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Effect of Infilled Frames on Reduction Factor (R) for RC Irregular Structure

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Abstract

Investigating the modification factors as a critical seismic design tool, delineating the anticipated level of inelastic behavior within structural systems during seismic events. Both damping and ductility are included in this factor, particularly at movement nearing maximum capacity. Moreover, it offers valuable insights into buildings' response during earthquakes and the anticipated behavior of structures compliant with building codes during design earthquakes. Essentially, it mirrors the structure's capacity to dissipate energy via an inelastic mechanism. In this research, the infill (RC) structures with various structural irregularities were focused. The selected irregularities included dimension, elevation, and mass. Infill location, number of bays, and seismic zone were the expected R factors for RC frames. Non-linear static pushover analysis was adopted in numerical simulation. The available data gathered from the literature was used to validate the outcomes of the developed models. Additionally, the effects of different types of soil were taken into consideration, and the research results demonstrated that the value of the modification factor (R) for change in stiffness and mass of high-rise buildings for bare and infill (RC) structures is less compared to irregular (RC) structures. It was concluded that the same structure with different types of soil and different parameters has a great effect on the value of R for bare and infill regular and irregular (RC) structures. Furthermore, recommendations for accurate R estimation for RC structures were discussed.

Keywords: Infill & Bare Reinforcement Concrete Buildings; Elevation Irregularity; Plan Irregularity; Nonlinear Analysis; Force Displacement for Assessment of Pushover; Response Reduction Factor (R).

1. Introduction

This research is concerned with the evaluation of the response reduction factor for infilled R.C. frames. This research is considered an extension of previous research by the same author in the field of evaluation of response reduction factors for regular and irregular buildings, considering the effect of soil structure interaction [1–5]. This research aims to evaluate the value of the response reduction factor for bar and infill R.C. frames, whether regular or irregular, to obtain the value of the response reduction factor that is closer to the truth than those values in the code during the analysis of existing buildings, especially since most codes don't give a value for the response reduction factor for existing buildings.

During inelastic deformation, the response modification factor (R) signifies the structure's energy dissipation capacity. This factor is vital in earthquake design, representing the structure's capability to absorb energy through inelastic deformations [6]. An accurate estimation of R is crucial for evaluating seismic response. Overestimating R can lead to reduced base shear and uneconomical designs, requiring precautions to ensure structural ductility [7-9]. Conversely, underestimating R may result in economically unfeasible designs. Design codes implicitly address structural nonlinearity by minimizing earthquake-induced base shear forces through R.

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Elsadany et al. [4] Study the effect of irregularities of R.C. frames in elevation and in plan The analysis results concluded that buildings with irregular vertical geometries have lower inelastic seismic capacities compared to regular buildings. Consequently, R should be reduced by 15–40% from the ECP 2020 standard before the design phase for such structures and also indicates that the reduced factor (R) is highly dependent on the seismic zone; higher seismic zones have reduced R less than those found in the Engineering Code of Practice (ECP), and R is getting closer to those found in the Euro Code. For irregular buildings in particular, it is necessary to evaluate and maybe lower the values indicated in the ECP. When it comes to design, it is deemed risky to follow the ECP values for irregular structures, especially after taking soil characteristics into account.

Devkota et al. [10] study of the response reduction factor for RC buildings with consideration of the effects of masonry infill It indicates that buildings with a greater number of floors, bays, and bay lengths have a lower over-strength factor. The ductility reduction factor of a building increases with more floors and longer bays but reduces with more bays. Variations in these numbers, combined with changes in the redundancy factor, affect the response reduction factor across different building configurations.

Abdelrhman et al. [2] study The Effect of Soil Structural Interaction on the Evaluation of Seismic Response Reduction Factor of Multi-Story Concrete Buildings for proposed reinforced concrete moment-resistant multi-story frame systems established according to the Egyptian Code of Loads ECP-203-2012 [11], the response modification factor at failure values was determined. A reduction in the stated R values was also observed. The response reduction factor is extremely dependent on the seismic zone and the structure's fundamental time period. It rises with a lengthened basic time period and declines with an increase in the seismic zone's size.

Elnashai & Mwafy [9] study over strength and force reduction factor of multi-story reinforced concrete building Originally introduced This research examines the impact of the force reduction factor on the conventional understanding of over strength and its implications. It accentuates the benefits of integrating an additional measure of response, known as the inherent over strength, into the analysis. The inherent over-strength is defined as the ratio between the over-strength factor and the force reduction factor in the seismic-resistant design process. This factor entails quantifying the seismic demand under the assumption of structural elasticity during expected excitation levels while also predicting the reserved capacity of the structural system.

ASCE/SEI 7-10 [12] categorizes the ductility of buildings into different classes: (Ordinary - Intermediate - Special) Moment Resisting Frames, each associated with modification factors 3 for (OMRF), 5 for (IMRF), and 8 for (SMRF), respectively. Notably, European and Mexican codes primarily consider ductility without factoring in reserve strength. Additionally, certain codes, such as EC 8 (2004) and ECP-201 (2012), adhere to similar principles.

Palancı et al. [3] study the investigation of displacement demands using single degree of freedom models using real earthquake records compatible with TBEC-2018, which indicates in this study, nonlinear dynamic analyses were conducted within the scope, investigating maximum displacement demands and their variations using TBEC-compatible earthquake records. As anticipated, both the mean and median responses exhibit an upward trend from stiff soil to soft soil conditions. Additionally, these responses escalate with higher levels of seismic ground motion. Furthermore, the variation in seismic demands fluctuates randomly, contingent upon the local soil class and the level of the earthquake. The priority is to build the structure so that the structural components can resist substantial ground motion without collapsing, and the non-structural members may sustain some damage while still staying safe. This is due to the fact that every construction is susceptible to earthquake destruction. The design lateral strength is less than the lateral strength necessary to keep the structure within the elastic range as a result of this design philosophy. Therefore, in order to be practical, the buildings are not intended to remain elastic under seismic stresses because the expense of building them would be prohibitive in such an unlikely scenario. The notion that a meticulously detailed structure can endure significant inelastic deformations without collapse, owing to its ductile characteristics, and can bolster lateral strength beyond its designed capacity due to reserved strength, is pivotal in designing structures to withstand seismic forces considerably lower than those anticipated during intense shaking. A factor known as reaction reduction factor R lowers the actual earthquake intensity. The ductility factor, strength factor, damping, and structural redundancy all affect the value of R. The R factor indicates a structure's ability to spread energy using inelastic behavior.

Ghimire & Chaulagain [13] study common irregularities and their effects on reinforced concrete building response which explores that irregular building construction has gained popularity due to its ability to meet both aesthetic and functional requirements. However, past earthquakes in Nepal and around the world have shown that such constructions exhibit a higher level of seismic vulnerability. In light of this, the current study focuses on identifying common irregularities and their impact on the response of reinforced concrete buildings. The effect of structural irregularities was investigated through numerical analysis, where geometrical, mass, and stiffness irregularities were induced by removing bays at different floor levels and columns at various sections. Finite element models were developed using the SAP2000 program, and structural performance was assessed through nonlinear static pushover and dynamic time history analysis. The findings highlight that the degree of irregularity significantly influences the behavior of structures.

Fayed et al. [7] study Evaluation of Seismic Response Modification Factor of Multistory Buildings Designed According to Egyptian Code The primary focus is to calculate the response modification factor values at failure for idealised reinforced concrete moment-resisting multistory frame systems designed according to the Egyptian code of loads (ECP-201-2012). Parametric studies are conducted for RC moment-resisting frames consisting of 3, 6, and 9 stories, modelled in three dimensions as residential buildings with various configurations and adjustable parameters. SAP2000 software is utilised for modelling and analysing these systems, employing three-dimensional nonlinear static pushover analysis considering material and geometrical nonlinearity. The buildings are examined under the influence of several parameters, such as single- or multi-bay frames, the number of stories, seismic zone intensity, and the type of spectrum as per the Egyptian code. The impact of these parameters on the pushover curve, R-factor, and its components is analyzed. Comparative assessments between the results highlight differences in some values while showing consistency in others, including R-factor values. The response reduction factor is significantly influenced by both the seismic zone and the fundamental time period of the structure. It decreases with higher seismic zone classifications and increases with longer fundamental time periods.

Sriwastav & Basu [14], study Vertical spectra consistent with horizontal seismic hazard which indicate that The construction of vertical spectra (V) for scenario- and intensity-based seismic performance assessment suggests a method based on scaling the horizontal spectral ordinates (H) using respective V/H spectral ratios. The geometric mean of the spectra along and perpendicular to the principal plane components is taken as the intensity measure for the horizontal component.

Abdelrhman et al. [2] study The Effect of Soil Structural Interaction on Evaluation of Seismic Response Reduction Factor of Multi-Story Concrete Buildings which explore The seismic behavior of concrete structures is significantly influenced not only by the structure's response but also by the soil beneath the foundations, the dynamic properties of the structure, the damping factor, the natural period, the mass, and the stiffness of the structure [6, 13, 15-18].

The code lacks categorization for the response reduction factor concerning masonry constructions with differing mechanical characteristics [19] Establishing the R for masonry structures with variable mechanical properties holds significance, as it informs the design process for such structures. Consequently, this article aims to examine the response reduction factor, denoted as "R," across various types of masonry building types [10, 20-22].

Numerous research endeavors have delved into exploring the ramifications of irregularities on the seismic performance of reinforced concrete structures [23], in which the structure's roof displacement is higher in regular than in irregular structures, and also because the irregular structures were initially used to demonstrate collapse avoidance and survival capabilities [4]. The actual overturning moment response for L-shaped models determined during the seismic study provided a clear illustration of the influence of plan irregularity; an incorrect structural component arrangement could jeopardise the building's stability. The reasons for the movement are the structure's mass and rigidity, and the simulation of the anomalies present on the bottom floor further shows the highest possible number of the story's slide ratios [24]. It was obvious that when seismic energy increased, base shear and lateral displacement would also increase, suggesting a higher seismic demand on the structure. In recent years., nonlinear static pushover analysis (NPA) has drawn a lot of interest from researchers. This offers an overview of different pushover analysis techniques for structural irregularities, both vertically and horizontally [21, 25].

This research focused on analysing the impact of the (R) factor for different reinforced concrete buildings for bare and infill structures.; second, utilising the pushover analysis (P.O.A.) approach for nonlinear seismic analysis in order to analyse seismic performance on irregular RC and regular RC structures for bare and infill structures; nonlinear pushover analysis has been used to evaluate the response modification factor for irregular RC and regular RC structures for bare and infill structures. The irregularity (dimension, elevation, mass, and infill location) of each structure's floor plan geometry was investigated. The three buildings have different areas and heights in addition to different earthquake regions at 0.15g and 0.20 g. After that, we will discuss the results obtained after the parametric study. The conclusions of the thesis are drawn, and recommendations for other researchers are made.

2. Response Reduction Factor

This factor was designed for precise analysis of the seismic force by combining nonlinearity with over strength, redundancy, and ductility of the structure. As recommended by previous studies [8, 5, 17, 23], for nonlinear static analysis, Figure 1 illustrates the theory of the response reduction factor. Usually, the modification factor (R) can be expressed as a function of several structural system parameters, such as redundancy, damping, ductility, and strength. This component is indicated as the behavior factor (in the Euro code) [26], and the modification coefficient in ASCE 2013 [24].

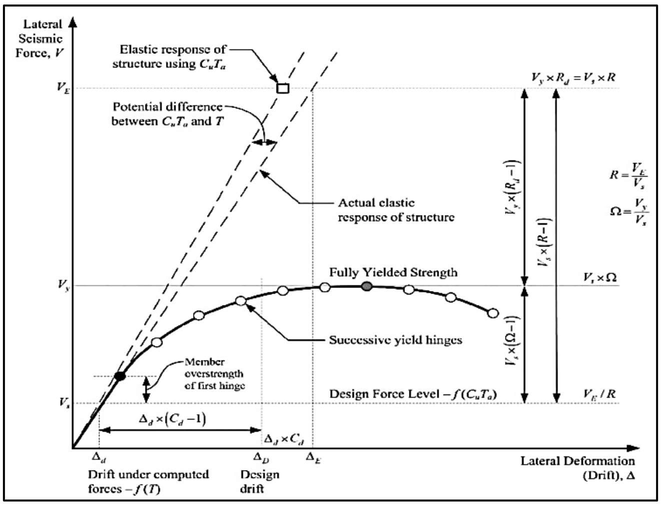


Figure 1. The theory of the response reduction facto elucidates the correlation between base shear and roof horizontal displacement

Overstrength factor is obtained as:

$$Rs = Vy/Vd \tag{1}$$

where Rs is the overstrength factor, which can be determined by dividing the maximum base shear in idealized behavior (Vy) by the design base shear (Vd) using the formula below. as shown in Figure 2.

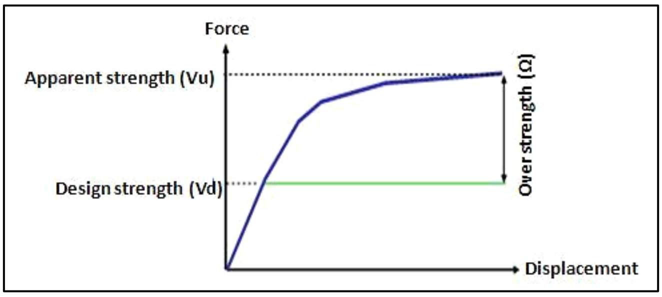


Figure 2. Over-strength force displacement relationship

R_R is the redundancy factor, in addition to what is considered essential or inherently excessive. A building's ability to withstand lateral loads should be highly redundant. Increased energy dissipation and over-strength are caused by construction with more redundancy. A single member failure in a no redundant system equals the failure of the entire structure; many member failures in a redundant system result in failure. Thus, a system's redundancy will determine how reliable it is; in other words, whether a system is redundant or not will determine its dependability.

R_ξ is the damping factor, in structures with more energy dissipation devices, the damping factor is employed to take into consideration the impact of greater viscous damping. If these appliances are not available, R_ξ is typically adjusted to be neglected.

Rμ is the ductility factor that reduces the elastic force demand to the idealised structural ultimate strength level. The ductility reduction factor, Rμ, is determined by structural attributes such as ductility and fundamental vibration period (T) is the ductility factor, that reduces the elastic force demand to the idealized structural ultimate strength level.

The ductility reduction factor, Rμ, is determined by structural attributes such as ductility and fundamental vibration period (T) [27], and the characteristics of earthquake ground motion [9, 27–30]. In this study, the formulation presented is employed [26].

$R\mu = 1.0$ for period of zero seconds (2-I)

$R\mu = \sqrt{2\mu - 1}$ a short period (2-II)

$R\mu = \mu$ for a long period (2-III)

Rμ = 1+ (μ-1) T/0.70 for structures with a fundamental period between 0.70 and 0.30 seconds (2-IV)

$\mu = \Delta max / \Delta y$. (2)

Thus, (R) is:

$R = R_S\ R_\mu$ (3)

Rs is the over strength factor;

Rμ is the ductility factor;

R_R is the redundancy factor.

The Response reduction factor ranges from ordinary to extra ordinary moment resistant frames, ASCE7 [31] and IBC (2012) [32, 33]. Utilise near-value ranges from 3.0 to 8.0, whereas the values for (R) range between 3.5 and 8.5 in UBC97. For limited (ordinary) to sufficient ductility frames, ECP (2012) and IS (1893) have established value ranges of 5-7 and 3-5, respectively. Furthermore, based on the structure configuration, while Euro code depended on Equation 1.

3. The Objective of Evaluation of Pushover

Nonlinear dynamical analysis of time histories is frequently considered an extremely effective approach to earthquake assessment in structurally nonlinear modeling. However, because of its substantial analytical requirements and the challenges of understanding the answers to design motives, it is considered inappropriate for ordinary structural design applications. A further major obstacle is determining suitable acceleration records for numerical analysis as well as accounting for torsional effects in irregular structures' nonlinear static responses.

An approach for performing non-linear static structural analysis is pushover analysis. It evaluates the mechanism of plastic hinge generation at each step of the post-elastic zone and determines the capacity curve based on base shear vs. displacement. In this approach, the increasing forcing function is described in terms of displacements or horizontal forces applied to a mathematical model of a building. The analysis becomes finished when the critical condition or target displacement is achieved (see Figure 3). The goal displacement or drift represents the greatest building displacement or drift during an earthquake [25, 30, 34, 35].

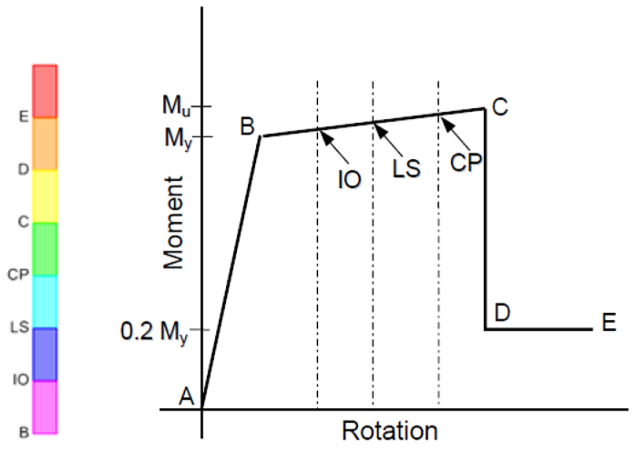


Figure 3. Typical Load - Deformation Relation for Pushover Analysis- M_U= Ultimate moment capacity- M_{Y}= Yield moment- IO = Immediate Occupancy- LS = Life Safety- CP= Collapse Prevention

4. Verification of Analytical Models

Determine the factors influencing the response reduction/modification factor (R). Parameters such as soil type, seismic zone, building irregularity, and spectral characteristics (Types I and II) were investigated, along with the number of stories, relative inertia between girders and columns, and reinforcement levels. Non-linear static pushover analysis using SAP2000 software was employed to simulate the impact of soil-structure interaction on RC-framed buildings, which served as the primary lateral load-resisting systems. Numerical models were generated for various buildings to explore the effects of these parameters on their behavior [4].

The study focused on numerically modeling the load-displacement behavior of RC frames, presenting analytical results for different irregular RC frames through parametric studies. Both elevation and in-plan irregularities were considered, highlighting that buildings with irregular vertical geometries exhibit lower inelastic seismic capacities compared to regular structures. A 10-story irregular RC frame structure (model B) was designed according to ECP-203 standards to withstand gravity and seismic loads (spectrum Types I and II) across various seismic zones (0.2 g). Soil classification was based on ECP-203, distinguishing between Type B and Type C soils. For each soil type, models were initially simulated assuming a limited ductility moment-resisting frame with R equal to 5, utilizing column sections ranging from 25×25, 30×30, 40×40, 50×50, and beam sections of 250 mm × 500 mm. The top and bottom reinforcements were kept constant at 8T16 for both top and bottom reinforcements (see Figures 4 and 5). Through modeling with SAP2000 software, the response reduction values for Model B under Spectrum I are 5.32 for soil type B and 7.62 for soil type C. While, under Spectrum II, these values are 4.392 for Type B and 3.31 for Type C, these values closely resemble those in Elsadany et al. [4].

