IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 5 Ser. IV (Sep. - Oct. 2019), PP 40-55
www.iosrjournals.org

Torsional Behavior of Irregular Structures during Earthquakes

Dr. Gamal Hussein[1],Dr. Nasr Eid[2]and Hussein khaled[3]
[1](*Structural Engineering Department, Faculty of Engineering / Ain shams university, Egypt)*
[2](*Structural Engineering Department, Faculty of Engineering / Ain shams university, Egypt)*
[3](*Structural Engineering Department, Faculty of Engineering / Ain shams university, Egypt)*

Abstract: *Many buildings in the present days have irregular shapes in both elevation and plan. Past earthquake studies show that buildings suffer severe destruction during earthquakes due to torsional irregularity.When and how to consider torsion effects is depended on the criterion andrelative restrictions for torsional irregularity. Relationship between the degree of irregularity and the change in behavior could developed which allows guidance as to a) When the effect of structural irregularity can be neglect, andb) The change in demands for different degrees of structural irregularity. Provisions in different earthquake codes about torsional irregularity are presented. This study was initiated to define the effect of different degrees of irregularity on structures designed for earthquake by investigation torsional irregularity behavior of different irregular structures using simplified analysis.At first focuses in studying the complex behavior of structure under asymmetric form; a study on the influence of the torsional moment effects on the behavior of structure is done by using Response spectrum method. Results are compared and precautions are given to avoiddamages caused by torsional irregularity under earthquake loads.Also, a simplified nonlinear pushover method has been used to determine inelastic behavior of irregular structures due to seismic load to reach collapse case, find the irregularity relation with successiveplastic hinges formations in structural elements and determined response reductions factor for different irregular structures to evaluate the relation with irregularity level. The results presents that buildings with severe irregularity are more suffering than those with regular or less irregularity resulting from torsion behavior, plastic hinges formation in structural elements rapidly formed with increasing irregularity level Also, Response reduction factor varies with irregularity level which as irregularity degree increase, the response reduction factor decrease.*

Keywords: *Torsional irregularity, Torsion, Failure analysis, Earthquake design, Response reduction factor, Floor rotations and irregular structure.*

Date of Submission: 20-10-2019 Date of acceptance: 02-11-2019

I. Introduction

The interest in better understanding of the seismic behavior of reinforced concrete building structures has increased in the past decade. Damage reports on past earthquakes have presented that one major cause of collapse in RC framed structures is the torsional response of the buildings.

Geometric irregularities, in plan of the structures can effect accidental torsion of floor diaphragm during seismic load. The difference between the center of rigidity and center of mass of the diaphragm will produce extreme additional forces due to lateral load.Seismic provisions specify typically standards for the design of new structures subjected to seismic loads with two goals[5]:

1- Minimize the danger to life associated to all structures types,
2- Developed the predictable performance of structures having an essential public hazard due to the specific occupancy or use.

.

Nowadays no real structure is perfectly regular as a result of non-uniform mass, stiffness, strength, structural form, or a grouping of these in the horizontal or vertical directions. Also structures with a high level of irregularity have the opportunity of behaving significantly differently than that of a regular structure[4]. This different behavior may result in larger demands and less safe irregular structures.So, provisions and precautions for the design of RC structures with structural irregularity appear in the most of the international codes for concrete buildings design.

Earthquake field surveys time after time confirm that irregular structures suffer more damage than their regular structures. Torsional behavior is one of the most significant factors, which produces damage (reached collapse) for the structures. A great number of studies presented which explorevarious aspects of torsional irregularity. So, the number of publications started rapidly growing as indicated in the histogram of fig: 1.

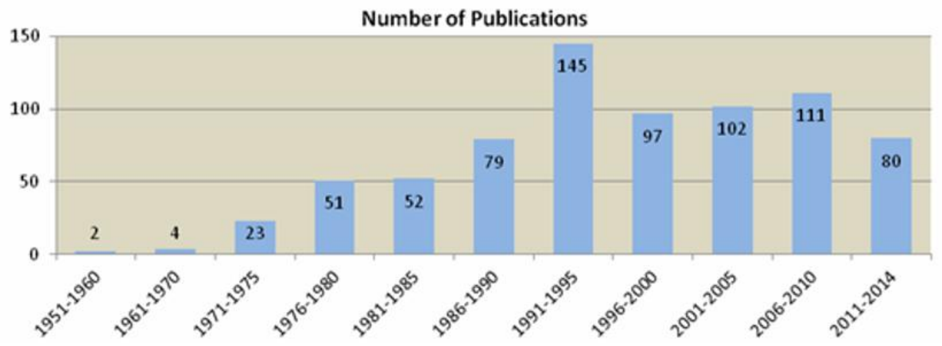


Fig. 1: Histogram of time of publications distribution on building torsion[1].

Many research studies have been carried out regarding the torsional effect of the multi-story structures. Anil Chopra and RakeshGaelevaluate the effects of plan asymmetry on the earthquake response of code designed, one story systems and to estimate how well these effects are signified by torsional provisions in building codes [2]. NFALLAH, POURZEYNALI and HAFEZI determineaccuracy Estimation of the Modal Pushover Analysis Method in the Prediction of Seismic Response of Vertically Irregular Frames [3]. Tezcan and Alhan have induced an increase in the estimatingeccentricity to confirm an added and inherent safety for the flexible side elements [4].Momen Mohamed, Shehta abd 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 Gharai have determined the seismic behavior of three intermediate moment-resisting concrete frames with irregular plan by using pushover analysis [6]. Yasser Al-Ashker, Sohaib Nazar & Mohamed Ismail represent a determination 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. Benavent Climent and L. Morillas represent an experimental study for seismicinelastic response of symmetric reinforced concrete frame structures by shaking table tests [9].Vipin Gupta and Dr. Pajgade presented a study about the determination done on torsional behavior of multistory buildings with plan as well as vertical irregularities [10].Amin and Alavi made an attempt to realize the seismic response of the structures, for various location of shear walls on RC building having re-entrant corners on high seismic zones [11].Stathopoulos and Anagnostopoulos used one, three, and five-story R.C frames with plastic lumped models of column and beams elements to assess the importance of accidental torsion designshow that the inclusion of accidental torsion in design does not improve the seismic performance of these buildings [12].

This paper objective is to investigate of the effects of irregularities on the spread of damage in progressive collapse and the effects of seismic loads on this damage through the assessment of elastic and inelastic behavior of different irregular structures compared to symmetric one to present the difference. So, to grasp the torsional irregularity behavior, the study done through evaluation of the base shear forces due to torsion action at base and each story level by story shear, structure performance due to irregularity in terms of lateral story displacement, torsional irregularity ratio and floor diaphragm rotation for different irregular structures. For evaluation the inelastic behavior, response modification factor values have been compared to understand more about torsional effects on performance base design. 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. Torsional Irregularity of structures

Building design and construction isarranged by codes. Most of the building codes identifytorsional behavior due to irregularity is one of the serious effects in buildings. The evaluation of torsional provisions in buildings codes founded on estimated responses of elastic as well as inelastic for asymmetric systems. This study briefly summarize the difference between three main codes used widely by Egyptian structural engineers (Egyptian code (ECP201)[15]-European code (EC8)[16]- American code (ASCE7)[17]). For that the study represent the points of view of three codes for “Torsional Irregularity”.

A) **Irregularity Types:**defined asany structure that has nature eccentricity. Most of codes produce criteria to judge structures from being regular or irregular structures.

