



# “Seismic Performance Evaluation Of Irregular Reinforced Concrete Buildings Due To Story Height Difference By Using E-Tabs”

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**Abstract:** - Soft-story construction is frequently used in high-rise or multi-story buildings due to architectural considerations that produce story height differences. These give the building structures irregularities in stiffness, which lessens the stiffness of the lateral load-resisting system. A sudden decrease in stiffness concentrates more stress at the stiffness-reduced story columns, making the columns incapable of providing sufficient resistance during an earthquake.

Given the aforementioned considerations, the impact of soft stories on the building's seismic performance must be taken into account while evaluating and designing the structural building frames.

This study's primary goal is to use numerical models based on finite element principles to investigate the seismic performance of stiffness irregular buildings caused by a large story height difference on RC structures. G+10 and G+20 are the basis case structures for these two regular buildings, while instances representing irregular structures are defined by altering the base case's vertical distribution stiffness. By extending the base case's ground and second floors' height by 200%, the stiffness irregularity is produced. Consequently, ETABS 2021.2.1 (CSI ETABS 2022, Integrated Building Design Software, Computers and Structures Inc. Berkeley) is used to study and design various model scenarios of RC buildings. According to the new Ethiopian Buildings Code Standards (ES EN: 2015), the suggested building model examples were analyzed and designed using the traditional design methodology. The numerical model on SeismoStruct is then based on the design outputs of the primary structural elements [SeismoSoft, 2016]. The response in terms of basic periods, base shear-top displacement, interstory drift, lateral displacements, and fragility curve at various performance levels is obtained by pushover and nonlinear dynamic studies.

As the number of soft stories and the number of stories or building height increase, the effect of stiffness irregularity on the fundamental period becomes more significant. In all cases, the story drifts demands increase in the soft story and decrease in most other stories, and the drift of most floors is greater than the low able drift according to the seismic base shear for stiffness regular buildings are greater than the stiffness irregular ones. Lastly, the probability of failure for each limit state capacities of stiffness irregular building models is greater than stiffness regular buildings models in all cases.

Keywords: - soft-story, fragility curves, pushover and limit state capacities

## Introduction

Points of weakness are where a structure begins to fail during an earthquake. This weakness results from irregularity, or discontinuity in the mass, stiffness, and geometry of the structure. These flaws frequently cause total collapse by emphasizing and concentrating the structural deterioration. As a result, the structural engineer must have a solid grasp of how various building types and configurations react to earthquakes. A thorough design process that addresses the reaction of structures with varying configurations—which may arise from various limitations imposed by owners, architects, and planners—should take uncertainties in seismic demands and structural capacities into account. Due to aesthetic considerations and city regulations, many structures currently have uneven elevations and plans, which could be vulnerable to devastating earthquakes in the future. Although it is impossible to completely prevent abnormalities in building construction, it is important to investigate how these structures behave during earthquakes. One of the main causes of structure collapses during earthquakes is vertical abnormalities. For instance, the most prominent structures that collapsed after previous earthquakes had soft stories and an uneven mass distribution.

Due to P-delta effects, excess mass can cause a sudden rise in lateral inertial forces, decreased column ductility, and an increased propensity for collapse. The strong columns-weak beam criteria is the essential design principle for earthquake resistance, which ensures occupant safety by causing the beams to yield before the columns fall during an earthquake. Because of the consequences of soft-story provisions, we can observe that many of the building structures that collapsed during the last earthquake had the opposite behaviour of strong beams and weak columns, meaning that the columns collapsed before the beams gave way.

Soft storeys can be caused by partial height infill, which is also prevalent in many buildings, or by omitting infill in a single level, as is frequently the case in the first story. They can also emerge from differences in floor height. As seen in fig. 1.1, shear during an earthquake has severely damaged the first-floor columns of several buildings. Therefore, it becomes crucial to consider how vertical irregularities affect a structure's seismic performance. Changes in mass and stiffness with height cause the buildings' dynamic properties to differ from those of a typical building. In some floors, where mass, stiffness, and strength alter, these kinds of irregularities can concentrate forces and stresses. The most crucial factor is the analysis approach to be applied when a structure exhibits irregularities in mass, stiffness, strength, or vertical geometric irregularity. The majority of mixed-use buildings nowadays use soft-story layouts, which enable different story heights, such as double-story first stories, a mezzanine for cafes and storage, and intermediate double-story heights when there The necessity of designing RC structures that differ from the typical design parameters, such as buildings with varied story heights, especially those with a significantly higher first floor than the others, or buildings with the so-called soft-story. In order to meet all of the investors' and architects' requirements, the construction must first be completely seismically stable in order to ensure public safety in the event of a major natural disaster, such as an earthquake (Kanno et al., 2014).

