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SEISMIC ANALYSIS OF RC BUILDINGS HAVING PLAN IRREGULARITY ACCORDING TO ASCE 7-10 USING ETABS SOFTWARE

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Abstract

The modern reports and research showed that the buildings with more irregularity are less safe in facing earthquakes. This study aims to study the behavior of regular and irregular building in seismic matter. Three irregular shapes (L-Shaped, T-Shaped and C-Shaped) having two types of plan irregularity (accidental torsion and reentrant corner) were compared with rectangular regular one in three seismic hazards (Low, Moderate and High). ETABS v19 is used to model and analyze 12 different models with 15-story and 20-story RC frame structures using dynamic response spectrum method to obtain the maximum displacement, story drift, maximum drift and accidental torsion committing to ASCE7-10 code. The purpose of the study is to alleviate the seismic risk on the irregular structures and make our buildings safer, less cost and more Sustainable. at the end, we provide a table to guide the architectural engineers choosing the best building configuration based on the area seismicity and seismic hazard in order to match the purposes and the structural design in addition to provide some solutions to avoid structural design problems. The results were as follow: In the 15-story RCC frame structures with special moment resisting frame, the L-Shaped buildings are not safe to use in high seismic hazard areas, and the T-Shaped buildings are not safe to use in low and high seismic hazard areas. In the 20-story RCC structures with special moment resisting frame, the L-Shaped buildings are not safe to use in high seismic hazard areas, and the T-Shaped buildings are not safe to use in all seismic hazard areas. The comparison between the irregular shapes and regular one was predicted in L-Shaped and T-Shaped building which have worse seismic behavior than regular shape, but the comparison with C-Shaped was different, the C-Shaped gave a better behavior compared to the rectangular regular building.

Keywords: Regular, Irregular, story displacement, L-Shaped, T-Shaped, C-Shaped, story shear, overturning moment, story drift, seismic hazard, ETABS.

1- INTRODUCTION

Due to modern building design, architectural aesthetics and buildings operational needs, our buildings became more irregular in shape than before, and this for sure will generate a new structural design issues and will affect the structural behavior especially with earthquakes. Now a days, Due to the advancing of technology and science development, the earthquakes now should not be harmed as before, because now we can design our buildings to resist the earthquakes effectively.

First thing first, we have to design our buildings with more regularity than before, if we do that, we can make our buildings safer, less cost and more Sustainable. But there are some barriers

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prevent us from using the regular and symmetric shapes such as building occupancy purposes and architectural issues, we admit that the irregular shapes have much more spectacular and magical view than the regular ones. But is that irregularity may cause some structural issues, what the limits of using that, that where our study begins to help preventing devastating earthquakes and mitigating the fatalities, casualties, and economic losses.

the earthquakes are such a nature catastrophe like any other disaster, the whole thing begun since ever, there is no way to predict that, but our duty as structural engineers is to prevent and mitigate the damage and risk of what the earthquakes do since we can't reduce the hazards.

The earthquakes do not kill people, buildings do. Earthquakes are usually caused when underground rock suddenly breaks and there is rapid motion along a fault. This sudden release of energy causes the seismic waves that make the ground shake. During and after the earthquake, the plates or blocks of rock start moving—and they continue to move until they get stuck again.

The spot underground where the rock first breaks is called the focus, or hypocenter of the earthquake. The place right above the focus (at the ground surface) is called the epicenter of the earthquake.

The ground shaking will lead to displace our buildings by applying acceleration coming from the ground motion, this displacement will generate internal stresses in the structural elements such as story shear and overturning moment.

2- RESEARCH OBJECTIVES

This study aims to find the structural behavior for the regular and irregular buildings and compare between them to find the best building shape and plan configuration based on seismicity and seismic hazard of the building location.

The objectives of the research could be summarized as follows:

1) To obtain which building plan configuration is better based on seismic hazard.
2) To make a guide for the pre-design phase to select the building shape.
3) To match between architectural design and structural design.

3- SIGNIFICANT OF THE STUDY

The earthquakes have much more impact and damage to the irregular buildings as we know, depending on the Earthquake Engineering Research Institute (EERI) reports [1], the Baguio city earthquake in Luzon**,** Philippines (1990) had a 7.8 magnitude, An estimated US $369 million worth of damages and a total of 2, 412 casualties were recorded after the disaster. One of the highest buildings damage was "HAYATT Hotel" -it's totally destroyed- the reason was this building has a horizontal plan irregularity.

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The West Sumatra (near Padang), Indonesia earthquake of 2007 had a magnitude of only 6.3. It caused 66 fatalities, 500 casualties, and severe damage or collapse of nearly 15,000 buildings. About 44,000 structures sustained damage; 60% of the buildings had medium to severe damage. As a result, over 135,000 people were displaced. About 300 school buildings collapsed and another 400 had moderate to severe damage.