This irregularity are classified as the following: First; the vertical irregularities that refer to sudden change of geometry , strength, stiffness and mass result in irregular spreading of forces over the height of the structure. Second; the plan irregularities which indicate to unsymmetrical plan shapes or discontinuities in the horizontal members (diaphragms) such as large openings, cut-outs, re-entrant corners and other unexpectedmodifications resulting in torsion, stress concentration and diaphragm deformations [18]. The presence of irregularities is considered as a major defect in the behavior of structures during earthquakes.

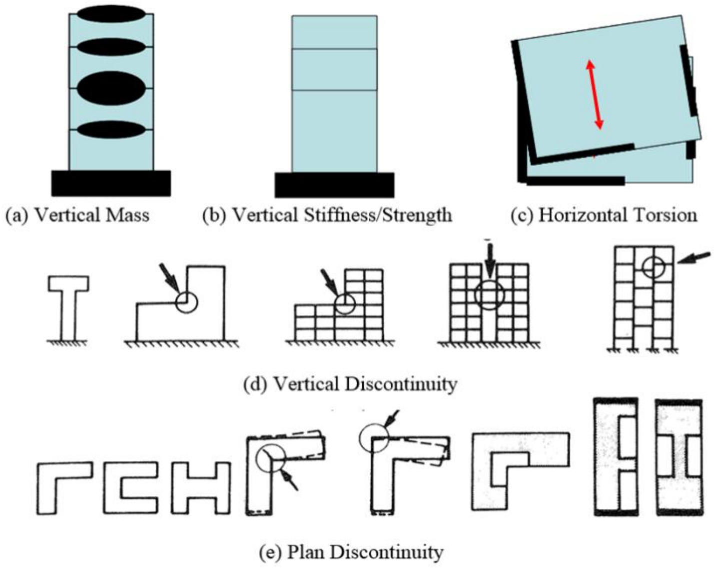


Fig. 2: Irregularity Types [18].

B) Code provisions for torsional behavior of structures

Torsion:is a twisting around longitudinal axis.Torsion occurs due to eccentricity creation on Structures due to two types of eccentricity which stated at most international codes.

Types of eccentricity

1. **Natural Eccentricity**: Due to The difference between center of Mass (C.M) and center of stiffness (C.S).

Where:

- (C.M) center of mass is: the location where the objectwill have an equally distributed mass in all directions from that point.
- (C.S) center of stiffness is: the point where whole bodyhave fully resisting against rotation.

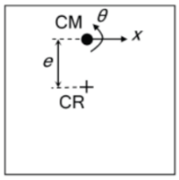


Fig. 3: Nature eccentricity

2. **Accidental Eccentricity**:Due to neglecting some factors that control Symmetry of structure such as,

- Stiffness: Error in geometry, material & nonstructural building can be considered.
- Mass : Error in mass distribution & Live load location.
- Strength: Unbalanced yielding take place in elements under severe EQ.

Most of codes use restricted values for accidental eccentricities through the moving of the center of mass of the floor in the perpendicular direction to the seismic analysis.

- Egyptian code (ECP201) as well as European code (EC8) determine two ways of analyzing accidental eccentricity, separating them into (static andsimplified analysis).

1) **Static analysis:** by producing an accidental torsion moment (Z-axis) in the center of gravity of each floor. This moment due to accidental torsion is estimated through the multiplication of accidental eccentricity (±5 % L) by the force got by the seismic action.

2) **Simplified analysis**: by increasing the forces and stresses in structure elements by a coefficient “δ”.

$$\delta = 1 + 0.6\frac{x}{L_e} \quad (1)$$

Where:

X: Distance of the element from the center of thebuilding measured perpendicular to thepath of the seismic action considered.

L_e: Distance between the two outer most lateral load resisting elementsmeasured perpendicular to the path of the seismic actionconsidered.

- Regarding to American code (ASCE7-16), the accidental lateral load eccentricities of ±5% are improved by the amplification factor.

$$A = \frac{\delta_{max}}{1.2\,\delta_{avg}} = \frac{\eta}{1.2} \qquad (2)$$

Where

η = Torsional irregularity coefficient which consider as criterion of torsional irregularity in ASCE code.

δ_{max} = the maximum displacement at Level x estimated assuming A_x = 1,

δ_{avg} = the average of the displacements at the extreme points of the structure at Level x computedassuming A_x = 1.

As shown in figure. 4

The torsional amplification factor (A_x) shall not be less than 1 and is not exceed 3.0.

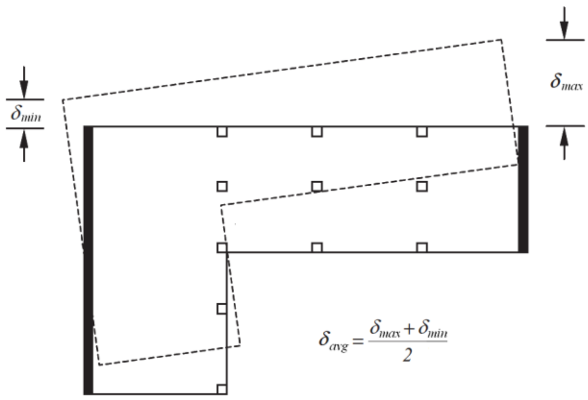


Fig. 4: Extreme displacement and average displacement [17].

III. Methods of Seismic Analysis

The selection of a suitable process to evaluate performance of structures under seismic loads is one of the most importance issues that structural engineers face. This would be especially important when dealing with irregular buildings, as the wrong choice of a procedure would lead to results that are remote from the real behavior. In this study three methods used to evaluate irregular structures behavior during seismic forces. Those methods are Equivalent static method – Response spectrum method – Nonlinear static Pushover analysis method.

1- **Equivalent static method:** Along any principal direction, the total design lateral force is produced in terms of seismic weight of the structure and design horizontal seismic coefficient. Design of horizontal seismic coefficient be subject toimportance of the structure,force reduction factor of resisting elements for lateral load, the zone factor of the site, and the fundamental period of the structure. As following the base shear equation according Egyptian code ECP-201[15].

$$V = \frac{W}{g} S_d(T)\, I\, \frac{1}{R} \qquad (3)$$

Where

W: Seismic structure weight.

S_d(T): Ordinate of the horizontal design spectrum for elastic structuralanalysis·.

R **:**Response modification factor (force reduction) according to thebuilding structural system

I **:**Importance factor for the structure.

2- **Response Spectrum Method:** is a method of determination of maximum responses (displacement, velocity and acceleration) of a group of SDOF structures subjected to a specified ground motion. The RSM (response spectrum method) give the structural designer a set of possible forces and deformations for design procedure [15].

3- **Non-Linear Static Push-over Analysis:** is a static nonlinear analysis below vertical loads and gradually growing lateral loads. The equivalent static lateral loads approximately represent earthquake persuaded forces. A curve of the total base shear vs. top displacement in a structure is determined by this analysis that would specify anyweakness or early failure. The analysis is carried out up to collapse, thus it enables evaluation of failure load and ductility demand. On a building frame, plastic rotation is controlled, and lateral inelastic forces vs. displacement response for the complete structure are analytically estimated. A performance check proves that structural and nonstructural components are not damaged beyond the acceptable limit of the performance objective for the forces and displacements implied by the displacement demand [13]. The pushover curve produces the lateral displacements as the function of force determined to the structure. Position of hinges in different stages can be evaluated from pushover curve as shown in Fig. 5. The AB range is elastic variety, B to IO is the immediate range of occupancy, IO to LS is the life safety range, and LS to CP is the collapse prevention range (ATC-40) [26]. If all the hinges are within the CP boundary then the building is said to be safe. But, regarding to the importance of building, the hinges after IO range may also require to be retrofitted.

