The effect of earthquake on architecture geometry with non-parallel system irregularity configuration

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1. Introduction

Indonesia is an area prone to earthquake that may cause casualties and damage to buildings. The fatalities or the injured are not largely caused by the earthquake, but by building collapse. The collapse of the building is resulted from the building behaviour against the earthquake, and it depends on many factors, such as architectural design, geometry configuration of structural elements in horizontal and vertical plans, earthquake zone, geographical location (distance to earthquake center), soil type, material quality, and construction quality [1,2]. One geometric configuration that may result in building collapse is irregular configuration of non-parallel system (figure 1). According to FEMA-451B [3], irregular configuration of non-parallel system is defined to have existed if the vertical lateral force-retaining elements are neither parallel nor symmetric with main orthogonal axes of the earthquake-retaining axis system.

Such configuration may happen on: 1). The building is regular, however as the walls of the room are tilted, the wall slides (figure 1a) or the beam arranged is also tilted (figure 1b), 2). The building is regular, but column arrangement is not in one axis, making the beam connecting the column tilted (figure 1b), 3). The building is irregular, for adjusting to the shape of the site, or the building is deliberately tilted for architect's aesthetic consideration (picture 1c). The irregular configuration of parallel system may lead to torsion, instability and local damage to buildings [4]. It does not mean that non-parallel irregular configuration should not be formed on architectural design; however the designer must know the consequence of earthquake behaviour against buildings with irregular configuration of non-parallel system. The present research has the objective to identify earthquake behaviour in architectural geometry with irregular configuration of non-parallel system.

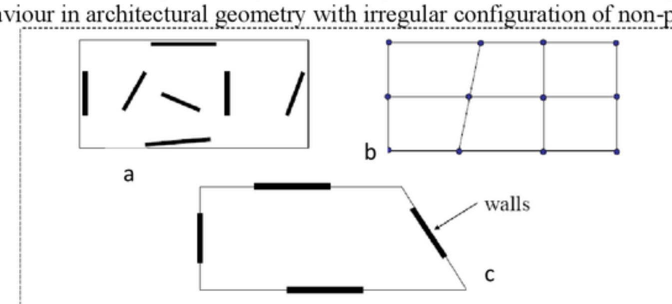


Figure 1. Non parallel system irregularity configuration

2. Methods

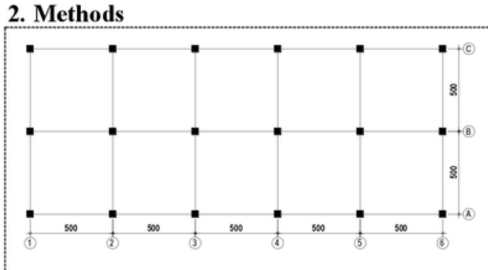


Figure 2. Model a

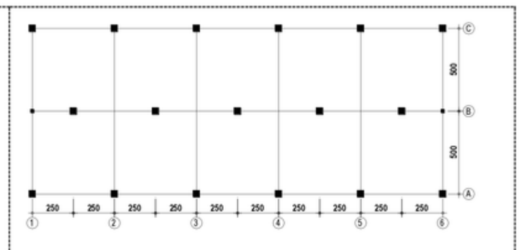


Figure 3. Model b

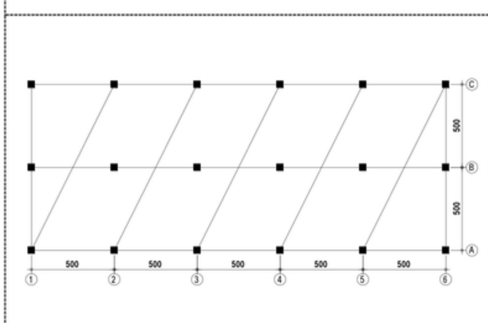


Figure 4. Model c

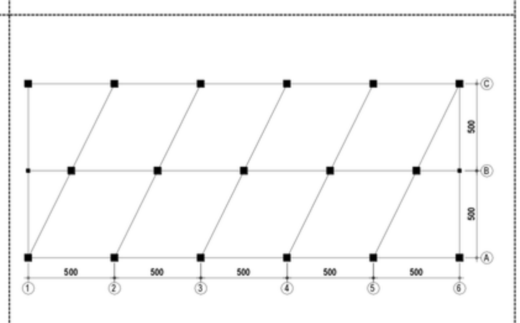
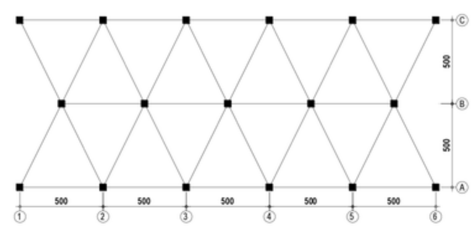


