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BEHAVIOUR STUDIES OF DIAGONAL BRACED AND CHEVRON BRACED STEEL FRAME STRUCTURE CBF (CONCENTRICALLY BRACED FRAMES) WITH PUSHOVER ANALYSIS

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ABSTRACT

This paper presents diagonal braced and chevron braced steel structure design with pushover analysis was conducted following ATC-40 guidelines. In this study, the lateral load used is increased gradually until plastic hinge and collapse occur. This analysis has purpose on acquiring capacity curve, performance point, and the process of plastic hinge until the building collapse. There are five steel structure models designed based on the various types of bracing and bracing configuration. Model 1 is steel structure without bracing, model 2 and 3 are chevron braced steel structure, model 4 and 5 are diagonal braced steel structure. The results of this study indicate that the performance level of five models structure for earthquake in x direction and y direction according to ATC-40 is IO (Immediate Occupancy). Model 4 has the best effectiveness in terms of plastic hinge mechanism compared to other models. In the last step, model 4 is able to reduce plastic hinge 84% from model 1 for earthquake in x direction and 79% from model 1 for earthquake in y direction. Model 3 has the greatest cability to withstand the forces of an earthquake compared to other models. It is 185% bigger than model 1 for x direction and 181% bigger than model 1 for y direction. Model 3 has the greatest effectiveness in reducing lateral displacements compared to other models in the amount of 65.474% of model 1 for x direction and 72,14% of model 1 for y direction. Model 3 has the greatest effectiveness in reducing storey drift compared to other models in the amount of 73,887% of model 1 for x direction and 80,55% of model 1 for y direction.

***Keywords**: pushover analysis, capacity curve, performance point, immediate occupancy*

INTRODUCTION

The level of an earthquake risk in Indonesia is very high, so the risk of building damages is very high too. In general, peredam gempa in concrete building is shearwall, but in steel building is bracing. Bracing has two type, there are concentrically braced frame (CBF) and eccentrically braced frame (EBF). Concentrically braced frame (CBF) is a steel frame structural system which has high elastic stiffness, while eccentrically braced frame (EBF) is a steel frame structural system which has a excellent elastic stiffness and good ductility. Concentrically braced frame (CBF) has many type, there are diagonal brace (tension/compression both), chevron brace (K-brace), X-cross brace (tension/compression only), and iverted chevron brace. Chevron braced give a best performance during earthquake, while diagonal braced tension, diagonal braced compression, dan X-braced (Chitte, 2014).

The method used to reduce a high risk of building damages due earthquake is performance based seismic design. The concept of performance based seismic design determines the performance level which is expected to be reached when the structure affected by earthquake with a certain intensity. Analysis is used in performance based seismic design is pushover analysis.

Pushover analysis is behaviour analysis of collapse building caused by earthquake, load of which is increased gradually until exceed load capacity, leads melt, deformation, and collapse. The purpose of pushover analysis is estimating maximum force, estimating deformation, and providing information about the critical part of building structure.

This study analyzes behaviour of diagonal braced and chevron braced steel frame structure CBF (concentrically braced frames) with pushover analysis was conducted following ATC-40 guidelines. The purpose of this study is to compare the performance level of structure, plastic hinge mechanism, and the effectiveness of the model structure in earthquake resistant and reducing lateral displacements.

PUSHOVER ANALYSIS

Pushover analysis is behaviour analysis of collapse building caused by earthquake, load of which is increased gradually until exceed load capacity, leads melt, deformation, and collapse. The purpose of pushover analysis is estimating maximum force, estimating deformation, and providing information about the critical part of building structure. Pushover analysis results in capacity curve which describes the correlation of total lateral shear force (V) lateral displacement at roof (D) as shown at Figure 1.

