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Prediction of RC multi-story construction performance with a new proposed design spectrum approach

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Abstract

The consideration of novel response spectrum analysis to check the reinforced concrete RC buildings resistance towards the seismic risks in Iraq has not been investigated so far. Due to the increasing of frequent earthquakes with moderate intensity in north of Iraq, caution should be taken into account in building design especially with considering the design codes. Where, there are no specific Iraqi standards of earthquake for building design. Thus, the proposing of new response spectrum relationship matching the properties of Kurdistan region (north of Iraq) soil is considered essential with considering of novel stiffness or inertia reduction factors for concrete sections. Present endeavor is devoted to develop new design spectra dynamic analysis of RC multistory building located in Duhok city-Iraq. Influence of proposed concrete section reduction factors on the analysis outcomes has been investigated also. Great role has been observed for introducing of stiffness reduction factors in present seismic analysis represent in magnifying of lateral deformation of building of more than 50%. Proper matching was obtained between current proposed spectrum design outputs and that for other analytical approaches.

Keywords: seismic analysis, RC multi-story building, stiffness reduction factors

Introduction

The main objectives of the seismic design of reinforced concrete buildings are threefold namely to design buildings resist a low grade of earthquake movement without structural and nonstructural damage, to design RC buildings resist moderate earthquake motion not involving RC structural damage and may include a nonstructural damage and to design buildings resist intensive earthquake ground motion with possibility of forming structural and nonstructural damages but collapse is prohibited [1, 2]. Reinforced concrete building response such as story shear, drift and maximum lateral displacement for diaphragms are essential parameters under consideration in the static and dynamic seismic analyses. These parameters are played a great role in the structural damage which strongly related to the displacement rather than the others [3, 4].

In seismic analysis of RC structures, the effective stiffness do not included extensively in the standards for design codes. Thus, the structural stiffness is usually computed based n the un-cracked concrete section of the element [5]. Accordingly, unuseful simulation of the structure with un-cracked stiffness will be performed which disregards the effect of concrete cracking under gravity and seismic actions. Therefore, to estimate the quasi actual relationship between applied seismic force and reinforced concrete building deformation, the stiffness reduction factors of structural elements (beams, slabs, walls etc.) should be taken into account in the analysis. Concrete cracking consideration will influence strongly on the lateral deformation of the building which leads to great effect of geometrical P-delta nonlinear deformation [6]. For concrete design purposes, the reducing of concrete stiffness was included in many international codes like ACI Code [7], New Zealand Standards [8], Europe Committee for Standardization [9], Iranian Standards [10], Canadian Standards [11], ASCE Code [12], Indian standards [13] and FEMA [14].

Many investigations have been launched to study the cracking effect on the concrete material stiffness. The flexural stiffness has been reduced and modified bu Yu and Winter [15] and Branson [16]. Nonlinear cracking event for concrete has been introduced also in curvature calculation of structural elements due to Ghali et al [17], Beeby [18] and CEB Commission [19]. Procedures for Paulay and Priestly [20], Priestly [21] and FEMA 356 [14] have been applied by Pique and Burgos [5] in the seismic design of a four-story building. They found that the outcomes from Paulay and Priestly procedure are close to that determined by Priestly approach. In 2008, Ahmed et al. [6] have been depended on Indian seismic design code for checking the cracking effect on the story drift of frame RC building. They demonstrated that an overestimation of the results is found when cracked analysis is considered. The material nonlinearity is introduced also in the analysis and design optimization of RC members for regular building by many researchers such as Smith and Coull [22], Ahmed and Perry [23], Tikka and Mirza [24], Kripanarayanan and Branson [25], Chan and Wang [26] and Kirsch [27].

Nowadays, multi-story buildings are widely constructed for various functions especially in the middle-east and developed countries to overcome the housing problem with increasing of population. These trendy building must be comprises of many units which constructed from many structural elements such as solid slabs, frames, ribbed slabs, shear walls and so forth. There are some of developed countries like Iraq are depended on other international codes for building design under lateral forces due to unavailability of local code. Iraq is suffered recently from repeated earthquakes with various intensities. Therefore, formulating new spectrum design curves for earthquake acceleration of this region is useful for quasi-real simulation of RC buildings under lateral seismic loadings. Concrete cracking analysis (reducing of inertia) procedure has not been introduced widely yet in the new proposed analysis approach of these concrete structures. Thus further researches are considered essential in this direction.

Present study includes the proposing of new response spectrum RC building analysis procedure which compatible with the seismicity of the soil for Duhok city that located in Kurdistan Region, north of Iraq. Present numerical analysis procedure is comprises of using new stiffness reduction factors for many structural elements, where numerous of experimental data available in literature have been used in formulating these factors. Moreover, the effect of introducing these reduction factors on the building static analysis outcomes has been investigated as well. As a case study, 10-story RC irregular building has been adopted in current work.

Methodology

The methodology of present work consists of three pivots namely seismicity of the region under consideration, developed static and proposed response spectrum analyses of the building, proposed inertia reduction factors and application.

1. Region seismicity

The case study (building) for present endeavor is located in Duhok city at north of Iraq (Kurdistan Region). Iraq has a well-recorded history of earthquake activity, where more than 70 seismic events have been documented during the period 1260 B.C. – 1900 A.D. This seismic behavior of Iraq is fitted with the tectonic boundaries [28]. The epicenter line is located in north of Iraq close to Zagros-Tauros mountain. Different intensities of seismic activity have been documented, where Kurdistan Region suffer from seismic strength higher than the rest of Iraqi regions.

According to UBC 97 code [29], the soil profile is separated into six types ranged between hard rock to soft soil. The soil for a place in Duhok city, at which present RC multi-story building is proposed to be constructed, is very dense soil and soft rock type. The shear wave velocity for this location is about 500 m/s. With respect to recent seismological data for Duhok region, it is categorized as 2B seismic zone. Thus, the zone factor is considered as 0.2, in the other words the acceleration for ground motion is 0.2 multiplied by the gravitational acceleration.

