Retrofitting of soft storey building by using different bracing system due to earthquake load

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Abstract. In this research, one residential building of soft storey situated at Seremban, Negeri Sembilan is selected. SAP 2000 which is structural analysis software is being used to determine the maximum displacement and base shear of the soft storey. Four different types of model are introduced to do the modeling. Aceh, Indonesia earthquake data is considered for time history analysis. The comparison of these models for different type of bracing system like X bracing type and V bracing type is carried out. Based on this comparative study, it can conclude that model 3 which is V bracing type is the best and effective method of bracing system for soft storey building. From the result obtained, it shown that V bracing has the lowest value for maximum displacement compared other 3 models. In addition, V bracing type also showed the lowest value of base shear. Thus, it proved that V bracing type reduces the maximum displacement and base shear of the soft storey building.

1. Introduction
Natural disasters can happen without notice but we as human can take a precaution measurement before it happened. This natural disaster can cause loss of life and property. Examples of natural disasters are earthquake, flood, landslide and others. Earthquakes can occur through the sudden movement of earth crust in faults zones. This sudden movement will trigger strain energy and causes seismic waves through the crust around the fault. It becomes a main concern of structural engineering and the performance of structural due to earthquake load is extensively studied in the last decade [1-4].

Earthquake will produce ground shaking that can make buildings and bridges collapsed, causing a problem to gas, electric and phone services [5]. Landslides, flash floods, fires, and huge destructive ocean waves (tsunamis) may happen due to ground shaking during the earthquake event. Besides, due to earthquake, major risk could happen to the buildings with foundations resting on unconsolidated landfill and other unstable soil. When the high population area has undergone an earthquake, it may affected numerous property damage and deaths. Therefore, there are a few of retrofitting technique that can be implemented to make sure that all kind building is safe to use.

Building which has open walls instead of closed walls at ground floor is known as soft storey building [6]. Normally, this space is used for parking or office. Soft storey can also located at the intermediate building instead of ground floor. Soft storey building may damage when columns have to resist excessive gravity loading when there are no structural walls to act as a bracing element [7]. When ground floor level served as recreational, parking, retail or commercial purposes and do not have structural walls are called as soft storey building which has a discontinuity in the stiffness of the building.

Soft stories are subjected to high lateral loads during the earthquake and this lateral force is not
equally distributed along the height of structure [8]. The lateral forces are concentrating on the storey which is having high displacement that causes structures collapse. Soft storey can be categorized as a structure which have lateral stiffness lower than 70 percent of that in the storey higher or lower than 80 percent of the average lateral stiffness of the three storeys above. Soft storey can form at any level of a high rise building to fulfill required functional necessity and serve many purposes [9].

The main reasons of the building collapse during previous earthquakes is because of building soft storey irregularity. Soft story due to increased story height is a well-known subject but soft story may also arise due to abrupt changes in amount of infill walls between stories, which are typically being neglected as a part of load bearing system [10]. Retrofitting method is required to make that structural building is not collapsed during earthquake event. There are several options to increase the strength, stiffness and ductility of the elements or the whole building [11]. A few goals of retrofitting techniques are to increase the lateral strength and stiffness of the building, increase the ductility and enhancing the energy dissipation capacity, eliminate sources of weakness or those that produce concentration of stress and it should be cost effective.

So, there are more than a few ways for retrofitting as stated in which soft storey irregularities can be prevented by additional shear walls, maximizing the rigidity of columns and shear walls, build wall at certain distance from columns and walls. Cross bracing can support the structure’s stability as it pushes the floor and ceiling against one another which make the performance of the building much better during the earthquake [12]. The purpose of this research is to exam the best retrofitting system among the different technique of bracing system due to earthquake load.

The bracing system can improve the structure of soft storey building. SAP2000 will be used to analysis the base shear and joint displacement of soft storey building. Malaysia is a country that has less prone to earthquake compare to other countries even situated near the epicentre of earthquake. However, there are some part of Malaysia that exposed to earthquake especially in Sabah and Sarawak. Although there were no report about life loss, but the earthquake occurred cause to other problem such as settlement of building and road.

Due to earthquake, some problem might be appeared. For example, the building might not safe to occupied. The structure can no longer perform it serviceability. So, it is important to retrofit the structure to prevent the building from collapsed. When the building is collapsed, it is not safe to use and people need to evacuate the building. Besides that, loss of death and property is the sequences of the collapsed building. Therefore, by doing this research, the problem related to this situation can be improved and overcome. The best retrofitting technique can be adopted to make sure that the building is safe to use and for improving the structural stability.