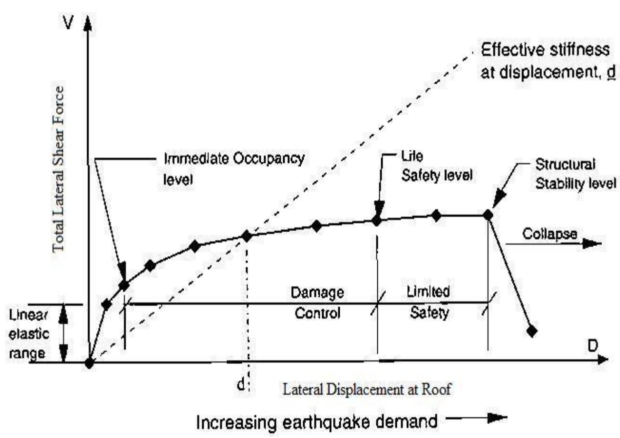


Fig. 1. Pushover curve (ATC-40)

The following is the explanation of pushover curve at Figure 1 based on structural and non-structural damages, such as:

1. At immediate occupancy level, damages caused by earthquake do not occur on structural and non-structural elements.
2. At life safety level, damages caused by earthquake do not occur on structural elements, but occur on non-structural elements such as fracture on walls.
3. At structural stability level, damages caused by earthquake occur on both structural and non-structural elements. As the result, the structure can not endure lateral force. If the load is increased then the structure will collapse.

The steps of pushover analysis in designing the structure of an earthquake resistant construction are:

1. Determining the control point to monitor the amount of displacement on structure.
2. Making capacity curve based on the various patterns of lateral force.
3. Estimating the amount of lateral displacement during earthquake plan or displacement target.
4. Evaluating the level of structure performance when the control point is located exactly on the target of displacement while using ATC 40.

The weakness of pushover analysis in designing an earthquake resistant construction are:
1. The analysis result is an approximation, because earthquake is two directional phenomenon in certain cycle, while the load in pushover analysis is static and monotonic.
2. The selection of lateral loading pattern used is crucial.
3. Non-linier analysis model is more complicated than linier.

The performance of building structure in ATC-40 is divided into six level, such as:
1. Immediate occupancy, SP-1
   On this level, the structural damage caused by earthquake is small. The characteristic and the capacity of vertical and lateral force resistant system do not change so the building is safe to use.

2. Damage control, SP-2
   On this level, the value of earthquake load which is probable to exceed the 50 years duration of serviceability limit states is 10%.

3. Life safety, SP-3
   On this level, some damages start to emerge significantly on the structure as the results of the earthquake occurrence. However, the structure can still endure the earthquake as the main component has not collapse. The structure is still usable with some reparation, but the damage often needs more cost.

4. Limited safety, SP-4
   The condition of the structure on this level may not be as good as the Life Safety level and not as bad as the next Structural Stability level.

5. Structural stability, SP-5
   On this level, the building has been damaged heavily on structural and non-structural component as the structure cannot endure the lateral force due to the consolidation.

6. Not considered, Sp-6
   On this level, the building has collapsed. As the result, the structure is not usable. The structure can only be evaluated seismically.

STRUCTURE MODEL

The building lay out used on the study is presented as Figure 2. The red line represents the bracing position on the building structure. The Portal used is 10 story building which is designed into five structure models based on various types of bracing and bracing configuration as shown at Figure 3.

