Pushover Analysis of a Reinforced Concrete Building According to Various Hinge Models

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ABSTRACT

In this study, behavior of a multi-story reinforced concrete frame building designed as three bays and six stories is investigated. Pushover analyses of the selected building are performed according to various lateral load patterns and hinge models. Uniform and inverted triangular shapes are selected for the load patterns while lumped and spread hinge (fiber hinge) models are used for hinge models. Analyses are performed by Sap2000 and Seismostruct programs. Capacity curves and interstory drifts of the building are compared with each other for various lateral load patterns and hinge models, and obtained results are evaluated.

INTRODUCTION

Static pushover analysis which shows nonlinear static behavior of buildings subjected to lateral loads has been used in structural engineering due to simplicity. This analysis method is a practice procedure for estimating the structural capacity of buildings in the post-elastic range. Capacity curve of a building shows the relationship between the base shear force and the roof displacement. For obtaining the capacity curve, lateral forces monotonically are increased until a certain level of deformation at the top of building is reached. While structural elements reach ultimate moment capacity, plastic hinges occur at the end of elements and sections between plastic hinges remain elastic [1-4].

The other plastic hinge type is fiber hinge which used in nonlinear analysis. In this hinge model, cross-sections of structural member are divided into fibers which monitor confined concrete section, unconfined concrete cover, and reinforcement. This plastic hinge approach allows prediction of the spread of inelasticity within the element cross-section and along the element length.

The first spread plasticity models date from the work of Bazant [5]. The concept of fiber element which considered a discretization of the element section to include the different constitutive materials was introduced in 1984 [6]. Later, the model was improved and important changes have been incorporated [7,8].

Many researchers performed structural analyses by using fiber hinge model. Mwafy and Elnashai [9], in their study named as static pushover versus dynamic collapse analysis in reinforced concrete buildings, used spread hinge approach for the nonlinear analysis. Dides and Llera [10] compared plasticity models which include fiber hinge model in dynamic analysis of buildings. Mwafy [11] assessed seismic design response factors of concrete wall buildings. For this study, five reference structures, varying in height from 20 to 60 stories, were selected. Analyses of structures were performed according to fiber hinge modeling. Kunnath and Kalkan [12] evaluated the seismic deformation demands of multistory steel and concrete moment frames using non-linear procedures based on spread hinge assumption. Duan and Hueste [13] investigated the seismic performance of a multi-story reinforced concrete frame building which designed according to the provisions of the Chinese seismic code. They used fiber hinge model for analyses. Kwon and Kim [14] studied a RC building which damaged during the 2007 Pisco-Chincha earthquake. They performed nonlinear analysis of this building by considering spread hinge model. Hankok and Bommer [15] investigated inelastic structural response using spectral matched records. They used fiber hinge approach in the numerical study. Kadid et al. [16] assessed behavior of reinforced concrete buildings under simultaneous horizontal and vertical ground motions considering fiber hinge model. Thomos and Trezos [17] generated a methodology to obtain pushover curves of reinforced concrete frames, taking into account the randomness of the basic variables. They used fiber hinge model in numerical studies. Sarno and Manfredi performed pushover and dynamic response history analyses for both built and retrofitted structures to investigate the efficiency of buckling restrained braces. They used fiber element model in nonlinear analysis [18].

In this study, static pushover analyses of a selected reinforced concrete building subjected to various lateral loads patterns are performed by using lumped and fiber hinge models. To obtain the capacity curves and interstory drifts of the selected building, SAP2000 [19] and SeismoStruct [20] programs which can simulate the inelastic response of structural systems subjected to static and dynamic loads are used. Obtained results are compared with each other for various lateral load patterns and hinge models.

Fiber Hinge Model

The fiber hinge model accounts distributed plasticity along structural element. In this model, the structural element is divided in three types of fibers: some fibers are used for modeling of longitudinal steel reinforcing bars; some of fibers are used to define nonlinear behavior of confined concrete which consists of core concrete; and other fibers are defined for unconfined concrete which includes cover concrete. Also, for each fiber, the stress/strain field is determined in the nonlinear range by using $\sigma - \varepsilon$ constitutive laws according to defined materials. Figure 1and 2 show fiber modeling of a RC beam and typical fiber model section of a RC element, respectively.

