SEISMIC EVALUATION OF DUAL HINGE DESIGN APPROACH OF RC SHEAR WALL IN DUAL STRUCTURAL SYSTEM CONSIDERING NEARFIELD EARTHQUAKES

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ABSTRACT

The impact of higher modes on the seismic response of dual structural system consists of concrete moment-resisting frame and RC shear walls is investigated against near-field earthquakes in this paper. a 20-story RC shear wall-special moment frame structure is designed in accordance with ASCE7 requirements and Nonlinear time history dynamic analysis with 2 near-field records is performed on them .In order to further understand the structural collapse behavior in the near field earthquake, the response of the structure at the moment of collapse especially the formation of plastic hinges is explored.

The results revealed that the amplification of moment at the top of shear wall as a consequence of higher modes, can cease formation of the plastic hinge in the upper part of wall in spite of the fact that it designed and detailed for plastic hinging at the base only (according to ACI code). On the other hand, shear forces in excess of capacity design values can develop due to the contribution of the higher modes can result in brittle shear or sliding failure modes.

The past researches on shear walls clearly showed that the dual plastic hinges design approach is effective at reducing the effects of the second mode of response. An advantage of this concept is that, when combined with capacity design, it can result in relaxation of special reinforcing detailing in large portions of the wall. In this study, to investigate the implications of multi hinge design approach, four models with various arrangements of plastic hinges at the base and along the height of the shear wall are considered. The time history analyses showed that the dual or multi plastic hinges approach can be useful in order to control the high moment and shear demand of higher mode effect.

INTRODUCTION

With the development of earthquake and structure sciences, structure codes and seismic provisions are being updated, but there are still many aspects that are not fully understood due to the random nature of earthquake motions as well as the complex features of higher mode effects on reinforced concrete structures.

Dual system, designed to provide greater strength and ductility, is one of the most common structural system especially in the tall buildings.

Past studies has revealed that in high-rise buildings, in addition to first mode, second and third structural modes can also have a considerable effect on performance of structures in earthquakes. DerechoA.T et al (1981)showed that higher dynamic modes, have a significant effect on the behavior of cantilever shear walls in high-rise buildings, and can considerably amplify the bending moment demand in the wall. Priestley and Amaris (2002)mentioned the amplification in bending moment and shear forces along the height of the wall after developing plastic hinges at its bottom. Therefore, they claimed that the philosophy of capacity design on basis of first mode response in high-rise buildings is wrong.

Moehleet al (2007), performing nonlinear analyses on high-rise buildings designed with aforementioned philosophy showed that when earthquake intensity is increased, bending moment at the base remains constant (equivalent to plastic bending moment), while it is amplified in other parts of the wall along its height. Studies have shown that this phenomenon will result in developing nonlinear behavior in other parts of the wall.

Higher mode effects can be far more important in near fault regions, because of high frequency content of these earthquakes. Time history analysis performed on an eight-story structure with reinforced concrete shear wall system located in Montreal by Panneton et al (2008) showed that shear demand obtained by time history analysis is two times larger than shear force specified by the code. Additionally, bending moment at middle parts of the wall were amplified which was a result of amplification in moment curvature and ductility demand and probably development of plastic hinges in upper parts.

Despite these results, higher mode effects are not still reflected in USA codes. Codes such as ACI-318are based on the hypothesis of centralized plastic behaviour at the bottom of the wall. Europeanand Canadiancodes take into account higher more effects by considering capacity design approach and linear bending moment push curve. Past researches showed that this method does not necessarily preclude nonlinear behaviour in other parts of the wall (Panneton 2006 and Priestley et al 2007). These codes do not restrict designers to consider plastic hinges only at the bottom of the walls, but do not require them to control and check details of other parts along the height of the wall which are probable to develop nonlinear behaviour (Panagiotou and Restrepo2009). This can result in developing inappropriate modes of response in some parts of the structure with inadequate ductility.

DPH DESIGN APPROACH

Fig. 1 shows three possible approaches as to where plasticity can develop in cantilever wall buildings. Fig. 1(a) shows the first approach. Plasticity develops anywhere along the height of the walls, and is termed here as extended plasticity (EP) in this paper. The second approach, shown in Fig. 1(b), is that of a SPH. This hinge develops only at the wall base.

Panagiotou and Restrepo (2009) proposed the third approach (Fig. 1(c)) allows formation of two plastic hinges in a wall, one at the base and the second one at mid-height and is termed as the DPH design approach. The EP and the SPH approaches have clear disadvantages. In the EP approach, yielding up the height in walls would typically require special reinforcement detailing along all the height of the walls and SPH approach is not appropriate against higher mode effect. The DPH design approach overcomes the disadvantages of EP and SPH approaches.