These are very high numbers for such a moderate earthquake in an area with a long history of much larger earthquakes. All of the schools collapsed have a plan irregularity. Turkey is another country that is subject to frequent and destructive earthquakes. The 7.4 1999 Marmara earthquake near Istanbul and Izmit, and the nearby1999 Duzce (M7.2) earthquake are just two of the more recent destructive earthquakes to strike the country. The fatalities and casualties from both events exceeded 18,000 and 50,000, respectively.

Most of the buildings collapsed are irregular in plan and elevation. There are many examples of a destructive earthquakes like those are discussed, all of them have buildings collapsed or damaged due to irregularities. The questions here which need to be answered are: we know the irregular buildings have a worse behavior during earthquakes, so, what is the possibility of using the irregular buildings in areas have an earthquake frequency? What is the number of stories limit we have?

Figure 1: Marmara earthquake, Turkey (1990)

Figure 2: the Baguio city earthquake in Luzon, Philippines (1990)

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Figure 3: West Sumatra, Indonesia earthquake (2007)

Figure 4: bhuj earthquake, India (2001)

Figure 5: spitak Armenia earthquake (1988)

4- FUTURE STUDIES

In future we may extend this study to include other factors that may affect the seismic behavior such as:

1) Study the effect of building height (number of stories) on plan irregularity
2) Study more irregular shapes (E, F and more) and compare with more regular shapes (H, O, and I).
3) Apply the same concept and procedure on other structural systems such as bearing wall system and dual system.
4) Extend the study to add some stiffening elements to reduce the stress concentration (collectors and bracing).
5) Add the severe (very high) seismic hazard in concern.

These studies will extend the guide tables to become a good reference for the engineers to use in pre-design step.

5- LITERATURE REVIEW

[2] Naveen and Chaya (2016) studied the response of the Regular and Irregular Structures having plan Irregularity located in Seismic zone V, in the analysis they used the response spectrum method for the 10-story building using ETABS 2015 software. The comparison was between rectangular regular building and T-Shaped irregular building, the factors involved for

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the comparison were; maximum story displacement, story drift, story stiffness, periods and frequencies of modes during earthquake.

[3] Anilkumar and Sharanabasava (2016) study was about the plan irregularity (reentrant corners) with more than one projection using non-linear elastic method (Pushover analysis). The study compared between rectangular regular building and L-Shaped building in zone IV & V. 3D models created using ETABS with 9 stories buildings. The main point there was to compare between these structures by story shear values which calculated by elastic and non-linear methods and the collapse pattern in each building.

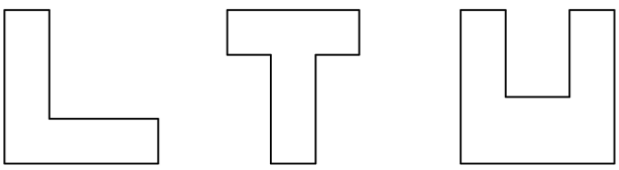
[4] Malviya et al. (2017) compared between Rectangular regular, L-Shaped and I-Shaped buildings with G+ 24 story RCC framed building using response spectrum method, The study of this research mainly emphasizes the structural behavior of multi-story building for different plan configuration. They used zone III & V with three different types of soil (Soft, Medium and Hard). Lateral displacements, story drift, base shear, maximum bending moment and design results are computed using STAAD. Pro software.

[5] As in this paper (Arvindreddy and Fernandes ,2015) an analytical study is made to find response of different regular and irregular structures located in severe zone V. Analysis has been made by taking 15 story building by static and dynamic methods using ETABS 2013 and IS code 1893-2002. The response spectrum method and time history analysis were performed to obtain the maximum displacement and story shear. The paper studied the plan irregularities with torsion and reentrant corners irregularity, L-Shaped, T-Shaped and X-Shaped statures were used in the comparison.

6- METHODOLOGY OF THE RESEARCH

In this research, twelve models of 15-story structures were chosed to compare, as four buildings shapes (Rectangular, L-Shaped, T-Shaped and C-Shaped) with three types of seismic hazards. Another twelve models with 20-story structure were used. the ETABS V19 software were used to model and analyze these structures with dynamic response spectrum method. All models shapes has the same area of 1460.25 m^2 and the same number of columns which is 36 columns and story hieght of 3.5m. ASCE 7-10 sorts the types of plan irregularity as torsion irregularity and reentrant corner irregularity as table 12.3-1 ASCE 7-10.

Figure 1: most commonly used irregular plan layouts (L, T, and U)



Rectangular Regular Shape

This model has a rectangular shape with 5x5 spans each has 7.55m length with as shown in the figures below and it will be used to compare with other irregular shapes.

