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SEISMIC VULNERABILITY OF BUILDINGS IN HILLY AREAS

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OF
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Submitted By:
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I, Ishant Singhal, Roll No. 2K19/STE/09 student of M. Tech (Structural Engineering), hereby declare that the project dissertation titled "SEISMIC VULNERABILITY OF BUILDINGS IN HILLY AREAS" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

This is to certify that the project report entitled "**Seismic Vulnerability of Buildings in Hilly Areas",** is the bonafide work of **Ishant Singhal** for the award of Master of Technology in Structural Engineering from Department of Civil Engineering, Delhi Technological University, Rohini, Delhi. The work has been carried out fully under my supervision. The content and results of this report, in full or in parts has not been submitted to any other institute or university for the award of a degree.

Hdubey 01/09/21

Place: Delhi
Date: 01/09/2021

Mr. HRISHIKESH DUBEY
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Singhal

ISHANT SINGHAL

ABSTRACT

Buildings on hill slopes have considerably different structural configurations than those on level land. The most popular layouts of structures on slopes have been commonly taken as step-back, step-and set-back designs, and sometimes for steep slopes, foundations sitting on two separate levels have been recorded during extensive field studies in the Indian Himalayan regions. The study in this paper focuses on the comparison of split foundation hill building and step-back hill buildings by response spectrum analysis, time history analysis, and fragility analysis (using Pushover Analysis). In this zone IV with rock and hard soil is considered for analysis.

In this study both the configurations are subjected to acceleration time data of earthquake at Uttarkashi in Oct 1991 (M_w=6.8, PGA=0.31g) and the analysis results of split foundation building and step back building are compared. It is observed that the step back building is more suitable in hilly areas as compared to split foundation designed building as step back building gives less displacement, less drift, less shear etc.

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CHAPTER 1

INTRODUCTION

From Jammu and Kashmir in the north to Arunachal Pradesh in the east, the Indian Himalayas encompass Himachal Pradesh, Uttarakhand, Meghalaya, Manipur, Nagaland, Mizoram, Tripura, Sikkim, Assam, and West Bengal. Several devastating earthquakes struck the above regions in the last century, including the earthquakes in Kangra (1905), Bihar and Nepal (1934), Assam (1950), Bihar and Nepal (1988), Uttarkashi (1991), Chamoli (2005), and Sikkim (2011).

The earthquake in Sikkim, India, in 2011 revealed the seismic susceptibility of multi-story buildings in the Indian Himalayas. According to the seismic zoning map of India, Sikkim is in Zone IV, which has an EPGA of 0.24g, but the destruction seen at 0.18g PGA was way higher than the expected damage, which could be attributed to the irregular configurations of these buildings, poor quality of materials used, and the fact that they were never designed to withstand earthquakes. However, the rising urbanisation of these areas increases the demand for earthquake-resistant structures in order to reduce the loss of life and property.

Structures on hill slopes have distinct structural configurations than buildings on flat land. In general, for mild slopes, building foundation levels follow the natural slope of the land, i.e., “Step Back,” while for steep slopes, buildings with “Split foundation” are common. The present paper discusses about the seismic vulnerability of the structures of two different types i.e., Step-Back, and split-foundation building and also discusses their seismic responses such as storey displacement, storey drift, storey force, spectral acceleration, base shear etc. when subjected to different sets of ground motion. The work discussed below includes the use of E-tabs software for response spectrum, time history analysis and pushover analysis.

CHAPTER 2

LITERATURE STUDIES

2.1 General

The literature studies have been summarized in this chapter based on research and findings of each author sequentially into three parts. The first part includes the scope of the research and methodologies developed during the research. The second part contains the conclusions drawn by the author after his research. The third part compiles the results derived from the studies which are relevant and beneficial to our project.

2.2 Literature Studies

The seismic assessments performed on 24 RC buildings with three various designs such as Step-back building, Step-back Set-back building, and Set-back building are provided by **B.G. Birajdar** and **S.S. Nalawade**. The response spectrum method was used to perform a three-dimensional study that included the torsional effect, the dynamic response features of a building layout on sloping terrain have been investigated. In case of hill ground slopes, it has been discovered that step-back set-back buildings are better suitable.

The following results were drawn based on dynamic study of three alternative building configurations:

- During seismic excitation, the performance of STEP back buildings may be more vulnerable than other building layouts.
- Torsional moments emerge more quickly in Step-back buildings rather than in Step-back Set-back buildings. As a result, Step-back Set-back buildings are shown to be at less risk to seismic ground motion than Step-back buildings.
- The extreme left column at ground level, which is short, is the worst affected in Step-back buildings and Step-back-Set back buildings. These columns should be given special attention.
- Although Set-back buildings on flat ground generate fewer action forces than Step-back Set-back structures, the overall economic cost of levelling the sloping terrain, as well as other relevant factors, must be thoroughly investigated.

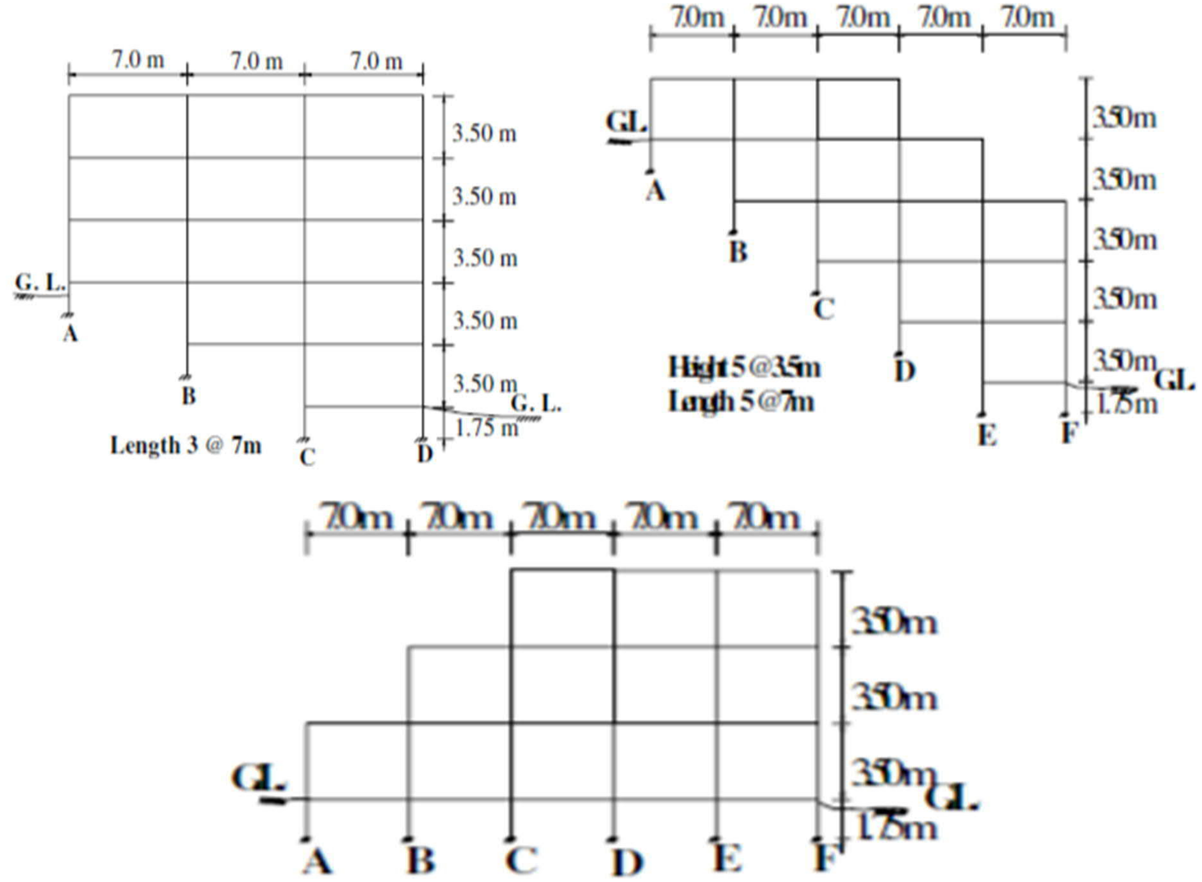


Figure 1. Step Back Building, Step Back Set Back Building on Sloping Ground and Set Back Building a Flat Ground

A.R. Vijaya Narayanan, Rupen Goswami and C.V.R. Murthy presents consequences of nonlinear investigations performed on run of the mill structures on steep slope inclines with two potential sorts of section base network to the ground. RC buildings with big plan sizes (either in the valley direction or in the road direction) are vulnerable to intense seismic shaking, according to the report. For development along steep hill slopes, only compact plan structures are best. Columns of different lengths along the slope are common characteristic of these structures, as is the lack of a solid foundation sufficiently embedded in the soil beneath to give enough translational fixity under lateral seismic shaking.

This study looked at two structures, A and B, each of which had three storeys above and four stories below ground level, but with different restrictions at the foot of the columns. Except for the tallest valley side column, Building A has permanent column bases while Building B has roller column bases.

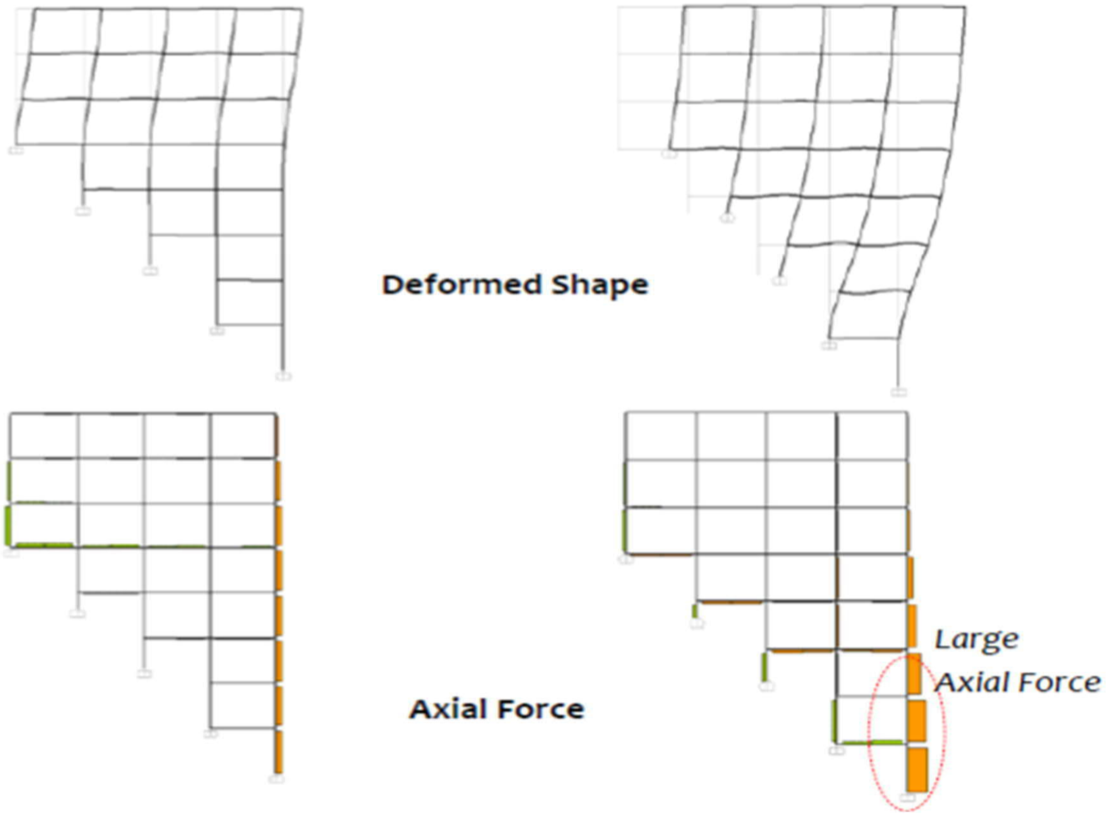


Figure 2. Deformed Shape and Axial Force in Building A and Building B

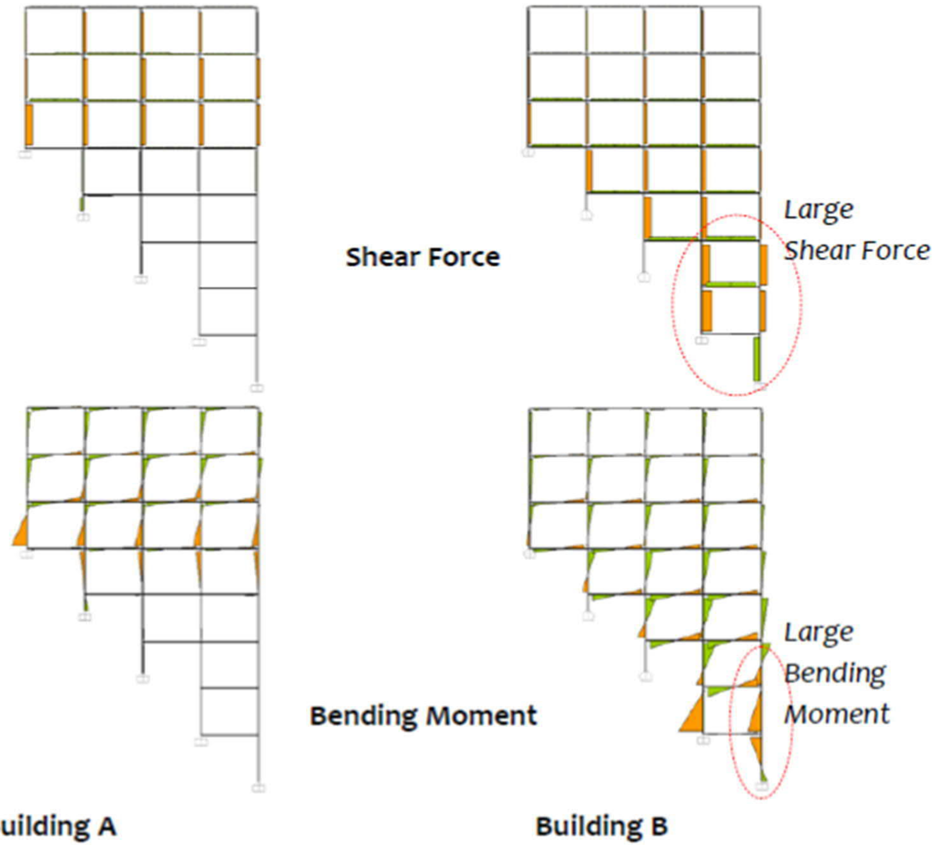


Figure 3. Shear Force and Bending Moment in Building A and Building B

Most section bases lose contact with the dirt during solid shaking, bringing about huge axial power, shear power, and bending moment in columns, particularly those BELOW the highest help (as in Building B), and is probably going to cause calamitous breakdown of structures because of the joined activity of axial power, shear power, and bending moment.

Buildings with superior seismic performance in high seismic locations have two main features, according to field research and primary assessments of buildings on hill slopes: compact plans (along both across and along directions) and only additional stories above the top ground support level.

R.B. Khadiranaikar and Arif Masali centers around survey of studies on the seismic reaction of structures on slope inclines and furthermore the dynamic reaction of the design on slope slant. The many floors of such structures step-back toward the hillside, and the building may also have a set-back. Buildings on hill slopes are characterized by unequal column heights within a storey, which results in drastic variation in stiffness of columns of the same storey, and this construction in seismically prone areas exposes them to greater shears and torsion than conventional construction. The uphill side's short, rigid columns attract substantially larger lateral stresses and are more vulnerable to damage.

From the above discussion following conclusions can be made:

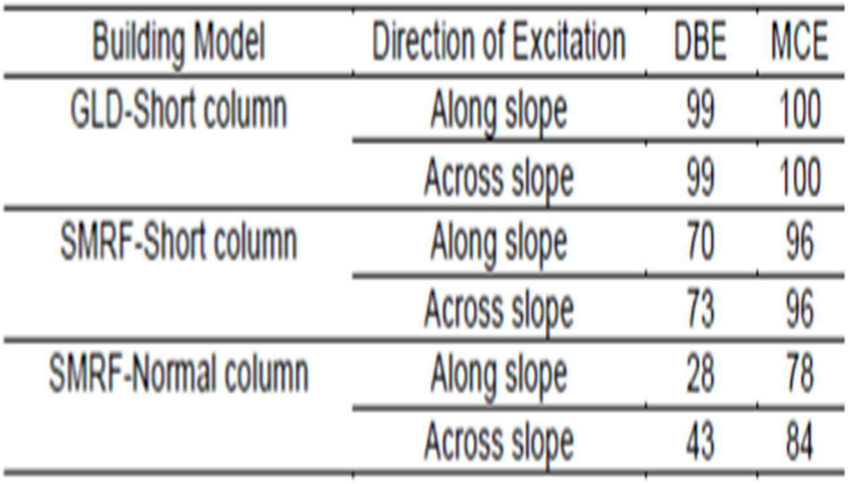
- In comparison to step back set back buildings, step back structures produce larger base shear, longer time periods, and larger top storey displacement.
- Short columns are shown to attract higher forces and are the most vulnerable to seismic excitation. From a design standpoint, the size, orientation, and ductility demand of a short column should be specially considered.
- Because of the uneven distribution of shear force in the various frames of the building, the hill slope buildings are prone to considerable torsional effects, which are observed to be larger in step back buildings.
- Majorly scholars believe that on sloping ground, step back set back buildings are preferable.
- According to the findings, the existence of an infill wall and a shear wall changes the behaviour of a building by significantly reducing storey displacement and storey drifts, but may also increase base shear, thus particular consideration should be made in the design to reduce base shear.

