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DYNAMIC INELASTIC ANALYSIS OF HI-RISE BUILDINGS USING LUMPED MODEL

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SUMMARY

The current earthquake design codes generally allow inelastic deformation in some structural members of a building subjected to severe earthquakes. Therefore the information about the post-elastic behavior of a building is very important in the evaluation of the safety against earthquake loading. However the three dimensional nonlinear dynamic analysis of high-rise building structures requires a lot of time and cost, and has difficulties for application in practice. Thus more simplified lumped model is often used for approximate results of the building behavior under earthquake loads. In this approach a building structure is idealized as a combination of masses and springs, and the behavior is predicted by analysis of the transformed system. In order to ensure the accuracy of the lumped model analysis it is important to provide appropriate values to the model parameters. In this study the parameters are determined from a nonlinear static push-over analysis, which is generally used to estimate member forces and global as well as local deformation capacity of a structure. Then the validity of the lumped model approach is investigated by comparing the results with those obtained from the three dimensional frame model. The nonlinear static and dynamic analysis are performed using the program 'Canny' (Li, 1996).

DETERMINATION OF MODEL PARAMETERS BY PUSH-OVER ANALYSIS

Modeling of The Structure

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The structural model used in the analysis is a 102 story moment resisting frames for lateral loads with concrete-filled-tube column (Figure 1, 2). Three dimensional inelastic push-over analysis is carried out to obtain the lumped parameters, such as elastic and inelastic stiffness, yield strength, etc. The building has irregular mass and stiffness distribution over its height due to set-backs in elevation (Figure 3).

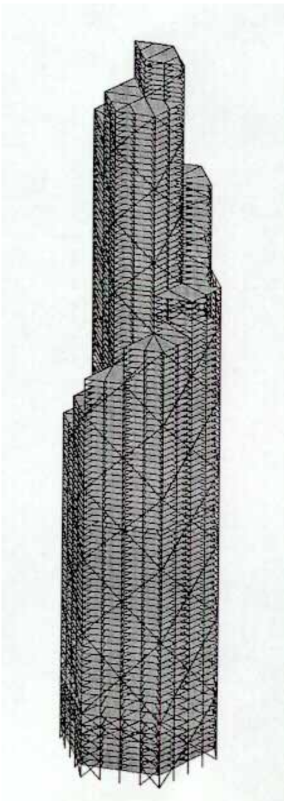
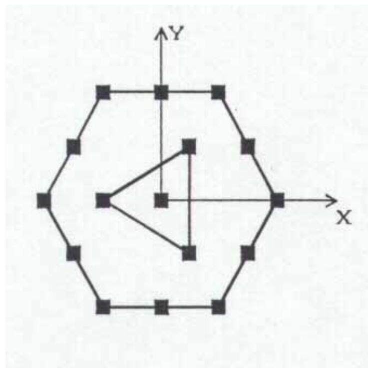
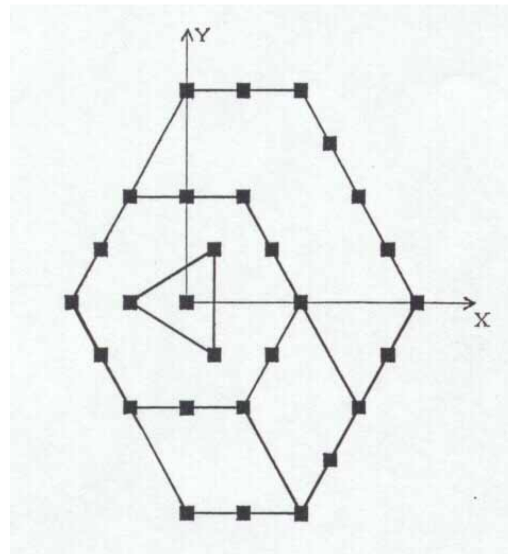