2 Numerical static and dynamic analyses of the building

In present work, the finite element analysis is regarded inevitable choice due to the complexity of the building shape and applied loads. New finite element procedure has been developed with introducing new design spectrum relationship or using of novel stiffness reduction factors to include the effect of concrete cracking. The beam and column elements are modeled with line elements having two nodes [30] as depicted in Fig. 1. The slabs (horizontal surfaces) and shear walls (vertical surfaces) are simulated by four-noded shell elements [31] shown in Fig. 2 except the slab with small thickness which used for ribbed slab floor is modeled by using membrane four-noded elements [32, 33]. Four-noded plate elements have been used to compare the deflection of the slab with that found by shell elements. In plate elements, the transverse shear deformation is neglected. Membrane elements have been used to transfer the whole applied vertical loads to opposite joist support in the ribbed slab.

The static analysis procedure for UBC 97 code [29] available in ETABS 9.7.4 has been adopted in present research to check the validity of present dynamic analysis. To neglect the recalculation of building time-period T after analysis, the period in second has been chosen as hereunder [34]:

$$T = 1.4C_t(h_n)^{3/4} \tag{1}$$

where, C_t = 0.0488 and h_n = height of building measured in m.

The total lateral base shear is distributed on the diaphragms level of the multi-story building, where the maximum lateral load is applied at upper diaphragm. Base shear V which resulted from earthquake action at the center of mass of the building is calculated as:

$$V = \frac{C_v I W}{R T} \tag{2}$$

Where, $0.11 C_a I W < V < 2.5\, C_a I W/R$

C_v = seismic coefficient from UBC code and it is equivalent to 0.32.

C_a = seismic coefficient from UBC code and it is equivalent to 0.24.

I = Importance factor for building, where I = 1.0 for present case study.

R = Over strength coefficient that is the indication for lateral force resistance of both shear walls and building frame.

W = Building weight.

In seismic zone 2 like Duhok city, it can be assumed that shear walls are mainly used to resist the seismic forces. Thus, the value of R is selected as 5.5 in present investigation. A checking has been done to recalculate the value of R after first analysis and the updated value of R is introduced in the program to read the final results. The new value of R is determined by interpolation approach depending on shear resisted by shear walls and frame members.

For seismic dynamic analysis, response spectrum analysis is widely used approach in building analysis. This approach has been given in design codes such as UBC 97 [29], IBC [35] etc and used by many researchers [36-39]. The response spectrum is the relationship between the normalized pseudo accelerations and time period of the building. Regarding present seismic dynamic analysis, new design spectrum has been proposed as given in Fig. 3 based on the values of spectra (Fig. 3) for many earthquakes given in various design codes such as UBC 97, IBC 2003, IBC 2006, Euro code 1998, Euro code 2004, New Zealand code NZS 1992, NZS 2004, Chinese standards 2010, Canada standards NBCC 1995, NBCC 2005, Australian standards 2007, Italian standards 3274. The typical design response spectrum data for aforementioned codes is constructed depending on seismic coefficients for Duhok city. Present response spectrum relationship has been proposed according to the linear and nonlinear regression analyses [40] as shown in Fig. 4. This novel design spectrum has been used in present study with consideration of new stiffness modifiers reduction factors. The advantage for using new design spectrum relationship is that to obtain more realistic spectrum acceleration – period case for Duhok city that located in north of Iraq. There is no specified code for this region and Iraq as whole. In addition to that, it is required to inquire the effect of using new proposed inertia reduction factors with present spectrum on the analysis outcomes to clarify the validity of current developed analytical approach.

3. Novel proposed stiffness reduction factors

Two categories of inertia reduction factors of reinforced concrete members have been considered in present study namely reduction factors for service loading case and factors corresponding with ultimate loading. According to present RC multi-story building, it is required to take into account the moment of inertia reduction factors for each of beams, slabs, columns and shear walls. New magnitudes of these factors have been formulated via calculation the average values for reduction factors (Table 1) given by different design codes and researchers such as ACI-Code [7], New Zealand Standards [8], Euro Code [9], Iranian Code [10], Canadian Code [11], FEMA [14], Paulay and Priestly [20], Elwood and Eberhard [41], Grossman [42], Wang [43], Vanderbilt and Corley [44], Moehle and Diebold [45], Pan and Moehle [46], Hwang and Moehle [47] and Han et al. [48]. The proposed magnitudes for reduction factors are given in Table 2. The average values of these factors are regarded the best choice if the country design code is unavailable as in present case study. These factors have been used in present study to introduce the effect of concrete cracking and get accurate simulation of RC building analysis close to nonlinear solution.

4. Present RC multi-story building

A structural three dimensional model illustrated in Fig. 5 is for the current building under consideration which comprises of ten stories. The ground story (Fig. 6) is allocated for car park and first story (Fig. 7) with regular rectangular shape is specified for celebration hall and administration sections etc. The rest of stories with irregular plan shape (Fig. 8) are occupied as residential rooms with the corridors. Columns have been available in different sizes and shapes in the building. The sizes of circular, rectangular and square columns are 0.8m in diameter, 0.4mx0.8m and 0.5mx0.5m respectively in the ground and first floors. The columns are of circular shape in the typical stories of the building (2^{nd} – 9^{th} story), where the column diameter is of 0.75 in both 2^{nd} and 3^{rd} stories and it is increased by 5 cm per each two upper stories. For ground floor level, there is a flat plate slab (no beams are existed). The size of the beams in first story solid slab is of 0.3m x 0.53m and the joist cross sectional dimensions for the same story ribbed slab is 0.4m x 1.4m. The beams in the other floors have a size of 0.3mx0.5m. Solid slabs on beams for typical stories are considered in present modeling with shell behavior of thickness equivalent to 15 cm, while solid slab with 18 cm is used in first story. The ribbed slab thickness is selected as 7 cm with membrane sort. The flat plate slab thickness in ground story is employed as 0.3m in present model. All walls are modeled with using shell elements with 0.2 m thickness. Material properties for reinforced concrete are given as hereunder:

Mass per unit volume = 25 kN/m^3

Modulus of elasticity = $4700\sqrt{concrete\ compressive\ strength}$ in MPa (3)

Concrete compressive strength is varied as 20 MPa, 24 MPa, 28 MPa

Steel yield stress = 420 MPa

Poisson's ratio = 0.2

Shear modulus = $\frac{\text{Modulus of elasticity}}{2(1+\text{Poisson's ratio})}$ (4)

The height of ground and first stories is 5m, while the height for other stories is 3.5 m. In simulation, the support of the building is considered fully restrained due to the mat foundation assumption for the building. Present centers of mass and rigidity are not close each to other with eccentricity more than 5% of perpendicular dimension to the earthquake forces. Thus, a large torsion will be occurred during the seismic actions and therefore the shear design should be considered for column also in addition to beams.