Mitesh Surana, Yogendra Singh and Dominik H Lang centers around the seismic delicacy investigation of step-back slope structures, which is the most ordinarily discovered design in the Indian Himalayas. The process for creating dynamic capacity curves, which are utilised for fragility analysis, is called incremental dynamic analysis. The intensity measure Sa has been used to scale a set of 30 ground motion time histories (T1, 5%).

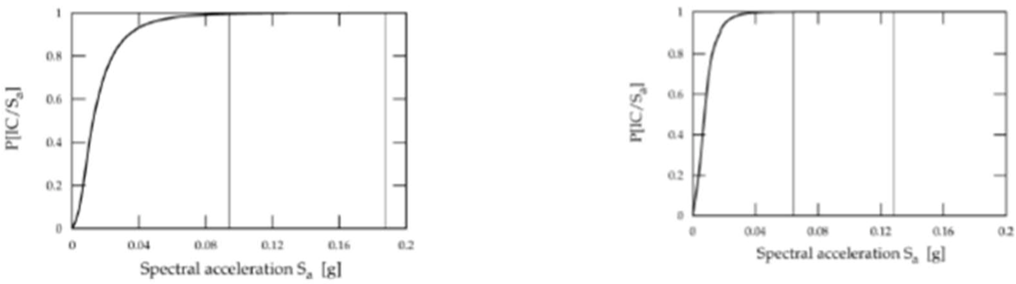
Since the sections have generally restricted shear limit, the GLD working with short segments has a practically 100% shot at falling even at the DBE level of seismic interest. For DBE and MCE levels of seismic interest, the SMRF working with short sections planned by current code arrangements for structures laying on level geology has an exceptionally high likelihood of breakdown, since short segments, being extremely inflexible, draw in practically the entirety of the story shear and fizzle under shear much before different individuals yield. When contrasted with SMRF structures with short segments, SMRF structures with standard stature segments have a lesser shot at falling on the grounds that story shear is better split between all segments and shear disappointment in sections happens after different components have yielded, bringing about higher pliability.

This means that the requirements of India's current seismic design codes, which were created for flat-land buildings, are insufficient for buildings on hill slopes. Additionally, minor adjustments in structural designs that result in a more regular distribution of stiffness and strength can increase performance.

Table 1. Collapse probabilities for different hazard levels

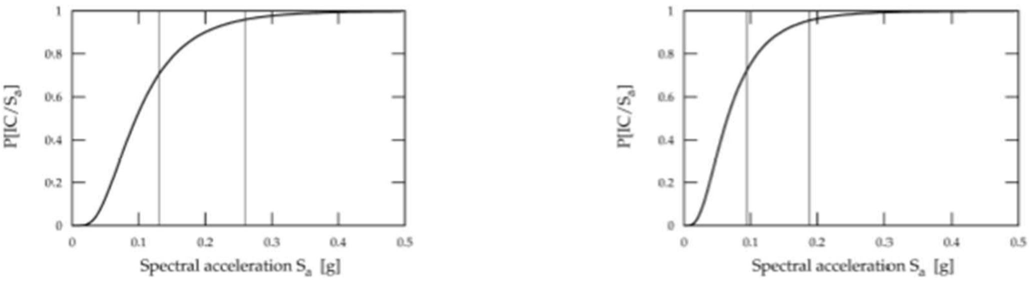


Building Model	Direction of Excitation	DBE	MCE
GLD-Short column	Along slope	99	100
	Across slope	99	100
SMRF-Short column	Along slope	70	96
	Across slope	73	96
SMRF-Normal column	Along slope	28	78
	Across slope	43	84



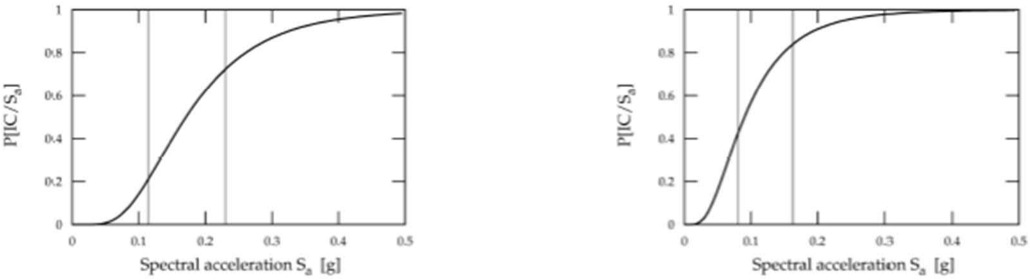
(a) GLD-short column, along slope

(b) GLD-short column, across slope



(c) SMRF-short column, along slope

(d) SMRF-short column, across slope



(e) SMRF-normal column, along slope

(f) SMRF-normal column, across slope

Figure 4. Fragility Curves for the considered building models

Mitesh Surana, Yogendra Singh and Dominik H Lang focuses on the seismic fragility analysis of hillside buildings designed for modern seismic design codes. Using the incremental dynamic analysis (IDA) approach, this study intends to evaluate the impacts of building height, seismic zone, and near and far field sites on the collapse fragility of RC frame hillside buildings of FL, SF, and SB structural configurations.

Although low and midrise buildings are common in mountainous areas, high-rise buildings are uncommon because building byelaws only allow for structures up to 12 metres in height. All structure models are intended to withstand the consolidated impacts of gravity and quake loads, as indicated by Indian Standards IS 1893 and IS 13920 for "special moment-resisting frame." The upper bound plan period dependent on the structure tallness over the highest establishment level is considered in the seismic plan of all the inspected constructing arrangements (FL, SF, and SB).

Table 2 shows the breakdown probabilities of the examined assembling models at all over field destinations, determined for two unique reaction spectra, specifically, site-explicit CMS and site-explicit CMS scaled to a similar Sa (T, 5%) as the MCE reaction range in IS1893, which was initially utilized in building plan.

The information additionally show that the SF structures are the most helpless, while the FL structures are the most un-defenseless. The improved torsional effects of SF structures in the inelastic reach can be credited to their higher delicacy. The discoveries plainly show that extra plan necessities for SF and SB structures are required, especially on account of elevated structure in higher seismic zones (V). Besides, the seismic delicacy of nearfield destinations is more prominent on the grounds that the site-explicit seismic risk surpasses the plan danger specified in the code. The current Indian seismic plan code sees no difference amongst close field and far-field destinations, and gives comparable seismic plan spectra paying little mind

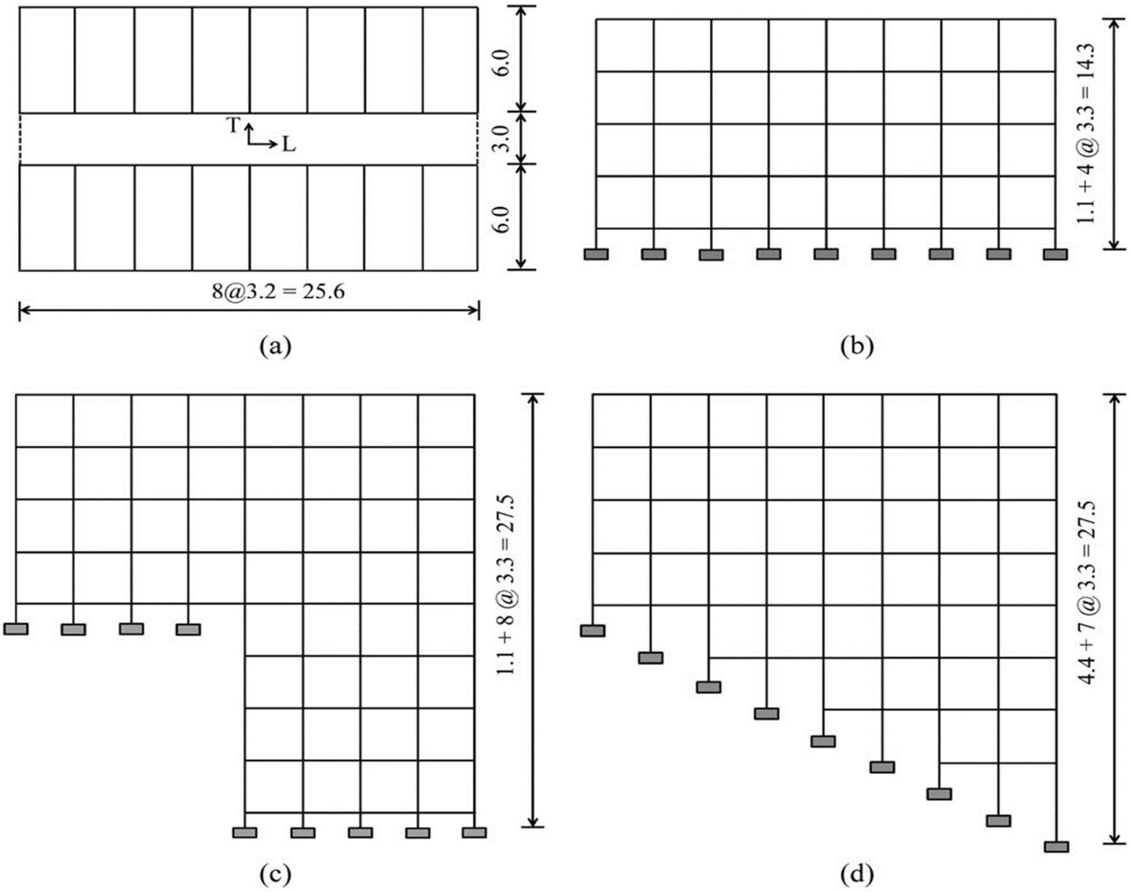


Fig. 5 (a) plan and elevation of a four-storey model, (b) flat land (FL), (c) split-foundation (SF), and (d) step-back (SB) to site vicinity to dynamic seismic sources. The breakdown delicacy gauges introduced show that in seismic plan of slope structures, the effects of underlying arrangement and nearfield site qualities should be considered.

Table 2. Collapse probabilities (MCE)

		Collapse probability							
		Site-specific hazard				Design code hazard			
Site	Building Height	FL (%)	SF (%)	SB (%)	Average (%)	FL (%)	SF (%)	SB (%)	Average (%)
NF Zone IV	2-Storey	1.95	7.24	2.32	3.84	1.95	7.24	2.32	3.84
	4-Storey	7.77	10.66	3.26	7.23	12.04	15.74	5.62	11.13
	8-Storey	18.51	36.76	21.56	25.61	42.67	60.88	48.00	50.52
FF Zone IV	2-Storey	0.13	0.66	0.22	0.34	2.64	8.19	3.87	4.90
	4-Storey	0.31	0.84	0.10	0.42	11.63	16.92	6.25	11.6
	8-Storey	0.91	4.43	1.20	2.18	41.90	56.42	47.64	48.65
FF Zone V	2-Storey	0.65	2.30	1.06	1.34	14.53	27.57	17.60	19.90
	4-Storey	1.77	3.66	1.96	2.46	27.68	36.93	27.23	30.61
	8-Storey	18.63	45.09	25.79	29.84	68.84	89.19	76.12	78.05

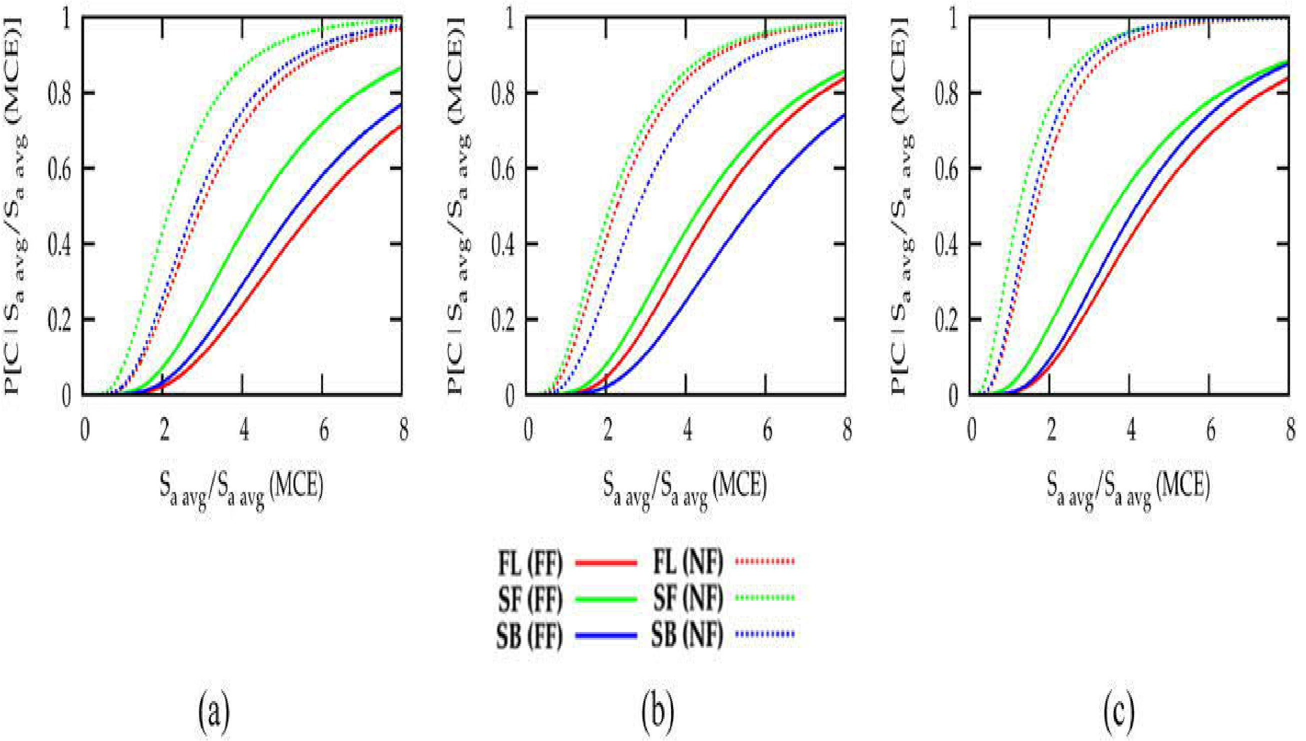


Fig. 6 Result of site on collapse fragility of considered structural configurations (a) two-storey buildings, (b) four-storey buildings, and (c) eight-storey buildings.

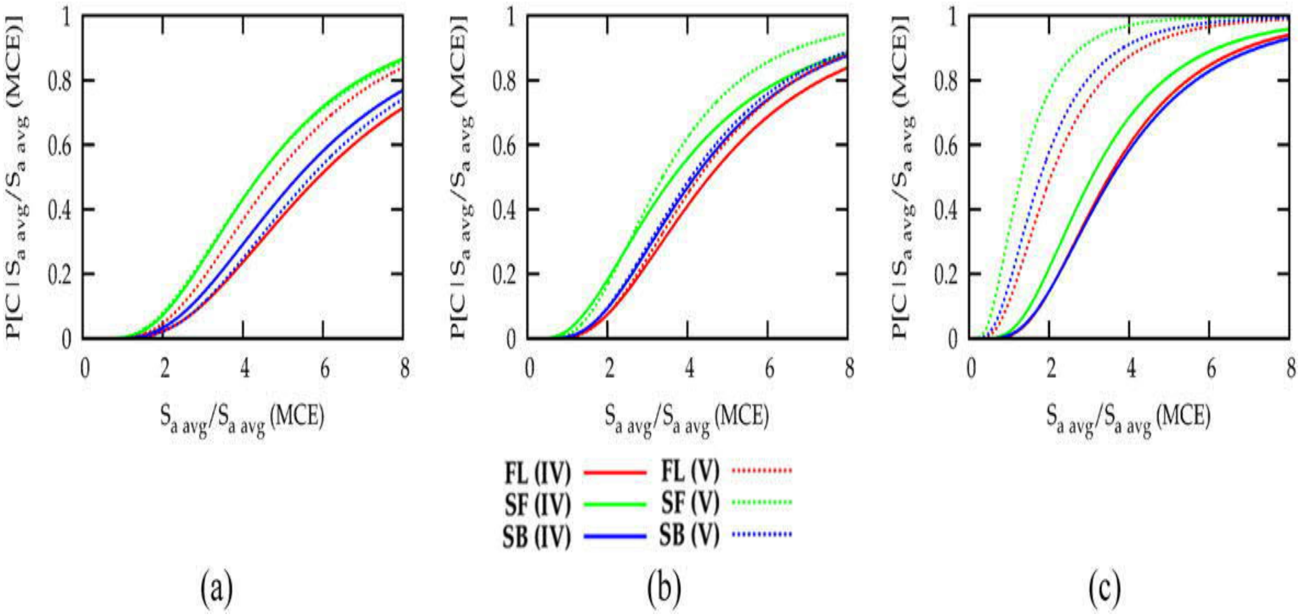


Fig. 7 Result of seismic zone on collapse fragility of considered structural configurations (a) two-storey buildings, (b) four-storey buildings, and (c) eight-storey buildings

Ajay Kumar Sreerama, Pradeep Kumar Ramancharla focuses on the behaviour of a G+3 building on varying slope angles i.e., 15°, 30°, 45° and 60° and compared with the same on the flat ground. The Applied Element Approach (AEM) is used to undertake incremental dynamic analysis, while the finite element method is utilised to examine static behaviour.

