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Effect of Irregularity in plan on Seismic Response Modification factor for Ordinary Moment Resisting Frames (OMRF)

Nasr E. Nasr[1,2], Gamal H. Mahmoud[3]and Hussein khaled[4]
[1]*(Associated Professor of Structural Engineering, Faculty of Engineering, Ain-Shams University, Egypt)*
[2]*(Vice Dean, Madina high institute for Engineering and technology, Egypt)*
[3]*(Professor of Structural Engineering, Faculty of Engineering, Ain-Shams University, Egypt)*
[4]*(Structural Engineering Department, Faculty of Engineering / Ain shams university, Egypt)*

Abstract: *the recent earthquakes, concrete structures have been severely damaged or collapsed, whichhas raised concerns against the seismic capacity of concretestructures. These reinforcedconcrete buildings need to be evaluated to determine the capacity to resist seismic loads. The behaviorof a building during earthquakes depends critically on its overall shape, size and geometry.Conventional approach to earthquake resistant design of buildings depends upon providing thebuilding with strength, stiffness and inelastic deformation capacity which are great enough towithstand a given level of earthquake-generated force. This is generally accomplished through theselection of an appropriate building configuration and the careful detailing of structural members.In this research, nonlinear pushover analysis has been used to evaluate the response modification factor (R) for three (OMRF) with three different plans having same area and height.The study includes some factors that affecting the value of response modification factor (R) such as PGA values (studied for 0.15g, 0.20g and 0.25g). Also, study the effect of story numbers on performance demands with studying 5 stories and 10 stories structures. This method determinesthe base shear capacity of the building and performance level of each part of building undervarying intensity of seismic force. The results of effects of plan irregularity, PGA value, and Story numbers on seismic response ofOrdinary Moment Resisting Frames (OMRF)have been presented in terms of displacement, base shear, plastic hinge pattern and Modification factor(R).*

Keywords: *Pushover Analysis, Seismic Performance, Base Shear, Building Configuration.*

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I. Introduction

The destructiveeffect of an earthquake can have major consequences on infrastructures and service life. The earthquake engineering community has been review its procedures in the past few years due to such earthquakes which have caused extensive damage, loss of life and property. These procedures mainly consider assessment of seismic force demands on the structure and then developing design procedures for the structure to withstand the applied actions. The seismic design in most of the structures is based mainly on elastic force. The nonlinear response of structure is not incorporated in design process but its effect is integrated by using a reduction factor called Response Reduction factor (R). There are differences in the way the response reduction factor (R) is specified in different codes for different kinds of structural systems .The concept of response reduction factor is to reduce the seismic force and incorporate nonlinearity with the help of over strength, redundancy and ductility effects.

The value of Response reduction factor varies in international code as per type of resisting system, but previous studies does not provide information on what basis R values are considered. Most of the past research efforts in this area have focused on finding the ductility component and over strength components of the response reduction factor [1]. The present work takes a rational approach in determining R factor for irregular RC structures.

Fig. 1: Damage to Reentrant corner and upper stories of the Ministry of Telecommunications Building in Mexico City after the 1985 earthquake.

No realistic structure is perfectly regular as a result of non-uniform mass, stiffness, strength, structural form, or a combination of these in the horizontal or vertical directions. Also structures with a high degree of irregularity have the possibility of behaving significantly differently than that of a nominally regular structure[4]. This different behavior may result in larger demands and less safe irregular structures.

So, provisions and assumptions for the design of RC structures with structural irregularity appear in the majority of the international codes for concrete buildings design.

The Study objective is to three buildings have been analyzed with different plans different plans having same area. The results are compared in terms base shear, displacement and plastic hinge pattern to evaluatethe effects of different plan aspect ratio on the performance level of buildings.The outcomes results confirm the important effects of torsional irregularity on seismic demands that recommended the importance of calibration between the architect and structure engineer from early planning stage of building to ensure a suitable structure with good safety and limit costs.

II. Literature review

Earthquake field investigations repeatedly confirm that irregular structures suffer more damage than their regular structures. Torsional irregularity is one of the most important factors, which produces damage (reached collapse) for the structures. A large number of studies exist which investigatevarious aspects of torsional irregularity. So, the number of publications started growing fast as indicated in the histogram of fig: 2.

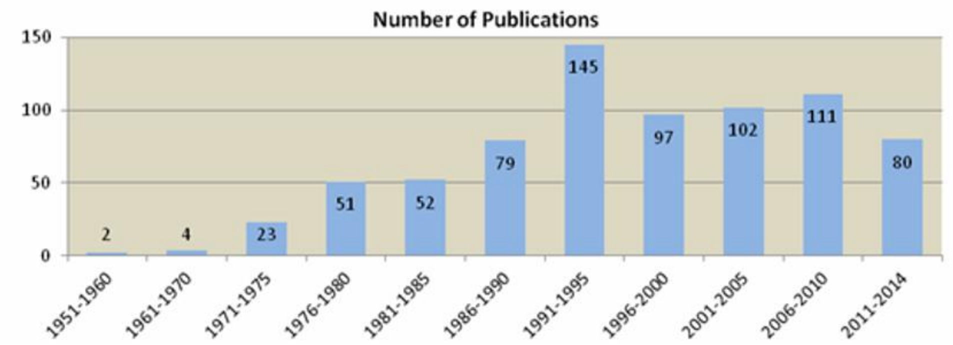


Fig. 2: Histogram of time distribution of publications on building torsion[1].

Anil K. Chopra and Rakesh K. Goel investigate the effects of plan asymmetry on the earthquake response of code-designed, one-story systems and to determine how well these effects are represented by torsional provisions in building codes [2]. NFALLAH, POURZEYNALI and M.I. HAFEZI evaluate Accuracy Evaluation of the Modal Pushover Analysis Method in the Prediction of Seismic Response of Vertically Irregular Frames [3]. Tezcan and Alhan have proposed an increase in the calculated eccentricity in order to ensure an added and inherent safety for the flexible side elements[4].Momen Mohamed, Shehtaabd el-Rahman, Mohamed Ahmed and Aly abd el-Shafy represent an evaluation of seismic performance on multi-story buildings due to shape. Size and geometry irregularity effects [5]. Mahdi and Gharaie have evaluated the seismic behavior of three intermediate moment-resisting concrete space frames with unsymmetrical plan by using pushover analysis [6]. Yasser Al-Ashker, SohaibNazar& Mohamed Ismail represent an evaluation of Effects of Building Configuration on Seismic Performance of RC Buildings by Pushover Analysis [7]. Malavika Manilal represent an evaluation of dynamic analysis of R.C regular and irregular structures using time history method [8]. A.

BenaventCliment and L. Morillas b represent an experimental study for “Inelastic torsional seismic response of nominally symmetric reinforced concrete frame structures: Shaking table tests [9].

III. Pushover Analysis

Static pushover analysis is an attempt by the structural engineers to evaluate the real strength of the structure andit promises to be a useful and effective tool for performance based design [1]. In pushover analysis; building is subjectedto incremental lateral loads at different levels representing the inertial forces due to ground shaking duringearthquake. Consequently, at each increment some elements of structure may yield due to loss of stiffness as shown in Figure 3. The sequence of crack propagation, plastic hinge formation and yielding of structural elementsof the building are recorded with respect to incremental lateral loads. The ATC-40 [18] and FEMA-356 [17]have developed modeling parameters, acceptance criteria and procedures of pushover analysis.

Pushover analysis significantly evaluates the expected performance level of the structural system by the capacitycurve of the building. Based on this capacity curve, target displacement is estimated which is expected to beproduced during the earthquake. Also analysis enables to determine the collapse load and ductility capacity. Theoutput of the analysis can better be explained by demand versus capacity curve.

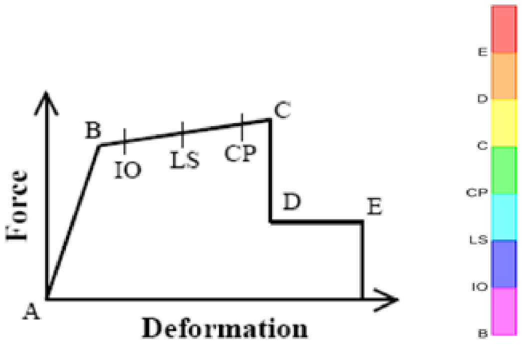


Fig. 3: Deformation relation and target performance levels

One of main parameters determined by using pushover analysis is response reduction factor or force modification factor (R). This factor imitates the capacity of structure to energy dissipation through inelastic behavior. R factor estimated for the nonlinear response of a structure by taking advantage of the fact that the buildingshavecapacity to energy dissipation and significant reserve strength calledductility and over strength, respectively [18]. Fig. 4 Represent the relationship between(R) factor,over strength (R_s) and ductility (R_μ)

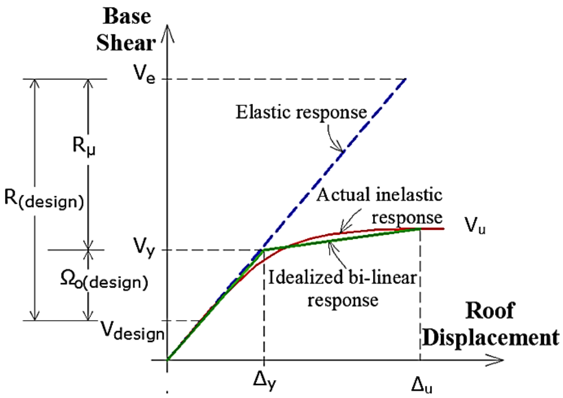


Fig. 4: Relationship between (R) factor, structural over-strength (Ω), and ductility reduction factor (Rμ) [13].

