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ARTICLE

# Study of the Use of Fiber Hinges in Non-Linear Static Analysis

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**Abstract**

Pushover analysis or also known as non-linear static analysis is one of the structural analysis procedures that is widely used in seismic assessment and performance evaluation of existing structures . In the nonlinear analysis procedure, the behavior of the structure due to external loads acting can be seen from the status of the joints formed. One of the joint models that is less commonly used in non-linear static analysis is the fiber hinge joint modeling. Fiber hinge is a nonlinear joint model that can consider distributed plasticity along with its structural elements. Study this learn possibility difference in results analysis use fiber hinge because properties component specified nonlinear researcher . In order to study the impact of the use of joint modeling variations in nonlinear analysis, a regular reinforced concrete structure model with 4 height variations namely 3, 4, 5, and 6 floors which were analyzed with two different types of joint modeling. Fiber hinges and conventional lumped hinges will be defined in the cross section. Research results show that the use of fiber hinge in each model produces score relative moment small however given rotation relatively more big than lumped hinge as well relative base shear value small than lumped hinges. Considering the fiber hinge is method that gives state of natural response so that deformation globally generated more big than lumped hinges. This thing take effect to determination structure performance value.

**Keywords:** Structure performance, Nonlinear analysis, Fiber Hinges, Pushover analysis

## 1. Pendahuluan

Pushover analysis or also known as non-linear static analysis is one of the structural analysis procedures that is widely used in seismic assessment and performance evaluation of existing structures. Pushover analysis is a method in which the structure is subjected to gravity loading and lateral thrust loading in one direction (monotonic) gradually during elastic and inelastic conditions until the structure collapses (Kurniawandy and Nakazawa 2020). In order to see the inelastic behavior that occurs during the nonlinear phase, a joint is modeled at a portion of the total length where the inelastic

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condition is anticipated to occur. When the structure is subjected to lateral loads, the maximum bending moment tends to occur at the ends of the beam. Therefore, under lateral loading, the inelastic action is expected to be mostly concentrated in the high bending moment region, so that the joint can be modeled by placing it at both ends of the cross section (Inel and Ozmen 2006).

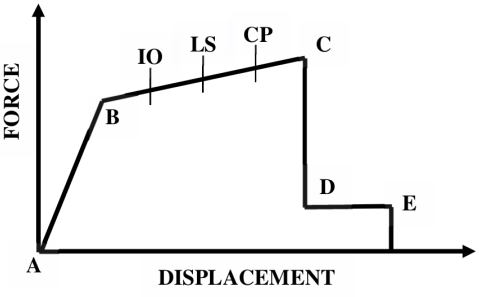
Fiber hinge modeling is one of the joint modeling in the frame that can take into account the distributed plasticity along the structural elements. Fiber hinges can be installed throughout the entire length of the structural element or for a fraction of the total length where inelastic conditions are anticipated to exist (Yön and Calayır 2013). Meanwhile, in the lumped hinge model approach, it is assumed that all inelastic deformations are concentrated at a certain point or location that is determined directly in the cross section to include nonlinear effects that affect the overall stiffness of the structure. Fiber hinge is considered more natural than in the lumped hinge, because the fiber hinge automatically takes into account the material interactions and changes the interaction in the moment-rotation relationship.

In this study, we will study the differences in the impact of joint modeling between fiber hinge and lumped hinge on a regular reinforced concrete structure model with 4 variations in height . namely 3, 4, 5, and 6 floors . The magnitude of the structure capacity and the maximum inelastic deviation that occurs with several variations in the height of the structure and types of joints will be analyzed using finite element analysis software.

## 2. Methodology

### *2.1 Pushover Analysis*

Linear analysis such as time history analysis or response spectrum analysis can calculate earthquake loads, but cannot be used to predict building performance against major earthquakes. The most commonly adopted method is non-linear static analysis, known as pushover analysis (Kovela et al. 2017). There are two commonly used nonlinear pushover static analysis methods , namely the Capacity Spectrum Method (CSM) and the Direct Coefficient Method (DCM) . In the CSM method, the intersection of the pushover capacity curve and the demand spectrum defines the " performance point " or the performance point of the structure being evaluated (Zou and Chan 2005). The results of this procedure will produce a curve of the relationship between the total thrust (base shear) and the displacement of the roof (roof displacement) which is commonly referred to as a pushover curve . These results will be processed to present data that can determine the performance of the structure. The performance of the structure is determined by the criterion of the structural-drift ratio which is obtained when the performance point is reached. The results are compared with the drift requirements , in this study will refer to ATC-40.