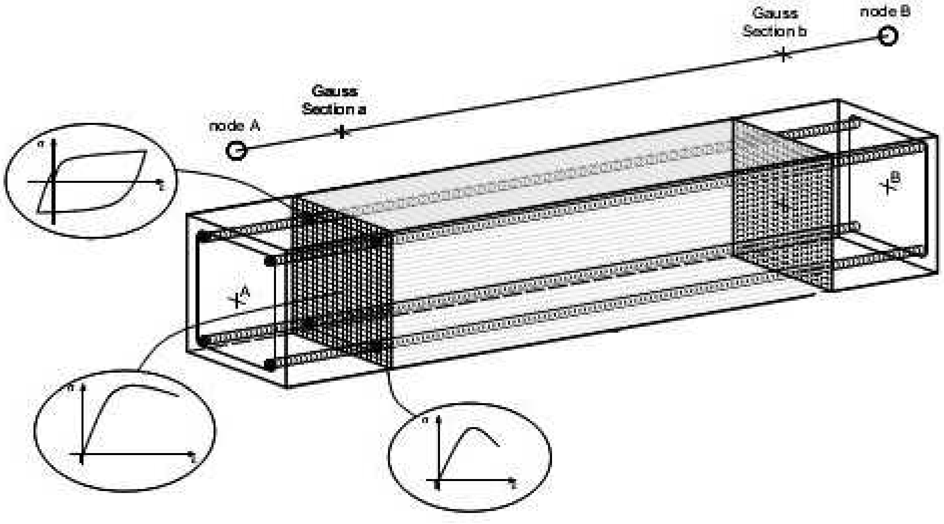


Figure 1 Fiber modeling of a reinforced concrete beam [20]

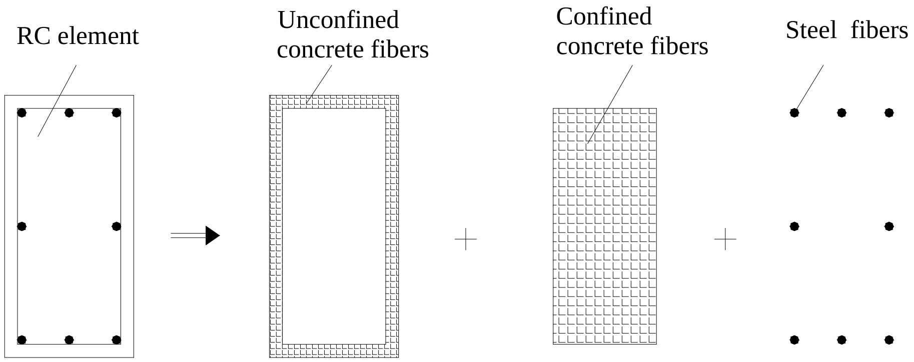


Figure 2 Typical fiber model of a RC element

NUMERICAL APPLICATION

In this study, behavior of a multi-story reinforced concrete frame building which designed as three bays and six stories are investigated. The total height of building is 19.0 m. In this building, height of first story is 4.0 m and height of other stories is 3.0 m. The elevation view of the building and the cross section properties of a typical column and beam including reinforcing bars are shown in Fig. 3. The cross sectional properties of all columns and beams are assumed to be same, respectively. Reinforcements of structural members are selected according to minimum requirements of Turkish Seismic Code (TSC). In this building, the slab thickness is 14 cm. The compressive strength of the concrete is 20 N/mm^2, and the yield strength of the reinforcement bars is 420 MPa. It is assumed that the building is located in Seismic zone 1 and Z3 local site class which defined in TSC.