It is combined effect of overstrength, ductility and redundancy represented as

$$R = R_S R_R R_\mu$$

Where:

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

$$R_s = {}^{V_y}\!/_{V_d}$$

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 principle direction of the building. The higher of the redundancy factor R_R Cannot be larger than one. So, R_R=1.00

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

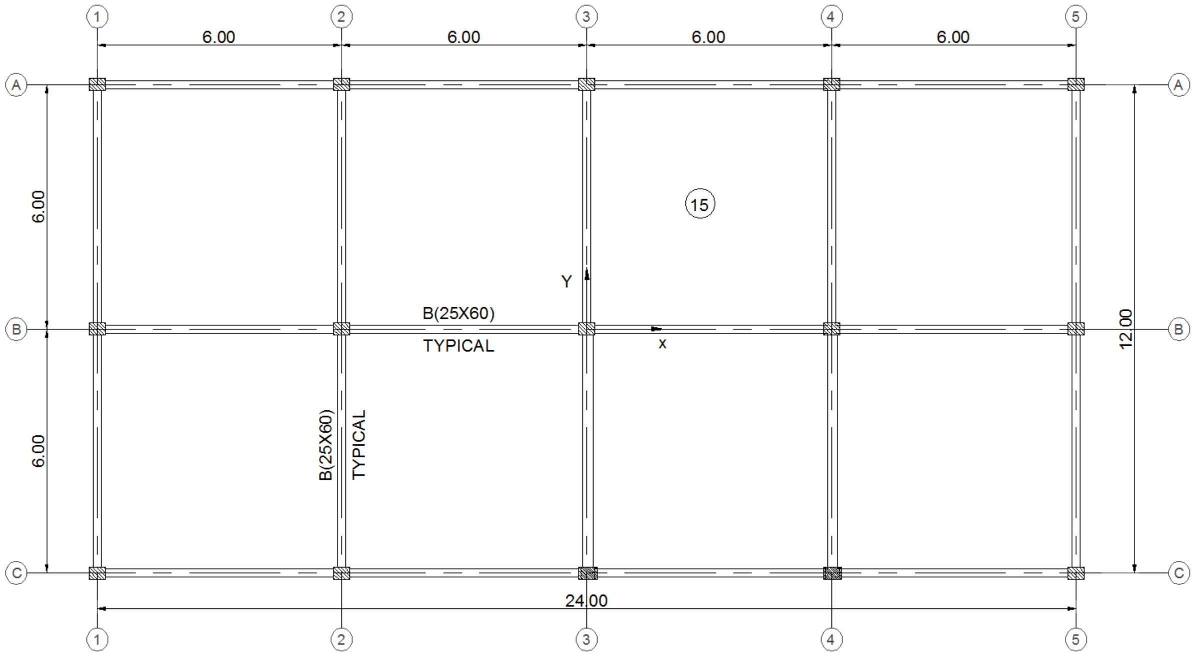
Ductility reduction factor Rμ is a function of structural features such as ductility and fundamental period of vibration (T), and the characteristics of earthquake ground motion (Mahri and Akbari [19]). Researchers represented different formulations in order to estimate the ductility reduction factor Rμ, (Newmark and Hall, (1973) [20]; Uang (1991) [21],Paulay and Priestly, (1992) [22], Miranda and Bertero, (1994) [23]; Kappos (1997) [32], Priestley, (2000) [24]; Elnashai and Mwafy (2002) [25], Mondal et al (2013) [26],

In this study, the formulation recommended byPriestley and Paulay (1992) [22] is used.
$R\mu = 1.0$ for zero-period buildings.
$R\mu = \sqrt{2\mu - 1}$for short-period building.
$R\mu = \mu$ for long-period building.
$R\mu = 1 + (\mu - 1)\, T/0.70$ $(0.70 < T < 0.30)$
Where
Rμ is the ductility reduction factor and μ is the displacement ductility.

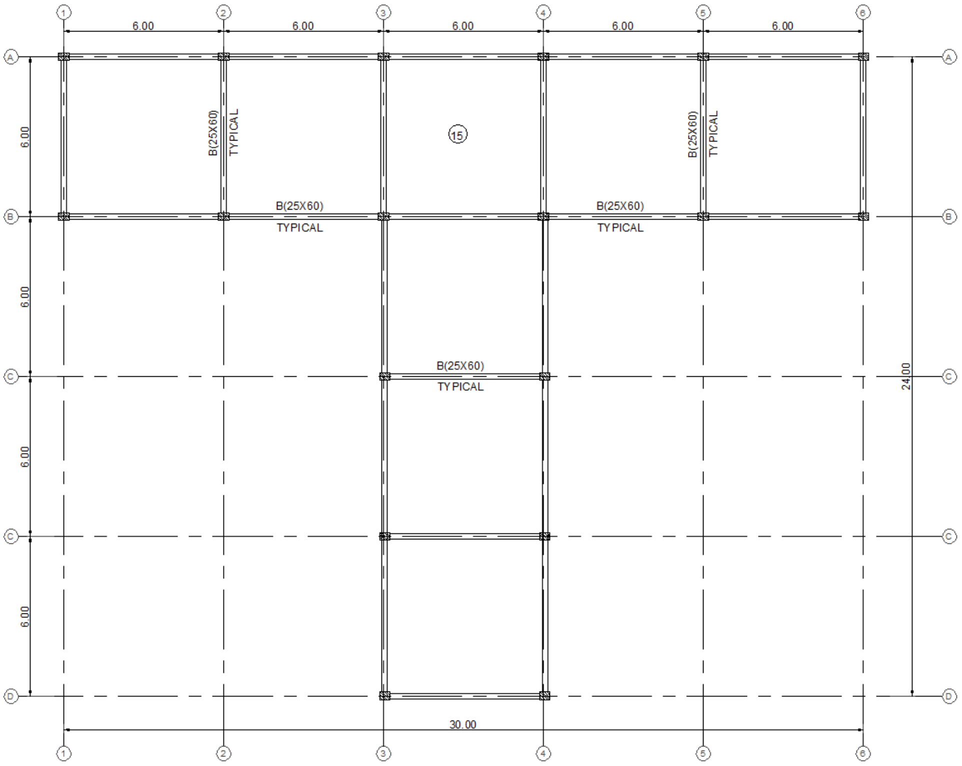
IV. Case of study

A parametric study was performed to understand torsional behavior effects on different structures using finite element analysis.An ideal symmetric structures having the distribution of loads is uniform along each story and two asymmetric structures were chosen for the study.

Asymmetric structures include L shape and T shape floor comparing to symmetric structure (TYPE A). All the structures are compared for their irregular plan and mass distribution.The structures studied with different height (5-stories & 10-stories). As shown inFigures 5, 6 &7.



TYPE (A)



