

Response Reduction Factor for Structures Irregularities in Plan and Elevation Taking into Account Soil-Structure Interaction

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Abstract - The structure's ability to release energy through inelastic behaviour is reflected in the response reduction factor (R). It results from a combination of redundancy, ductility, and over strength. Thus, determining R with accurate values plays a critical function in the process of seismic design. This study aims to determine the response factor of structures of reinforced concrete (RC). With different structural irregularities, additionally, determine the impact of the interaction between soil and structure (SSI) using non-linear static pushover analysis was adopted in numerical simulation by using SAP2000. The selected irregularities included elevational and in-plan changes. It was determined that, in comparison to regular buildings, buildings with irregular vertical geometries had poorer inelastic seismic capacities. Therefore, R is less than that which is stated in the ECP 2020, so it ought to be reduced by 15–40% before the design stage. The outcomes demonstrated that it isn't concluded that irregularity has a considerable effect on weak soil (C). The reduction in R, considering (SSI), reached 20.3% and 13.1% for fixed and isolated supports, respectively, in case of loose soil. Moreover, it became obvious that for the same structure the stiffer the base soil the greater the R's value.

Keywords: Irregular RC Buildings, Elevation Irregularity, Plan Irregularity, Nonlinear Static Pushover Analysis, Response Reduction Factor, Soil Structure Interaction.

I. INTRODUCTION

A structure requires being capable of withstanding an intense seismic event without suddenly collapsing, even though it may sustain some structural and nonstructural damage. This is the fundamental idea behind earthquake-resistant design. That is possible because the structure is built with less seismic force than necessary because of its energy dissipation and inelastic performance [1-3]. Recent earthquakes suggest that elastic analysis is unsuitable method

for assessing the reinforced concrete buildings' actual seismic performance. Although it is difficult and based on the contents of ground motion, nonlinear time history analysis (NTHA) can determine the likely inelastic response of structures [4]. To produce safe designs with optimal costs, a structure's inelastic response is taken into account by elastic analysis techniques by magnifying deformations and lowering seismic forces. Therefore, seismic design response elements are crucial for both economy and safety [30]. Thus, several seismic codes contain response reduction, or behavior factor (R) inside their studies of seismic analysis. NTHA is substituted with other performance-based seismic evaluation techniques, such as nonlinear pushover analysis (NPA). Numerous methods, incorporating the FEMA440 displacement coefficient technique [5], the capacity spectrum technique of ATC-40 [6], the N2 method by Fajfar and Fischinger [7], and the modal pushover analysis (MPA) [9], are considered as NPA to ascertain a structure's inelastic performance. The response factor (R) is an essential component in earthquake design and is denoted as structure's ability to disperse energy via inelastic deformations [2]. Most constructions use reduction factors to minimize seismic loads and get the building closer to the inelastic range. Consequently, to release energy from the structure, more deformation is needed, so we need to keep the economy in mind while certifying the performance and safety of constructions during earthquakes, and that is the behaviour factor's significance in the seismic design process. The behavior factor (R) is the main component involved in the seismic design of new construction materials. This is also used in the equivalent static analysis as a seismic design parameter. It ascertains the nonlinear behaviour of structural buildings during intense earthquakes. R is established by engineering judgment and experimental testing; a standard method to calculate this value under various circumstances is not available. Building response characteristics, which primarily impact the rates assigned to R, must be systematically assessed to enhance the reliability of modern earthquake-resistant buildings [40]. Proper estimation of R can lead to

better assessment of a structure's seismic response. Overestimating the modification factor can cause a lowering of base shear and consequently economic design could be obtained. Some precautions should then be taken to make sure the structure's ductility performance [2-4]. Whereas, underestimating of R might end in the uneconomic design of structures. Non-linearity of structures is implicitly considered in design codes by decreasing the seismic base shear of structures by R.

The structural systems of buildings are frequently required by the architectural specifications to contain several geometric irregularities, either in the horizontal or vertical plane. In fact, many existing structures have severe irregularities that might not be covered by design codes. Therefore rigorous researches are required to properly design those structures [3]. In the event of an earthquake, prior experiences demonstrate that irregular constructions are more susceptible to catastrophic damage than regular structures [10]. Actuality, most extant structures are asymmetrical, and some of them were intentionally made that way to serve various reasons, as the commercial basements made possible by removing central columns. Additionally, to meet functional specifications and for additional commercial objectives like the storage of large mechanical appliances, smaller beams and columns were added in highest stories. This variation in utilization over a floor's length from its neighboring floors causes irregularities in the distribution of mass, stiffness, and strength. Many other structures also unintentionally become irregular because of a variety of factors, including inconsistent building techniques and materials. The building's mass, strength, and stiffness might be distributed irregularly along its design as well [2]. So Previous experiences demonstrate that the system of structures performs poorly inelastically when vertical structures with irregularities are located in an active area. Therefore, reliable requirements are necessary for the earthquake design. with reference to the impact of these irregularities [11-12].

Brahmavathan, D., & Arunkumar, C. [2] stated that how many stories there are has big influence on decreasing R for non-regular structures. The research showed that R factor value has been reduced by 37.53 % and 31.04 % for ordinary moment resisting frames (OMRF) and stiff moment resisting frames (SMRF) structures, respectively. ECP-201 (2012), has set values for R ranged from 3 to 5 for sufficient to limited ductility framed structures, these values should be readjusted to accommodate severe irregularities. Fayed, M. N. [3] calculated values of the behavior factor at failure for idealised multistory frame systems with moment resistance made of RC and developed in compliance with the ECP-201 (2012) and was also noticed a decrease in the stated R values. The structure's fundamental TP and seismic zone have a significant

impact on the reduction factor. It decreases when the seismic zone becomes larger and increases as the basic TP is longer. Hussein, M. M., Gamal, M., & Attia, W. A. [1] assessed the impact of irregularity in floor heights and span lengths affects the behavior factor for common RC frames used in various structures. The outcomes showed R values' inconsistency compared to structures with uniform bay length and floor height. The researcher El-Mahdy, O.[13] added that the R values for the cases covered in this research differ in the X- and Y-directions, which is more realistic than the design code-specified constant value. The lowest amount that R-values It was determined to be constructions with a loose ground story and a coupled asymmetric setback. R's sensitivity to the vertical irregularity index (V_{tm}) was additionally found which has an R-squared of 80%, through what that Ahmed [14] performs.

Moreover, SSI's impact on R is addressed in the current article. The interaction of soil and foundation has considerable consequences for the response of the structure [15,16]. three interconnected systems, namely the construction, the foundation, and the soil surrounding the foundation, influence the structure's behavior during an earthquake (SSI) is the process through whereby the soil's response affects the structure's motion and the motion of the structure affects the soil's response [15,17]. The codes of design don't offer enough guidance on how to take into consideration SSI effects on structures. For practical engineers to be encouraged to incorporate SSI into the design process, a well-defined computational technique is necessary. Bapir [18] it becomes important, to make sure safety and earthquake-resilience of non-regular RC buildings, a thorough seismic risk evaluation should take into account both site selection and geometric irregularity. Safer structures and more successful mitigation measures will result from properly considering these issues while designing and strengthening stages. El Janous [29] According to certain studies, the flexible base condition affects the building's response differently than the fixed base condition, which lowers the structure's stiffness and reduces the response spectrum [42].

The degree of affects the structure's response is dependent on the stiffness of the soil, The Structure's dynamic characteristics, damping factor, the natural period, mass, and stiffness of the structure [20-23]. For instance, the amount of scientific investigation in the United States that has considered SSI rose towards the end of the 2000s, and some of them were summarized in the FEMA-440 report [5] where nonlinear analysis was considered. The findings of such research were also incorporated into US code requirements (ASCE 2013) [24]. The phrases in FEMA-440 and the (ASCE 2013) [24] standards, however, are not advised for (NLT) assessments; therefore this circumstance emphasized the demand for new

studies. In 2012, the results of additional research on SSI in performance-based seismic engineering were compiled, and an approach that might be applied to NLT analysis was suggested Palanci, M., & Kalkan, A. (2020) [8], Abdelrhman et. al. [17] investigated the impact of soil structure interaction. A significant decrease in R due SSI for the investigated instances 3, 6, and 9 stories buildings was 16% (R fixed support vs R isolated footing type D) in loose soils. For multi-story multi-bay frames, according to ECP-201(2012), 3.9 is the suggested value of the response reduction factor R for limited ductility reinforced concrete moment frame buildings. when a foundation is built on soft soil, the displacement increases, and as the soil's stiffness increases, the value of lateral displacement decreases with increasing soil rigidity Maharjan, S., & Thapa, K. B. (2021) [26] the natural period becomes longer when taking the soil's flexibility into account. The characteristics of the footings affected the buildings' performance. Requena-Garcia-Cruz et al. [20], M. V., Bento, R. Ali et al. [6] Irregularities' Influence on RC Structures' Seismic Performance studied by many researchers which Regular buildings have larger roof displacement values than irregular buildings, while non-regular buildings were the first to achieve life safety and collapse prevention. Krishna, G., & Hemchandra, C. [21]. The influence of plan irregularity (L-shaped structures) was well illustrated by the actual overturning moment response determined from seismic analysis for L-shaped models; improper layout of building elements could compromise the stability of the building. Abdel Raheem, S. E., Ahmed, M. M.,(2018). [19], when the building's increased total mass and rigidity were what caused more displacement in the structure; Top displacement is greater in irregular building models than it is in standard frames. Furthermore, the maximum value of the story drift ratio is displayed in the model of the vertical irregularities included in the bottom story. Tomer, & Bhandari [22]. Allena, P., & Chowdary, T. B. (2020, December). [23] Investigated how irregularities affected high-rise buildings' seismic performance. When the center of gravity and center mass were aligned, the reduction in frequency was not significantly affected by mass irregularity. The model was substantially stiffer and showed more resistance Because of the lumping mass at lower stories. Joseph, P., & Kuruvilla, R. (2021) [27]. It was obvious that base shear and lateral displacement would rise as seismic energy rises, indicating greater seismic demand for the structure. Nonlinear static POA has gained a lot of attention among researchers in recent years. Which provides a review of various pushover analysis approaches for vertical and horizontal irregularity of structures? [28]. The factor R was affected by the hysteresis loop's shape, ductility, natural period, structural system, and construction materials, Just 8% of previous research attempts were dedicated to assessing the seismic response of irregular buildings.