Figure 1: Structural model



(a) 91st floor



(b) 61st floor

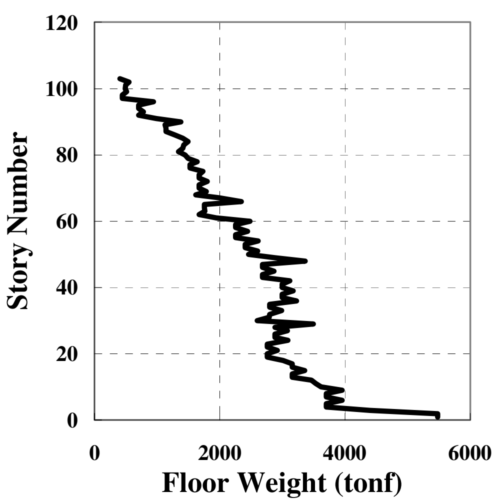
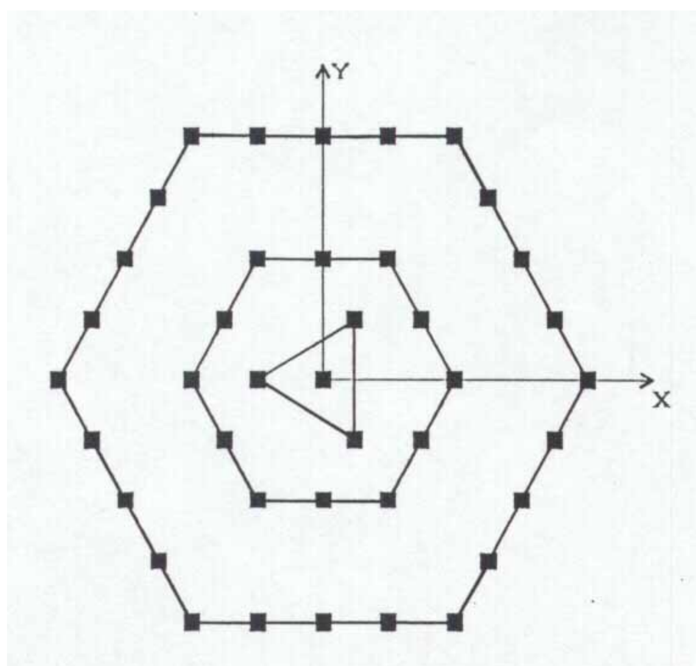


Figure 3: Weight distribution

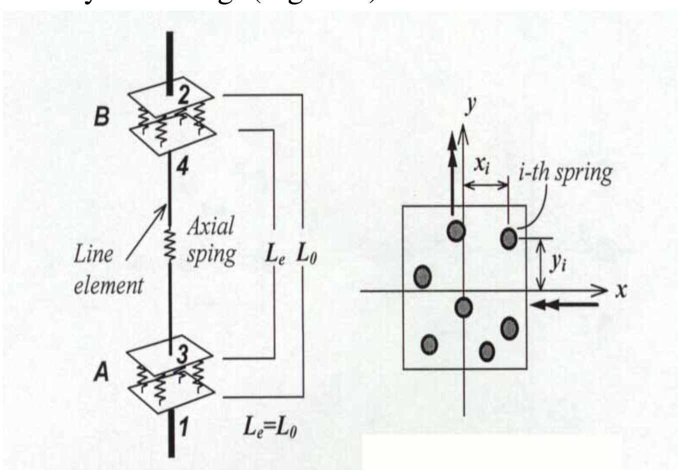


(c) typical floor

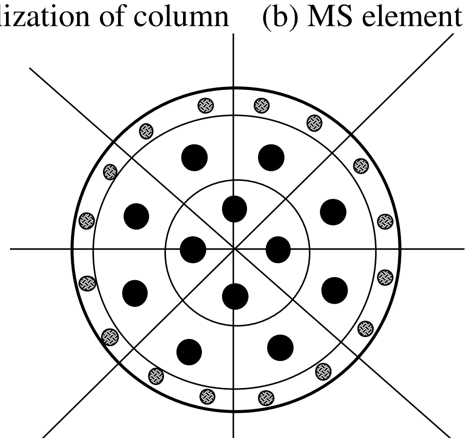
Figure 2: Structural plan

The columns are modeled by multi-springs at the ends and by axial and shear springs in the (Figure 4). The number of the springs varies according to material properties, section size and reinforcing bar. It is necessary to model with the minimum number of springs as long as they are enough to ensure the desired accuracy.