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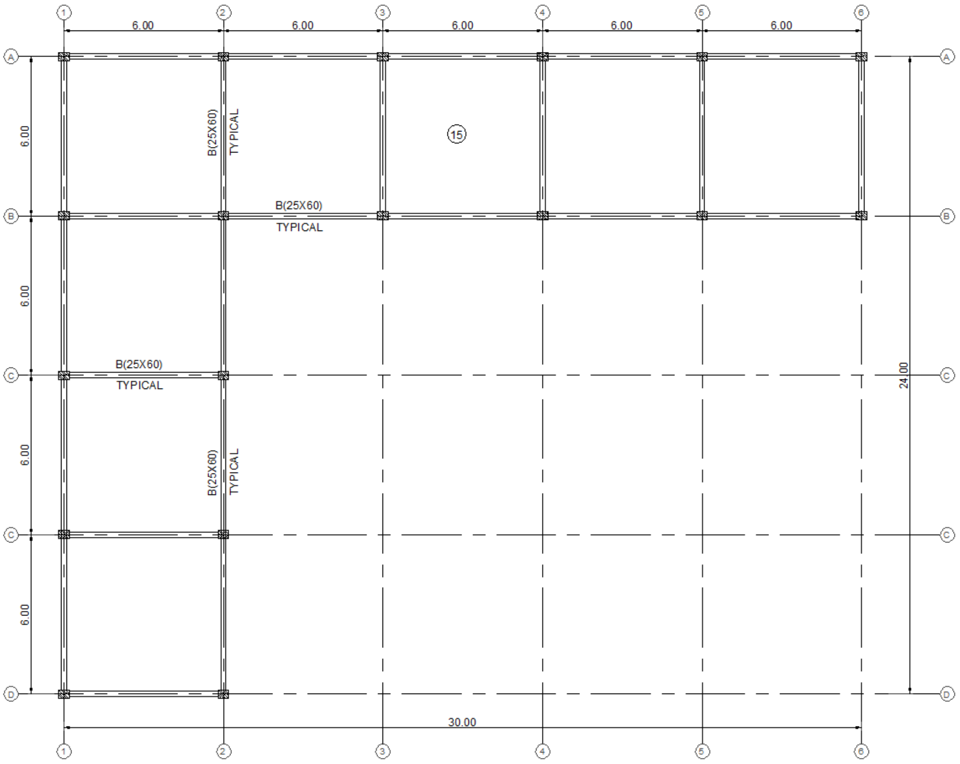
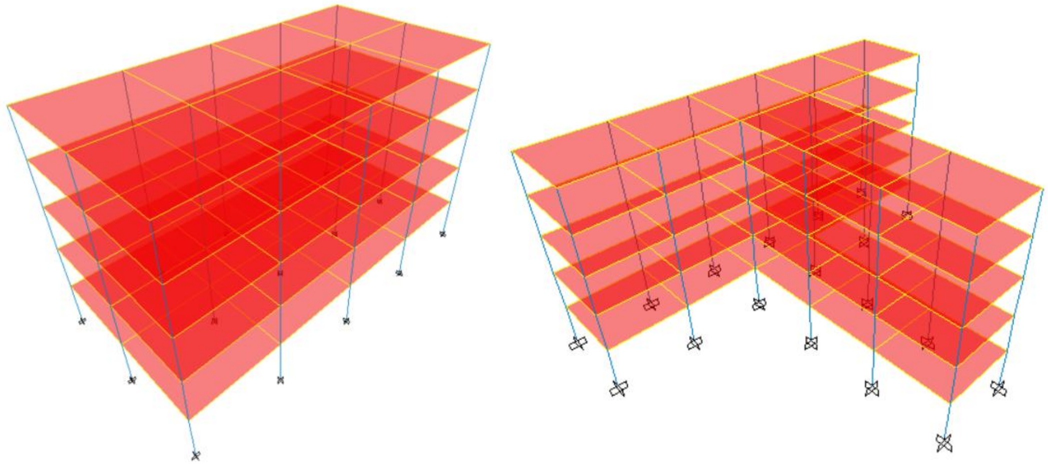
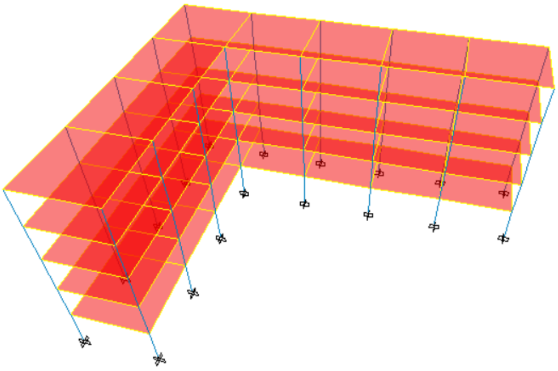


TYPE (C)

Fig. 5: Floor Plans of Typical Structures.

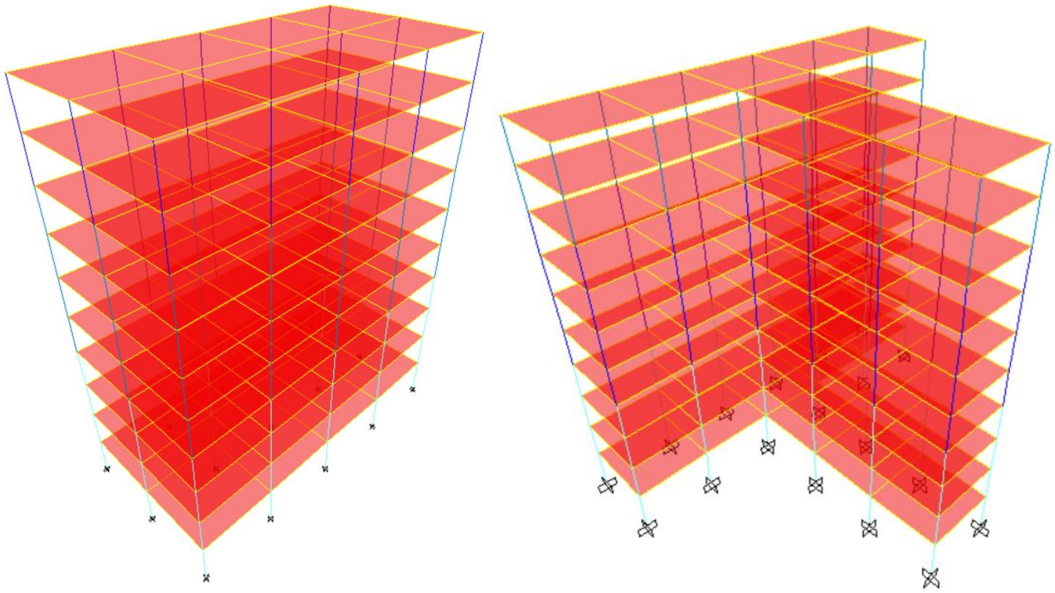


TYPE (A) TYPE (B)

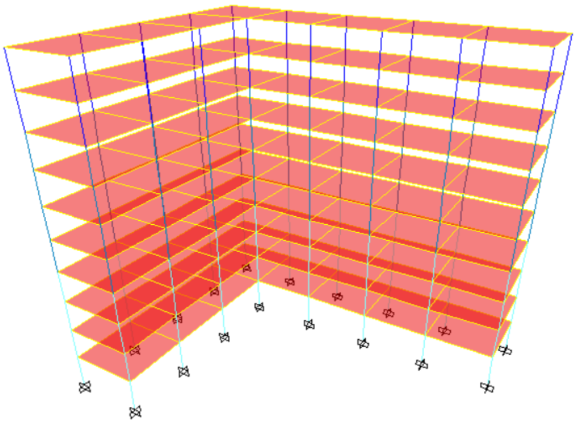


TYPE (C)

Fig. 6: 3D model of 5-stores structures.



TYPE (A) TYPE (B)



TYPE (C)

Fig. 7: 3D model of 10-stores structures.

The buildings are composed of moment resisting RC frame with solid slab, 150 mm thickness. Beams sizes are 250 × 600 mm and has been modelled as frame elements while in-plane rigidity of the slab is simulated using rigid diaphragm action. The columns are assumed to be fixed at the base.Column dimensions vary as shown in table 1.

Table 1: Columns cross sections (Dimensions in cm)

Total number of stories	story No.	Col Dim (cm x cm)
5	1 ~ 5	40 x 40
10	1 ~ 3	40 x 40
	4~ 6	40 x 50
	7 ~ 10	40 x 60

The structure members are made of in-situ reinforced concrete. The overall same area is288 m^2. The buildings arefive-stories with height of 15 m and ten-stories with height 30 m.Dead load and live load are 1.5 kN/m2 and 2.0 kN/m2, respectively.

The material properties used are: fcu = 25 MPa for concrete and fv = 360 MPa for reinforcement. The building is analyzed as per seismic provisions provided by ECP201 [10].

Theseismic load according to the relevant code has been estimated and the building is analyzed for combined effectof gravity and seismic loads as shown in Table 2,

Table 2: Seismic Elastic Parameters Assumptions

Analysis code	Egyptian code
	ECP201-ED2012
Soil Profile	C
Zone Factor	0.15
R	5
Ct	0.075
ECC %	5%
I (Importance Factor)	1
Load Combination	1.4DL+1.6LL
	0.9DL+QX
	0.9DL+QY
	1.12DL+0.25LL+Qx+0.3QY
	1.12DL+0.25LL+0.3Qx+1.0QY

This paper used 3D finite model of the building. The software package Etabs2017.0.1, developed by Computer & Structures Inc. [14], was utilized for this purpose. Beams and columns are simulated with frame element while slabs are simulated with shell element.

RC buildings have been designed refer to ECP-203 against gravity and seismic loads using ECP-201.The assumed steel ratio for the columns is varying from 0.8% to 1.2% relative to cross section area [14]. The capacity/demand ratios for most columns are in lower stories of all the studied buildings and within the range from 0.70 to 0.85.

- **Cases of study:**

The following cases of study have been considered for RC buildings with different irregularity degree:

1- Variation of peak ground acceleration (PGA):

The variation in PGA (Seismic Zone Factor)0.15g, 0.20g and 0.25g acceleration. Estimating the structures demand through response modification factor (R) for different PGA.