In SAP2000, five different G+3 building scenarios with variable slope angles of 0°,15°,30°,45°, and 60° are planned and analysed according to IS 456. The properties of the building configuration studied in this study are listed below.

Table. 3 Modelling Data

Structural element sizes	
Beams	300x300mm
Columns	300x300mm
Slab thickness	120 mm
Material properties	
Grade of concrete	M25
Grade of Steel	Fe 415
Loading	
Live	3 kN/m2
Floor finish	1kN/m2
Self-weight of slab	3kN/m2

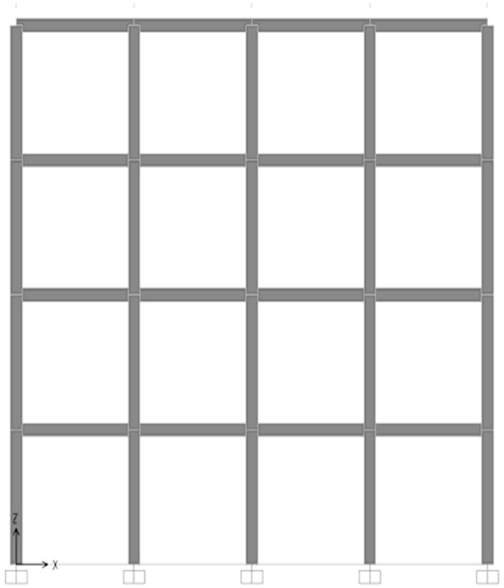


Fig. 8 G+3 RC framed structure

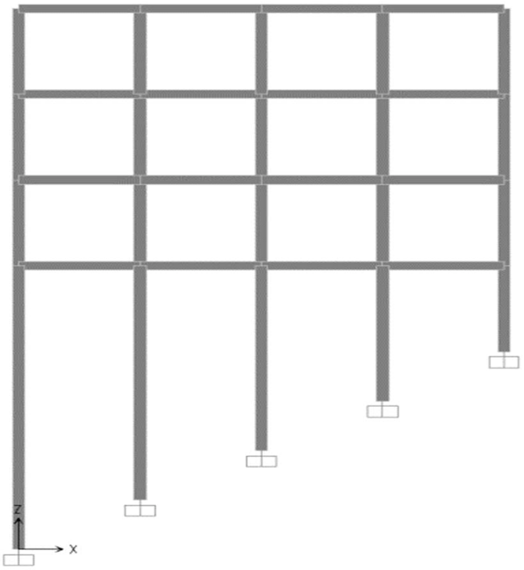


Fig. 9 Model of Building on slope

The research clearly demonstrates the huge variation in seismic behaviour between buildings on slopes and buildings on level surfaces. Because other columns are flexible and tend to oscillate as the slope angle increases, it is seen that the short column resists practically all storey shear. As the slope angle increases, a hinge mechanism forms at the shorter column zone and is destroyed sooner. We can see from the fragility curve that the structure is more vulnerable when it is at a steep angle.

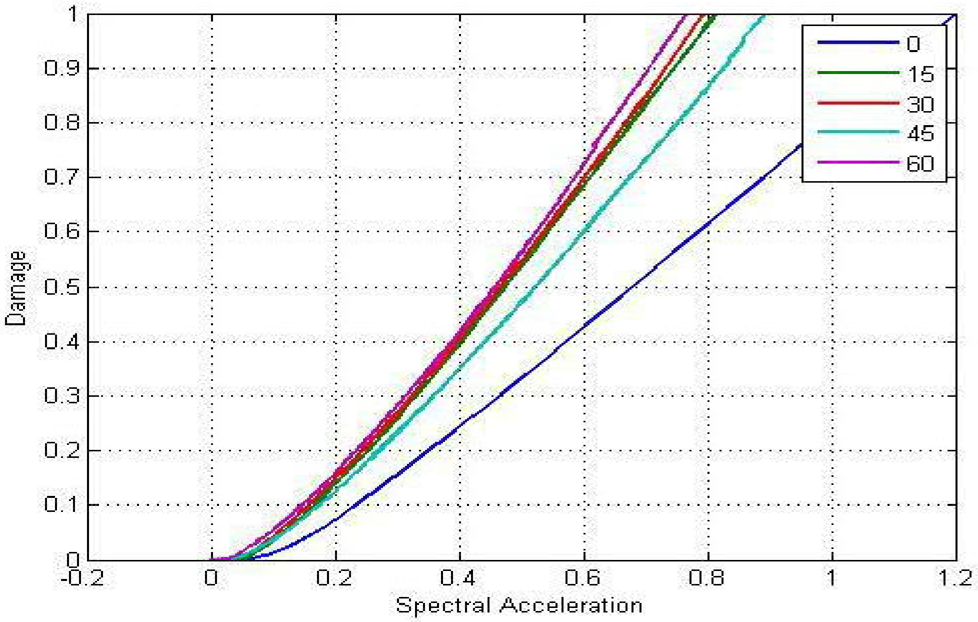


Fig. 10 Fragility Curves

Jelena Milosevic, Serena Cattari and Rita Bento proposes a system for the assessment of the delicacy bends that expects to restrict the computational exertion without losing the dependability of the accomplished outcomes. As is notable, the utilization of nonlinear static techniques requires the determination of a specific number of alternatives to decide the worth of the power measure that is viable with the accomplishment of a particular harm level (imDL). The way to deal with use [the N2 Method (CEN EC8-12004) or the Capacity Spectrum Method (Freeman1998)] ought to be made, for instance, to characterize the harm level on the sucker bend and to contrast limit and request.

The research demonstrates how to use nonlinear static analysis to derive seismic fragility curves for masonry and mixed masonry-RC buildings. The approach is described in a standardised manner so that it can be simply replicated for other building stocks than the one investigated in this study.

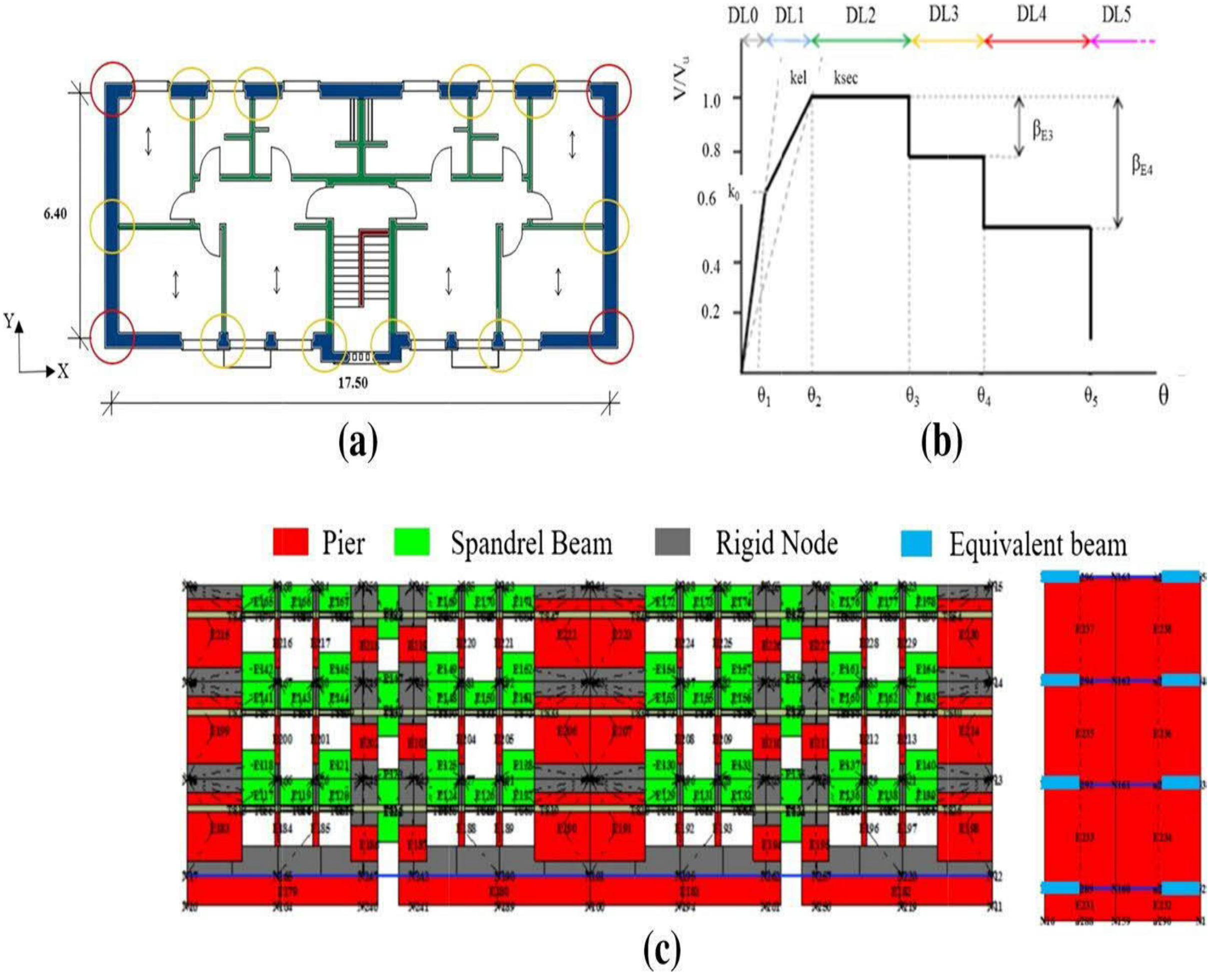
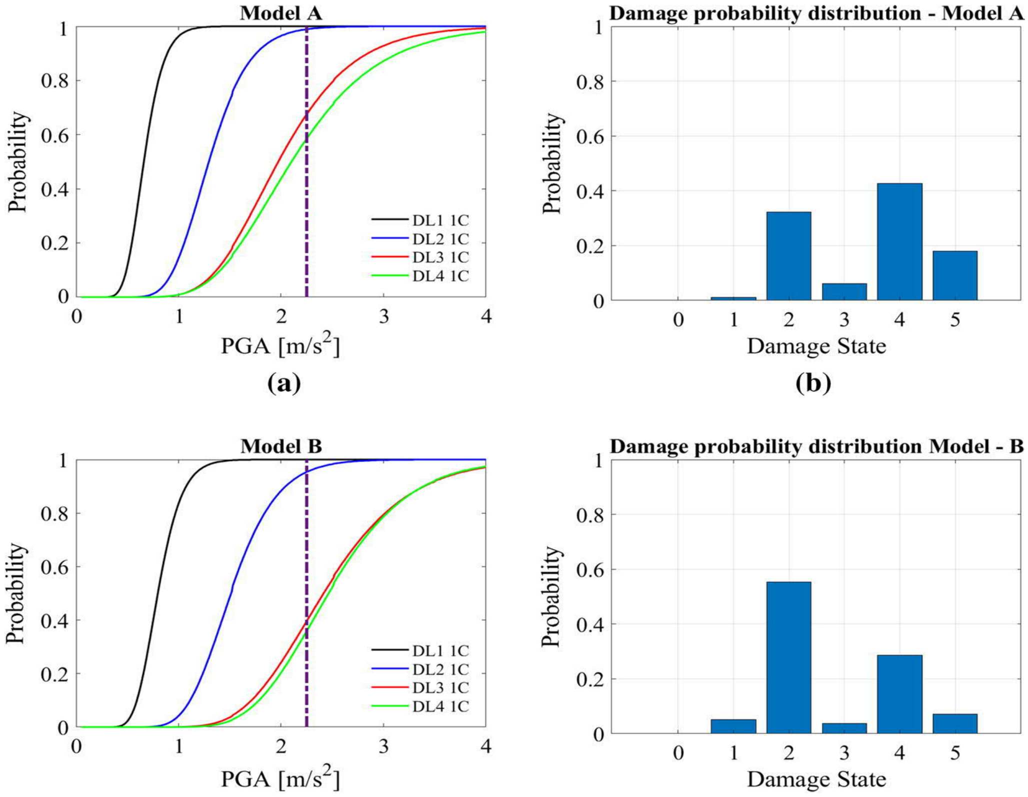


Fig. 11 (a) plan showing the position of the bad connections between walls; (b) multilinear constitutive law for masonry panels; (c) comparable casing glorification of the front façade (left) and the wall showing the beams adopted to understand the effectiveness of wall-wall connection (right)

- Nonlinear static analyses, which are less taxing than nonlinear dynamic analyses, are used. This form of analysis also allows for a flexible quantification of the factors that are used to create fragility curves, such as the median value of the intensity measure and its dispersion.
- Using a Bayesian technique, derive the relevant mechanical parameters;
- The aleatory and epistemic uncertainty are taken into account. The aleatory uncertainties are handled as mechanical parameters with a wide range of values, whereas the epistemic uncertainties are concerned with structural details, such as wall connections.



(a) (b)

(c) (d)

Fig. 12 Final fragility curves and damage probability distribution

- The utilization of nonlinear unique investigations as an extra instrument to support the determination of the most agent delicacy bends of the structure class most probable anticipated seismic conduct (e.g., identified with the decision on the most dependable burden example to be applied every fundamental way). Nonlinear unique examinations are not needed for this methodology; however, they can be entirely significant when proof from prior research on the structure class being scrutinized is inaccessible.

B. Gencturk, A. S. Elnashai, and J. Song offer a new approach for analysing the fragility of building populations. The technique is separated into four parts: I building capacity; (ii) earthquake demand; (iii) structural assessment; and (iv) development of fragility curves. Finally, fragility curves are available in two formats: traditional and HAZUS-compatible.

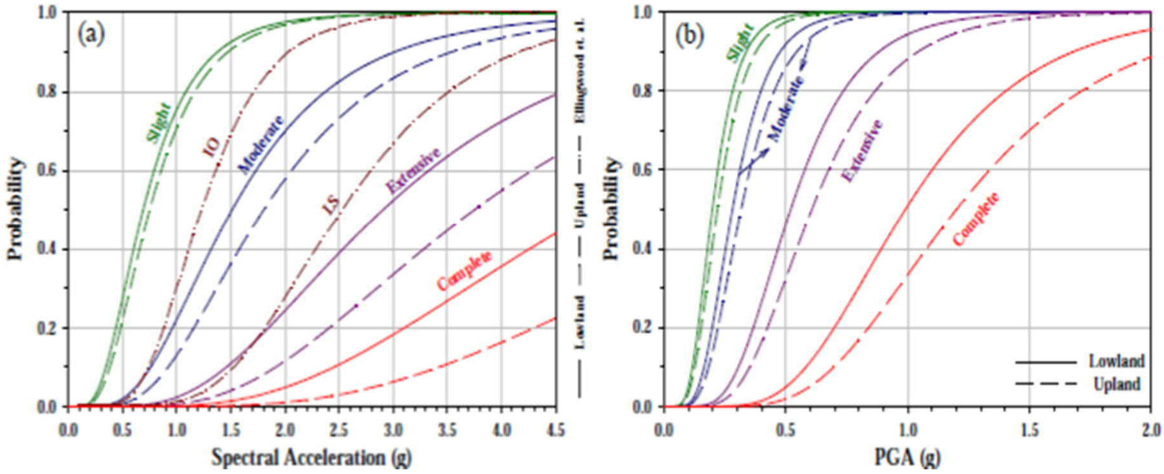


Fig. 13 (a) Fragility relationships by Ellingwood et al. (b) Effect of soil profile

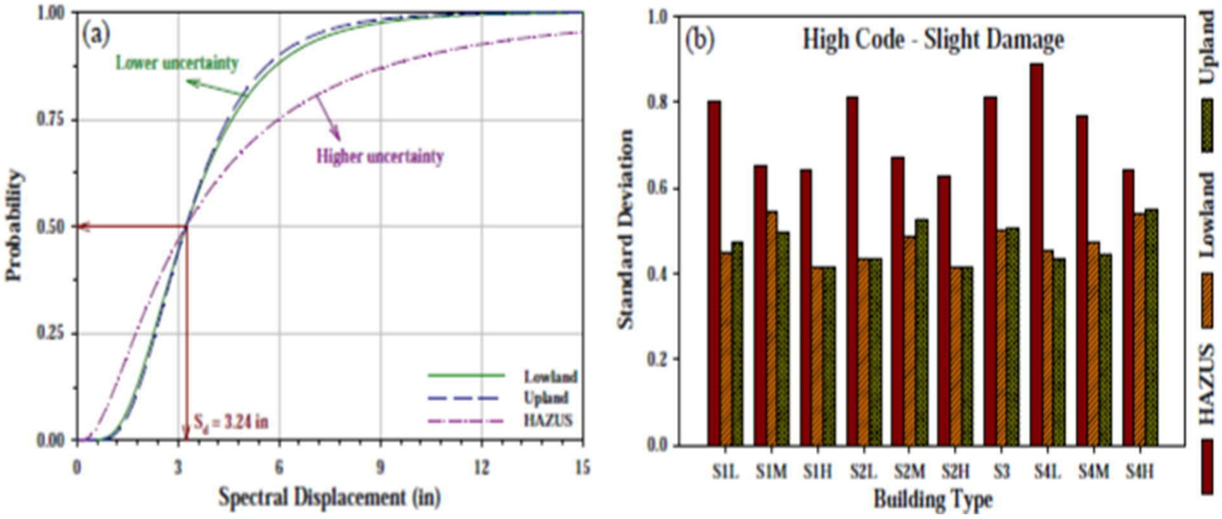


Fig 14 (a) HAZUS compatible fragility relationships (b) Effect on uncertainty parameter

This research describes a new approach for determining the fragility of building populations in a consistent manner. For each component of the approach, such as I building capacity, (ii) earthquake demand, (iii) structural assessment, and (iv) fragility curve generation, rigorous formulations are presented while maintaining the simplicity of formulation to facilitate a large number of assessments. Because the approach is generic, it can be used on any type of structure (or set of structures) whose earthquake reaction can be described by a pushover curve. The new method also allows for the inclusion of acceleration time histories, which may be used to reflect the peculiarities of region-specific earthquake data in the fragility correlations. The fragility correlations arising from the proposal presented in this study are recommended for use in regional impact assessment studies because to their enhanced accuracy and consistent reliability.

