PERFORMANCE EVALUATION OF RC HIGHRISE BUILDING UNDER LONG PERIOD GROUND MOTION AND FORMULATION OF NONLINEAR MODELING

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ABSTRACT

This study proposed new models for beam and column elements based on experimental results which enable to consider the strength degradation by long period loading. The performance evaluation of a 36 story model RC highrise building was conducted by adopting the proposed element models under long period ground motions.

The dynamic analysis was conducted using STERA 3D software by inputting El Centro 50 Kine, BCJ-L2, Osaka and Sannomaru ground motions. It was found that the performance of the building was within the safety criteria of design standard except that under Sannomaru ground motion. Under Sannomaru ground motion, 75% of beams were damaged and it may require a large amount of repair work. To avoid such severe damage, retrofitting of highrise building will be necessary.

Keywords: Highrise building, long period ground motion, STERA 3D.

INTRODUCTION

Highrise building is one option in the rapid industrialized world to fulfill housing and commercial needs within limited land space. These buildings are considered as safe structure in seismic region when compared with small buildings. But, the 1985 Mexico earthquake changed this thought and it damaged many highrise buildings. This incident changed direction of many researchers and to think about the vulnerability of the highrise buildings. It has been observed that these highrise buildings have long natural period and those will respond largely to the ground motions having the period same as that of the natural period of the highrise buildings. These ground motions are called long period ground motions. Long period ground motions are produced in the large river basins having soft and thick layer of sediment deposits due to large distant earthquake by means of path and site effects.

It is very essential to know the performance of highrise building under long period ground motions. So it is important to have an accurate analytical method for conducting the performance study of the highrise buildings. This study mainly focuses on the formation of element model for beam and column elements of RC highrise building. Also the objective of this study is performance evaluation of RC highrise building under long period ground motion and damage estimation.

CONSTRUCTION OF TRILINEAR SKELETON MODEL

Study on Beam:

The experiment study on beam specimens was conducted by the joint research team comprised of Building Research Institute and six private companies in March 2008. As shown in the Table 1 eight types of beams specimens were used for the experiment. Here N indicates normal loading representing the short period ground motion and L indicates long period loading representing long period ground motion. The beam details are given in Table 1 and the cross section of the beam is given in Figure 1. The experimental data were obtained from this research team was used in this study.

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Table 1 Types of beam

	Beam Type	Main bar SD490	Tie bar UHY685
With Slab	B1-N	Top 6-D19 Bottom 4-D19	4-D6@75
	B1-L		
	B2-L		4-D6 @150
	B2-N		
With out slab	B3-L		4-D6 @75
	B4-L	Top 6-D19 Bottom 6-D19	
	B4-N		
	B5-L		4-D6 @150

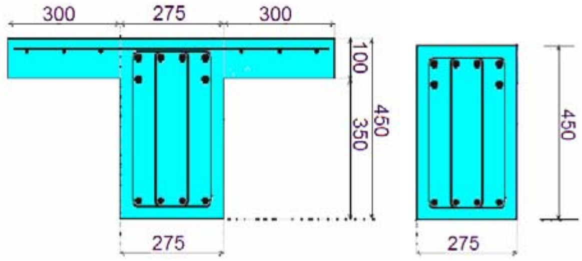


Figure 1 Cross section of beams

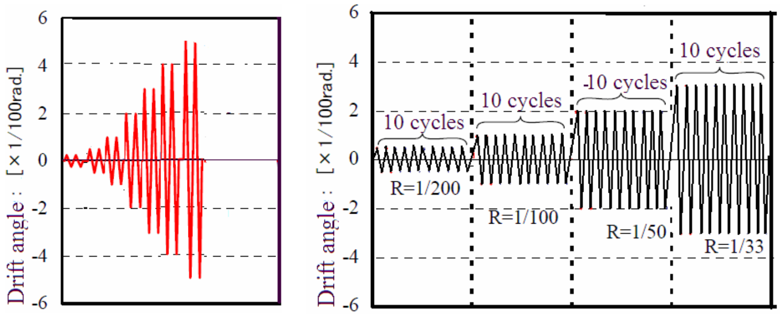


Figure 2 Normal and Long Period Loading

Loading for the study: Two types of loads were used in the experiment, namely normal loading and long period loading. Here normal loading represents the short period ground motion and long period loading represents the long period ground motions. As shown in Figure 2 in this experiment the story drift ratio (R=δ/a) is maintained as 1/400, 1/200, 1/100, 1/50, 1/33, 1/25, 1/20 and each ratio was maintained for 2 cycles for normal loading. Then the story drift ratio was maintained as R= 1/200, 1/100, 1/50 and 1/33 and 10 cycles were given for long period loading