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Figure 2: Rectangular model plan layout

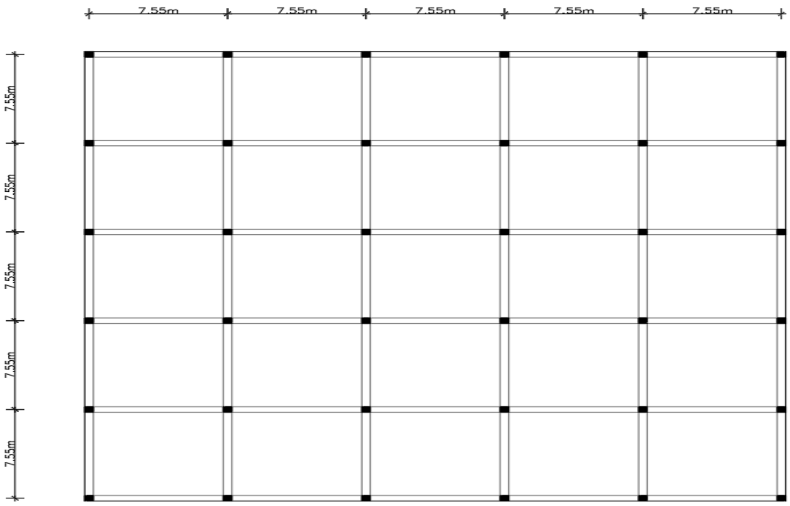
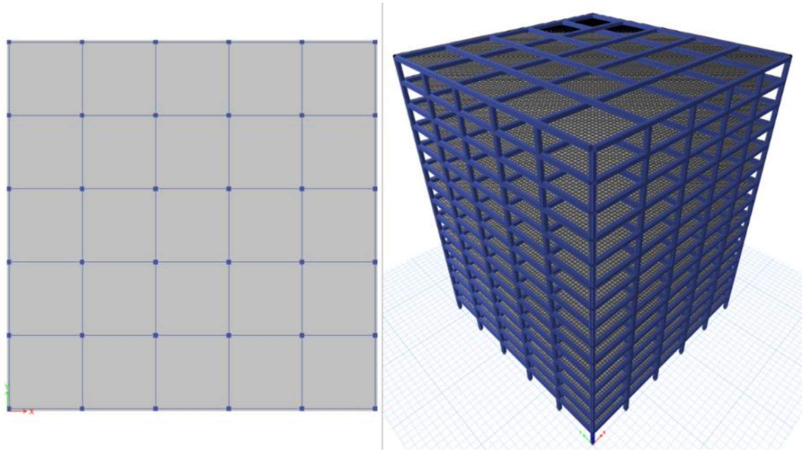


Figure 3: Plan & 3D View for rectangular model



L-Shaped

The L-Shape model has a 6x7 spans each has 8m length with the same area of rectangular model as shown in the figures below.

This plan has reentrant corner irregularity as defined previously which has an extend projection equals to 32m of total 48m, the percentage is 66.7% which greater than 15% in X-Axis. In the Y-Axis the extend dimension is 40m of total 56m, so the percentage is 71.4% which is also greater than 15%.

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Figure 4: L-Shape model plan layout

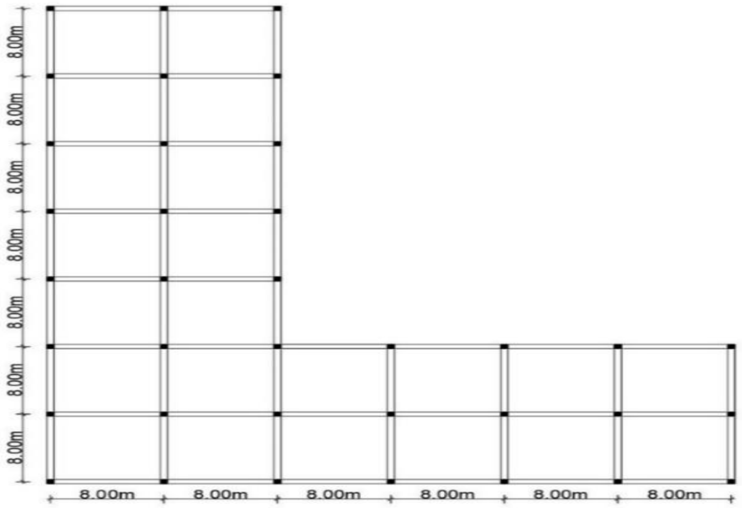
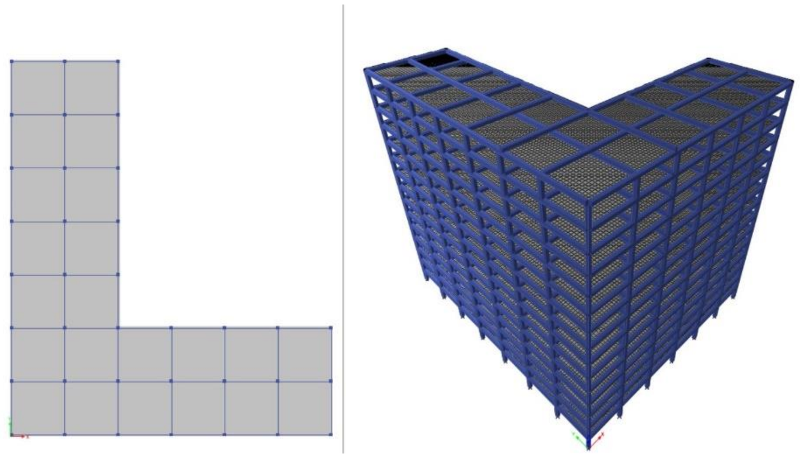