Hussain (2024)[30] Three branches were focused on this study; the first was evaluating the modification factor for irregular RC structure; the second was to employ nonlinear seismic analysis using the pushover analysis (P.O.A.) method to evaluate seismic performance on irregular buildings, while the third was incorporating (SSI) to assess the influence of the soil and foundation type on evaluating R. Thus, nonlinear POA has been used to evaluate the modification factor R for three RC structures with structural plan and elevation irregularities. For each structure, changes in floor plan geometry were conducted. The three buildings have different areas and heights. The influence of various soil types on various subgrade response modulus (ks), additionally various seismic regions – with ground acceleration of 0.15g, 0.20g and 0.25g were addressed. Finally, the two stated response spectra identified by ECP were considered and investigated.

II. RESPONSE MODIFICATION FACTOR

The idea behind the response factor was to combine nonlinearity with overstrength, redundancy, and ductility of construction to correctly evaluate the seismic force. Figure (1) shows the relationship between a structure's base-shear (total horizontal load) and its roof displacement – as stated by [1,2,3] for nonlinear static analysis.

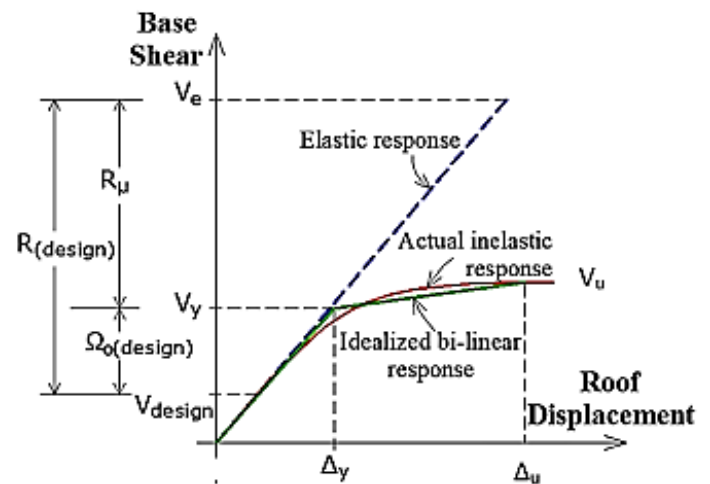


Figure 1: Relationship between applied base shear and roof horizontal deformation for regular buildings [31]

The reduction factor is typically represented as a function of many structural system factors, including strength, ductility, damping, and redundancy. This factor is known as the response modification factor (R-factor) in the Egyptian code (ECP 2020), the behavior factor (in the Euro code) [25], and the response modification coefficient in (ASCE 2013) [24].

Thus, the response factor (R) is:

$$R = R_S R_{\mu} R_{\xi} R_R \quad (1)$$

Where:

R_s : is the over strength that is defined as the ratio of the base shear at yielding to the design lateral strength.

$$R_s = V_y / V_d \quad (2)$$

R_R : This factor is intended to quantify the improved reliability of seismic framing system that uses multiple lines of vertical seismic framing in each principal direction of the building. The higher of the redundancy factor R_R Cannot be larger than one. Therefore, R_R was taken equal to unity.

R_d : The damping factor is used to account for the influence of additional viscous damping in constructions that have additional energy dissipation devices. If such devices are not provided, the damping factor is normally set at 1.0.

R_μ : The ductility reduction factor is the ratio of the displacement at yield to the allowable displacement or maximum considered displacement.

Factor that reduces ductility R_μ based on the properties of earthquake ground motion additionally features of structure including ductility and basic period of vibration (T) (Mahri and Akbari [32]. Various formulations were proposed by the

researchers for assessing the ductility reduction factor R_μ . (Newmark and Hall, (1973) [33]; Uang (1991) [34], Paulay and Priestly, (1992) [35], Miranda and Bertero, (1994) [36]; Kappos (1997) [37], Priestley, (2000) [38]; Elnashai and Mwafy (2002) [10], Mondal et al (2013) [39], In this study, the formulation recommended by Priestley and Paulay (1992) is used.

$$R_\mu = 1.0 \quad \text{for zero-period structures} \quad (3-a)$$

$$R_\mu = \sqrt{2\mu - 1} \quad \text{for short-period structure} \quad (3-b)$$

$$R_\mu = \mu \quad \text{for long-period structure} \quad (3-c)$$

$$R_\mu = 1 + (\mu - 1) T / 0.70 \quad (0.70 < T < 0.30) \quad (3-d)$$

Where, R_μ is the ductility reduction factor and μ is the displacement ductility.

Many codes and standards had addressed ranges for R , UBC97 has set values for (R) ranges between 3.5 – 8.5 while IBC 2012 and ASCE7 uses near values ranges from 3.0 – 8.0 for ordinary to special moment resisting frames, respectively. ECP 2012 and IS 1893 have set values ranges from 5.0 – 7.0 and 3.0 – 5.0 for limited (ordinary) to Sufficient ductility frames, respectively. Moreover, Eurocode related the value of (R) to the ratio (V_u/V_y) based on the structure configuration.

III. NONLINEAR STATIC ANALYSIS (PUSHOVER ANALYSIS) (POA)

Nonlinear dynamic time history (NDTH) analysis is generally acknowledged as the most accurate method for the seismic evaluation when it comes to nonlinear analysis of a structure. The design of the structures. But because it takes an excessive amount of time and computer power and the responses it produces are difficult to employ for design, it is too demanding. Furthermore, there is a major problem in choosing the appropriate acceleration records for the numerical analysis.

The torsion effects must be considered in irregular buildings' nonlinear static responses.

The results of nonlinear static studies in irregular multi-story RC were considered to be suitable by Magliulo et al. (2012)[40]. Structures created in compliance with Eurocode. A 3D pushover approach was developed by Moghadam and Tso (2000)[41], Chopra and Goel (2004)[42], Kaliar and Fajfar (1997)[43], and Rodrigues et al. (2012b)[44] for the investigation of non regular building structures. Considering the previously mentioned research therefore, it can be stated that nonlinear static POA provides good results when used to irregular building analysis. Consequently, nonlinear static POA has been used to calculate the response factor for a building model.

POA is a technique for performing non-linear static structural analysis. It calculates the capacity curve based on base shear vs. displacement and assesses the mechanism of plastic hinge creation at each stage of the post-elastic zone. The growing forcing function in this analysis is expressed in terms of horizontal forces or displacements placed on a mathematical model of a building. Upon reaching the critical condition or target displacement, the analysis is finished. The target displacement or drift indicates the greatest building displacement or drift during the earthquake.

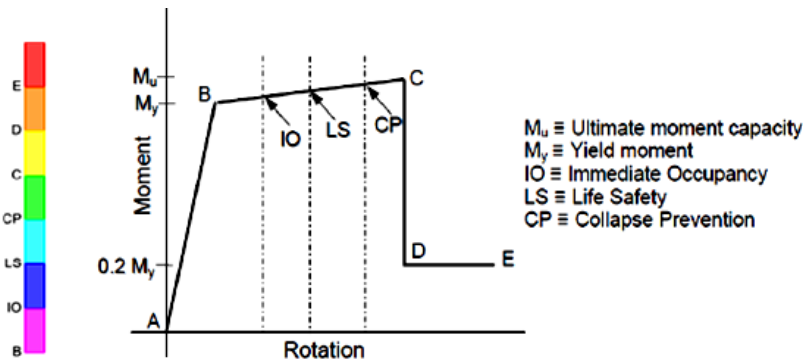


Figure 2: Moment - Rotation Graph for Pushover Analysis

IV. METHODOLOGY

In the present comparative analysis, the equivalent static approach for seismic analysis of buildings of 6, 7, and 10 stories was used. Finite Element Models were simulated using commercially used software SAP2000 [39]. Beams and columns were modeled using frame elements whereas shell elements were used to simulate slabs. A parametric study was performed where soil type, seismic zone, irregularity of buildings, and lastly different spectrums I and II were among the main parameters. ECP-203 was employed as guidance for design and comparison. Figure 3 summarizes the sequence of test procedures additionally an estimation of the number of trials to fulfill the study. At the beginning three models of structures with irregularities were focused namely A, B, and C with different irregularity percentages of 28.6%, 30%, and 21%, respectively. The percentage of irregularity was calculated as the total surface area of the cut floors of a building to the total surface area of all floors of the corresponding regular building. Corresponding regular models were also used for control and were named A', B', and C'. The six models were constructed on different soil stratum namely B, and C as per ECP-203 classification. The producing twelve models were then subjected to two types of response spectrum each simulated at different seismic zones. The total number of models was then 72. Nonlinear pushover static analysis was used to determine the status of plastic hinges at the yield and ultimate states. The structures were pushed horizontally until reaching pre-characterized failure conditions.

