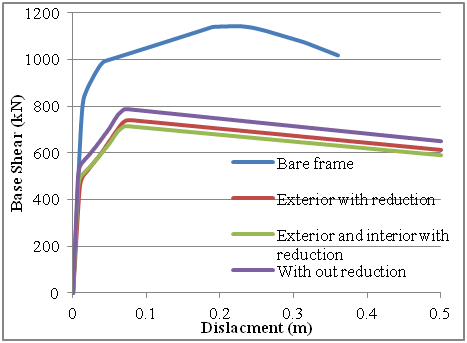
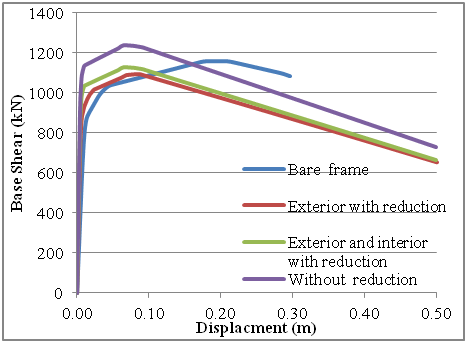
Figure 5 illustrates the pushover curves for all eight models in both the X and Y directions. The moment curvature relationship of the structural elements plays a major role while defining hinges for the pushover analysis, depending on the moment curvature relationship of a element the hinges developed in the element will change from different damage states while performing pushover Analysis. The following are the moment curvature graphs plotted for a beam and column in both the Three-storey and Five-storey model which are generated using the section designer tool in the SAP2000. The materials in the section designer are of Mander concrete model with confined reinforcement according to IS456:2016. It is observed that with the increase of area of steel and cross sectional area of section the yield moment is increasing. For the three-story models, the bare frame exhibits the highest base shear values in both directions, likely due to the absence of a soft story, which enhances its overall stiffness. This is followed by the model without infill wall reductions, which shows the second highest base shear values. The models with reduced exterior and interior walls, and those with only exterior wall reductions, show progressively lower base shear values. In the five-story models, the trend is slightly different. The model without any reductions in the infill walls has the highest base shear value, followed by the model with both exterior and interior wall reductions, then the model with only exterior wall reductions, and finally the bare frame model. Unlike the three-story models, the pushover curves for the five-story models show significant differences between the X and Y directions, attributed to the 1:2 aspect ratio of the lateral dimensions in the five-story model, compared to the 1:1 aspect ratio in the three-story model. Overall, models without any reductions in infill walls demonstrate the highest base shear values, highlighting the importance of stiffness provided by the full infill walls. it is observed that the formation of hinges in bare frame models initial hinges are forming in the beam elements and are then forwarding to the adjacent columns and similarly forming all over the structure, where as in the models with soft story effect the initial hinges are forming at the bottom storey columns then the external walls and then the internal walls hinge formation is taking place it is observed that the models with external and internal walls are showing better performance and the required sequence of hinge formation when they are subjected to the pushover, the hinge formations are also observed in both the X and Y directions in this the models having larger widths in the direction are subjected to form hinges at higher pushover loads rather than the models having lesser widths this is due to the formation of the stiffness increases with the length , larger the length higher will be the stiffness and higher the load required for the formation of hinges similarly when the models are with external and internal walls the stiffness is increased as a result the above scenario is been repeated

**INCREMENTAL DYNAMIC ANALYSIS**

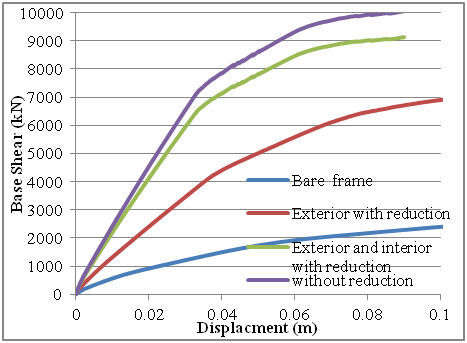
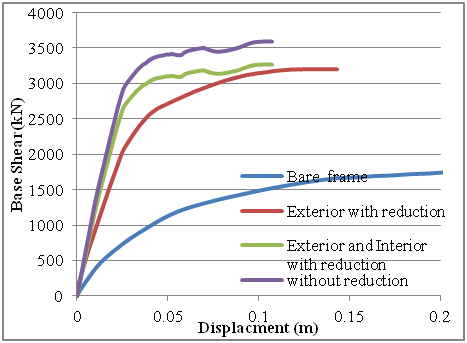
To develop the Incremental Dynamic Analysis (IDA) plots, outputs from the pushover analysis were converted from a Multi-Degree-of-Freedom (MDOF) system to an equivalent Single-Degree-of-Freedom (SDOF) system. Key parameters considered include story masses, story displacements, base shear, and roof displacement values at yield, maximum, and ultimate stages. Fig.6 to presents typical IDA plots for the four models. The results indicate that all three-story models reach the complete damage stage at a ground motion intensity of approximately 1.0g. In contrast, the five-story model in the X direction withstands higher ground motion intensities, up to 2.0g, due to its longer length in the X direction. Among the ground motions considered, the Dharamshala earthquake subjected the structure to damage more quickly at lower intensity levels. Following Dharamshala, the Bhuj, Ghokra, Uttarkashi, Koyna, Chamoli, and Sikkim earthquakes also pushed the structures to reach their damage stages relatively quickly.