The past investigation on shear walls clearly shows the dual plastic hinge design approach is effective at reducing the effects of the second mode of response such as high moment and shear demand. An advantage of the concept is that, when combined with capacity design, it can result in relaxation of special reinforcing detailing in large portions of the walls (Panagiotou and Restrepo 2009).

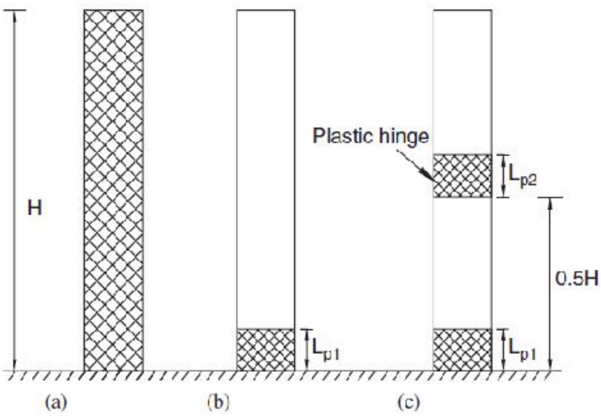


Figure 1. Three different cases of plasticity location in a shear wall : (a) extended plasticity (EP); (b) single plastic hinge (SPH); and (c) dual-plastic hinge (DPH).(Panagiotou and Restrepo 2009)

CHARACTERISTICS OF STUDIED STRUCTURAL MODEL

In this paper, concrete moment frame with shear wall system have been studied. A two-dimensional 20-story frame is selected from a structural system with symmetric plan and identical stories. Each frame constitutes of five identical spans with width of 6 m, and story height in all of them is 3.2 m. Schematic plan and view of this frame are shown in Fig. 2 and Fig. 3.

Compressive strength of concrete is 300 kg/cm2 and yielding strength of steel profiles is 4000 kg/cm2. As suggested by ATC72, when modeling the structure in order to analyze its behavior, all parameters related to strength should be considered the expected ones. Therefore, yielding strength of steel and compressive strength of concrete are considered 1.25 and 1.2 times, respectively, the amount of nominal ones. Rayleigh damping model was used, in which the damping ratio was assumed to be 5% of the critical damping for the first and third modes. The design dead and live loads are 700 kg/m^2 and 200 kg/m^2 respectively.Main characteristics of buildings which were considered in this study are listed in Table1.

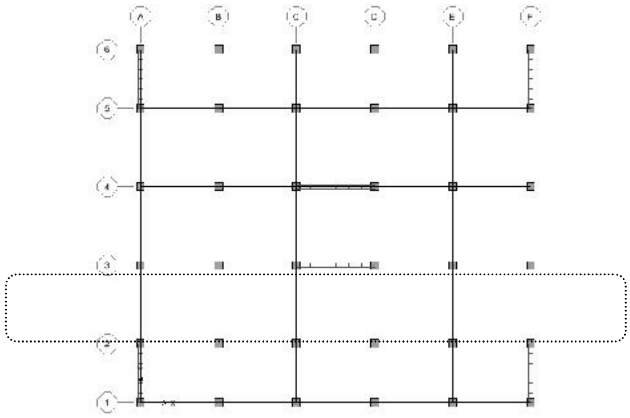


Figure 2. Structural plan and the selected frame

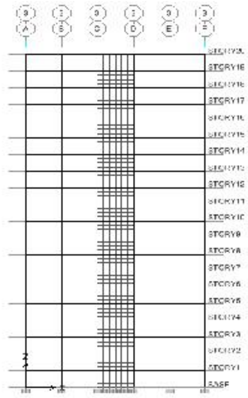


Figure 3. Schematic view of 20-story frame

Table 1.Main characteristics of buildings considered.

	20 story model
soil class	C
seismic design category	D
building height (m)	64
frame span length (m)	6
wall length (m)	6
thickness and width of wall edges at 1-6 stories (m)	0.75
thickness and width of wall edges at 7-12 stories (m)	0.65
thickness and width of wall edges at 13-20 stories (m)	0.55
thickness of wall core at 1-6 stories (m)	0.4
thickness of wall core at 7-12 stories (m)	0.35
thickness of wall core at 13-20 stories (m)	0.25
Longitudinal reinforcement ratio of wall edges at 1-6 stories	0.004
Longitudinal reinforcement ratio of wall edges at 7-12 stories	0.003
Longitudinal reinforcement ratio of wall edges at 13-20 stories	0.003
Longitudinal reinforcement ratio of wall core at 1-6 stories	0.031
Longitudinal reinforcement ratio of wall core at 7-12 stories	0.029
Longitudinal reinforcement ratio of wall core at 13-20 stories	0.023
first mode period (s)	2.01
second mode period (s)	0.527
third mode period (s)	0.231

MODELING

In order to investigate the seismic performance and collapse behavior of the structure, two-dimensional modeling is done using OpenSees platform. Elastic and plastic behavior of beams and columns at macro level is modelled using Haselton concentrated plasticity method (haselton 2008), in a way that each member constitutes an elastic element with two plastic hinges at the ends.