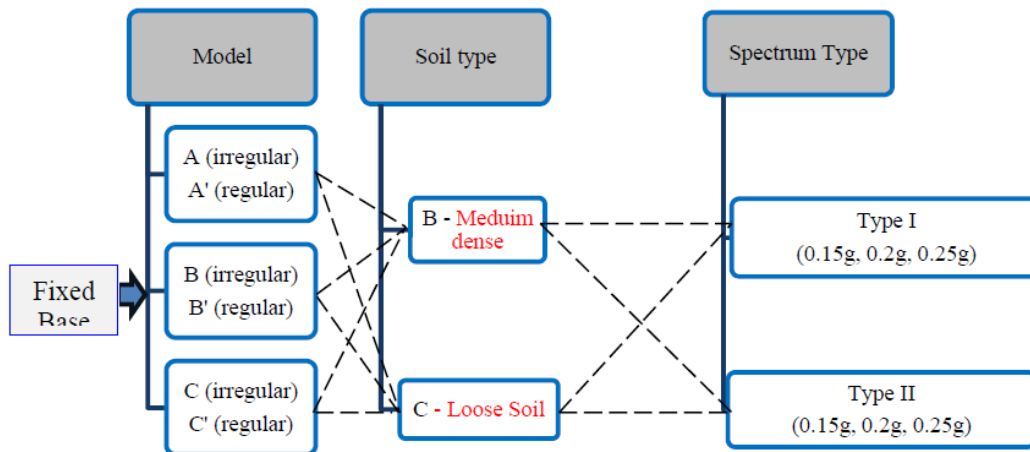


Figure 3: Sequence of numerical trails

V. MODEL DESCRIPTION

In this section, three different categories of structures were numerically simulated. The first was denoted as Model (A) and Model (A') representing relatively short buildings with 7 floors and having stepped reduction in floor area in one direction only. The second group was denoted as Model (B) and Model (B') and represented relatively taller buildings with 10 stories. The third group was named Model (C) and Model (C') and represented a random reduction in floor areas of 6-story buildings. Figure (4) shows different cross-sectional views for the three models. Whereas Figure (5) shows 3D views for all structures. The irregularity percentage of the structure was determined by calculating the total surface area of the regular structure subtracting the missing area until the irregularity percentage of buildings A, B, and C became 28.6%, 30%, and 21%, respectively.

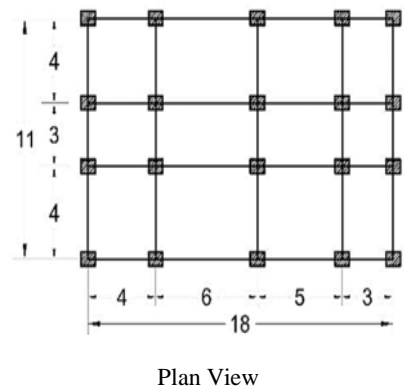
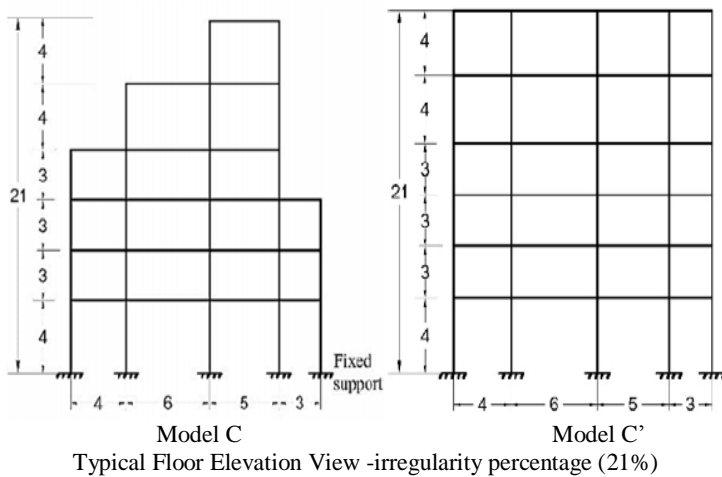
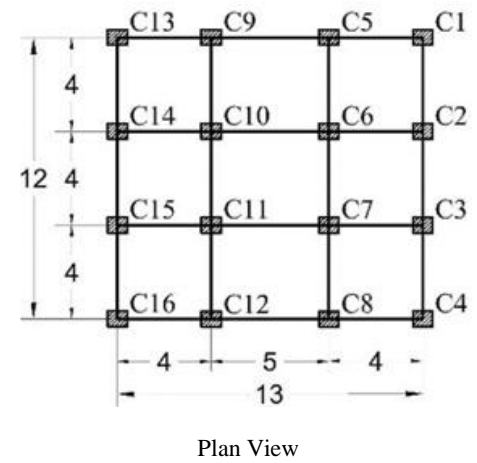
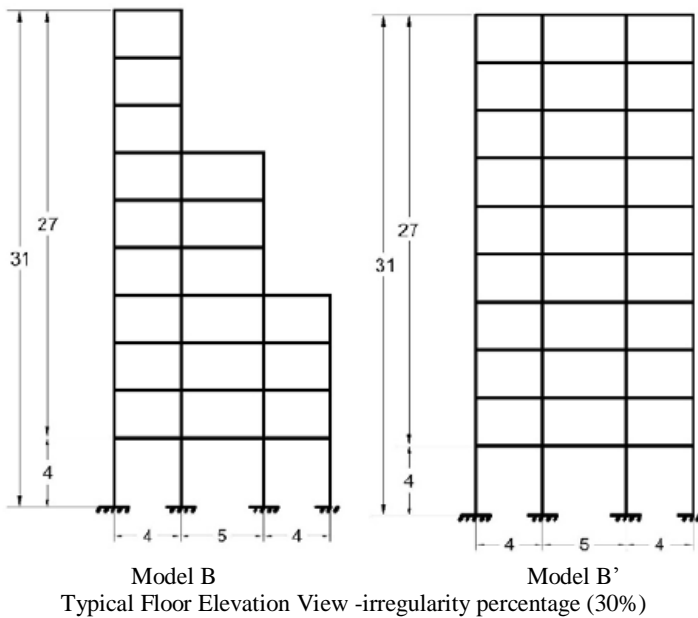
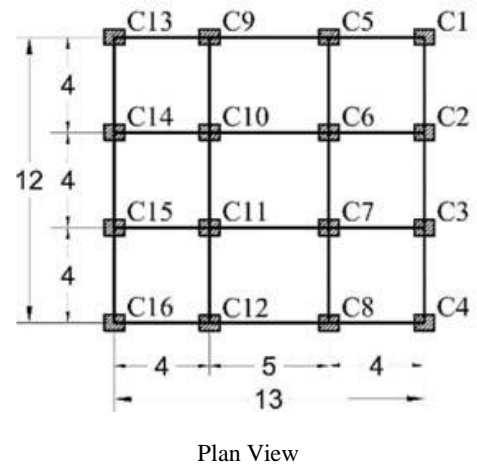
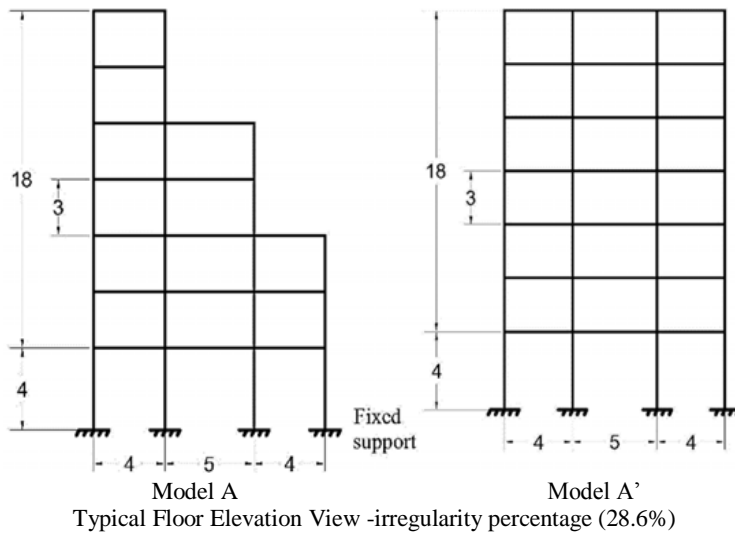


Figure 4: Description of Models

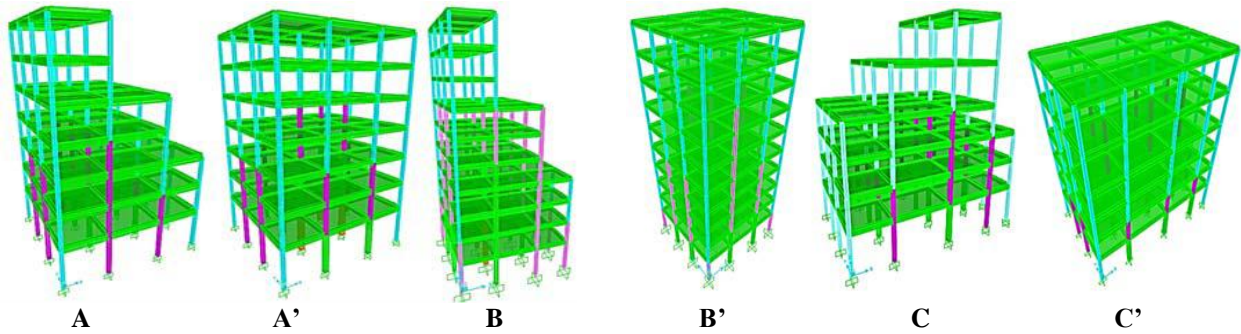


Figure 5: 3D simulation of all Multistory Buildings

SAP2000 [39] was used to perform non-linear static analysis. Variable parameters were considered during modeling. Material properties with different stress-strain relationships, expected locations and lengths for plastic hinges and their types, moment curvature relationship for are necessary for nonlinear static analysis. The geometry, material properties, longitudinal reinforcement, shear reinforcement, and loads applied to a specific member all affect the value of these points derived from an element's moment curvature relationship.