Figure 5. Model d



Gambar 6. Model e

Table 1. The property of structure model a-e

Model	Number of floors (height-m)	Dimension beam (cm)	Dimension column (cm)	Thickness of floor plate (cm)	Dimension building (m)
a	4 (16 m)	25X40	40X40	12	10X25
b	4 (16 m)	25X40	20X20, 40X40	12	10X25
c	4 (16 m)	25X40	40X40	12	10X25
d	4 (16 m)	25X40	20X20, 40X40	12	10X25
e	4 (16 m)	25X40	40X40	12	10X25

Table 2. Grade of structure model a-e

Model	Grade		
	Concrete (Kg/cm2)	Reinforcement (Kg/cm2)	Stirrup (Kg/cm2)
a	300	3000	2400
b	300	3000	2400
c	300	3000	2400
d	300	3000	2400
e	300	3000	2400

It is a simulated experimental study by using pushover analysis, and center of mass and rigidity analysis. In order to conduct both analyses above using the geometry model of the buildings (figure 2 to 6) and the structural properties (table 1 and 2), those were inputted to SAP2000/ETABS softwares, and were then analyzed by static pushover earthquake analysis method to be identified for its performance level and to be analyzed for its eccentricity to find out the potential torque occurred. The numerical outputs of the analyses were tabulated and compared between models and graphs. It is assumed that the models are in a high earthquake zone with spectral value of $S_S = 0.97$ g and $S_1 = 0.328$ g with medium soil (D) condition and office function.

3. Discussion

3.1. Target displacement

Pushover analysis is a static non-linear analysis in which the effect of earthquake plans on the structure of a building is considered as a static load capturing at the center of mass of each floor, which value is gradually increased to exceed the loading that causes the first yield (plastic joint) in the structure of the building, then through further load increase, it has a changing major post-elastic shape until it reaches the expected target displacement or until it reaches the plastic condition [3].

Table 3. Target displacement model a-e

Model	Target displacement	
	X (m)	Y (m)
a	0.187	0.197
b	0.201	0.246
c	0.183	0.235
d	0.158	0.208
e	0.163	0.178

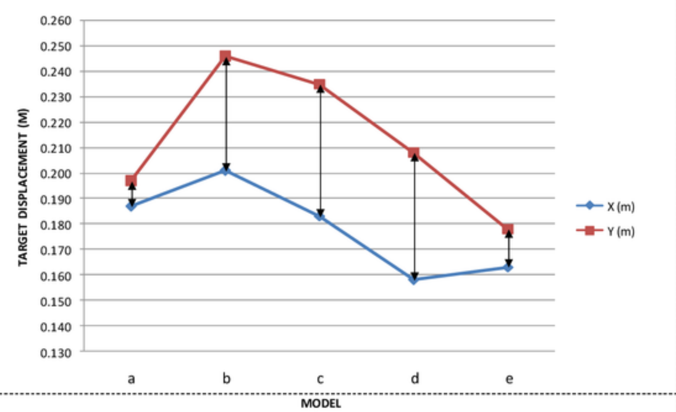


Figure 7. Target displacement model a-e

Reviewed from the results of pushover analysis in table 3 and figure 7, it can be concluded as follows:

- For the –X axis, all columns in one axis and its rigidity are dominated by the models with tilted beams (model c, d and e) rather than those that do not have tilted beams (model a and b). It means that there is an angle formation on the beams which can give additional rigidity to the structure of the building.
- For the –Y axis, model a and b of all beams are in one axis, while model c, d and e have their beams not in one axis. For columns in one axis are model a and c, while model b, d and e the columns are not in one axis. On the –Y axis, model a and e have the largest rigidity compared to other models, whereas the weakest rigidity is in model b. It means that the ideal building structure is when the beams and columns are in one axis but if it is inevitable, connect the columns with the triangle module beams so that it will have more rigidity. In addition, the columns which are not in one axis have weaker rigidity than the beams which are not in one axis.
- For regular buildings, the target displacement for the –X and –Y axes are generally relatively similar (model a and d), and the more irregular the building geometry the larger the target displacement of both axes, –X and –Y. It should be avoided, since both axes should have the same ability in facing the seismic loads.

It is similar with Shopping Center in Ercis District's-Turkey which has an irregular geometry (see figure 8). In order to reduce the irregularity, the building is blocked and separated by dilatation, but from these three blocks A to C, block C have greater non-parallel irregular configurations than others. When the earthquake stroke Ercis District's -Turkey in 2011, from the three blocks, block C was more severely damaged than blocks A and B. Based on the research results, the non parallel irregular configuration in the two-way axes -X and –Y, block C compared to blocks A and B which only on the X-axis, gives a significant contribution to the severe damage of block C in this shopping center building [6].