Additionally, concrete shear wall is considered equivalent to an elastic beam column element in the center of the wall, with two nonlinear rotational springs at the ends, in series with the elastic element. Nonlinear behaviour of these rotational springs are specified using FEMA-356 methodology.

SELECTED RECORDS

The near-fault record set includes superstition Hilles earthquake record and erzikan turkey earthquake record have pulses (Pulse-like subset) selected from the PEER NGA database as recommended by FEMA-P695 for nonlinear dynamic analyses.

INCREMENTAL DYNAMIC ANALYSIS

Incremental Dynamic Analysis (IDA) is used in order to investigate the collapse behavior of the structure. Each record is scaled to a small amount of Intensity Measure (IM) which triggers the elastic behavior in model. Then dynamic analysis is done on structure with this IM. The process of increasing IM with increasing the amount of scaling factor is continued until collapse is occurred. In this algorithm, all records should be scaled in a way that the entire range of structural response is covered, from elasticity, to yielding, and finally global dynamic instability. That can be achieved by professional algorithms such as hunt & fill (Vamvatsikos and Cornell 2004). Damage Measure (DM) is obtained for each IM and the distribution of IM versus DM is plotted. This process is done for all selected records.

In order to investigate structural performance in collapse limit state a numerical measure is needed. FEMA350 methodology specifies the collapse of structure when one of these three are happened, numerical no convergence in structural analysis, reaching a slope equivalent to the 20% of initial elastic slope in IDA curve, and exceeding maximum interstory drift a specified amount (each of which happens sooner) .

Collapse mechanism of structure

In this step, using the results of nonlinear dynamic analysis of structure, rotation demands are obtained for each hinge and for each record. Then, collapse mechanism is specified in a level before collapse is occurred. It should be noted that, the behavior and response of the structure is different for each record. Structural mechanism is plotted schematically for Superstition Hills record in Fig. 4.

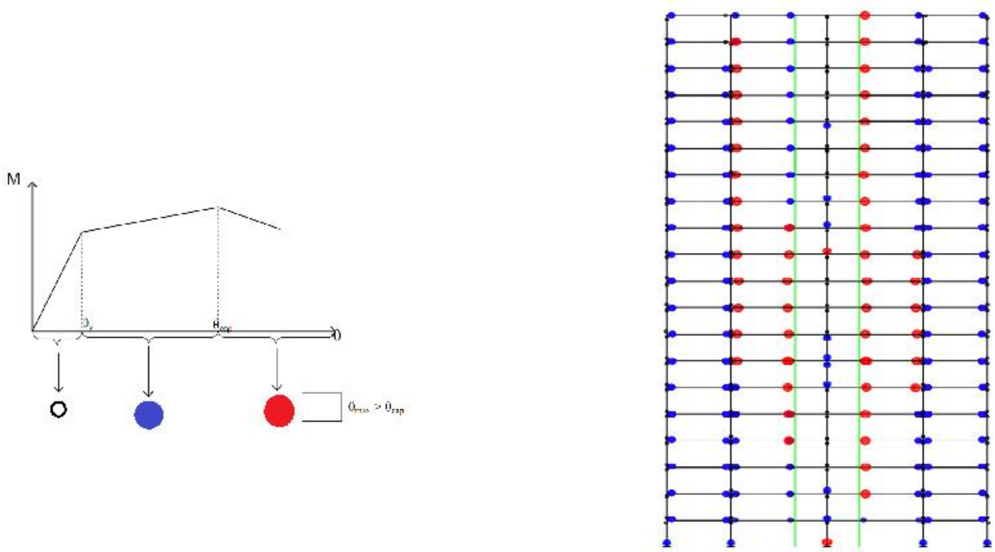


Figure 4. formation of plastic hinges at the moment of collapse against Supersitition Hills record