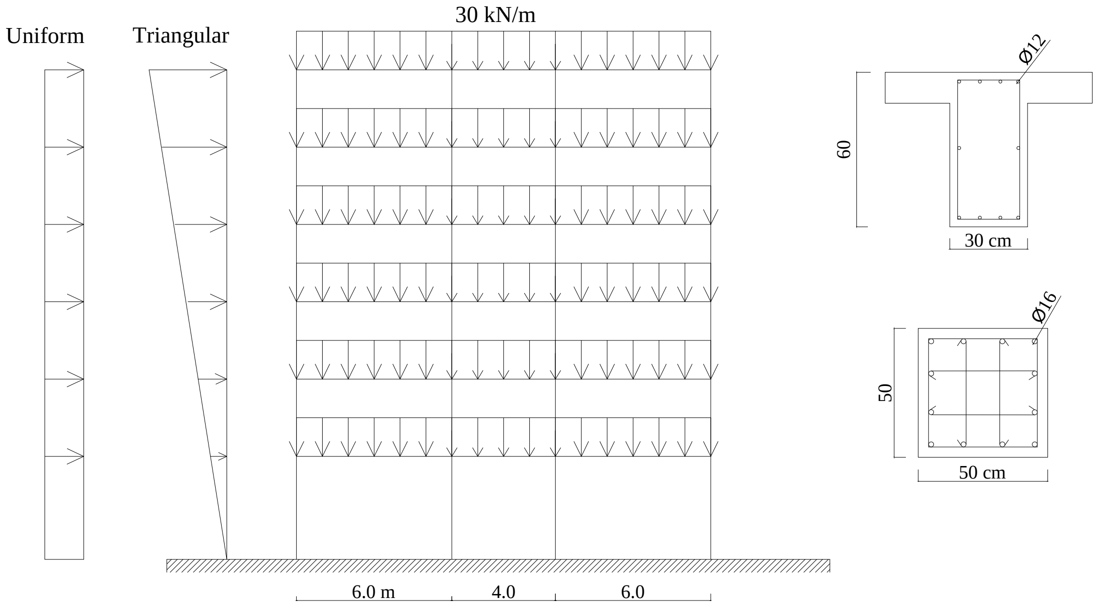
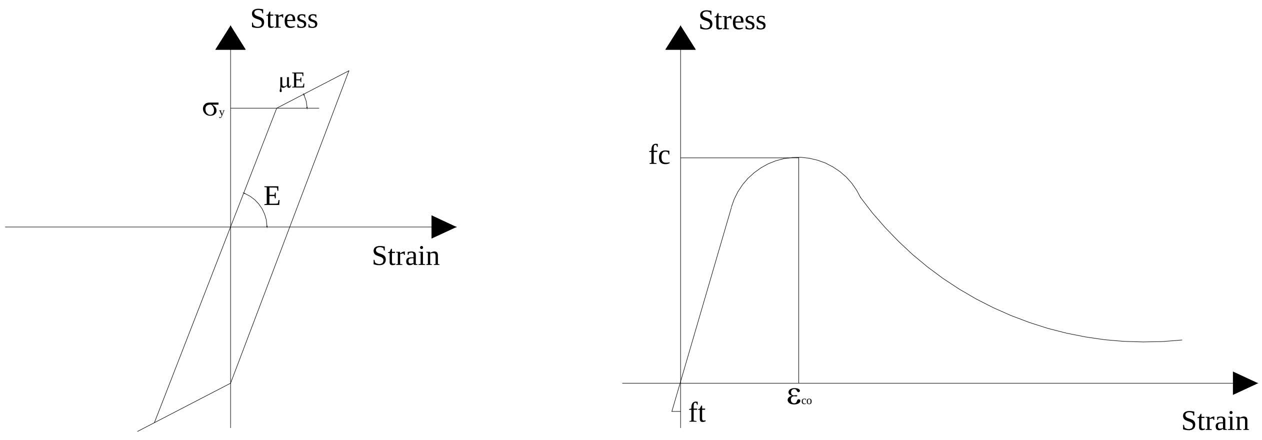


Figure 3 Selected building and, cross section properties of a typical column and beam

Selected material constitutive models for steel and concrete are shown as in Fig. 4. The bilinear elastic–plastic material model with kinematic strain-hardening is used for the steel reinforcement, and the concrete material is defined by the uniaxial constant confined model. The material model properties of concrete and steel are given in Table 1. The confinement effect is taken into account using the model proposed by Mander et al.[23].



(Steel)

(Concrete)

Figure 4 Material constitutive models [20]

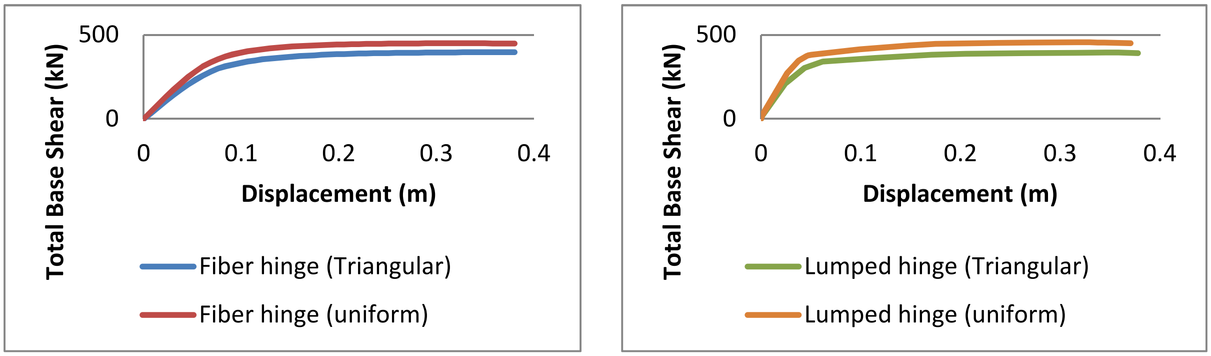
Table 2 Material model parameters used in numerical solutions