Figure 5: Plan & 3D View for L-Shape model



T-Shaped

The T-Shape model has a 6x7 spans each has 8m length with total area nearly the same with rectangular model as shown in the figures below.

This plan has two reentrant corner irregularities as defined previously which has an extend projection equals to 40m of total 56m, the percentage is 71.4% which greater than 15% in X-Axis. In the Y-Axis the extend dimension is 16m of total 32m, so the percentage is 50% which is also greater than 15%.

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Figure 6: T-Shape model plan layout

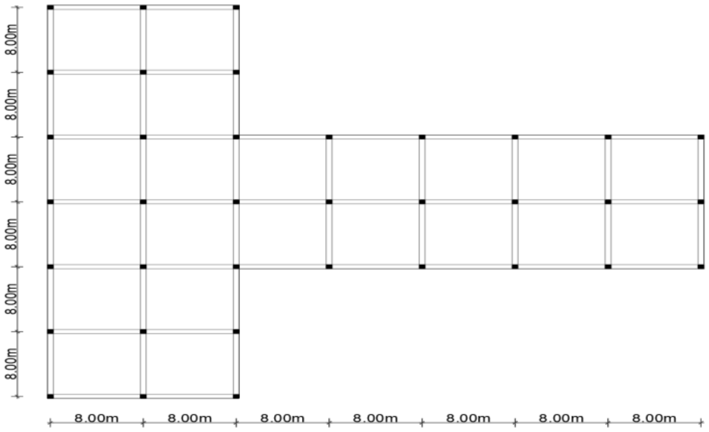
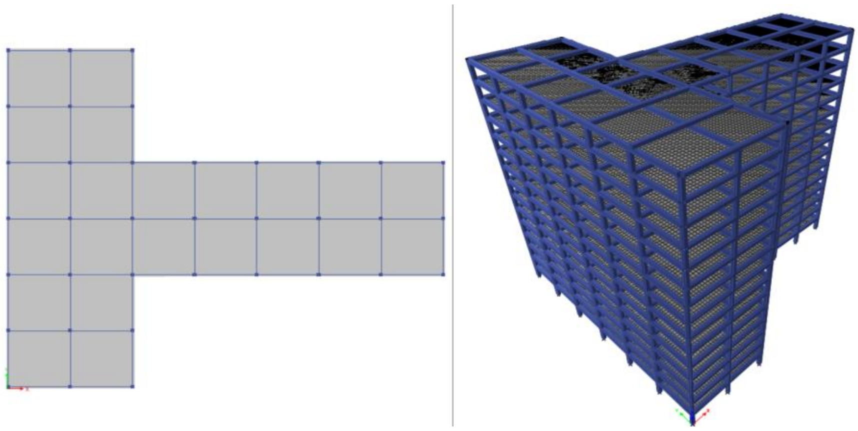


Figure 7: Plan & 3D View for T-Shape model



C-Shaped

The C-Shape model has a 7x4 spans each has 8m length with total area nearly the same with rectangular model as shown in the figures below.

This plan has two reentrant corner irregularities as defined previously which has an extend projection equals to 24m of total 40m, the percentage is 60% which greater than 15% in X-Axis. In the Y-Axis the extend dimension is 16m of total 32m, so the percentage is 50% which is also greater than 15%.