Current scientific and technical developments indicate that there are two distinct methods for evaluating the seismic performance of reinforced concrete structures: probabilistic (performance-based) and deterministic (code-based) approaches. In order to evaluate the strength and ductility for the necessary building performance, the focus on seismic design and assessment of reinforced concrete frame buildings has changed from code-based (force-based design) to performance-based design. Depending on the degree of design rigor, RC frame structures may sustain varying degrees of damage from seismically generated ground vibrations, with the possibility of hinge creation in structural parts. The standard building design process in code-based design is not performance-based; instead, design experts choose, scale, and detail building elements to meet prescriptive requirements outlined in the building code. Although many of these criteria were created with the intention of providing some degree of seismic performance, the intended performance is sometimes unclear, and it is rarely assessed or understood if the resulting designs can actually offer the expected performance.

The formal process of designing new buildings or seismically upgrading existing ones that incorporates a clear aim to meet predetermined performance objectives in the event of future earthquakes is known as performance-based seismic design. Expectations about the extent of damage a building may sustain from seismic shaking and the effects of that damage on all end users of the building and its linked equipment are related to performance objectives. Operational, Immediate Occupancy, Life Safety, and Collapse Prevention are the separate performance levels that are used to indicate performance in procedures of the current generation. These performance standards are evaluated at a predetermined seismic hazard level and are applied to both structural and non-structural elements. Seismic analysis and building structure design include a number of characteristics, many of which are unclear. Therefore, using a deterministic (code-based) technique to obtain accurate and trustworthy results is not always feasible due to the uncertainty inherent in seismic analysis for building structures. Changes in material qualities, the building's structural characteristics, dynamic excitation, time history data, loading profiles, etc., could all contribute to the uncertainty.

Given the aforementioned considerations, the impact of soft stories on the building's seismic performance must be taken into account while evaluating and designing the structural building frames. This study's primary goal is to use numerical models based on finite element principles to investigate the seismic performance of stiffness irregular buildings caused by a large story height difference on RC structures. ETABS 2016.2.1 (CSI ETABS 2016, Integrated Building develop Software, Computers and Structures Inc. Berkeley) is used to study and develop these many model scenarios of RC buildings.

According to the new Ethiopian Buildings Code Standards (ES EN: 2015), the suggested building model examples were analysed and designed using the traditional design methodology. However, SeismoStruct [SeismoSoft, 2016], a fibre-based finite element software program that can forecast the massive displacement behaviour of space frames, is used to compute numerical modelling and nonlinear time history analysis of planned building model situations.

### **Problem Statement:**

When a story level is less rigid than the story level above it (some codes allow for a variance of up to 70%), the building is called a soft-story building. These irregularities in stiffness are typical of multi-story buildings and cannot be prevented by architectural considerations. As a result, the soft-story becomes insufficiently stiff to withstand horizontal seismic stress, leaving the structure vulnerable to partial or whole damage. . Therefore, it is crucial to take into account and assess how stiffness irregularity affects the structure's seismic performance in order to prevent and lessen building collapse. It is widely acknowledged that most building constructions will exhibit a nonlinear reaction to earthquakes of medium to high intensity. However, it is generally recognized that this phenomenon is typically not adequately modeled, particularly during the design phase, where only straightforward linear techniques have proven to be successful. Since the majority of earlier research has concentrated on stiffness irregularities caused by infill walls, it is necessary to investigate stiffness irregularities caused by variations in story height.

Therefore, the purpose of this study is to assess how soft stories affect the seismic performance of reinforced concrete buildings. The research primarily uses finite element software packages to design reinforced concrete buildings with varying story heights and number of stories in order to ascertain how these factors affect the building's seismic performance. For the purpose of numerical analysis, reinforced concrete frames are suggested for two different buildings (G+10 and G+20). According to ETABS 2016.2.1 and ES EN: 2015, the conventional method was used in the design of this RC building. The numerical model on Seismo Struct is then based on the design outputs of the primary structural elements [Seismo Soft, 2016]. The response in terms of basic periods, base shear-top displacement, inter story drift, lateral displacements, and fragility curve at various performance levels is obtained by pushover and nonlinear dynamic studies.

### **OBJECTIVES:**

#### **GENERAL OBJECTIVE**

Evaluating the seismic performance of stiffness irregular buildings with large story height differences on RC buildings during seismic excitation is the main goal of this study.

## SPECIFIC OBJECTIVE

Limit state capacities are established at various damage limit states.

Probabilistic seismic demand models (PSDM) are being developed.

The creation of fragility curves for different building performance levels when seismic hazards are present.

## SIGNIFICANCE OF THE STUDY:

The study used to help and give awareness to design engineers in order to make their design by considering the effects of story height difference on RC buildings in seismically active regions.

The researcher proposes to answer the following problems

- 1.How does a stiffness irregular building behave seismically when there is a large story height differential on an RC structure under seismic excitation?
- 2.How likely is it that a stiffness irregular building would fail because of a large variance in story height?
3. Does an increase in the number of stories affect seismic performance due to differences in story height?