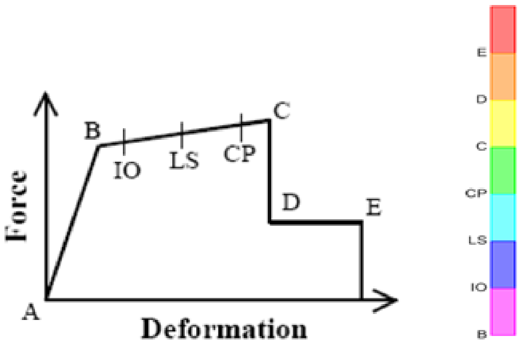


Fig. 5: Deformation relation and target performance levels

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 [14].

Fig. 6 Represent the relationship between(R) factor,over strength (R_s) and ductility (R_μ)

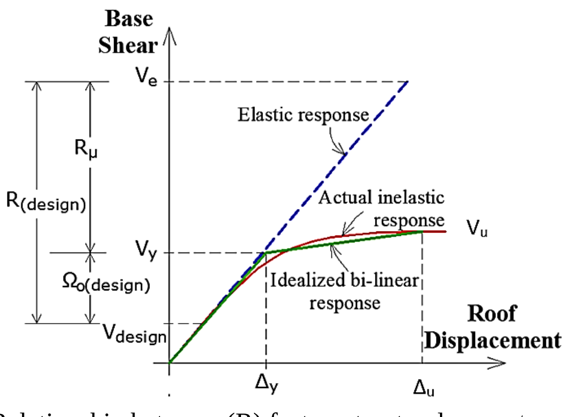


Fig. 6: Relationship between (R) factor, structural over-strength (Ω), and ductility reduction factor (Rμ)[14].

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

$$R = R_S\, R_R\, R_\mu \qquad (4)$$

Where:

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

$$R_s = {}^{V_y}\!/_{V_d} \quad (5)$$

R_R:This factor is intended to quantify the improved reliability of seismic framing system that uses multiplelines 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 [27]). Researchers represented different formulations in order to estimate the ductility reduction factor Rμ, (Newmark and Hall, (1973) [28]; Uang (1991) [29], Paulay and Priestly, (1992) [30], Miranda and Bertero, (1994) [31]; Kappos (1997) [32], Priestley, (2000) [33]; Elnashai and Mwafy (2002) [34], Mondal et al (2013) [35],

In this study, the formulation recommended byPriestley and Paulay (1992) [30] is used.

Rμ = 1.0 for zero-period buildings.

Rμ = $\sqrt{2\mu - 1}$for short-period building.

Rμ = μ for long-period building.

Rμ = 1+ (μ-1) T/0.70 (0.70 < T < 0.30) (6)

Where

Rμ is the ductility reduction factor and μ is the displacement ductility.

IV. Numerical application for irregular structures

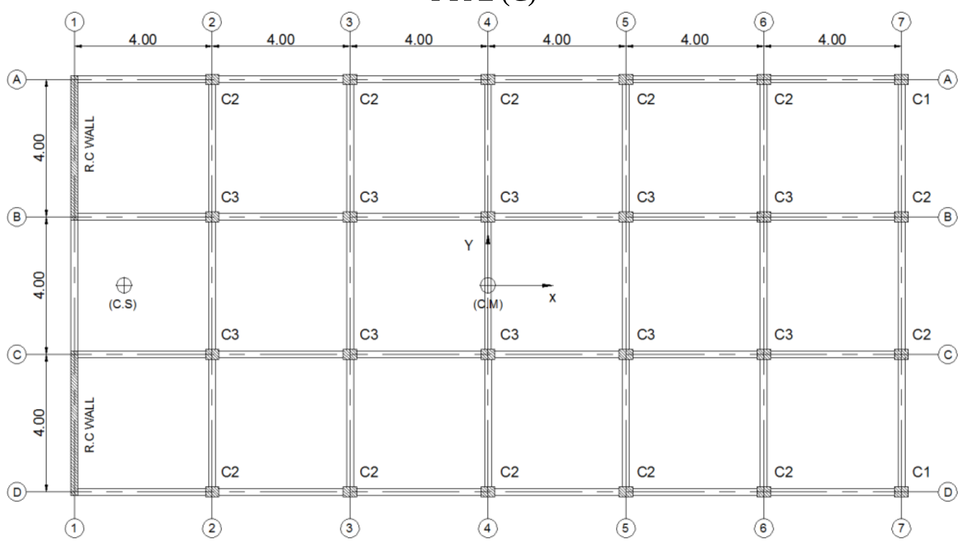
A) Description Of Buildings Model Designed According To Egyptian Code

A parametric study was performed to understand torsional behavior effects on different structures using finite element analysis by ETABS structural analysis software package (2017).Fourgroups' typical structures, whichare selected to carry out the parametric study, are chosen as multi-story buildings composed of frames and walls.The typical structures are selected as having unsymmetrical walls. All structures are having 7 axes in direction X, which are designated as types A, B, C and D, as shown in Fig. 7

TYPE (A)

TYPE (B)

TYPE (C)



TYPE (D)

Fig. 7: Floor Plans of Typical Structures.

Structure (A) is symmetric one and types (B, C and D) are obtained by shifting R.C walls in direction X. All wall thicknesses are 25 cm, Slabs 15 cm and beam cross sections are 25x50. Column dimensions vary as shown in table 1.

Table 1: Columns cross sections (Dimensions in cm)

Total number of stories	story No.	C1	C2	C3
3	1 ~ 3	30x30	30x30	30x30
7	1 ~ 4	30 x 40	30 x 40	40 x 40
	5 ~ 7	30 x 30	30 x 30	35 x 35
11	1 ~ 4	30 x 50	30 x 60	45 x 45
	5 ~ 7	30 x 45	30 x 50	40 x 40
	8 ~ 11	30 x 40	30 x 40	35 x 35
15	1 ~ 4	30 x 70	30 x 70	40 x 70
	5 ~ 7	30 x 60	30 x 60	40 x 60
	8 ~ 11	30 x 50	30 x 50	40 x 50
	12 ~ 15	30 x 40	30 x 40	40 x 40

The arrangement of Types according to irregularity level is as following from high to low degree (D, C, B Then A). Type D is the highest one & Type A is the lowest one.Structure types B, C and D are obtained by shifting the centers of gravity of walls by 4m, 8m and 12m modules, respectively.

The RC building has a story height of 3 m. Dead load and live load are 2.5 kN/m^2 and 2.0 kN/m^2, respectively. The material properties used are: f_{cu} = 25 MPa for concrete and f_v = 360 MPa for reinforcement. 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 shear wall and slabs are simulated with shell element. Seismic limits used in the analysis and design of typical structures are as follows 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%
Section Modifier for Elastic investigation	SLAB : 0.25
	BEAM: 0.50
	COLUMN: 0.70
	WALL: 0.35
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

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 0.60 to 0.80.

B) Cases of study

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

1-Elastic behavior Investigation:

To study torsional behavior related to the following aspects:

-***Fundamental Time "T":***Compare the empirical equation of fundamental period of vibration (T) given by the code and the accurate value calculated by Etabs software for different structures type.

- ***Story Drift:*** compare the story drift value for different structures type.

- ***Torsional irregularity factor"η":*** compare the torsional irregularity factor values for different structures type.
- ***Floor diaphragm rotation"Ɵ" :*** compare the Floor diaphragm rotation for different structures type.

2-In-elastic behavior Investigation:
Perform nonlinear pushover static analysis to estimate response modification factor R for different irregular structure.