Beam elements are modeled to have uniaxial bending with shear and axial deformation and have no effect to the floor rotation. The inelastic flexural deformation of the beam element is assumed to be concentrated at its ends (Figure 5). Braces are subject to elastic/inelastic tension and compression with no bending, and compression yield strength can be different from tension yield strengt (Figure 6).



(a) Idealization of column (b) MS element



(c) MS Model of CFT column

Figure 4: Column model

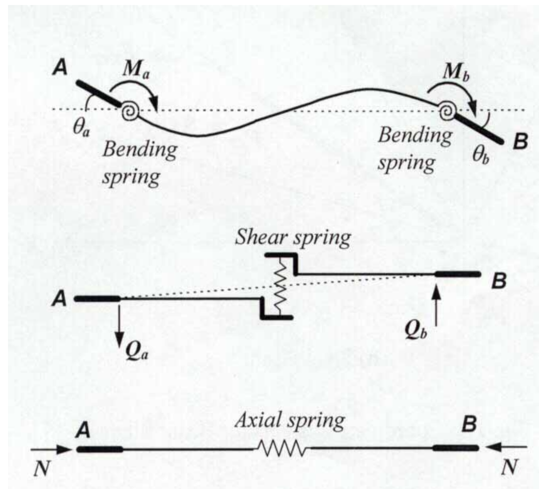
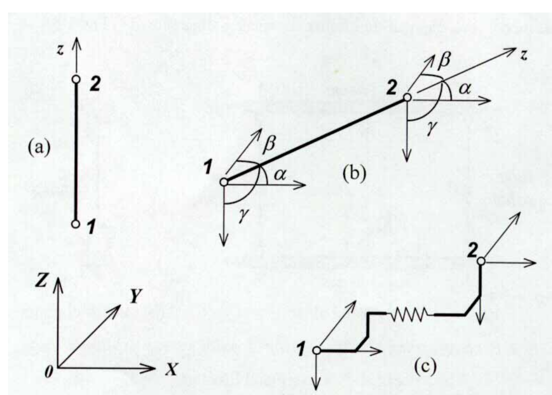


Figure 5: Beam model



(a) Parallel to global cartesian axes; (b) In 3D space; (c) Global displacements

Figure 6: Brace model

Push-over Analysis

The equivalent static lateral loads, calculated based on the Korean earthquake code, were applied to the building with gradual increments in magnitude until the maximum relative story drift reaches 1/50 of the story height. The dead and live loads were also applied simultaneously in the analysis. The equivalent earthquake load in each story obtained has inverted triangular force pattern as described in Figure 7.The static analysis was carried out on the three dimensional frame model with an appropriate combination of load and displacement control. Figure 8 shows the story shear force when the maximum story displacement reaches 2% of the story height under the static loads.