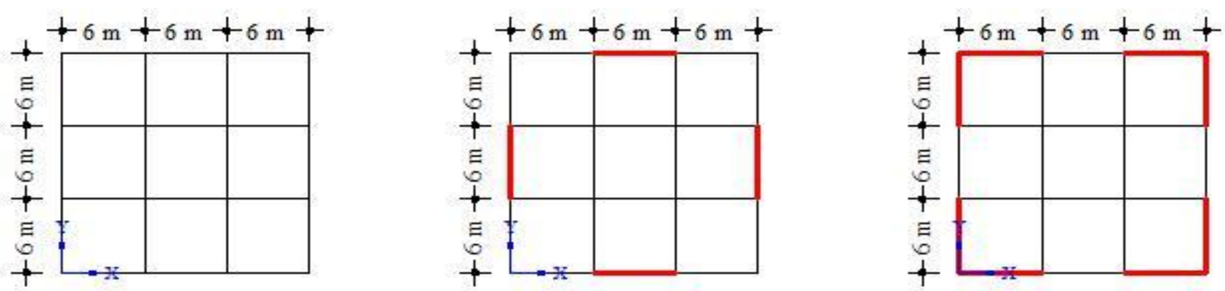


Fig. 2. Building layout

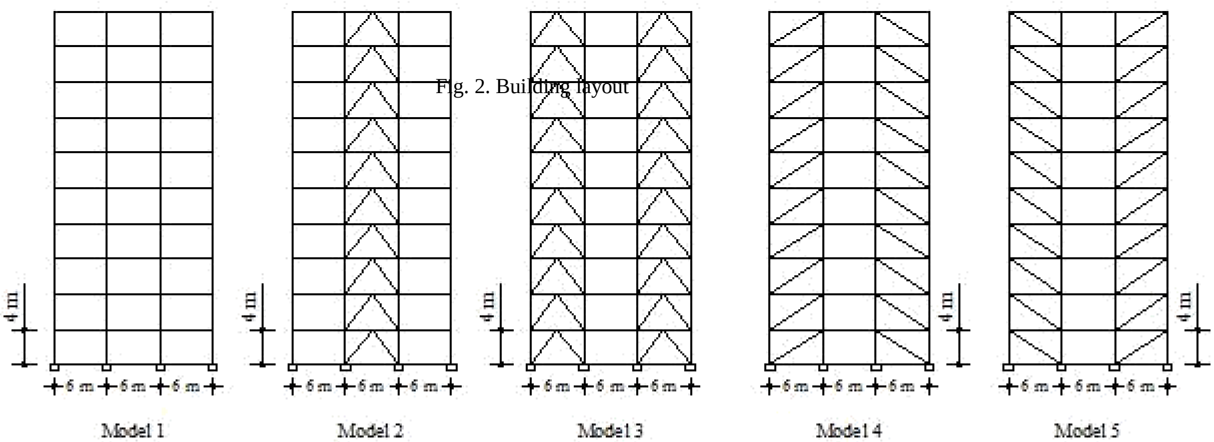
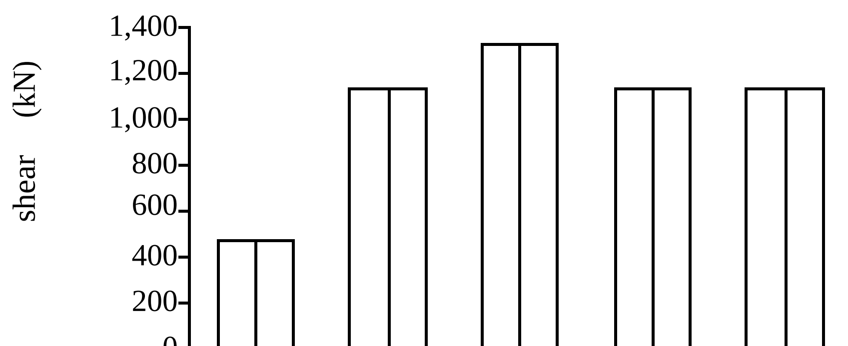


Fig. 3. Structure model

RESULT AND EVALUATION

4.1. Base Shear

The comparison of base shear on each model is presented as Figure 4 and Table 1.



	Model 1	Model 2	Model 3	Model 4	Model 5
x direction	471	1,130	1,341	1,146	1,162
y direction	471	1,130	1,326	1,134	1,142

Fig. 4. Base shear

Table 1. The comparison of base shear

Model	Base shear (kN)		Difference with model 1(%)	
	x direction	y direction	x direction	y direction
1	471	471	0	0
2	1,130	1,130	140	140
3	1,341	1,326	185	181
4	1,146	1,134	143	141
5	1,162	1,142	147	142

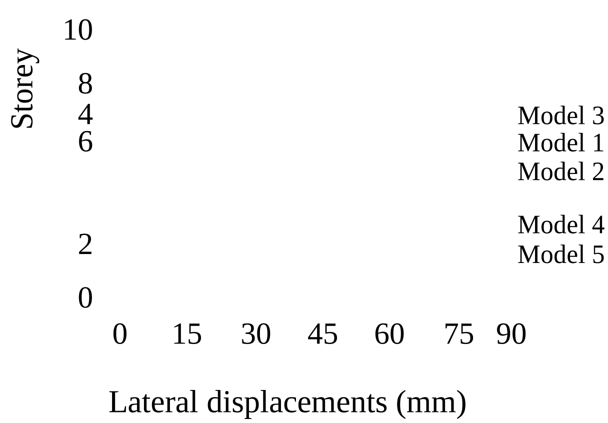
Based on Figure 4 and Table 1, model 1 capability to withstand the forces of an earthquake is the least of all models. It is able to withstand 471 kN in both x direction and y direction. On the contrary, Model 3 has the greatest cability to withstand the forces of an earthquake compared to other models. It is able to withstand 1.341 kN in x direction and 1.326 kN in y direction. Model 3 is 185% bigger than model 1 for x direction and 181% bigger than model 1 for y direction.