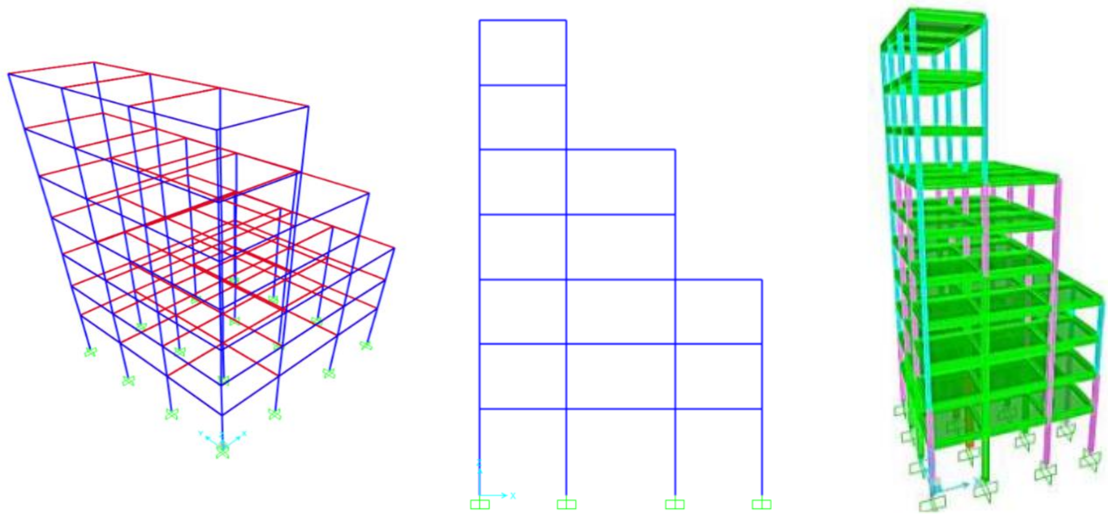


Figure 4. Irregular Bare RC Frame Structure –10 stories - model B

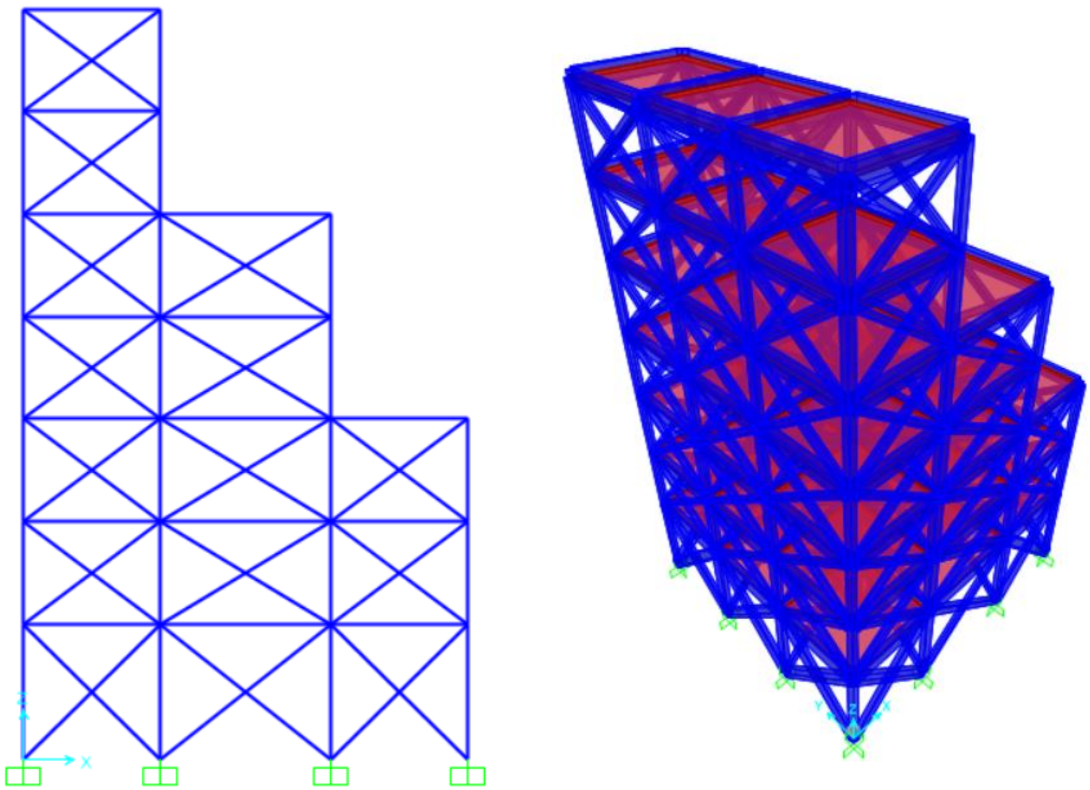


Figure 5. Irregular infill RC Frame Structure –10 stories - model B

Infill walls are modeled using empirical Equations 4 and 5, which are explained in the computer simulation, treating them as single diagonal struts. These diagonal struts are connected to the intersection centerlines of the beam and column, with the strut width set at one-fourth of the diagonal length of the masonry wall. Only compression is carried by the strut, effectively preventing the transfer of bending moments from the RC frames to the masonry [36].

The response reduction values for irregular infill RC frames under Spectrum I are 11.4 for soil type B and 7.24 for soil type C. while, under Spectrum II, these values are 8.79 for Type B and 6.89 for Type C. The reinforced concrete structure with infill shows increased R values compared to the bare RC structures, ranging from 47% to 50%, across various soil types.

5. Modeling Specifications

Three distinct structures were subjected to analytical simulation. The initial group, referred to as Model (A - A'), consisted of relatively short, four-story buildings. The subsequent group, referred to as Model (B-B'), represented elevated buildings with five floors. The final group, named Model (C-C'), is detailed in Table 1. Figure 4 displays various cross-sectional illustrations for the different models, while Figure 6 showcases 3D modeling representations of different structures.

Table 1. model description for RC structures

Height	Structure models		Number of stories
	Regular (RRC)	Irregular (IRRC)	
13	A’	A	4
16	B’	B	5
22	C’	C	7

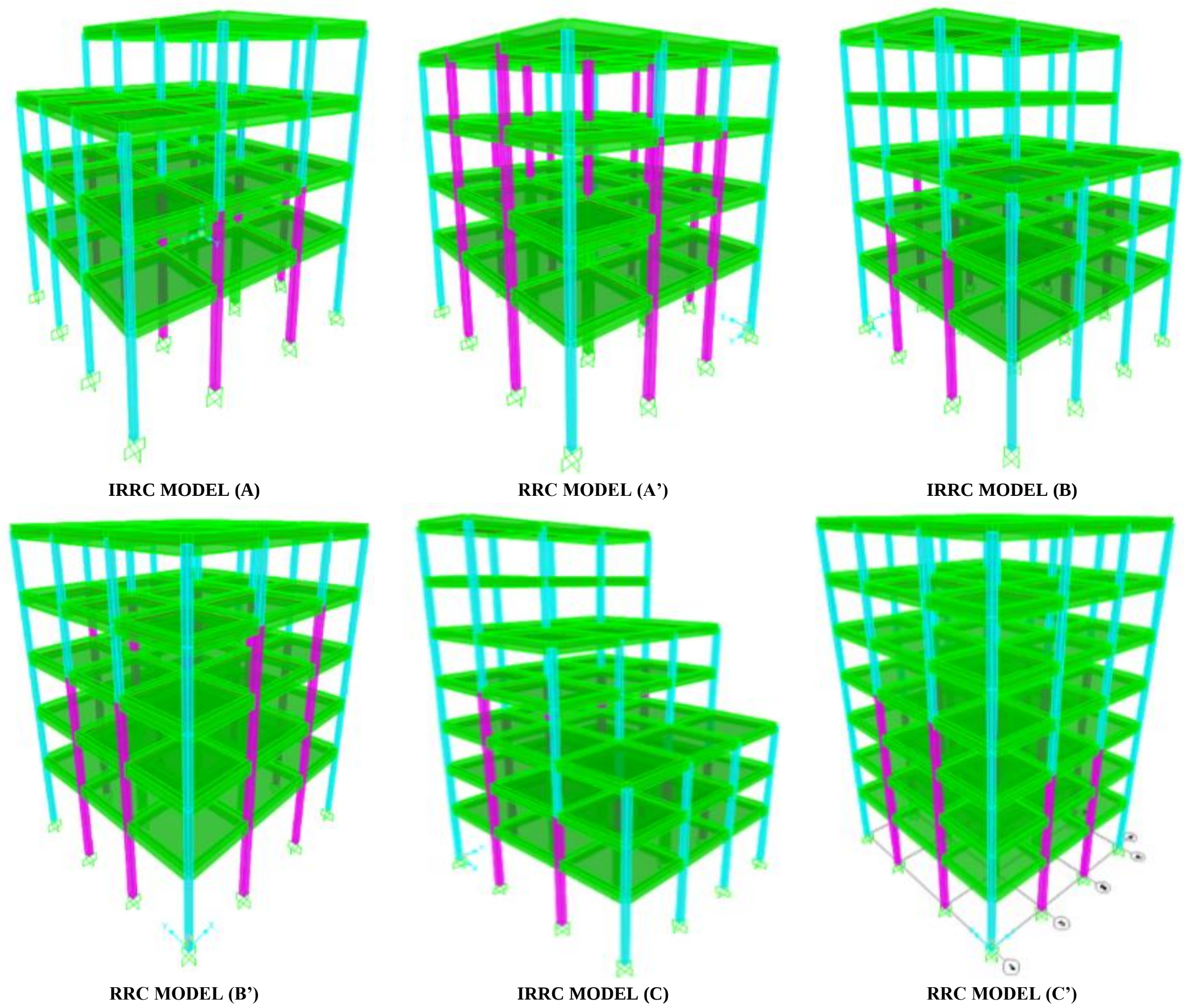
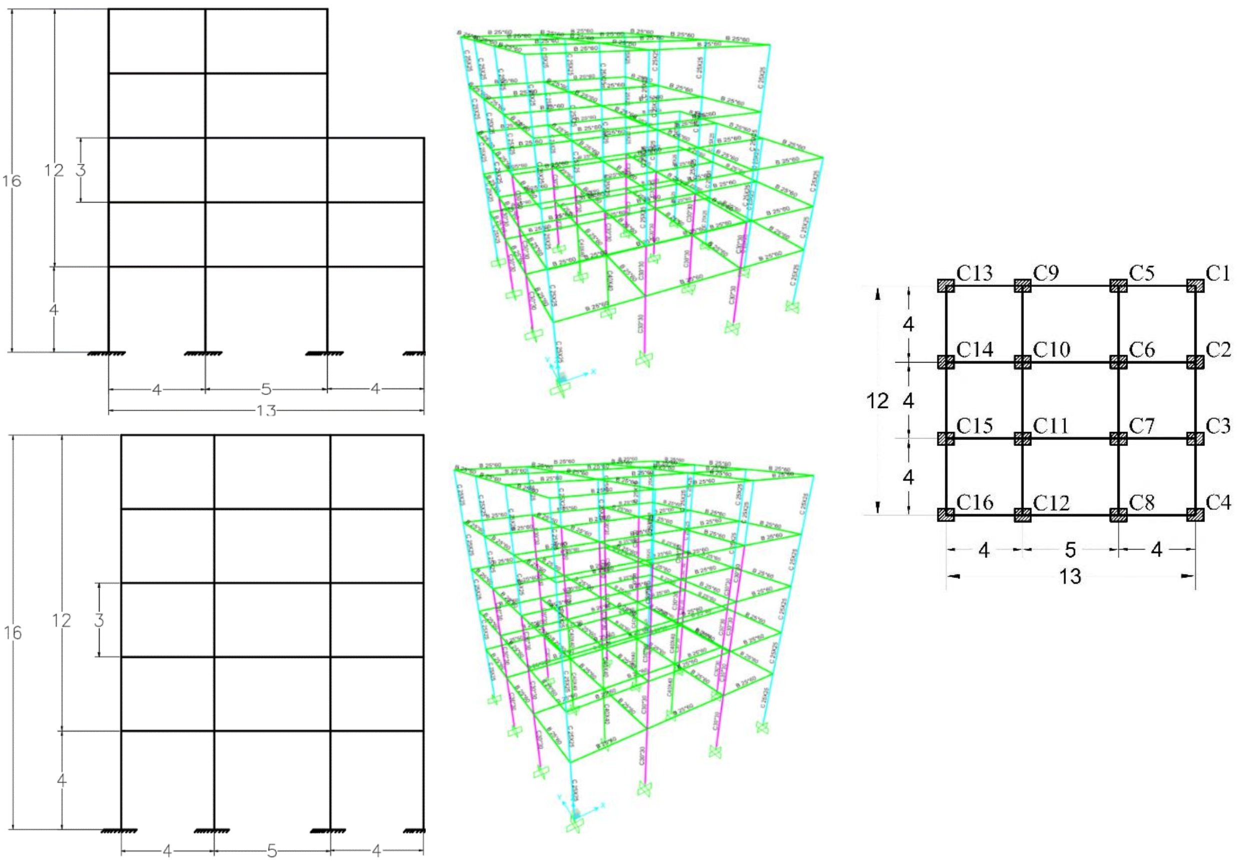
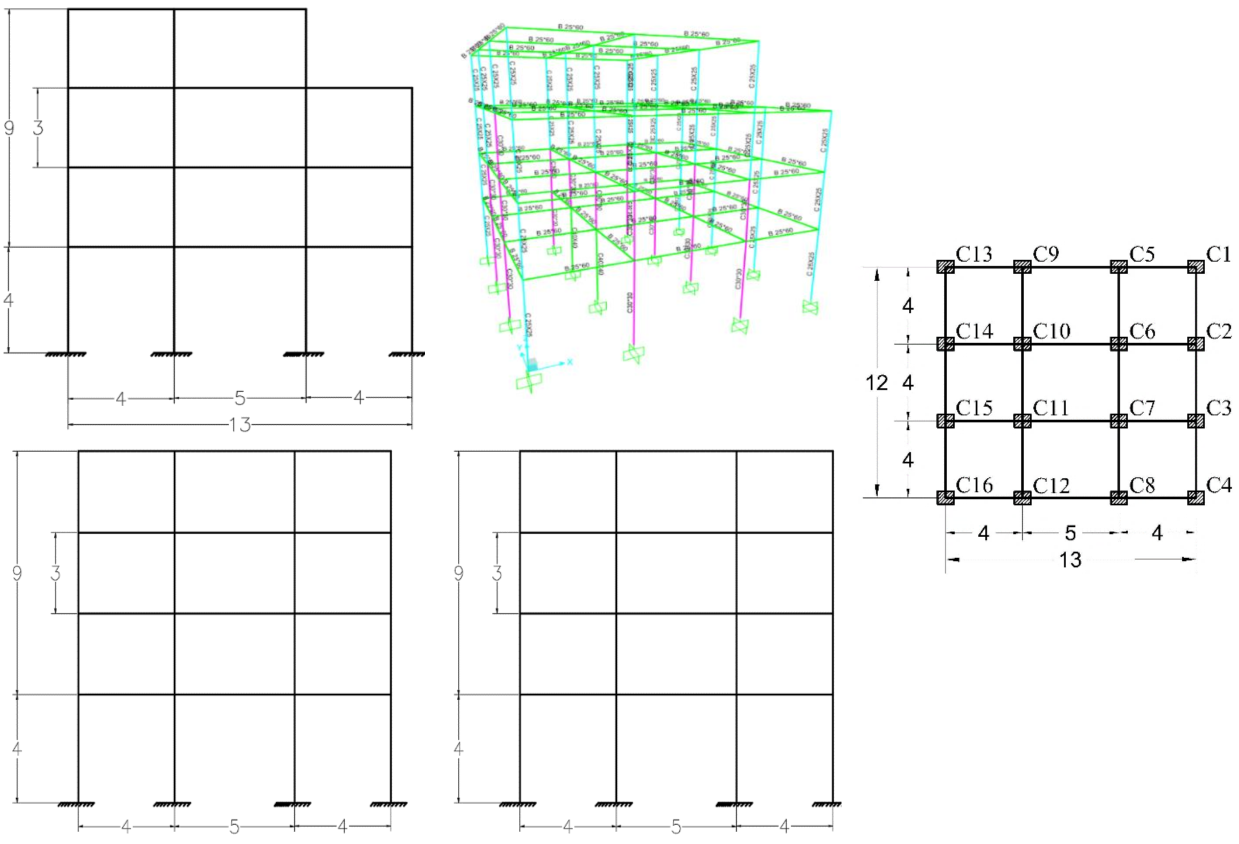


Figure 6. Three-dimensional Modelling of BARE - Regular and Irregular Buildings

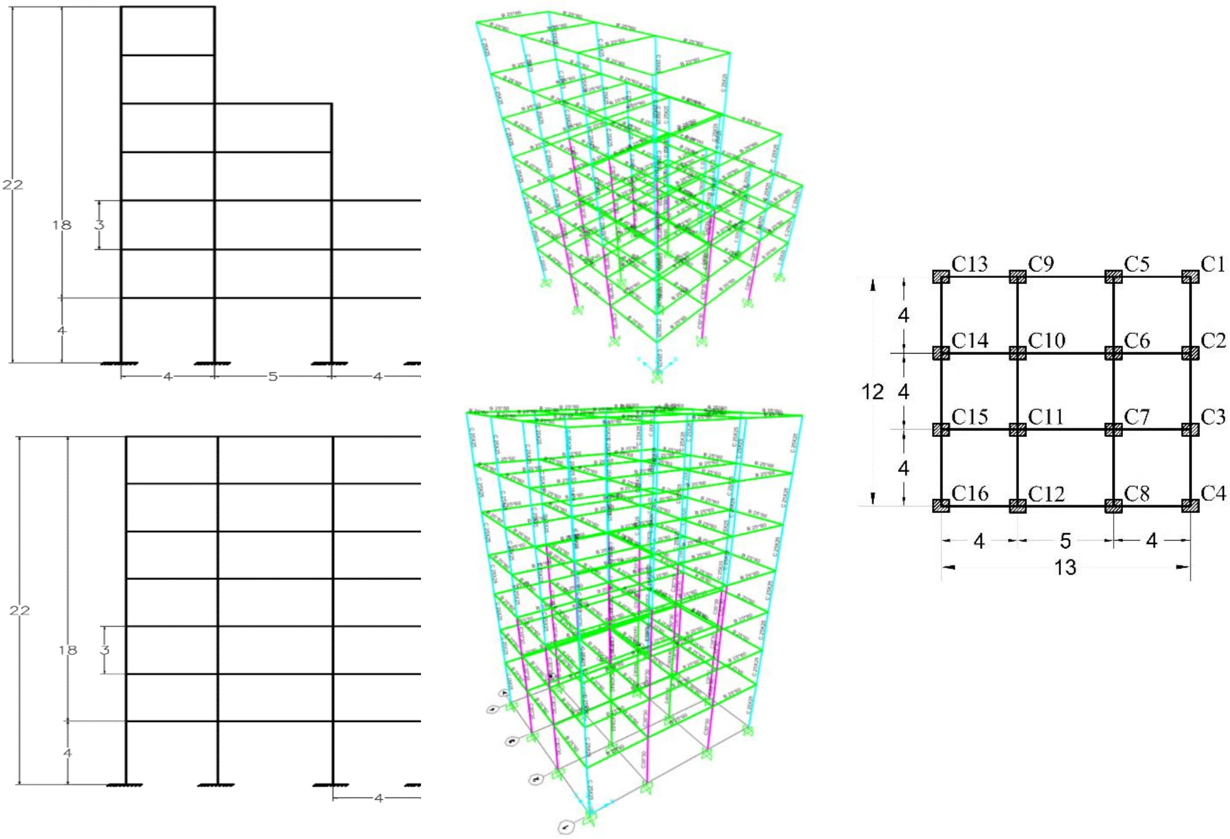
For the nonlinear static analysis, SAP2000 [37] was utilized. Multiple properties were incorporated during modeling, encompassing material attributes, structural positioning, soil classification, and details regarding infill and irregularities, spanning dimension, elevation, and mass. Figure 7 illustrates diverse cross-sectional perspectives of the three models, while Figure 6 provides comprehensive 3D views of the structures. Moment-curvature measurements delineate component properties, encompassing considerations of material qualities, reinforcement, and applied stress.