5. Static and dynamic loadings

Static analysis is represented as an essential pre-dynamic analysis for scaling the dynamic solution. The static loads have been taken into account as dead and live vertical loadings, lateral earthquake forces in horizontal x and y directions as well as lateral wind loading in these directions. Dead load is used as combination of member self-weight and partitions weight. Live load is considered as 5 kN/m^2 for celebration hall floor and 3 kN/m^2 for other floors. The static earthquake loadings are applied at center of mass of the building with an eccentricity from the center of rigidity of 5% of perpendicular dimension of building to the x or y earthquake direction. Two cases of each earthquake direction have been assumed in analysis namely earthquake with eccentricity on left of center of mass and earthquake with eccentricity to the right of mass center for the building. An overriding of this eccentricity has been performed after first analysis to increase the effect of twisting moment on the story. The structure is subjected to static wind loading as well to compare the solution with other loading cases and obtain the worst maximum applied loading case in the analysis. Present wind loading is complied with UBC 97 code [29], where windward coefficient is 0.8 and leeward coefficient is 0.5. The wind speed in Duhok city has been used as 67.5 mph with exposure type B and building importance factor of 1.0. The working and ultimate loading combinations given by UBC 97 code have been employed to find the maximum internal forces and deformations of the building.

In present dynamic analysis, response spectrum loading cases have been considered with using the proposed design spectrum relationship with new stiffness reduction factors. The seismic coefficients for the building location are used with damping coefficient of 0.05. Same criteria for static analysis have been applied in the dynamic solution regarding eccentricity and its overriding. Scaling of dynamic outcomes is implemented via comparing static and dynamic base shear values of the building to check the matching between them which should be at least 90%. This will be achieved with increasing the number of modes of building vibration that should be more than the number of stories; twenty modes have been used in present work.

To include the effect of secondary lateral moment in the analysis, P-delta approach [49] has been used with load combination of 1.2 multiplied by dead load and half of live load. The iterative solution has been adopted for secondary moment analysis with maximum number of iterations of four and tolerance value of 0.001.

3. Analysis outcomes

The actual deflection of the slabs has been determined under service loading condition with consideration of both shell and plate elements. The effect of concrete cracking or stiffness reduction factors on slab deflection has been investigated as well in static and dynamic solutions as given in Table 3. No difference has been demonstrated between using these elements in slab modeling. It is worth to mention that there is an increasing in slab deformation of 37.25% with using present inertia modifiers. According to the story shear magnitudes (Figs. 9 and 10), it is observed that the base shear which resulted from present dynamic analysis is about 90% of that obtained from current static analysis and UBC 1997 [29] static analysis. This indication proved that the proposed design spectrum has proper outputs which are one of the analysis requirements.

The maximum lateral drifts for each diaphragm level have been determined with considering the proposed inertia reduction factors and design spectra in addition to different concrete resistances to compression force. The approximate suitable value for maximum drift is varied within the range of (height of building/500 – height of building/350) to overcome the damage [50]. The proportional horizontal displacement x_i for each floor is calculated as follows [50]:

$$x_i = building\ maximum\ drift\left({hi}/{hs}\right)^2 \qquad (5)$$

where, *hi* is height of story and *hs* is the total height of entire building

Three compressive strength values Fc' have been used in present dynamic numerical analysis namely 20, 24 and 28 MPa. Maximum drifts were calculated in two perpendicular directions x and y as depicted in Figs. 11 and 12. Good matching has been noticed between current analytical results and that found by using equation 5. The resistance to lateral x and y base shear forces has been estimated also by calculating the ratio of force resistance by walls and building frame (columns and beams).

The increasing of wall shear resistance (in both x and y directions) has been found with taking into account the inertia reduction factors (Fig. 13). In the other words, the using of these stiffness modifiers is essential to increase the resistance of shear wall to play as main portion in the dual system building for lateral force resistance as in present study.

The validity of present proposed analysis spectrum approach has been checked in determination of drift ratio of the building in x and y directions. The drift ratio is the drift of a story to its height. A comparison has been performed between the results for UBC 97 analysis with introducing the proposed inertia reduction factors and the outcomes for present response spectrum analysis. The great role of stiffness reduction factor for concrete analysis has been clearly observed in Fig. 14, where an amplification in the diaphragms drift ratios has been got with introducing there factors. Moreover, excellent correlation has been seen between drifts ratios of present response spectrum approach and that based on UBC 97.

Conclusions

New design spectra relationship and inertia reduction factors have been proposed in present work to develop a novel response spectrum dynamic analysis procedure for RC multi-story building located in North of Iraq. According to present analysis outcomes, the following conclusions have been drawn:

1- The proposed design spectrum analysis solution is valid for dynamic analysis of RC building subjected to vertical and horizontal loadings.
2- Present stiffness modifiers give dynamic base shear more than and close to 90% of static base shear which comply with design requirement of buildings.
3- There is good agreement between lateral diaphragm displacement determined by present analytical approach and that given by other design codes with respect to the outcomes of parametric study in terms of compressive strength variation. Where, the diaphragm displacement decreased with increasing the compressive strength. The maximum lateral displacement of the building is within the required range.
4- The consideration of new proposed stiffness modifiers in the analysis gives a magnification of building lateral deformation by more than 52% which is deemed as good indication for importance of these modifiers in the solution.