2.3 Research Gap

In all the above discussed papers a comparison of seismic vulnerability between step-back and step-back set-back building is done but there is also a third type building which is common in hilly regions having very steep slopes i.e., Split foundation. In this report we have compared the seismic performance and vulnerability of step-back and split foundation building.

CHAPTER 3

METHODOLOGY AND PROCEDURE

3.1 General

One of the targets of this work is to evaluate the performance of Reinforced Concrete (RC) frame structures of step-back and split foundation type, explicitly in Himalayan Region because of potential quakes. The seismic performance for the given hazard level can be obtained from fragility curves.

3.2 Reinforced Concrete Frame Structures

Low to mid-rise RC frame structures situated in hilly region generally subjected to moderate to high seismic hazard were commonly planned without thought of lateral loads, since wind load only from time to time administered for low-height construction. Along these lines, such constructions have been masterminded as gravity load planned, or GLD structures, Step-Back Structures and Split Foundation Structures. Step-back, step-and split foundation layouts have been recognised as the most common construction configurations on slopes. The current research examines the seismic vulnerability of step-back and split foundation hill structures, which are the most typical configuration in the Indian Himalayas. When the mechanism builds up, the structure's obstruction is given exclusively by the post-yield quality of the pivoting segment closures and characteristic segment flexibility. Consolidating the absence of adequate segment quality with the absence of adequate itemizing in segment areas for flexibility, fragile delicate story failure components might be noticeable during strong quakes.

3.3 Techniques to Determine Seismic Vulnerability

To appraise the seismic vulnerability of a particular structure type, two unique methodologies can be considered. In the first approach, each structure stock is analysed independently and the weakness of the structure stock is gotten by joining the fragility data related with each structure. Very detail displaying and investigation methodology are utilized; consequently, the outcome will be exceedingly exact. Then again, this methodology is for all intents and purposes and financially unfeasible. The second methodology is to lead the fragility studies by utilizing the statistical properties of the structure populace. Basic models and techniques are utilized in this methodology. The upside of this strategy is that it is straightforward and monetarily possible.

What's more, the nontechnical leaders incline toward such basic and fast estimates of anticipated losses to build up the best possible judgment to execute their mitigation plans. However, the obtained outcomes will be rough and the impediments of the models or the techniques ought to be deliberately comprehended. The seismic performance of the RC framed structures is determined by using three analysis methods, i.e., response spectrum analysis, time history analysis and pushover analysis which further helps in determining the fragility of the structure.

3.4 Response Spectrum

The primary reaction to a specific quake can be summed up utilizing a reaction range, which gives significant data on the expected impacts of ground movement on the design. A reaction range shows the pinnacle reaction of a SDOF construction to a specific seismic tremor, as an element of the normal time frame and damping proportion of the design. The plan reaction range is a smooth reaction range indicating the degree of seismic opposition needed for a plan. Seismic examination necessitates that the plan range be determined. IS 1893 (Part 1): 2016 specifies a plan speed increase range or base shear coefficients as an element of normal period. This relationship functions admirably in SDOF frameworks. Fig. 15 identifies with the proposed 5% damping for rough or hard soil locales.

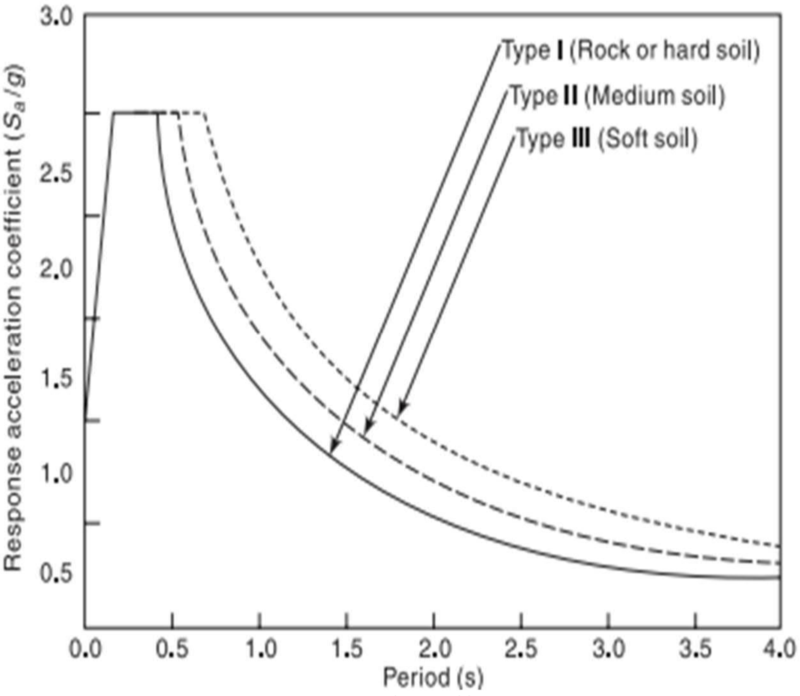


Fig. 15 Response spectrum chart for different soil sites at 5% damping

3.4.1 Response Spectrum Analysis

The technique is appropriate to those designs where modes other than the essential one altogether influence the reaction of the construction. This technique depends on the way that, for specific types of damping—which are sensible models for some structures—the reaction in every normal method of vibration can be processed freely of the others, and the modular reactions can be joined to decide the all-out reaction. This strategy is otherwise called modular technique or mode superposition strategy. A total modular examination gives the historical backdrop of reaction—powers, relocations, and miss happenings—of construction to a predetermined ground speed increase history. Specifically, it is material to the examination of powers and disfigurements in multi-story structures because of medium-force ground shaking, which causes a decently huge yet basically direct reaction in the design. The overview of the procedure for response spectrum analysis is given as follows:

- Make the required model, without entering pushover data, using basic modelling procedure.
- Go to **define** and then to **load patterns** to define the loads applied during response spectrum analysis.
- Go to **define** again to make **load cases** and add new load case to define a response spectrum load case.
- Then finally go to **analyse** and press **run analysis** to run the analysis for response spectrum analysis.
- To plot storey displacements, drifts and forces, go to **display** and select **storey response plots**. Additional variables are also available for plotting.

3.5 Time History Method

Albeit the range strategy, illustrated in the past segment, is a helpful method for the versatile investigation of constructions, it's anything but straightforwardly adaptable to inelastic examination in light of the fact that the standard of superposition is at this point not appropriate. Additionally, the examination is liable to vulnerabilities innate in the modular superimposition strategy. The real interaction of consolidating the distinctive modular commitments is a probabilistic procedure and, in certain cases, it might prompt outcomes not completely illustrative of the genuine conduct of the construction. The THA strategy addresses the most refined technique for dynamic investigation for structures. In this strategy, the numerical model of the structure is exposed to speed increases from seismic tremor records that address the normal quake at the foundation of the design. The strategy comprises of a bit-by-bit direct combination throughout a period span; the conditions of movement are settled with the removals, speeds, and speed increases of the past advance filling in as starting capacities.

3.5.1 Time History Analysis

The time-history strategy is appropriate to both versatile and inelastic examinations. In versatile examination the solidness qualities of the design are thought to be consistent for the entire term of the quake. In the inelastic investigation, in any case, the solidness is thought to be steady through the gradual time as it were.

The procedure usually includes the following steps.

- A quake record tending to the arrangement quake is picked.
- The record is digitized as a progression of modest time periods 1/40 to 1/25 of a second.
- A mathematical model of the design is set up, generally speaking containing a lumped mass at each floor. Damping is seen as comparative with the speed in the PC plan.
- The digitized record is applied to the model as speed increments at the base of the development.
- The states of developments are then planned with the help of programming program that gives an absolute record of the speed increment, speed, and evacuation of each lumped mass at each stretch.

3.6 Pushover Analysis

Pushover analysis give satisfactory data on seismic requests. Sucker investigation assess the normal presentation of an underlying framework by assessing its solidarity and twisting requests in plan quakes. Assess the normal exhibition through a static inelastic investigation.

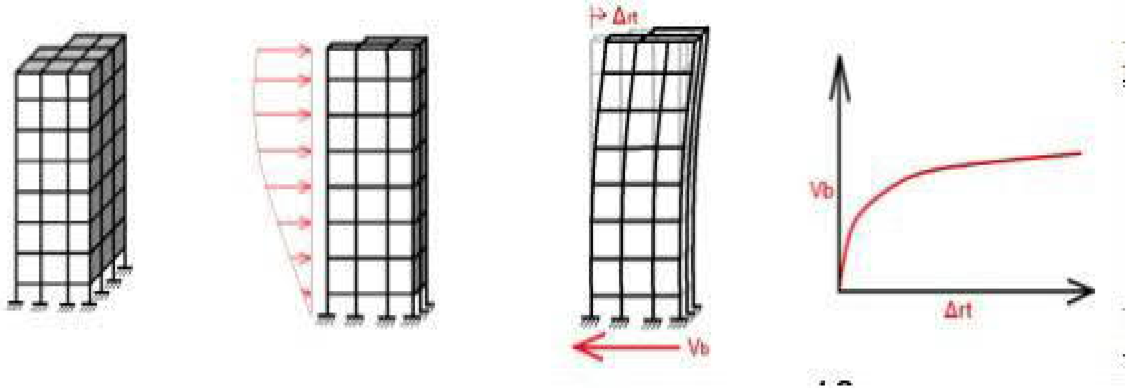


Fig. 16 Pushover analysis

Federal Emergency Management Agency (FEMA) and Applied Technical Council (ATC) are the two agencies which formulated and suggested the Non-linear Static Analysis or Pushover Analysis under seismic rehabilitation programs and guidelines. This included documents FEMA-356, FEMA-273 and ATC-40

3.6.1 FEMA-356

The primary job of FEMA-356 chronicle is to give indeed strong and extensively sufficient guidelines for the seismic recuperation of designs. The rules for the seismic recovery of the plans are proposed to fill in as a coordinated instrument for plan capable for doing the plan and evaluation of the plans, a reference report for the plan administrative subject matter experts and an establishment for the future improvement and execution of the advancement law approaches and principles.

3.6.2 ATC-40

Seismic assessment and retrofit of substantial constructions consistently implied as ATC-40 was made by the Applied Technology Council (ATC) with financing from California Safety Commission. Notwithstanding the way that the frameworks endorsed in this report are for substantial designs, they are pertinent to most construction types.

3.6.3 Different Pushover Approaches

As of now, there are two non-direct static examination methodologies available, one named as the Displacement Coefficient Method (DCM), recorded FEMA-356 and other the Capacity Spectrum Method (CSM) filed in ATC-40. The two methodologies depend upon parallel burden contorting assortment obtained by non-direct static examination under the gravity stacking and sidelong stacking as a result of the seismic action. This assessment is called Pushover Analysis.

3.6.3.1 Capacity Spectrum Method

Capacity Spectrum Method is a non-direct static investigation framework which gives a graphical depiction of the typical seismic exhibition of the design by intersection the construction's ability range with reaction range of the shake. The convergence point is called as the presentation point, and the dislodging coordinate dp of the exhibition point is the assessed relocation interest on the construction for the foreordained element of seismic danger.

3.6.3.2 Displacement Coefficient Method

Displacement Coefficient Method is a non-straight static examination strategy which gives a mathematical technique to surveying the removal interest on the construction, by using a bilinear depiction of the limit bend and a movement of change components or coefficients to figure a goal relocation. The point on the limit bend at the target dislodging is the thing that might measure up to the presentation point in the limit range technique.

3.6.4 Building Performance Level

Building execution is the joined presentation of both basic and non-basic parts of the structure. Distinctive performance levels are utilized to portray the structure execution utilizing the pushover analysis, which are depicted below.

3.6.4.1 Operational Level (OL)

As indicated by this presentation level construction are needed to proceed with no lasting damages. Construction holds unique strength and firmness. Significant breaking is found in segment dividers and rooftops similarly as in the primary segments.

3.6.4.2 Immediate Occupancy level (IO)

Designs meeting this exhibition level are needed to proceed with no float and construction holds unique strength and solidness. Minor parting in parcel dividers and fundamental segments is noticed. Lifts can be restarted. Fire assurance is operable.

3.6.4.3 Life Safety Level (LS)

This estimation is shown when some additional strength and robustness are left accessible in the plan. Gravity inconvenience bearing parts work, no out-of-plane dissatisfaction of dividers and staggering of the railing is seen. Some buoy can be seen with some frailty to the package dividers and the development is past moderate fix. Among the insignificant fragments bombarding hazard mitigates regardless different construction and mechanical frameworks get injured.

3.6.4.4 Collapse Prevention Level (CP)

Developments meeting this show level are relied on to have unimportant extra quality and steadfastness, despite the pile bearing fundamental sections limit, for example, load bearing dividers and fragments. Building is relied on to help gigantic enduring buoy, dissatisfaction of fragments infill and railings and extensive underhandedness to non-hidden sections. At this estimation the plan stays in breakdown level.

3.6.5 Formation of Hinges

A plastic pivot, in underlying designing, alludes to the distortion of a piece of a bar any place plastic bowing occurs. Pivot implies that having no ability to oppose second. In this way, a plastic pivot acts like a standard pivot - allowing free turn. The idea of plastic pivot is significant in understanding primary disappointment.

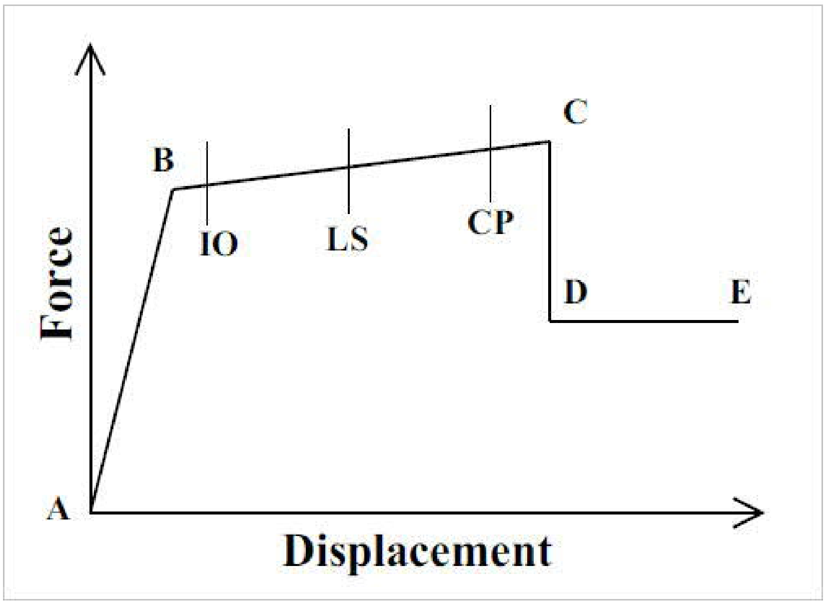


Fig. 17 Force - Displacement curve of a Hinge

The greatest second achieved by the earthquake happen near the terminations of the pillars and sections, the plastic pivots are likely going to frame there and most pliability necessities apply to portion near the crossing point.

An overview of the procedure for pushover analysis is given as follows:

- Make the required model, without entering pushover data, using basic modelling procedure.
- Then go to **define**, select **section properties** to provide **hinge properties** to the structure.
- Then to assign hinges to the structure go to **assign**, click on **frame** and then on **hinges**.
- Go to **define** and then to **load patterns** to define the loads applied during pushover analysis.