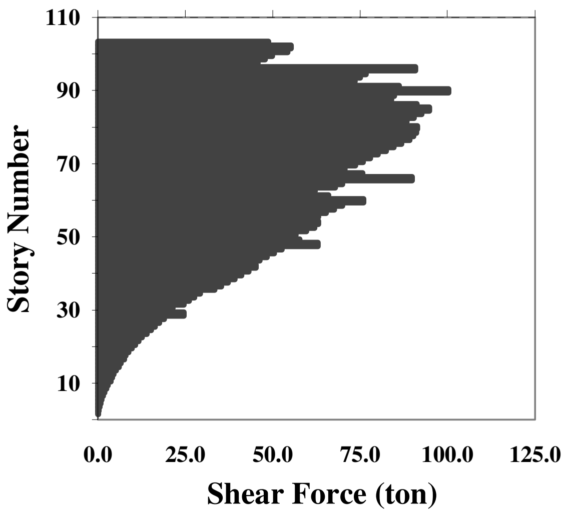


Figure 7: Eqv. static earthquake load

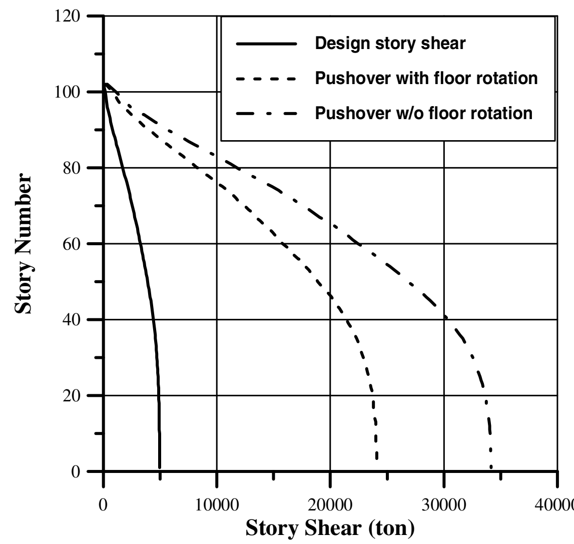


Figure 8: Story shear distribution

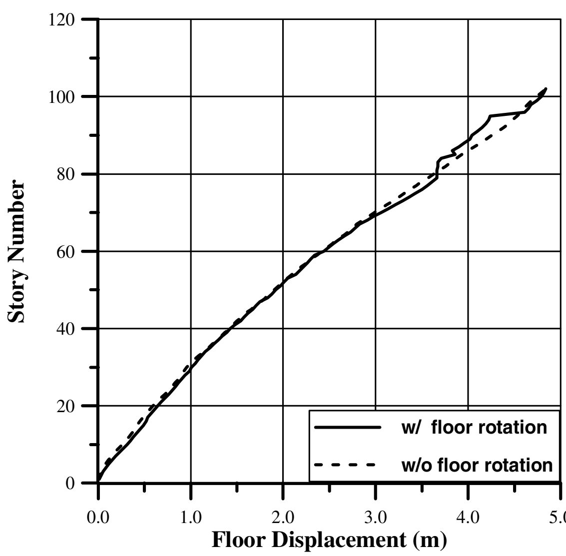


Figure 9: Story displacement distribution

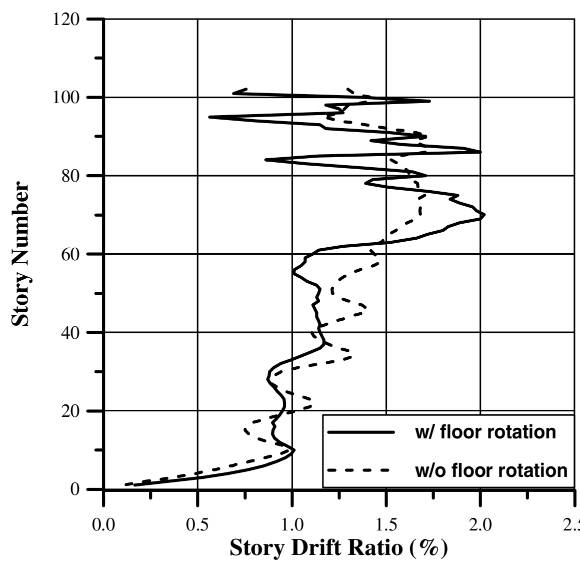


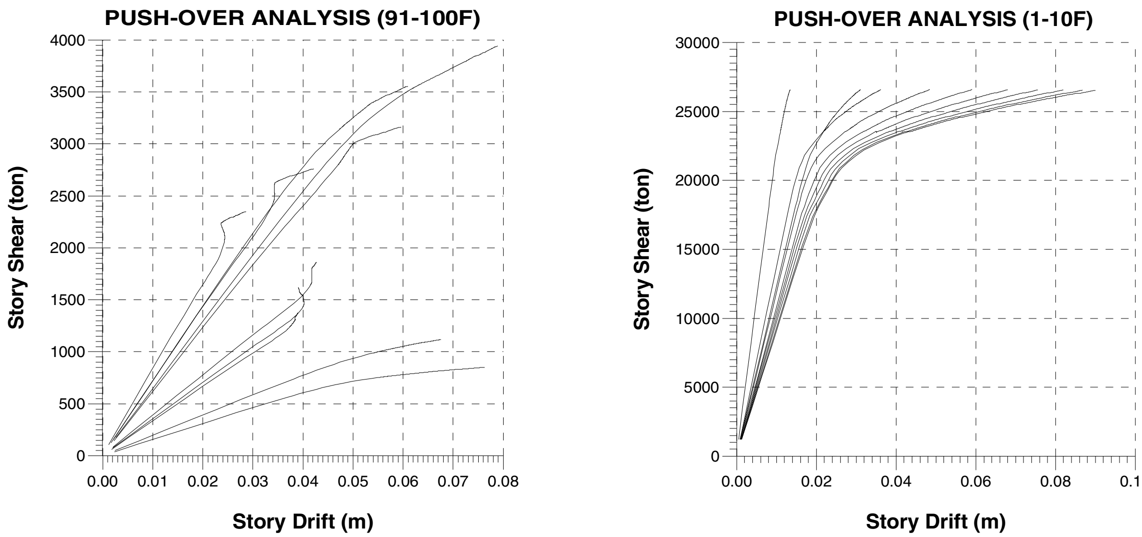
Figure 10: Story drift distribution

The curves for the force-displacement relationship are described in Figure 11. The curves show similar trend of inelastic behavior in each story, and clearly show the decrease in stiffness after yielding. It can be also observed that the stories with identical structural properties, such as plan shape, structural members and the story height, show noticeable discrepancy in their force-displacement