2- Variation of height:

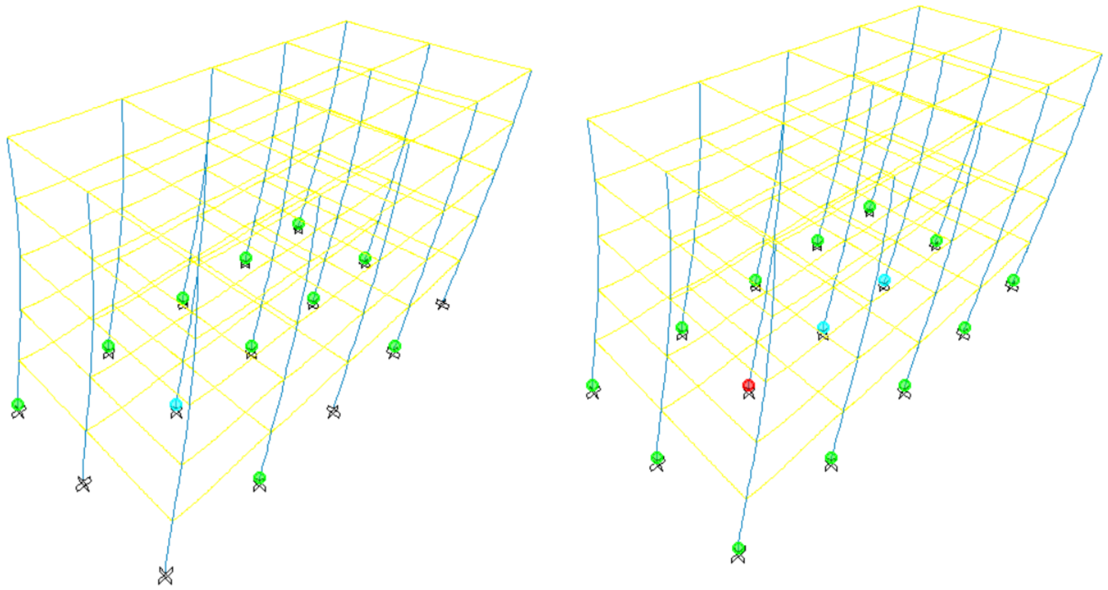
The variation in height. G+5 and G+10 structures. The plan layout of the structures shown in the fig 6 &7. Estimatingthe structures demand through response modification factor (R) for different structure heights.

V. Results

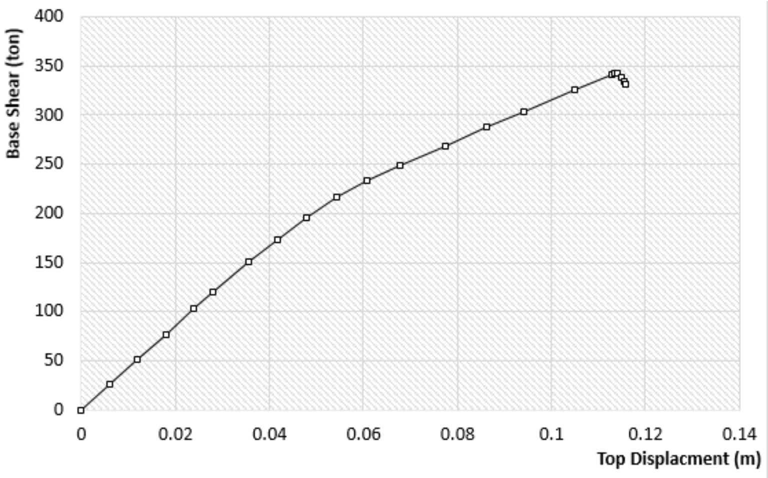
All three buildings were analyzed in both X and Y directions for static nonlinear (pushover) analysis. The response reduction factor or force modification factor (R) reflects the capacity of structure to energy dissipation through inelastic behavior.

The procedure for determination for response modification factor start with carrying out pushover analysis in order to determine the performance level and deformation capacity (capacity curve) of the studied building.At each deformation step of the pushover analysis, the program determined the following, (a)hinges which have got one of the three FEMA 356 rules IO, LS and CP limit states for hinge rotation. (b) The position and plastic rotation of hinges in beams and columns [17]. Hinge status at yield and ultimate states for all the studied buildingshave been evaluated.

The following figures from Fig.8to Fig. 13show the procedure for determination for response modification factor for all studied structures for 5 stories and PGA (0.15g).

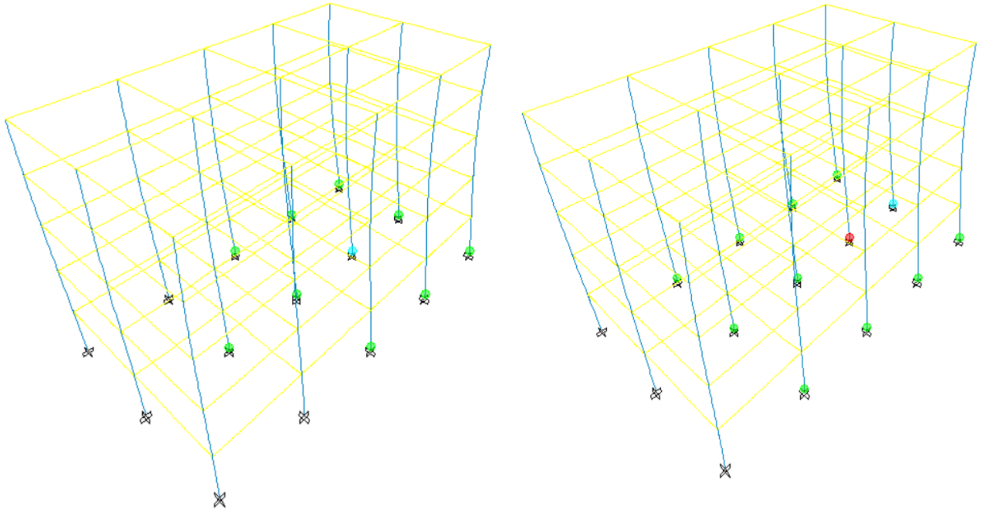


At Yield StageAtUltimate Stage

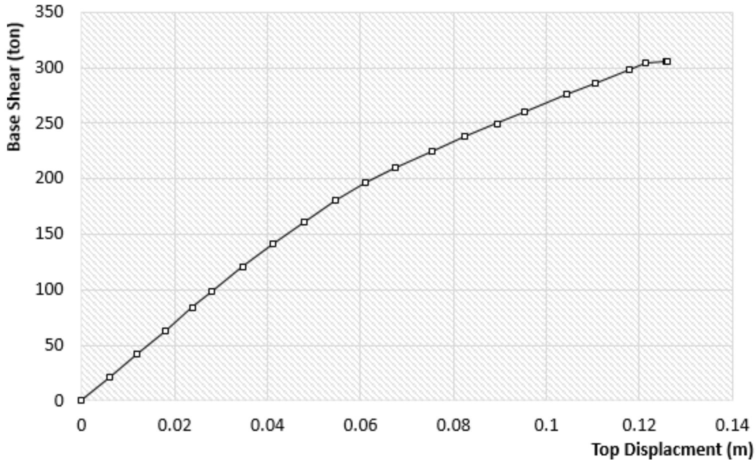


V_{des}(ton)	V_y(ton)	V_{ult}(ton)	Δ_y(mm)	Δ_{ult}(mm)	µ	R
55.17	303.92	325.61	94.19	104.91	1.11	6.14