C) Results& Discussions
Many factors play essential role in the response of structural systems subjected to Acting loads such as,

1- Periodic Time (T)

The period of vibration is a fundamental factor in thebased force design of structures as it describes the spectral acceleration and the force of base shear to which the building should be designed.The fundamental period of vibration "T" is a function of *M* and the stiffness *k*of the lateral resisting system.The fundamental period in most of codes is functions of structure height such as ECP201 ($T = C_t \, x \, H^{0.75}$) is not influenced by the change of floor-plan stiffness or shape but depends only on the building height, *H* [5].

$$T = 2\pi/\omega \quad = 2\pi\sqrt{(M/k)} \qquad (7)$$

Where: ω is natural vibration frequency.

$$T_{codal} = C_t \text{ x } H^{0.75} \qquad (8)$$

Where: H is building height.

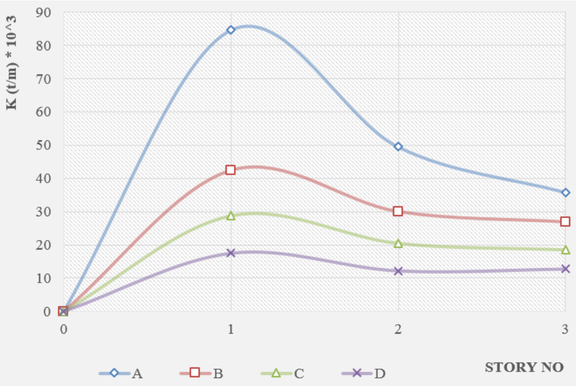
In both regular and irregular buildings, the empirical code expression get shorter than computed from structure models as shown in table 3.Which introduce more conservative forces on structures that need more stiff lateral systems to resist this forces which increasing the cost of structure. But in reality there is a large differencebetween the fundamental period of empirical code period height equation and the period of vibration from modal analysis.

Table 3: Fundamental periods

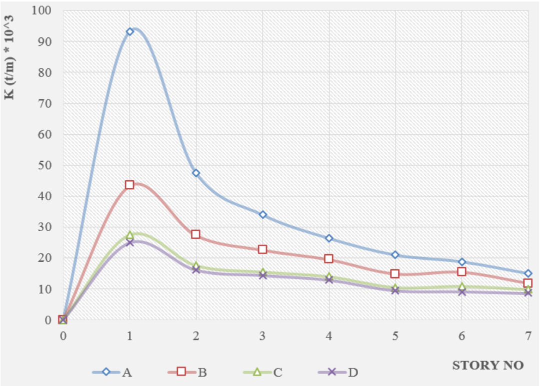
No of Stories	Empirical Code Value	1st Mode (sec)				2nd Mode (sec)			
		TYPE A	TYPE B	TYPE C	TYPE D	TYPE A	TYPE B	TYPE C	TYPE D
3	0.39	0.64	0.64	0.64	0.62	0.60	0.60	0.61	0.61
7	0.74	1.44	1.42	1.42	1.37	1.19	1.21	1.24	1.26
11	1.03	2.13	2.12	2.10	2.00	1.63	1.70	1.73	1.76
15	1.30	2.87	2.86	2.83	2.69	2.10	2.20	2.24	2.27

As the floor-plan irregularity increases, the fundamental period of the structural model decreases

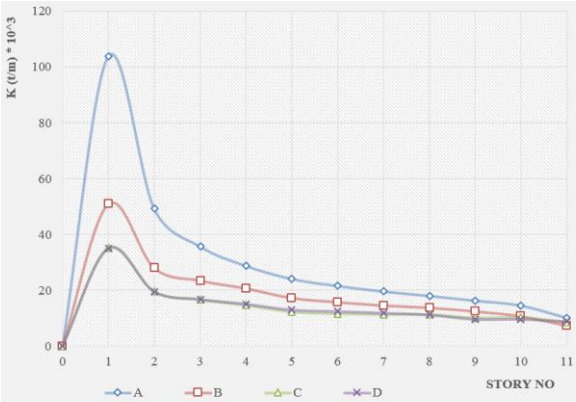
The empirical value may be sensible for buildings which have a small eccentricities of the center of story stiffness with the center of floor mass. It is rather obvious that if the eccentricities are large, lateral and torsional motions will be strongly coupled [8]. According to curves in Fig. 8, as irregularity & eccentricities increase the lateral floor stiffness decrease.



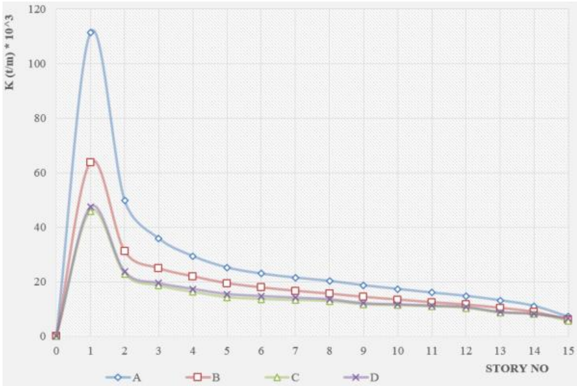
(a) 3 stories



(b) 7 stories



(c) 11 stories



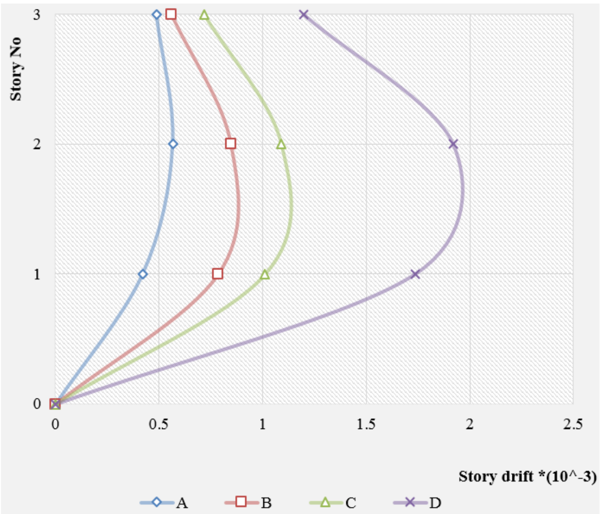
(d) 15 stories

Fig. 8: Floor stiffness's for Typical Structures

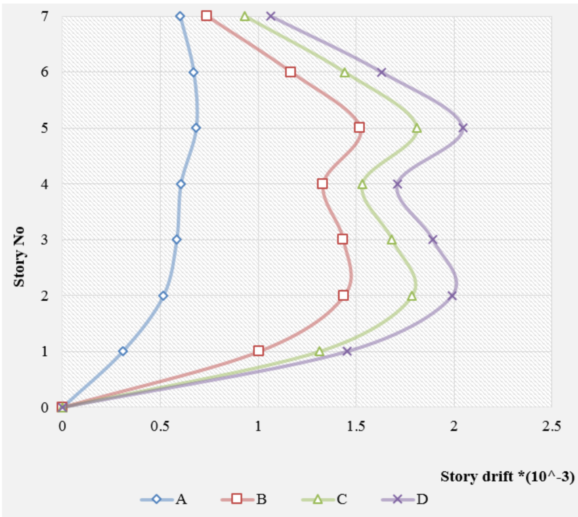
Therefore, if the flexural stiffness of slabs in structural system is totally ignored, the lateralglobal frames stiffness may be underestimated [18]. According to table 3 shows the comparison between the codal and analytical fundamental vibration period; codal period calculated from conventional method neglecting effective parameter which is building's irregularity. But for analytical values, floor plan shape had been assigned as a vital factor whereas the fundamental vibration period had been reduced by increasing the accidental irregularity, stated significant defect in calculation of vibration period which is considered themain parameter for lateral force procedure.

