subtractive

By Livian Teddy

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Behavior Identification of Subtractive Transformation in Building Design Process against Earthquakes

Livian Teddy *[1], Gagoek Hardiman[2] and Nuroji[3]

[1]Lecturer, Department of Architecture, Sriwijaya University, Indonesia
[2]Lecturer, Doctoral Program of Architecture and Urban, Diponegoro University, Indonesia
[3]Lecturer, Doctoral Program of Civil Engineering, Diponegoro University, Indonesia

Abstract

Indonesia is an earthquake-prone region, so that the building in Indonesia should be designed to withstand earthquakes. Earthquake resistant building design should start from the subtractive transformation architectural design. Subtractive transformation is a form that can be changed by reducing the partial volume. This transformation also changes the behavior of the building structure against earthquake loads.

This study will examine the basic model building of ten floors and the basic model will then be subtracted 89%, 78%, 60%, 56%, 47% and 33% of the basic model. From the configuration changes, researchers studied the behavior of the building initial structure and the subtractive against earthquakes.

This study utilizes simulated experimental research. From this study, researchers discovered a number of points that can be summed up as follows: seismic shear force is highly dependent on the building with the weight of the building itself, there are three conditions of the building which possess a relatively small potential event of eccentricity and torque to the building, namely a). Ordinary condition of horizontal- vertical and two-axis symmetric b). irregular condition of vertical and two-axis symmetric and c). irregular condition of horizontal and two-axis asymmetric but only possesses little subtractive on buildings, for example ± 10% of building mass, and the performance level of ten-floor building of strong earthquake zone with a rigid frame system will cause minor to moderate damage and require a dual system.

Keywords: earthquake, irregular, regular, subtractive, transformation

1. Introduction

Indonesia is an earthquake-prone region that is traversed by many subduction earthquakes paths such as the Eurasian, Indo-Australian, Pacific and faults such as Sumatra, Java, Sulawesi and West Papua faults. Thus, there have been many earthquakes that cause casualties and the loss of properties. One of the largest contributors to loss of life caused by the earthquake has been the damage and the collapse of the building.

Performing the design of building to be able to receive a strong earthquake in elastic condition is not economical. The possibility is that the building could have been damaged but did not collapse. And the work of creating a building with such conditions can not be left to structural experts alone. There must be a great cooperation between architects and structural engineers (Arnold and Stewart, 2000; Hoedajanto and Riyansyah, 2015). The process of designing earthquake resistant buildings should be started from the architectural design process by considering the geometry aspect of the building which will affect the structure behavior in receiving earthquake mainly lateral loads.

Form finding process is known in the architectural design process as the process of finding forms until a suitable form is finally discovered. It is usually started with simple shapes and then a transformation is made to obtain a more complex form. One type of transformation forms is the subtractive transformation form. Subtractive transformation is a form that can be transformed by reducing half of its volume in which, depending on its level of subtractive process, form can maintain its original identity or transformed into other forms of group (Ching, 2008). But the architect of this transformation process is usually more focused on the aesthetic aspect alone. Whereas the changes from basic forms into more complex forms can result in building configuration changes that may affect the response of structures against earthquakes. In principle, there are no restrictions to create complex forms but the concern is more to the consequences of applying these complex forms in the earthquake behavior problems to buildings (Harmankaya & Soyluk, 2012). The object of this study is to find out how the response changes of building configuration against earthquakes from basic form into a more complex form as a result of subtractive transformation process. The objective is to determine the geometry of the

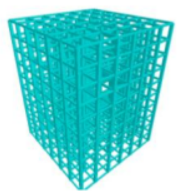
* Contact Author:

Livian Teddy
Jl. Peternakan Raya No. A4 Palembang
Tel: 081367673139
e-mail: livianteddy@gmail.com

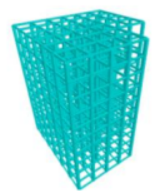
building toward the structure behavior in receiving earthquake loads.