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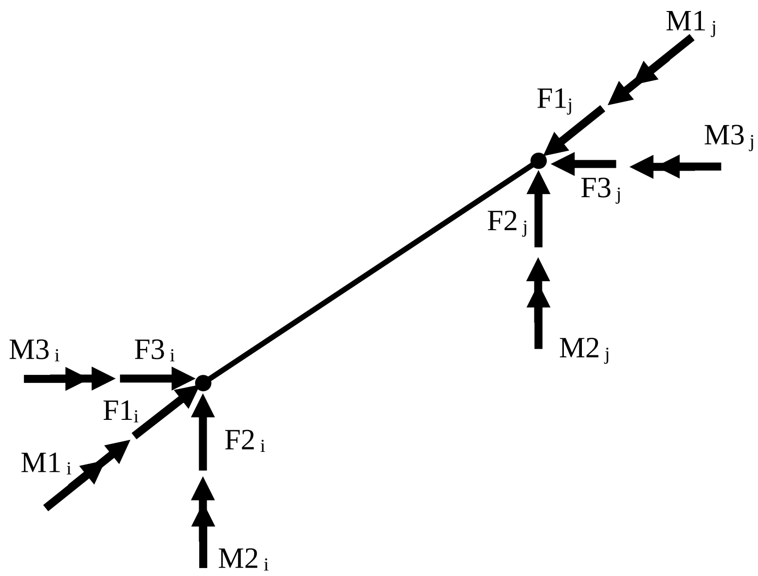