2-Story Drift (d_r)

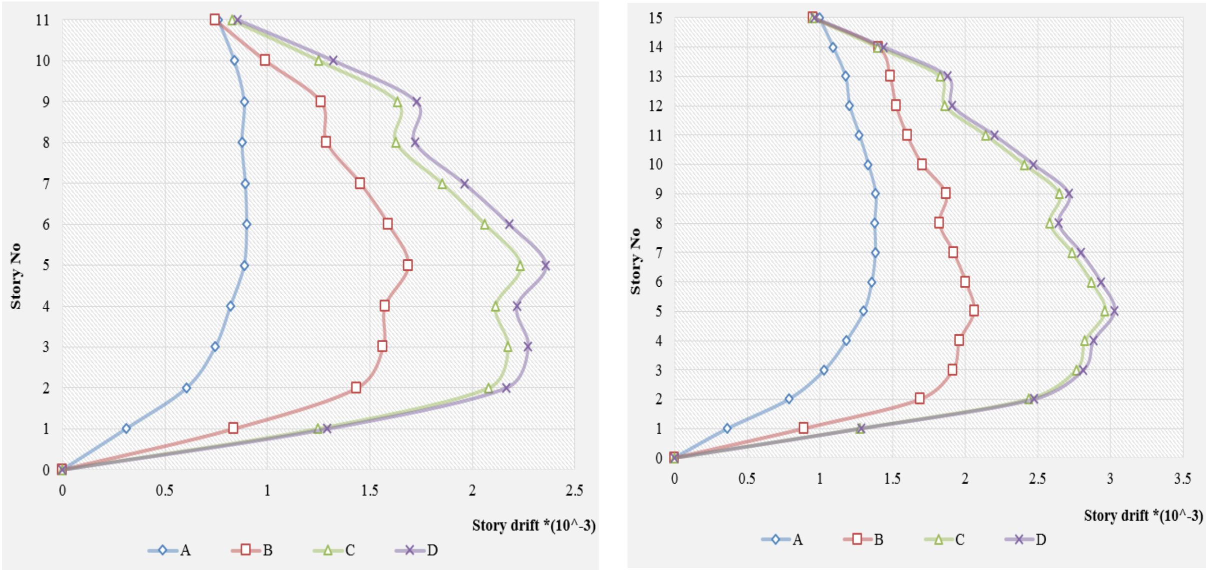
Story drift ratio is the maximum relative displacement of each floor divided by the height of the same floor is an important parameter that has been evaluate. According to the response spectrum analysis method the following Fig. 9represents the stories drift for studied structures.



(a) 3 stories



(b) 7 stories



(c) 11 stories (d) 15 stories

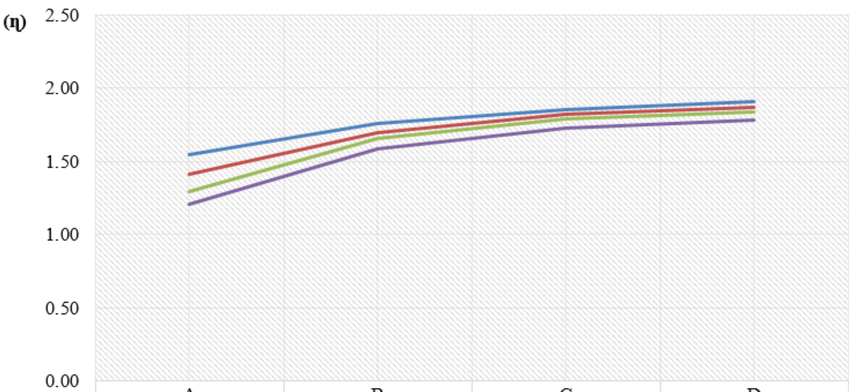
Fig. 9: Story Drift for Typical Structures

According to the pervious results. Total story drift responses increase as the floor plan irregularity gradually increase. Story drift response along the height of the building shows that the middle stories are more affected than Lower and upper stories.

3-Torsion Irregularity Factor "η"

Torsional irregularity factor is one of the most important factors to consider structure irregularity. Torsional Irregularity Ratio is definite that where the maximum story drift, estimatedcontaining accidental torsion, at the end of the structure transverse to the average of the story drift at the end of the structure.

The following Fig. 10 represents the torsional irregularity factors for different typical structures



	A	B	C	D
3	1.55	1.76	1.85	1.91
7	1.41	1.70	1.82	1.87
11	1.29	1.66	1.79	1.84
15	1.21	1.58	1.72	1.78

Fig. 10: Torsional irregularity factor for typical structures

It observed that from pervious results:

- For all the investigated structures, torsional irregularity coefficient"η" increase as the story number decease.
- Max torsional irregularity coefficient"η" reach max values at lowest story number.
- As shown in Fig. 9 the torsional irregularity coefficient "η" differs from story to another. So, there is no clear which one should be considered.

From the previous points, it seems that the parameter η is not proper to represent the torsion effects of the structures and defined as the criterion of torsional irregularity [19].

4-Floor Rotation "Ɵ"

In the seismic analyses, it is assumed that the floors act as rigid elements in their own planes and the structures produce a displacement as shown in Fig. 11.

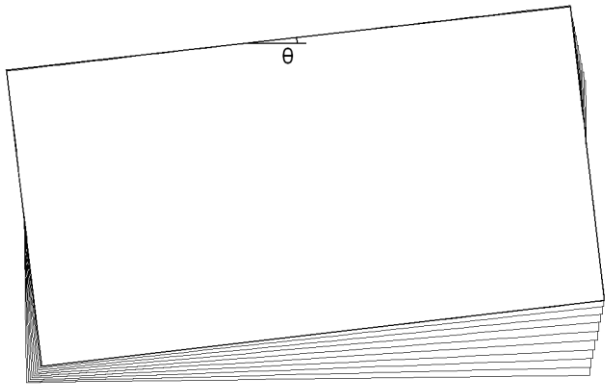
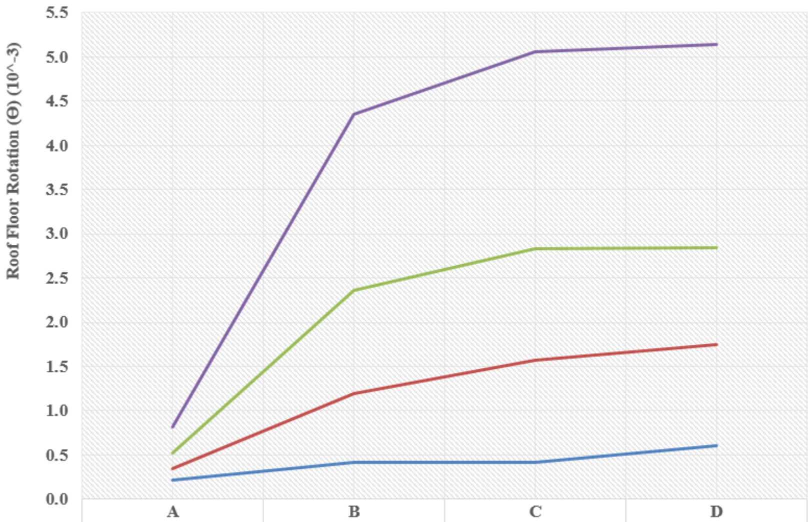


Fig. 11: Diagram Rotation prediction for rigid floor

Torsional diaphragm rotation is considered significant parameter to evaluate torsion moment plus probability of local failure for outer elements. The relationship for rotation "θ" about the center, moment "M" and the stiffness coefficient "K" is then determined for a unit rotation as M = K Ɵ

The following Fig. 12 represents the diaphragm rotation for different typical structures



	A	B	C	D
3	0.22	0.42	0.42	0.61
7	0.35	1.20	1.58	1.75
11	0.52	2.36	2.83	2.84
15	0.82	4.35	5.06	5.13

Fig. 12: Torsional Rotation prediction for rigid floor

It observed that from pervious results.