## METHODOLOGY:

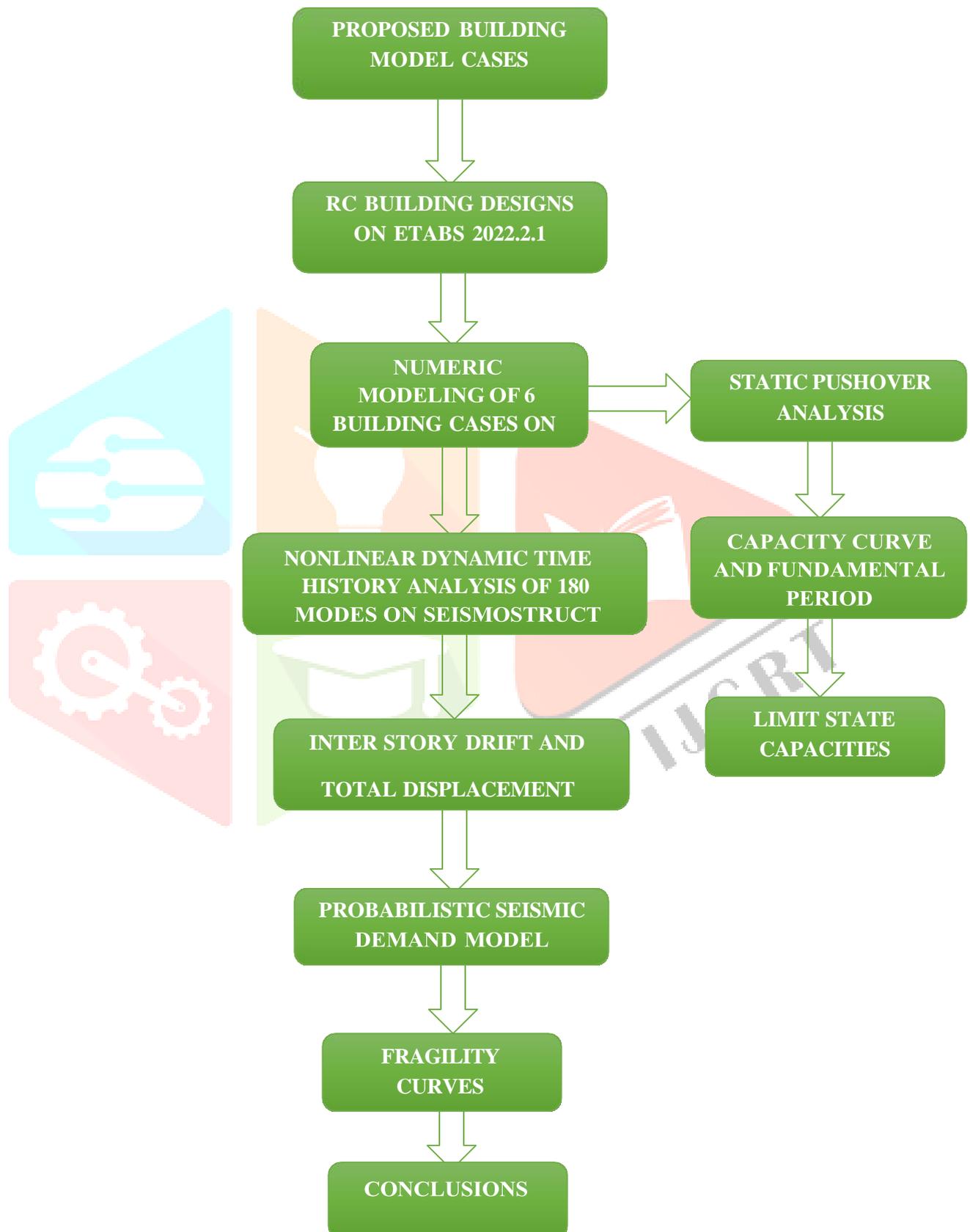
According to the new Ethiopian Building Code analysis and design methodology, seismic design of planned RC buildings is carried out on ETABS. The response spectrum method is used to place the suggested research site area in Addis Ababa (earthquake zone-III) and assess all building model instances for both seismic and gravitational loads. RC frames are then numerically modeled using a finite element software program using the numerical values discovered in the design section. All model scenarios undergo pushover and nonlinear time history analysis. Last but not least, the model structures' performance at various performance levels has been examined, and the findings are described in terms of the primary response characteristics, including seismic fragility curves, fundamental periods, total base shears, inter story drifts, and lateral displacements.