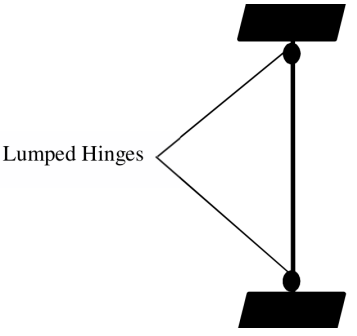

(Ismaeil 2018)

**Figure 1.** Pushover Capacity Curve

Pushover analysis may provide more relevant information than static or dynamic linear analysis. Pushover analysis tends to show non-linear behavior that occurs in structures and important structural damage at the level of displacement (Peter and Badoux 1999). Determination of the non-linear behavior of the structure is not only limited to the magnitude of the drift that occurs but also the response of structural elements as a whole, such as beams and columns based on the rotational capacity of plastic hinges (Hakim, Alama, and Ashour 2014). As for the Curve Pushover capacity can be seen in Figure 1.

### *2.2 Lumped Hinge*

Lumped hinges are something analysis joints plastic concentrated on a potential point at the joint zone plastic . Behavior non-linear material effect will concentrated on a single layer with base fully plastic condition without existence take into account influence material elasticity straight away . In a lumped system , non-linear behavior is represented by to connection moment of curvature or rotation , however in assumption this approach not enough conservative consequence the difficulty behavior inelastic effect arrested (Al-jassim and Husssain 2018) . As for the Lumped Hinge System could seen in Figure 2.




(Kim et al. 2019)

**Figure 2.** Lumped Hinges System

### *2.3 Fiber Hinges*

Fiber hinge modeling is one of the joint modeling in the frame that can take into account the distributed plasticity along the structural elements. Each particular fiber will apply a uniaxial stress-strain relationship that captures various non-linear aspects of the material. Fiber hinges can be installed throughout the entire length of the structural element or for a fraction of the total length where inelastic conditions are anticipated to exist (Yön and Calayır 2013). In this model, the structural elements are divided into three types of fiber , some fibers are used in the main reinforcement, some fibers are used to determine the nonlinear behavior of the concrete core and other fibers are used in the concrete blanket (Powell 2010) . Typical modeling of the fiber hinge can be seen in Figure 3.

In the modeling of fiber types, each fiber will respond in an inelastic condition according to the stress-strain capacity of the material. Reinforced concrete buildings will directly depend on the ability of the material in inelastic conditions to be affected by confinement in critical sections (Terrenzi, Spacone, and Camata 2020). The following Figure 4 is a stress-strain relationship with an approximation on a nonlinear basis.

The thing that distinguishes fiber hinge modeling from conventional plastic hinges is that the fiber hinge modeling approach is based on defining non-linear properties directly at the material level which then manifests at the cross-sectional, finite element level of the structure. The fiber hinge can

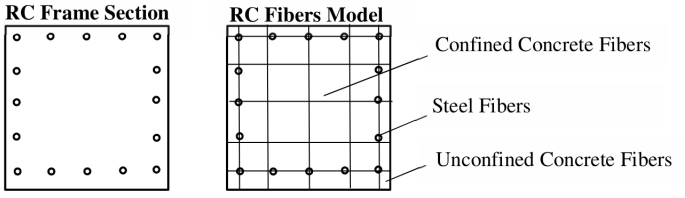
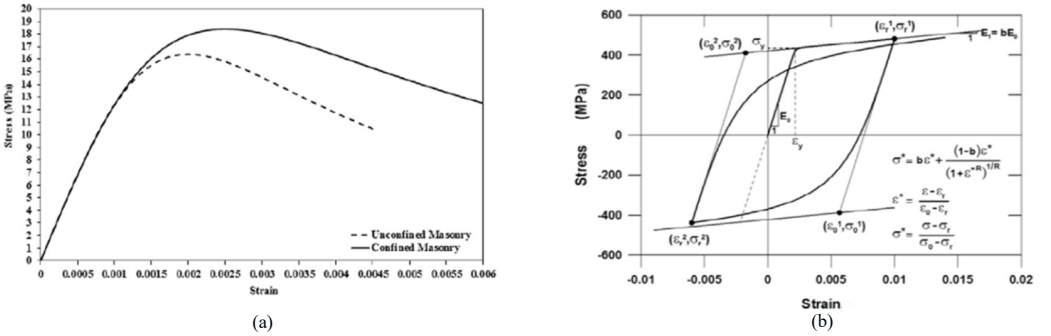



**Figure 3.** Hinge Fiber Modeling Illustration




(Abdellatif et al. 2019)

**Figure 4.** (a) Stress-Strain Mandel model (b) Menegetto-pinto steel model

take into account the axial and moment interactions simultaneously and the modeling is simple and the model approach is more concise when compared to the plastic hinge theory. The fiber hinge also has the advantage of accommodating concrete cracks during the elastic range before the reinforcing steel begins to melt.