Elevation of five storey – (IRRC) percentage terms (12%) – Bare (RC) Structures (A-A')



Elevation of four storey – (IRRC) percentage terms (7.6%) – Bare (RC) Structures (B-B')



Elevation of seven storey – (IRRC) percentage terms (29%) – Bare (RC) Structure (C-C')

Figure 7. Description of models

6. Numerical Simulation

In this study, for the earthquake analysis of structures of 4, 5, and 7 stories, the corresponding static technique was applied. With the commercial software SAP2000 [32, 38, 39], finite element models were used. Shell elements were used to simulate slabs, while frame elements were used to represent beams and columns. A parametric study was carried out, with the primary parameters being soil type, seismic zone, building regularity and irregularity, and, finally, distinct spectrums I and II.

ECP-203 served as the design and comparison guide. The procedure for computing structure models and an estimate of the number of trials required to complete the study are presented in Table 2. Three (IRRRC) structures (A, B, and C) were the focus of the initial phase. With different irregularity percentages of 7.6%, 12.2%, and 29%, respectively, Corresponding (RRC) models with the names A', B', and C' were also employed.

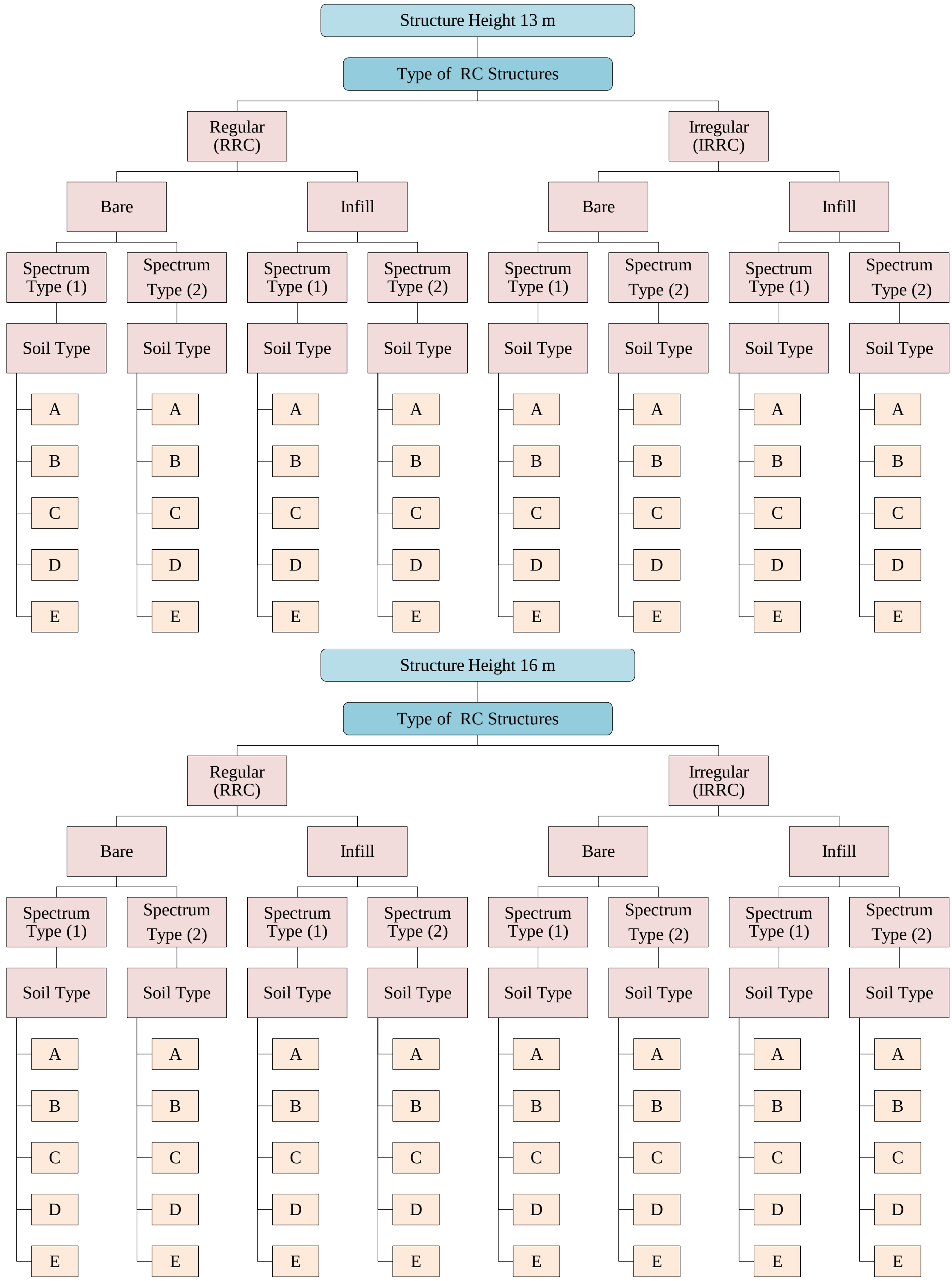
Table 2. Procedure of computation structure model

<table>
<tr><th rowspan="2"></th><th rowspan="2">Structure Frames</th><th rowspan="2">Height</th><th colspan="5">Type of Soil</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th></tr>
<tr><td rowspan="6">Bare and Infill</td><td rowspan="3">Regular (RRC)</td><td>13</td><td colspan="5">model (A')</td></tr>
<tr><td>16</td><td colspan="5">model (B')</td></tr>
<tr><td>22</td><td colspan="5">model (C')</td></tr>
<tr><td rowspan="3">Irregular (IRRC)</td><td>13</td><td colspan="5">model (A)</td></tr>
<tr><td>16</td><td colspan="5">model (B)</td></tr>
<tr><td>22</td><td colspan="5">model (C)</td></tr>
</table>

According to the ECP-203 categorization, five different soils named A (rock soil), B (dense soil), C (medium soil), D (weak soil), and E (very weak soil) were used to build the six models [3, 16, 18, 40]. After that, two different response spectrum types (0.15 g and 0.2 g) were applied to each of the twelve models, each of which was simulated in a separate seismic zone. At that point, there were 120 models in all. The plastic hinge status at the yield and final states was ascertained using nonlinear pushover static analysis. The buildings were pushed horizontally until they reached the failure condition that had been previously determined.

The research literature has offered a wide range of methods for simulating infilled frames, which fall into two categories: simplified macro models and micro-models. The micromodel accounts for the extensive discretization of the infill panel. The method advocated by previous studies [10, 18, 37, 38] was employed. In this study, the diagonal strut is connected to the intersection centerlines points of the beam and column, and the strut width is determined as one-fourth of the diagonal length of the masonry wall. Compression is only carried by the strut. To prevent the transfer of the bending moment from RC frames to masonry, the moment was specified. Conversely, the model is used as a technique due to its simplicity.

Figure 8 shows the flowchart of the research methodology through which the objectives of this study were achieved.



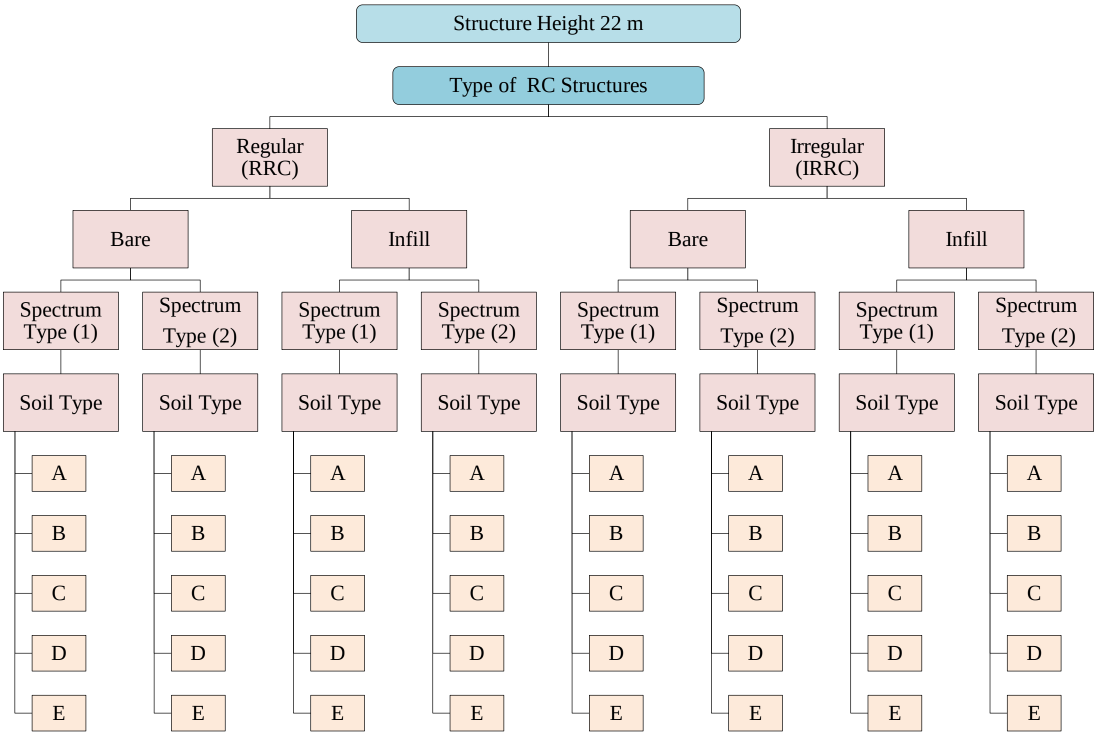
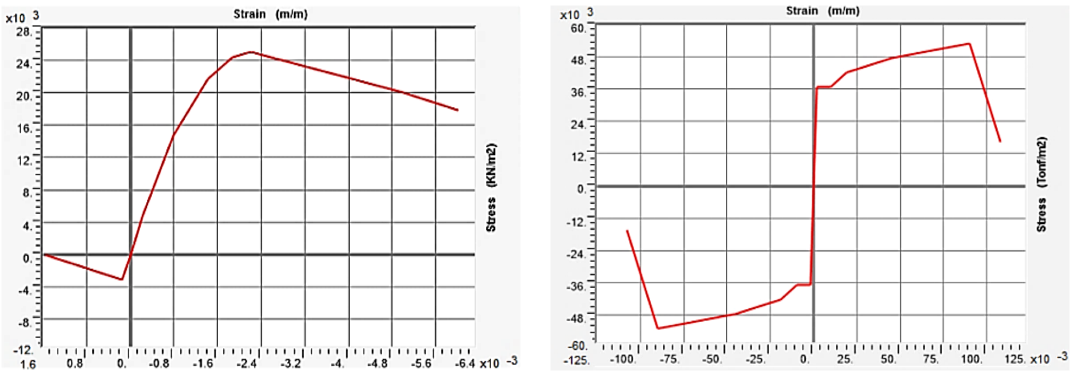


Figure 8. Flow chart for the process of methodology

SAP2000 [10, 37, 41] was utilized in the non-linear static analysis process. During modeling, variable parameters were taken into account. Nonlinear static analysis requires material properties with distinct stress-strain relationships, anticipated plastic hinge positions and lengths, and moment-curvature correlations (Figure 9). The value of these points, which are obtained from the moment-curvature relationship of an element, is affected by dimension, properties of material, reinforcement, and stresses applied to a particular member (see Table 3).

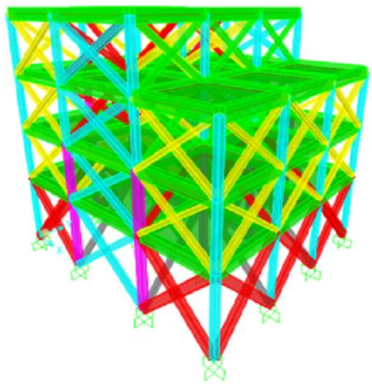


(a) Stress-strain curve for concrete (b) Stress-strain curve for steel bare

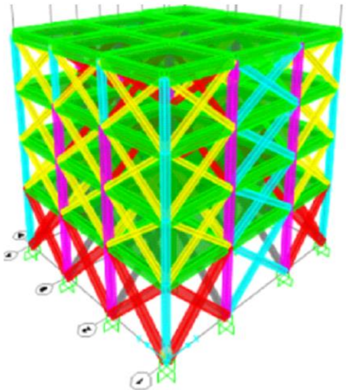
Figure 9. Stress-strain curves

Table 3. Simulated material properties

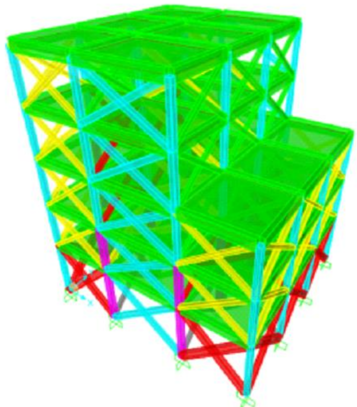
Material Properties	Value
Modulus of elasticity of rebar (ES)	200000000 kN/m^2
Rebar yield strength (F_Y)	360000 kN/m^2
Concrete characteristic strength (Fc)	25000 kN/m^2
Modulus of elasticity of concrete (E_C)	22000000 kN/m^2
Shear modulus – Concrete (G)	9166667 kN/m^2
Concrete (Yc)	0.2
Steel (Ys)	0.3



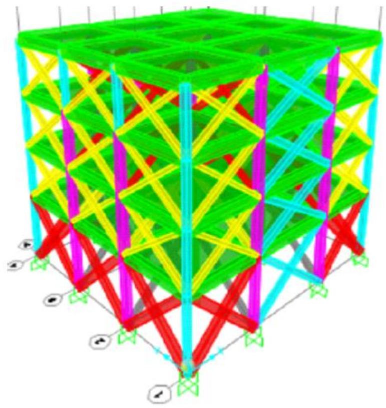
IRRC MODEL (A)



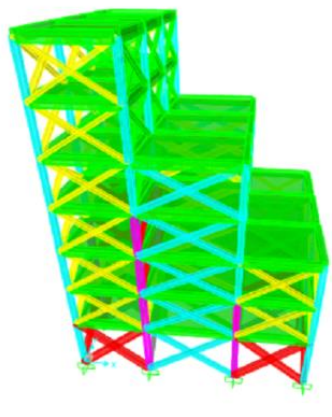
RRC MODEL (A')



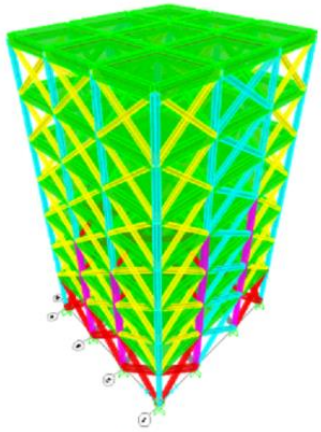
IRRC MODEL (B)



RRC MODEL (B')

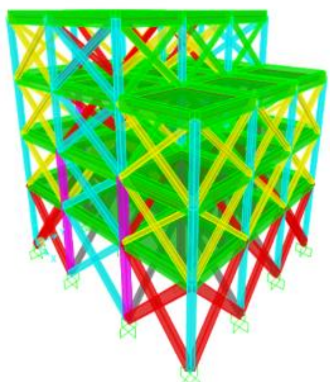


IRRC MODEL (C)

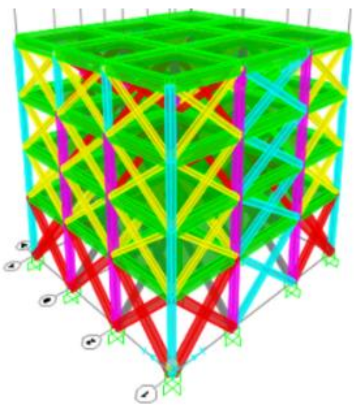


RRC MODEL (C')

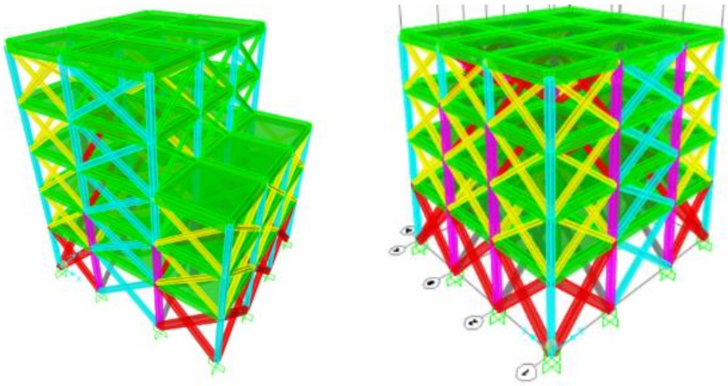
Figure 10. Three-dimensional Modelling of infill - Regular and Irregular Buildings



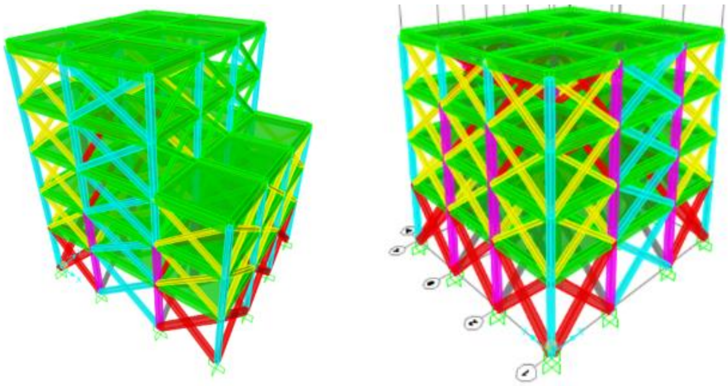
IRRC MODEL (A)



RRC MODEL (A')



IRRC MODEL (B) **RRC MODEL (B')**



IRRC MODEL (B) **RRC MODEL (B')**

Figure 11. Three-dimensional Modelling of infill - Regular and Irregular Buildings

Infill walls as shown in Figures 10 and 11 are simulated with the empirical equations provided as a single diagonal strut. Via Part I of IS 1893: 2016 and Equations 4 and 5, establish the diagonal strut's width [36]. The masonry infill's material characteristics and nonlinearity were described. Employing the conceptual model that Kaushik et al. (2007) [38] suggested. The inflexible conduct by incorporating axial hinges at the diagonal centre of the strut members (Figure 12).