- Go to **define** again to make **load cases** and add new load case to define a nonlinear static load case. The load case applied can be force-controlled or displacement-controlled.
- Then click on **other parameters** and save the results to multiple states so that different graphs may be plotted for each increase in applied loading.
- Then finally go to **analyse** and press **run analysis** to run the analysis for static pushover analysis.
- To make a graph base shear vs. monitored displacement, go to **display** and select **show static pushover curve**.
- To plot a graph between hinge deformation vs. applied loading, go to **display** and then click on **show hinge results**.
- For examining displacement and the step-by-step hinge formation, go to **display** and then click on **show deformed shape**.
- For examining the member forces step-by-step, go to **display** and click on **show forces/stresses** and then **frames/cables**.
- Finally go to **display** again and click on **show plot functions** to show the plots of joint displacement, frame member forces, etc.

3.7 Fragility Curves

As noted, fragility (or weakness) can be depicted as far as the conditional probability of a system achieving a recommended limit state (LS) for a given framework request D = d, P (LS/D = d).

$$P\ (LS/D=d) = \Phi\ ((\ln d-\mu_{\ln d})/\sigma_{\ln d})$$

In above equation, $\mu_{\ln X}$ indicates that the mean of the natural logarithm of uncertain Variable D. The logarithmic standard deviation is the standard deviation of the natural logarithm of the variable D. Limit -states identified with structural conduct run from un-functionality to different degrees of harm including beginning breakdown. Requests can be as greatest power, uprooting caused by seismic tremor ground movements, or all the more by and large an endorsed force proportion of the ground movement, over a given timeframe. Communicated in this broad manner, the delicacy (or weakness) is a part of as far as possible against each cutoff state and furthermore the weakness in the breaking point. The cutoff controls the central space of the Fragility Curve (FC) and the weakness in the breaking point controls the shape (or dissipating) of the FC. For a deterministic system with no restriction weakness, the FC is a stage work. Completely, FC is fundamentally a property of the structure subject quite far state. A delicacy assessment is a central component of the totally coupled peril examination embodied in it, moreover can be used to choose probabilistic wellbeing edges against express perceived events for decision purposes. Recognizable proof of probabilistic security edges is major to modem designed office hazard the executives. Despite the way that giving a less informational extent of security than that got from the totally coupled danger examination. Danger educated dynamic ward on the results of delicacy assessment has a couple inclinations:

1. The probabilistic framework investigation is successfully uncoupled from the risk examination.
2. A suitably coordinated delicacy investigation is less mind boggling, less exorbitant, and incorporates less educates than a totally coupled peril assessment.
3. The weakness ought to be depicted in regards to the likelihood of a course of action of given cut-off states being come to of a structure at a given region over a given time period (0, t). Understanding the delicacy bend, the breaking point state (LS) likelihood throughout the day and age (0, t) can be evaluated.

CHAPTER 4

RESULTS

4.1 General

In this study Response spectrum, Time History and Pushover Analysis results of Step Back building and Split Foundation building is compared. The different analysis results comparison by the above methods between step back and split foundation building on hill slopes are represented in this section of this study.

4.2 Structure Properties

All the common material properties, section properties, earthquake characteristics, soil type etc. used further in the dynamic analysis of the different structures are given below in the Table-4. There are G+3 buildings of two types i.e., Step Back building and Split Foundation building.

Table. 4 Input Data

Floor to Floor Height	3 m	Response Reduction Factor (R)	5
Base Floor Height	3 m	Zone Factor (Z)	0.24
Column	300 X 300 mm	Importance Factor (I)	1
Beam	230 X 350 mm	Soil Type	Hard Soil-I
Slab Thickness	125 mm	Ecc. Ratio	0.05
Grade of Concrete	M 25	Damping Ratio	5%
Grade of steel	Fe 500		

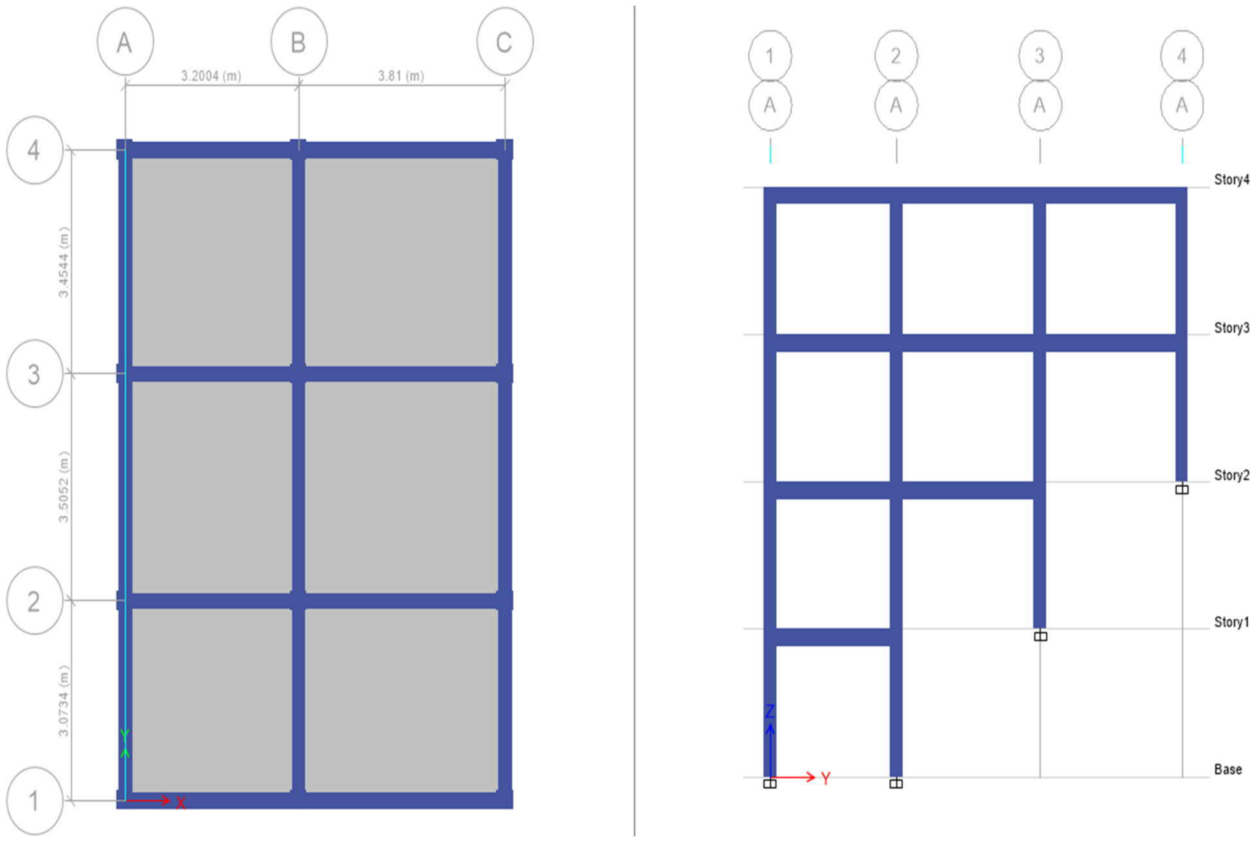


Fig. 18 Step- Back building model

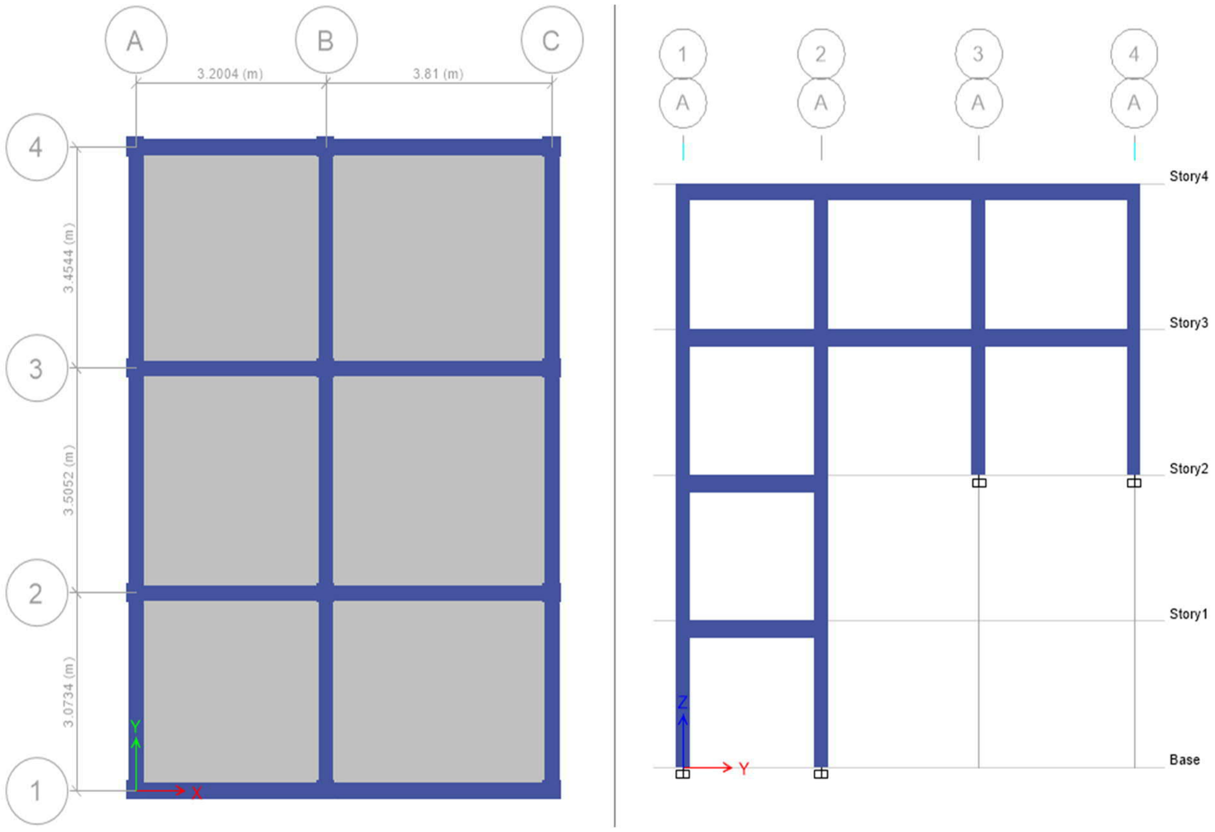


Fig. 19 Split-foundation building model

The given below is the graph of acceleration time data of Uttarkashi earthquake (1991) (M_w=6.8, PGA=0.31g) used for Time history analysis of the modals.

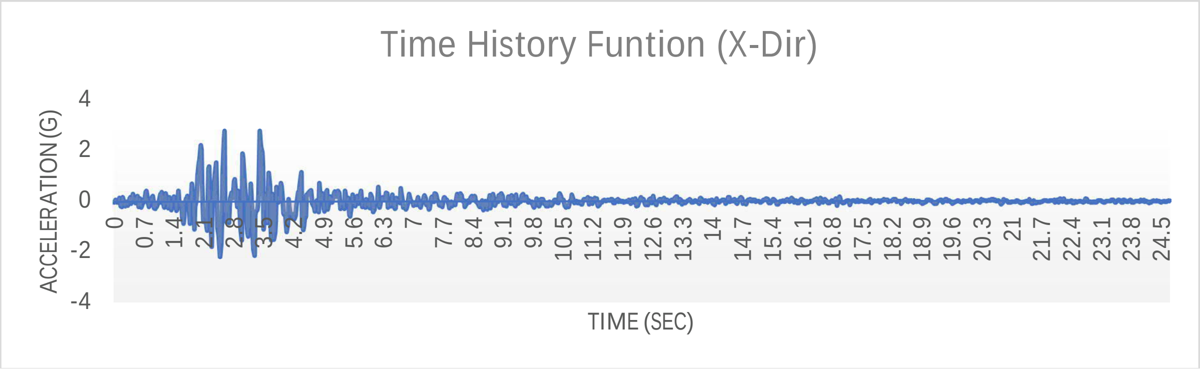


Fig. 20 Acceleration-Time Data (X- direction)

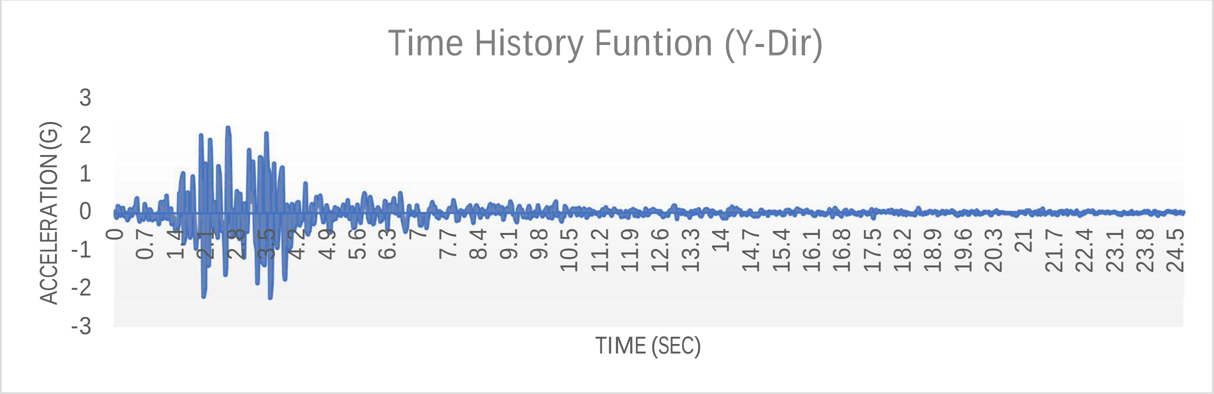


Fig. 21 Acceleration-Time Data (Y- direction)

4.3 Results Obtained

The above data is used in the dynamic analysis of the models. The above analysis came out with certain results as shown further in this paper.

The following results were obtained by the response spectrum and time history analysis of the buildings:

Storey Displacements

Storey displacement is the movement of the storey w.r.t ground when struck by an earthquake. Fig. 5 shows the comparison between the storey displacements of step back and split foundation building carried out by response spectrum analysis. The result for the top storey of step back building comes out to be 4.6mm whereas for split foundation building it is 4mm with 13%

difference. Fig. 6 shows the comparison between the storey displacements of step back and split foundation building carried out by time history analysis. The result for the top storey of step back building comes out to be 5.8mm whereas for split foundation building it is 6.4mm with 10.34% difference. The displacement through time history analysis comes out to be little bit more than the response spectrum analysis. Step Back Building proves to be more stable in terms of displacement due to earthquake.

Table 5. Storey Displacement comparison by response spectrum method

Storeys	Displacement (mm)	
	Step Back	Split Foundation
Storey4	4.6	4
Storey3	3.6	2.8
Storey2	2.4	2.3
Storey1	1.2	1.2
Base	0	0

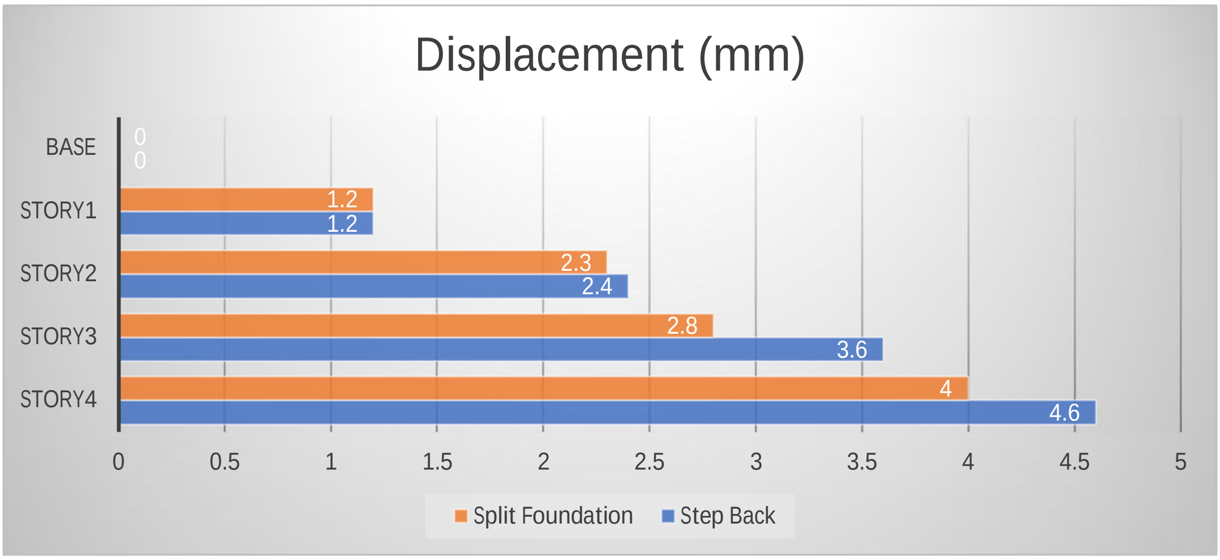


Fig. 22 Storey Displacement comparison by response spectrum method

Table 6 Storey Displacement comparison by Time History method

Storeys	Displacement (mm)	
	Step Back	Split Foundation
Storey4	5.8	6.4
Storey3	4.5	4.7
Storey2	3.1	3.5
Storey1	1.7	1.5
Base	0	0