4.2. Displacements

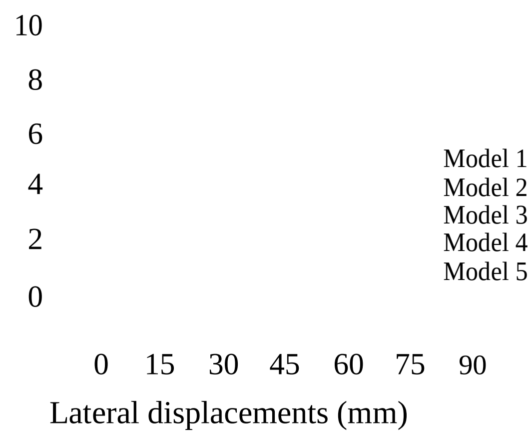
There are two types of displacements caused by earthquake, such as lateral displacements and storey drift.

4.2.1. Lateral Displacements (δe)

The comparison of lateral displacements on each model is presented as Figure 5. Based on Figure 5, model 1 has the highest lateral displacements which reaches the amount of 63,092 cm for x direction and 78,393 cm for y direction. It means model 1 has the highest ductility compared to other models. On the contrary, model 3 has the lowest lateral displacements which reaches the amount of 21,783 cm for x direction and 21,835 for y direction. Then, model 3 is described as the model with the highest stiffness compared to other models. Model 3 has the greatest effectiveness in reducing lateral displacements compared to other models in the amount of 65.474% of model 1 for x direction and 72,14% of model 1 for y direction.



(a)



(b)

Fig. 5. Lateral displacements (a) x direction (b) y direction

4.2.2. Storey Drift (Δ)

The comparison of storey drift on each model is presented as Table 2. Based on Table 2, model 1 has the highest storey drift that reaches the value of 49,209 cm on 4 floor for x direction and 65,632 cm on 3 floor for y direction. On the contrary, model 3 has the lowest storey drift that reaches the value of 12,85 cm on 5 floor for x direction and 12,765 cm on 5 floor for y direction. Model 3 has the greatest effectiveness in reducing storey drift compared to other models in the amount of 73,887% of model 1 for x direction and 80,55% of model 1 for y direction.

Table 2. The comparison of storey drift

Model	Δ_{maks} (cm)		Percentage of storey drift reduction to model 1 (%)	
	x direction	y direction	x direction	y direction
1	49,209	65,632	0	0
2	20,030	20,265	59,296	69,123
3	12,850	12,765	73,887	80,550
4	14,405	14,360	70,727	78,120
5	14,250	14,095	71,042	78,524