Fig. 1: Two-noded line element

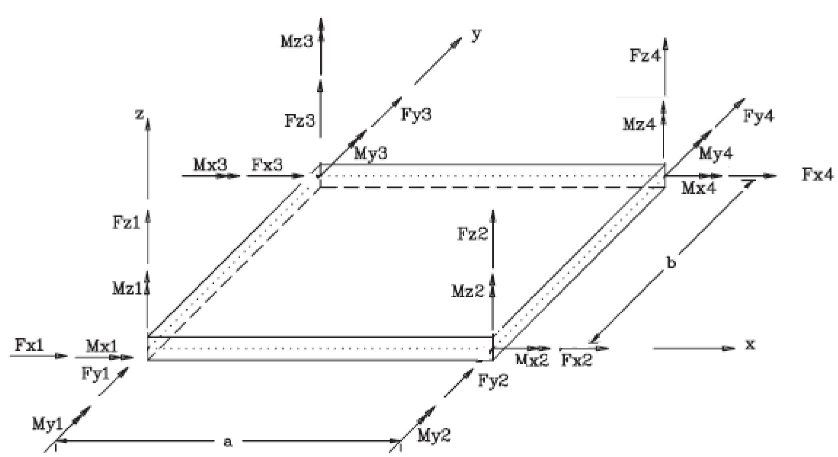

Fig. 2: Four-noded shell element

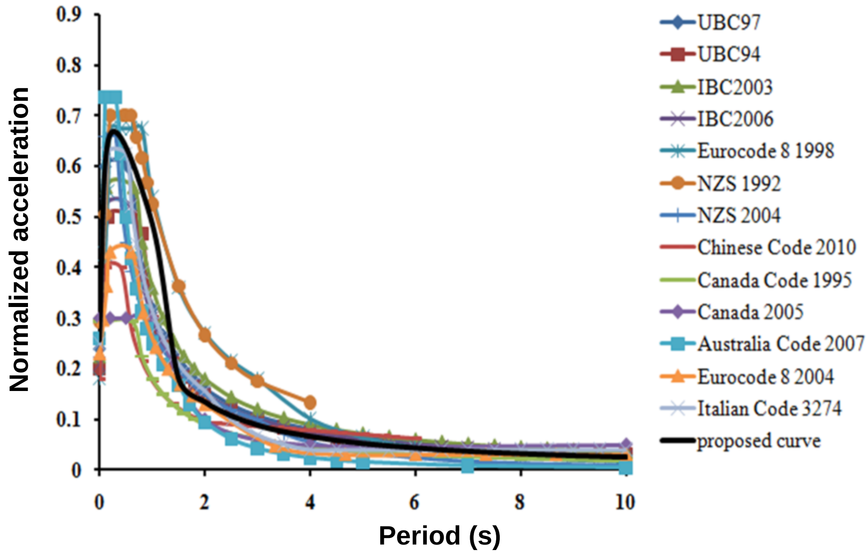

Fig. 3 Acceleration spectra values given by considered codes

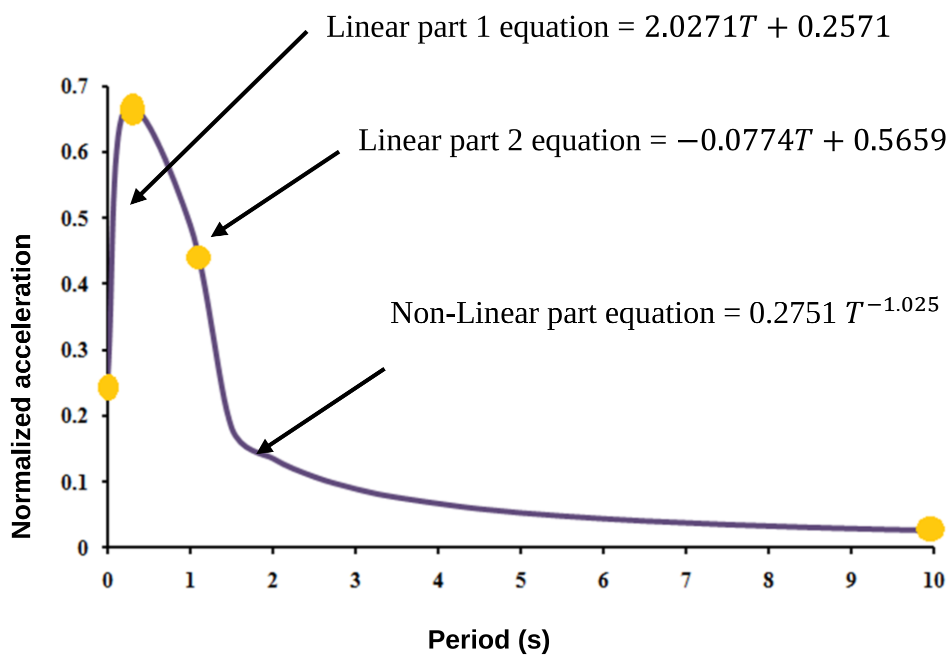

Fig. 4: Proposed design spectrum

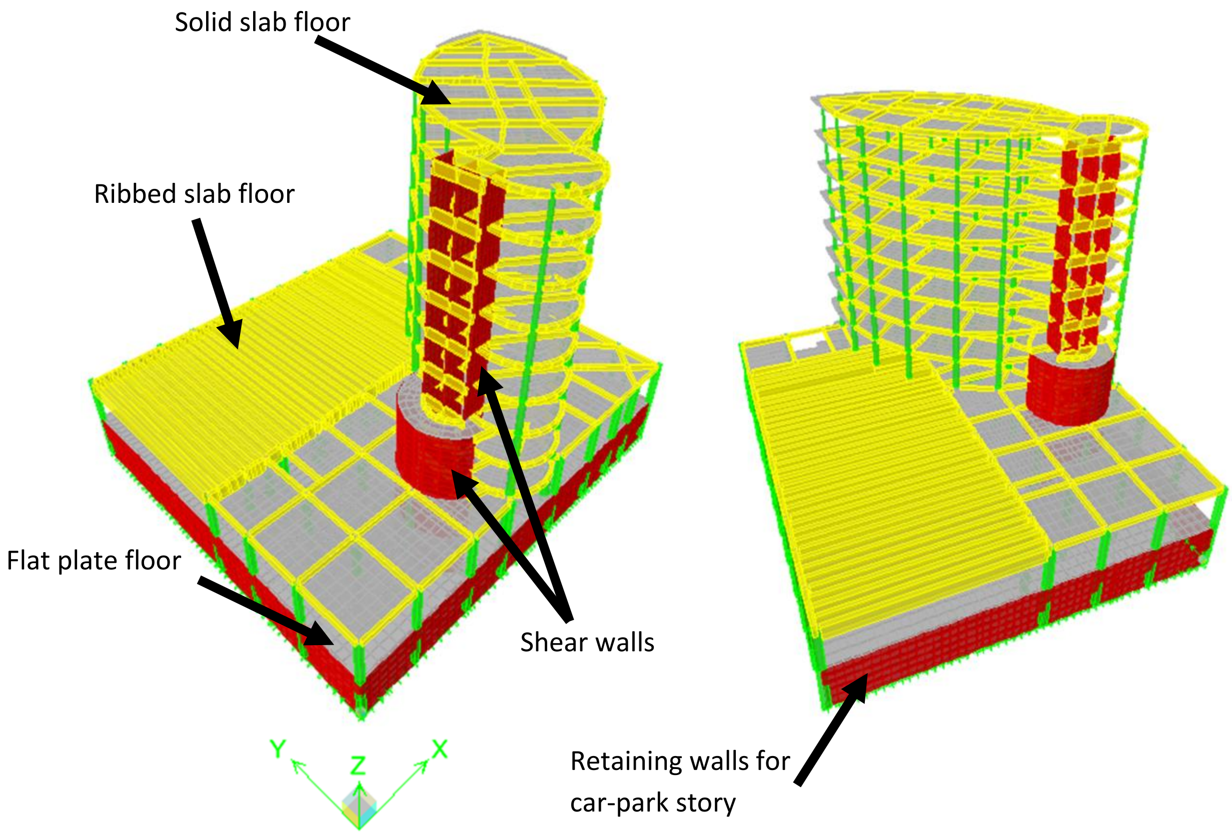

Fig. 5: Modeling of RC multi-story building under consideration

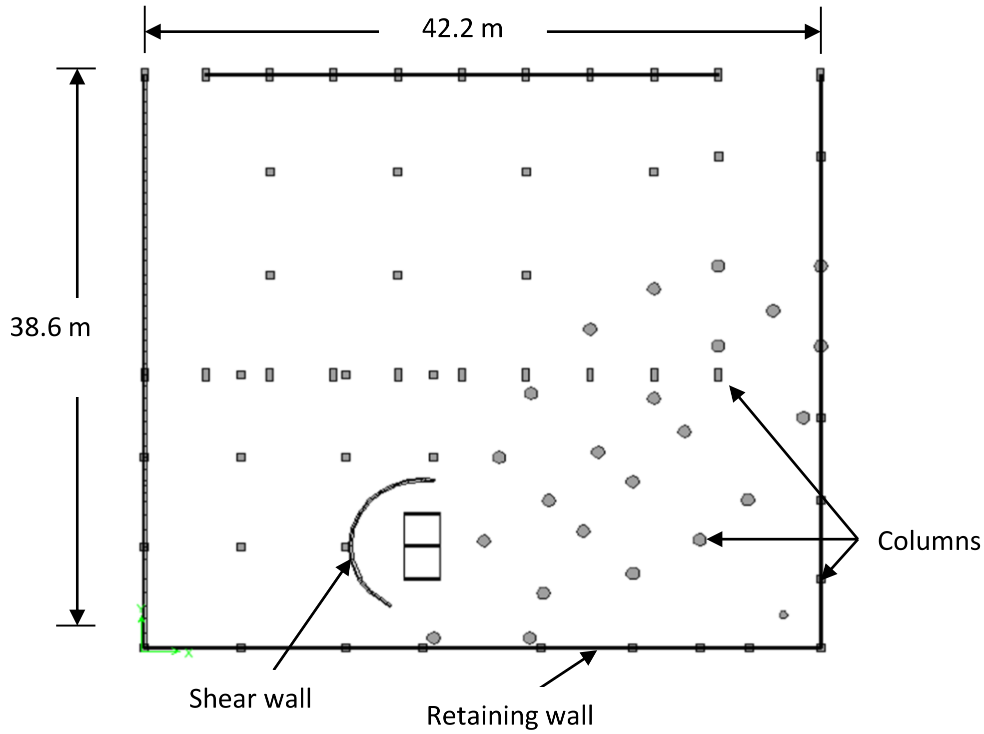

Fig. 6: Ground floor plan

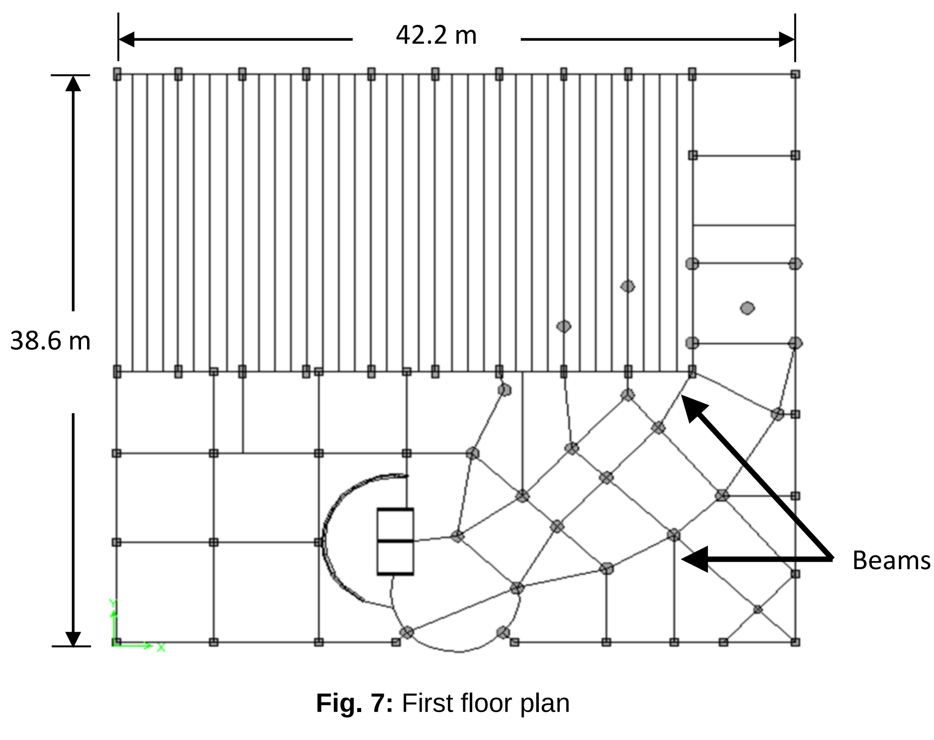

Fig. 7: First floor plan

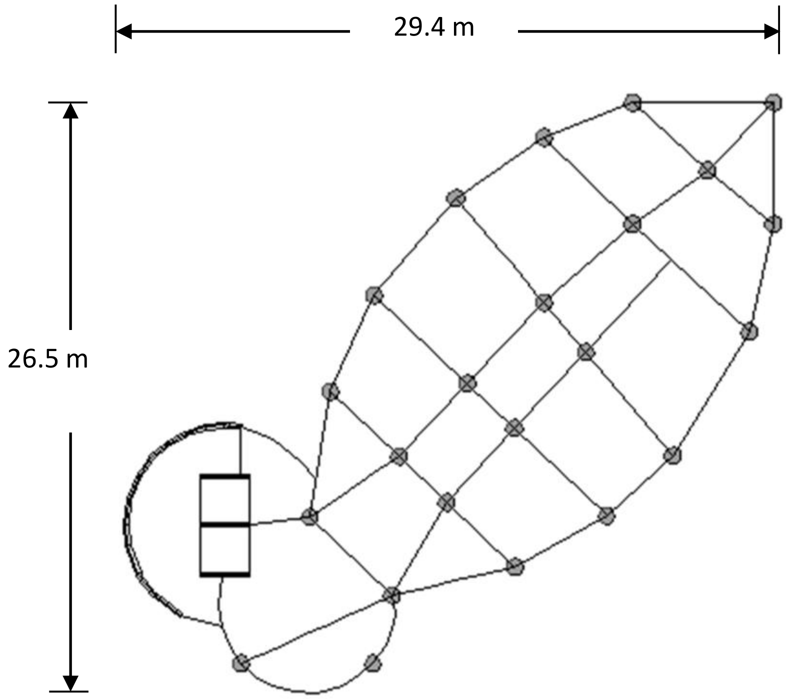

Fig. 8: Typical floor plan

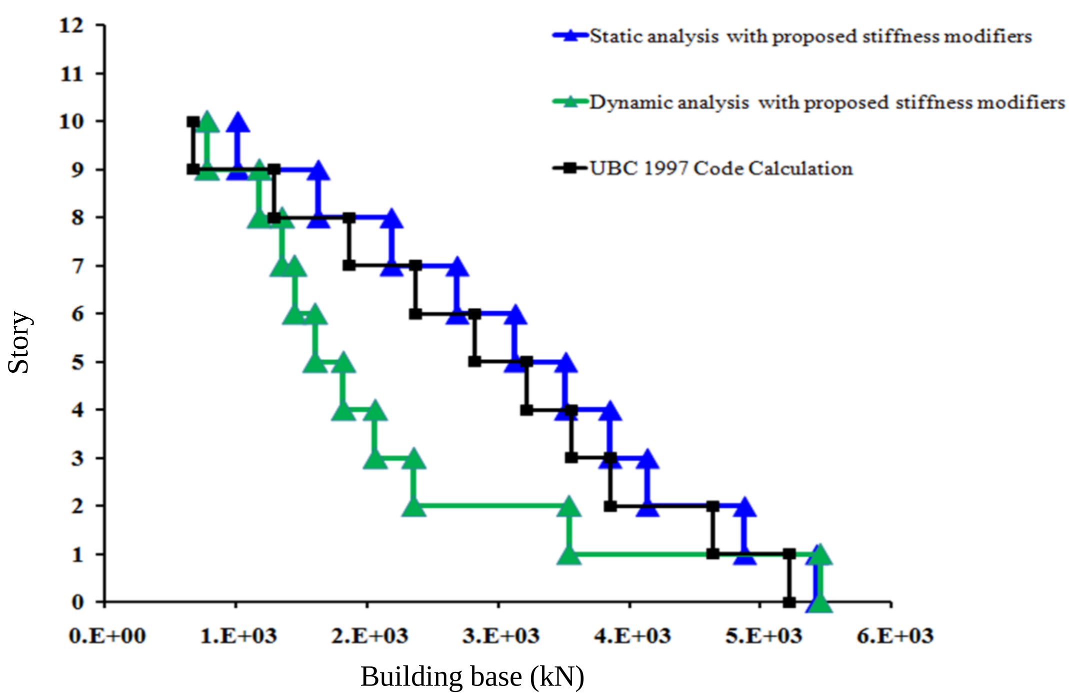