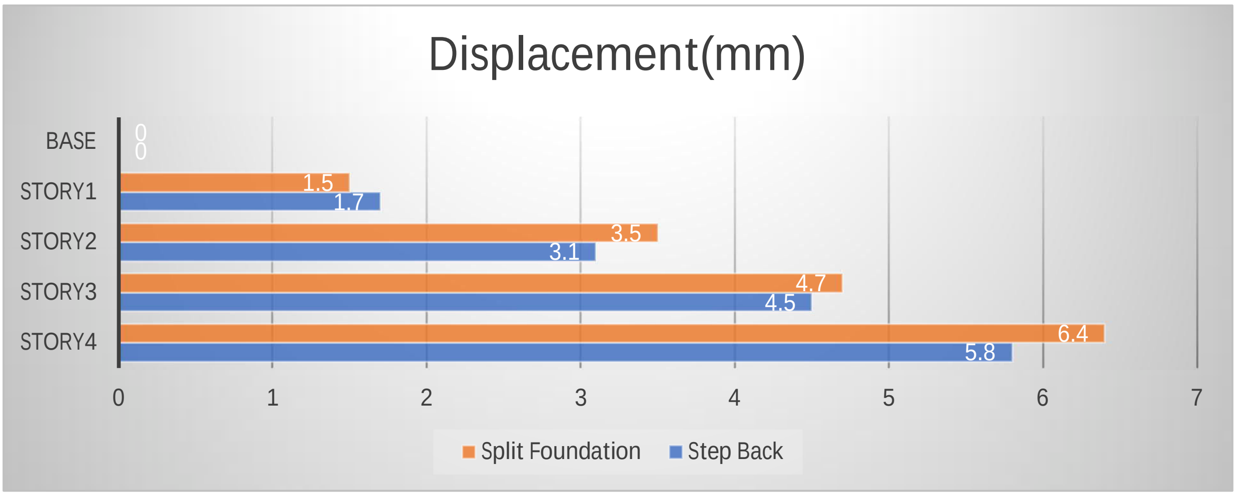


Fig. 23 Storey Displacement comparison by Time History method

Storey Drifts

Story drift is the lateral displacement of one level relative to the level above or below and the story drift divided by the story height is said to be storey drift ratio. Fig. 7 shows the comparison between the storey drift of step back and split foundation building carried out by response spectrum analysis. The result for the top storey of step back building comes out to be 0.000402 whereas for split foundation building it is 0.000405 with 0.75% difference. Fig. 8 shows the comparison between the storey drift of step back and split foundation building carried out by time history analysis. The result for the top storey of step back building comes out to be 0.000539 whereas for split foundation building it is 0.00058 with 7% difference. The drift through time history analysis comes out to be little bit more than the response spectrum analysis. Step Back Building shows less drift in storeys due to earthquake.

Table 7 Storey Drift comparison by response spectrum method

Storeys	Drift	
	Step Back	Split Foundation
Storey4	0.000402	0.000405
Storey3	0.000714	0.000795
Storey2	0.00086	0.000763
Storey1	0.000384	0.000395

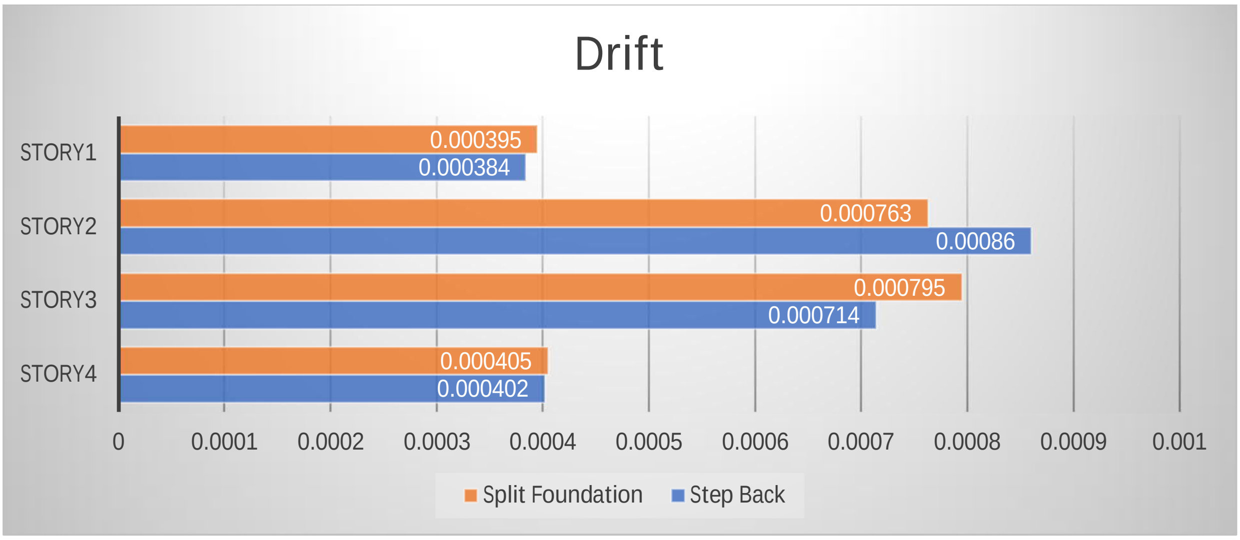


Fig. 24 Storey Drift comparison by response spectrum method

Table 8 Storey Drift comparison by Time History method

Storeys	Drift	
	Step Back	Split Foundation
Storey4	0.000539	0.00058
Storey3	0.001493	0.001559
Storey2	0.001049	0.000652
Storey1	0.000497	0.0005

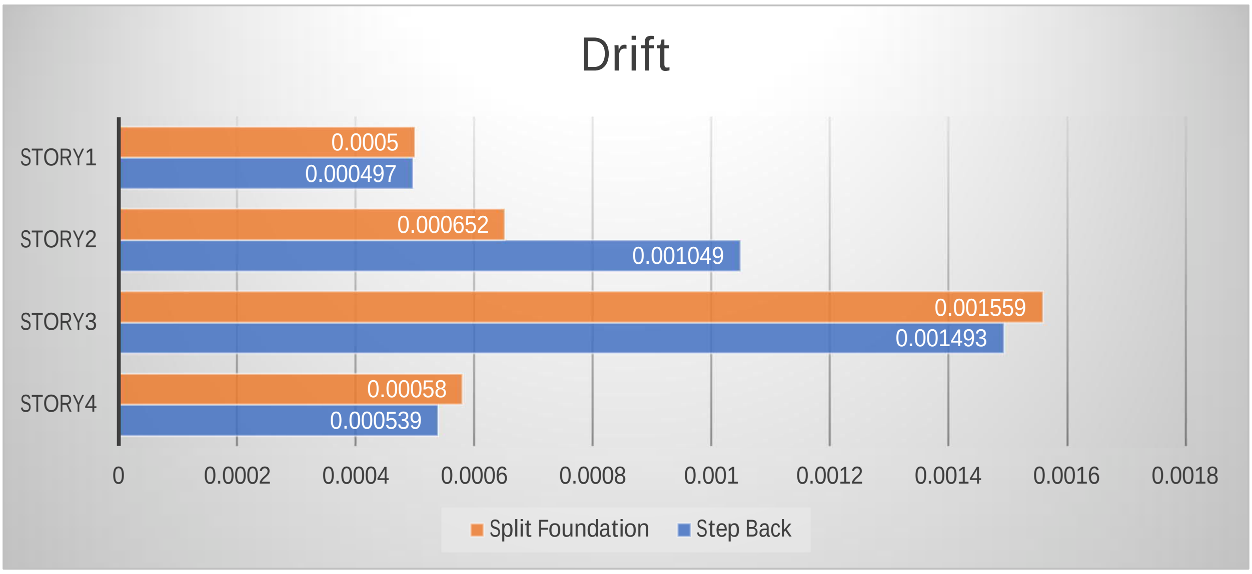


Fig. 25 Storey Drift comparison by Time History method

Storey Forces

Storey Forces is the graph showing how much lateral (horizontal) load due to seismic action, is acting per storey. Fig. 9 shows the comparison between the storey forces of step back and split foundation building carried out by response spectrum analysis. The result for the top storey of step back building comes out to be 41.23KN whereas for split foundation building it is 45.45KN with 9.3% difference. Fig. 10 shows the comparison between the storey forces of step back and split foundation building carried out by time history analysis. The result for the top storey of step back building comes out to be 48.68KN whereas for split foundation building it is 53.85KN with 9.6% difference. The Storey Forces through time history analysis comes out to be more than the response spectrum analysis. Forces induced in each storey of Step Back Building due to seismic action comes out to be less.

Table 9 Storey Forces comparison by response spectrum method

Storeys	Forces (KN)	
	Step Back	Split Foundation
Storey4	41.2288	45.4467
Storey3	95.8079	105.3919
Storey2	62.1973	23.5773
Storey1	34.2057	35.3153

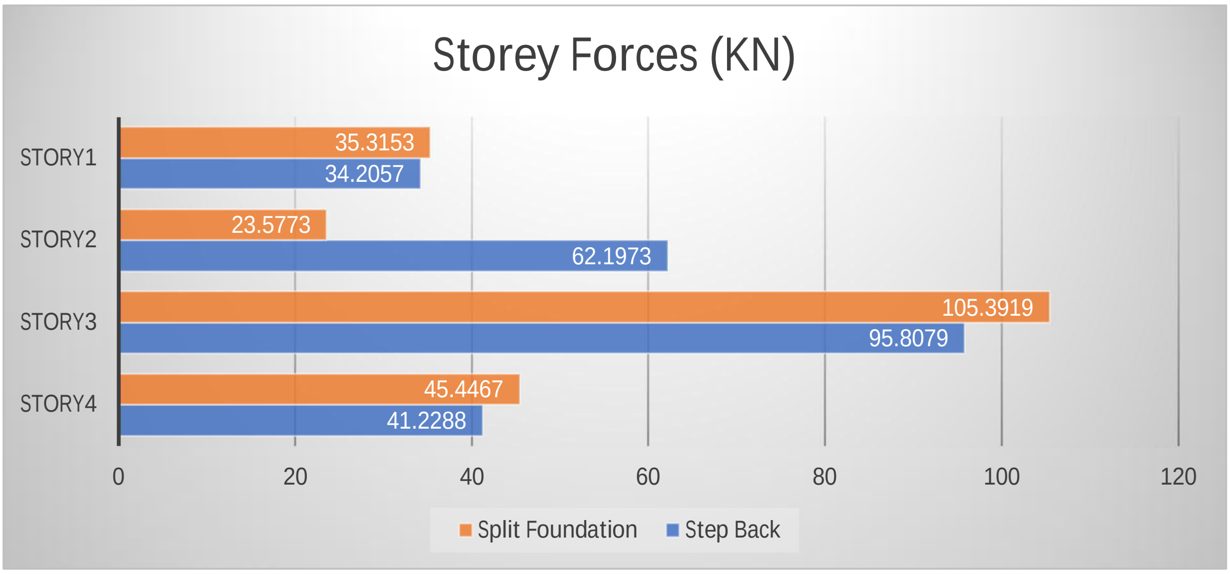


Fig. 26 Storey Forces comparison by response spectrum method

Table 10 Storey Forces comparison by Time History method

Storeys	Forces (KN)	
	Step Back	Split Foundation
Storey4	48.6753	53.8526
Storey3	102.3097	131.8993
Storey2	59.5232	30.4086
Storey1	29.8951	48.9223

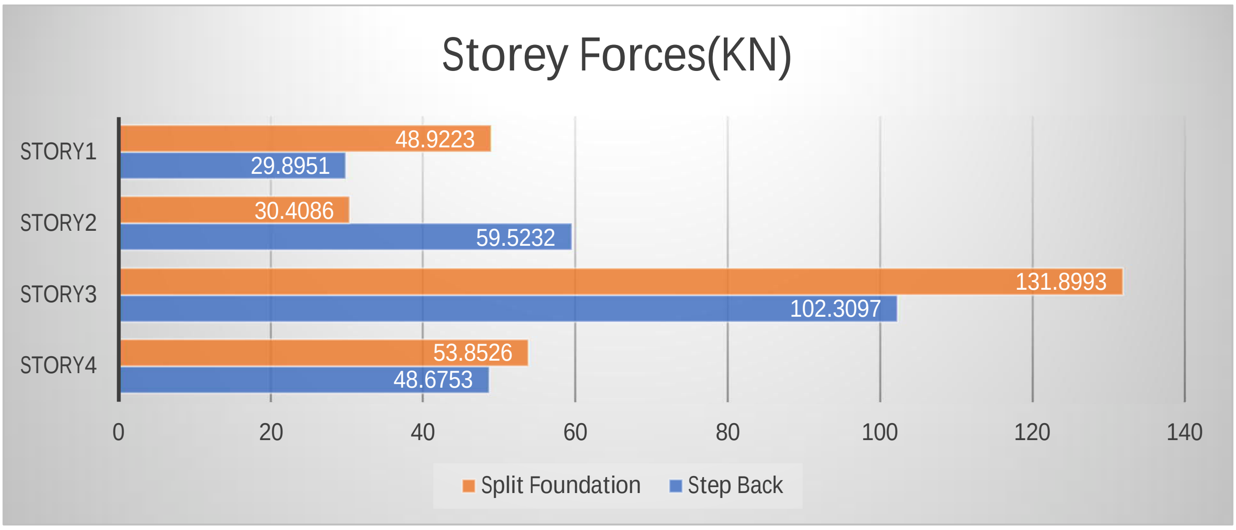


Fig. 27 Storey Forces comparison by Time History method

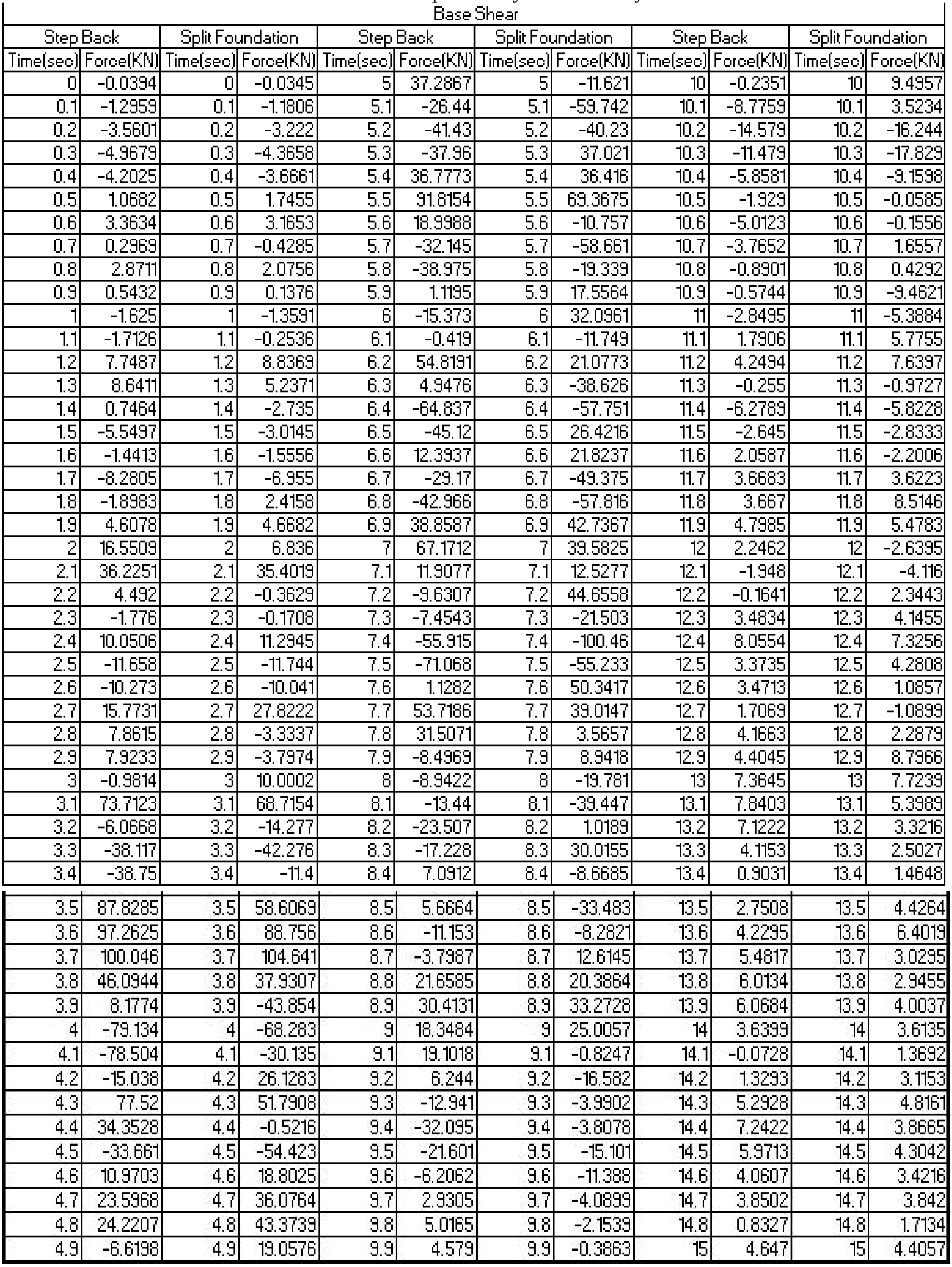
Base Shear

Base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. It depends on:

- the zone of the earthquake location
- soil material on which the structure is built
- building code defining the lateral force equations

Fig. 28 shows the comparison between the base shear forces of step back and split foundation building carried out by time history analysis. The maximum base shear result for the step back building comes out to be 100.046KN whereas for split foundation building it is 104.64KN with 4.3% difference and minimum base shear result for the step back building comes out to be -78.5KN whereas for split foundation building it is -100.46KN with 21.85% difference. Base shear both the maximum and the minimum induced in Step Back Building due to seismic action comes out to be less.