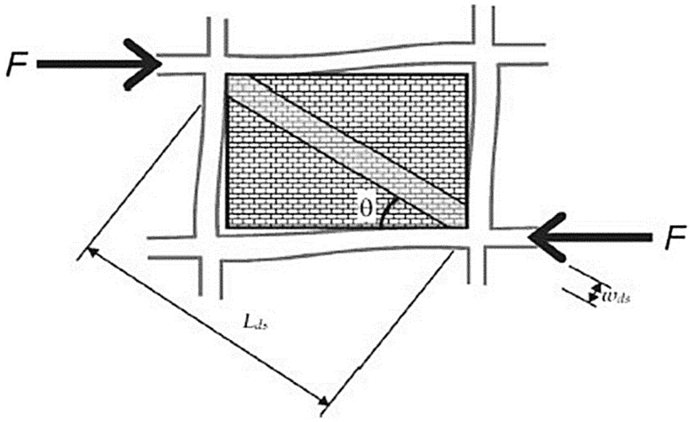


Figure 12. Typical infill modelling

The pivot hysteretic law is chosen to simulate the behavior in the comparable diagonal strut, as shown in Figure 13 of the structural program SAP 2000:

$$W_{ds} = 0.175\alpha_h^{-0.4} L_{ds} \tag{4}$$

$$\alpha_h = h(4\sqrt{\frac{E_M t \sin 2\theta}{4 t_c I_c h}}) \tag{5}$$

where W_{ds} is the diagonal strut's equivalent width and L_{ds} is the diagonal strut's length, E_M is the Masonry elasticity modulus, t_c is Concrete's elasticity modulus, I_c is the moment of inertia of the concrete component, h is the height of the wall, t is the thickness of the infill wall, and θ is the angle of the diagonal strut with respect to the horizontal are its measurements.

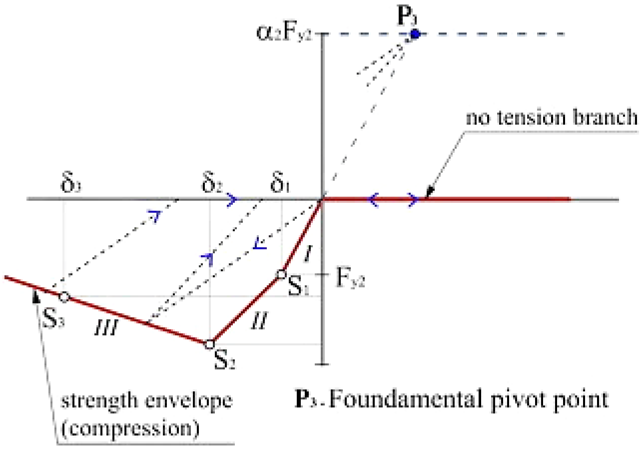


Figure 13. Hysteretic model [39]

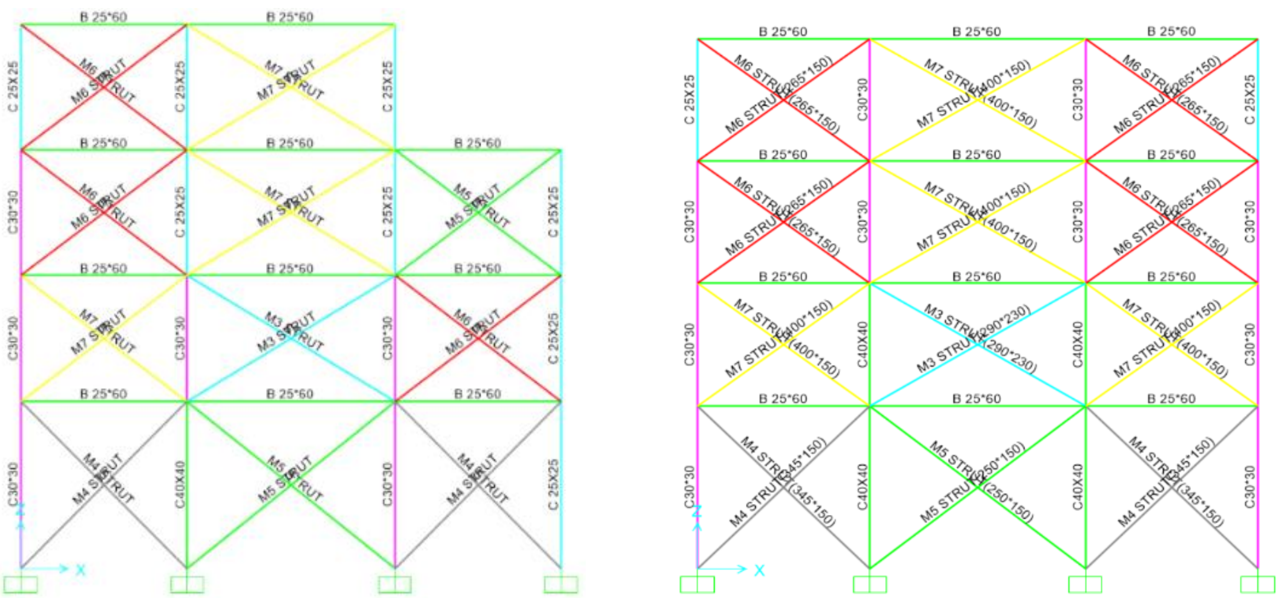
RC-framed buildings of four, five, and seven stories are designed against earthquake loads (with different response spectrums) within distinct earthquake zones using ECP-203. (0.15g, 0.2g). Soil was categorized as Type A and Type B, Type C, Type D, and Type E, per ECP-203. The simulations for each type of soil were created using either bare regular-irregular RC structures or infill regular-irregular RC structures based on the design result. Initially, a restricted ductile MRF with a response reduction factor equal to 5 was used to simulate the models [9]. The following elements were taken into account when designing:

- In order to ensure compliance with the damage-limitation recommendations, the inter-story drift must not surpass 0.005.
- Cross-sectional dimension was utilized to develop the beams.

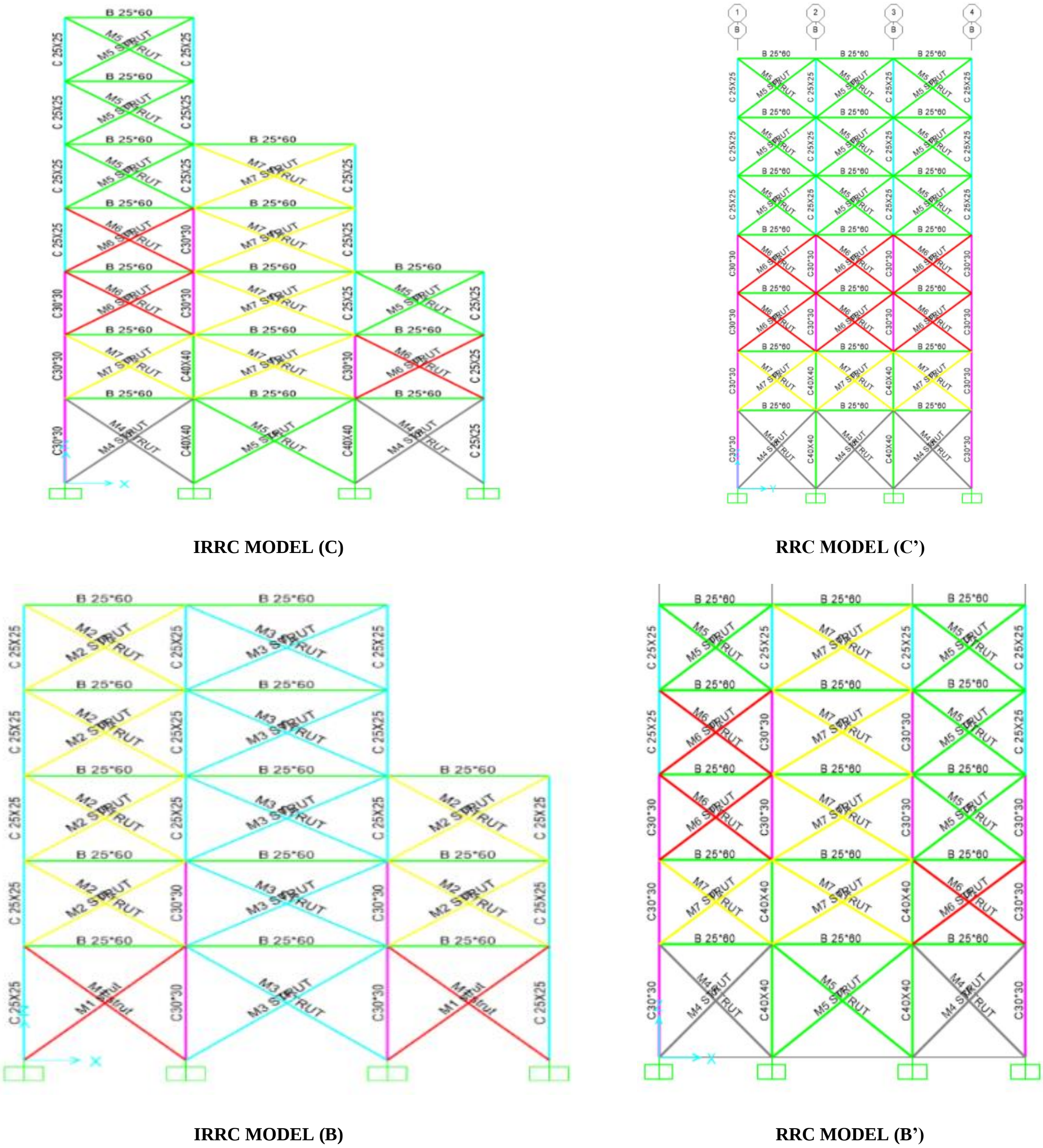
For every model, the beams were designed with dimension, as represented by Table 4 and Figure 14. Similar to (8T16), the reinforcement at the top and bottom were maintained constant. Table 4 for columns, under study. For the sectional reinforcement percentages, %53 to %75.

Table 4. The reinforcement ratio for the column sections

Reinforcement Ratio	Column Section		
	25×25	30×30	40×40
μ %	2.57	2.75	2.36



IRRC MODEL (A) **RRC MODEL (A')**



IRRC MODEL (C) **RRC MODEL (C’)**

IRRC MODEL (B) **RRC MODEL (B’)**

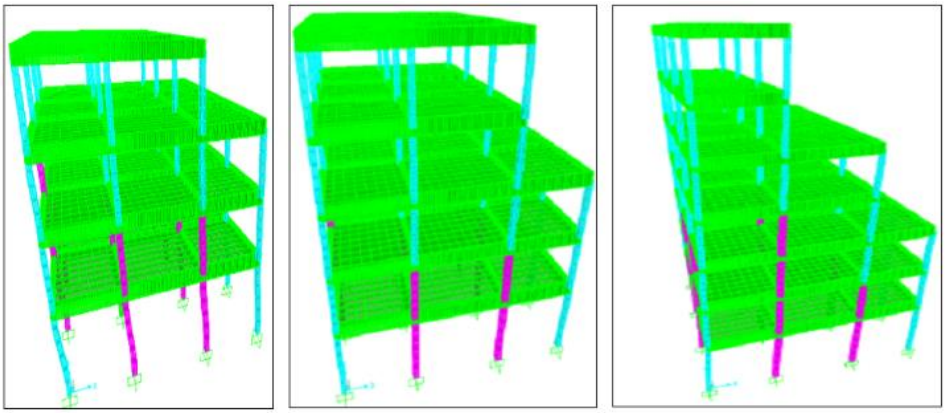
Figure 14. Typical Floor Elevation View of Infill - Regular and Irregular Buildings

7. Results and Discussion

The simulation outcomes reflect the modeling results, which include contributing particular natural frequencies, the impact of various soils, earthquake regions, and bare and infill-reinforced concrete structures. The effects (IRRC) structures were investigated. A comparison was made between the resulting response reduction factor and the equivalent value of RRC structures.

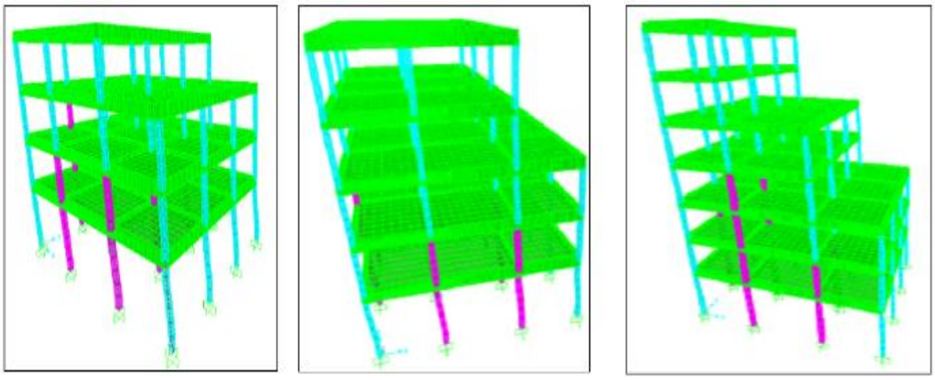
7.1. Structures Natural Period

For both bare and infill RC structures, the essential periodic times for all regular and irregular structures were identified. The first four periods for (IRRC) periods are shown in Figure 15. Furthermore, it was found that for both the bare and infill RC structures, the first forms represented overall basic bending motions [2, 16]. On the third natural period for the bar RC structures, the structures appear in torsion rotation motion. For every mode, there is an indication of the natural [40-42].



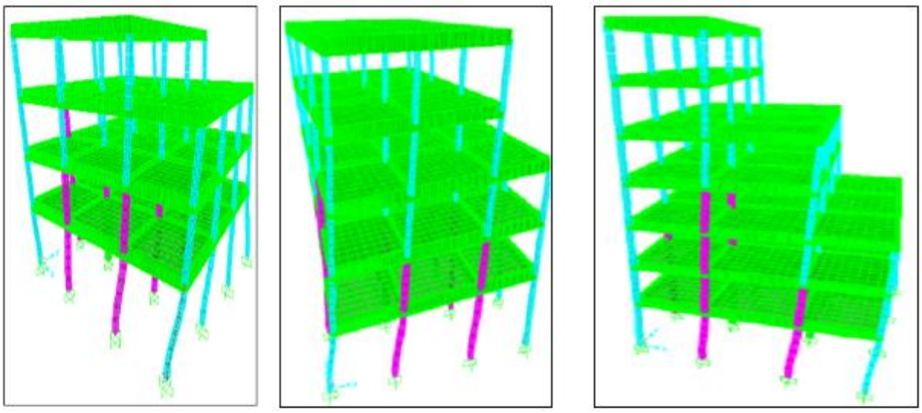
A,T_1=0.896 Sec B,T_1=1.062 Sec C,T_1=1.212 Sec

a) First mode for Bare RC structure



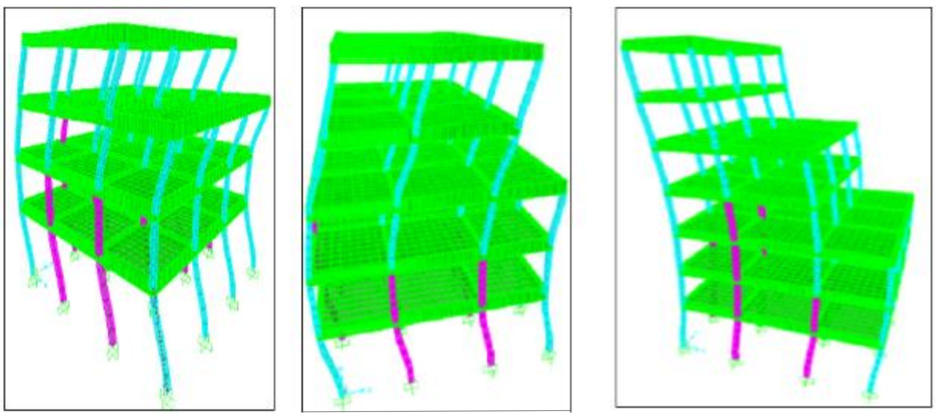
A,T_2=0.8947 Sec B,T_2=1.06 Sec C,T_2=1.154 Sec

b) Second mode for Bare RC structure



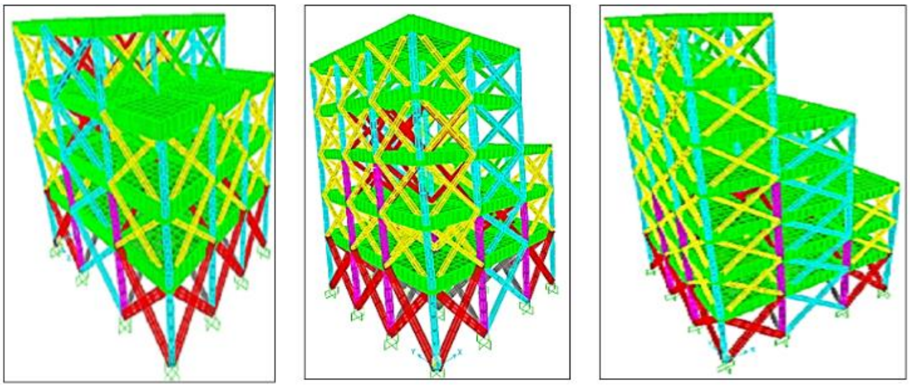
A,T_3=0.779 Sec B,T_3=0.885 Sec C,T_3=0.91 Sec

c) Third mode for Bare RC structure



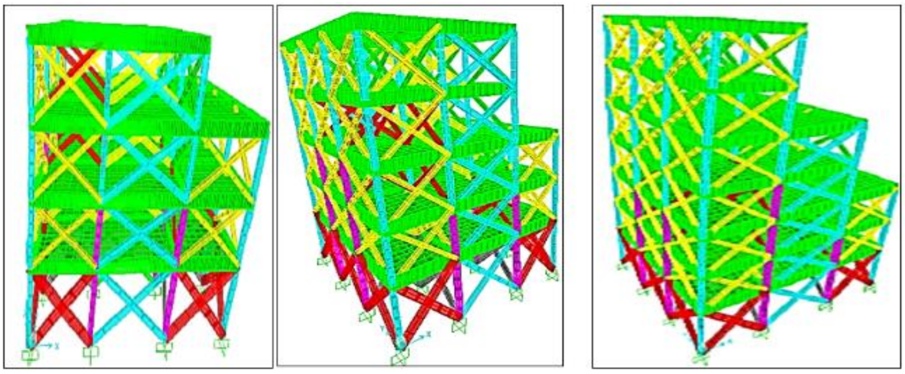
A,T_4=0.33 Sec B,T_4=0.418 Sec C,T_4=0.51 Sec