2. Methodology
During the modelling process, the model was assigned with dead load for each floor of the structural model. The bracing is provided for one bay on all storey. There are four models are being analysed in SAP2000;

A. Model 1 (without bracing)
Model 1 is based on the existing of the structural building. Figure 1 show that there is no bracing system on the structural building.
B. Model 2 type X bracing
For Model 2, the structural building is added with the X type of bracing system to improve the structural stability of the building as shown in Figure 2. The model is viewed in 3D and y-z plane.
C. Model 3 type V bracing
Meanwhile, Model 3 is added with the V type of bracing system to the structural building as shown in Figure 3. The model is viewed in 3D and y-z plane.
D. Model 4 (eccentric bracing)
Figure 4 shows Model 4 which is an eccentrically type of bracing system is added to improve the structural stability of the building. The model is viewed in 3D and y-z plane.
Figure 1. Model 1 (without bracing)

Figure 2. Model 2 (X bracing)

Figure 3. Model 3 (V bracing type)

Figure 4. Model 4 (Eccentrically bracing)

2.1 Finite element modelling

In this research, a residential building was selected to do the modelling which is located at Seremban 2, Mukim Rasah, Daerah Seremban, Negeri Sembilan, Malaysia. The ground type at this site can be considered Type B [10]. The residential building is a Reinforced Concrete (RC) and the bracing system was made out of steel. Table 1 shows the data required to model the building.

Table 1. Data Model of Building

| Structure          | Details                              |
|--------------------|--------------------------------------|
| No of stories      | 7                                     |
| Storey height      | Ground floor = 4.2m                   |
|                    | First floor - Roof floor = 3.5m       |

| Material properties | Details   |
|---------------------|-----------|
| Grade of concrete   | C30/35    |
| Grade of steel      | S275      |
| Density of concrete | 25 kN/m³  |
| Density of brick masonry | 2.88 kN/m³ |

| Member properties   | Details         |
|---------------------|-----------------|
| Thickness of slab   | 125 mm          |
| Beam size           | 300 mm x 500 mm |
| Column size         | 600 mm x 600 mm |
| Thickness of wall   | 300 mm          |

SAP2000 software was used to design and analysis the structural building. Table 2 shows summarize
for each type of bracing. All models are using materials of steel and S275 of grade of steel. Boundary condition is pinned-pinned and bracing system is used to cater the lateral load.

Table 2. Summarize of Model

| Model | Bracing type    | Material properties | Boundary condition |
|-------|-----------------|---------------------|--------------------|
| 1     | Without bracing | -                   | Pinned-pinned      |
| 2     | X bracing       | S275 kN/mm²         | Pinned-pinned      |
| 3     | V bracing       | S275 kN/mm²         | Pinned-pinned      |
| 4     | Eccentric bracing | S275kN/mm²       | Pinned-pinned      |

3. Result
An analysis has been conducted to determine the lateral displacement by using SAP2000. The objectives of this study, to determine the maximum displacement and base shear on each type of bracing system. The result was analyzed from time history analysis by different type of bracing system. The result for both maximum displacement and base shear is based on 0.05 second of peak ground acceleration. One element is selected as a critical element which located the highest maximum displacement.

3.1 Comparison maximum displacement for different types of model
Table 3 shows the value of displacement that has been conducted by using SAP 2000. 1A element has been selected to make a comparison of value of maximum displacement between four different types of model.

Table 3. Time History Analysis for Different Type of Model

| Floor Level | Model 1- Without bracing (mm) | Model 2 – X bracing (mm) | Model 3 – V bracing (mm) | Model 4 – Eccentric bracing (mm) |
|-------------|--------------------------------|--------------------------|--------------------------|----------------------------------|
|             | Y-direction | Z-direction | Y-direction | Z-direction | Y-direction | Z-direction | Y-direction | Z-direction |
| GF          | 0           | 0           | 0           | 0           | 0           | 0           | 0           | 0           |
| 1F          | 0.652       | 0.318       | 0.732       | 0.248       | 0.575       | 0.208       | 0.576       | 0.298       |
| 2F          | 0.865       | 0.395       | 0.948       | 0.309       | 0.692       | 0.267       | 0.755       | 0.371       |
| 3F          | 1.120       | 0.420       | 1.195       | 0.321       | 0.858       | 0.299       | 0.971       | 0.395       |
| 4F          | 1.362       | 0.425       | 1.433       | 0.330       | 1.033       | 0.321       | 1.177       | 0.402       |
| 5F          | 1.570       | 0.419       | 1.635       | 0.324       | 1.214       | 0.340       | 1.373       | 0.400       |
| 6F          | 1.713       | 0.416       | 1.775       | 0.323       | 1.403       | 0.350       | 1.475       | 0.398       |
Figure 5. Comparison Maximum Displacement between different type of model along y direction

Figure 6. Comparison Maximum Displacement between different type of model along Z direction

A comparison of maximum displacement between types of model has been interpreted into the chart. The value of maximum displacement was observed for each level of floor. Figure 5 shows comparison maximum displacement between types of model along Y direction. Meanwhile, Figure 6 shows a comparison of maximum displacement along Z direction.