## 3. Numerical Model

The structural model that will be analyzed in this study is a regular reinforced concrete structure with a different number of levels in each model. Data related to geometry and cross-sectional dimensions that will be used in this study can be seen in Table 1 below.

**Table 1.** Preliminary Data Structure

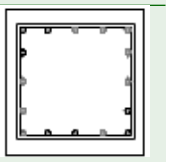
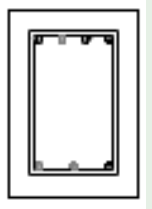
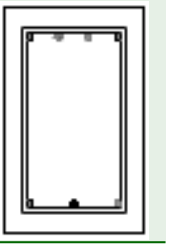
| Model | Trape-X | | Trape-Y | | Level | Tall | Column cross section | | Beam cross section | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Exterior | Interior | Y-dir (5 m) | X-dir (4 m) |
| Model 1 | 3 | 4 m | 2 | 5 m | 6 | 5-4-4 | 55/55 | 55/55 | 45/30 | 35/25 |
| Model 2 | 3 | 4 m | 2 | 5 m | 6 | 5-4-4 | 55/55 | 55/55 | 45/30 | 35/25 |
| Model 3 | 3 | 4 m | 2 | 5 m | 6 | 5-4-4 | 55/55 | 55/55 | 45/30 | 35/25 |
| Model 4 | 3 | 4 m | 2 | 5 m | 6 | 5-4-4 | 55/55 | 55/55 | 45/30 | 35/25 |

concrete strength 30 MPa
reinforcement steel BCTS 420B

On the table on for modeling in study study this There are 4 models with use method Lumped hinges system and there are 4 models using method combination fiber hinges and lumped hinges .

System combination use method of fiber hinges on the column and for beam use lumped hinges As for the details of the cross section could seen in Table 2.

**Table 2.** Section Details

| Cross section | Reinforcement configuration | Sketch |
|---|---|---|
| Column | 16D16 |  |
| Beam X | 4D13 | |
| | 3D13 |  |
| Beam Y | 4D13 | |
| | 3D13 |  |

Property joints non – linear parameter dependent plastic can be applied in part and along element. The lumped system approach which is analysis in level cross section that can connected using (moment-rotations) already estimated previously (Beer et al. 2020). Property parameters joints plastic will depending on cross section element column and beam but those parameters must get done with ASCE-41 (ASCE 2017) , for block (M3) can seen in Figure 5.

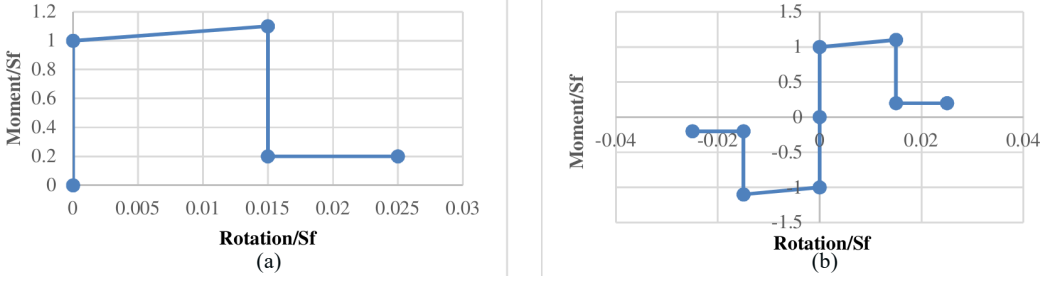



**Figure 5.** Modeling Lumped Hinges Column and Beam Properties

Fiber hinges are elastoplastic material analysis move of non-linear cross-sectional material (Wang, Peng, and Dong 2018). Quantity forced displacement and moment of rotation curve score no determined by method specific this . On the program element until cross section will shared Becomes several fibers distributed on the surface cross section . Each fiber location has location , area and stress-strain curve . As for the modeling could seen in Figure 6.