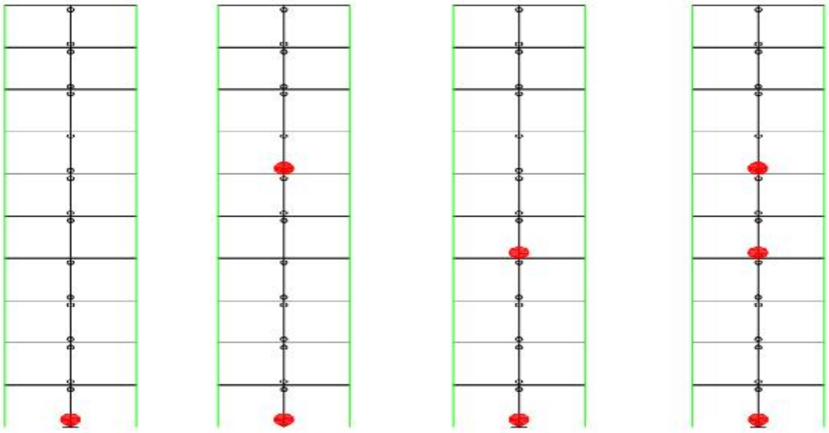
Regarding to the collapse mechanism which is presented to this figure, plastic hinges can develop at the height of the shear wall .Since this factor is not considered in American codes, and sufficient ductility is not provided, it can result in weak performance of structure.

EVALUATION OF MULTI PLASTIC HINGES DESIGN APPROACH

In this paper, multi plastic hinges design approach is used, so that the higher mode effects are decreased. In order to evaluate the performance of this method and comparing it with traditional methods that assumed a single plastic hinge at the bottom of the wall, the 20-story frame was modeled in OpenSees in four different ways. Different arrangements of plastic hinges are shown schematically in Fig. 5.

- A single plastic hinge at the bottom of wall (this model is called SPH in all figures)
- Two plastic hinges, one at the bottom and the other one in upper part of the wall (story 7) (this model is called DPH (0.3h) in all figures)
- Two plastic hinges, one at the bottom and the other one in lower part of the wall (story 12) (this model is called DPH (0.6h) in all figures)
- A model which contains all three plastic hinges mentioned above (this model is called TPH in all figures)

It is worth noting that, other parts of the wall are considered elastic.



a)SPH b)DPH(0.3h) c) DPH(0.6h)d)TPH
Figure 5.Considered models for shear wall

For each model, time history analysis is done by near fault records scaled to MCE earthquake (Maximum Considered Earthquake) in accordance to ASCE7-05 methodology. At the end, shear and moment demands and story accelerations are compared for these models in order to evaluate the seismic behavior of frame. Results are shown in Fig. 6 to Fig. 11.

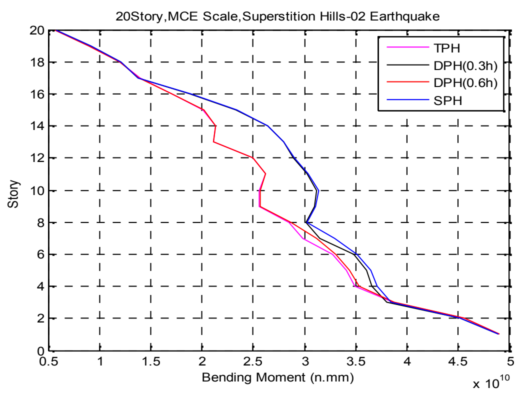


figure 6. Bending moment envelopes obtained from the superstition Hilles earthquake