d) Forth mode for Bare RC structure



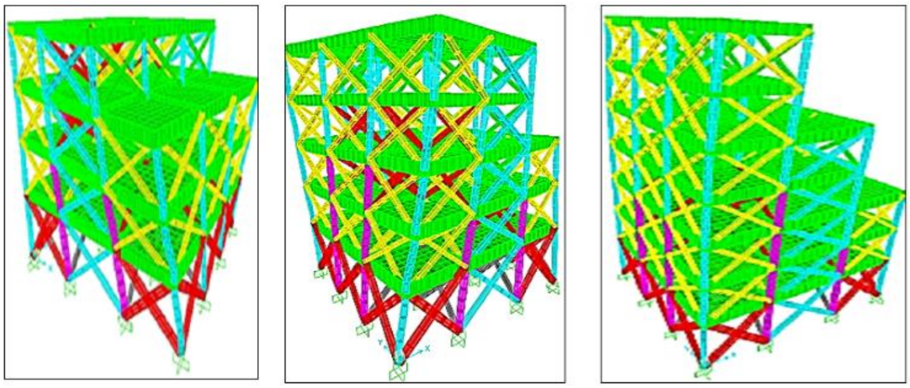
A,T_1=0.237 Sec B,T_1=0.298 Sec C,T_1=0.382 Sec

a) First mode for Infill RC structure



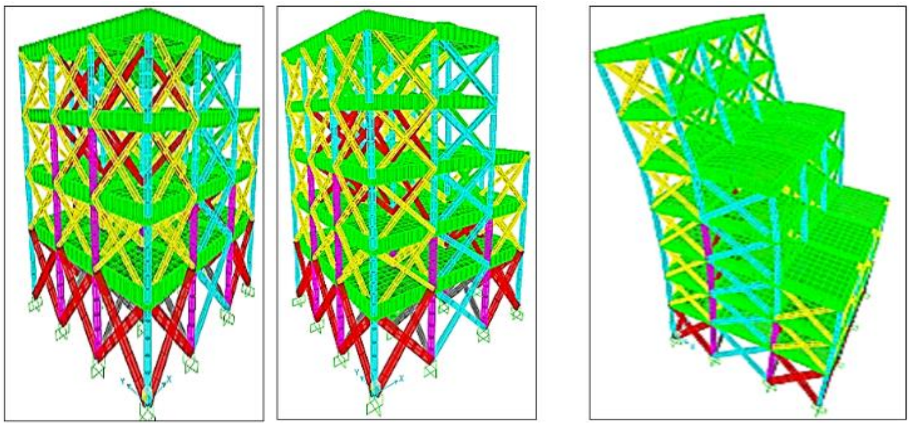
A,T_2=0.2306 Sec B,T_2=0.258 Sec C,T_2=0.373 Sec

b) Second mode for Infill RC structure



A,T_3=0.1615 Sec B,T_3=0.189 Sec C,T_3=0.22 Sec

c) Third mode for Infill RC structure



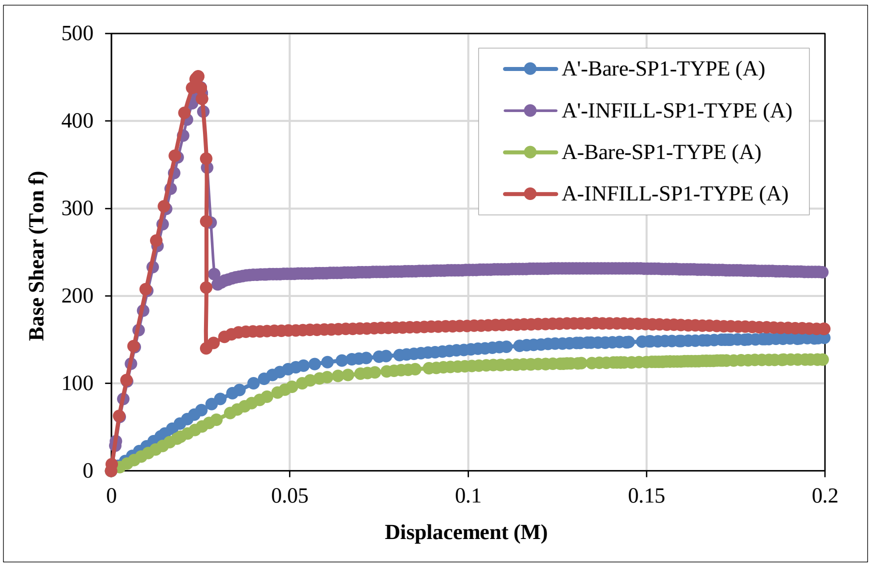
A,T_4=0.1254 Sec B,T_4=0.132 Sec C,T_4=1.154 Sec

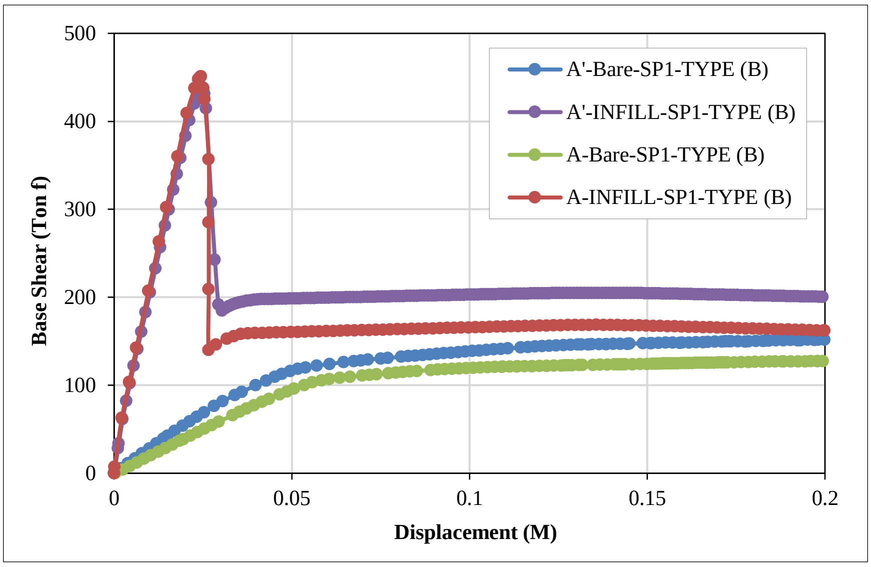
d) Forth mode for Infill RC structure

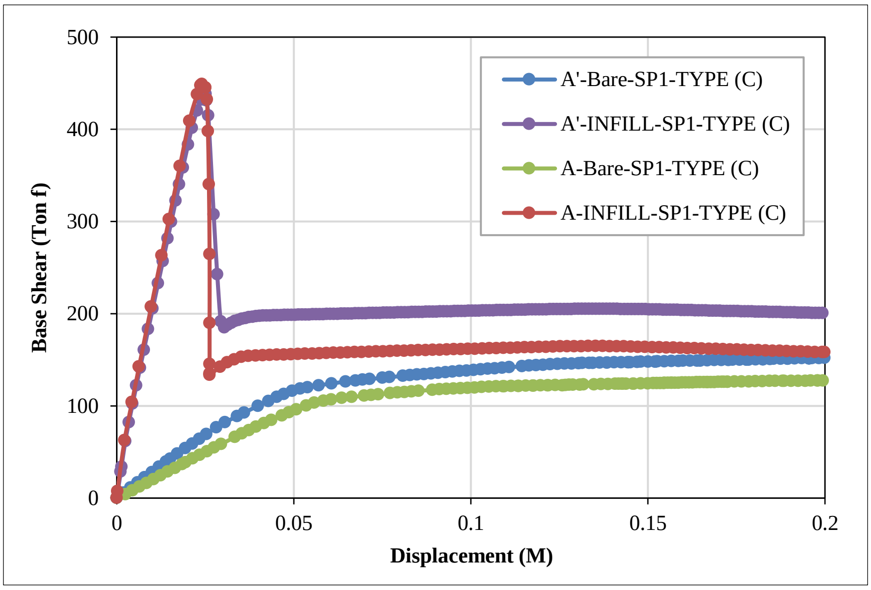
Figure 15. Three-dimensional Modelling of Structures natural period studied Bare and Infill RC Structure models for first four vibration mode shape

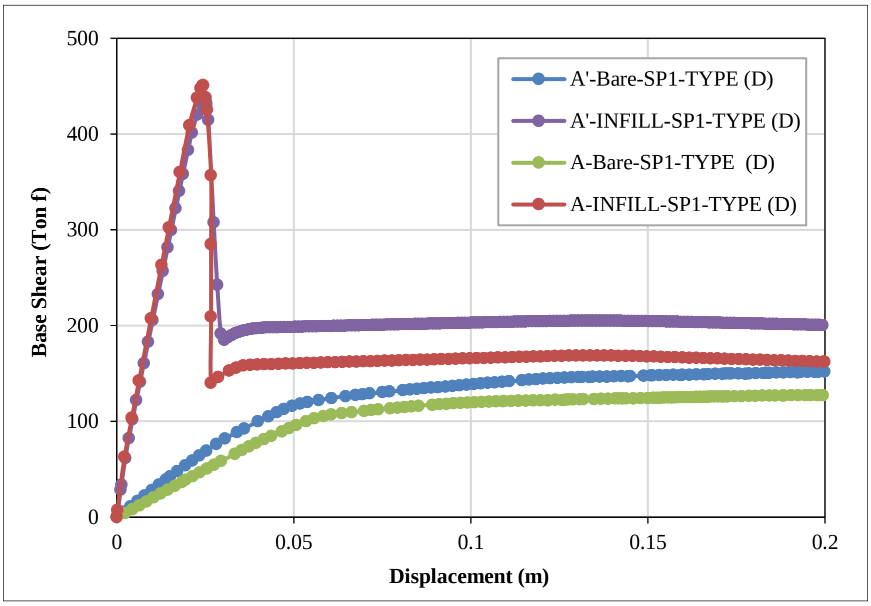
7.2. The Performance of Buildings and Infrastructure Under Seismic Loads (P.O.C)

Pushover analysis is an effective method for evaluating how well infrastructure and buildings function under earthquake loads. This approach gives engineers an extensive understanding of how structures behave beyond the elastic limit. Figures 16 to 21 illustrate the connection between the culminating base shear and the shift of the roof of the structure [34, 37, 40, 43].









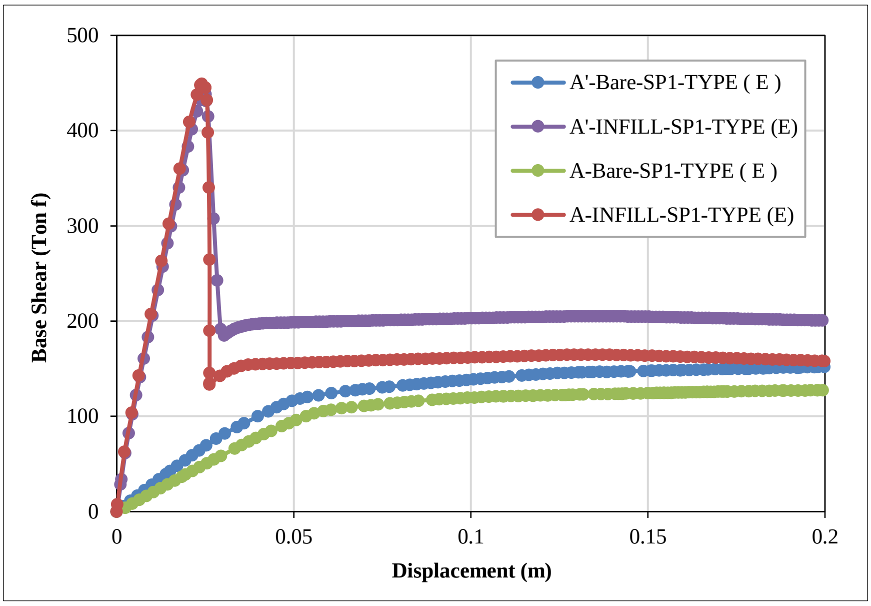
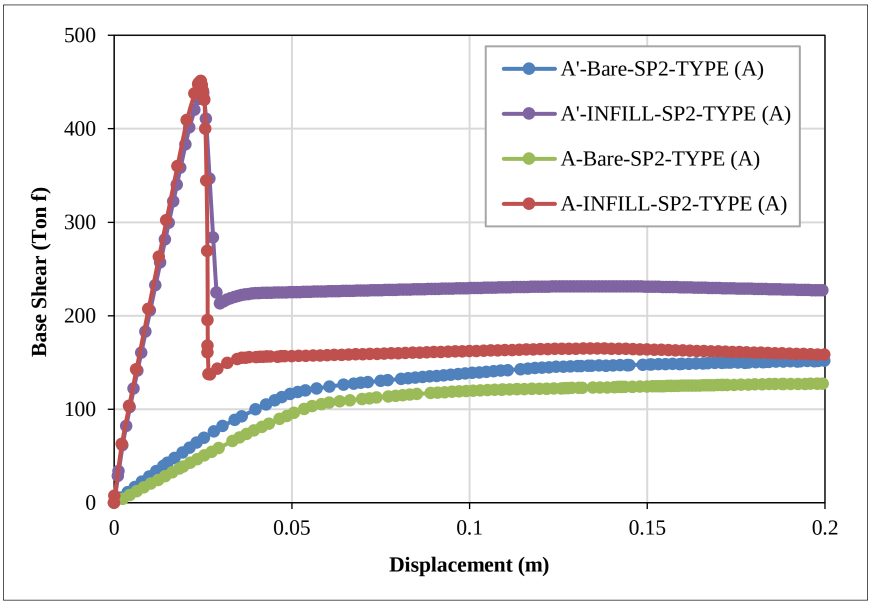
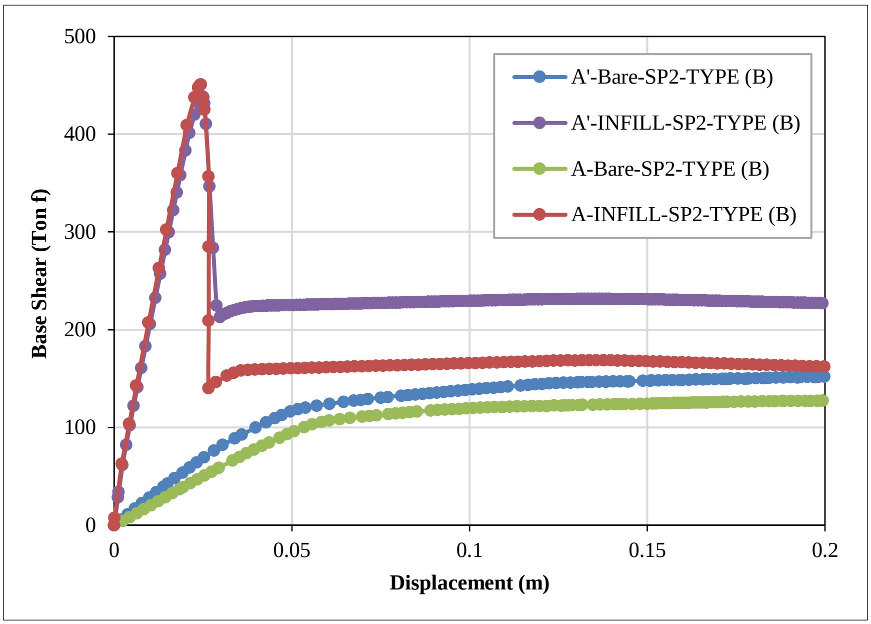
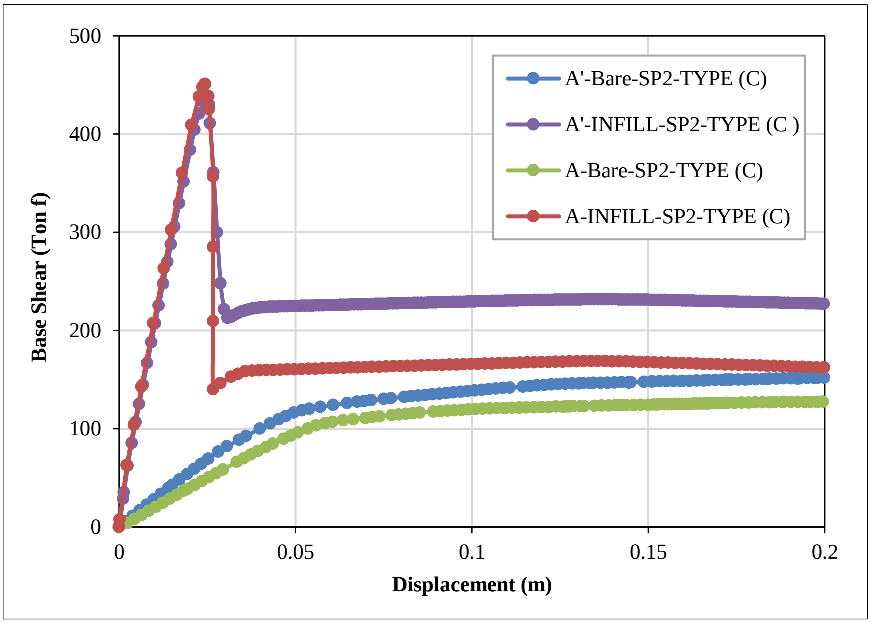


Figure 16. The seismic performance of buildings –response spectrum 1 for four storey for different types of soil

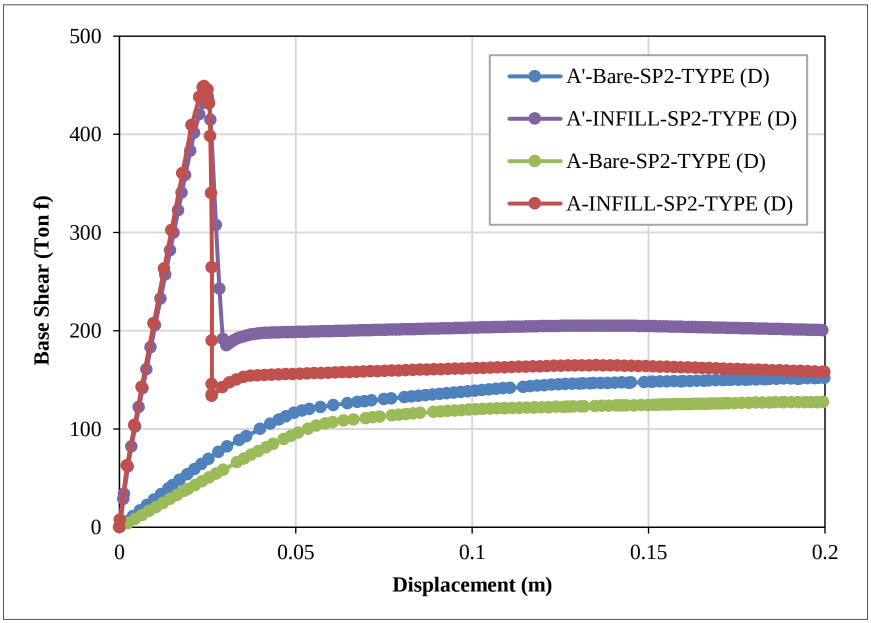




A'-Bare-SP2-TYPE (B)
A'-INFILL-SP2-TYPE (B)
A-Bare-SP2-TYPE (B)
A-INFILL-SP2-TYPE (B)
Base Shear (Ton f)
Displacement (m)
0
100
200
300
400
500
0
0.05
0.1
0.15
0.2



A'-Bare-SP2-TYPE (C)
A'-INFILL-SP2-TYPE (C)
A-Bare-SP2-TYPE (C)
A-INFILL-SP2-TYPE (C)
Base Shear (Ton f)
Displacement (m)
0
100
200
300
400
500
0
0.05
0.1
0.15
0.2