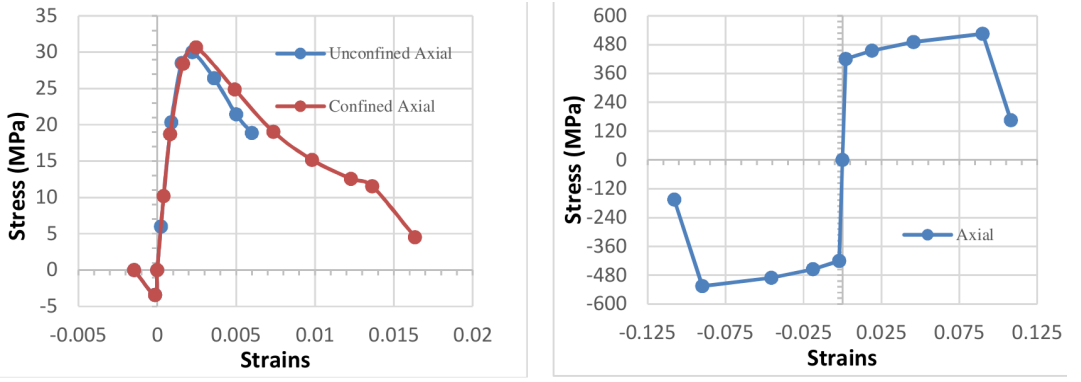



**Figure 6.** Modeling Hinges Fiber Properties

## 4. Results and Discussion

### *4.1 Structure Period*

The period of the structure is the ability of the resonant structure in one cycle in a static position. The value of the period of the structure will depend on the mass function and the stiffness of the structure which has a unique relationship or called the eigenproblem , this relationship will determine the angular frequency and period of vibration of the structure. The following is the result of the period structure in each model that can be seen in Table 3 .

**Table 3.** Period Structure

| | Period (second) | |
|---|---|---|
| Model | X-dir | X-dir |
| Model 1 | 0.525 | 0.647 |
| Model 2 | 0.604 | 0.790 |
| Model 3 | 0.722 | 0.950 |
| Model 4 | 1.210 | 1.017 |

In the table above, it can be observed that the largest structural period occurs in model 4 with the magnitude of the period in the X direction of 1.210 seconds and in the Y direction of 1.017 seconds. This is also in line with the increase in the height of the structure due to the addition of the number of floors of each different model.

### *4.2 Basic Earthquake Force*

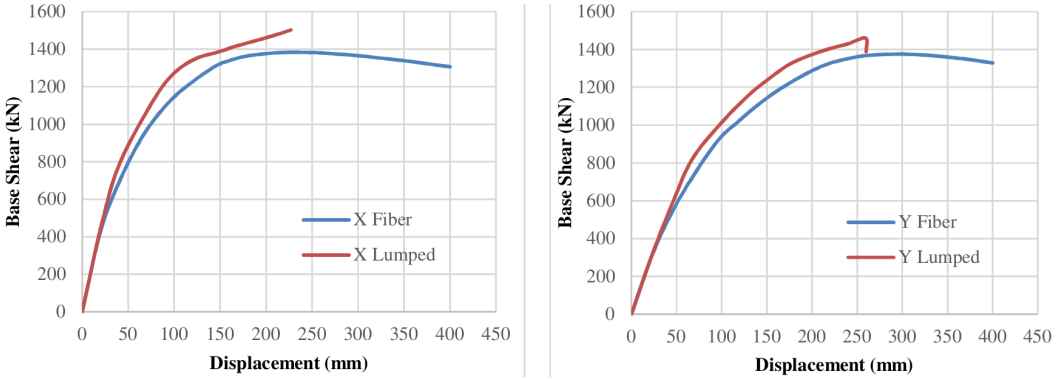
The basic earthquake force is a simplification of earthquake vibrations acting on the base of the building and is used as a design earthquake force. The basic earthquake force will be distributed at the center of mass of the building as a horizontal force at each level of the building. The following is the basic earthquake force in each model that can be seen in Table 4 .

### *4.3 Capacity Curve*

Capacity curve describes the strength of the structure, the magnitude of which is highly dependent on the deformation ability of each member of the structure. The capacity curve is obtained from the pushover analysis by applying a certain lateral static load to the structure and gradually increasing it until the structure reaches a certain limit. In the curves of Figures 7 to 10 below, you can see the comparison of base shear and displacement in each modeling.

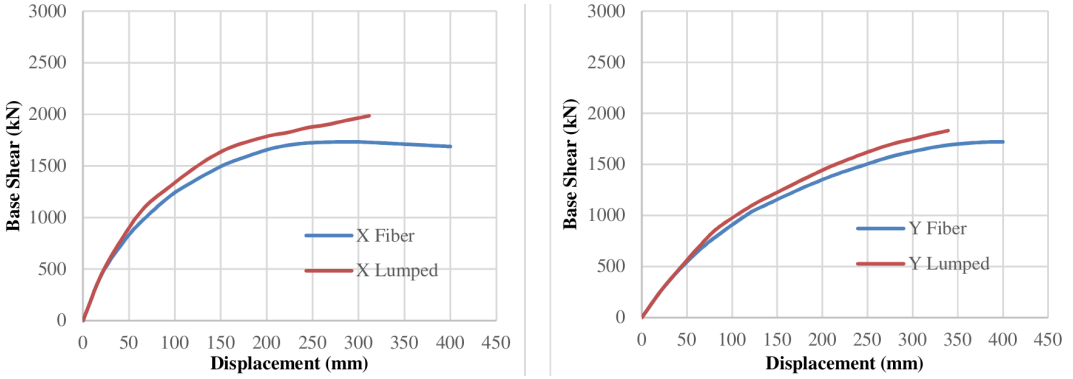
**Table 4.** Comparison Basic Earthquake Force

| | Basic Earthquake Force | |
|---|---|---|
| Model | X-dir (kN) | X-dir (kN) |
| Model 1 | 100.138 | 100.138 |
| Model 2 | 137.868 | 137.868 |
| Model 3 | 168.123 | 168.123 |
| Model 4 | 208.699 | 211.702 |