Fig. 9: Building base shear in x – direction

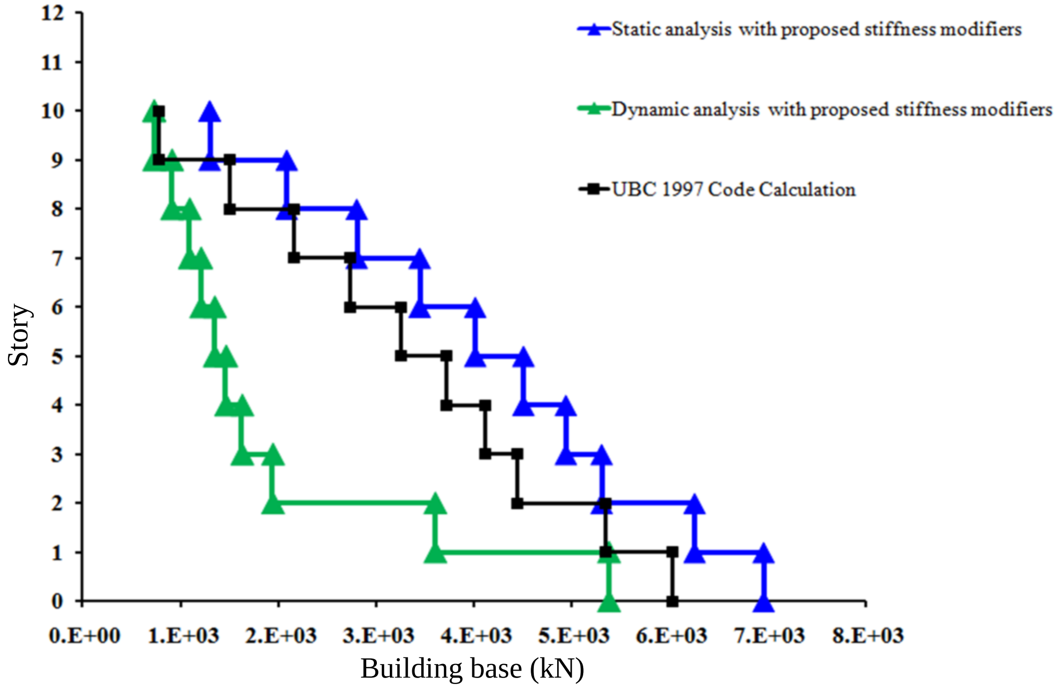

Fig. 10: Building base shear in y – direction

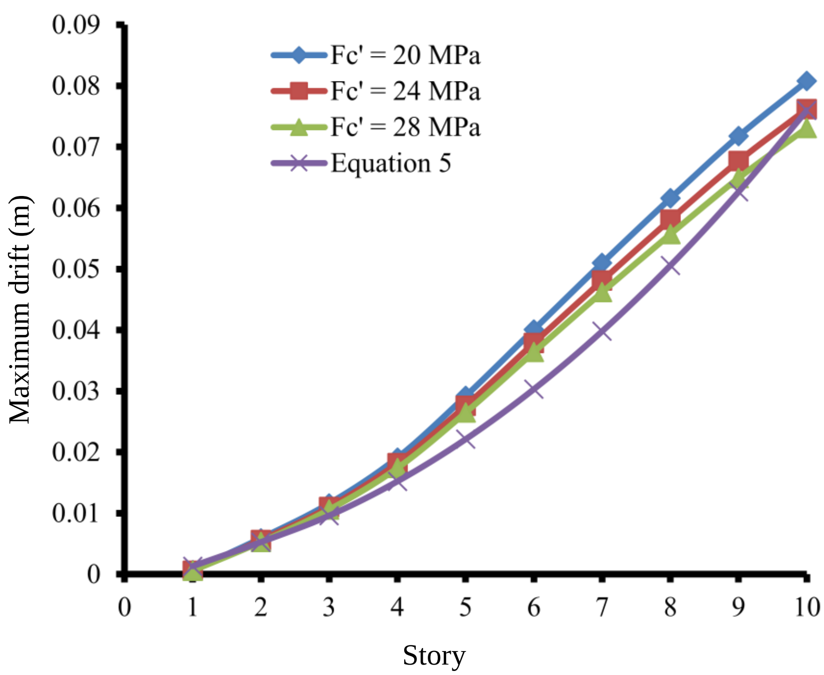

Fig. 11: Lateral Drifts of the building at diaphragms level in x-direction

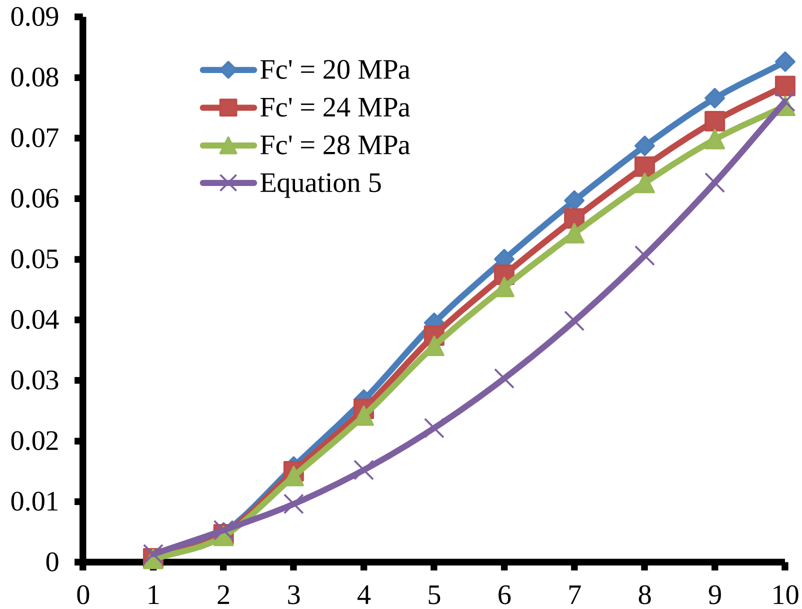

Fig. 12: Lateral Drifts of the building at diaphragms level in y-direction

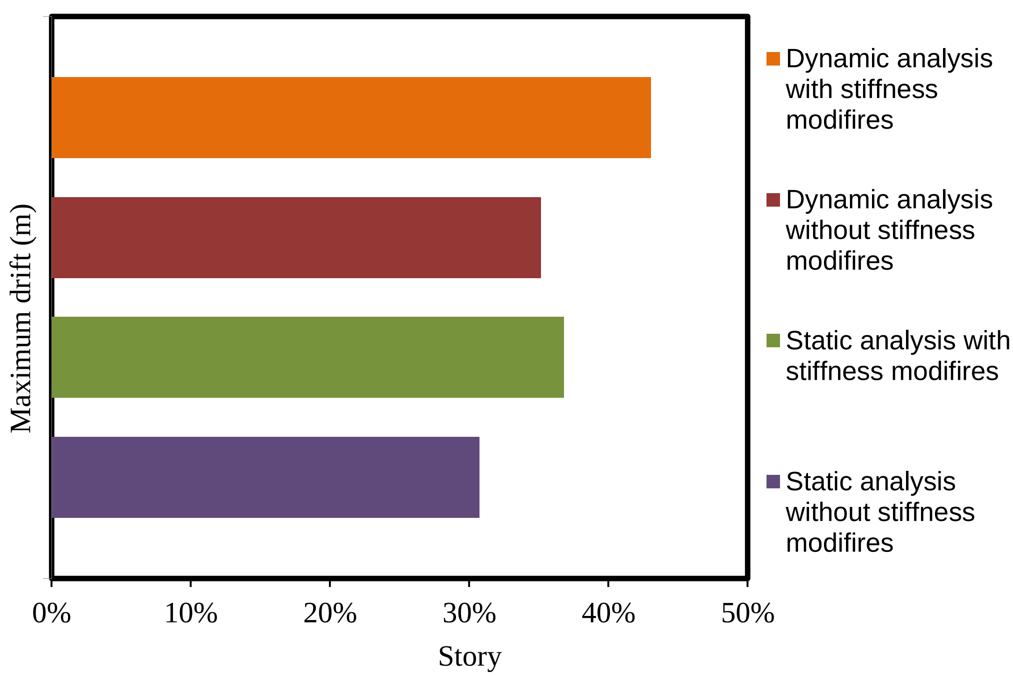

Fig. 13: Effect of present inertia reduction factor on shear wall resistance to lateral force

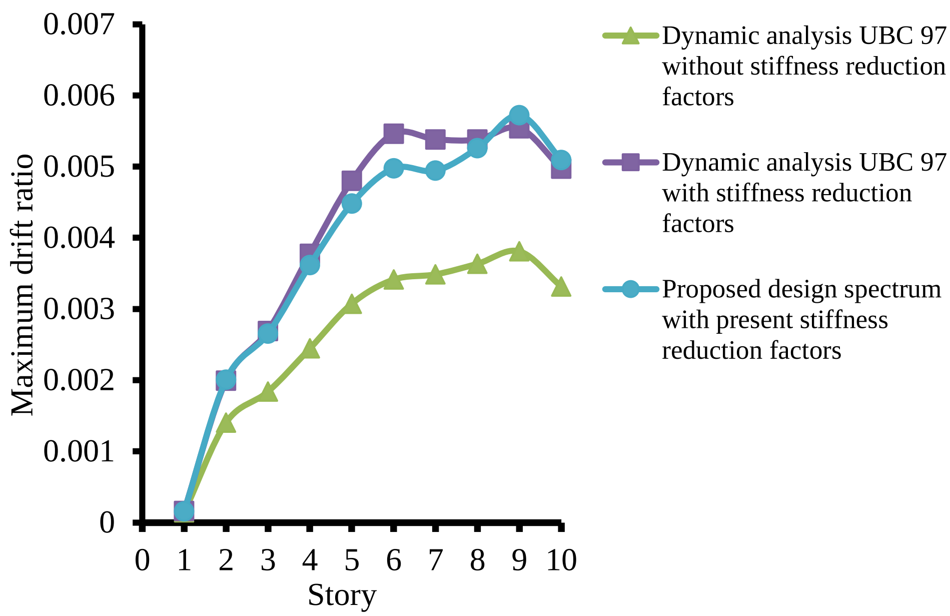

Fig. 14: Maximum drift ratio of the building in x - direction

Table 1: Inertia reduction factor for concrete members given in literature