3.2 Comparison base shear on different type of models

Another comparison of different type of model is based on base shear as shown in Table 4. Base Shear on Different Types of Model. Base shear is total force reaction on all the supports in the direction of Y and Z. The value of base shear then translated into chart by comparison between different types of model as shown in Figure 7.

Table 4. Base Shear on Different Types of Model

| Type of model         | Base Shear (kN) |
|-----------------------|-----------------|
|                       | Y direction     | Z direction   |
| Model 1-without bracing | 3200.292       | 180.884       |
| Model 2-X bracing     | 3054.799        | 180.574       |
| Model 3-V bracing     | 1760.516        | 44.376        |
| Model 4-Eccentric bracing | 2950.348      | 156.083       |
The value of base shear then translated into chart by comparison between different types of model as shown in Figure 7. Earthquake data give different impact on the soft storey building including lateral displacement. From the result that have been tabulated from Figure 5 and Figure 6, it is clear that majority of displacement in the direction of Y is more than majority displacement in the direction of Z. All the value of displacement either from Y direction or Z direction is varies linearly from ground floor to the top floor. Chart shows the maximum displacement for both directions is higher when going up the floor.

From the tabulated data for Figure 5 and Figure 6 also can show that, among all 4 models, model 3 which is V bracing has the lowest value of maximum displacement (0.575mm first floor) compared to others for both directions. Even if the value of maximum displacement of Y direction for model 2 is higher than model 1, the value of maximum displacement of Z direction is contradicted where this shows that the X bracing will contribute to the building movement in the Y direction and not suitable for soft storey structures.

The lowest value of base shear is model 3 which is 44.376kN for Z direction and same goes to Y direction. From the Figure 7, it is observed that the value of base shear increase when model 2 which is X bracing type, added to model 1 (without bracing). Thus, is have been all four different model have a different value for both maximum displacement and base shear during analysis. It is has been shown that when V bracing type (mode 3) and Eccentric bracing type (model 4) is added, the value of maximum displacement and base shear is decreasing compared to model 1. Each model has its own advantages. Model 2-X bracing cross bracing system is consider to improve the performance of the building. The structure’s stability become stronger when the cross bracing pushes the floor and ceiling against one another. Model 3-V bracing means that the buckling capacity of the compression brace is significantly less than the tension yield capacity of the tension brace. Once the braces reach their resistance capacity, the load is resisted in the bending of the horizontal member. Model 4-Eccentric bracing is similar to V-bracing instead of the bracing members meeting at a center point there is space between them at the top connection. Bracing members connect to separate points on the horizontal beams. This is so that the space between the bracing members absorbs energy from seismic activity through plastic deformation.

4. Conclusion
A comparative study has been done to determine the best bracing type to be applied for structural stability. All different type of model, are included without bracing, X bracing type, V bracing type and Eccentric bracing type. All four different models are created and the time history analysis is performed based data peak ground acceleration. Maximum displacement and base shear have determined.
Based on this comparative study, it can conclude that model 3 which is V bracing type is the best and effective method of bracing system for soft storey building. From the result obtained, it shown that V bracing has the lowest value for maximum displacement compared other 3 models. In addition, V bracing type also showed the lowest value of base shear. Thus, it proved that V bracing type reduces the maximum displacement and base shear of the soft storey building.

X-bracing can reduce lateral storey displacement, storey drift as well as axial force and bending moment in columns remarkably. However, from the results, it can conclude the X-bracing is not suitable for the soft storey buildings.

5. Recommendations

There are many retrofitting techniques can be used for improving the structural stability of the building. Bracing system is an example of retrofitting techniques that can improve the structural stability. Perhaps in future, others technique of retrofitting can be implemented and modeling can be done to improve the structural stability. Every retrofitting technique have its own advantages and disadvantages yet depend on different condition and situation of the soft storey building. It is not necessarily for using bracing system to improve the structural stability.

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