curves. This is because the behavior of a story is affected by the stiffness and drift of the nearby stories. The relative displacement is found from the upper gravity center point to the point of its projection on the lower floor level as follows.

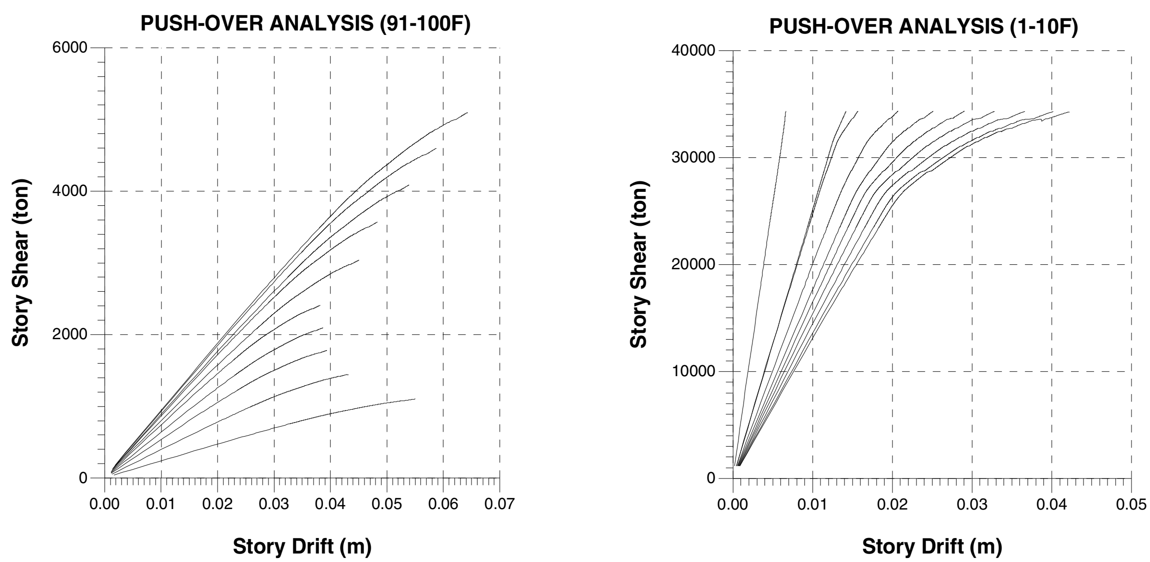
$$\Delta S = D_{upper} - \{ D_{lower} - \theta_{lower} \Delta Y_g \}$$

where ΔS denotes relative displacement, D displacement, subscript upper and lower upper floor and lower floor, ΔYg the eccentricity between the centers of two floors.

The parameters for the lumped model, which are summarized, were obtained through a static push-over analysis. The force-displacement relationship of each story was modeled by degrading bi-linear curve as described in Figure 12.