Table 11 Base shear comparison by Time History method



Base Shear											
Step Back		Split Foundation		Step Back		Split Foundation		Step Back		Split Foundation	
Time(sec)	Force(KN)	Time(sec)	Force(KN)	Time(sec)	Force(KN)	Time(sec)	Force(KN)	Time(sec)	Force(KN)	Time(sec)	Force(KN)
0	-0.0394	0	-0.0345	5	37.2867	5	-11.621	10	-0.2351	10	9.4957
0.1	-1.2959	0.1	-1.1806	5.1	-26.44	5.1	-59.742	10.1	-8.7759	10.1	3.5234
0.2	-3.5601	0.2	-3.222	5.2	-41.43	5.2	-40.23	10.2	-14.579	10.2	-16.244
0.3	-4.9679	0.3	-4.3658	5.3	-37.96	5.3	37.021	10.3	-11.479	10.3	-17.829
0.4	-4.2025	0.4	-3.6661	5.4	36.7773	5.4	36.416	10.4	-5.8581	10.4	-9.1598
0.5	1.0682	0.5	1.7455	5.5	91.8154	5.5	69.3675	10.5	-1.929	10.5	-0.0585
0.6	3.3634	0.6	3.1653	5.6	18.9988	5.6	-10.757	10.6	-5.0123	10.6	-0.1556
0.7	0.2969	0.7	-0.4285	5.7	-32.145	5.7	-58.661	10.7	-3.7652	10.7	1.6557
0.8	2.8711	0.8	2.0756	5.8	-38.975	5.8	-19.339	10.8	-0.8901	10.8	0.4292
0.9	0.5432	0.9	0.1376	5.9	1.1195	5.9	17.5564	10.9	-0.5744	10.9	-9.4621
1	-1.625	1	-1.3591	6	-15.373	6	32.0961	11	-2.8495	11	-5.3884
1.1	-1.7126	1.1	-0.2536	6.1	-0.419	6.1	-11.749	11.1	1.7906	11.1	5.7755
1.2	7.7487	1.2	8.8369	6.2	54.8191	6.2	21.0773	11.2	4.2494	11.2	7.6397
1.3	8.6411	1.3	5.2371	6.3	4.9476	6.3	-38.626	11.3	-0.255	11.3	-0.9727
1.4	0.7464	1.4	-2.735	6.4	-64.837	6.4	-57.751	11.4	-6.2789	11.4	-5.8228
1.5	-5.5497	1.5	-3.0145	6.5	-45.12	6.5	26.4216	11.5	-2.645	11.5	-2.8333
1.6	-1.4413	1.6	-1.5556	6.6	12.3937	6.6	21.8237	11.6	2.0587	11.6	-2.2006
1.7	-8.2805	1.7	-6.955	6.7	-29.17	6.7	-49.375	11.7	3.6683	11.7	3.6223
1.8	-1.8983	1.8	2.4158	6.8	-42.966	6.8	-57.816	11.8	3.667	11.8	8.5146
1.9	4.6078	1.9	4.6682	6.9	38.8587	6.9	42.7367	11.9	4.7985	11.9	5.4783
2	16.5509	2	6.836	7	67.1712	7	39.5825	12	2.2462	12	-2.6395
2.1	36.2251	2.1	35.4019	7.1	11.9077	7.1	12.5277	12.1	-1.948	12.1	-4.116
2.2	4.492	2.2	-0.3629	7.2	-9.6307	7.2	44.6558	12.2	-0.1641	12.2	2.3443
2.3	-1.776	2.3	-0.1708	7.3	-7.4543	7.3	-21.503	12.3	3.4834	12.3	4.1455
2.4	10.0506	2.4	11.2945	7.4	-55.915	7.4	-100.46	12.4	8.0554	12.4	7.3256
2.5	-11.658	2.5	-11.744	7.5	-71.068	7.5	-55.233	12.5	3.3735	12.5	4.2808
2.6	-10.273	2.6	-10.041	7.6	1.1282	7.6	50.3417	12.6	3.4713	12.6	1.0857
2.7	15.7731	2.7	27.8222	7.7	53.7186	7.7	39.0147	12.7	1.7069	12.7	-1.0899
2.8	7.8615	2.8	-3.3337	7.8	31.5071	7.8	3.5657	12.8	4.1663	12.8	2.2879
2.9	7.9233	2.9	-3.7974	7.9	-8.4969	7.9	8.9418	12.9	4.4045	12.9	8.7966
3	-0.9814	3	10.0002	8	-8.9422	8	-19.781	13	7.3645	13	7.7239
3.1	73.7123	3.1	68.7154	8.1	-13.44	8.1	-39.447	13.1	7.8403	13.1	5.3989
3.2	-6.0668	3.2	-14.277	8.2	-23.507	8.2	1.0189	13.2	7.1222	13.2	3.3216
3.3	-38.117	3.3	-42.276	8.3	-17.228	8.3	30.0155	13.3	4.1153	13.3	2.5027
3.4	-38.75	3.4	-11.4	8.4	7.0912	8.4	-8.6685	13.4	0.9031	13.4	1.4648
3.5	87.8285	3.5	58.6069	8.5	5.6664	8.5	-33.483	13.5	2.7508	13.5	4.4264
3.6	97.2625	3.6	88.756	8.6	-11.153	8.6	-8.2821	13.6	4.2295	13.6	6.4019
3.7	100.046	3.7	104.641	8.7	-3.7987	8.7	12.6145	13.7	5.4817	13.7	3.0295
3.8	46.0944	3.8	37.9307	8.8	21.6585	8.8	20.3864	13.8	6.0134	13.8	2.9455
3.9	8.1774	3.9	-43.854	8.9	30.4131	8.9	33.2728	13.9	6.0684	13.9	4.0037
4	-79.134	4	-68.283	9	18.3484	9	25.0057	14	3.6399	14	3.6135
4.1	-78.504	4.1	-30.135	9.1	19.1018	9.1	-0.8247	14.1	-0.0728	14.1	1.3692
4.2	-15.038	4.2	26.1283	9.2	6.244	9.2	-16.582	14.2	1.3293	14.2	3.1153
4.3	77.52	4.3	51.7908	9.3	-12.941	9.3	-3.9902	14.3	5.2928	14.3	4.8161
4.4	34.3528	4.4	-0.5216	9.4	-32.095	9.4	-3.8078	14.4	7.2422	14.4	3.8665
4.5	-33.661	4.5	-54.423	9.5	-21.601	9.5	-15.101	14.5	5.9713	14.5	4.3042
4.6	10.9703	4.6	18.8025	9.6	-6.2062	9.6	-11.388	14.6	4.0607	14.6	3.4216
4.7	23.5968	4.7	36.0764	9.7	2.9305	9.7	-4.0899	14.7	3.8502	14.7	3.842
4.8	24.2207	4.8	43.3739	9.8	5.0165	9.8	-2.1539	14.8	0.8327	14.8	1.7134
4.9	-6.6198	4.9	19.0576	9.9	4.579	9.9	-0.3863	15	4.647	15	4.4057

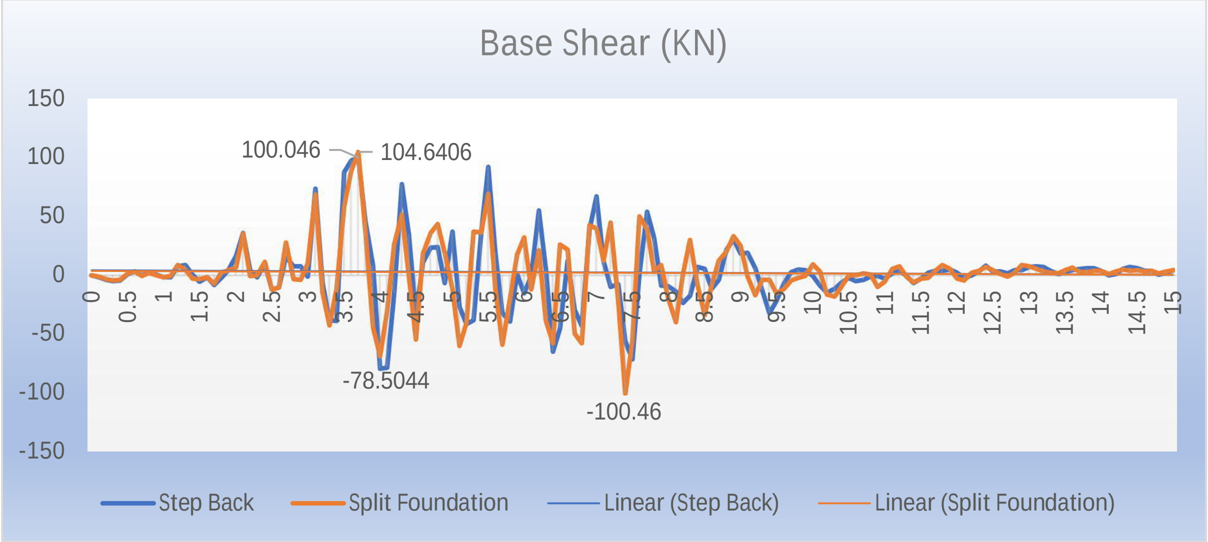


Fig. 28 Base shear comparison by Time History method

Spectral Acceleration

Peak Ground Acceleration (PGA) is defined as the maximum ground acceleration that occurred during ground motion at a site. PGA is equivalent to the sufficiency of the biggest total speed increase recorded on an accelerogram at an area during a particular seismic tremor. Tremor normally happens in each of the three bearings. In this manner, PGA is frequently partitioned into the level and vertical segments. Level PGAs are for the most part more noteworthy than the upward PGAs in this way flat one is utilized more in designing applications.

In the present study, the maximum value of spectral acceleration is compared for both step back and split foundation model as shown in fig. 12. By taking into consideration the type of soil as per IS code, the maximum value for step back and split foundation model comes out to be 2919.96 mm/sec^2 and 4625.52 mm/sec^2 respectively. The results of PGA generated completely shows a major difference of 36.8% making clearly step back model more stable for hilly regions.

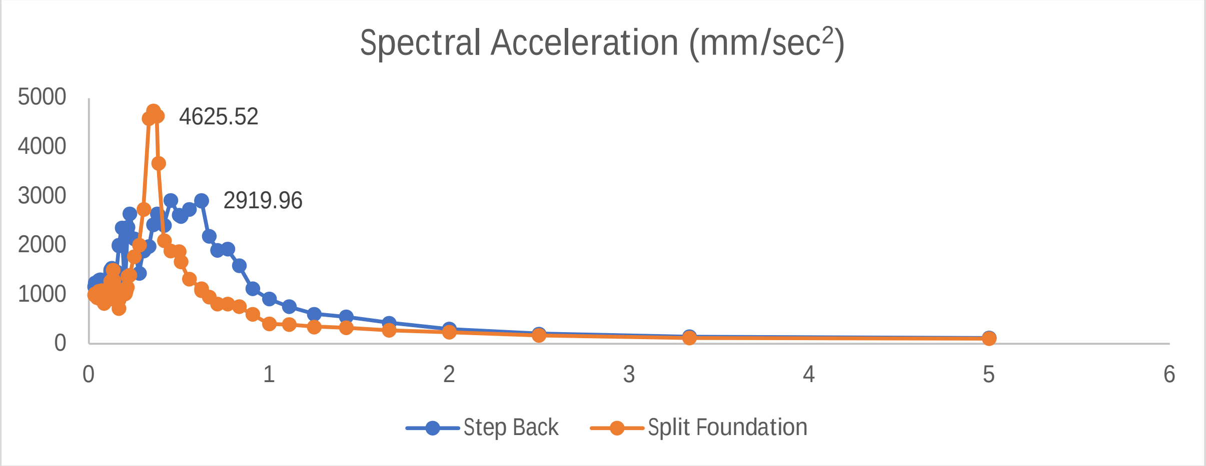


Fig. 29 Spectral acceleration comparison by Time History method

Table 12 Spectral acceleration comparison by Time History method

Spectral Acceleration (5% Damping)							
Step Back		Split Foundation		Step Back		Split Foundation	
Time	S_a(mm/sec^2)	Time	S_a(mm/sec^2)	Time	S_a(mm/sec^2)	Time	S_a(mm/sec^2)
0.03	1158.92	0.03	987.39	0.213	2182.88	0.213	1155.04
0.036	1242.32	0.036	1018.22	0.216	2365.26	0.216	1374.61
0.04	1191.92	0.04	991.48	0.227	2646.84	0.227	1392.11
0.045	1122.92	0.045	940.51	0.25	2140.28	0.25	1769.96
0.05	1196.3	0.05	991.53	0.278	1430.81	0.278	2008.31
0.056	1296.88	0.056	1068.42	0.303	1891.15	0.303	2732.14
0.061	1303.42	0.061	918.07	0.333	1980.56	0.333	4584.31
0.067	1187.33	0.067	991.99	0.357	2418.09	0.357	4737.95
0.071	997.82	0.071	1088.24	0.378	2636.75	0.378	4625.52
0.077	1071.81	0.077	1004.51	0.385	2623.44	0.385	3673.9
0.083	1002.25	0.083	826.34	0.417	2415.29	0.417	2091.44
0.091	1081.82	0.091	904.64	0.455	2917.44	0.455	1892.33
0.098	1178.82	0.098	991.78	0.5	2611.5	0.5	1879.7
0.1	1196.52	0.1	995.91	0.509	2595.37	0.509	1674.52
0.109	1316.58	0.109	1104.03	0.556	2738.26	0.556	1314.14
0.111	1335.28	0.111	1108.89	0.625	2919.96	0.625	1126.72
0.111	1343.79	0.111	1139.16	0.626	2898.9	0.626	1077.97
0.118	1452.62	0.118	1183.32	0.667	2183.9	0.667	950.43
0.121	1501.65	0.121	1271.39	0.714	1906.92	0.714	808.54
0.125	1544.24	0.125	1297.91	0.769	1924.61	0.769	806.98
0.133	1497.93	0.133	1503.68	0.833	1591.56	0.833	756.98
0.136	1461.45	0.136	1287.05	0.909	1117.2	0.909	601.09
0.136	1453.33	0.136	1187.92	1	909.52	1	404.03
0.143	1393.44	0.143	1143.7	1.111	756.16	1.111	391.3
0.154	1462.8	0.154	858.24	1.25	606.12	1.25	346.33
0.167	1992.46	0.167	722.59	1.429	546.69	1.429	329.05
0.167	2004.31	0.167	885.15	1.667	422.24	1.667	276.33
0.182	2359.34	0.182	992.46	2	300.45	2	235.59
0.2	1168.6	0.2	1016.14	2.5	206.2	2.5	169.25
0.204	1352.69	0.204	1076.86	5	120.75	5	105.67

The following results were obtained by the Pushover Analysis of the model of buildings:

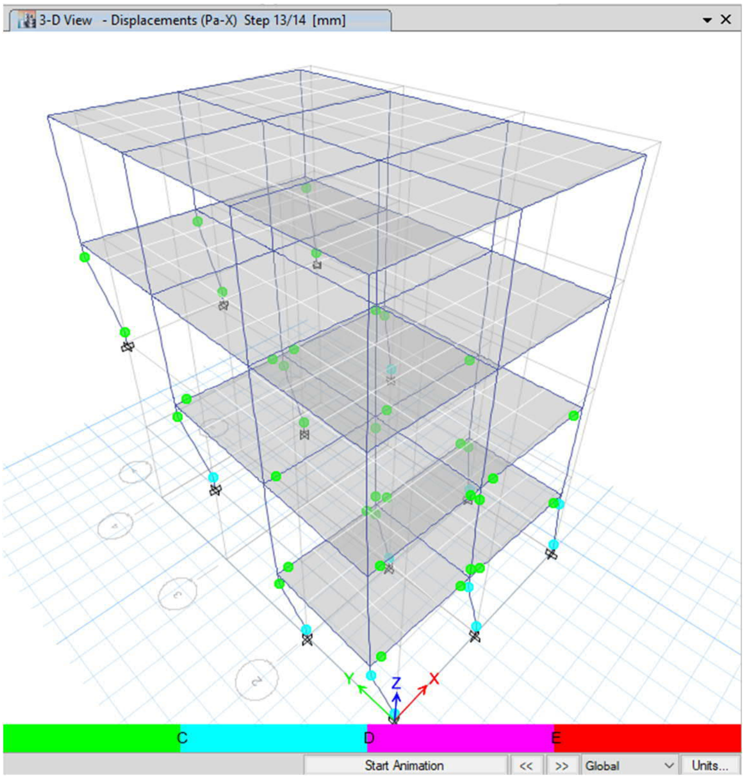


Fig. 30 Hinge Formation of Step Back Model

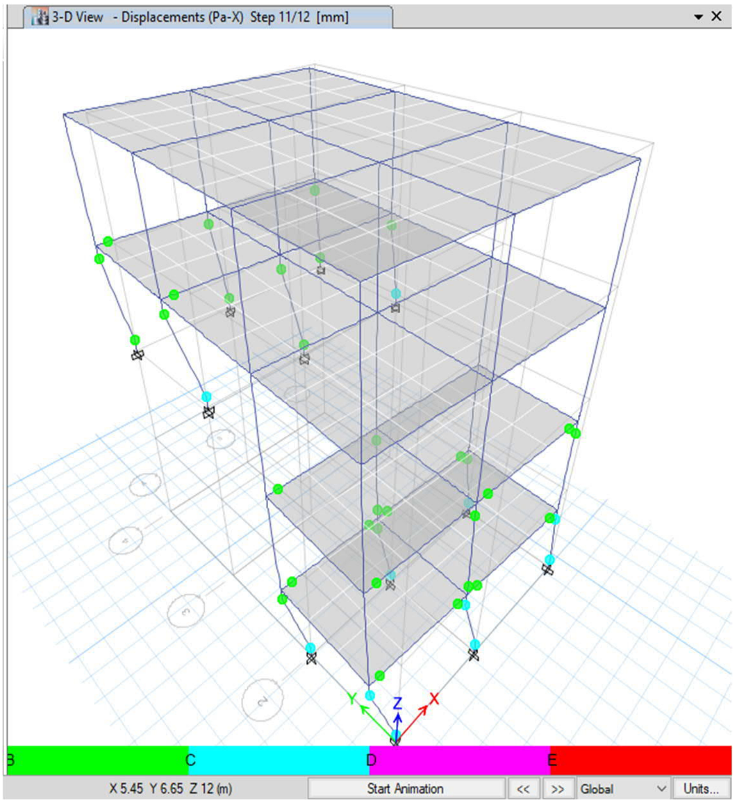


Fig. 31 Hinge Formation of Split Foundation Model

Capacity Curves

The plot between base shear and rooftop removal is referred as capacity curve. Additionally, referenced as pushover curve.

Demand Curve

It is plot between average spectral acceleration versus time period. It represents the seismic tremor ground movement in capacity spectrum technique.

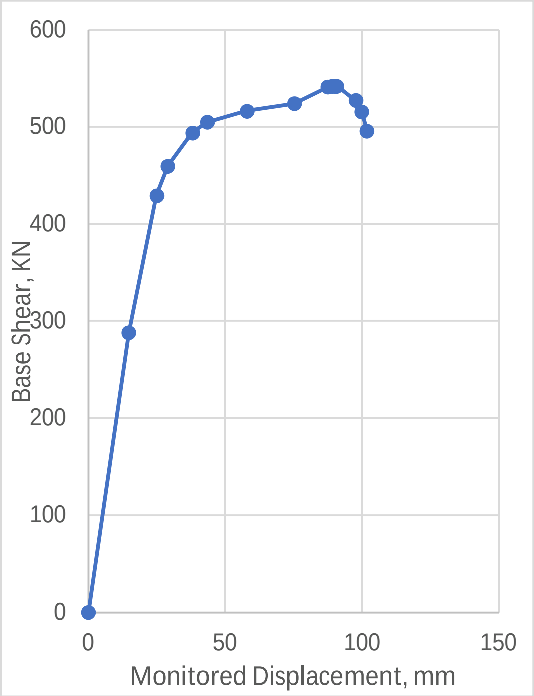


Fig. 32 Capacity Curve (Step back)

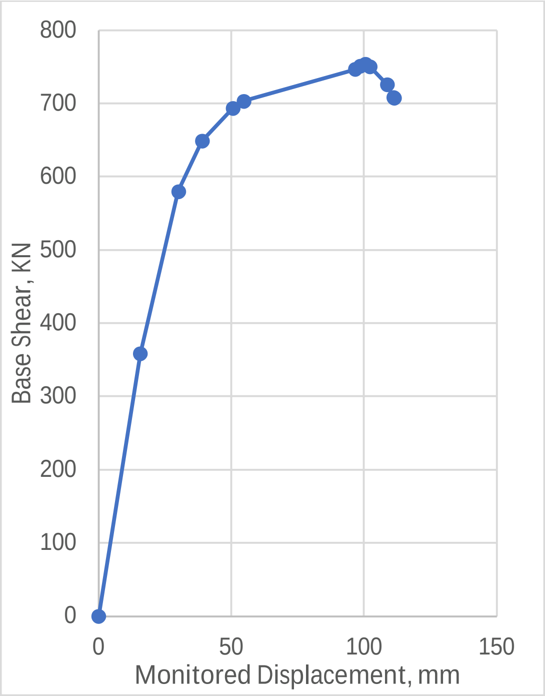


Fig. 33 Capacity Curve (Split Foundation)

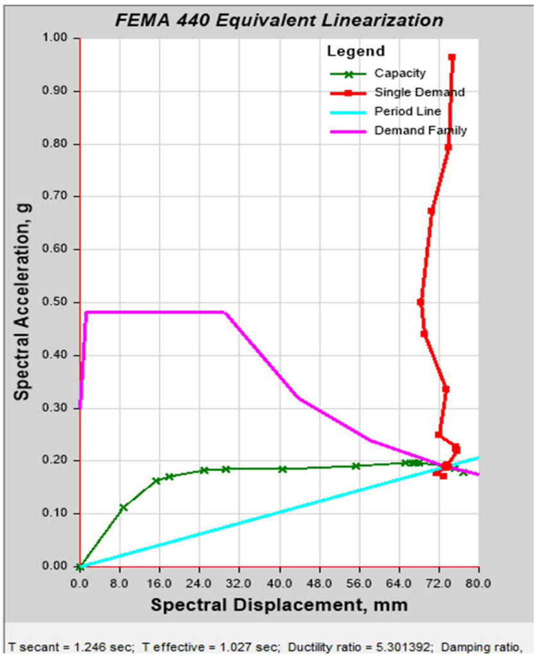


Fig. 34 FEMA 440 Curve (Step Back)

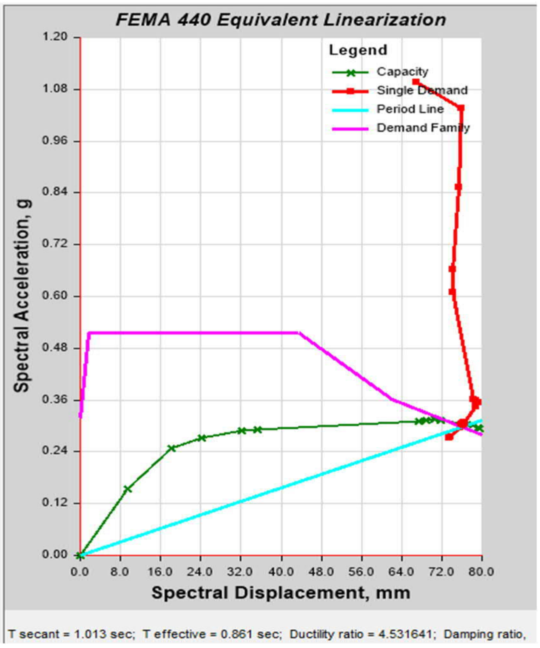


Fig. 35 FEMA 440 Curve (Split Foundation)

A nonlinear static methodology that produces a graphical representation of the normal seismic performance of the structure by crossing the structure's capacity curve with a response spectrum representation of tremor's displacement demand on the structure, the meeting point is called **performance point** and the relocation coordinate dp of the performance point is the evaluated displacement demand on the structure for the predetermined level of hazard.

Fragility Curve

Fragility (or weakness) can be depicted as the conditional probability of a system achieving a recommended limit state (LS) for a given framework request D = d, P (LS/D = d).

$$P\ (LS/D=d) = \Phi\ ((\ln d-\mu_{\ln d})/\sigma_{\ln d})$$

In above equation, $\mu_{\ln X}$ indicates that the mean of the natural logarithm of uncertain Variable D. The logarithmic standard deviation is the standard deviation of the natural logarithm of the variable D. In this paper the fragility curves are determined using the results obtained by doing pushover analysis on the above model. Fig. 13 shows that in case of step back building Immediate Occupancy (IO) is achieved at 0.16g, Life Safety (LS) around 0.20g and the Collapse Limit (CL) around 0.22g and from Fig. 14 in case of split foundation building Immediate Occupancy (IO) is achieved at 0.15g, Life Safety (LS) around 0.19g and the Collapse Limit (CL) around 0.21g. The below shown fragility curve clearly shows that the split foundation reaches both IO and CL limits at a lower PGA than the step back building. This clearly shows that split foundation building is more fragile than step back building.

Table 13 Mean and SD

Type	$\mu_{\ln(d)}$	$\sigma_{\ln(d)}$
SB	3.45961	0.436412
SF	3.548817	0.450197

Table 14 Statistical Probability of Density function of displacement (Step back)

PGA	Displacement(mm)	IO	LS	CL
0.10g	0	0	0	0
0.12g	-14.8	0	0	0
0.13g	-22.7	0.44	0	0
0.14g	-25.7	0.69	0	0
0.15g	-33.6	0.92	0	0
0.16g	-36.7	0.97	0.32	0
0.17g	-71.4	1	0.51	0
0.18g	-72.9	1	0.67	0
0.19g	-84.2		0.79	0.29
0.20g	-85.5		0.92	0.48
0.21g	-86.4		0.99	0.68
0.22g	-91.4		1	0.88
0.23g	-93.7		1	0.98
0.24g	-101.8			1
0.25g	-106.6			1

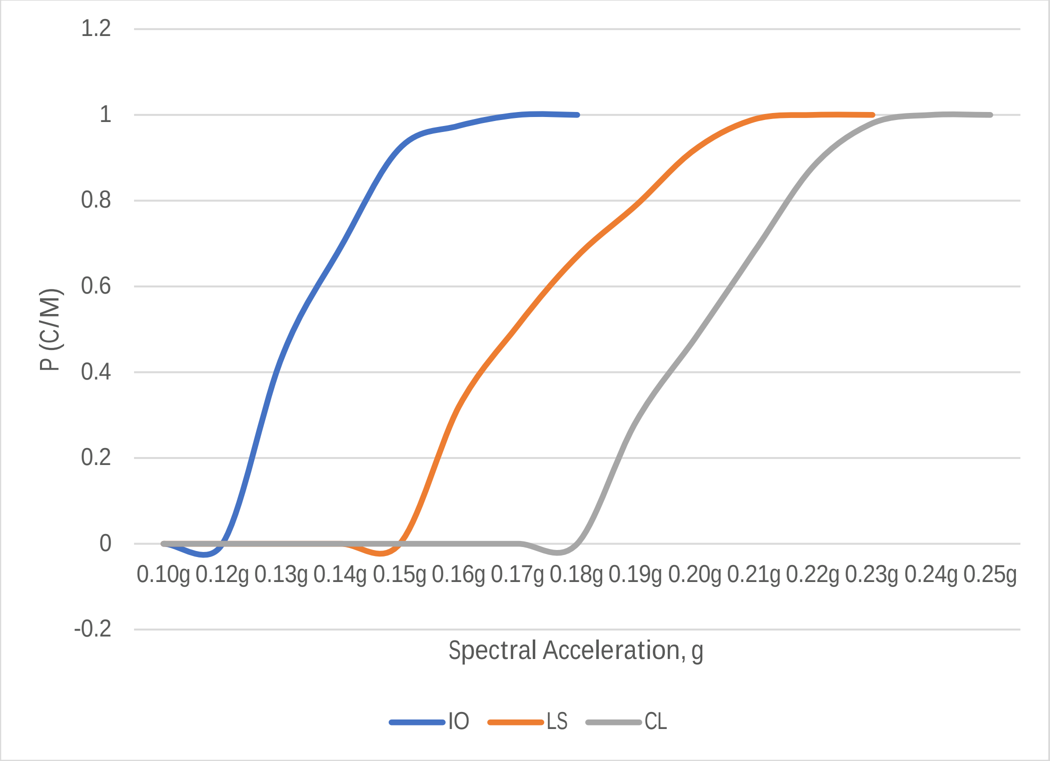


Fig. 36 Fragility Curve of Step Back Building

Table 15 Statistical Probability of Density function of displacement (Split Foundation)

PGA	Displacement(mm)	IO	LS	CL
0.10g	0	0	0	0
0.12g	-15.7	0	0	0
0.13g	-30	0.37	0	0
0.14g	-39	0.73	0	0
0.15g	-50.5	0.95	0.22	0
0.16g	-54.8	1	0.41	0
0.17g	-96.7	1	0.63	0.18
0.18g	-98.6		0.78	0.35
0.19g	-100.6		0.91	0.58
0.20g	-102.2		1	0.76
0.21g	-108.7		1	0.88
0.22g	-111.2		1	0.98
0.23g	-111.3			1

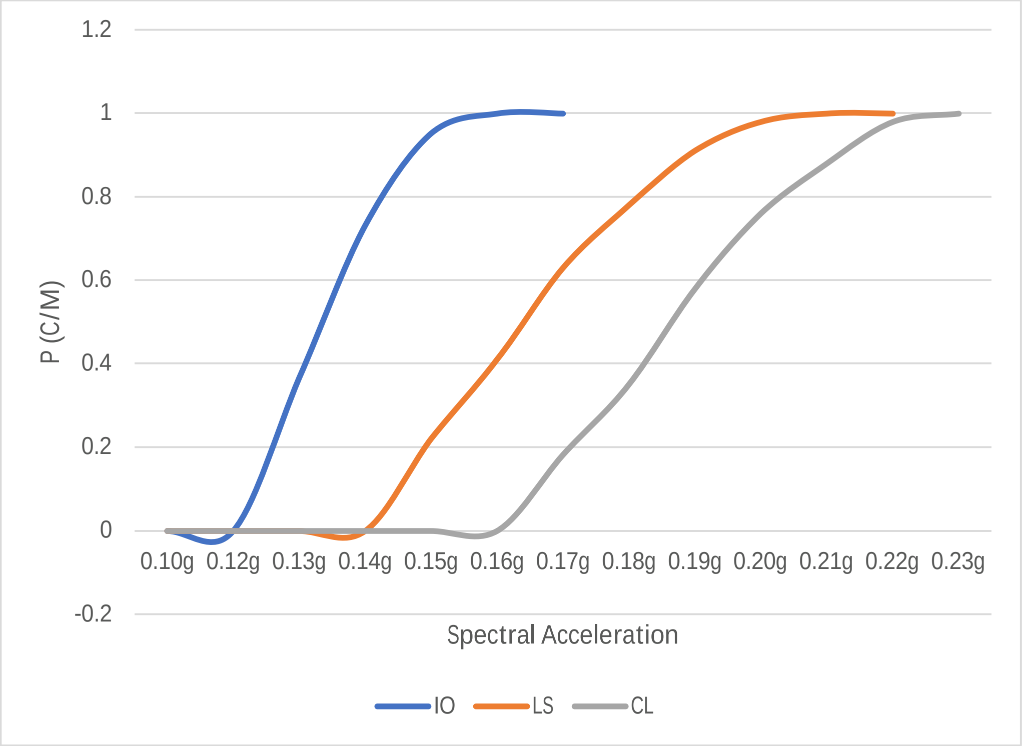


Fig. 37 Fragility Curve of Split Foundation Building

The above results showing comparison between step back and split foundation model in hilly regions under the seismic action provide us with the following conclusion.

Chapter 5
Conclusion

- As it is clearly visible through the geographic map of India that almost all the hilly region of India comes under zone-IV or zone-V which makes them more vulnerable to major loss of life and property due to seismic action.
- It is the destruction of the property due to earthquake which leads to the loss of major part of life everywhere therefore we need to reduce this destruction of property.
- In this study we compared the models of two majorly constructed buildings in hilly regions i.e., step back and split foundation buildings.
- The conclusion drawn from the results mentioned above is that step back buildings are proved to be a better option for hilly regions by response spectrum method, time history method and fragility curve obtained by performing pushover analysis.
- The storey displacement, storey drift and storey forces in step back comes out to be less showing its better reaction towards same seismic action in both response spectrum and time history analysis performed.
- Whereas, even the base shear and PGA generated due to seismic action comes out to be less in step back building than split foundation building and also, the split foundation building is more fragile than step back building.
- Even when the fragility curves obtained by using pushover analysis shows that step back building is much more safe than split foundation building in every limit state (i.e., IO, LS and CL).
- This shows that Step Back buildings should be preferred more than Split Foundation buildings in hilly regions for mild and medium slopes.

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