Fig. 8: Pushover output for Type A @ X-Dir

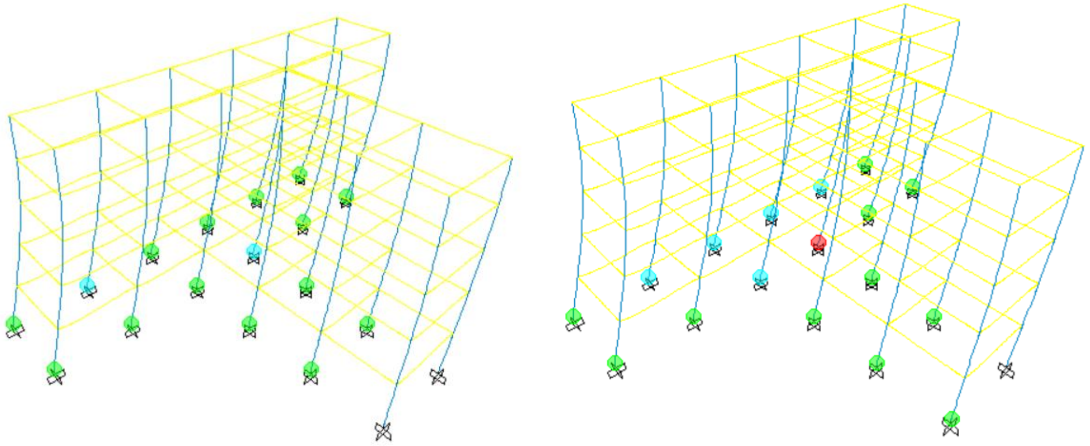


At Yield StageAtUltimate Stage

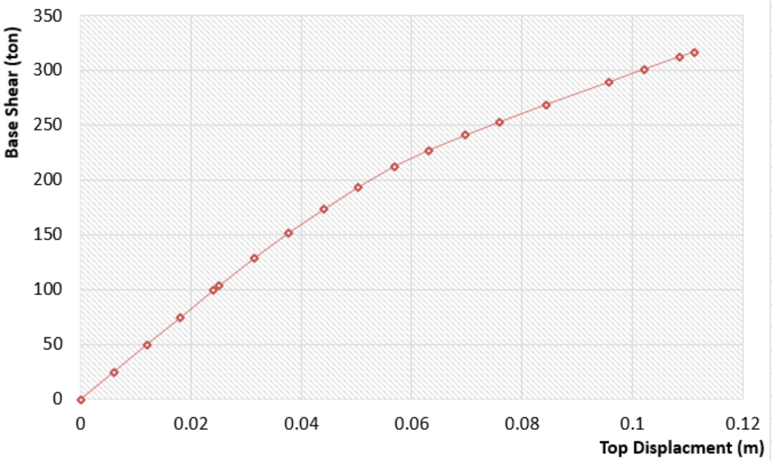


V_{des}(ton)	V_y(ton)	V_{ult}(ton)	Δ_y(mm)	Δ_{ult}(mm)	µ	R
55.17	275.92	298.44	104.47	117.85	1.13	5.64

Fig. 9: Pushover output for Type A @ Y-Dir

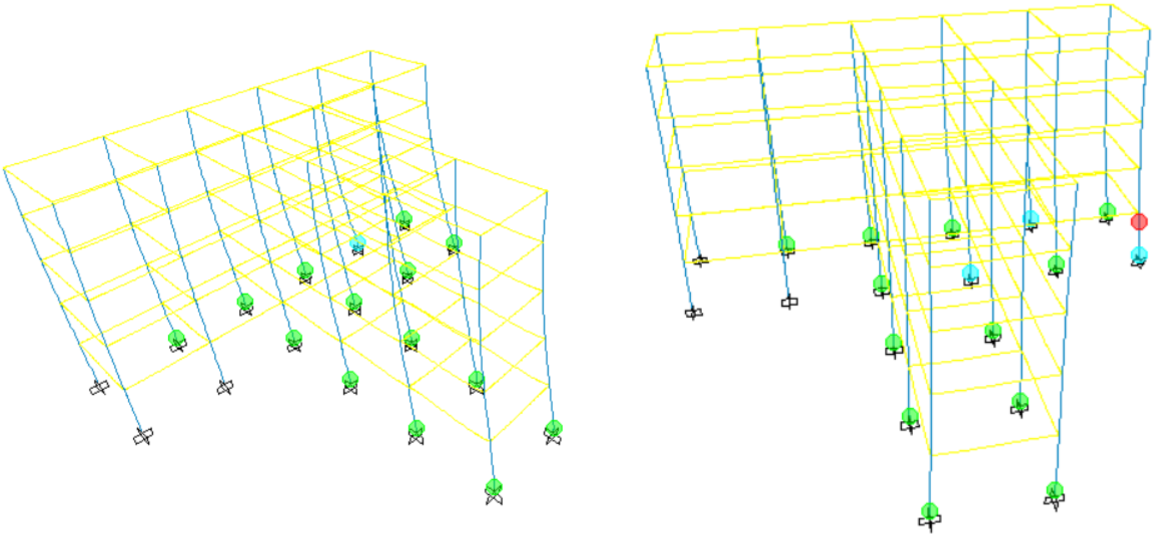


At Yield StageAtUltimate Stage

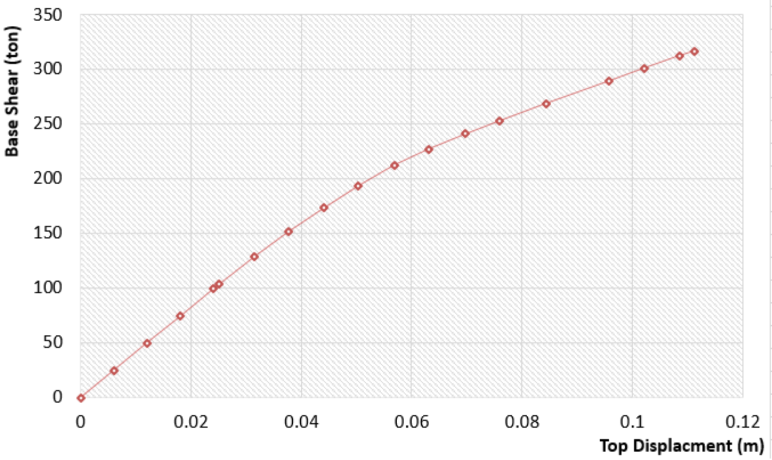


V_{des}(ton)	V_y(ton)	V_{ult}(ton)	Δ_y(mm)	Δ_{ult}(mm)	µ	R
58.43	306.46	321.70	88.91	96.62	1.09	5.70

Fig. 10: Pushover output for Type B @ X-Dir

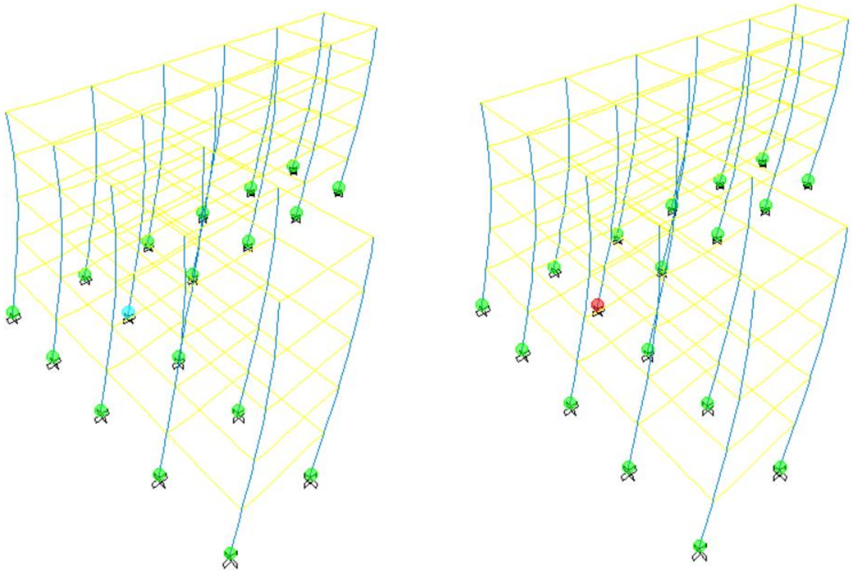


At Yield StageAtUltimate Stage

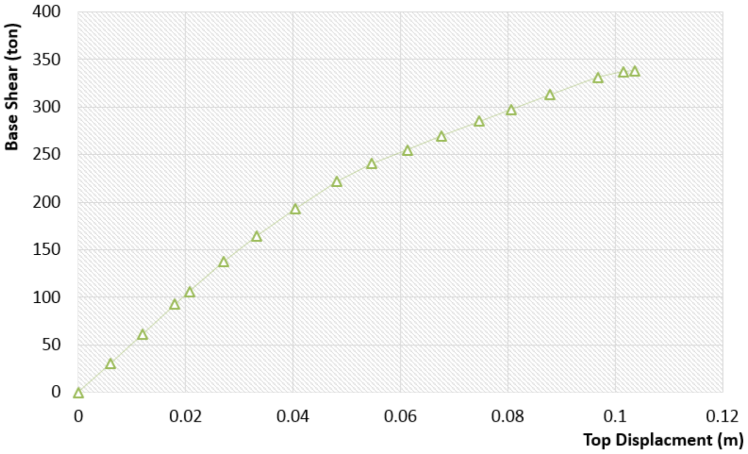


V_{des}(ton)	V_y(ton)	V_{ult}(ton)	Δ_y(mm)	Δ_{ult}(mm)	μ	R
58.43	289.72	301.27	95.80	102.12	1.07	5.29