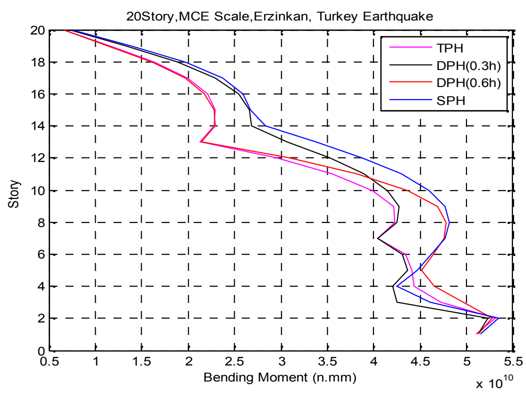


Figure 7. Bending moment envelopes obtained from the turkey earthquake

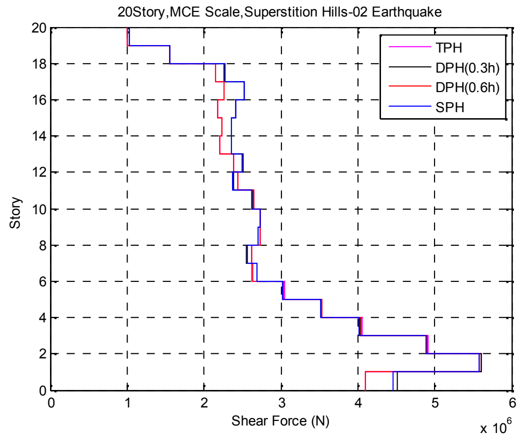


Figure 8. shear force envelopes obtained from the superstition Hilles earthquake

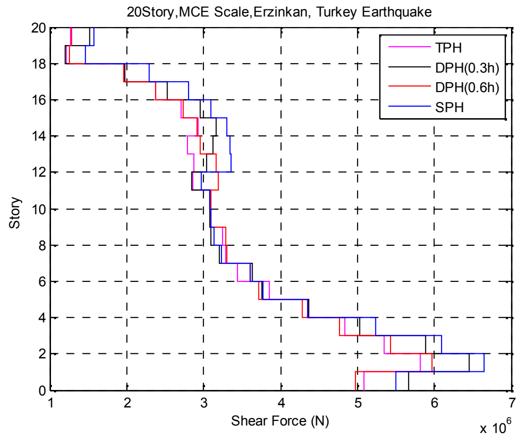


Figure 9. shear force envelopes obtained from the turkey earthquake

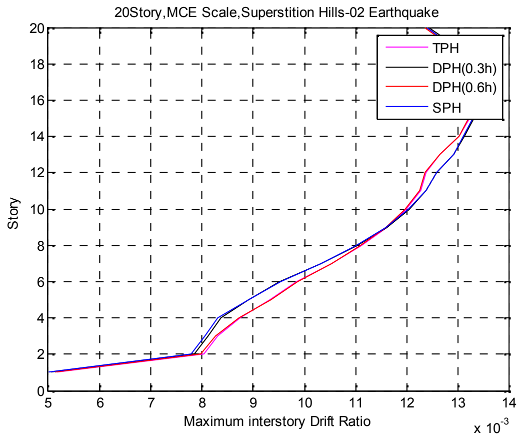


Figure 10. maximum interstory drift ratio envelopes obtained from the superstition Hills earthquake

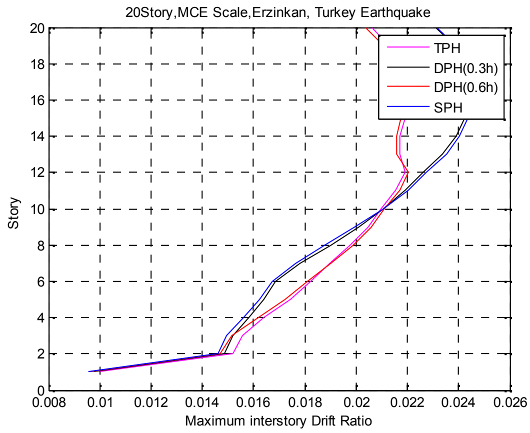


Figure 11. maximum interstory drift ratio envelopes obtained from the turkey earthquake

These figures show that maximum moment and shear demands usually happen in the mid-part of the wall. The plastic hinge formed in 0.6 height of the wall was far more effective to reduce the moment demand than the plastic hinge which was formed in 0.3 height. Overall performance of TPH model was better than other models.).

In this structure, the development of plastic hinges along the height of the wall has been effective in reducing shear demand, but sometimes shear in the middle of the wall is intensified. The amount of inter story drift ratio along the height of the wall does not have a specific behavior. In some cases, using multi plastic hinges approach does not result in increasing the inter story drift ratio. In some cases reduction is seen, and the amount of drift is approximately equivalent to the drift limits requested in codes. For some earthquakes, drift ratio in stories above the story in which the hinge is formed is reduced; and in stories below it, drift ratio increased.

CONCLUSIONS

Higher modes can impose a large shear and moment demand on higher parts of the wall in the structure. Maximum bending moment is noticed at the middle of the wall. Results showed that using multi plastic hinges approach led to the reduction in large moment and shear demands along the height of the wall due to higher modes. In addition, it was noticed that the location of plastic hinge along the height of the wall can be very effective in reducing this demand. In some cases, shear is increased in DPH models, but in TPH model, in nearly all cases shear demand decreased or remained constant.

It can be concluded that using multi plastic hinges approach for design, can result in the reduction of required longitudinal and transverse steel profiles for other parts of the wall (other than the location of plastic hinge) due to the reduction in moment and shear demands. Therefore, it will lead to an efficient and economical design. Additionally, it is beneficial from the execution point of view because of reduction in the volume of reinforcement and execution details.

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