2. Related Work

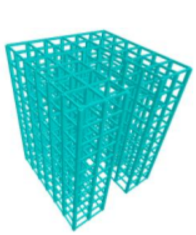
2.1 Model and Research Method



a. Basic model 100%



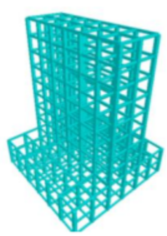
b. Subtractive model 89%



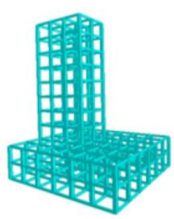
c. Subtractive model 78%

d. Subtractive model 60%

e. Subtractive model 56%



f. Subtractive model 47%



g. Subtractive model 33%

Figure 1. Basic model (100%) and subtractive model 89%, 78%, 60%, 56%, 47%, 33%

This study will examine a basic model of a building with a width, length and height of the building: 30x30x40 m, the height per floor is 4 m or a total height of 10 floors, the module structure is 5x5 m, the dimension of the column corresponding level number is 40/40, 50/50, 70/70 and the beam dimension is 25/50. The building is assumed to be an office, located in the strong earthquake zone and owns a reinforced concrete structure design of intermediate level. The basic model will be subtracted 89%, 78%, 60%, 56%, 47% and 33% of the basic model. This study utilizes quantitative method with the research type of simulation experiments. Building structure model above was placed in software and analyzed with the method of equivalent static seismic analysis then the numerical results were tabulated, graphed and analyzed with existing theories.

2.2 Result and Discussion

The results of this study obtained the following results:

1) Base Shear Force and Vertical Distribution

From Figure 2, it appears that a large base shear force that occurs is proportional to the weight of each building. The smaller the subtractive transformation (33%) with a building total weight of 2946.94 tons of base shear force, the lighter the weight being hold, at only 207.72 tons. The heavier the building (100%) with a building total weight of 9153.35 tons of the base shear force, the heavier the weight being hold, that is 615,87 tons. Thus, in designing buildings, architects should consider to avoid designing buildings that are too heavy by selecting the type of material that possesses a small mass to minimize the mass of the building.

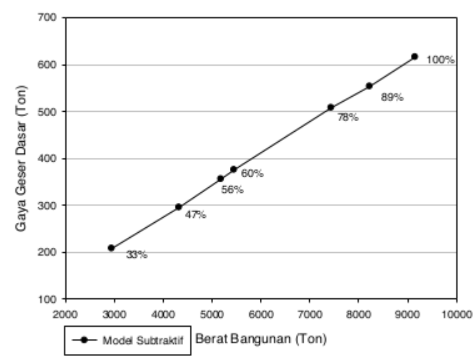


Figure 2. Building Weight Vs Base Shear Force (source : analysis)

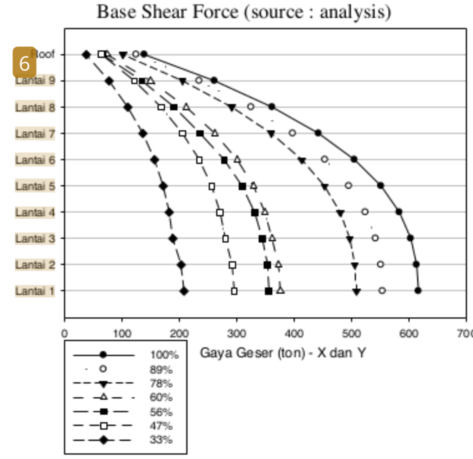


Figure 3. Shear Force Vertical Distribution (source : analysis)

Vertical distribution of shear force is proportional to the cumulative column weight bearing its above weight (Figure 3). Of all the building models (33% - 100%), the higher the floor level, the smaller the cumulative weight and the shear force level. The most important thing to be kept in mind is that the magnitude of the shear force vertical distribution depends on the magnitude of the shear force base. Which means it is determined by the weight of the building. From both axes-X and Y all shear building model owns a relatively equal basis.