- For all the investigated structures, Floor Rotation "Ɵ" increase as the story number increase.
- Floor Rotation "Ɵ" reach max values at highest story number.

From the previous points, it seems that the parameter Ɵ is may be consider as the real criterion of torsional irregularity. This conclusion agree Nina and Zhihong [16] who studied alternative factor to represent irregularity in structures.The study reached that the dependency of "ɳ" as criterion for torsional irregularity not the ideal factor for representing torsional irregularity but it proposed the relative eccentricity which is the main factor cause floor rotations.

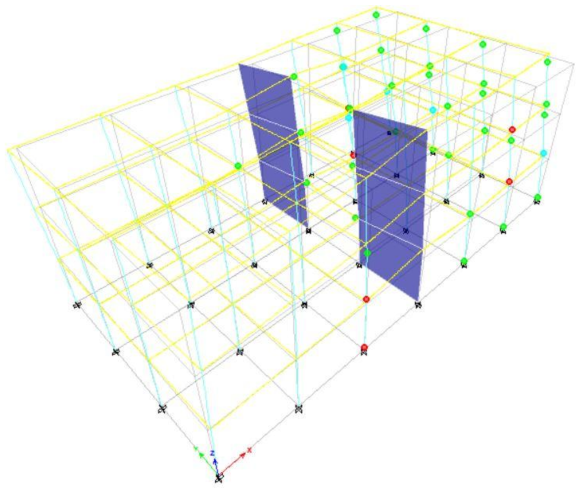
5- Response modification factor "R"

The response reduction factor or force modification factor (R) reflects the capacity of structure to energy dissipation through inelastic behavior. Over strength and ductility factors were obtained from nonlinear static pushover analysis that has been recommended in FEMA365 [17] and ATC40 [18]. The ATCand FEMA stated include modeling procedures, acceptance criteria and analysis procedures for pushover analysis.

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 [14]. Hinge status at yield and ultimate states for all the studied buildingshave been evaluated.

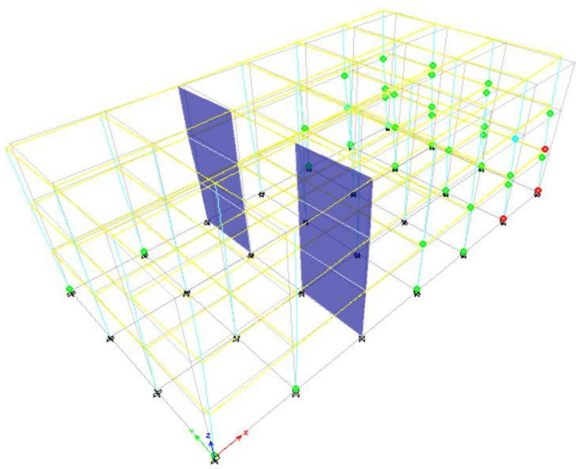
The following figures from Fig.13 show the procedure for determination for response modification factor for all studied structures.

Hinges Formation Type (A)



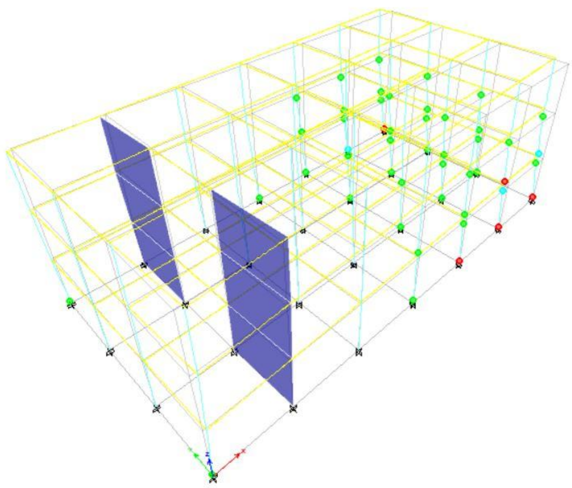
Du=55.25mm Vu=590.93 ton
Dy=51.18mm Vy=573.78 ton

Hinges Formation Type (B)



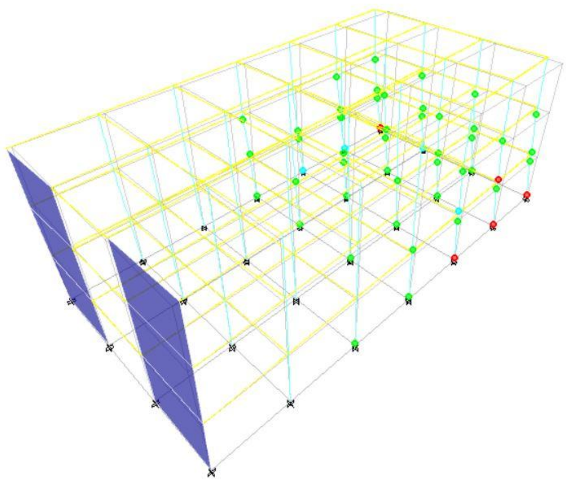
Du=80.42mm Vu=343.72 ton
Dy=43.69mm Vy=264.1 ton

Hinges Formation Type (C)



Du=81.12mm Vu=252.67 ton
Dy=49.85mm Vy=209.58 ton

Hinges Formation Type (D)



Du=86.78mm Vu=213.68 ton
Dy=57.40mm Vy=187.36 ton

Fig. 13: Pushover output for Typical structures (3 stories)

As, Pervious procedure steps, applying for other structures (7, 11 & 15 stories). The following curves, Fig. 14 to 17 represents a comparison for pushover curves for different typical structures.

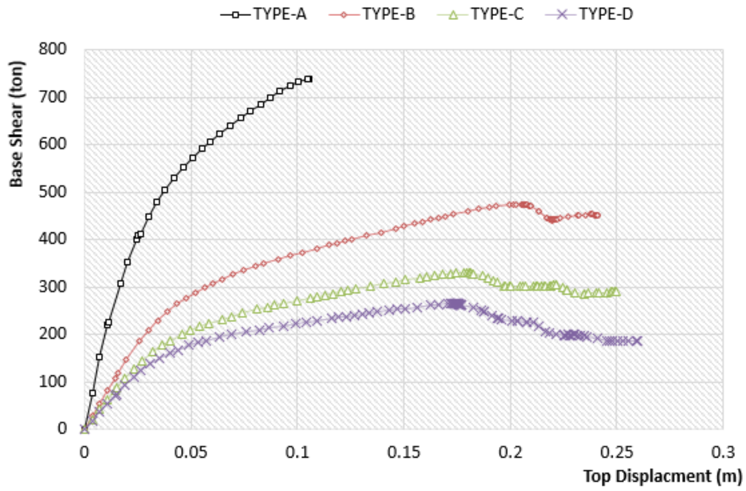


Fig. 14: Pushover Curves for Typical structures (3 stories)