Table 1: Material Properties used in simulation

| Material Properties | Value |
|---|----------------------------|
| Concrete characteristic strength (F_C) | 25000 kN/m ² |
| Rebar yield strength (F_Y) | 36709780 kN/m ² |
| Modulus of elasticity of rebar (E_S) | 360000 kN/m ² |
| Modulus of elasticity of concrete (E_C) | 22433756 kN/m ² |
| Shear modulus – CONCRETE (G) | 93473980 kN/m ² |
| Poisson's ratio for concrete (Y_c) | 0.2 |
| Poisson's ratio for steel (Y_s) | 0.3 |

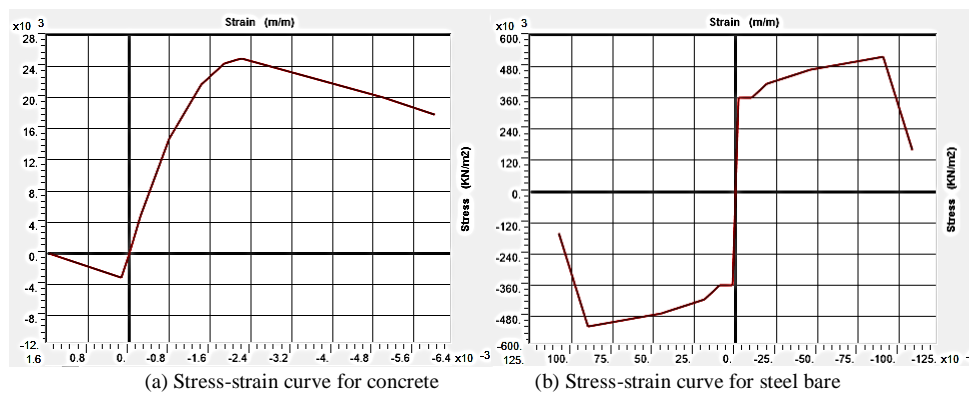


Figure 6: Stress-strain curves for used materials

RC frame structures with 6, 7, and 10 stories were designed using ECP-203 (2020) against gravity and seismic loads (spectrum type I and II) at different seismic zones (0.15g, 0.2g, and 0.25g) – Figure 7. Soil was classified as Type B and Type C according to ECP-203. For each type of soil, the models were simulated using either fixed support considering a rigid foundation as well as an isolated footing system according to design outcomes. Initially, the models were simulated assuming limited ductility moment-resisting frame with R equal to 5. Through the design process, the following factors were considered:

- To ensure that the standards for damage limitation are met, the inter-story drift should not be greater than 0.005 of the story height.
- Stirrups were assumed to carry shearing forces in columns as well as to enhance their ductility.

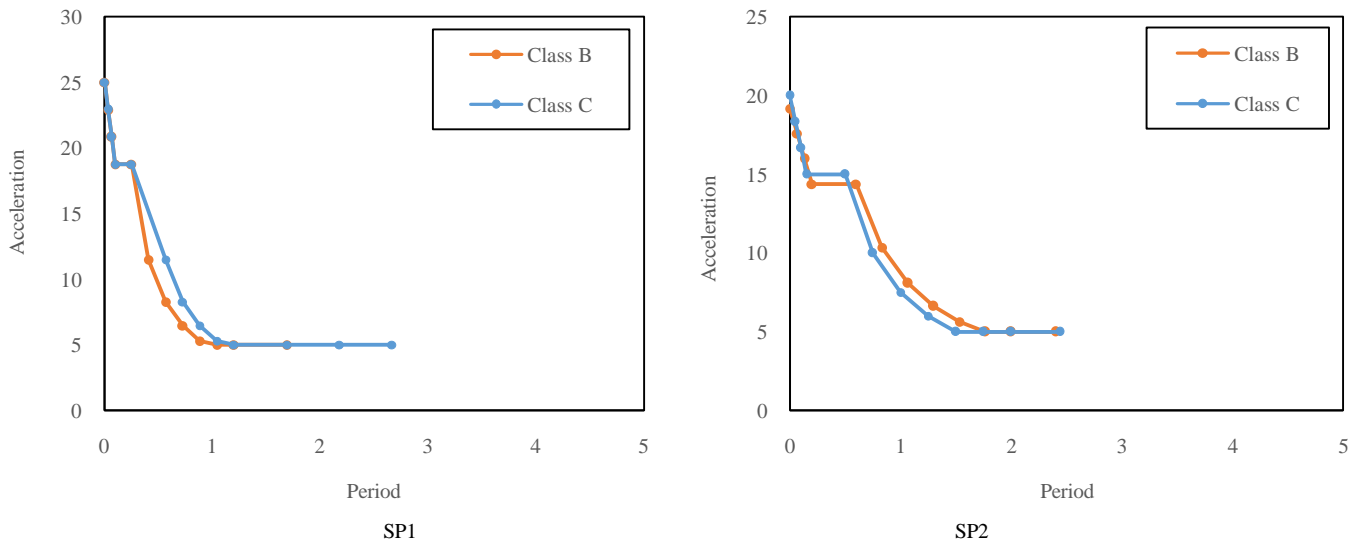


Figure 7: Applied Response Spectrum at seismic zone (0.25g)

For all models, the beams were designed of same cross-sectional area (250 mm x 500 mm). The top and bottom reinforcement were also kept constant as (8T16) for top and bottom reinforcement.

It was noticed that the capacity/demand ratios for most columns are in lower levels of all the analyzed buildings and within the range from 0.75 to 0.90 the reinforcement ratio of sections is shown in Table 2.

Table 2: Column sections with corresponding reinforcement ratio

| Reinforcement Ratio | Column Section | | | |
|---------------------|----------------|----------|-------|-------|
| | 25x25 | 30x30 | 40x40 | 50x50 |
| μ % | 1.44 : 2.5 | 1 : 1.79 | 1.5 | 1.287 |

VI. RESULTS AND DISCUSSION

The results of the simulation including contributing mode shapes, effect of different soils, and seismic zones are introduced in the next sections. The effect of different irregularities was discussed. The obtained R was put into a glance with the corresponding value of regular buildings.

1. Mode Shapes

A structure's modes are its intrinsic characteristics. They are independent of the loads or forces applied to the structure. If the structure's boundary conditions (mountings) or material attributes (mass, stiffness, damping properties) change, the modes will as well. Because mode forms lack distinct values, they are not associated with any units. Mode shapes are unique, though. In other words, a point's motion to another at resonance is unique. Therefore, the structure's irregularity percentage plays a crucial role in changing the mode shape since higher irregularity percentages result in higher torsional moments on the structure. The fundamental natural periods for all regular and non regular buildings were obtained. Figure 8 shows the first four periods for irregular periods. During analysis, these modes have a modal participation factor over 95%. It was also noted that the first two modes represented global structural bending motions. Torsional modes appeared on the third mode. Whereas significant bending modes for the higher floors in irregular buildings appeared in the fourth mode. The natural period is written under each mode. Generally, for accurate assessment of the dynamic response of the structure, greater number of modes are required for irregular structures.[22-23] So, we need to take into account the torsion effects in irregular buildings' nonlinear static responses.