2) Eccentricity and Torque

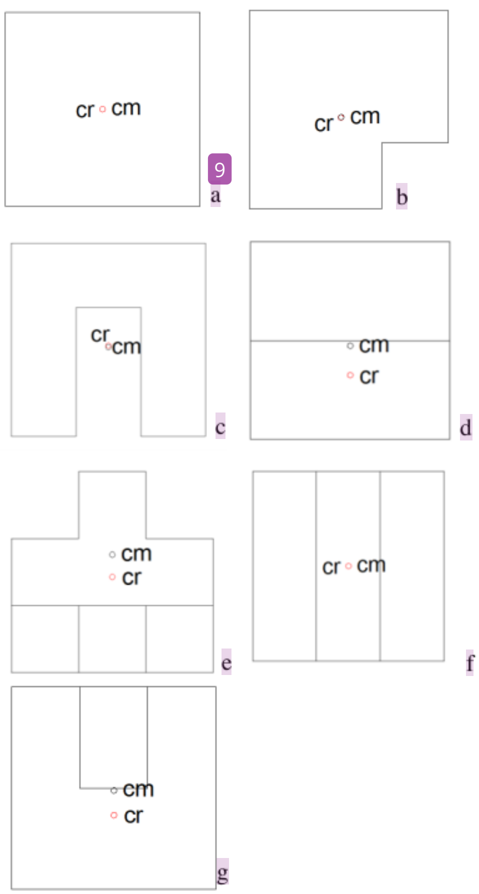


Figure 4. Plan Eccentricity Center of Mass (cm) and Center of Rigidity (cr): a). model 100%, b). 89%, c).78%, d). 60%, e). 56%, f). 47% & g). 33% (source : analysis)

The non-coincide of center of mass and center of rigidity building will result in eccentricity, while the eccentricity will cause a torque on the building and this should be avoided because the effect is damaging the buildings (Moon, 2012). The eccentricity distance should be made as small as possible by arranging the building configuration.

Based on SNI 1726:2012, model of 100% is regular, subtractive model of 89% and 78% belongs to the category of irregular horizontal building, subtractive model of 60%, 47% and 33% belongs to the category of irregular vertical building and subtractive model of 56% belongs to the category of irregular horizontal and vertical building. While based on the form, model of 100% and 47% is included in two-axis symmetrical building, subtractive model of 89% belongs to asymmetrical, and subtractive model of 60%, 78%, 56%, 33% belongs to one axis-Y symmetrical building.

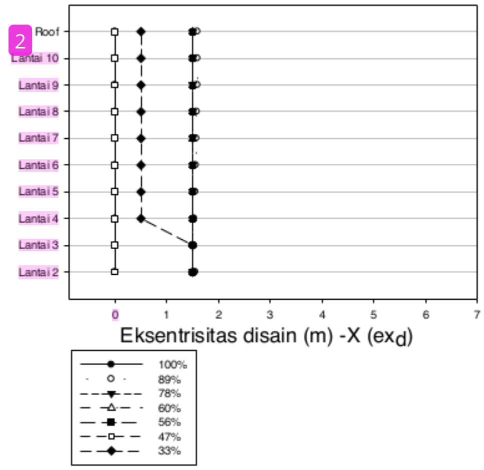


Figure 5. Design eccentricity of axis -X (source : analysis)

As can be observed from the graph of figure 4 and 5, the eccentricity design of axis-X (ex_d) with earthquake weight direction of axis-Y owns design eccentricity value of 0 because of its two-axis symmetric form which are model 100% and subtractive model 47%. Actually, model 47% is included in irregular vertical category, but the two-axis symmetric configuration evidently minimize the potential occurrence of torque. Subtractive model 56%, 60% and 78% possess one axis symmetric configuration, irregular horizontal which is axis-Y direction and design eccentricity axis-X (ex_d) = 1.5 m from the first floor up to the roof although potential torque of axis-Y direction occurs but its design torque is regular. Subtractive model 89% owns irregular horizontal configuration and asymmetric axis results in a slightly bigger design eccentricity-X (ex_d) than those of subtractive model 56%, 60% and 78% and a relatively irregular eccentricity from the first floor up to the roof that can lead to irregular potential torque as well. Subtractive model 33% actually owns a one symmetric axis-Y but changes in the mass of the building occurs on that axis and the setback between the podium and the tower is quite dramatic, causing a drastic change on the 3rd floor to the 4th floor also on its eccentricity which means the torque potential on podium floor is bigger than its tower.