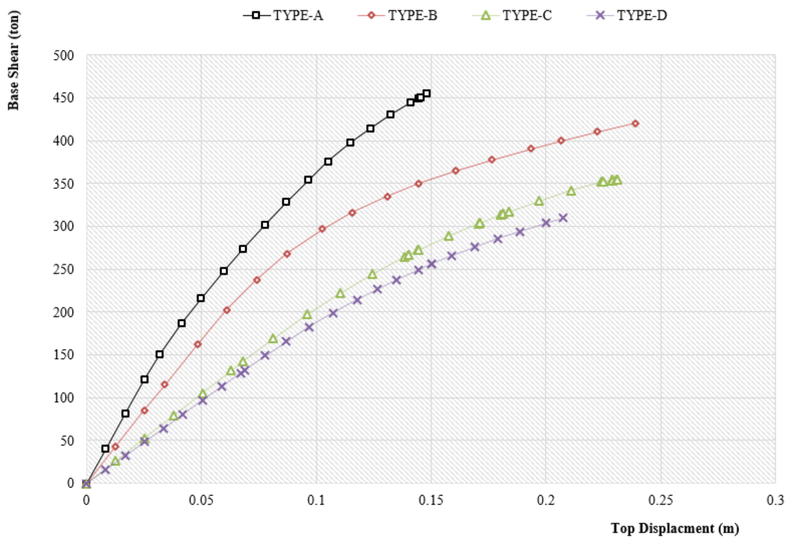


Fig. 15: Pushover Curves for Typical structures (7 stories)

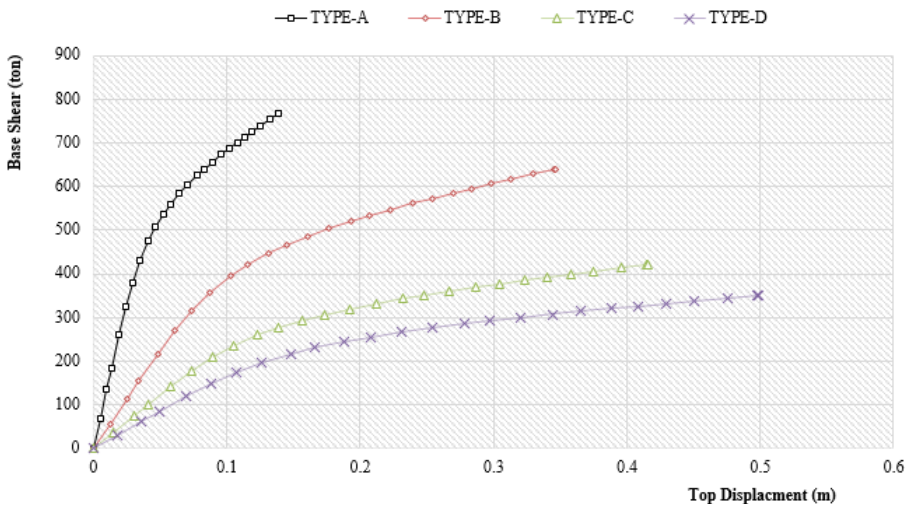


Fig. 16: Pushover Curves for Typical structures (11 stories)

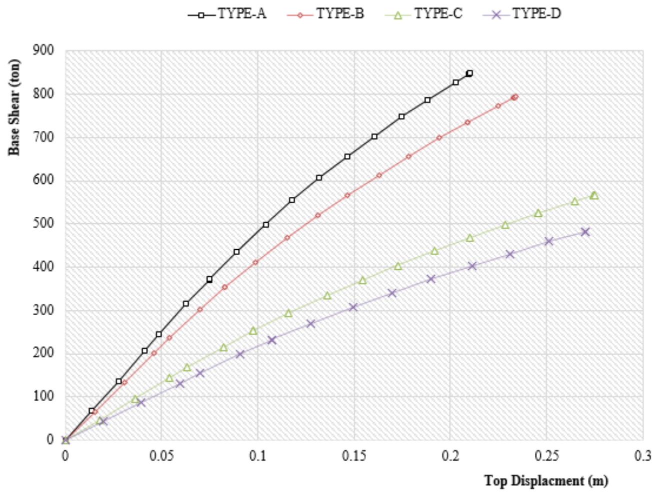


Fig. 17: Pushover Curves for Typical structures (15 stories)

The following Table 4 and Fig. 18 represents a summery for Response modification factor for different typical structures.

Table 4: Response modification factor "R"

TYPE		3	7	11	15
A	PUSH-Y	8.95	7.63	6.21	5.46
B	PUSH-Y	8.56	6.66	5.83	5.32
C	PUSH-Y	7.23	5.91	5.57	4.84
D	PUSH-Y	5.10	4.58	4.43	4.21

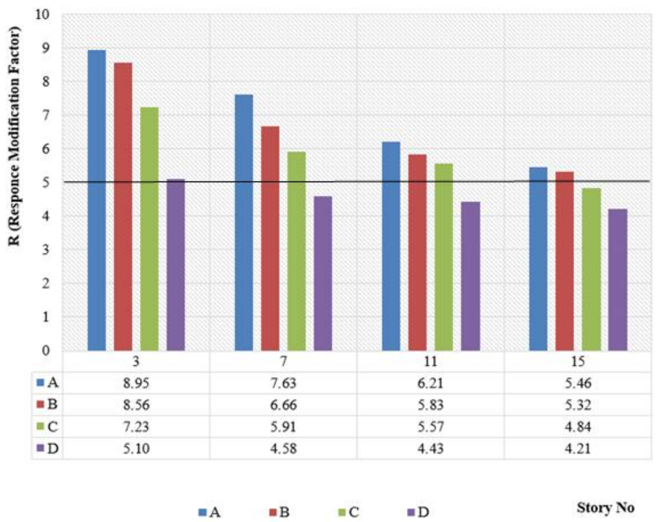


Fig. 18: Response modification factor for typical structures

It founded that from pervious results, when degree of torsional irregularity increases, R factor decrease which reaches at high torsional degree to values less than value recommended in Egyptian code (ECP201) which constant value "5". So, it's very important to evaluate the response reduction factor related to torsional irregularity level. The formation for plastic hinges early formed as torsional irregularity degree increase. So, it's necessary to consider this effect in design elements faced early plastic deformations.

V. Conclusion

The torsional response of unsymmetrical plan RC building structures during earthquake have been investigated. The results of this study are summarized as follows:

- As the floor-plan irregularity increases, the fundamental period of the structural model decreases, this means that the fundamental period is not only a function of building height as conventional method presented but accumulates a function of building's shape. The degree of lateral-torsional coupling due to additional torsional moment of the vibration modes significantly increases with the irregularity level increase because as fundamental period decrease, lateral force increase.

- Total story drift responses ratio increases as the floor plan irregularity gradually increase. Story drift response along the height of the building shows that the middle stories are more affected than Lower and upper stories.
- Coefficient of Torsional irregularity increase as the story numbers decrease. Maximum irregularity coefficients occur for lower stories of structures. From the previous points, it seems that the parameter ƞ is not proper to represent the torsion effects of the structures and defined as the criterion of torsional irregularity.
- Floor diaphragm rotation increase as the story numbers increase. Maximum Floor diaphragm rotation occur for higher stories of structures. From the previous points, study the relation between irregularity with floor rotation and relative past researches had been deal with accurate criterion for structure irregularity [16], it seems that the parameter ϴ is may be consider as the actual criterion of torsional irregularity.
- It's important to evaluate the response reduction factor related to torsional irregularity level. As irregularity level of the building increase, response reduction factor (R) decrease. At high torsional irregularity level, real response reduction factor values are less than those value recommended in Egyptian code (ECP201).