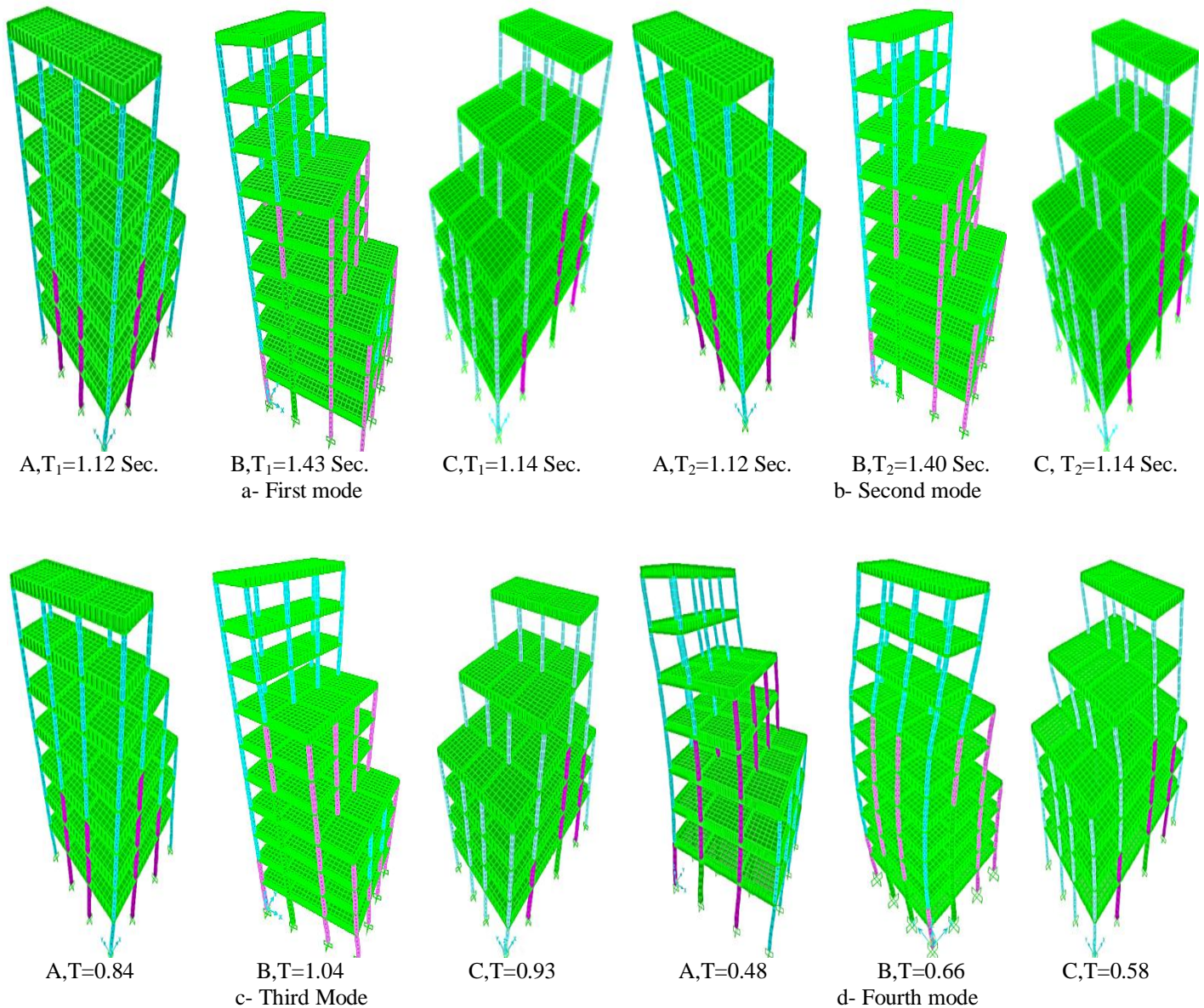


Figure 8: 3D view of vibration mode shapes of studied building models. a) 1st vibration mode shape, b) 2nd vibration mode shape, c) 3rd vibration mode shape, and d) 4th vibration mode shape

The fundamental natural periods for all regular and non-regular buildings were obtained. Figure 8 shows the first four periods for irregular periods. During analysis, these modes have a modal participation factor of over 95%. It was also noted that the first two modes represented global structural bending motions. Torsional modes appeared on the third mode. Whereas significant bending modes for the higher floors in irregular buildings appeared in the fourth mode. The natural period is written under each mode. Generally, for an accurate assessment of the dynamic response of the structure, a greater number of modes are required for irregular structures.[35] So, we need to take into account the torsion effects in irregular buildings' nonlinear static responses.

2. Pushover curves

The pushover curves listed in Figures (11 to 16), which draw the relationship between the top displacement and the ultimate base shear.

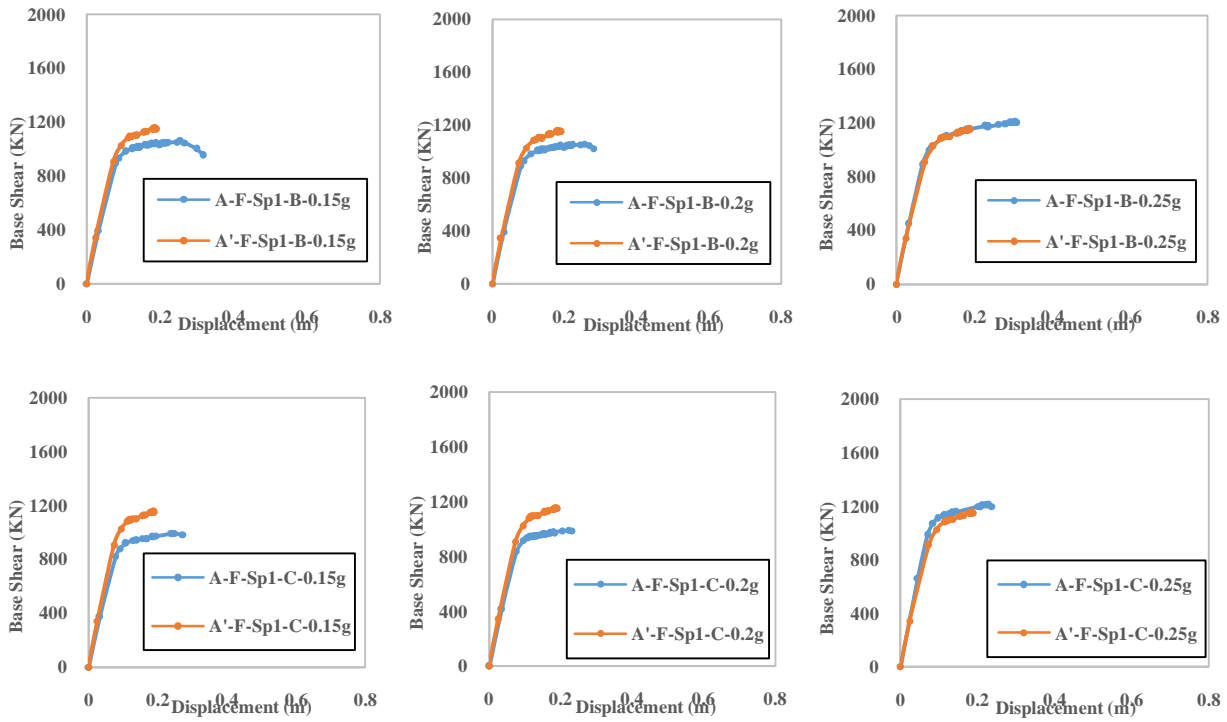


Figure 9: Pushover curves (P.O.C.) for the spectrum type 1 for models A, A'

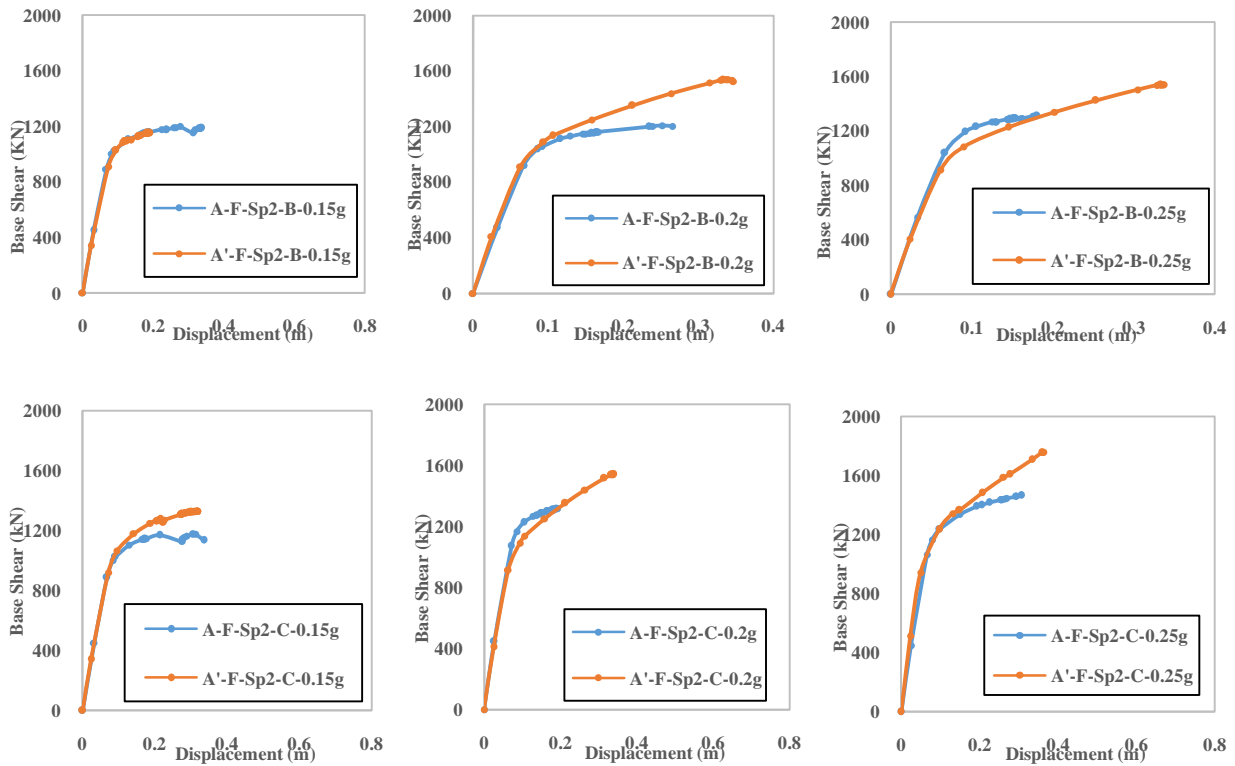


Figure 10: Pushover curves (P.O.C.) for the spectrum type 2 for models A, A'