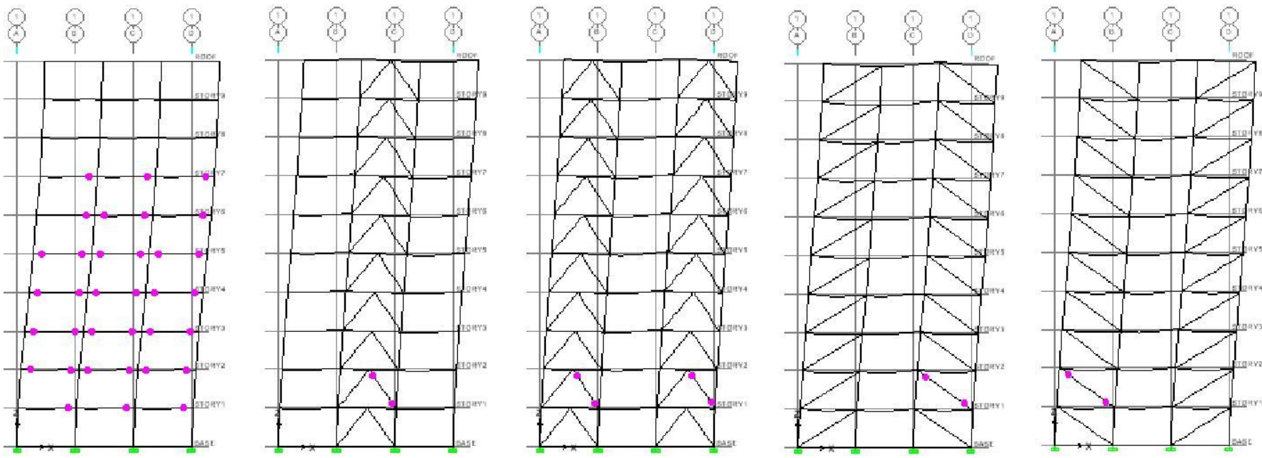
4.3. Drift Ratio

The result of storey drift analysis is used to estimate drift ratio. Drift ratio is used to estimate which floor will has critic first. Drift ratio is the comparison of storey drift and storey. Drift ratio on each model is presented as Figure 6.

4.5. Plastic Hinge Mechanism

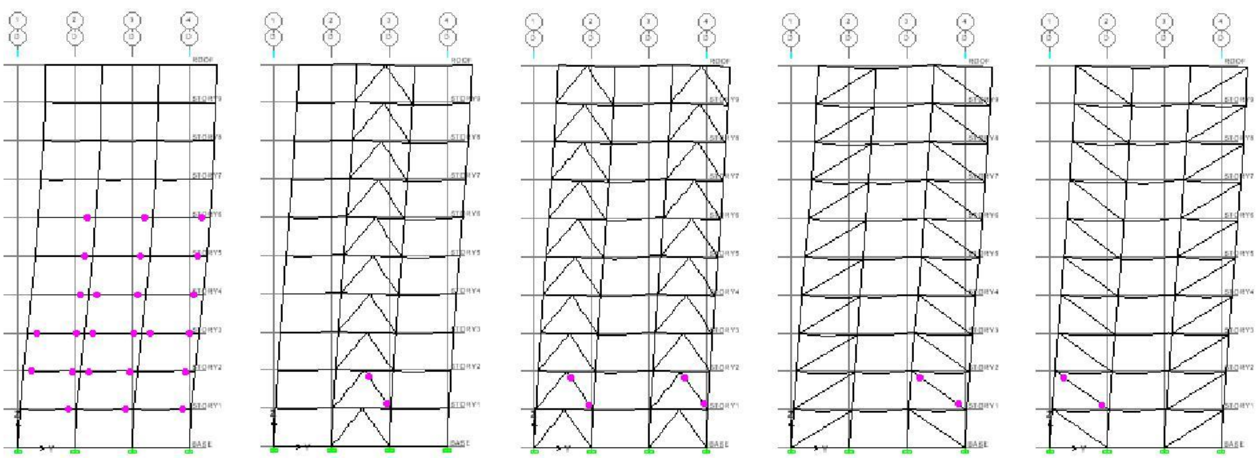
Plastic hinge mechanism on each model is presented as Figure 8 until Figure 11. The percentage of plastic hinge reduction in the last step as shown at Table 3. The following symbolizes the description of plastic hinge level for Figure 8 until Figure 11:

B : IO : LS : CP :
C :
D :
E :