The scope and methodology of the research includes the following;

- To determine study needs, building selection, seismic record selection, analysis method, performance criteria, and the effects of several parameters on the seismic performance and fragility curve development, a thorough literature survey was carried out.
- Based on ETABS 2016.2.1 and ES EN: 2015, six mixed-use RC building model instances are suggested for Addis Ababa. Modal response spectrum analysis was used for earthquake analysis. The traditional design and optimization of buildings ensures that the entire analysis and design process adheres to the current code approach, construction practice, and overall economy and safety.
  - The above-designed building model examples' structural features are supplied in an easy-to-use manner for the numerical modeling that comes next.
- SeismoStruct 2016 is used to prepare and model six building model cases for each designed model.
- To serve as earthquake recordings for nonlinear time history analysis, 30 synthetic accelerograms of varying magnitudes are created, scaled, and matched with the Ethiopian response spectrum on SeismoArtif [SeismoSoft, 2016]. With the use of several calculation techniques and a range of assumptions for nonlinear dynamic analysis of new or existing structures, SeismoArtif is a program that can create synthetic earthquake accelerograms that correspond to a particular target response spectrum.
- As a result, 180 model cases are ready for the nonlinear time history analysis, with six building model cases filled with 30 artificial accelerograms each.
- To create Probabilistic Seismic Demand Models (PSDMs) and seismic fragility curves in Microsoft Excel, nonlinear time history analysis is carried out for 180 numerically modeled building examples.
- The results of pushover and nonlinear time history analysis are then combined for all building model examples at different performance levels to create seismic fragility curves. By merging the limit state capacities and the PSDMs using Microsoft Excel, fragility responses are calculated and fragility curves—

an indicator of the chance of failure—are created for each building model case for varying performance levels in terms of PGA. This paper examines a method based on nonlinear time history analysis and the probabilistic demand model proposed by Cornell et al. (2002), out of the many known approaches for developing fragility curves. Fragility curves are thus created for the chosen structures.

• Final thoughts and conclusions have been reached, and detailed results for each building model example are presented.



**Figure 1-2-** Flow Chart Diagram Representing the Overflow Methodology

## RESULTS AND DISCUSSION:

Every building has a range of natural frequencies at which it provides the least amount of protection from earthquake-induced shaking. A building's natural oscillation mode is made up of all of these inherent frequencies and the corresponding deformations. The fundamental mode is the oscillation mode with the fewest natural frequencies (and the greatest natural period); the fundamental natural period is the corresponding natural period; and the fundamental natural frequency is the corresponding natural frequency. Therefore, the time it takes for the building to go through one full oscillation cycle is its natural vibration period. It is a natural feature of the structure that is governed by its stiffness and mass. When the building is shook at its natural frequency, it provides the least amount of resistance. Therefore, when shook at its inherent frequencies, it oscillates more than when shaken at other frequencies.

A building begins to shake when seismic forces excite it. Since frequency and time period are inversely proportional ( $T = 1/f$ ), a structure's longest time period ( $T$ ) of vibration corresponds to its lowest natural frequency ( $f$ ). This is also known as the fundamental period of vibration or the initial mode vibration. There will be several natural vibrational modes in the structure, each with a greater frequency and a shorter time period than the fundamental period.

Understanding the worldwide demands on the structure during an earthquake may be greatly aided by a sufficient and accurate calculation of the natural duration of vibration. In both seismic design and assessment, its evaluation is a crucial stage in estimating the seismic response. Mass, strength, and stiffness are the primary determinants of this crucial aspect of the building's seismic behavior, and as a result, all the variables that influence them (height and plan dimensions, morphology, irregularities, section characteristics, stiffness, cracking, etc.). The fundamental period of vibration is estimated for the various building model scenarios in the current study, and a comparison analysis is conducted in the section that follows. The following answer to the fundamental periods was discovered from the monitored pushover analysis in the governing direction (+X) of the simulated three-dimensional G+10 and G+20 buildings.