Fig. 11: Pushover output for Type B @ Y-Dir

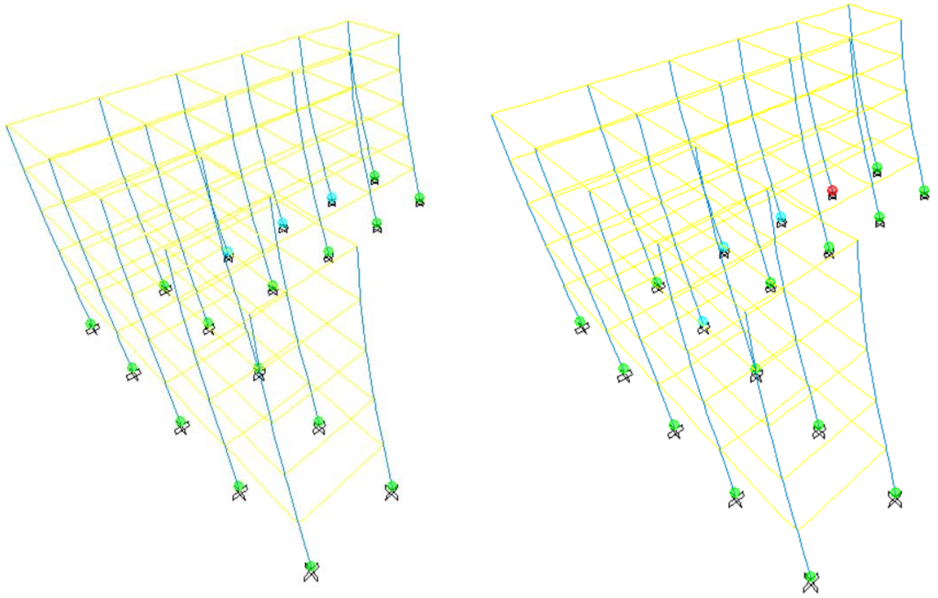


At Yield StageAtUltimate Stage

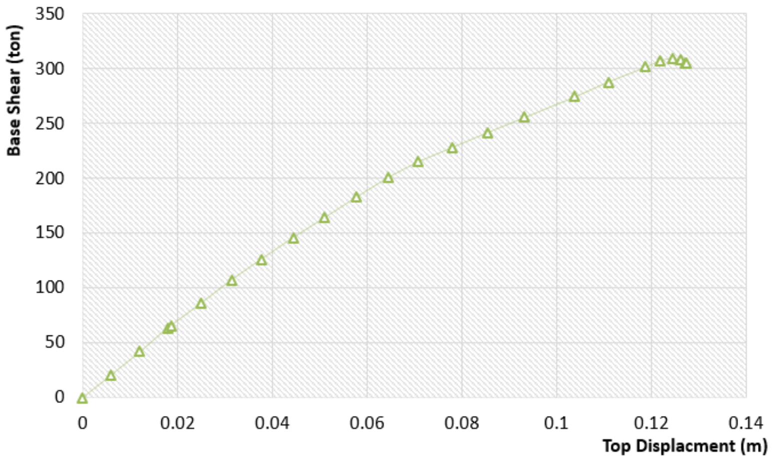


V_{des}(ton)	V_y(ton)	V_{ult}(ton)	Δ_y(mm)	Δ_{ult}(mm)	μ	R
58.43	297.7	313	80.67	87.77	1.09	5.54

Fig. 12: Pushover output for Type C @ X-Dir



At Yield StageAtUltimate Stage



V$_{des}$(ton)	**V**$_{y}$(ton)	**V**$_{ult}$(ton)	**Δ**$_{y}$(mm)	**Δ**$_{ult}$(mm)	**μ**	**R**
56.28	279.63	290.81	111.03	114.83	1.03	5.14

Fig. 13: Pushover output for Type C @ Y-Dir

As, Pervious procedure steps, applying for others. The following curves, Fig. 14 to 21 represents a comparison for pushover curves for different typical structures.

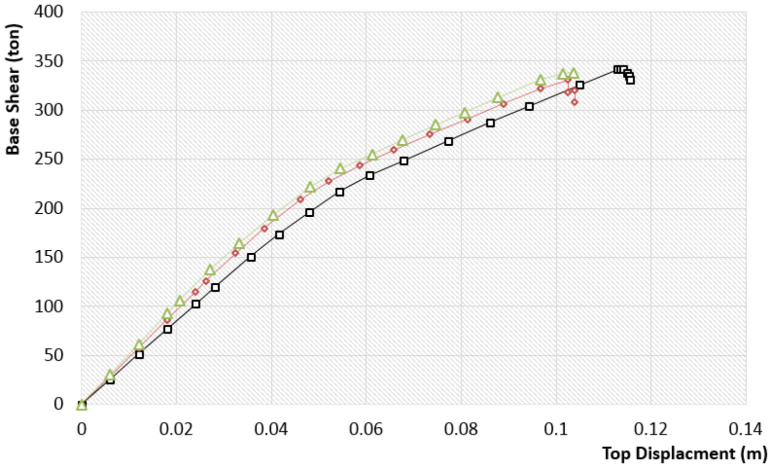


Fig. 14: Pushover Curves for Typical structures @ X-Dir (5 Stories – 0.15 PGA).

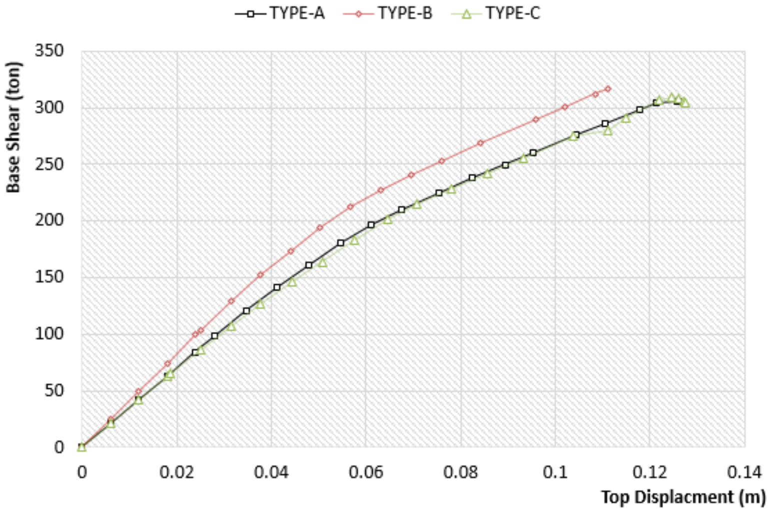


Fig. 15: Pushover Curves for Typical structures @ Y-Dir (5 Stories – 0.15 PGA).

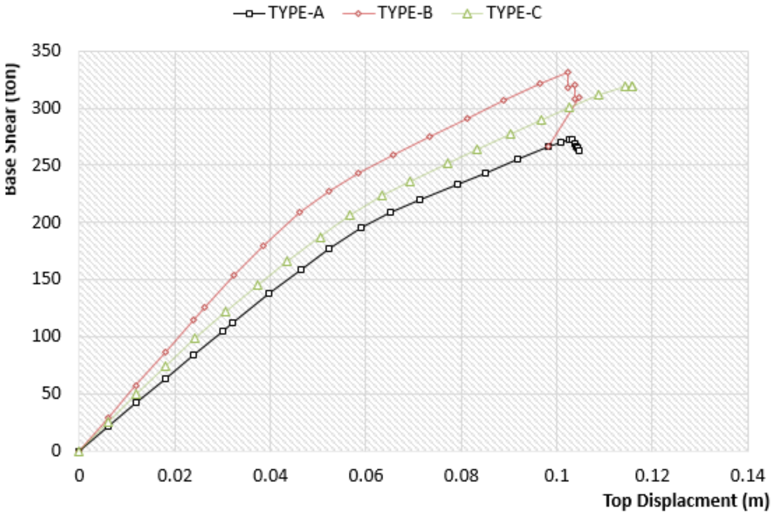


Fig. 16: Pushover Curves for Typical structures @ X-Dir (5 Stories – 0.20 PGA).

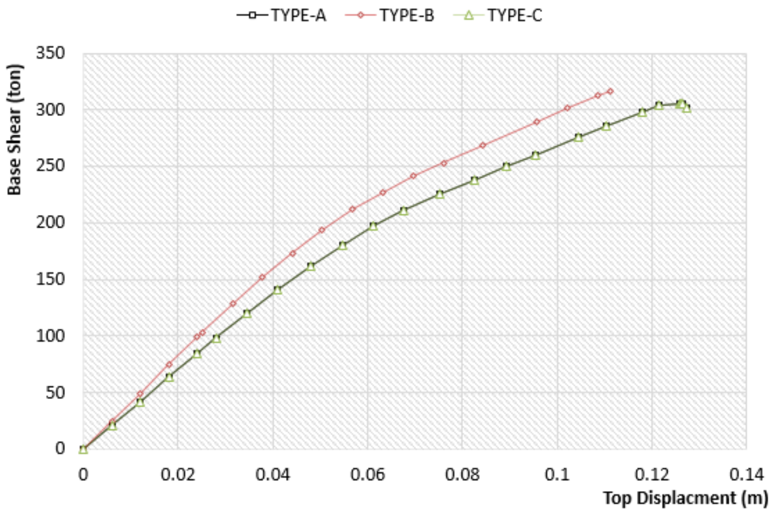


Fig. 17: Pushover Curves for Typical structures @ Y-Dir (5 Stories – 0.20 PGA).