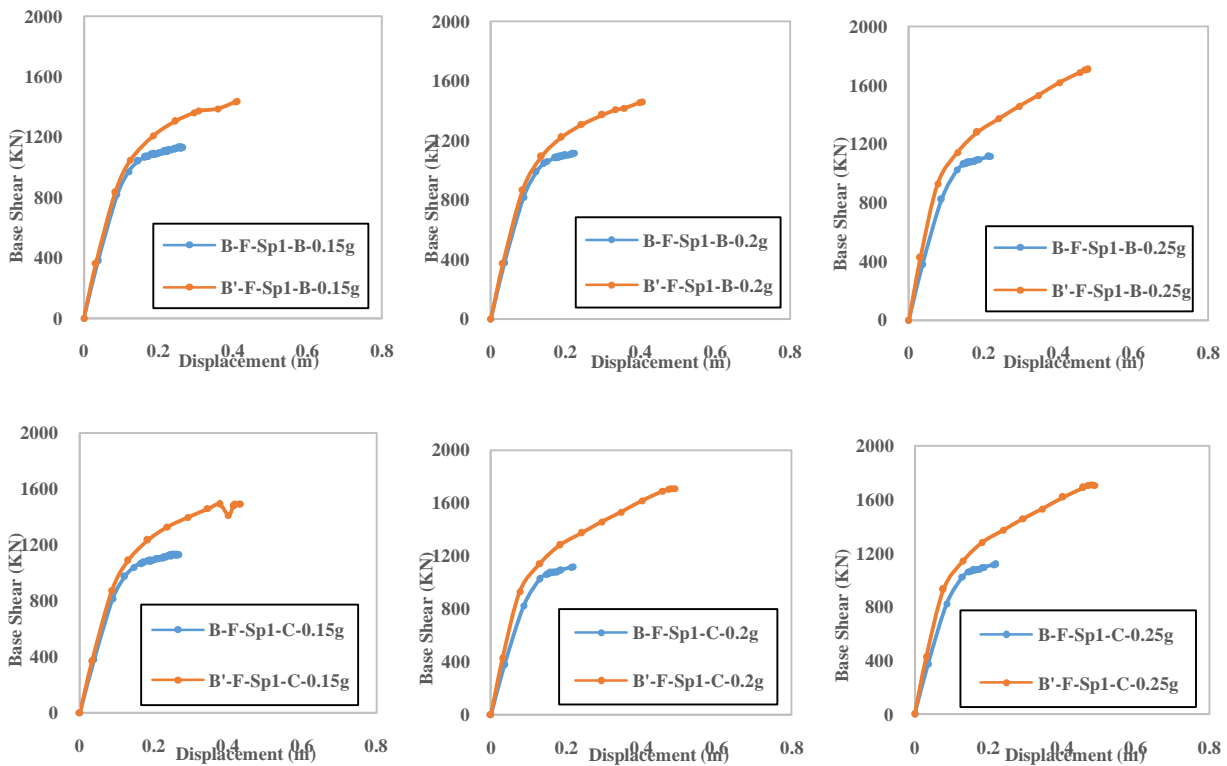


Figure 11: Pushover curves (P.O.C.) for the spectrum type 1 for models B, B'

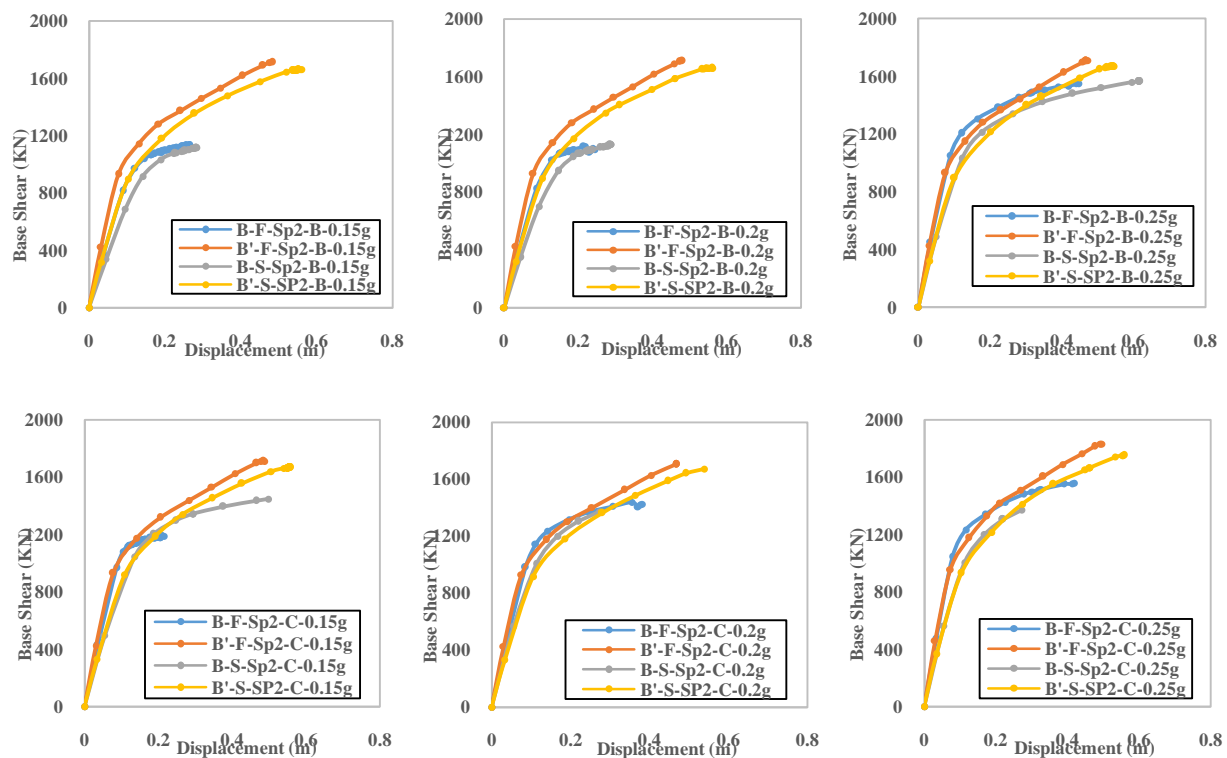


Figure 12: Pushover curves (P.O.C.) for the spectrum type 2 for models B, B'

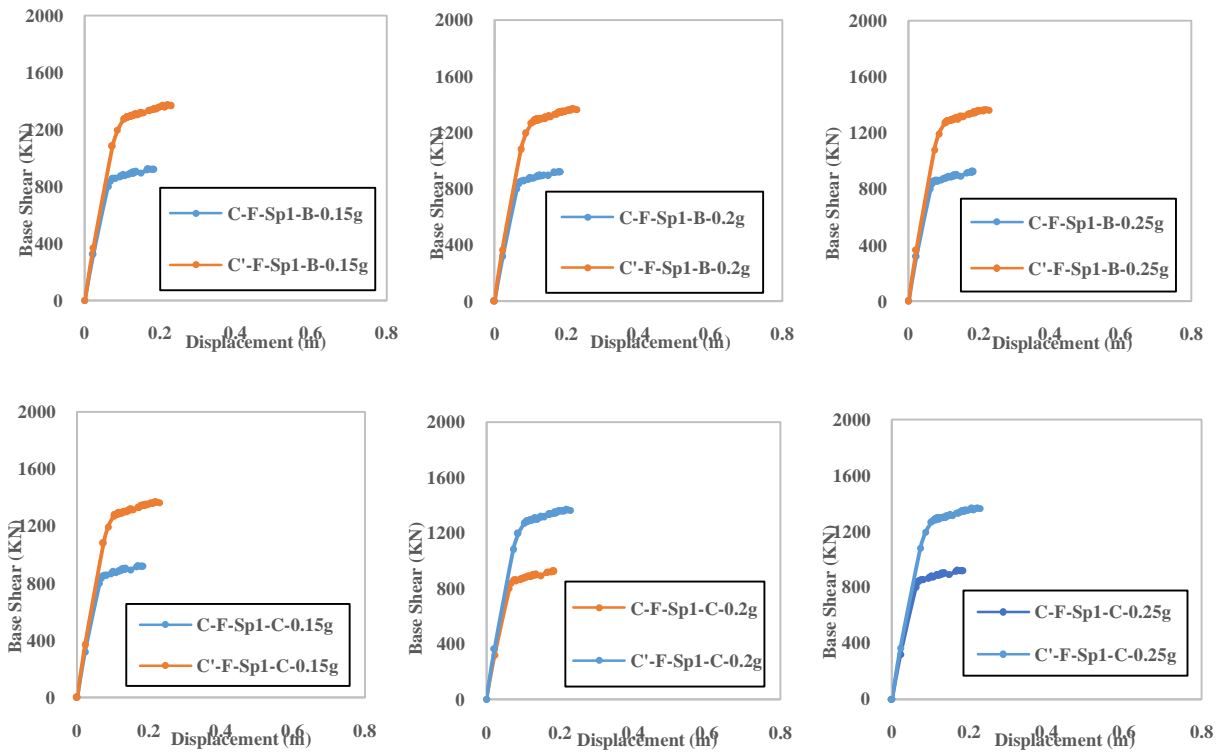


Figure 13: Pushover curves (P.O.C.) for the spectrum type 1 for models C, C'