### G+10 BUILDING MODEL CASES

**Table 6-1- Fundamental Periods of G+10 Building Models**

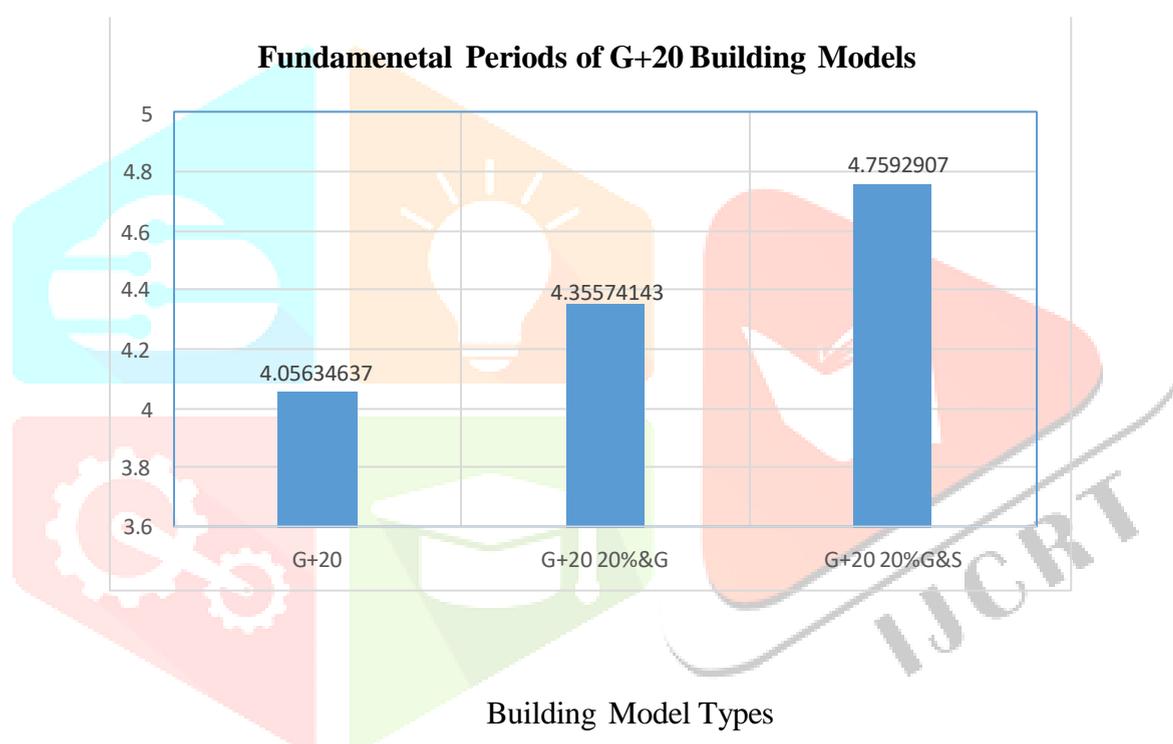
Building Model Types	Case Designation	Fundamental Period (Sec.)	Deviation From Model-4 (%)
G+10	Model-4	2.23	0
G+10 20%G	Model-5	2.35	5.35
G+10 20%G&S	Model-6	2.97	33.00

Building Model Types

## G+20 BUILDINGS MODEL CASES

**Table 6-3-** Fundamental Periods of G+20 Building Models

Building Model Types	Case Designation	Fundamental Period (Sec.)	Deviation From Model-1 (%)
G+20	Model-1	4.055	0
G+20 200%G	Model-2	4.354	7.36
G+20 200%G&S	Model-3	4.758	17.32



In comparison to other stiffness irregular building model examples with different story heights, the stiffness regular building model (G+20) was determined to have the lowest fundamental natural vibration period (i.e., 4.056 Sec.), as indicated in table 6.2 and figure 6.2. The basic period increased to 4.355 seconds (a 7.37% increment) when the ground floor's story height was increased by 200%. Maximum basic vibration in nature

The lowest natural frequency of a structure's vibration, or period, is correlated with the comparatively lowest structural stiffness. It is evident that raising the story height of a few of the building's floors lengthens the structure's basic periods, which lessens the building's lateral stiffness.

The basic periods will therefore be increased to 4.355 (7.37% increment) and 4.759 (17.33% increment) seconds, respectively, by adding a 200% increase in the ground floor story height and a 200% increase in the story height of the ground and second levels. The basic time period of the constructions increases by 5.37% when the ground floor story height is increased, and by more than 17% when the ground and second floor story heights are increased.

## CONCLUSION ON FUNDAMENTAL PERIODS

- summary of Fundamental Periods of all Building Models

Building Model Types	Case Designation	Fundamental Period (Sec.)	Deviation From Model-1 (%)
G+20	Model-1	4.055	0
G+20 200%G	Model-2	4.354	5.36
G+20 200%G&S	Model-3	4.758	17.32
Building Model Types	Case Designation	Fundamental Period (Sec.)	Deviation From Model-4 (%)
G+10	Model-4	2.237	0
G+10 200%G	Model-5	2.357	5.35
G+10 200%G&S	Model-6	2.976	33.01

This indicates that the effect of stiffness irregularity on fundamental period has more significant contributions as the soft-story number increases. As can be seen above, the percentage deviations of fundamental periods of two stories (G+10 200%G&S) stiffness irregular building from the stiff one (G+10) for G+10 building models are greater than the corresponding values for G+20 building models. Additionally, its contributions become increasingly substantial as the building's story count or height increases.