(a) analysis results with floor rotation



(b) analysis results without floor rotation

Figure 11: Story shear-story drift relationship

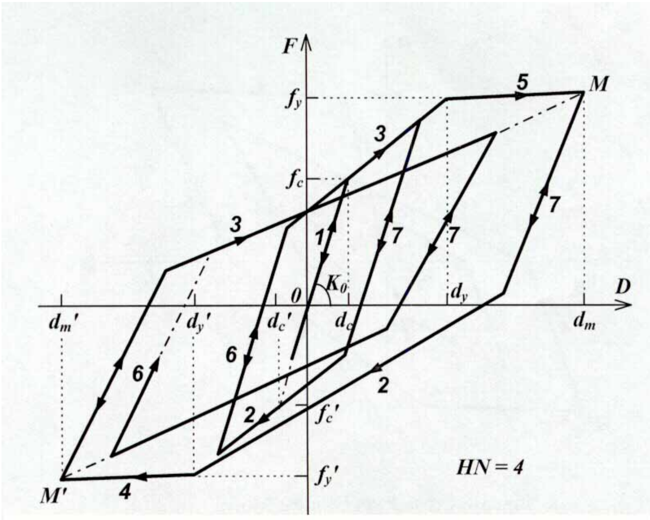


Figure 12: Degrading bi/tri-linear model

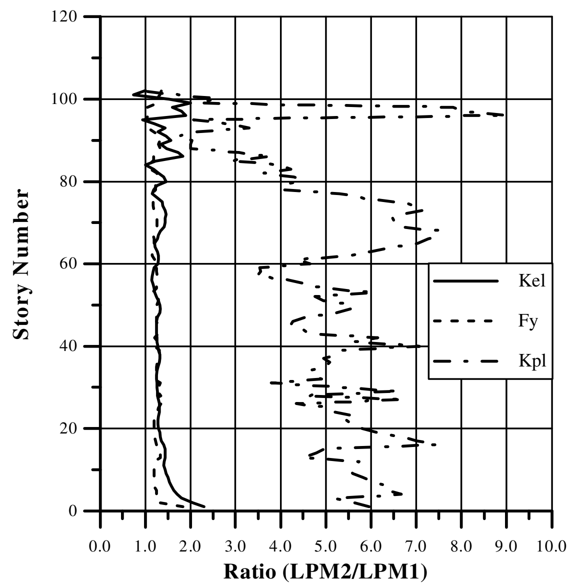


Figure 13: LPM parameters

Comparison of LPM parameters

Figure 13 shows the ratio of parameters from two models. It is recognized that the ratio of post-yield stiffness is remarkably greater than others. This implies that post-yield stiffness of a asymmetric building is much affected by torsional behavior of the building. Elastic stiffness ratios of LPM1 and LPM2 are over 2.0 in lower stories and have the value of 1.2-1.3 in typical stories and are scattered over large interval in 80th - 102nd stories. Meanwhile yield strength ratios have a uniform value over the height. This means floor rotation have much lager influence on elastic stiffness than yield strength. Post-yield stiffness ratios have relatively small value at 90th floor because the building has hexagonal plan from 90th to 96tn floor and symmetrical mass and stiffness. This hexagon reduces to a diamond shape at 96th floor and this floor has maximum eccentricity. So, the post-yield stiffness ratio has maximum value of 9.0.

DYNAMIC ANALYSIS WITH FRAME MODEL AND LUMPED MODEL

The natural frequencies of model without floor rotation are reduced about 13-15%, which results in a different dynamic behavior (Figure 14). The El-Centro NS components were used as an input ground excitation for the dynamic time history analysis. Three type of analysis model was used; 3-D frame model(3D), LPM with rigid floor rotation(LPM1), LPM without floor rotation(LPM2). For elastic responses the El-centro earthquake record was scaled to have the peak ground acceleration (PGA) of 0.12g. From the analysis it was found that all members remained in elastic region, and the three responses are somewhat different from each other. In elastic region the response of 3D model turned out to be a little larger than those of LPM1 and LPM2. The results of time history analyses with the ground excitation are shown in Figure 15. In Figure 15(a) the response time histories of the lumped model and the 3D frame model subjected to the ground excitation were compared. It can be noticed that the coincidence of the two responses are reasonably close in the early phase.