(a) Push X Direction (b) Push Y Direction

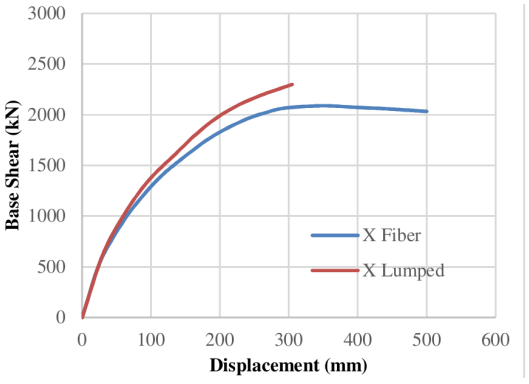
**Figure 7.** Capacity Curve of Model-1



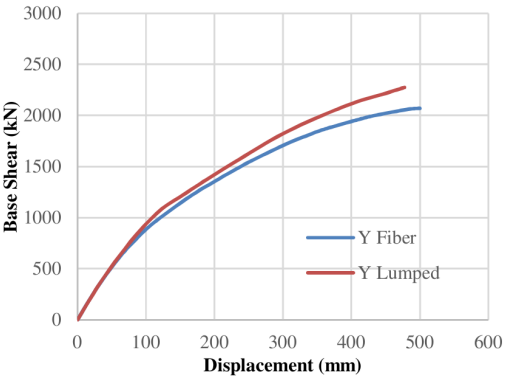

(a) Push X Direction (b) Push Y Direction

**Figure 8.** Capacity Curve of Model-2

In the curve above, it can be observed that the fiber hinge provides a longer displacement than the lumped hinge. This occurs uniformly in all variations in the height of the structural model where the largest deviation occurs in the 4-way X model of 700 Mm with a total base shea of 2361 kN. The curve also shows that the lumped hinge produces a larger base shear capacity when compared to the fiber hinge modeling, this can indicate that the lumped hinge model provides a higher initial stiffness value when compared to the fiber hinge. Fiber hinge provides a longer total displacement where this can also be caused by the mechanism of joint failure that occurs gradually marked by the gradual yielding of each fiber .