(a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4 (e) Model 5

Fig. 8. The plastic hinge in the first step for earthquake in x direction

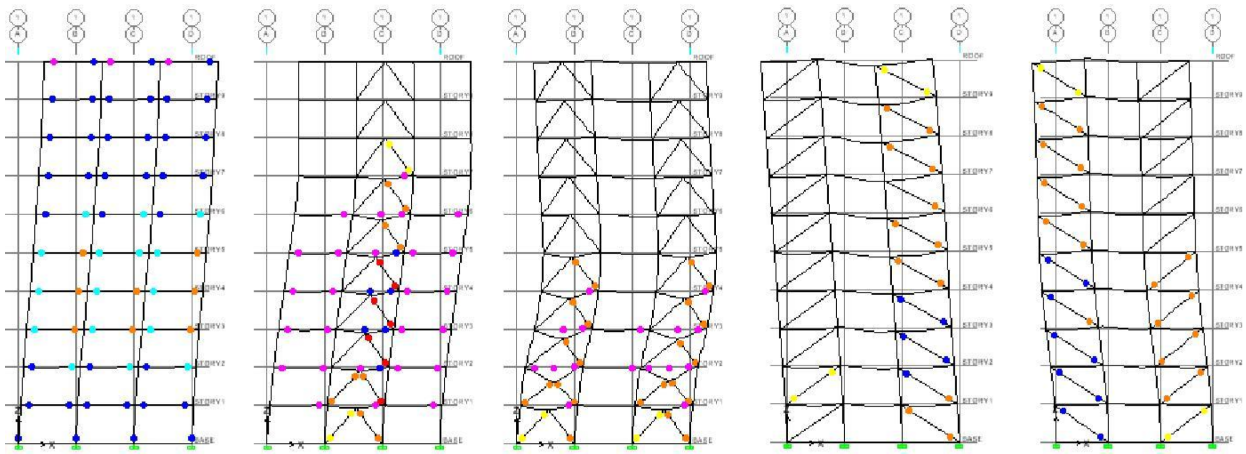


(a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4 (e) Model 5

Fig. 9. The plastic hinges in the first step for earthquake in y direction

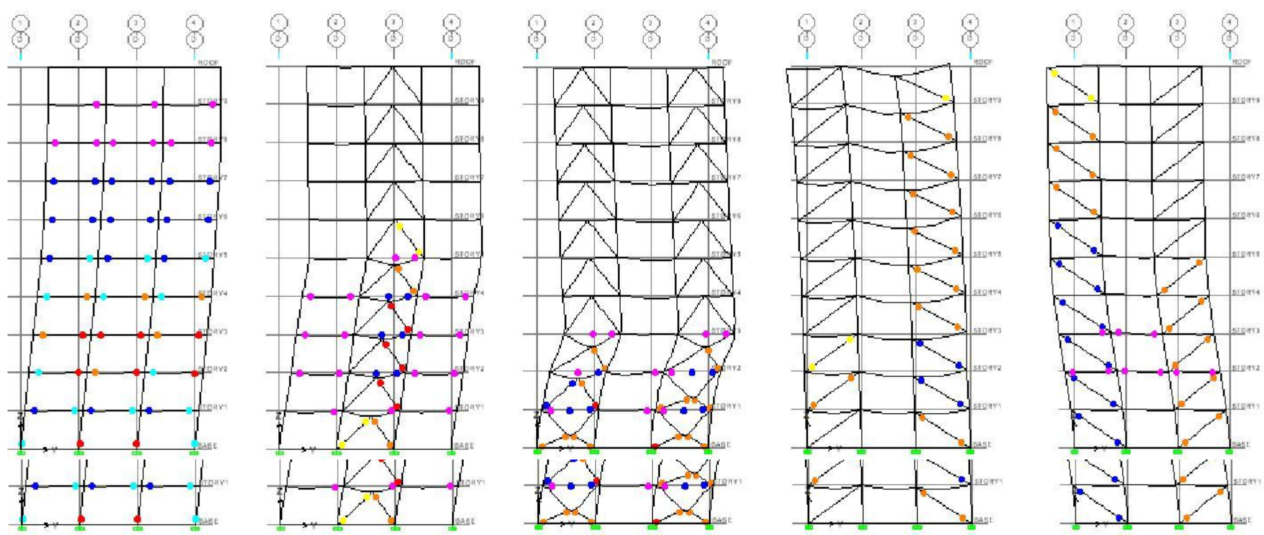
Based on Figure 8, the plastic hinge in the first step of model 1 for earthquake in x direction has 34 plastic hinges on beam. Model 2, 4, and 5 have 2 plastic hinges on bracing. Model 3 has 4 plastic hinges on bracing. All plastic hinges occurs at B level.

Based on Figure 9, the plastic hinge in the first step of model 1 for earthquake in x direction has 24 plastic hinges on beam. Model 2, 4, and 5 have 2 plastic hinges on bracing. Model 3 has 4 plastic hinges on bracing. All plastic hinges occurs at B level.