A'-Bare-SP2-TYPE (D)
A'-INFILL-SP2-TYPE (D)
A-Bare-SP2-TYPE (D)
A-INFILL-SP2-TYPE (D)
Base Shear (Ton f)
Displacement (m)
0
100
200
300
400
500
0
0.05
0.1
0.15
0.2

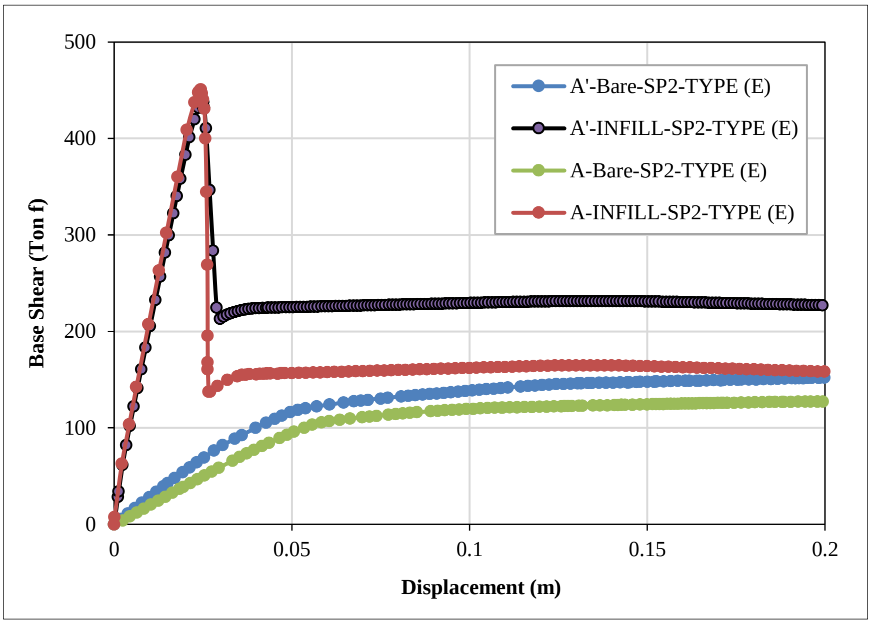
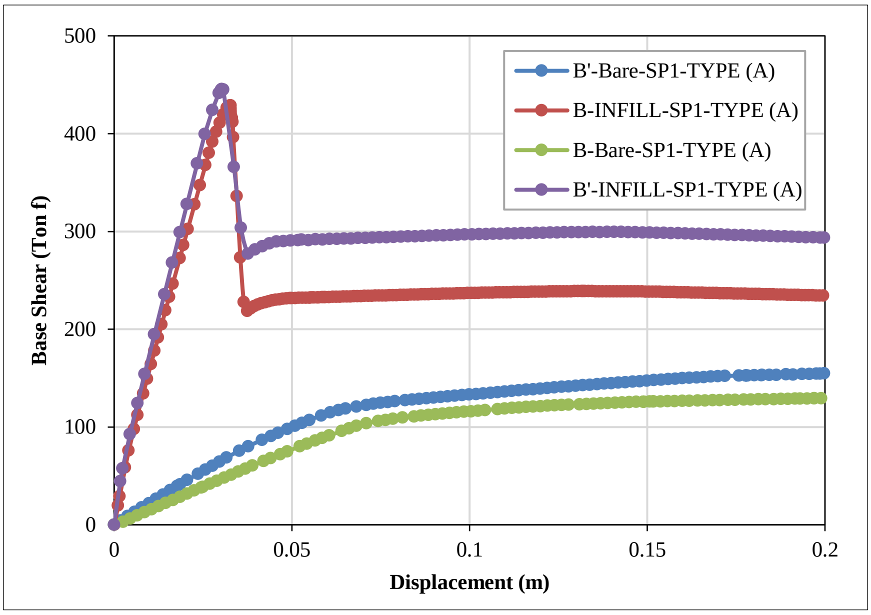
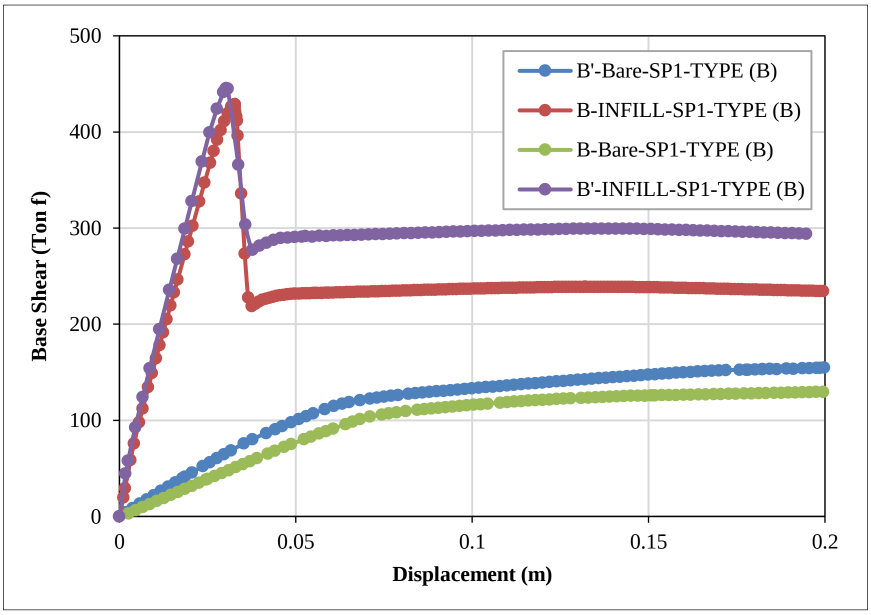


Figure 17. The seismic performance of buildings –response spectrum 2 for four storey for different types of soil





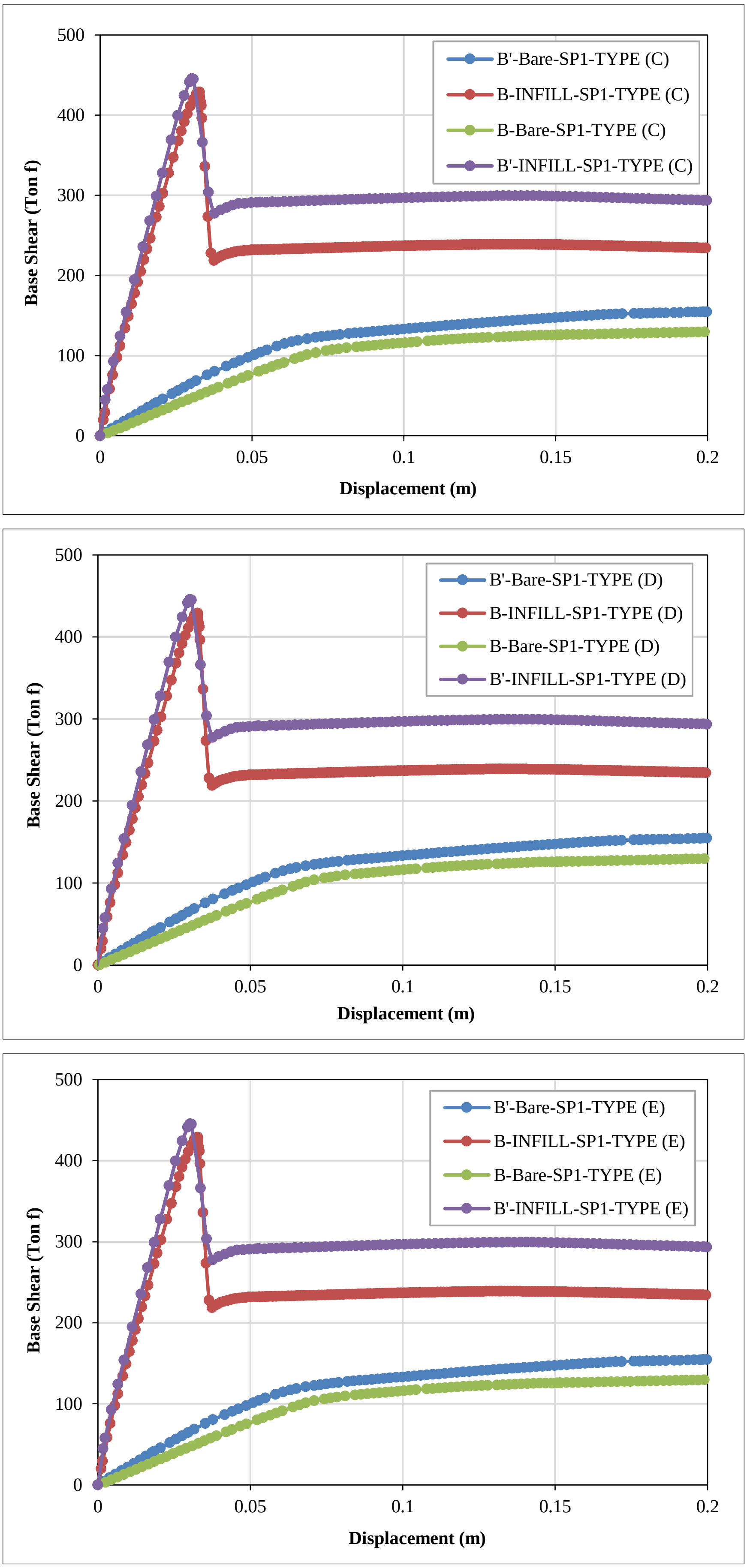
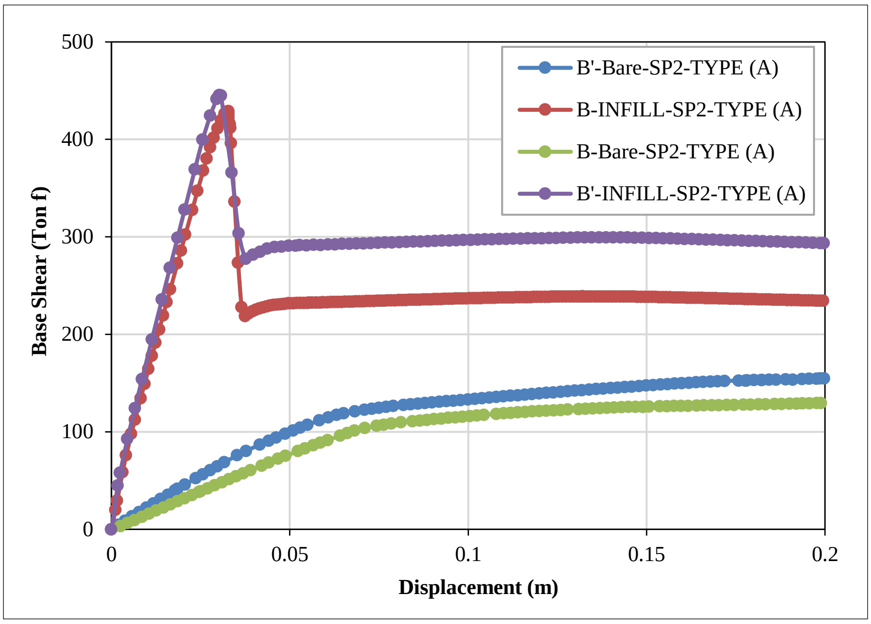
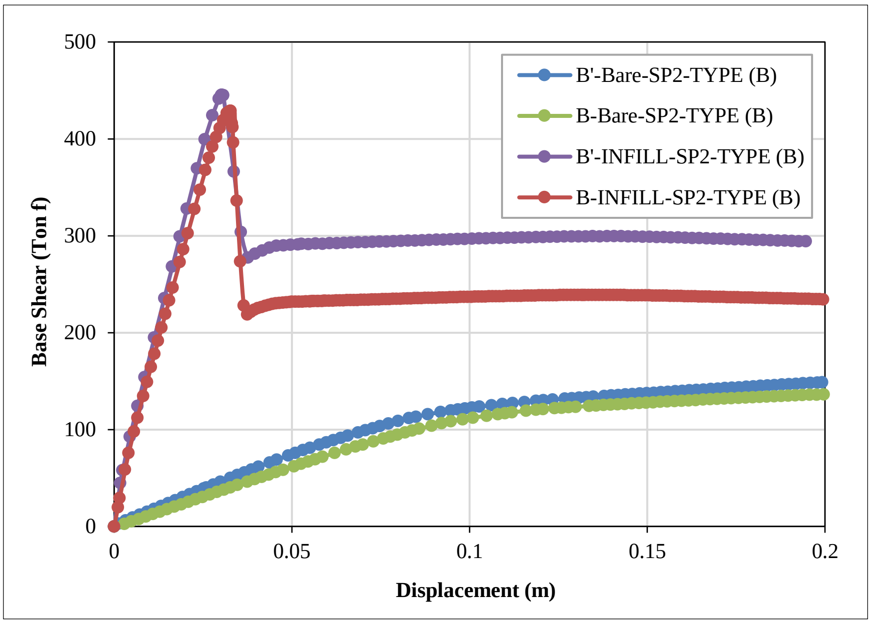


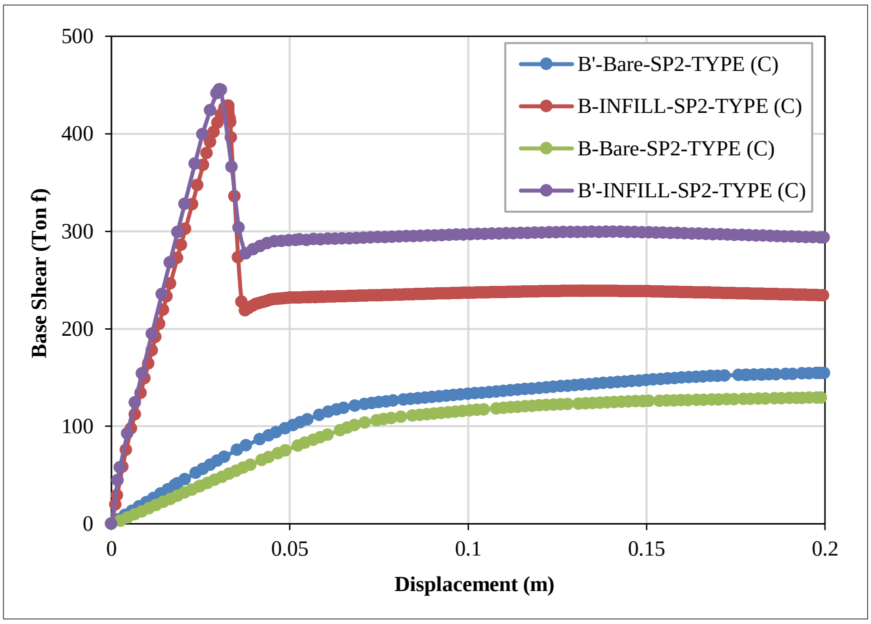
Figure 18. The seismic performance of buildings – response spectrum 1 for five storey for different types of soil



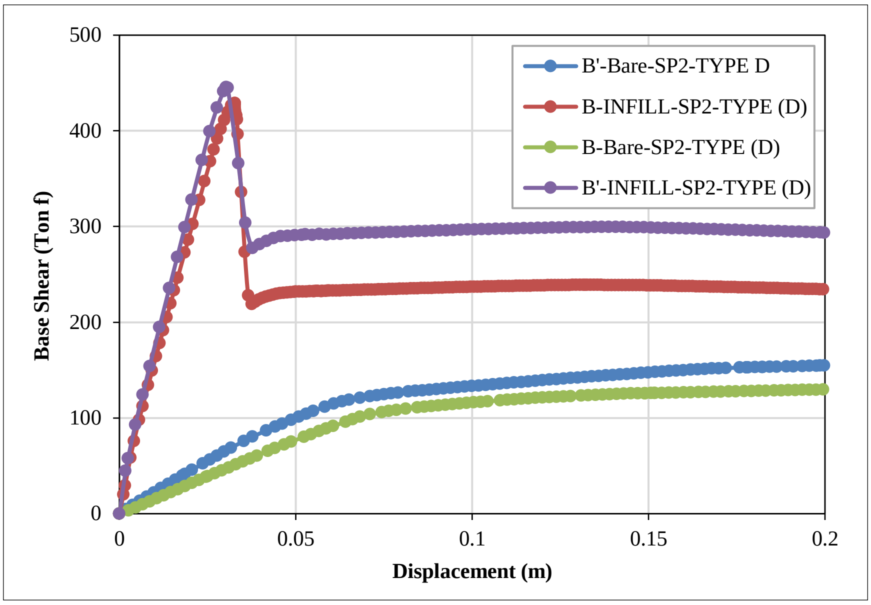
500
400
300
200
100
0
Base Shear (Ton f)
0
0.05
0.1
0.15
0.2
Displacement (m)
B'-Bare-SP2-TYPE (A)
B-INFILL-SP2-TYPE (A)
B-Bare-SP2-TYPE (A)
B'-INFILL-SP2-TYPE (A)



500
400
300
200
100
0
Base Shear (Ton f)
0
0.05
0.1
0.15
0.2
Displacement (m)
B'-Bare-SP2-TYPE (B)
B-Bare-SP2-TYPE (B)
B'-INFILL-SP2-TYPE (B)
B-INFILL-SP2-TYPE (B)



500
400
300
200
100
0
Base Shear (Ton f)
0
0.05
0.1
0.15
0.2
Displacement (m)
B'-Bare-SP2-TYPE (C)
B-INFILL-SP2-TYPE (C)
B-Bare-SP2-TYPE (C)
B'-INFILL-SP2-TYPE (C)