Parameters	Concrete		Steel
	Unconfined Concrete	Confined Concrete	Longitudinal & Transverse
f_c (Compressive Strength)	20 Mpa	23 Mpa	-
f_t (Tensile Strength)	2.0 Mpa	2.3 Mpa	-
ε_{co} (Maximum Strain)	0.002		-
E_c (Concrete Elasticity Module)	28500 Mpa		-
μ (Strain Hardening Coefficient)	-	-	0.02
E_s (Steel Elasticity Module)	-	-	2e5 Mpa
Transverse Spacing	-	-	0.10 m

Sap2000 and Seismostruct structural analysis programs are used for numerical solutions. Pushover analyses of the building are performed according to various lateral load patterns and hinge models. Two load shapes are used in the analyses. The first load pattern is a uniform distribution, representing lateral forces that are proportional with the mass. The second one is an inverted triangular distribution which represents the first mode shape. In these analyses, lumped and spread hinge (fiber hinge) approaches are used for hinge models.

Figure 5 shows capacity curves of the building. The uniform load pattern yields higher initial stiffness and base shear capacity according to the triangular load pattern, in cases both lumped and spread hinge models. In other words, the uniform load pattern gives lower roof displacement with respect to the triangular one for the same base shear force in cases two hinge models. It is noted that the uniformly distributed load gives a better prediction of the ultimate strength of structures influenced by higher modes compared with the inverted triangular load [11].

Comparison of capacity curves of the building according to various hinge models for same load patterns is given in Figure 6. Although, for two load patterns, the lumped hinge model yields higher initial stiffness according to the fiber hinge model, the base shear capacity is to be same approximately in case two hinge models.



a)Fiber hinge model b) Lumped hinge model

Figure 5 Capacity curves of the building according to various load patterns and hinge models

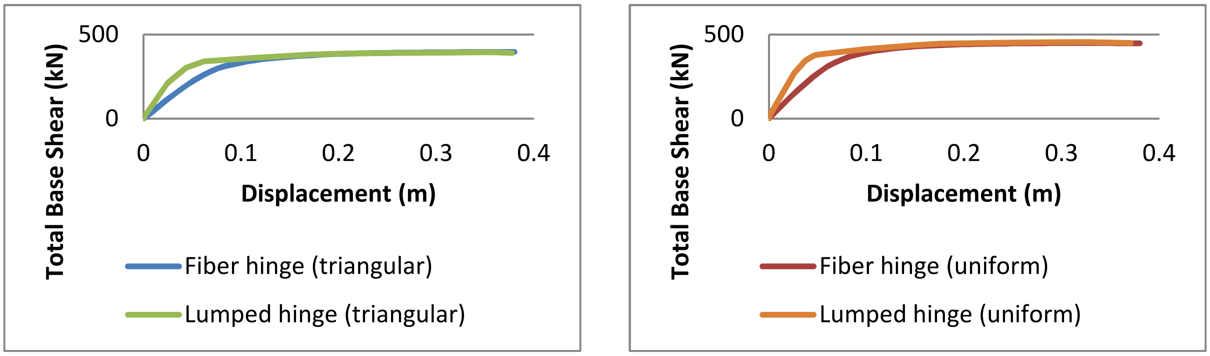
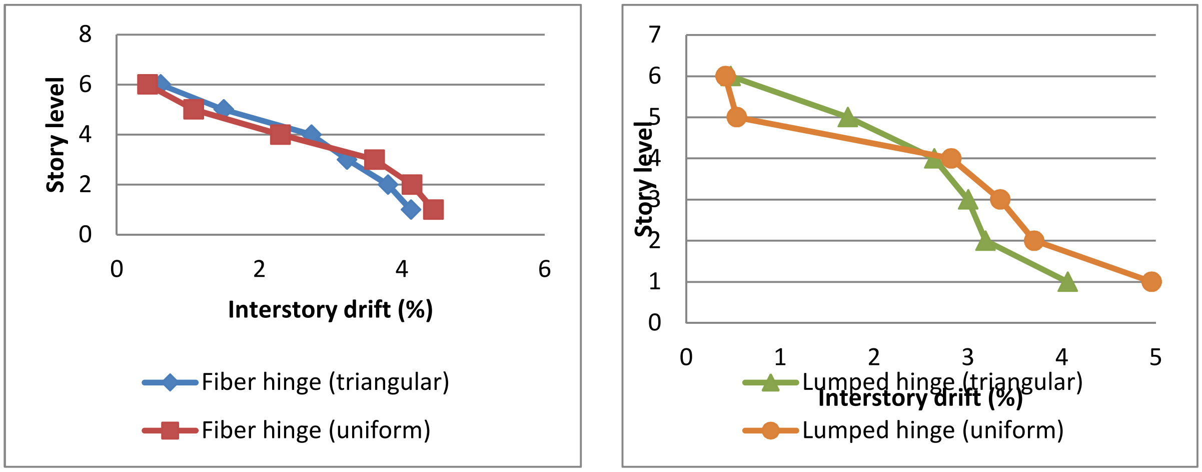