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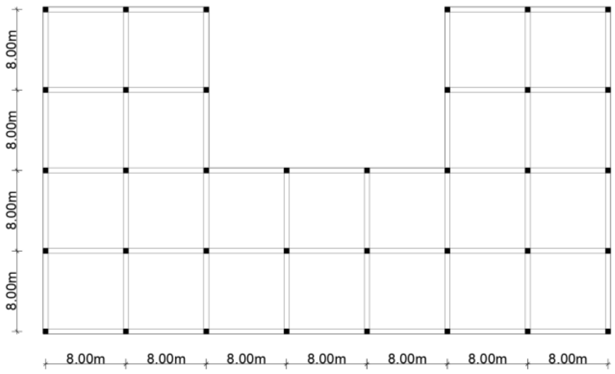

Figure 8: C-Shape model plan layout

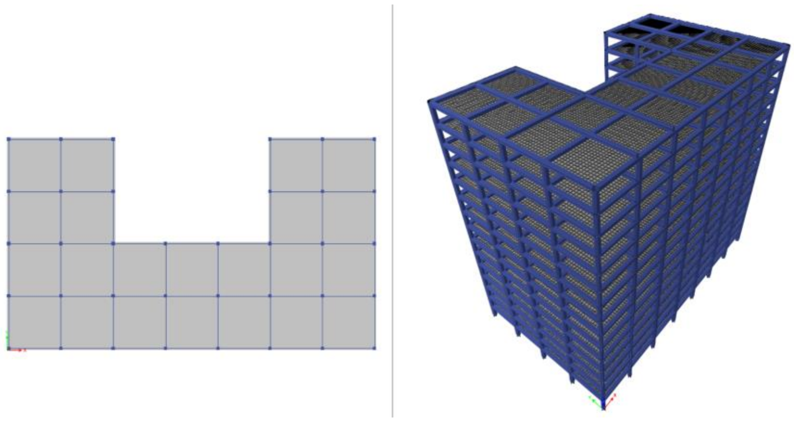

Figure 9: Plan & 3D View for C-Shape model

Buildings Data

The materials which were used in the models, concrete sections, reinforced concrete design code and loads are listed below.

Concrete compressive strength	25MPa
steel yield stress (main reinforcements)	420MPa (Grade 60)
steel yield stress (transverse reinforcements)	280MPa (Grade 40)
Columns sections	500mm x 500mm
Beams sections	500mm depth and 500mm width
Slab section	Solid Slab with 200mm thickness
Structural system	Special moment-resisting frames
Concrete Design Code	ACI 318-14
Diaphragms	Rigid
Super Imposed Dead Load=	3.5 Finishing + 1 Partitions = 4.5 kN\m^2
Live Load	4 kN\m^2
Mass source included in seismic design	100% Dead load +25% Live load. (Section 12.7.2-1 ASCE 7-10)
Mesh	rectangular 0.5m element size

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7- RESULTS

Analysis by dynamic response spectrum was conducted and the data was collected from the ETABS software and grouped to excel sheet. The final results of tables and charts were shown and compared in this chapter. Three irregular shapes were compared with the rectangular regular case. Displacements, drifts, story drift limits and accidental torsion were used in the comparison.

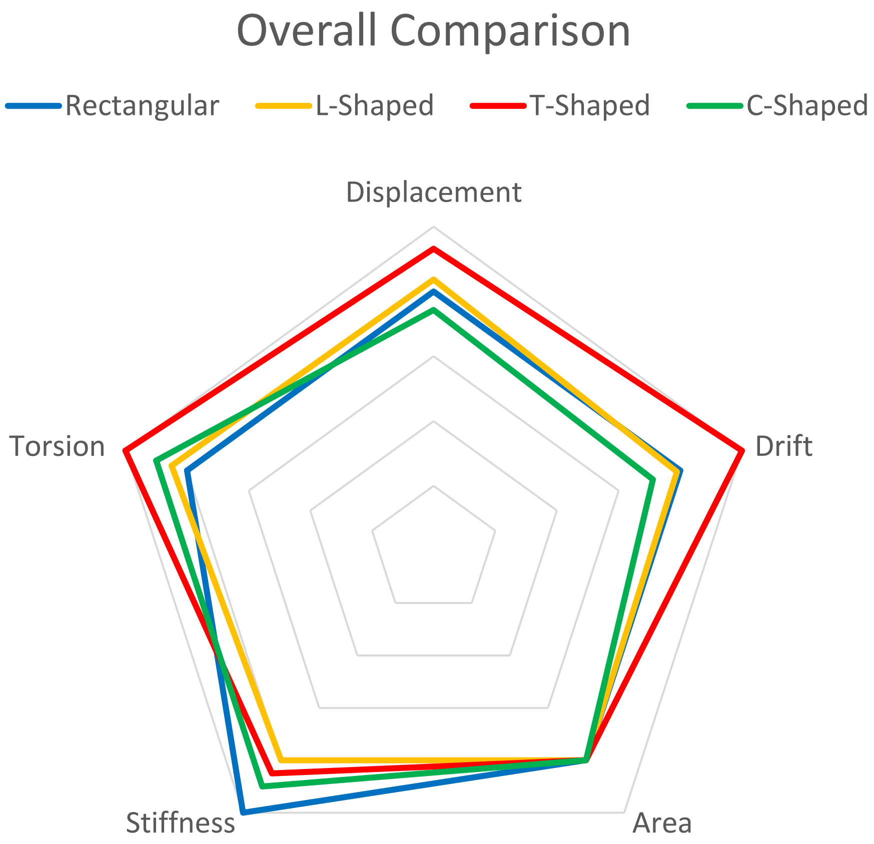

Figure 10: Overall comparison using radar plot

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Displacement (m)