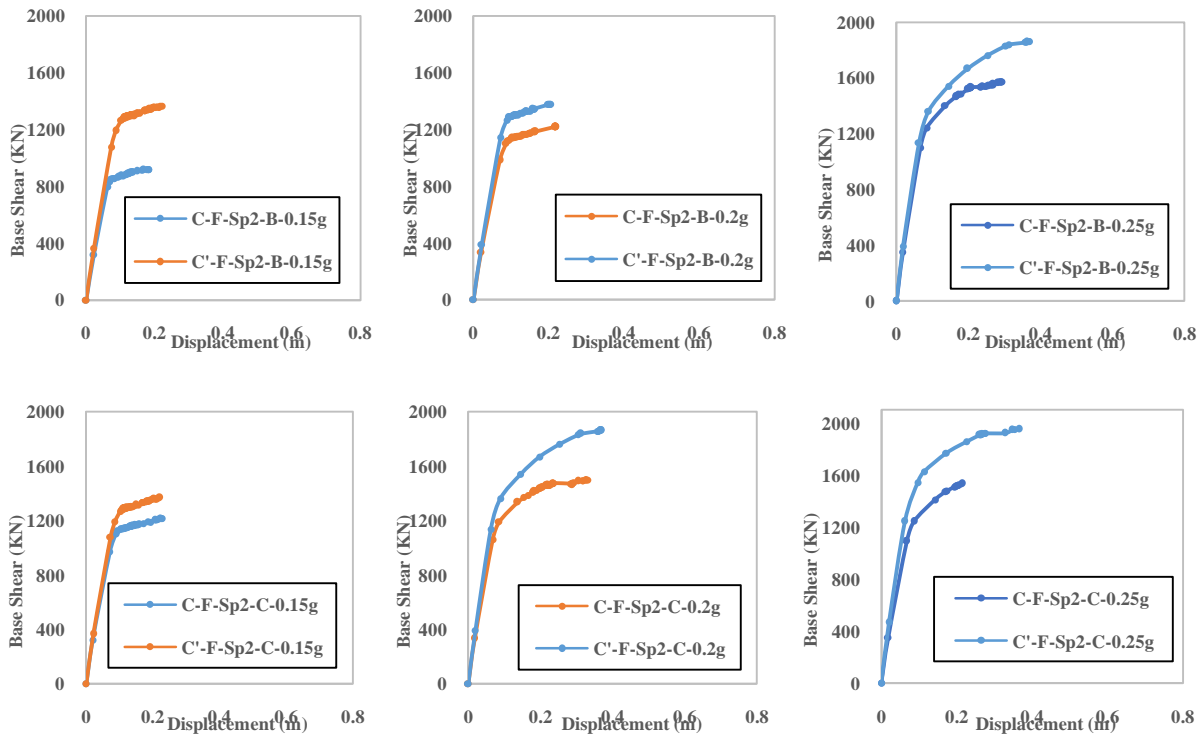


Figure 14: Pushover curves (P.O.C.) for the spectrum type 2 for models C, C'

The behavior of structures during a weak earthquake is almost similar, even when the geometry and characteristics of all structures differ. At higher seismic values, the mass, stiffness, and geometry of the construction have a clear effect on the shape of the POC. The greater the number of floors and the percentage of irregularity, the greater the area under the curve, and thus the displacement ratio is higher, especially when the effect of the SSI is taken into account. This allows all elements of the structure to reach the highest formation and give higher displacement values.

Table 3: Response modification factor value for fixed base (F) and Isolated footing (S), for models

| MODELS | | | A | A' | B | B' | C | C' | |
|-----------|---|-------|-------|------|-------|-------|-------|-------|------|
| | | | Fixed | | | | | | |
| Soil Type | B | 0.15g | 6.72 | 7.35 | 5.893 | 6.41 | 7.123 | 7.52 | |
| | | 0.2g | 6.52 | 6.87 | 5.297 | 5.82 | 6.857 | 7.37 | |
| | | 0.25g | 5.42 | 5.87 | 4.060 | 5.00 | 6.126 | 6.65 | |
| | C | 0.15g | 5.40 | 5.72 | 4.590 | 4.89 | 5.827 | 6.12 | |
| | | 0.2g | 4.67 | 4.94 | 3.489 | 4.11 | 5.126 | 5.55 | |
| | | 0.25g | 3.79 | 4.18 | 2.523 | 3.29 | 4.495 | 5.14 | |
| | B | 0.15g | 5.24 | 5.44 | 4.800 | 4.98 | 5.723 | 5.78 | |
| | | 0.2g | 4.81 | 5.11 | 4.401 | 4.72 | 5.312 | 5.58 | |
| | | 0.25g | 4.64 | 5.05 | 4.139 | 4.45 | 4.895 | 5.27 | |
| | | C | 0.15g | 4.26 | 4.67 | 3.997 | 4.35 | 4.533 | 4.91 |
| | | | 0.2g | 3.75 | 4.16 | 3.193 | 3.64 | 4.170 | 4.66 |
| | | | 0.25g | 3.26 | 3.72 | 2.597 | 3.46 | 3.816 | 4.39 |

3. Effect of Irregularity

It was clear how the structure's irregularity on the pushover curve affected the structure's strength and how it behaved during the earthquake. The deducted area from the structure, or the degree of irregularity of the structure.

The outcome of irregularity appears greater in the flexible structure, as seen in model B, and is therefore apparent the more flexible the model is regular and non-regular structures behave similarly in response of a weak earthquake. (Figure 9 to Figure 14), as can be observed the structures (models A, B and C), exhibit low ductility. But in the case of (A', B', and C') models exhibit good ductility, and a Decrease in maximum displacement cause of irregularity is observed for A, B, and C by 0%, 54%, and 18 % respectively for Sp I than that of regular one. It's decreased by 22.5%, 16%, and 23 % respectively for Sp II (for fixed base).

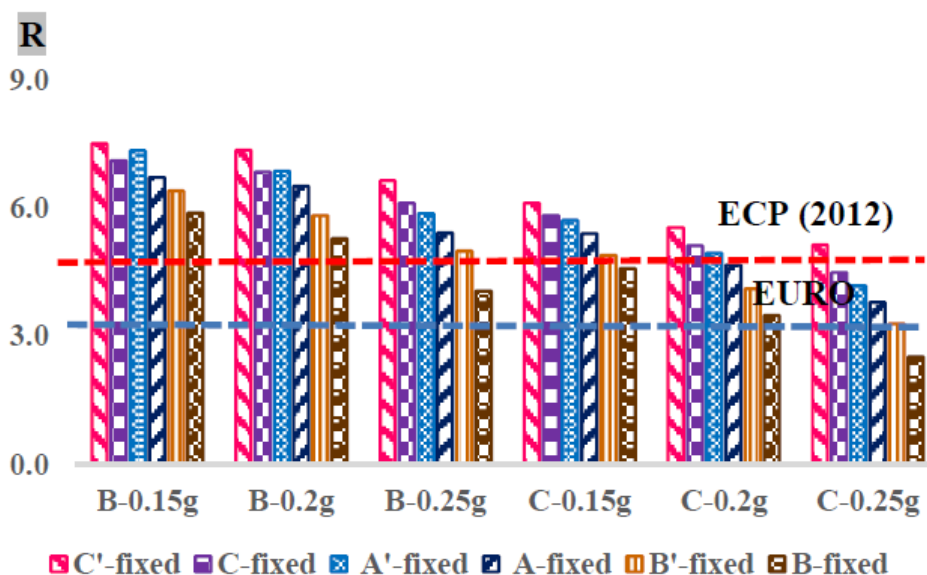


Figure 15: Response Modification factor (R) for models, (spectrum type 1)

R
9.0

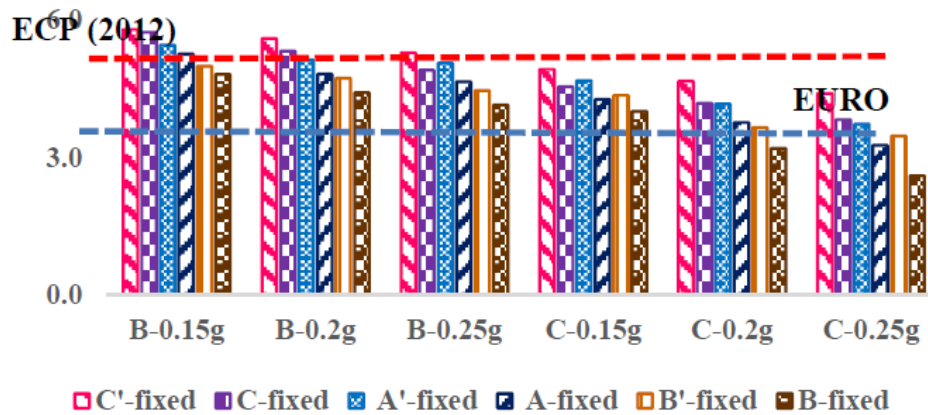


Figure 16: Response Modification factor (R) for models, (spectrum type 2)

With fixed base: In regular and irregular buildings, as the density of the seismic zone increases, the value of R decreases, as it was close to the values found in the ECP(2012) code in soil type B. As for soil type, C was 9.3%, 23.4% and 12.61 for models A, B and C respectively for SP1. It was 12.4%, 25% and 13.12 for models A, B and C respectively, for SP II With representing soil with springs: In regular and irregular buildings, as the density of the seismic zone increases, the value of R decreases, as it was close to the values found in the ECP (2012) code in soil type B. As for soil type C was 11.13%, 16.5% and 9.1 for models A, B and C respectively for SP1. It was 16.2%, 28% and 15% for models A, B and C respectively for SP II, in a tall building with high floors, the percentage of decrease in the structure's response was higher as the seismic zone increased, specifically in weak soil (type C).

The structure's response to the seismic load was clearly impacted by the variability in the study's models' percentage irregularity. This is because the irregularity percentage of the construction has to be kept in mind by design requirements and code standards in order to make seismic load designs more stable and secure. This was demonstrated by the 30% irregularity rate, which caused the reduction factor to reduce to 23.4% for soil type C and 18% for type B (for SP1), It also reduced to 25% for soil type C and 7% for type B (for SP II).