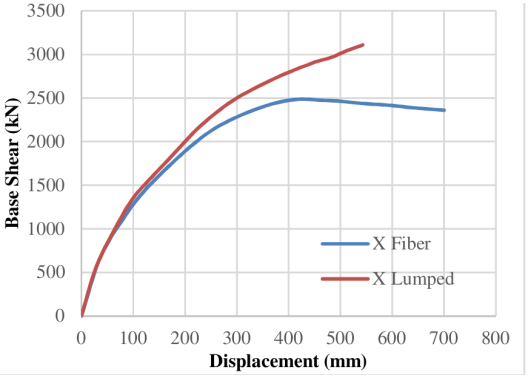



(a) Push X Direction

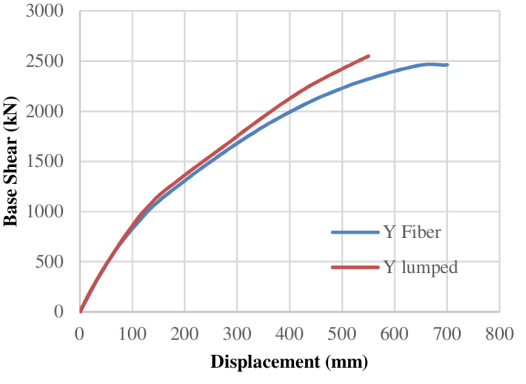



(b) Push Y Direction

**Figure 9.** Capacity Curve of Model-3




(a) Push X Direction




(b) Push Y Direction

**Figure 10.** Capacity Curve of Model-4

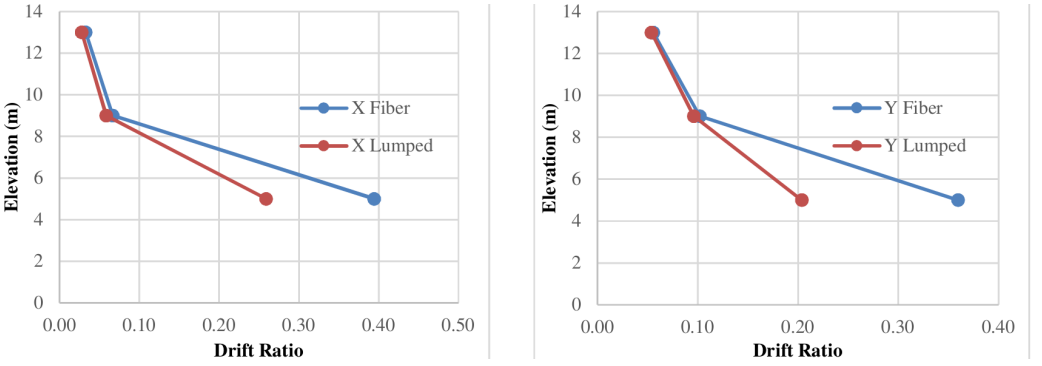
### *4.4 Drift Ratio*

Drift ratio is a parameter in determining the strength of a level, the ability of the cross-section to deform will depend on the stiffness and cross-sectional material. Lumped system which is concentrated at a point in receiving the load directly, so that changes in stiffness due to local failure are not effective so that the deformation results are relatively inaccurate. In fiber hinges where the inelastic action can be distributed thoroughly along the cross-section, changes in stiffness due to local failure can be captured implicitly in the cross-section so that the deformation of the cross-section approaches the actual condition. Could seen in Figure 11 to Figure 14 Drift Ratio from each modeling .

From the curve above, it can be seen that the drift ratio story results in inelastic analysis, for fiber modeling, is relatively larger than the lumped hinge. this generally occurs in all structural models where the fiber hinge model 4 model has the largest drift ratio value of 0.462 which is on the most basic floor of the structure.

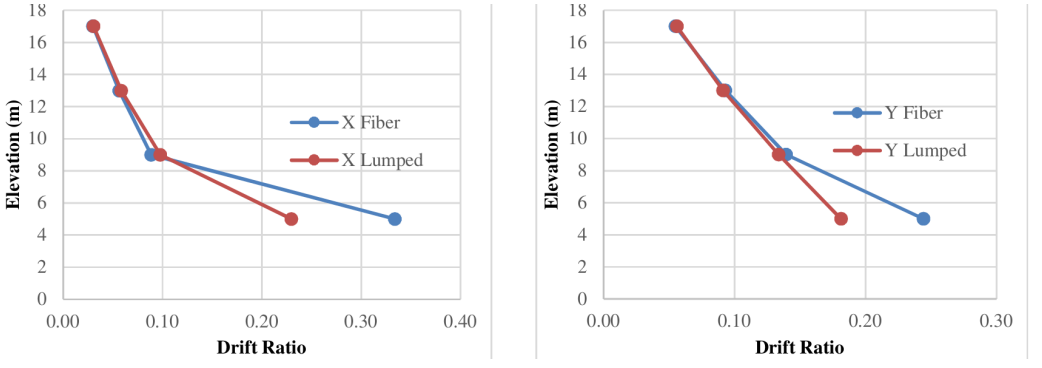
### *4.5 Moment -Rotation*

Behavior element structural good column and beam in respond non-linear plastic can be represented through behavior moment and curvature. Behavior element when accept burden incrementally will show the usual local failure happened to the area moment maximum and yield curvature along