Observing the graph of figure 4 and 6, the eccentricity design of axis-Y (ey_d) with earthquake weight direction of axis-X owns design eccentricity value of 0 because of its two-axis symmetric form which are model 100% and subtractive model 47%. Aside from these two models, the other models in this axis-X are not symmetrical, thus causing irregular eccentricity from the first floor up to the roof. Model subtractive 33% and 60% with podium and tower configuration with a mass change and drastic setback cause a bigger eccentricity at the bottom and it becomes smaller at the next levels or floors as well as its potential torque. Subtractive model 56% with complex setback configuration generates a very irregular design eccentricity and torque. In subtractive model 78%, the higher the floor, the bigger the eccentricity design and potential torque, but compared to subtractive model 33%, 56% and 60%, the design eccentricity is relatively regular. Model subtractive 89%, which is included in the category of two-axis asymmetric and irregular horizontal, proved to own the most regular eccentricity design compared to subtractive model 33%, 56%, 60% and 78%. Evidently, small curvatures as in model 89% still carry regularity behavior of its main model 100%.

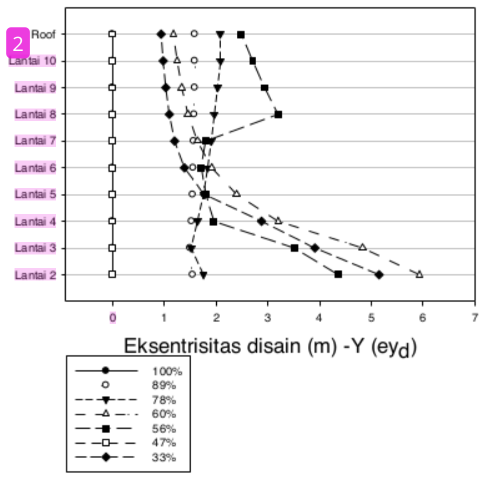


Figure 6. Design eccentricity of axis-Y

(source : analysis)

3) Level of performance and Drift Floor by Floor

The target of the performance consists of the magnitude of design earthquake and tolerated damage level or performance level of the building's response to the earthquake load. The structure performance level is based on FEMA 273 (FEMA, 1997), namely:

- Immediately occupied (IO = Immediate Occupancy),
- Safety guaranteed occupants (LS = Life-Safety),
- Protected from total collapse (CP = Collapse Prevention).

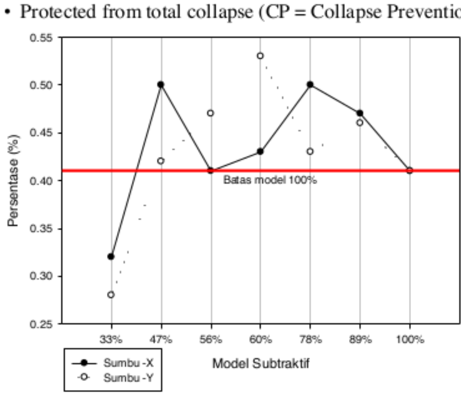


Figure 7. Performance level of the subtractive model (source : analysis)

In general, the performance level of 0.28% to 0.53%, expected in the event of a strong earthquake on the model, will be on Immediate Occupancy and Life-Safety condition. This means there will be a mild to moderate level damages to the building. This performance level is still allowed for office-function buildings. From the graph of Figure 7, it can be observed that the performance level of each model does not possess a specific pattern. It means that it is highly dependent on the configuration of each model.

Restriction of drift floor by floor according to SNI 1726:2012 (Budiono & Supriatna, 2011) is to prevent excessive building shake due to the dynamic effect of earthquake that can cause damage to the building and cause the collapse of the building. Permit deviation among levels of these models based on SNI 1726:2012 is 6.154 cm. The graph of figure 8 and 9 show the drift pattern among levels associated with the magnitude of vertical shear force distribution and configuration of the building. In general, the drift among levels at lower floor is relatively small despite its greater shear force. This occurs due to the still affected clamps on the foundation column. Then, when the levels are higher, in the intermediate levels, the deviation among levels reached its maximum level.