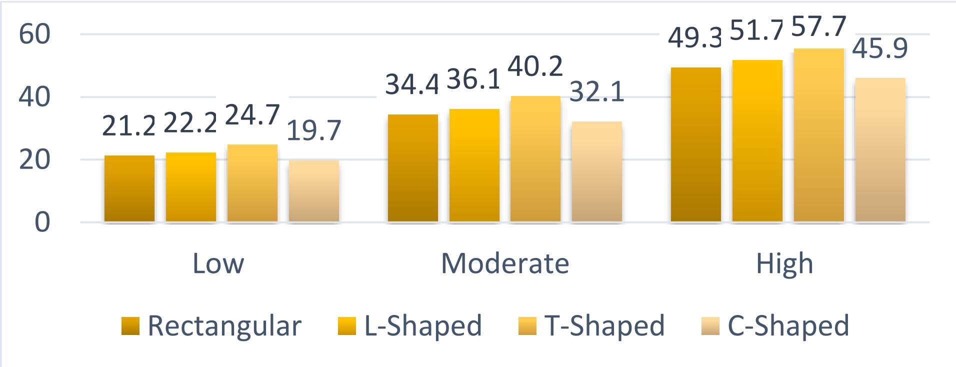

Figure 11: Displacement values for each building

Maximum Story Drift

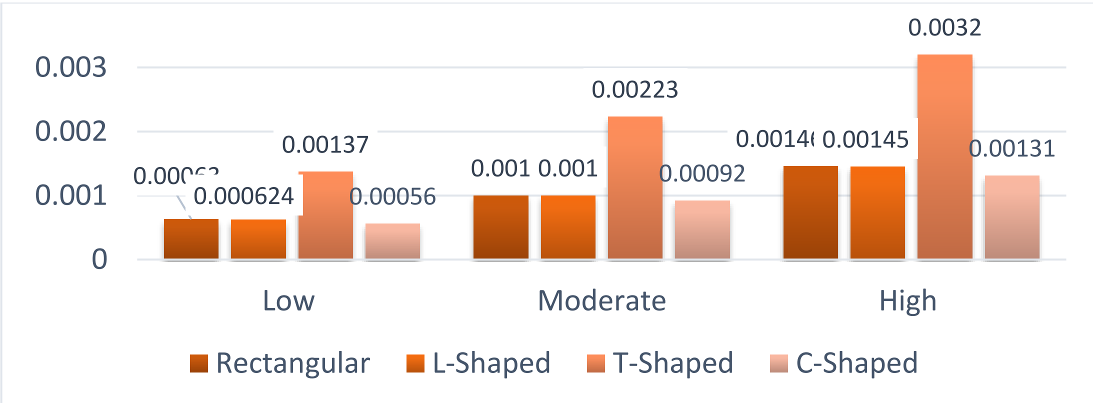

Figure 12: Drift values for each building

Torsion (kN.m)