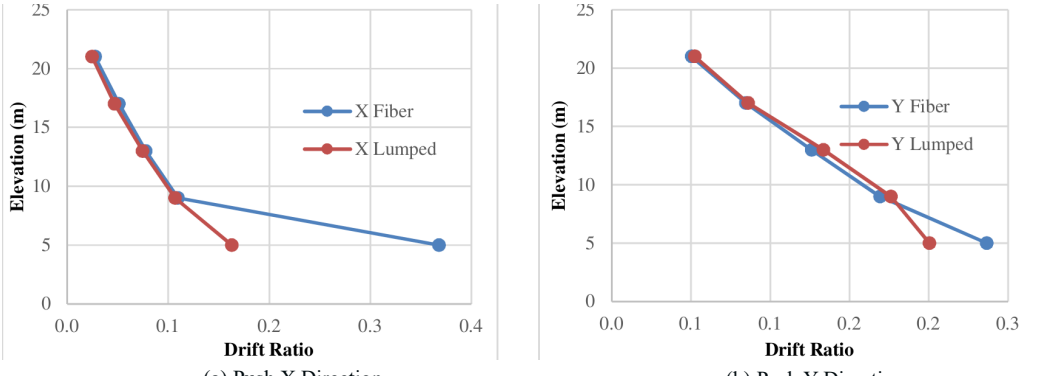

(a) Push X Direction (b) Push Y Direction

**Figure 11.** Drift Ratio of Model-1




(a) Push X Direction (b) Push Y Direction

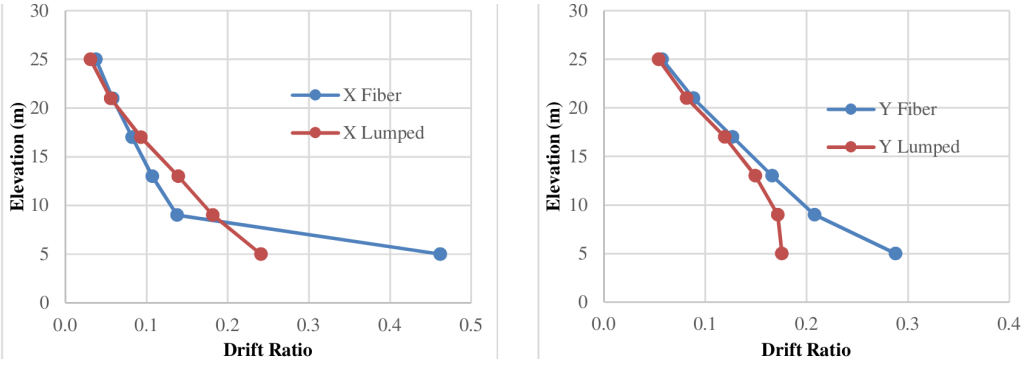
**Figure 12.** Drift Ratio of Model-2




(a) Push X Direction (b) Push Y Direction

**Figure 13.** Drift Ratio of Model-3

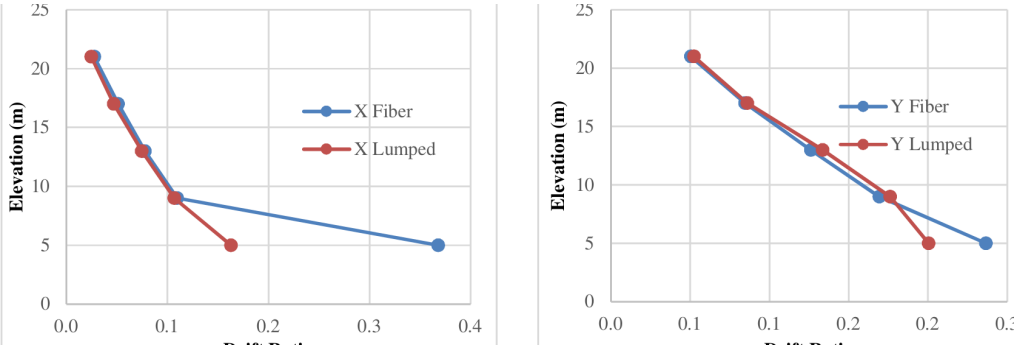
plastic hinge that can give score rotation ( rotation) . Following results moment generated rotation through two method hinges approach in Figure 15 to Figure 18 below .




(a) Push X Direction (b) Push Y Direction

**Figure 14.** Drift Ratio of Model-4

On the chart on with using model 1 with dimensions column 40/40 can seen that difference inelastic response in the column through connection moment and curvature. For lumped method produces capacity more moments big however given rotation relatively small , while capacity fiber method given moment small however element could rotate enough long.




(a) Push X Direction (b) Push Y Direction

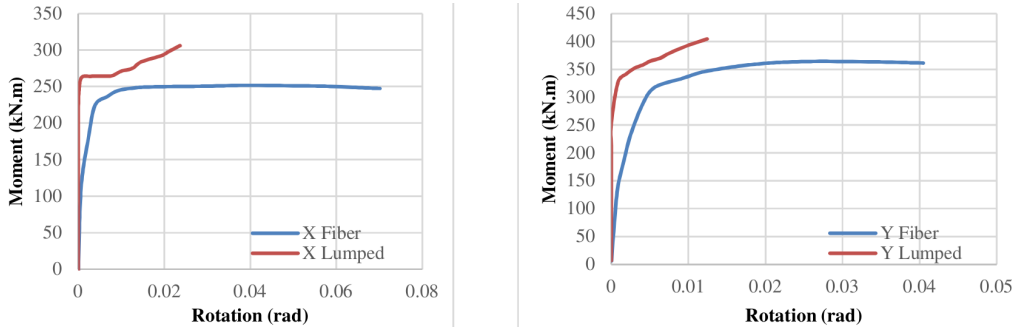
**Figure 15.** Curvature Moment Column Element Model 1

On the chart on with using model 2 with dimensions column 45/45 can seen that difference inelastic response in the column through connection moment and curvature still give Different analysis lumped model gives relative value big to moment and fiber give relative value small to moment .