Loading case	Beams	Columns	Slabs	Walls
Service	0.5 [7] 0.5 [9]	1.0 [7] 0.5 [9]	0.5 [9]	1.0 [7] 0.5 [9]
Ultimate	0.35 [7] 0.35 [8] 0.5 [9] 0.35 [10] 0.4 [11] 0.5 – 0.8 [14] 0.35 – 0.4 [20] 0.35 [42]	0.4- 0.7 [8] 0.5 - 0.8 [14] 0.4 - 0.8 [20] 0.7 [7] 0.5 [9] 0.7 [10] 0.7 [41] 0.7 [43]	0.25 [7] 0.5 [9] 0.33 [44] 0.33 [45] 0.33 [46] 0.4 [47] 0.2 – 0.33 [8]	0.7 [7] 0.7 [8] 0.5 [9]

Table 2: Present proposed inertia reduction factors

Loading case	Beams	Columns	Slabs	Walls
Service	0.5	0.75	0.75	0.5
Ultimate	0.41111	0.6375	0.5	0.324

Table 3: maximum vertical deformation of building slab

Item	Analysis case	Maximum deflection of the slab (m)
1	Static analysis using shell elements without stiffness reduction factors	-0.0196
2	Static analysis using shell elements with present stiffness reduction factors	-0.0269
3	Dynamic analysis using shell elements without stiffness reduction factors	-0.0196
4	Dynamic analysis using shell elements with present stiffness reduction factors	-0.0269
5	Static analysis using plate elements without stiffness reduction factors	-0.0193
6	Static analysis using plate elements with present stiffness reduction factors	-0.0269
7	Dynamic analysis using plate elements without stiffness reduction factors	-0.0193
8	Dynamic analysis using plate elements with present stiffness reduction factors	-0.0269