**FRAGILITY CURVES**

Fig7 to 10 depict the fragility curves for four damage states across all eight models in both X and Y directions. These curves were developed from the IDA plots, which were generated using the pushover curves via the II-DAP software. The development of different damage states for the fragility curves is based on the HAZUS MH5 Page 245 Table 2.8 methodology where as the development of the fragility curve of collapse damage state is completely based on the data obtained from the incremental dynamic analysis curves. Threshold values or fragility median values of fragility curves are taken considering the special high code for low rise concrete moment frame from HAZAS MH MR-5 .For the three-story models, the probability of collapse in the X direction is highest for the bare frame model, followed by the models with exterior wall reductions, exterior and interior wall reductions, and finally the model without any reductions. In the Y direction, the probability of collapse is also highest for the bare frame model, with the other models following a similar trend as in the X direction. In the five-story models, the probability of collapse in the X direction is consistent across all four models, following the order: bare frame, exterior wall reductions, exterior and interior wall reductions, and no reductions. In the Y direction, the probability of collapse follows the same pattern. Overall, the fragility is observed to be higher in models with shorter lateral dimensions. As the length of the building's side decreases, the fragility increases. The bare frame model performs more efficiently in the three-story structure compared to the other models. In the five-story models, the structure without any reduced infill walls shows the lowest probability of collapse, indicating superior performance compared to the other three models.

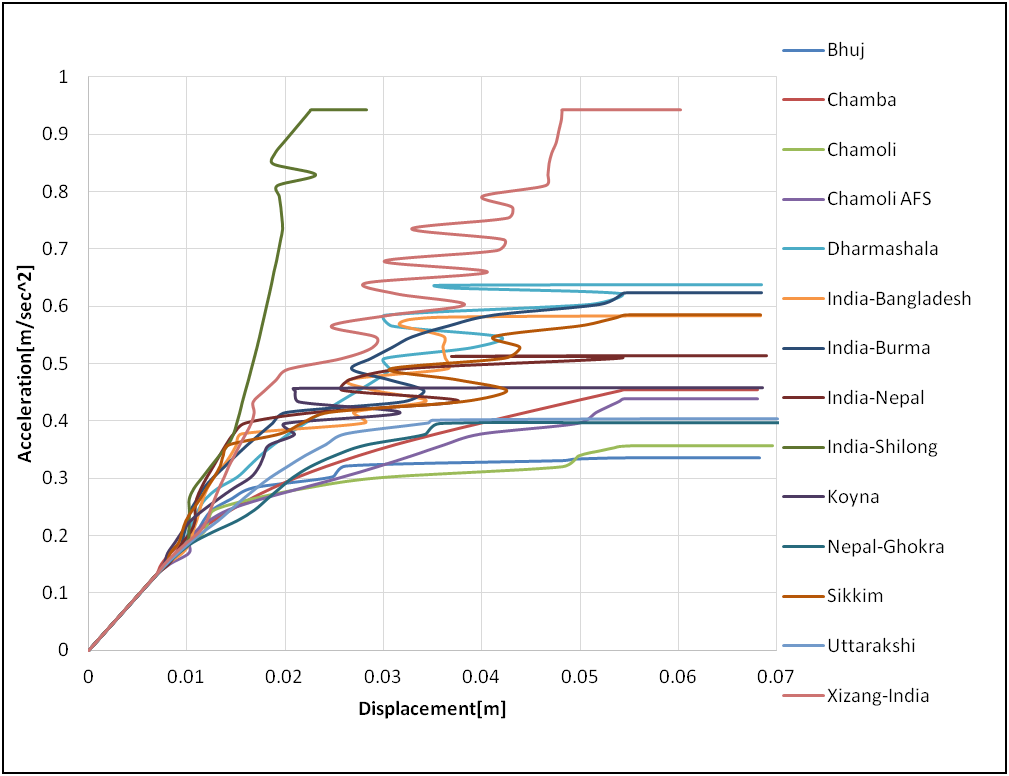
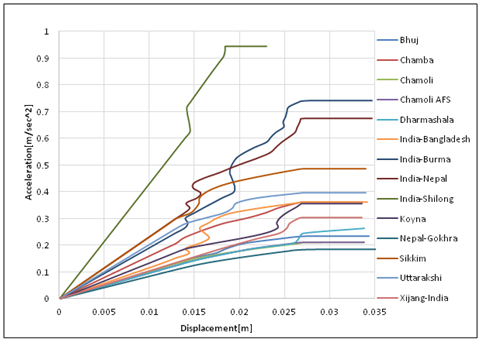
 