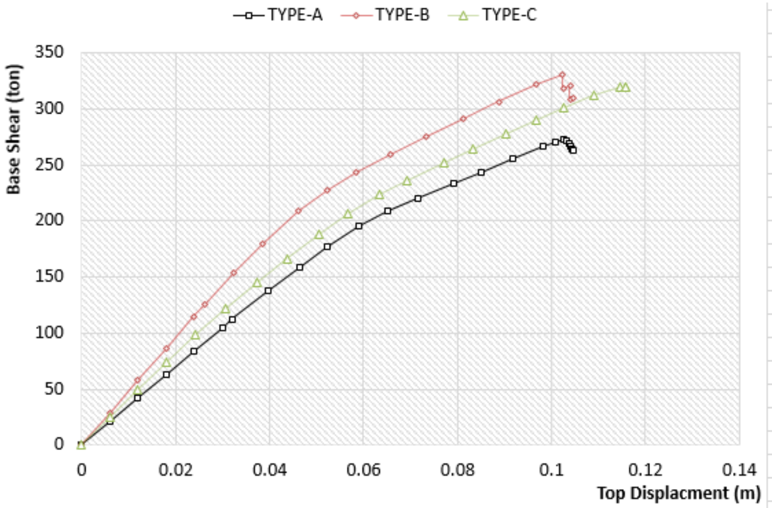


Fig. 18: Pushover Curves for Typical structures @ X-Dir (5 Stories – 0.25 PGA).

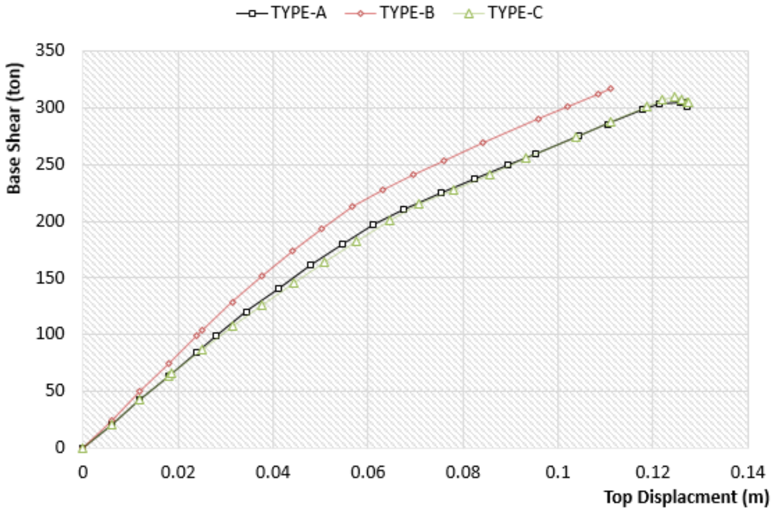


Fig. 19: Pushover Curves for Typical structures @ Y-Dir (5 Stories – 0.25 PGA).

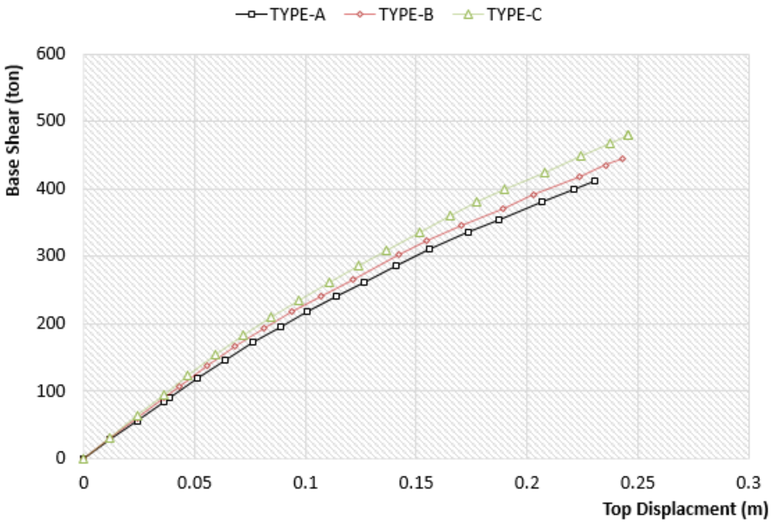


Fig. 20: Pushover Curves for Typical structures @ X-Dir (10 Stories – 0.15 PGA).

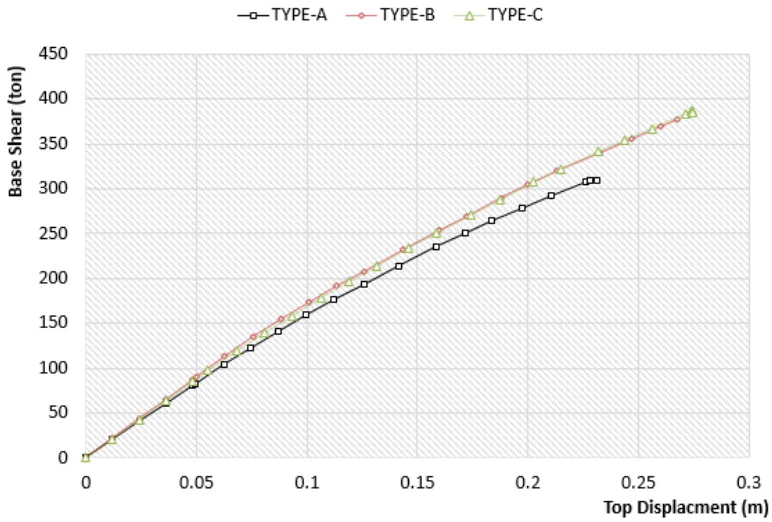


Fig. 21: Pushover Curves for Typical structures @ Y-Dir (10 Stories – 0.15 PGA).

The following Table 3& 4 represents a summery for Response modification factor for different typical structures with different PGA values.

Table 3: Response modification factor for different typical structures with different PGA @ X-DIR

MODEL (A) - 5 STORIES								
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	μ	Ω	**R**	**PGA**
303.92	325.61	55.17	94.19	104.91	1.11	5.51	**6.14**	**0.15g**
287.06	314.25	75.05	85.10	98.28	1.15	3.82	**4.42**	**0.20g**
287.06	314.25	90.32	85.10	98.28	1.15	3.18	**3.67**	**0.25g**
MODEL (B) - 5 STORIES								
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	μ	Ω	**R**	**PGA**
306.46	321.70	58.43	88.91	96.62	1.09	5.24	**5.70**	**0.15g**
306.46	321.70	77.91	88.91	96.62	1.09	3.93	**4.27**	**0.20g**
306.46	321.70	97.39	88.91	96.62	1.09	3.15	**3.42**	**0.25g**
MODEL C - 5 STORIES								
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	μ	Ω	**R**	**PGA**

297.7	313	56.8.43	80.67	87.77	1.09	5.09	**5.54**	**0.15g**
290.00	301.26	75.00	96.72	102.72	1.06	3.87	**4.11**	**0.20g**
290.00	301.26	93.80	96.72	102.72	1.06	3.09	**3.28**	**0.25g**

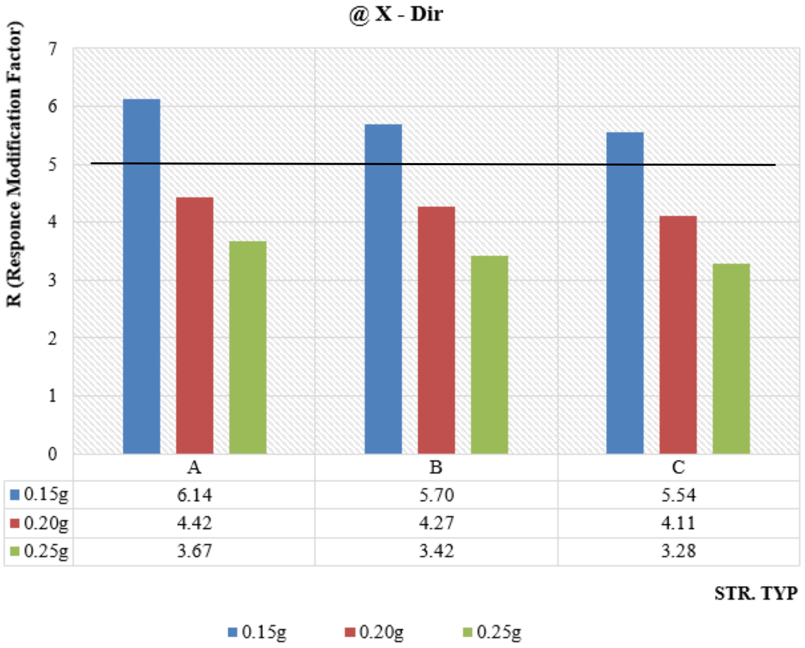


Fig. 22: Comparison for Response modification factor for different PGA @ X-Dir.