On the chart on with using model 3 with dimensions column 50/50 can seen that difference inelastic response in the column through connection moment and curvature still give Different analysis lumped model gives relative value big to moment and fiber give relative value small to moment .

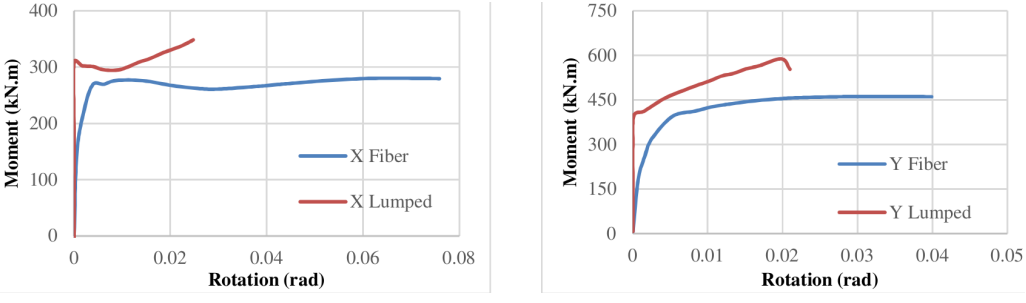
On the chart on with using model 4 with dimensions column 55/55 can seen that difference inelastic response in the column through connection moment and curvature still give Different analysis lumped model gives relative value big to moment and fiber give relative value small to moments , but on behavior rotation element for lumped method produces rotation relatively small while fiber produces relative rotation more big.

Based on connection response moment of curvature of the element which special on element column ,



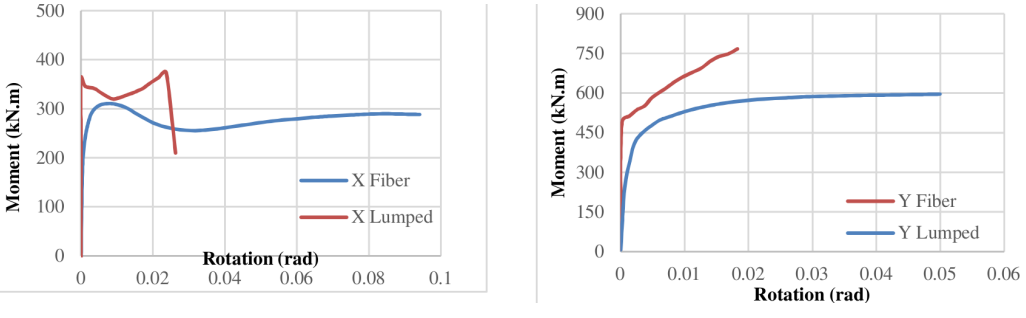

(a) Push X Direction (b) Push Y Direction

**Figure 16.** Curvature Moment Column Element Model 2




(a) Push X Direction (b) Push Y Direction

**Figure 17.** Curvature Moment Column Element Model 3




(a) Push X Direction (b) Push Y Direction

**Figure 18.** Curvature Moment Column Element Model 4

can seen that lumped method of 4 models that have been analyzed produce response relative moment big however for rotation produce relative value small , thing this occur based on on lumped behavior

approaching response maximum concentrated fully plastic as single layer , state behavior elastic on lumped or not considered so that implication to results score rotation on the element . While in the analysis using fiber, results showing generated moment relatively enough small however capable rotate enough far away , thing This fiber is analyzed as layer by layer with draft elasto plastic that considers behavior non linear platic until material level .

## 5. Conclusion

In this study, non-linear static analysis has been applied to a reinforced concrete structure model with 4 models with use lumped hinges system and 4 models use method combination fiber hinges and lumped hinges with variation amount levels and variations dimensions column . At level elements , Lumped hinges analysis using response maximum element give results capacity relative moment big however given rotation relatively more small , thing this based on on lumped behavior single layer only behave fully plastic without considering elastic condition . While in the analysis use fiber with approach layer by layer and using draft elastoplastic where elastic action taken into account when occur plastification . The results show the method fiber hinge s, the resulting moment relatively small however given rotation relatively more big than lumped hinges Consequence difference response at level element from two method the will implicate to capacity curve globally , results show for lumped hinges capacity base shear relatively more big but on deformation globally relative more small , thing this occur because move from behavior level element . Different in method fiber hinges , results show capacity base shear relatively more small however could deformed globally more far than method lumped hinges, hal this move from behavior at level capable element deformed enough far away . From analysis a number of condition , for method fiber hinges is method that gives natural state of response , with move to behavior elastoplastic materials. Existence elastic behavior in plastic condition make element behave in condition actually , so deformation globally generated more big than lumped hinges method , hal this of course very decisive in determination performance point structure in calculate performance level structure as well as calculation quantity score ductility structure building .

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