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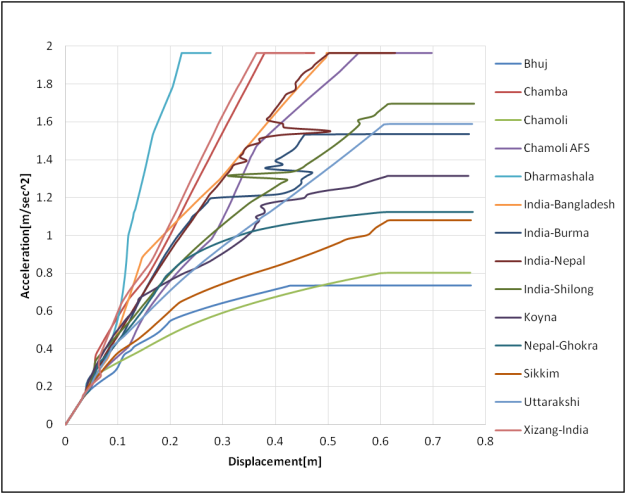
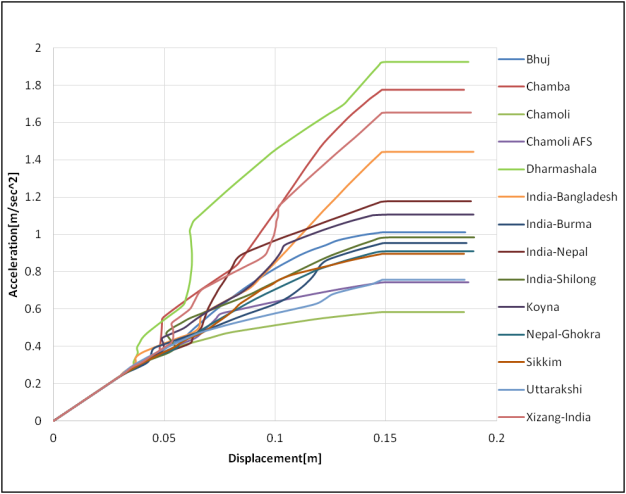
 

(c) (d)

Fig.5 Pushover curves (a) Three story X-direction (b) Three story Y-direction (c) Five story X-direction (d) Five story Y-direction

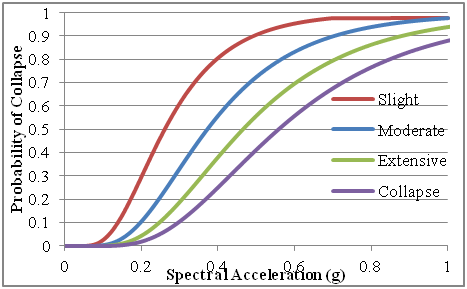
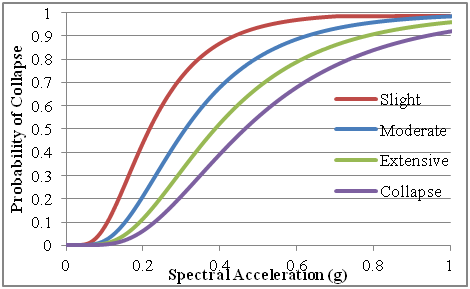


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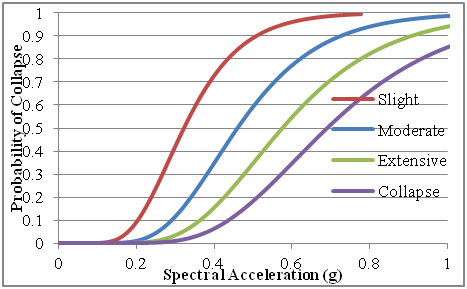
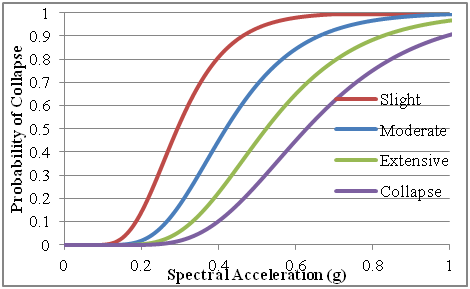
 