Table 4: Response modification factor for different typical structures with different PGA @ Y-DIR

MODEL (A) - 5 STORIES								
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	μ	Ω	**R**	**PGA**
275.92	298.44	55.17	104.47	117.85	1.13	5.00	**5.64**	**0.15g**
275.92	298.44	75.05	104.47	117.85	1.13	3.68	**4.15**	**0.20g**
275.92	298.44	90.32	104.47	117.85	1.13	3.05	**3.45**	**0.25g**
MODEL (B) - 5 STORIES								
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	μ	Ω	**R**	**PGA**
289.72	301.27	58.43	95.80	102.12	1.07	4.96	**5.29**	**0.15g**
289.72	301.27	77.91	95.80	102.12	1.07	3.72	**3.96**	**0.20g**
289.72	301.27	97.39	95.80	102.12	1.07	2.97	**3.17**	**0.25g**
MODEL C - 5 STORIES								
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	μ	Ω	**R**	**PGA**
279.63	290.81	56.28	111.03	114.83	1.03	4.97	**5.14**	**0.15g**
275.92	298.44	75.00	104.47	117.85	1.13	3.68	**4.15**	**0.20g**
287.83	301.81	93.80	111.03	118.83	1.07	3.07	**3.28**	**0.25g**

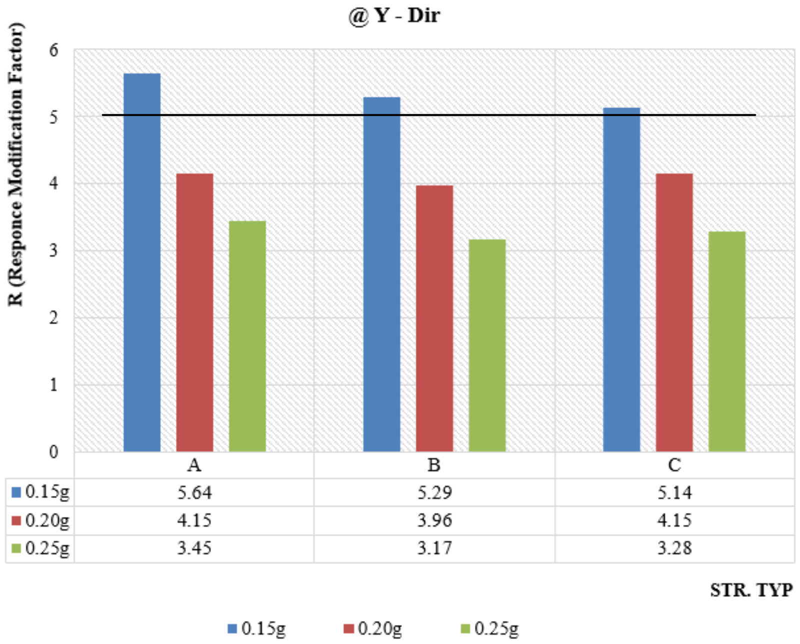


Fig. 23: Comparison for Response modification factor for different PGA @ Y-Dir.

It founded that from pervious results,the plan dimensions significantly influence the seismic behavior of the buildings.When degree of torsional irregularity increases, R factor decrease. And Seismic zone factor significantly influences in R factor value. So,when PGA values increases, R factor decrease.

The following Table 5& 6 represents a summery for Response modification factor for different typical structures with 10 stories Height.

Table 5: Response modification factor for different typical structures with 10 stories @ X-DIR

MODEL (A) - 10 STORIES							
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	µ	Ω	**R**
380.02	399.84	71.04	207.00	221.34	1.07	5.35	**5.72**
MODEL (B) - 10 STORIES							
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	µ	Ω	**R**
376.54	401.02	74.72	201.25	218.83	1.09	5.04	**5.48**
MODEL C - 10 STORIES							
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	µ	Ω	**R**
358.75	383.04	74.59	181.56	199.01	1.10	4.81	**5.27**

Table 6: Response modification factor for different typical structures with 10 stories @ Y-DIR

MODEL (A) - 10 STORIES							
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	µ	Ω	**R**
326.90	344.39	71.04	236.04	260.49	1.10	4.60	**5.08**
MODEL (B) - 10 STORIES							
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	µ	Ω	**R**
320.41	333.13	74.72	222.31	234.40	1.05	4.29	**4.52**
MODEL C - 10 STORIES							
Vy (ton)	Vmax (ton)	Vdes (ton)	Disp(mm)Y	Disp(mm)Max	µ	Ω	**R**
348.79	383.09	74.59	243.46	257.71	1.06	4.68	**4.95**

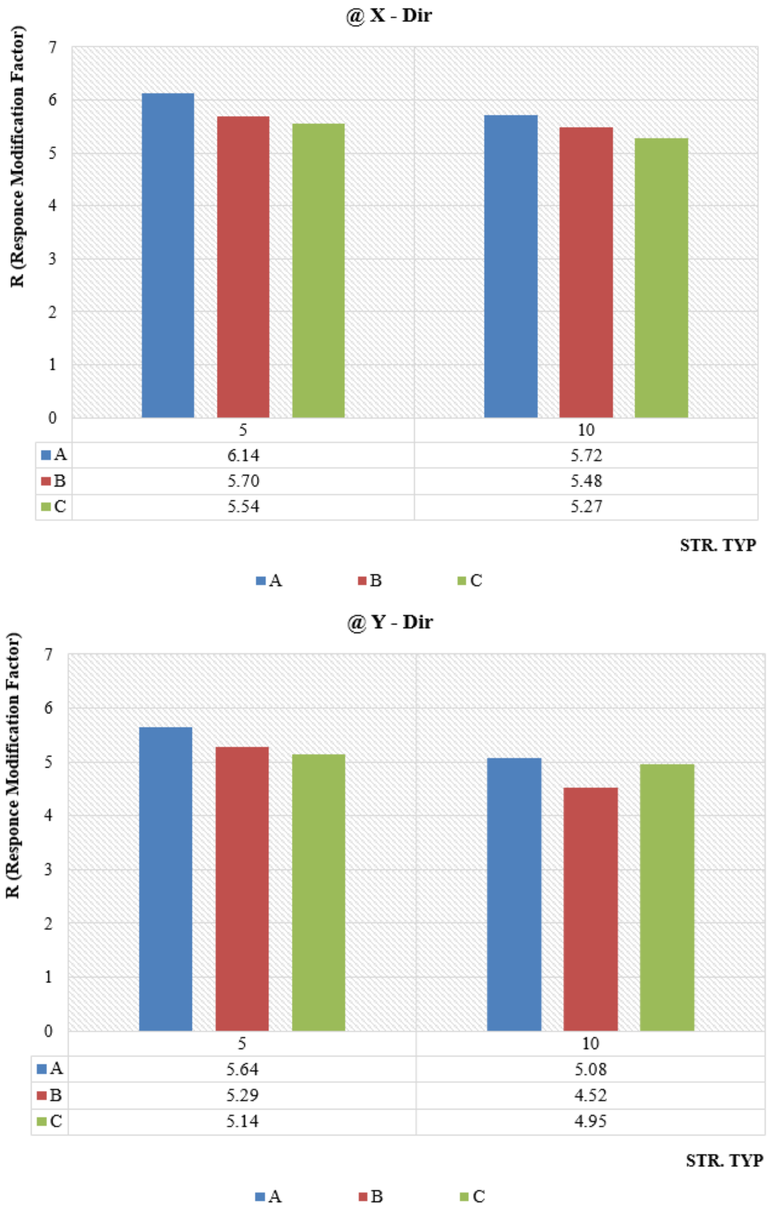


Fig. 24: Comparison for Response modification factor for different stories Height.

It founded that from pervious results,the stories height significantly influence the seismic behavior of the buildings.As number of story increases, the value of response reduction factor goes on decrease.

VI. Conclusion

Seismic torsional response for irregular structures has been a major cause of structural failure in every earthquake.Because torsional response changes the uniform translational seismic floor displacements and causes concentration of demand in elements at the perimeter of the building.

Irregular structures are more used in new architectural design. In these structures the torsion phenomenon can induce large stresses.Seismic codes try to take into account the torsion effect during modeling; however it is difficult to include all the parameters that affect the behavior of this type of structures.

In this paper, The Geometry effect of RC building structures for predicting the seismic responses were investigated. This study aims to introduce a reference for seismic design for plan irregular structures taken the effect of torsional behavior under seismic forces for geometry changes although same Area. The results of this study show that, ThePush over Curves differ from shape to another although same base area. The building height significantly influence on response modification factor. The elements on perimeter should be necessary consider torsional effects due to early plastic deformations.

The evaluated values of “R” in the present work were obtained by nonlinear static (pushover) analysis of structures with plan irregularities are found to be less than as those specified in ECP-201. So, it’s very important to evaluate the response reduction factor related to torsional irregularity level due to building geometry.

Finally, the architect and engineer should both employ ingenuity and imagination of their respective disciplinesto reduce the effect of irregularities, or to achieve desired aesthetic qualities without compromisingstructural integrity.

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