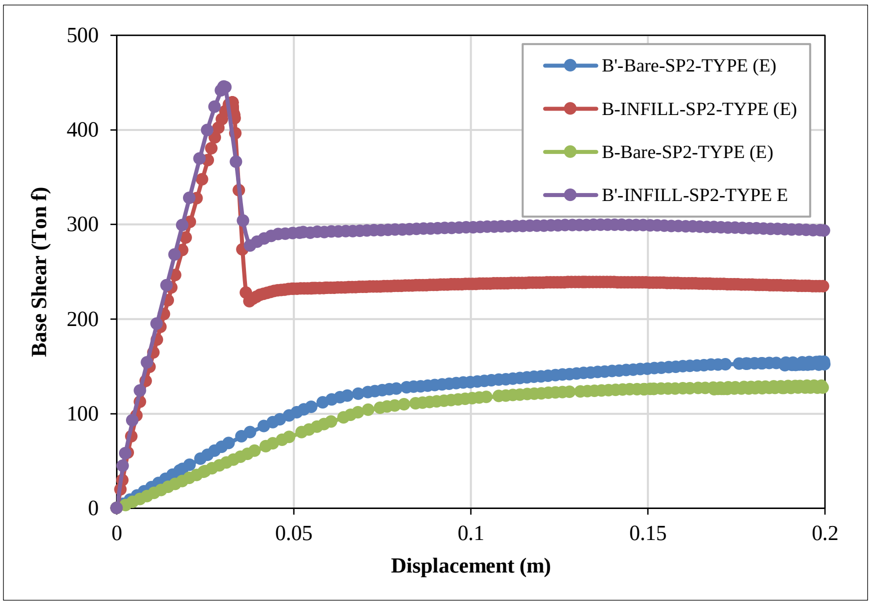
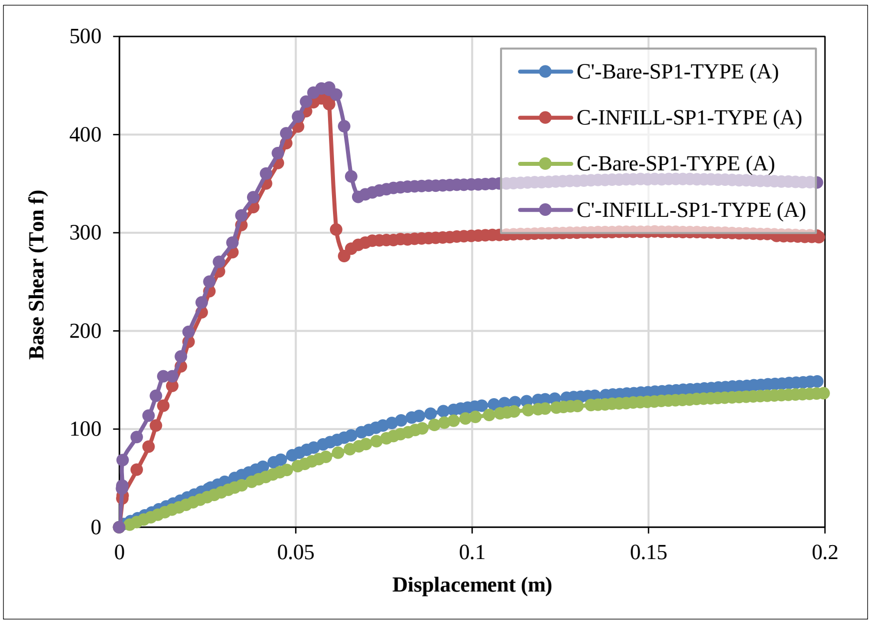
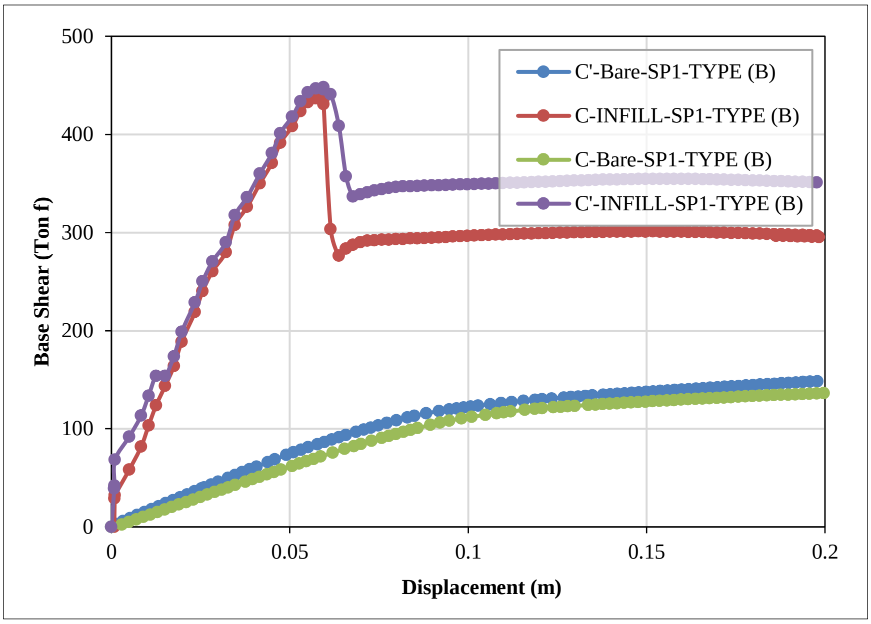
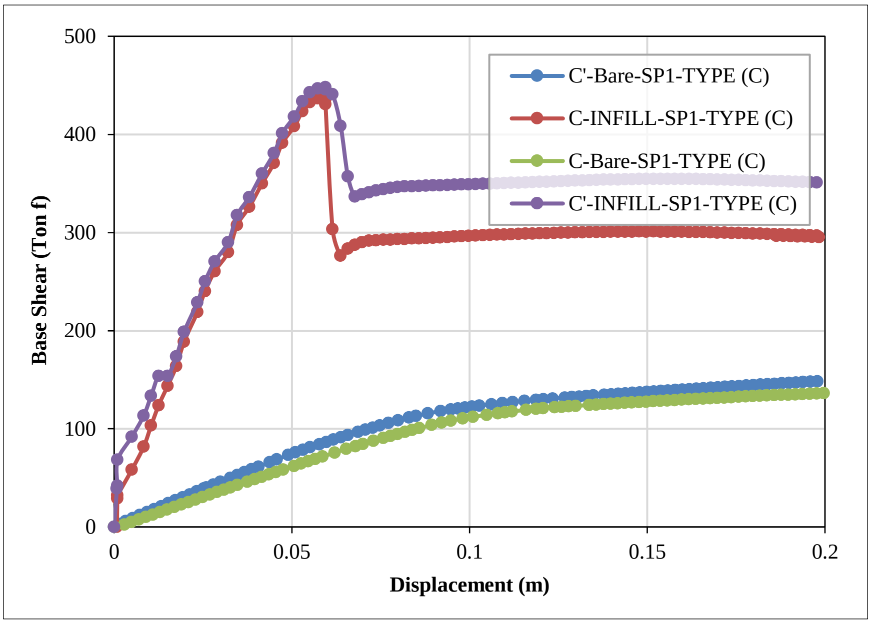


Figure 19. The seismic performance of buildings – response spectrum 2 for five storey for different types of soil

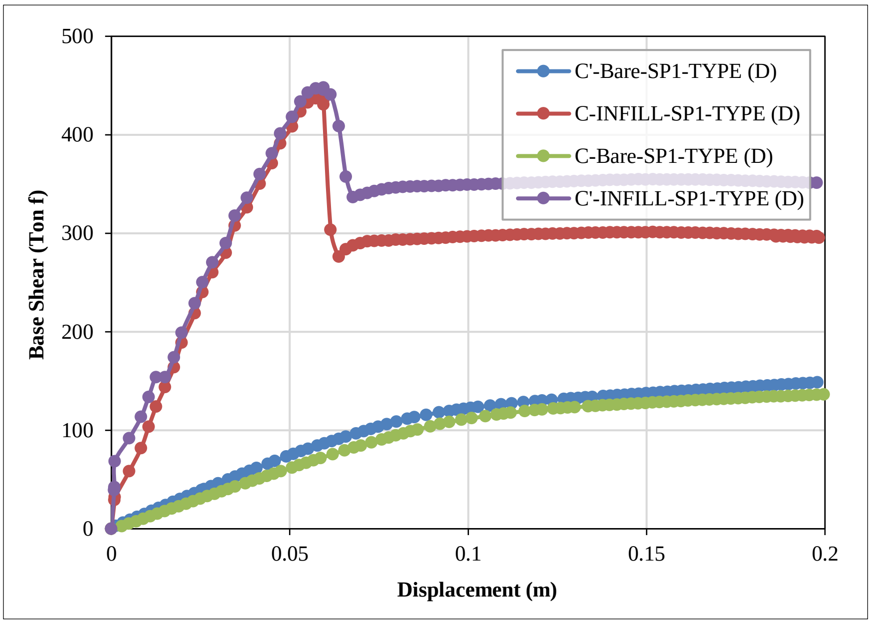




500
400
300
200
100
0
Base Shear (Ton f)
0
0.05
0.1
0.15
0.2
Displacement (m)
C'-Bare-SP1-TYPE (B)
C-INFILL-SP1-TYPE (B)
C-Bare-SP1-TYPE (B)
C'-INFILL-SP1-TYPE (B)



500
400
300
200
100
0
Base Shear (Ton f)
0
0.05
0.1
0.15
0.2
Displacement (m)
C'-Bare-SP1-TYPE (C)
C-INFILL-SP1-TYPE (C)
C-Bare-SP1-TYPE (C)
C'-INFILL-SP1-TYPE (C)



500
400
300
200
100
0
Base Shear (Ton f)
0
0.05
0.1
0.15
0.2
Displacement (m)
C'-Bare-SP1-TYPE (D)
C-INFILL-SP1-TYPE (D)
C-Bare-SP1-TYPE (D)
C'-INFILL-SP1-TYPE (D)

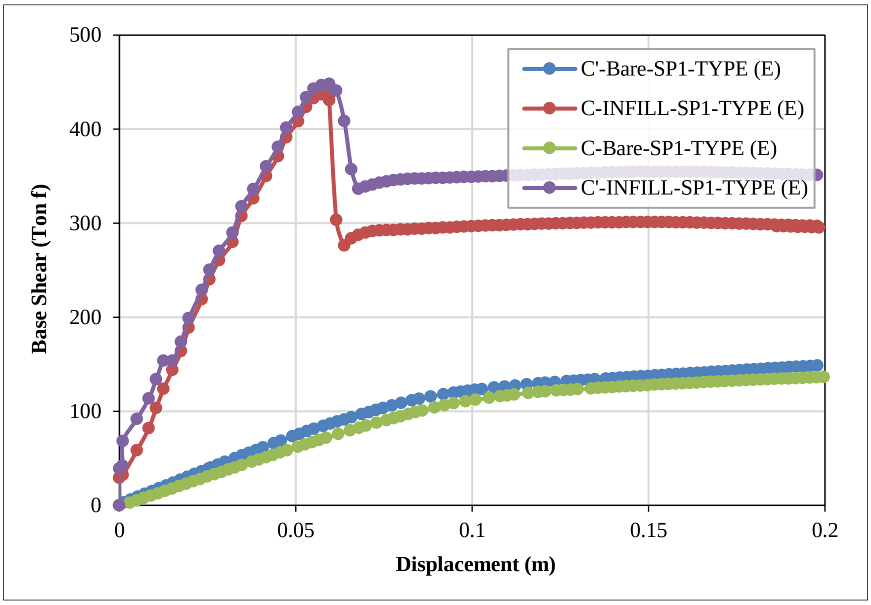
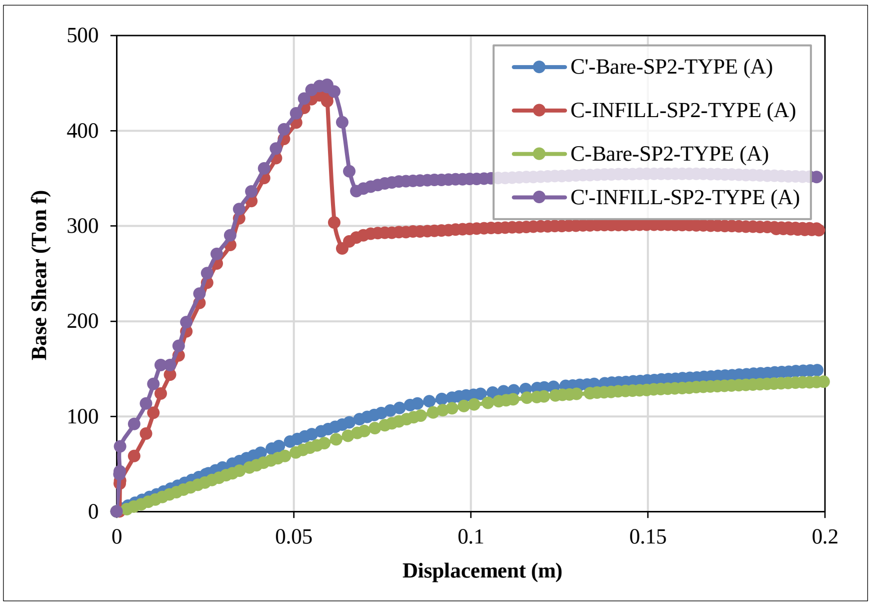
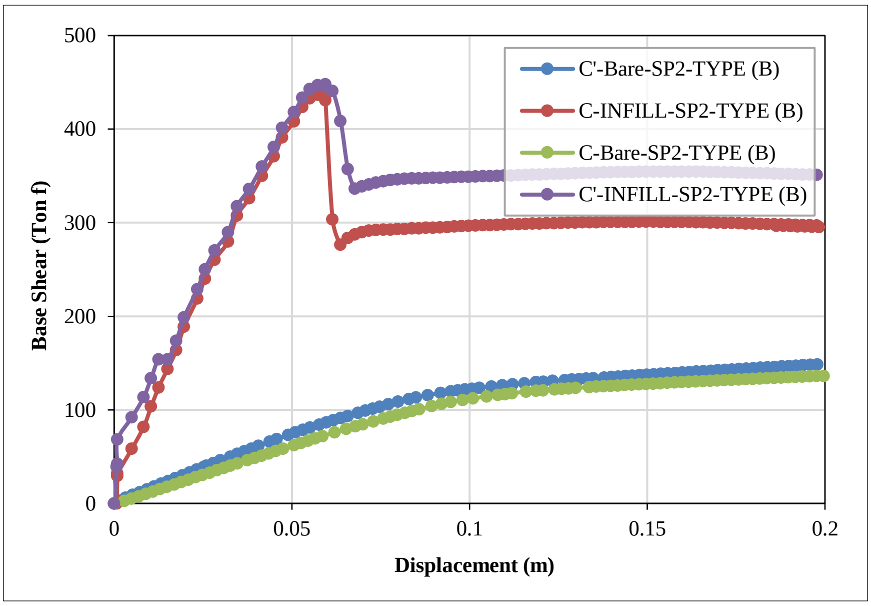


Figure 20. The seismic performance of buildings – response spectrum 1 for seven storey for different types of soil





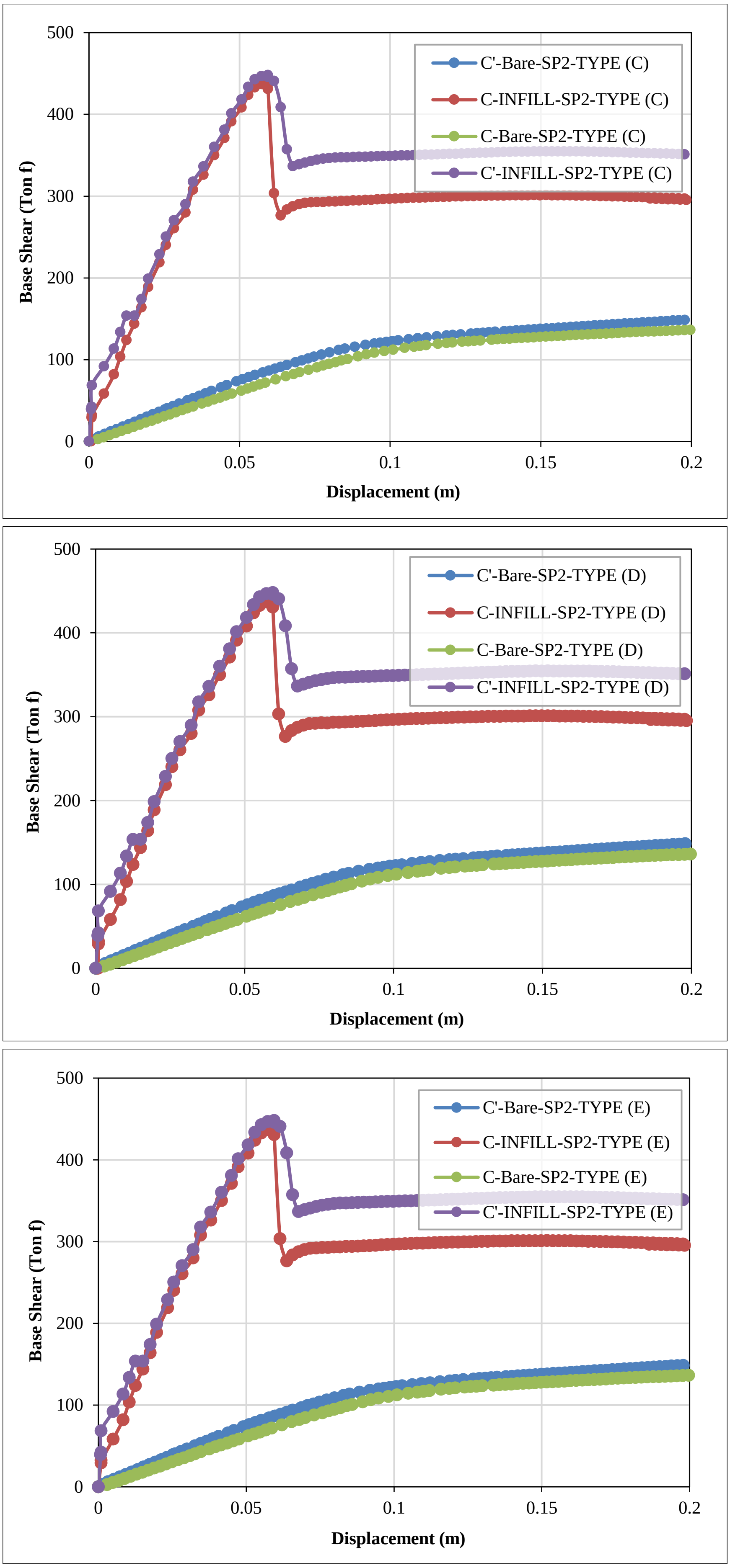


Figure 21. The seismic performance of buildings – response spectrum 2 for seven storey for different types of soil

Figures 16 to 21 illustrate the relationship between base shear and displacement for reinforced concrete frames with and without infill, encompassing both regular and irregular configurations. The irregularities, including variations in dimensions, elevations, mass distribution, and infill locations, were analyzed for each structure's floor plan geometry. These structures differ in area, height, seismic regions (at 0.15 g and 0.20 g), and soil types.

During a mild earthquake, structural responses generally align across diverse buildings, despite their differing geometries and characteristics. However, as seismic activity escalates, factors such as building mass, stiffness, geometry, and soil type come into play, significantly impacting the shape of the pushover curve (POC). In irregular infilled building models with more floors, the displacement at the top tends to be lower compared to regular infilled frames. Despite these variations, the behavior of structures seems consistent in the pushover curve, with base shear and the area under the curve showing near-identical patterns.

7.3. Effect of Irregularity

All models indicate a gradual increase in base shear and lateral displacements as zone factors increase. Regular forms have smaller lateral displacements than vertical irregular models. Response spectrum analysis of seismic zones using code provisions demonstrates the importance of building mass, stiffness, and geometry. We can draw broad conclusions about the impact of vertical anomalies in mass and stiffness on seismic demands. We can deduce that as seismic energy increases from zone I to zone II, base shear and lateral displacement increase, indicating that the structure should be adequate to meet higher seismic demand. Because base shear is affected by seismic weight, mass irregularities are more noticeable than other irregularities. It was obvious that regular and irregular structures behaved equally in response. It was clear that regular and irregular structures behave similarly in the response of a weak earthquake (Figures 16 to 21). It can be seen that the structures (models A, B, and C) have low ductility. But in the case of (A', B', and C') models, they have good ductility [6, 15, 18, 44, 45].