(c) (d)

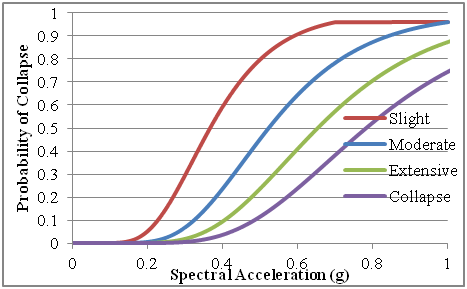
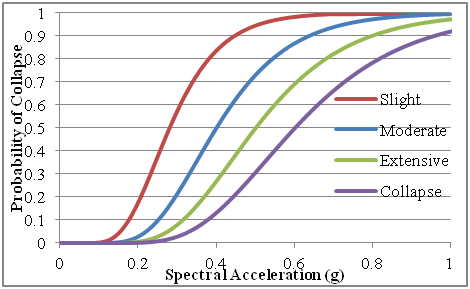
Fig.6 IDA Plots (a) Three story bare frame X-direction (b) Three story exterior walls with reduction Y-direction (c) Five story exterior walls with reduction X-direction (d) Five story without reduction X-direction



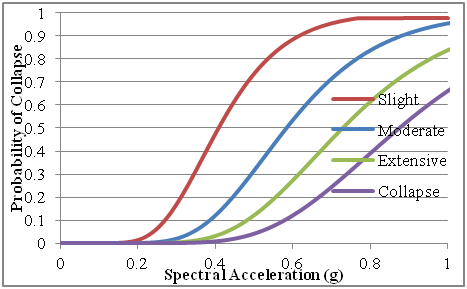
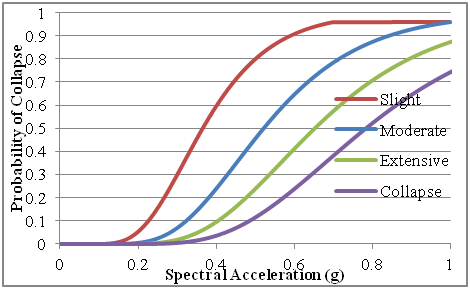
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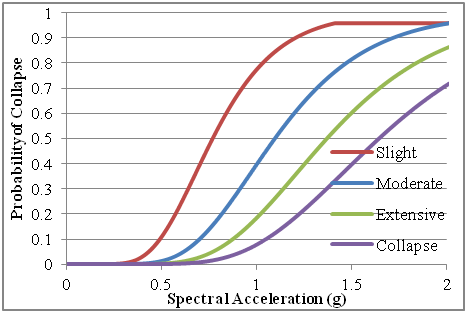
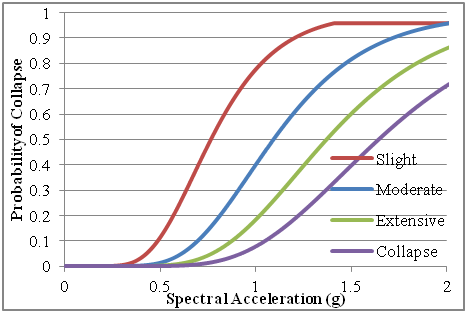
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Fig.7 Fragility Curves Three story X-Direction (a) Bare frame (b) Exterior with reductions (c) Exterior and Interior with reduction (d) without reduction



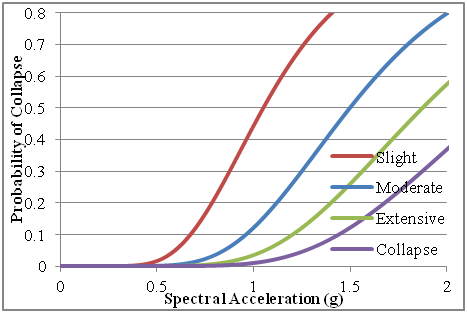
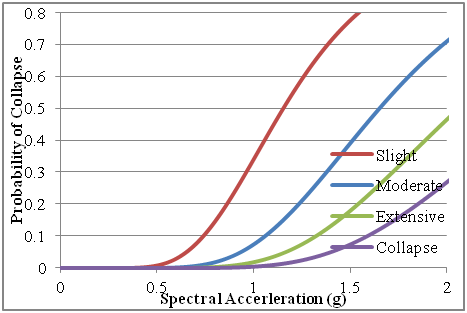
(a) (b)