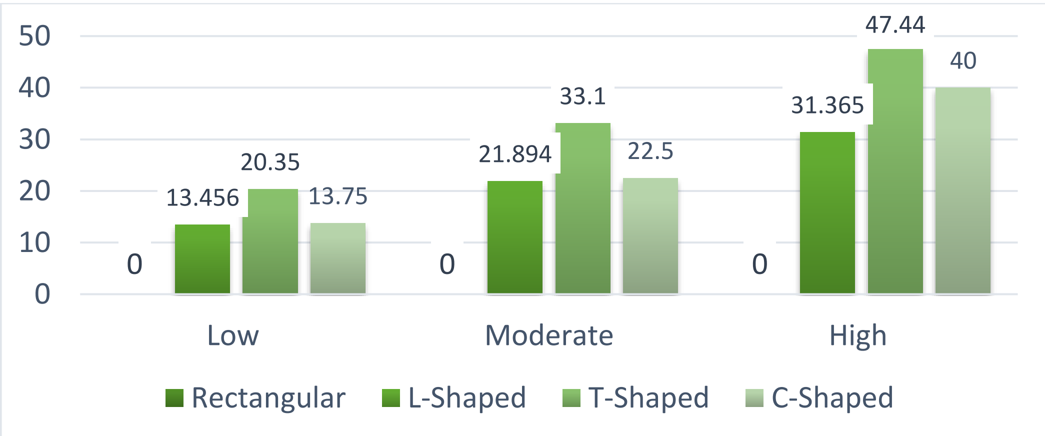

Figure 13: Torsion values for each building

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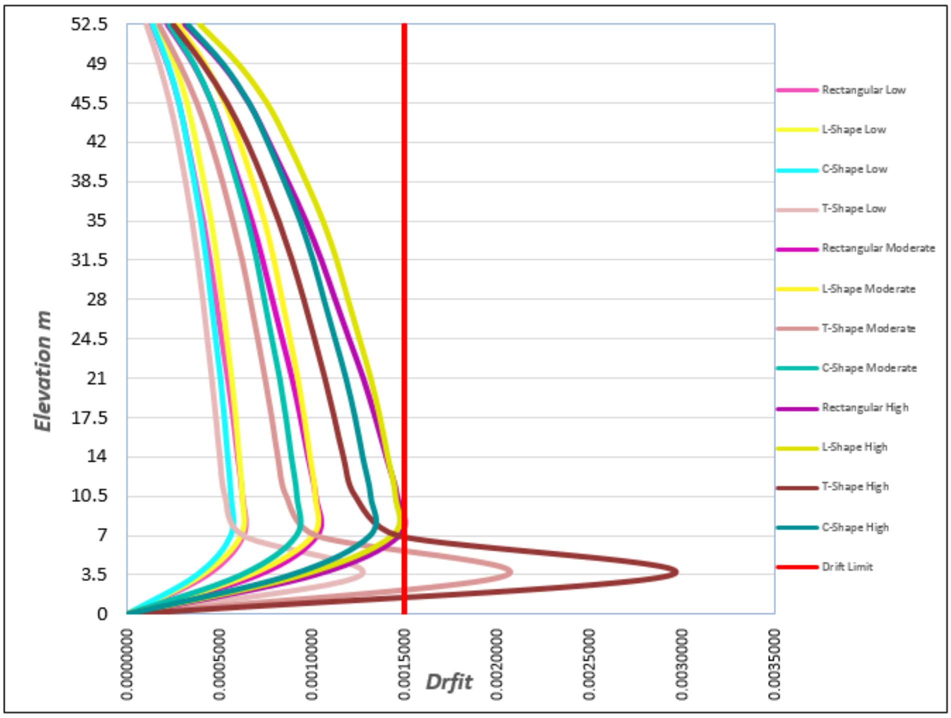

Figure 19: Drift Values in X-direction for 15 story buildings

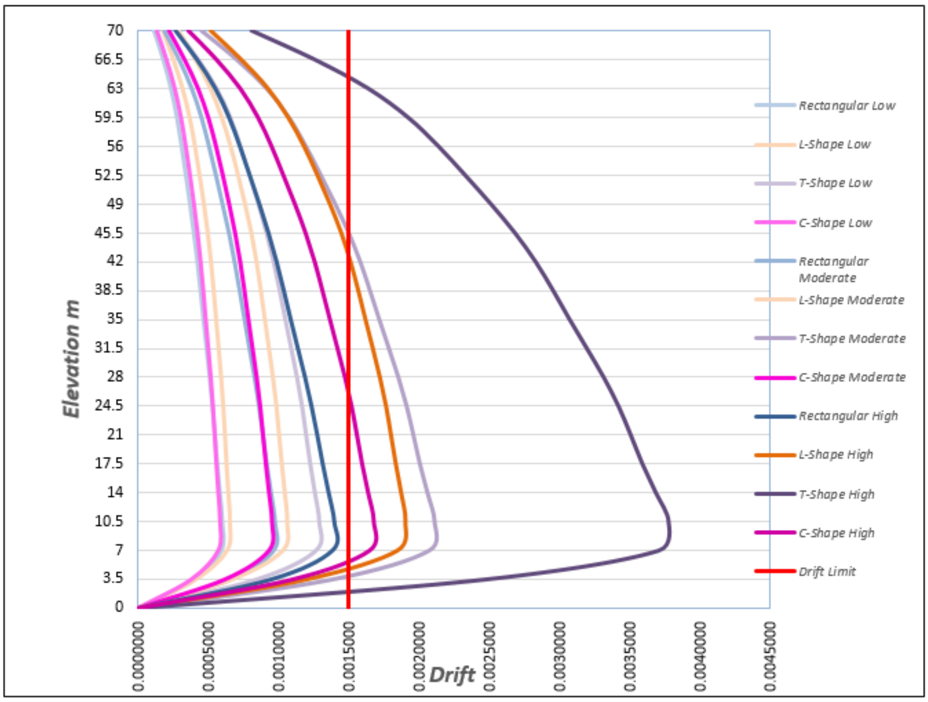

Figure 20: Drift Values in X-direction for 20 story buildings

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8- CONCLUSIONS

- **For 15-story RCC frame structures**

In 15-story buildings with special moment resisting frame structural system with 36 number of columns, we can use the rectangular regular buildings in any seismic hazard. In L-Shaped irregularity buildings we can use it in low and moderate hazards but in high hazard it gives maximum drift just equals to the limit. The T-shaped in Safe to use only in low hazard, and the C-Shaped is safe to use in all hazards.