Furthermore, with the increasingly shrinking level shear force, at the top-levels of drift among levels, it shrinks back to normal levels. But in the model configuration that is relatively complex such as subtractive model 56%, a slightly deviation pattern occurs (see fig. 8). Of all permit deviation limit from drift among levels of most of the models, only the 1st floor, the 9th floor and the roof level which own a deviation among levels below the deviation permit. This indicates that a 10th floor building with a rigid frame system in a powerful earthquake zone requires a dual system with other lateral barrier, for example shear wall.

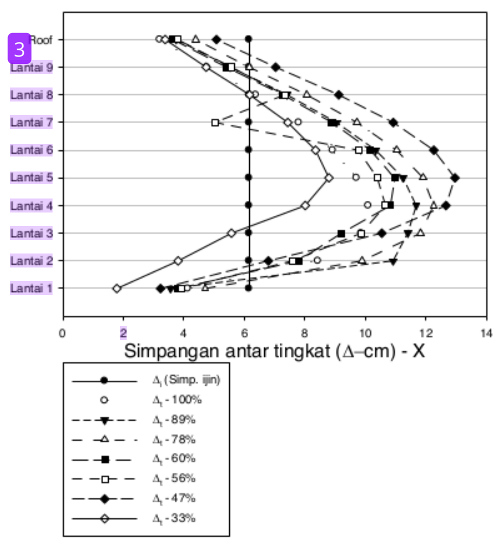


Figure 8. Deviation among levels of subtractive model Axis-X (source : analysis)

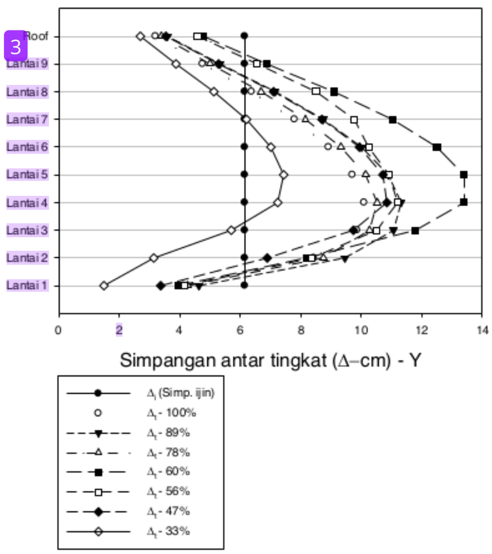


Figure 9. Deviation among levels of subtractive model Axis-Y (source : analysis)

3. Conclusions and Suggestions

From the discussion above, several points can be concluded as follows:

- Basic shear force and vertical distribution of seismic shear force on the building is highly dependent on the weight of the building itself. The heavier the building is, the greater the shear force is and vice versa.
- There are three conditions of the building which own a relatively small potential occurrence of eccentricity and torque on buildings, namely a). horizontal-vertical regular conditions and two-axis symmetric, b). vertical irregular conditions and two-axis symmetric and c). horizontal irregular conditions and two-axis asymmetric but owning only a little subtractive on buildings for example ±10% of the building mass.
- The performance level of 10th floor building in strong earthquake zone with a rigid frame system will result in mild to moderate damage and requires a dual system with other lateral barrier for example a shear wall to increase the stiffness of the building.

From the conclusions above, there are some points that should be considered by the architect to design earthquake resistant buildings:

- To lighten the building, try not to design a building with a huge mass. Then, use a relatively lightweight building materials such as Hebel wall, glass materials and others.
- Not only regular configuration building which owns resistance to earthquakes but irregular configuration building can also be made as a relatively earthquake resistant building by manipulating building mass procedures.
- In a strong earthquake zone, intermediate level building design has considered the use of dual system which is a combination of shear wall and rigid frame.

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