However when time goes on, the correspondence of the two results is no longer good enough. The result of 3D model lies between LPM1 and LPM2. This indicates the fact that the lateral stiffness of 3D model is stronger than LPM1 and weaker than LPM2, because LPM1 is a extreme case in which every floor rotates in the same direction and LPM2 is the other one in which every floor does not rotate. From this results, in the case of torsionally weak structures like the model building, the results of 3-D dynamic analysis cannot be properly evaluated using simple lumped model either with floor rotation or without floor rotation.

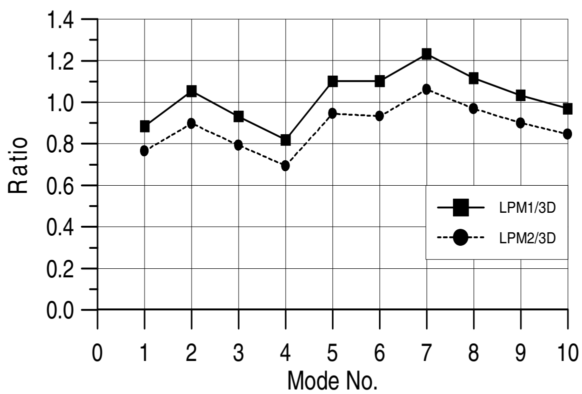


Figure 14: Comparison of natural frequency

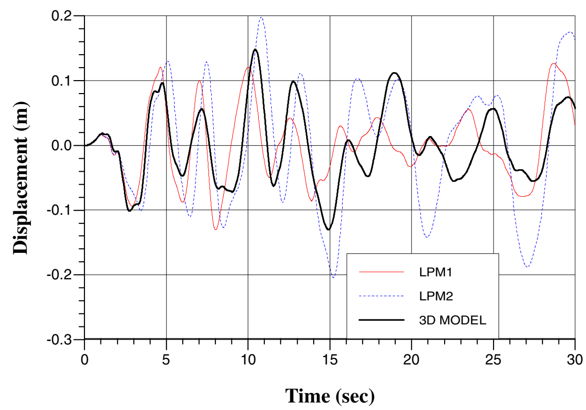
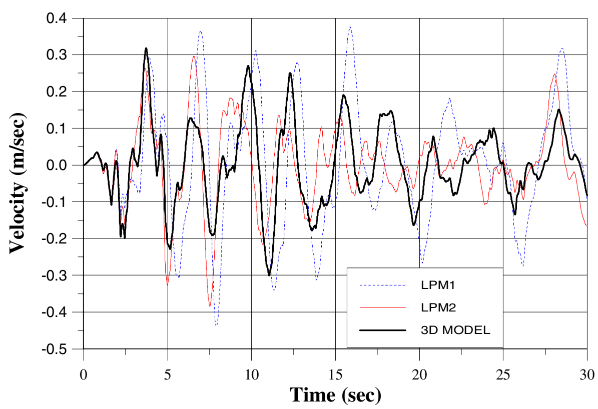
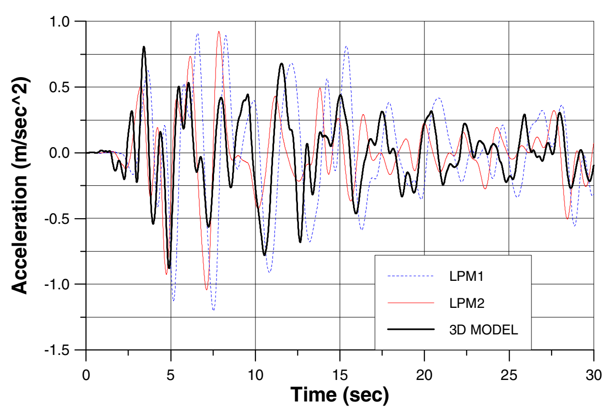