(a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4 (e) Model 5

Fig. 10. The plastic hinges in the last step for earthquake in x direction



(a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4 (e) Model 5

Fig. 11. The plastic hinges in the last step for earthquake in y direction

Based on Figure 10, the plastic hinge in the last step of model 1 for earthquake in x direction has 3 plastic hinges on beam at B level, 33 plastic hinges on beam and 4 plastic hinges on column at IO level, 16 plastic hinges on beam at LS level, and 8 plastic hinges on beam at D level. Model 2 has 26 plastic hinges on beam at B level, 6 plastic hinges on beam at IO level, 4 plastic hinges on bracing at C level, 9 plastic hinges on bracing at D level, and 7 plastic hinges on bracing at E level. Model 3 has 16 plastic hinges on beam at B level, 4 plastic hinges on bracing at C level, and 23 plastic hinges on bracing at D level. Model 4 has 5 plastic hinges on bracing at IO level, 4 plastic hinges on bracing at C level, and 12 plastic hinges on bracing at D level. Model 5 has 9 plastic hinges on bracing at IO level, 4 plastic hinges on bracing at C level, and 17 plastic hinges on bracing at D level.

Based on Figure 11, the plastic hinge in the last step of model 1 for earthquake in y direction has 9 plastic hinges on beam at B level, 18 plastic hinges on beam at IO level, 11 plastic hinges on beam and 2 plastic hinges on column at LS level, 6 plastic hinges on beam at D level, and 7 plastic hinges on beam and 2 plastic hinges on column at E level. Model 2 has 17 plastic hinges on beam at B level, 6 plastic hinges on beam at IO level, 4 plastic hinges on bracing at C level, 4 plastic hinges on bracing at D level, and 6 plastic hinges on bracing at E level. Model 3 has 10 plastic hinges on beam at B level, 7 plastic hinges on beam and 2 plastic hinges on bracing at IO level, 16 plastic hinges on bracing at D level, and 2 plastic hinges on bracing at E level. Model 4 has 4 plastic hinges on bracing at IO level, 3 plastic hinges on bracing at C level, and 16 plastic hinges on bracing at D level. Model 5 has 9 plastic hinges on beam at B level, 12 plastic hinges on bracing at IO level, 2 plastic hinges on bracing at C level, and 16 plastic hinges on bracing at D level.

Table 3. The percentage of plastic hinge reduction in the last step

Model	Total of plastic hinge		Percentage of plastic hinge reduction to model 1 (%)	
	Earthquake in x direction	Earthquake in y direction	Earthquake in x direction	Earthquake in y direction
1	256	220	0	0
2	164	122	36	45
3	100	86	61	61
4	42	46	84	79
5	60	104	77	53

Based on Table 3, model 4 has the best effectiveness in terms of plastic hinge mechanism compared to other models because model 4 in the last step has the least plastic hinge and plastic hinge on beam is not occur. It is 42 plastic hinges for earthquake in x direction and 46 plastic hinges for earthquake in y direction. In the last step, model 4 is able to reduce plastic hinge 84% from model 1 for earthquake in x direction and 79% from model 1 for earthquake in y direction.

CONCLUSIONS

As the pushover analysis succesully executed, we can conclude these six conclusions, such as :

1. The performance level of five models structure for earthquake in x direction and y direction according to ATC-40 is IO (Immediate Occupancy).
2. Model 4 has the best effectiveness in terms of plastic hinge mechanism compared to other models and plastic hinge on beam is not occur. In the last step, model 4 is able to reduce plastic hinge 84% from model 1 for earthquake in x direction and 79% from model 1 for earthquake in y direction.
3. Model 3 has the greatest cability to withstand the forces of an earthquake compared to other models. It is 185% bigger than model 1 for x direction and 181% bigger than model 1 for y direction.
4. Model 3 has the greatest effectiveness in reducing lateral displacements compared to other models in the amount of 65.474% of model 1 for x direction and 72,14% of model 1 for y direction.
5. Model 3 has the greatest effectiveness in reducing storey drift compared to other models in the amount of 73,887% of model 1 for x direction and 80,55% of model 1 for y direction.

6. Model 3 has the greatest effectiveness in reducing drift ratio compared to other models in the amount of 74,5877% for x direction and 82,3484% for y direction.

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