The T-Shaped building is the worst case of horizontal irregularity in displacement and drift values, and it gives a high torsion value in columns and beams which leads to high construction costs in concrete and reinforcement.

The C-Shaped building is the best choice for the plan irregularity types because it gives the lowest values of displacement, drift and torsion caused by the compact shape of it.

When we apply seismic forces in the symmetric direction, the L-Shaped gives displacement 5% more than the rectangular regular building and the same drift values. The T-Shaped will behave the same as rectangular building in displacement and double the drift values. The C-Shaped gives displacement 15% less than the rectangular building and 11% in drift.

When we apply seismic forces in the asymmetric direction, the L-Shaped gives displacement 5% more than the rectangular regular building and the same drift values. The T-Shaped gives 17% of rectangular displacement values and more the double the drift values. The C-Shaped gives displacement 17.5% less than the rectangular building and 11% in drift.

- **For 20-story RCC frame structures**

The T-Shaped buildings are not safe to use in low, moderate and high seismic hazard, and the L-Shape is not safe to use in high seismic hazard only.

The L-Shaped buildings have the highest displacement values in X-direction. In the low hazard, the L-Shaped has a 16.7%, 19.4% and 15.4% increase of displacement comparing with rectangular, T-Shaped and C-Shaped respectively. In the moderate hazard, the L-Shaped has a 17.1%, 19% and 15.8% increase of displacement comparing with rectangular, T-Shaped and C-Shaped respectively. In the high hazard, the L-Shaped has a 46.3%, 19.2% and 15.8% increase of displacement comparing with rectangular, T-Shaped and C-Shaped respectively.

The T-Shape has the highest displacement values in the Y-direction -because of its axis of symmetry- and it has a larger value than the L-Shaped in its axis of asymmetry.

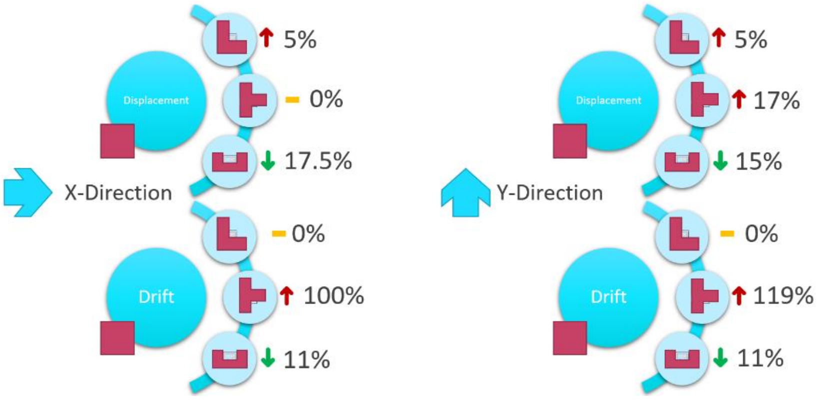

Figure 14: Conclusion

9- POSSIBILITY OF APPLICATION

As we saw above, there is some irregular buildings shapes exceeded the drift limit. Now, based on the study and data collected, we can make a guide for the pre-design step to help choosing the best building shape with special moment resisting frame structural system based on the seismic hazard. This guide will help the architectural engineers in choosing the building shape in order to match the structural design without any problems. This study covered the 15-story and 20-story towers. In future there is an opportunity to expand the study to include any number of stories may use in design.

Table 1: possibility of using 15-story framed irregular shapes in different seismic hazard

	Seismic Hazard		
Building Shape	**Low**	**Moderate**	**High**
Rectangular	S	S	S
L-Shape	S	S	N. S
T-Shape	S	N. S	N. S
C-Shape	S	S	S

S: Safe to use, N. S: Not Safe to use

Table 2: possibility of using 20-story framed irregular shapes in different seismic hazard

	Seismic Hazard		
Building Shape	Low	Moderate	High
Rectangular	S	S	S
L-Shape	S	S	N.S
T-Shape	N.S	N.S	N.S
C-Shape	S	S	S

S: Safe to use, N. S: Not Safe to use

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