Figure 6 Comparison of capacity curves of the building according to various hinge models for same load patterns

Interstory drifts of the building are shown in Figure 7 and 8 for various hinge models and load patterns. The uniform load pattern yields higher interstory drifts at lower stories while this load shape gives less interstory drifts at upper stories according to the triangular load pattern, in cases both lumped and spread hinge models. This indicates the lower stories usually have the potential to act large displacement under significant lateral demands for the uniform load pattern. It is clearly seen that from the Figure 8, the fiber hinge model yields higher interstory drifts at lower stories for triangular load pattern. However, this situation is not clear for the uniform load shape.



a)Fiber hinge model b) Lumped hinge model

Figure 7 Interstory drifts of the building according to various load patterns and hinge models

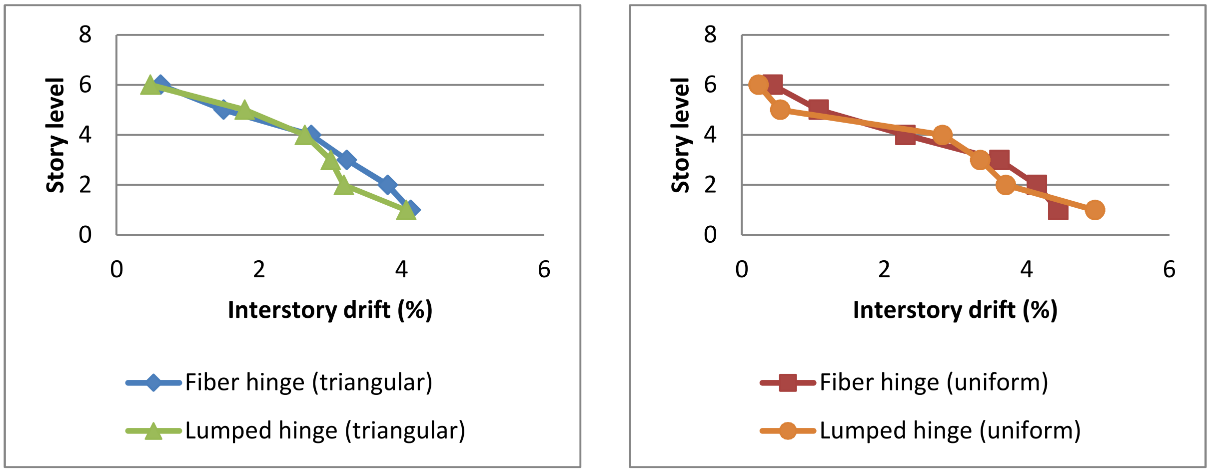


Figure 8 Comparison of interstory drifts of the building according to various hinge models for same load patterns

CONCLUSION

In this study, static pushover analyses of a selected reinforced concrete building subjected to various lateral loads patterns (inverted triangular and uniform shapes) are performed by using lumped and fiber hinge models.

Obtained results show that the uniform load pattern yields higher initial stiffness and base shear capacity according to the triangular load pattern, in cases both lumped and spread hinge models. Although, for two load patterns, the lumped hinge model yields higher initial stiffness according to the fiber hinge model, the base shear capacity is to be same approximately in case two hinge models. From the point of view of interstory drifts, the uniform load pattern yields higher interstory drifts at lower stories while this load shape gives less interstory drifts at upper stories according to the triangular load pattern, in cases both lumped and spread hinge models. Also, the fiber hinge model yields higher interstory drifts at lower stories for triangular load pattern. However, this situation is not clear for the uniform load shape.

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