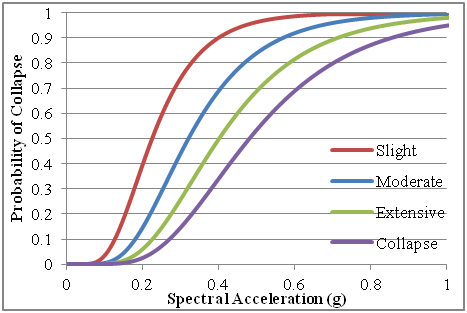
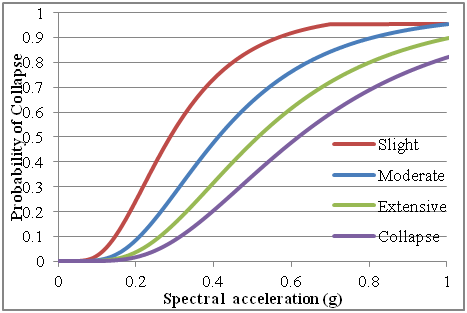
(c) (d)

Fig.8 Fragility Curves Three story Y-Direction (a) Bare frame (b) Exterior with reductions (c) Exterior and Interior with reduction (d) without reduction. 

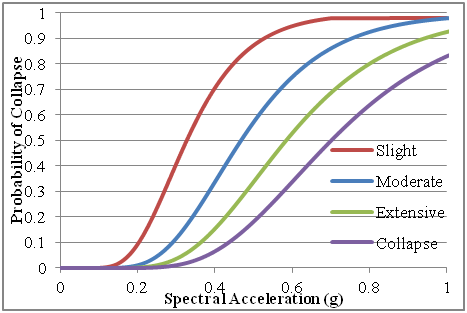
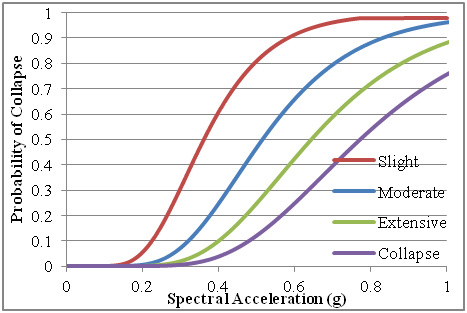
(a) (b)

(c) (d)  
Fig.9 Fragility Curves Five story X-Direction (a) Bare frame (b) Exterior with reductions (c) Exterior and Interior with reduction (d) without reduction

(a) (b)

(c) (d)  
Fig.10 Fragility Curves Five story Y-Direction (a) Bare frame (b) Exterior with reductions (c) Exterior and Interior with reduction (d) without reduction

**CONCLUSIONS**

The comparison of infill walls with varying degrees of reduction using fragility curves reveals that reductions in infill walls significantly increase a structure's vulnerability to earthquakes, potentially leading to greater losses. The structural integrity of a building is strongly influenced by the pattern of infill wall placement and the percentage of reductions made to accommodate openings for doors and windows. The presence of a soft story in a structure further exacerbates its susceptibility to seismic events.

* The time period of a structure increases with height and decreases with mass. For a three-story bare frame, the first mode time period is 0.31 seconds, while for a five-story frame, it is 0.47 seconds. Adding interior walls reduces the time period: 0.31 seconds (three-story bare frame) vs. 0.29 seconds (three-story with walls) and 0.56 seconds (five-story bare frame) vs. 0.43 seconds (five-story with walls).
* In bare frame models, hinges form initially in beams and then progress to columns. In models with infill walls, hinges form first in the struts and then propagate to beams and columns, which is preferable for localized damage.
* Bare frame models exhibit lower base shear and displacement at yield compared to models with walls due to lower stiffness. Larger plan dimensions lead to higher base shear values during pushover analysis.
* Fragility and IDA results indicate a higher probability of collapse for bare frame models, which reach higher damage stages with lower ground motion intensity.
* Three-story structures are more vulnerable to earthquakes in Chamba and Chamoli, while five-story structures are at higher risk in Bhuj, Dharamshala, and Uttarkashi.
* Fragility increases with decreasing lateral dimensions and decreases with increasing plan dimensions. Models without reductions in infill walls perform better, showing a lower probability of collapse. Reductions in infill walls increase vulnerability to earthquakes. Structural integrity is significantly affected by the placement pattern of infill walls and the extent of reductions for openings.
* The height and plan dimensions of a structure are interdependent. Increasing height with the same plan dimensions raises fragility, whereas increasing plan dimensions reduces fragility. The presence of a soft story further increases susceptibility to earthquakes.

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