References

[1]. Anagnostopoulos S.A., Kyrkosa M.T and Stathopoulos K.G. (2015). "Earthquake induced torsion in buildings: critical review and state of the art".Techno-PressISSN: 2092-7614.

[2]. Anil K. Chopra and Rakesh K. Goel (1987). "Evaluation of torsional provisions in seismic codes". Earthquake Engineering Research Centre, University of California, Berkeley, Calif.

[3]. NFALLAH, POURZENALI and M.I.HAFEZI (2011) "Accuracy evaluation of the Modal PushoverAnalysisMethod in the Prediction of Seismic Response of Vertically Irregular Frames" IJST, Transactions of Civil EngineeringVol. 35, No. C2, pp 171-184.

[4]. Tezcan, S.S., Alhan, C., (2001) "Parametric-analysis of irregular structures-under seismic loadingaccording to the newTurkish Earthquake Code"Engineering Structures, 23, (2001), pp.600–609.

[5]. Momen Mohamed, Shehta abd el-Rahman, Mohamed Ahmed and Aly abd el-Shafy (2016) "irregularity-effects on the seismicperformance of l-shaped multi-story buildings "Journal of Engineering Sciences Assuit UniversityVol. 44 NO.5.

[6]. Mahdi and Gharaie (2011) "Plan irregular RCframes: comparison of pushover with nonlineardynamic analysis"AsianJournal of Civil Engineering (Building and Housing) Vol. 12, No. 6,(2011), pp.679-690

[7]. Yasser Al-Ashker, Sohaib Nazar & Mohamed Ismail (2015) "Effects of Building Configuration on SeismicPerformance of RC Buildings by PushoverAnalysis"Open Journal of Civil Engineering, 2015-5, 203-213.

[8]. Malavika Manilal (2017) "Dynamic Analysis of RC.Regular and IrregularStructures Using T.H.M" IJRET: International Journal of Researchin Engineering andTechnology eISSN: 2319-1163 | pISSN: 2321-7308.

[9]. A. Benavent Climent and L. Morillas b (2014) "Inelastic torsional seismic response of symmetric reinforcedConcreteframe structures: Shakingtable tests" ScienceDirect journal Engineering Structures 80 (2014) 109–117.

[10]. Gupta and Dr. P.S. Pajgade(2015)," Torsional behavior of Multistorey Buildings with Different Structural Irregularities-A Review". International Journal of Research in Engineering, Science and Technologies (IJRESTs), ISSN 2395-6453, Vol 1.

[11]. Amin Alavi and Prof.P.Srinivasa Rao (2013)," Influence of TorsionalIrregularities of RC Buildings in High Seismic Zone". AustralianJournal of Basic and Applied Sciences, 7(13).

[12]. Stathopolos KG, Anagostopoulos SA. Accidental design eccentricity: is it important for the inelasticresponse ofbuildings to strong earthquakes Soil Dynamics and Earthquake Engineering 2010; 30:782–797.

[13]. Mr. Sandesh N. Suryawanshi, Prof. S. B. Kadam, Dr. S. N. Tande (2014) "TorsionalBehaviour of Asymmetrical Buildings in Plan under.Seismic Forces" International Journal of Emerging Engineering Research and TechnologyVolume 2, Issue 4, July 2014, PP 170-176.

[14]. Fayed, M. N., Aboul Nour, L. A., and El-Masry, S. S. (2018) "Evaluation of Seismic Response Modification Factor of Multistore Buildings Designed According to Egyptian Code" e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 1 Ver. III (Jan. - Feb. 2018), PP 66-86

[15]. ECP 201: ECL Committee. Egyptian Code for calculating loads and forces in structuralwork and masonry (Code N 201 – Ministerial Decision 431/2011). 8. Dokki (Giza, Egypt): Housing and Building National Research Centre (HBRC); 2012–2017.

[16]. EC8: Eurocode 8. Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings (European Standard EN 1998-1). Chapters 1–5. European Committee.for.Standardization (CEN); Brussels (Belgium), 2004.

[17]. ASCE7: Committee ASCE. Minimum design loads for buildings and other structuresASCE/SEI 7–10. Reston (VA, USA): American Society of Civil Engineers (ASCE); 2013.

[18]. Monish S., S. Karuna (2015). "A study on seismic.performance of high rise irregular RC.framed buildings." International Journal of Research in Engineering and Technology (IJRET) 4(5):340-346.

[19]. Fenwick R, Lau D, Davidson B. A comparison of the seismic.design requirements in.the New Zealand.Loadings Standard with other majordesign codes. Bull New Zealand Soc Earthquake Eng. 2002; 35(3):190–203.

[20]. Ahmed M., Hoda Sayed , Ayman A. (2018). "Comparison of.Egyptian Code 2012 with.Eurocode 8-2013, IBC 2015 andUBC 1997 for seismic analysis of residential shear-walls RC buildings in Egypt" Ain Shams Engineering Journal 9 (2018) 3425–3436.

[21]. Z.A. Lubkowski, & B. Aluisi (2012) "Deriving Ss and S1 parameters from PGA maps" 15th world conference in earthquake engineering. Lisbon.

[22]. Computer & Structures Inc. Structural Analysis Programs, Etabs, Computer Software Package. California: CSI Inc. 2005.

[23]. Abdel Raheem K. A., S. E. Abdel Raheem, H. M. Soghair, M. H. Ahmed (2010). "Evaluation of seismic performance of multi-story structures designed according to Egyptian code." Journal of Engineering Sciences, Assiut University38 (2): 381-402.

[24]. Nina ZHENG1 Zhihong YANG Cheng SHI1 Zhongren Chang, (2004). "Analysis of criterion for torsional irregularityof seismic structures" 13th World Conference on Earthquake Engineering. Paper No. 1465.

[25]. FEMA365. Evaluation.of.Earthquake damaged concrete andmasonry wall building - Basic procedures manual.Washington, D.C.: Federal Emergency Management Agency 1997.

[26]. ATC40. Seismic evaluation and Retrofit of Concrete Buildings,Applied Technology Council, Redwood City, CA. 1996.

[27]. Maheri, M.R. and Akbari, R. (2003). "Seismic behavior factor, R, for steel X– braced and knee-braced RC buildings", Engineering Structures, 25, 1505-1513.

[28]. Newmark NM and Hall(1973), "Seismic-Design CriteriaFor. NuclearReactor. Facilities," Report No 46, Building Practices for Disaster Mitigation, National Bureau of Standards, U.S. Department ofCommerce.

[29]. Uang CM (1991), "Establishing R and Cd Factors for Building Seismic Provisions," Journal of Structural Engineering, ASCE, and 117(1): 19−28.

[30]. Paulay T and Priestley MJN (1992), Seismic Design of Reinforced-Concrete and Masonry Buildings, Wiley Interscience, New York, USA.

[31]. Miranda E and Bertero VV (1994), "Evaluation of Strength-ReductionFactors for Earthquake-resistant Design," Earthquake Spectra, 10(2): 357−379.

[32]. Kappos, A.J. (1997). Seismic.damage.indices for RC buildings: evaluation of concepts and procedures.Progress in Structural Engineering and Materials, 1:1, 78-87.

[33]. Priestley M (2000), "Performance.Based.Seismic.Design," 12th WCEE, Paper No. 2831.

[34]. Rodrigues H, Arede A, Varum, H. and Costa, A. (2012a), "Comparative-Efficiency Analysis ofDifferentNonlinear Modeling Strategies to Simulate the Biaxial Response of RC Columns," Earthquake Engineering and Vibration,11 : 553–566.