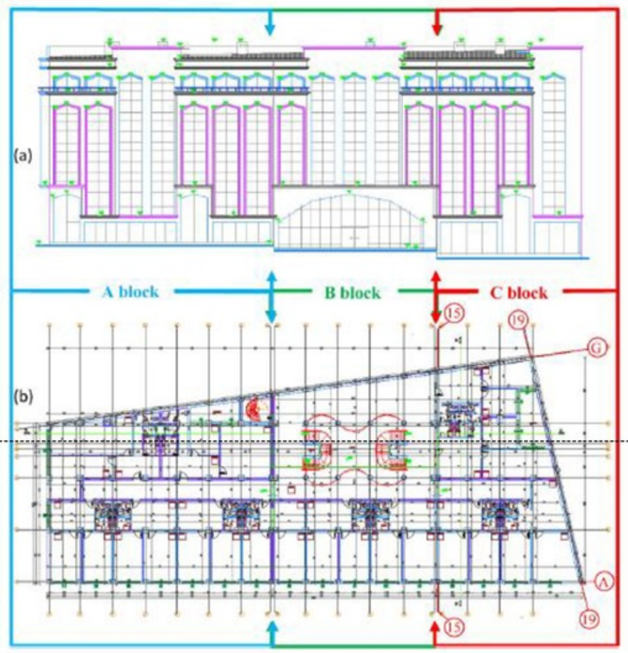


Figure 8. Shopping Center in Ercis-Turki District's: (a). Fasad architectural, (b). Building plan (source : [6])

In order to avoid the occurrence of the above, simple formula is proposed to evaluate the potential for the formation of non-parallel irregular configuration in the building that is still in the process of architectural design:

$$j_r = \sum j / \sum j_t \tag{1}$$

Table 4. Ratios quality level of the number of beams, columns and shear walls elements (j_r) irregular configuration of non-parallel system

Source	Quality Level		
	Good	Moderate	Poor
Recommendation	$j_r<30\%$	$30\% \leq j_r \leq 50\%$	$j_r>50\%$

Where, j_r= ratios quality level of the number of beams, columns and shear walls elements, Σj=the number of beams, columns and shear walls elements that do not follow the orthogonal axis and Σj_t=the total number of beams, columns and shear walls elements at the level being reviewed . The result of j_r is then compared with table 4 so as to find out whether the formation of non-parallel system irregular configuration is still in tolerance level (good), moderate or poor.

3.2. Eccentricity

The torque force formed inside the building is caused by the lack of balance between the location of the retaining elements and the mass structure of the building. It is the eccentricity between the center

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of mass and rigidity which makes the building experience a twisting ground motion around the center of rigidity, which results in torque - twisting effects in the building plan. This effect is undesirable and allows the danger of stress concentration [2].

Table 5. Eccentricity model a-e

Floor	Center of mass (m)		Center of rigidity (m)		Eccentricity (e)	
	Xm	Ym	Xr	Yr	X=Xm-Xr	Y=Ym-Yr
1st Floor	12.5	5	12.5	5	0	0
2nd Floor	12.5	5	12.5	5	0	0
3rd Floor	12.5	5	12.5	5	0	0
Roof Floor	12.5	5	12.5	5	0	0

According to table 5, the models a-e does not form eccentricity or in other words, the center of mass and the center of rigidity are overlapped, making its eccentricity= 0. It also negates the potential for torsion in the building model. Therefore, the main eccentricity occurs by building mass geometry form, and the irregularity effect of the beam/column arrangement is relatively minimal but it can cause another irregularity, i.e. non-parallel irregular configuration. Eccentricity can cause torsion in the building, the causes include uneven loading, rigidity and strength, and others [7] (see figure 9).

For avoiding excessive torque, then a simple formula is propose to evaluate the potential for the formation of torsional irregularity configuration in buildings that are still in the process of architectural design :

$$e_r = e/w \qquad (2)$$

Where, e_r= the ratio between the length of eccentricity (e) and the width of the building being reviewed (w).

Table 6. The eccentricity ratio quality level (e_r) of torque irregularity configuration

Source	Quality Level		
	Good	Moderate	Poor
JBDPA [8]	$e_r \leq 0.1$	$0.1 < e_r < 0.3$	$e_r \geq 0.3$

The result of e_r is then compared with table 5, so it is known whether the configuration of torque irregularity being formed is included in tolerance level (good), moderate or poor.

Figure 9. Building damage from torque eccentricity (source : [2]).

4. Conclusion

From the explanations above, there are some conclusions that could be useful for architects in designing the building, as follows:

- The ideal building structure is when the beams and columns are in one axis but if it is inevitable, connect the columns with the triangle module beams so that it will have more rigidity.
- Columns which are not in one axis have weaker rigidity than the beams which are not in one axis.
- The random seismic motion requires both axes to have equal ability in facing the seismic loads.
- Primarily, eccentricity occurs by the geometric shape of the building mass and the effect of irregularity of the beam/column arrangement is relatively minimal but can cause another irregularity, the non-parallel irregularity configuration.
- Avoiding the excessive formation of torque irregular configuration and non-parallel irregular configuration in the building design can be done by evaluation using formula 1 and 2 above.

For future research can be investigated the effect of earthquake on geometry architecture with non-parallel system irregularity configuration in irregular form.

5. Acknowledgments

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