In structural engineering, pushover analysis is an effective method for evaluating how well infrastructure and buildings function under earthquake loads [18, 35]. This approach gives engineers an extensive understanding of how structures behave. Seismic design criteria take into account the substantial reserve rigidity and flexibility of structures, which are qualities that allow for the dissipation of energy. A reduction factor is used to decrease design forces. The current research shows how structural irregularity influences R as shown in Table 5, especially in poor-quality soils that experience considerable seismic energy. The value of the response reduction factor decreases considerably lower than the Egyptian code rate and gets closer to the European code rate as the region of earthquakes becomes more intense [46]. Therefore, it is critical to evaluate and reduce the ECP values, especially in the case of irregular structures. It is seen as a risky design approach to use the ECP rate for irregular buildings, particularly after taking soil representation into account as shown from Figures 22 to 25.

Table 5. The value of (R) Factor for regular& irregular Bare & Infill RC structure - Different type of soil

Soil Type	Response Spectrum. (I)											
	Four storey				Five storey				seven storey			
	(IRRC)		(RRC)		(IRRC)		(RRC)		(IRRC)		(RRC)	
	Bare	Infill	Bare	Infill	Bare	Infill	Bare	Infill	Bare	Infill	Bare	Infill
A	5.31	11.9	5.933	13.55	3.97	8.09	4.87	11.65	2.75	3.68	3.76	7.09
B	5.85	13.11	6.299	14.2	3.952	8.73	4.2759	10.835	2.79	4.5	4.25	7.8
C	5.76	13.17	6.009	13.8	3.969	8.979	4.428	10.72	2.8	4.69	4.91	8.49
D	5.79	13.88	5.91	14.6	4.1	9.17	4.758	11.077	2.804	4.73	3.84	6.98
E	5.88	14.086	6.5	15.01	3.96	9.15	4.23	10.14	2.85	4.78	3.7348	7.489
Soil Type	Response Spectrum. (I I)											
	Four storey				Five storey				seven storey			
	(IRRC)		(RRC)		(IRRC)		(RRC)		(IRRC)		(RRC)	
	Bare	Infill	Bare	Infill	Bare	Infill	Bare	Infill	Bare	Infill	Bare	Infill
A	5.30	11.7	5.23	13.01	3.96	8.012	4.515	10.825	2.69	3.72	3.026	6.926
B	5.058	12.268	6.25	13.89	3.8	8.56	4.16	10.707	2.57	4.23	3.9026	7.115
C	5.23	12.86	5.89	12.96	3.801	8.61	4.352	10.68	2.769	4.56	3.812	6.989
D	5.53	13.5	5.32	14.025	3.9529	8.96	4.706	10.47	2.8	4.52	3.7413	6.8106
E	5.68	14.01	5.93	14.32	3.84	8.73	4.203	10.003	2.702	4.61	3.659	6.976

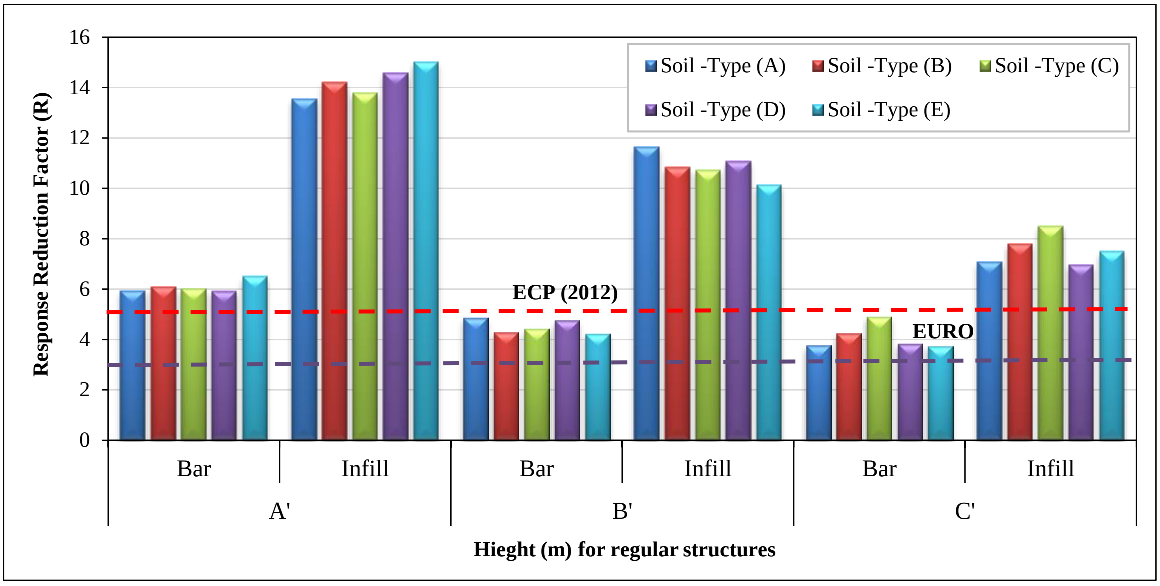


Figure 22. Response Reduction Factor value for regular Bare and Infill RC structure (Spectrum I)

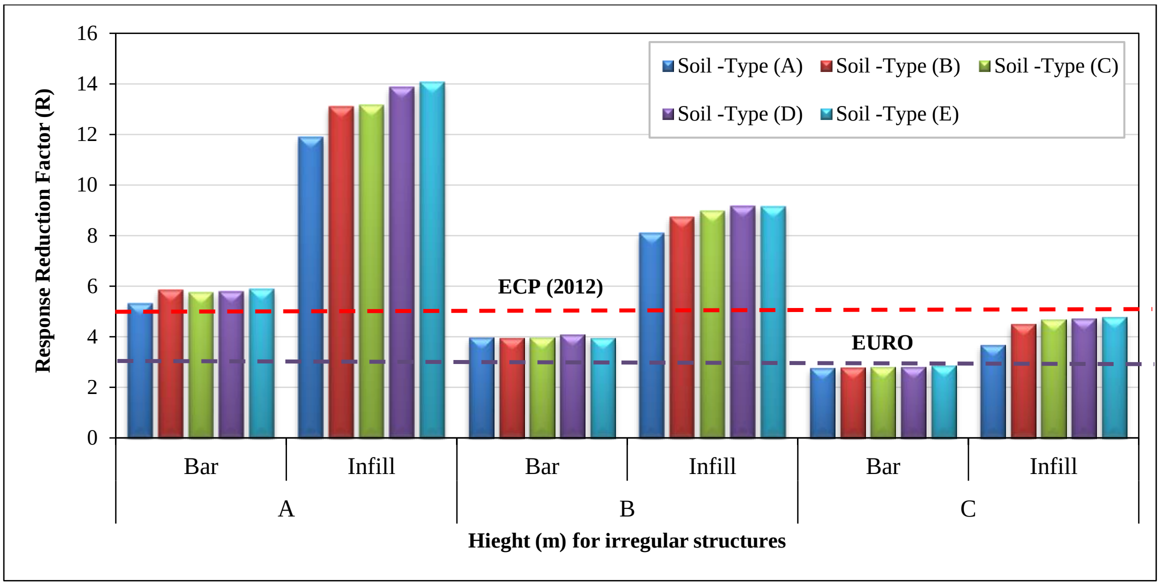


Figure 23. Response Reduction Factor value for irregular Bare and Infill RC structure (Spectrum I)

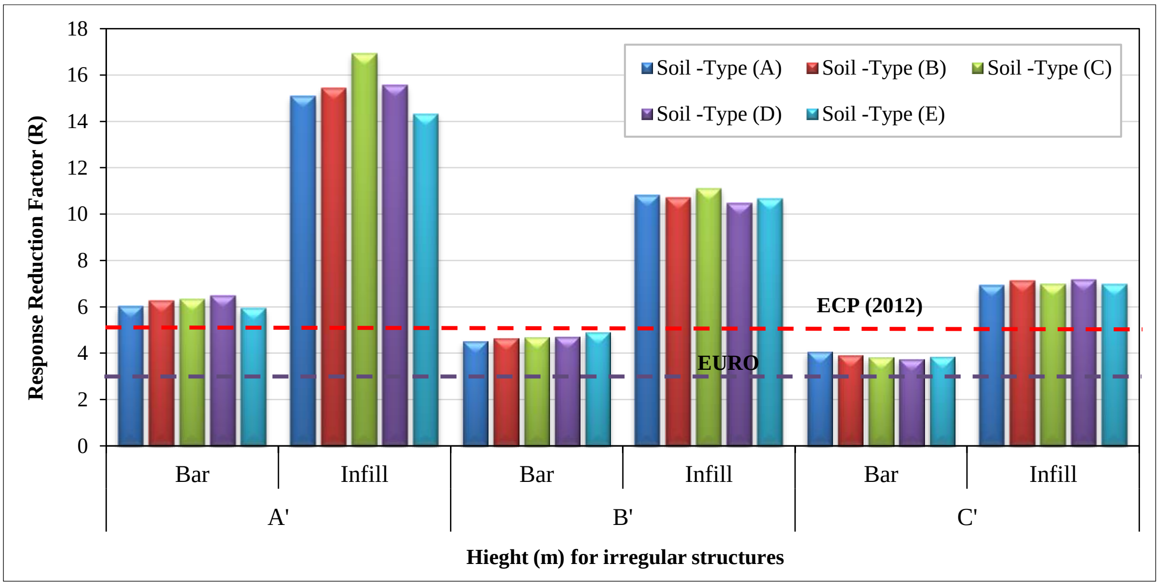


Figure 24. Response Reduction Factor value for regular Bare and Infill RC structure (Spectrum II)

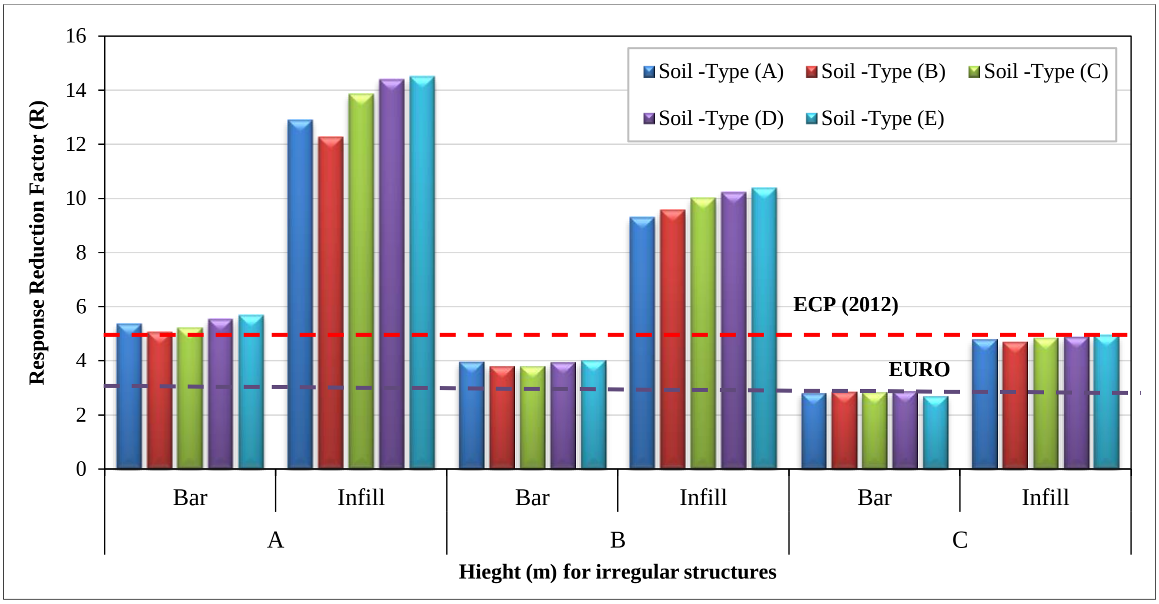


Figure 25. Response Reduction Factor value for irregular Bare and Infill RC structure (Spectrum II)

7.4. Effect of Bare and Infill Structures

Infills significantly reduced structural time by 38–62% compared to bare frames as shown in Table 6. The incorporation of infills Masonry increases base shear, but infilling minimizes displacement. The ductility factor Infill-based structural models have higher over-strength and ductility factors compared to bare frame models. This indicates that the structure's dynamic features have changed.

Table 6. Response modification factor value for Bare and Infill irregular structures

Increase in Response Modification Factor (R) due to Infill regular and irregular frame %						
	Response Spectrum. (I)					
Soil Type	**Four storey**		**Five storey**		**Seven storey**	
	(IRRC)	**(RRC)**	**(IRRC)**	**(RRC)**	**(IRRC)**	**(RRC)**
Soil Type (A)	2.2411	2.284	2.04	2.40	1.34	1.89
Soil Type (B)	2.2410	2.254	2.21	2.57	1.61	1.84
Soil Type (C)	2.2865	2.297	2.26	2.45	1.68	1.73
Soil Type (D)	2.3972	2.470	2.24	2.22	1.69	1.82
Soil Type (E)	2.3956	2.309	2.31	2.38	1.68	2.01
	Response Spectrum. (I I)					
Soil Type	**Four storey**		**Five storey**		**Seven storey**	
	(IRRC)	**(RRC)**	**(IRRC)**	**(RRC)**	**(IRRC)**	**(RRC)**
Soil Type (A)	2.208	2.488	2.023	2.398	1.383	2.289
Soil Type (B)	2.425	2.222	2.253	2.574	1.646	1.823
Soil Type (C)	2.459	2.200	2.265	2.454	1.647	1.833
Soil Type (D)	2.441	2.636	2.267	2.225	1.614	1.820
Soil Type (E)	2.467	2.415	2.273	2.380	1.706	1.907

As the area subject to earthquakes increased, the numerical value of the response reduction factor decreased for all models. Considering the identical kind of ground and earthquake region, the infill structure had a noticeable impact on the residue reduction factor; additionally, the design and asymmetry of the structure have an indirect effect. The height of structures had an evident impact on the (R) factor as shown in Figure 26, and additionality caused an impact.

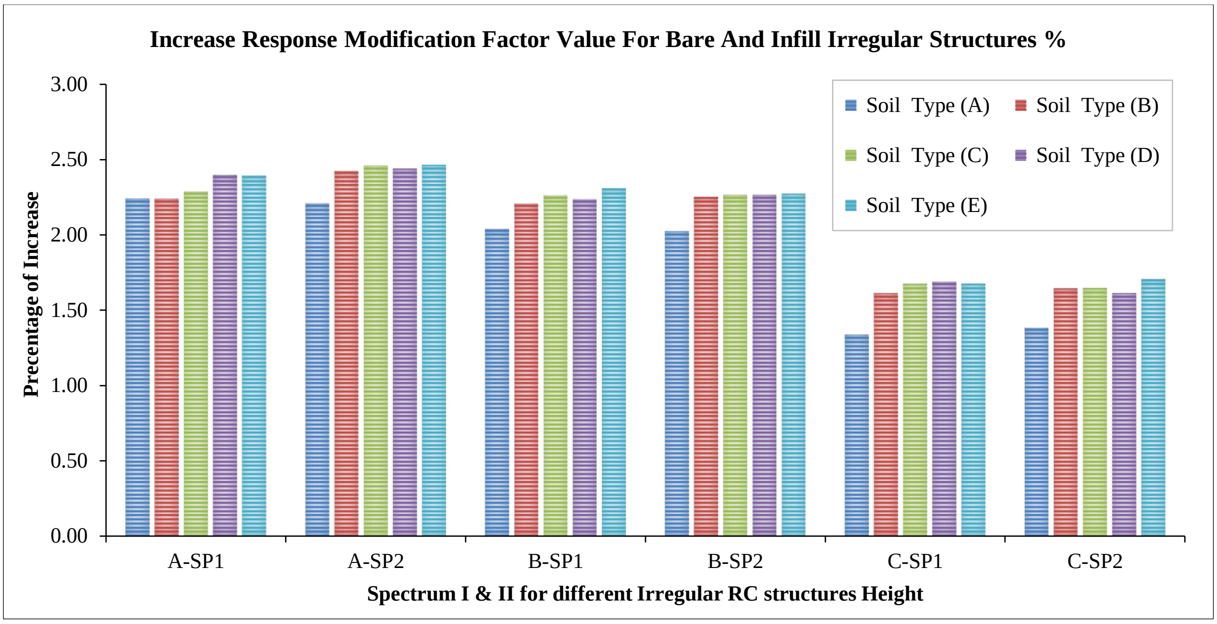


Figure 26. Response modification factor value for Bare and Infill irregular structures %

8. Conclusions and Recommendations

The aim is to explore the modification factor for both RRC and IRRC masonry-infilled frames, considering various parameters. This investigation delves into the response reduction factor (R) for RC-framed buildings, considering the impact of response spectra types outlined in ECP-201 (2012). Seismic and pushover analyses were conducted on RC frames ranging from 4 to 7 stories, representing buildings with diverse dynamic characteristics. The study investigates the effects of irregularity, seismic zone, infill site, and soil type. Some key findings of the research include:

- The infilled R.C. structure exhibits higher R values than the bare RC structures by 38% to 75%. With diverse seismic zones and soil types.
- The base shear and lateral displacements exhibit a gradual increase with higher zone factors across all models.
- The base shear values are notably higher in full RC-infilled frames compared to all other frames. The addition of infill panels significantly enhances the stiffness of structures, leading to a reduction in fundamental periods.
- From the analysis results, it can be recommended to take the effect of the infilled frame to calculate the response reduction factor during the analysis of the existing building to get a value that is higher and closer to the truth than those values in the code.
- The (R) Factor is significantly impacted by the earthquake region. The fundamental time period increases along with the earthquake region, which results in a decrease in the value of (R) factor.
- Irregularity is more noticeable in flexible structures, such as seven-story models. In response to a weak earthquake, regular and irregular structures behave similarly. The influence of irregularity has not been proven to have a distinct effect in soft soil (C). The behavior of structures appears to be the same in the pushover curve, and the base shear and area under the curve were nearly identical. The response modification factor due to irregularities in bare and infill RC structures increased from 44% to 60% in 4, 5, and 7 stories, respectively, for loose soil class C.
- In irregularly infilled building models, the displacement at the top is observed to be lower compared to regular infilled frames.
- Infill panels in frame structures significantly enhance their stiffness, consequently leading to a reduction in fundamental period.
- The R factor is overestimated in the ECP code for bare frames, specifically referring to moment-resisting frames without infills. This overestimation leads to a notably lower estimate of the design base shear, consequently rendering the structure more vulnerable to seismic events.
- The seismic zone and structure's fundamental time period both have an effect on the modification factor. Which decreases as the earthquake region expands and rises as the time period extends.
- The evaluation of "R" values in this study, derived from nonlinear static (pushover) analysis of structures with irregularities in elevation and plan, indicates values lower than those specified in ECP 2020. For instance, the recommended "R" value in ECP-201(2012) is 3.9 for multi-story multi-bay frames while for single-bay multi-story frames is 3.6. This difference underscores the consideration of non-uniformity of spans and heights in determining "R" values.

9. Declarations

9.1. Author Contributions

Conceptualization, M.R.E. and N.E.N.; methodology, N.E.N. and M.E.N.; software, M.E.N.; formal analysis, N.E.N. and M.E.N.; investigation, M.E.N.; resources, N.E.N.; writing—original draft preparation, M.R.E. and M.E.N.; writing—review and editing, M.E.N.; visualization, M.E.N.; supervision, M.R.E. All authors have read and agreed to the published version of the manuscript.

9.2. Data Availability Statement

The data presented in this study are available in the article.

9.3. Funding

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9.4. Acknowledgments

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9.5. Conflicts of Interest

The authors declare no conflict of interest.

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