Model C has a 21% irregularity percentage, For SP1, the % of reduction varied from 7 to 6 in weak soil (type C) and from 5 to 4.5% in soil type B in the same seismic zone where the % of reduction varied between 4.5 and 3.8% and between 5.7 and 4.9% in soil type B. Conversely, however, the decrease for models B, A, and C was around 17, 11, and 9%, respectively, when the soil or springs were used to represent it.

Because the structures have a large reserve strength and the ability to dissipate energy—a property known as overstrength and ductility, respectively—seismic design regulations take this into account and reduce design loads. By use of a reduction factor, these two considerations are integrated into the structural design. In this study, it is evident that structural irregularity has an impact on R's value. is more evident in weak soil exposed to strong seismic intensity, where model B has an irregularity rate of 30%, While the seismic zone improves, the decrease in the value of R was significantly less than the values listed in the ECP and is considered close to the values of the Euro Code, so it must be Taking into consideration that the ECP values need to be reviewed and this percentage reduced, especially in irregular buildings, where taking the Egyptian Code values for irregular buildings, specifically after representing the soil and taking it into account, is considered an unsafe design.

Table 4: Response factor value for fixed base (F) and Isolated footing (S), for models

| MODELS | | | A (28.6%) | B (30%) | C (21%) | |
|-------------------|--------------------|-------|-----------|---------|---------|--|
| | | | F | F | F | |
| Spectrum I | | | | | | |
| Soil Type | B | 0.15g | 8.61 | 8.12 | 5.28 | |
| | | 0.2g | 5.22 | 9.08 | 6.96 | |
| | | 0.25g | 7.67 | 18.83 | 7.92 | |
| | C | 0.15g | 5.56 | 6.32 | 4.84 | |
| | | 0.2g | 5.53 | 15.25 | 7.69 | |
| | | 0.25g | 9.30 | 23.39 | 12.61 | |
| | Spectrum II | | | | | |
| | B | 0.15g | 3.60 | 3.67 | 1.06 | |
| | | 0.2g | 6.03 | 6.78 | 4.87 | |
| 0.25g | | 8.11 | 7.03 | 7.26 | | |
| C | 0.15g | 8.76 | 8.13 | 7.82 | | |
| | 0.2g | 9.79 | 12.49 | 10.56 | | |
| | 0.25g | 12.39 | 24.96 | 24.96 | | |

The value of R decreased as the seismic zone increase for all models, the shape or irregularity of the structure had a clear impact on the values of R with the same soil type and seismic zone, indicating that the value of R was close to the values of the Euro Code clearly in the poor soil in SP2. It is indirectly impacted by the structure's shape and irregularity. The reduction in modification factor is clearly influenced by the number of floors, and the % irregularity also had an impact Which the maximum decrease in modification factor reached 23% in model B in loose soil (type C)- for spectrum I. For springs the maximum decrease reached 17.7% in model B - for spectrum I. The decrease reached 16.2% in model A, 28% in model B, and model C 15.4% for spectrum II, that in loose soil (type C).

4. Effect of Seismic Zone

Figure 17 shows that as the zone increases Displacement also increases [37], and Base shear and lateral displacement increase with increase in the seismic intensity.

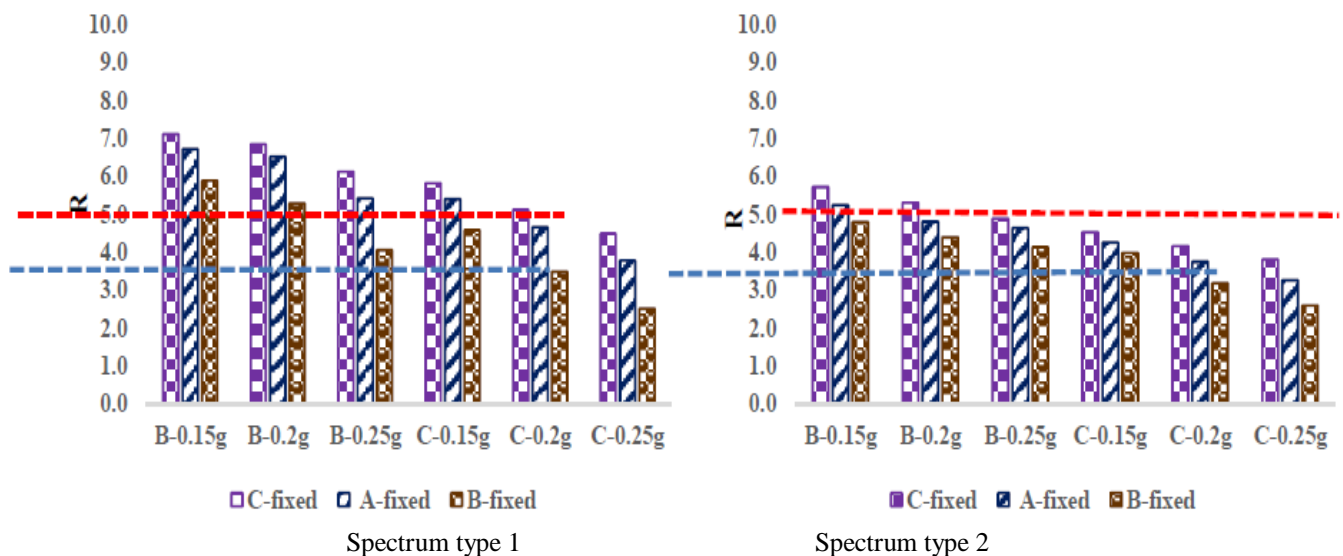


Figure 17: Response Modification factor (R) for models

The figure illustrates how SSI affects the strength reduction factors for weak soils. Because of this, applying fixed-base strength reduction factors for interacting systems results in non-conservative design forces; hence interaction effects for weak soils cannot be ignored [36].

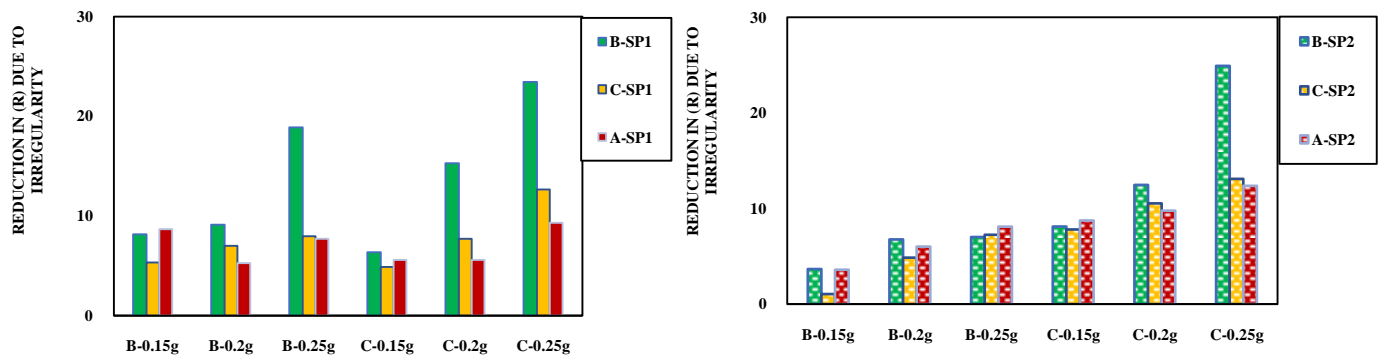


Figure 18: Reduction in Response factor due to irregularities% (R), for SP I and SP II

The seismic zone has an impact on the reduction in R's value. In models A, B, and C with poor soil, the reduction value achieves its greatest value at 9.3, 23.4, and 12.6 % in the seismic zone. The class of soil and the characteristics of the structure, such as the number of floors, mass, and percentage of irregularity, indicated the decrease in R's value caused by an increase in the seismic zone.

VII. CONCLUSION

The present study makes an effort to determine the efficacy of the plan and elevation irregularities with differences in proportion to the seismic reaction within the seismic zones I, II, and III, on medium and poor soil (type B & C), For both types of design response spectra given in ECP-201 (2012). The study also extends to finding the significance of SSI or representing the soil interaction with footing (using isolated footing with springs) on R-value, Base shear, lateral displacement of buildings, and the fundamental natural period of the regular and irregular models. The investigation reveals the following main conclusions:

There is an observed enhancement of the natural period, roof displacement, base shear, and structure's deformation with an improvement in soil flexibility. Essentially, the conclusion will have an impact on the response factor. If the SSI approach is not appropriately included in the investigation and design, it may be difficult to find out how safe a structure is from earthquakes with accuracy. When the seismic zone increases the basic time period (TP) increases and therefore the response factor decreases. The natural period of the structure gets longer as a result of the SSI influence. The effect is more pronounced in soft soil. One of the main factors controlling the building's lateral seismic reaction is NTP. As a result, if this value is evaluated without taking seismic design into account, significant errors could result. It has been demonstrated that when soil flexibility increases, so does the NTP. What irregularity results from increased structural rigidity seems not significant for buildings supported by isolated footings. Regular and non-regular buildings assisting weak soil deposits may not have enough structural safety guaranteed by standard design techniques if the SSI method is

not used. Regular and non-regular structures behave similarly in response to weak earthquakes. The seismic zone has a significant impact on the reduction factor. As the seismic zone enhances, the decrease in R's value was significantly less than the values listed in ECP and is considered near to the Euro Code values, so it must be taken into consideration that the ECP values must be reviewed and this percentage reduced, especially in irregular buildings, where taking the ECP Code values for irregular buildings, specifically after representing the soil and taking it into account, is considered an unsafe design.

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