Figure 15 (a): top floor displacement



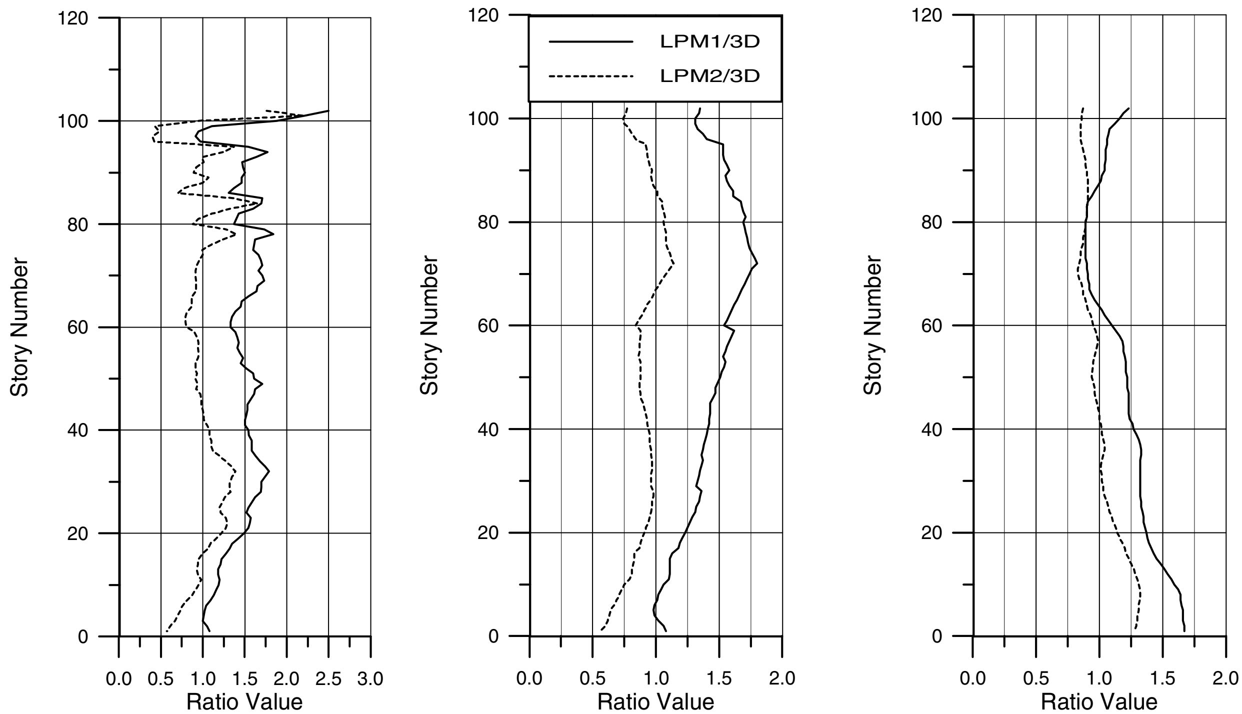
(b): top floor velocity time history



(c): top floor acceleration time history

Figure 15 Top floor time history responses

Figure 16 shows the ratio of the story drift at 102nd floor obtained from the frame model to those from the lumped model. The displacement ratio varies from about 1.0 in the higher floors to 1.7 in the first floor. In the inelastic region the ratio varies from 0.66 to close to 1.0. The ratio of story shear follows a similar trend (Figure 16). If the results from the frame model are considered as exact values, the stiffness of the lumped model were overestimated in the elastic region. Therefore it is necessary to take into account this phenomenon when the lumped model parameters are to be determined from the push-over analysis.



(a) Overturning Moment (b) Story Drift Ratio (c) Max. Displacement

Figure 16 : Comparison of results

CONCLUSIONS

In this study the dynamic behaviors of the lumped model for a 102 story building under earthquake excitations were compared with those of the three dimensional model, and the effects of the parameters for the lumped model were investigated. Due to the influence from the adjacent floors the story shear vs displacement curves in stories can be different even though the structural properties are the same. The lumped model with the parameters obtained from the static push-over analysis displays quite similar dynamic behavior compared to that of the original structural model in the elastic region. As the ground excitation becomes large enough to cause inelastic deformation in the structure the results from the lumped model and the original model begin to deviate from each other. Although the maximum responses are close each other the phase angles tend to become different. This may be because the natural frequencies of the two systems become different in the inelastic region, which can be expected considering the fact that the static push-over analysis can simulate only the first vibrational mode of the building.

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