## CAPACITY CURVE PARAMETERS

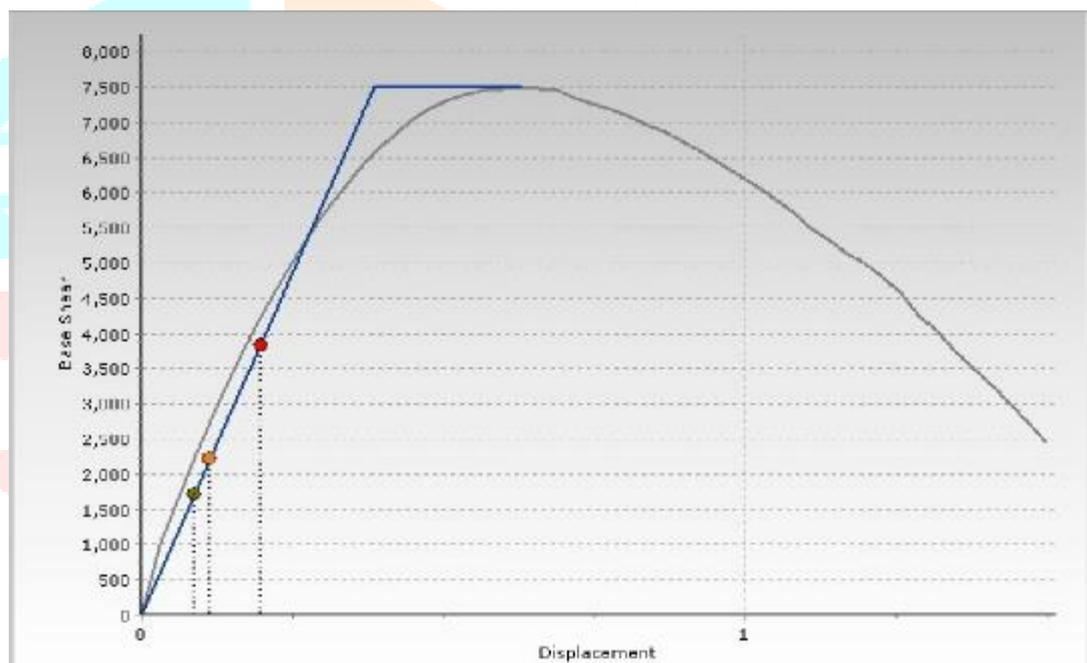
Earthquakes have the capacity to inflict the most damage among the natural disasters. Engineering tools must be improved for studying structures under the influence of seismic forces because these forces are unexpected and random. It is important to carefully analyze earthquake loads in order to evaluate the actual behavior of structures while keeping in mind that damage is inevitable but should be controlled. Pushover analysis, an iterative process, is considered an alternative to traditional analysis methods in this context. It is commonly believed that the fundamental mode of the structure governs its behavior, and that the predetermined pattern is stated either in terms of basic mode form or story shear. From the structure's

initial condition of rest to its eventual failure, it shows the load vs deflection curve. The load is indicative of the structural basic mode's corresponding static load. It is typically interpreted as the structure's overall base shear, and the top-story deflection is chosen as the deflection.

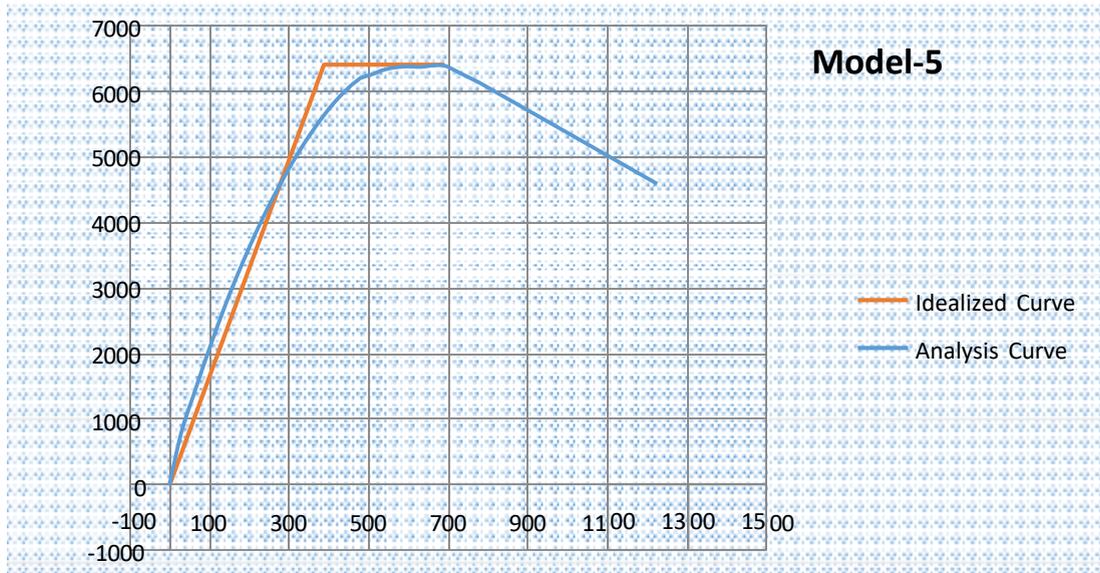
A building's pushover curve, performance point, displacement ductility, plastic hinge development, and other characteristics can all be used to assess its seismic performance. The pushover analysis yields the base shear vs. roof displacement curve, which provides the structure's maximum base shear capacity. As previously mentioned, seismic base shear and roof displacement are the two factors that contribute to the push-over curve. The greatest anticipated lateral forces that will result from seismic ground motion at a structure's base is estimated by seismic base shear.

The seismic performance of a building can be evaluated using its pushover curve, performance point, displacement ductility, plastic hinge development, and other features. The base shear vs. roof displacement curve, which gives the structure's maximum base shear capacity, is produced by the pushover analysis. The push-over curve is caused by two elements, as was previously mentioned: seismic base shear and roof displacement. Seismic base shear estimates the largest expected lateral forces that will arise from seismic ground motion at the base of a structure.

### CAPACITY CURVES OF G+10 BUILDING MODELS

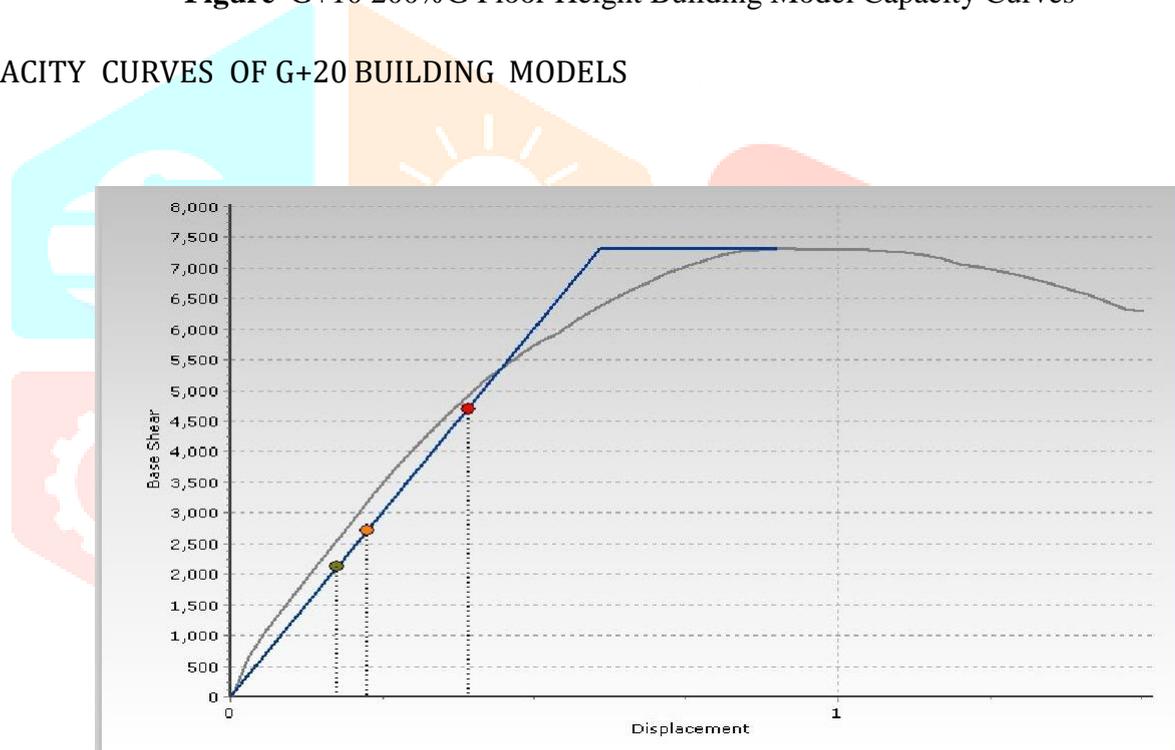


**Figure G+10 (Similar Story Height) Building Model Capacity Curves**

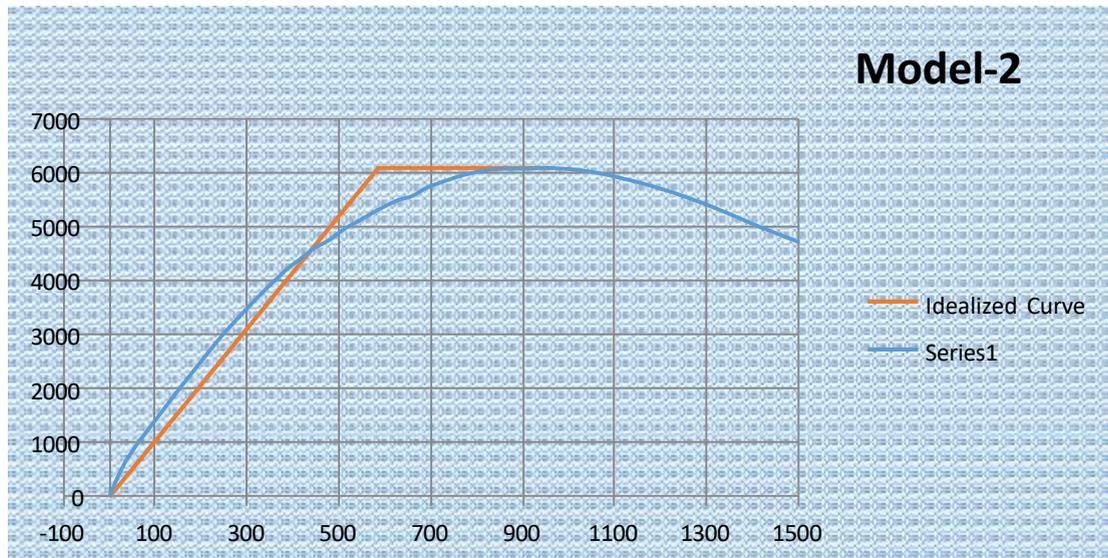


**Figure** G+10 200%G Floor Height Building Model Capacity Curves

CAPACITY CURVES OF G+20 BUILDING MODELS



**Figure** G+20 (Similar Story Height) Building Model Capacity Curves



**Figure** G+20 200% Floor Height Building Model Capacity Curves

### CONCLUSION ON CAPACITY CURVES

summary of Seismic Base Shears at DL Performance Level for all Building Cases

Building Model Types	Case Designation	Base Shear at DL Performance Level (kN)	Deviation From Model-4 (%)
G+10	Model-4	5670	0
G+10 200%G	Model-5	4820	15.00
G+10 200%G&S	Model-6	3900	31.22
Building Model Types	Case Designation	Base Shear at DL Performance Level (kN)	Deviation From Model-1 (%)
G+20	Model-1	5170	0
G+20 200%G	Model-2	4420	14.5
G+20 200%G&S	Model-3	3710	28.24

The load-displacement envelopes of the structures, or capacity curves (base shear versus roof displacement), show how the structures respond globally. The pushover assessments utilizing the previously indicated lateral load patterns on methodological and numerical modeling sections yielded capacity curves and case study frames. Additionally, there was a thorough discussion of the deformation level and the seismic base shear that corresponds to it at the immediate occupancy/operational level. Based on the results thus far, it has been determined that the introduction of stiffness irregularity into the frame

models has a major impact, with remarkable outcomes documented. As the chosen floor levels (ground and second floors) increased in story height, there was a noticeable decrease in seismic base shear, which contributes to the story's softness. A basic period of vibration will be reduced by increasing the structure's stiffness, which will raise the seismic base shear and increase the design spectrum ordinate. All structural elements of the building model instances were created in such an efficient and suitable manner that it was discovered that changes in the number of stories were precisely proportionate to changes in stiffness and basic vibration periods. The effect of stiffness irregularity on seismic base has more significant contributions as the number of soft-stories increases, as demonstrated by the fact that the percentage deviations of seismic base shear for G+10 building models are nearly identical to the corresponding values for G+20 building models.

## STORY DISPLACEMENTS

Estimating the seismic deformation demand is a main or fundamental concern in the performance evaluation of reinforced concrete structures under seismic excitation since seismic performance evaluation is directly related to displacement or deformation. The fundamental analysis method uses three-dimensional nonlinear analysis on SeismoStruct software to perform nonlinear dynamic time history analysis for a given structure and ground motion. Under randomly chosen individual ground vibrations, the case study building models' story displacement was examined. Consequently, one ground motion was taken into consideration for assessing the building's performance in relation to story displacements out of the thirty ground motions that were used in the dynamic analysis.

## CONCLUSION

The seismic performance of buildings with rigidity abnormalities is examined in this study. By making the ground and second floors 200% taller than the remaining floors, stiffness irregularities are produced. All model scenarios undergo pushover and nonlinear time history analysis. Lastly, the model structures' performance at various performance levels has been examined, and the findings are explained in terms of the primary response parameters, including fundamental periods, total base seismic fragility curves, lateral displacements, understory drifts, and shears. Thus, the following findings are derived from this study:

1. For G+10 building models, the basic periods of two-story (G+10 200%G&S) stiffness irregular buildings deviate from the stiff one (G+10) by a larger proportion than the comparable values. The G+20 building model demonstrates that as the number of soft stories increases, the impact of stiffness irregularity on fundamental period becomes increasingly substantial. Additionally, its contributions become increasingly substantial as the building's story count or height increases.
2. Both G+10 and G+20 stiffness regular building models have seismic base shears that are higher than those of stiffness irregular buildings (G+10 200%G, G+10 200%G&S, G+20 200%G, and G+20 200%G&S).
3. Roof displacement demands are not affected by the existence of stiffness abnormalities in cases of inelastic analysis. Roof displacement needs for stiffness modification factor scenarios do not differ from the base case by more than 15%.
4. For every case examined, the distribution of tale drift changes over height as a result of stiffness abnormalities. Demands for story drifts rise in the soft story and fall in the majority of other stories. We can infer from the results that most floors' drift exceeds the ES EN limit's allowable drift ( $dr_v \leq 0,005h$ ).
5. For every performance level (DL, SD, and CP), the stiffness irregular building model has a higher failure probability than the stiffness regular construction model.
6. In every situation, the likelihood of failure for G+20 building models is higher than that of G+10 building models for each performance level (DL, SD, and CP).

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