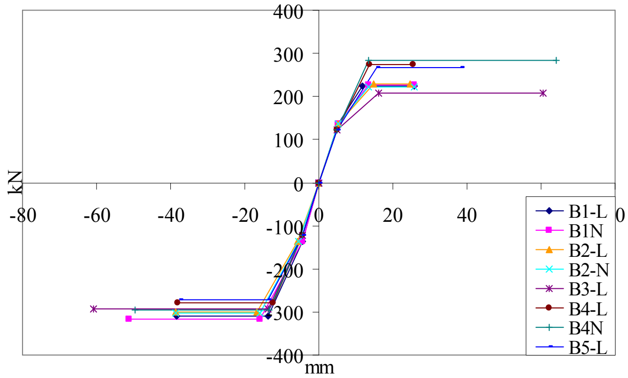


Figure 3 Trilinear skeleton model for beam

The trilinear skeleton models were constructed based on the experiment results. The skeleton models of the specimens are shown in Figure 3.

Study on Column: Two types of column specimens were used for the study namely C1 and C2 with same cyclic loading as given before and axial load of 2880kN and 4800kN respectively. Two columns from each type namely C1-N, C1-L, C2-N, C2-L were prepared for normal loading (N) and long period loading (L).

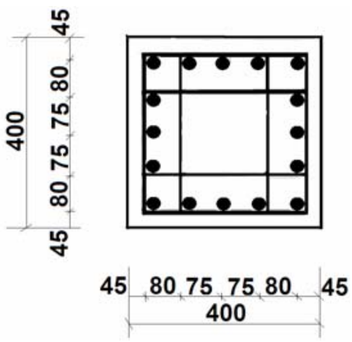


Figure 4 cross section

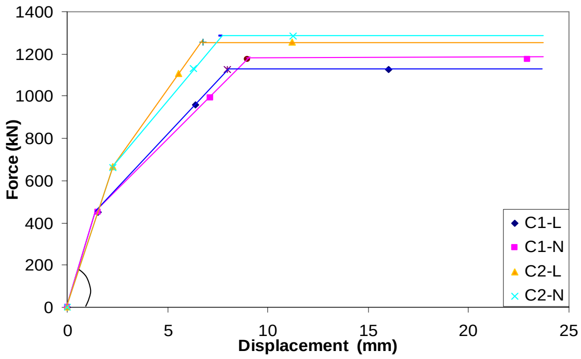


Figure 5 Trilinear skeleton model

The cross section of the column is shown in Figure 4. Main bar of 16-D19 and tie bar of 4-D6@40mm spacing were used. Same cyclic loading was applied for columns and tri linear skeletons were prepared as shown in Figure 5.

FORMATION OF ELEMENT MODEL

Formation of element model for beam:

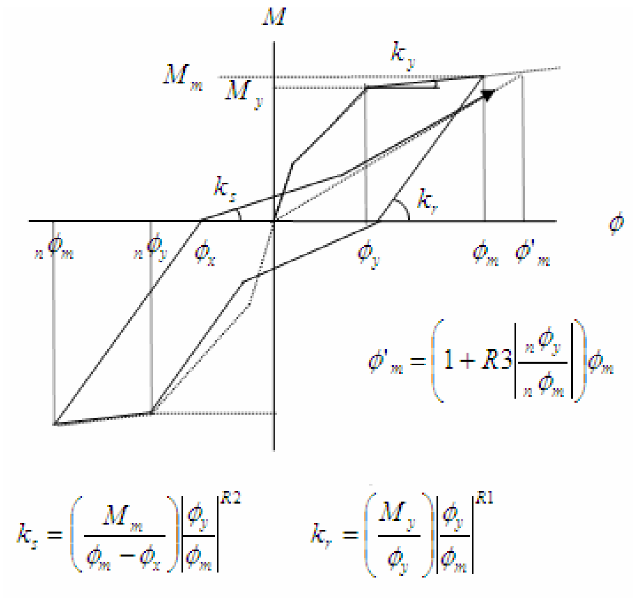
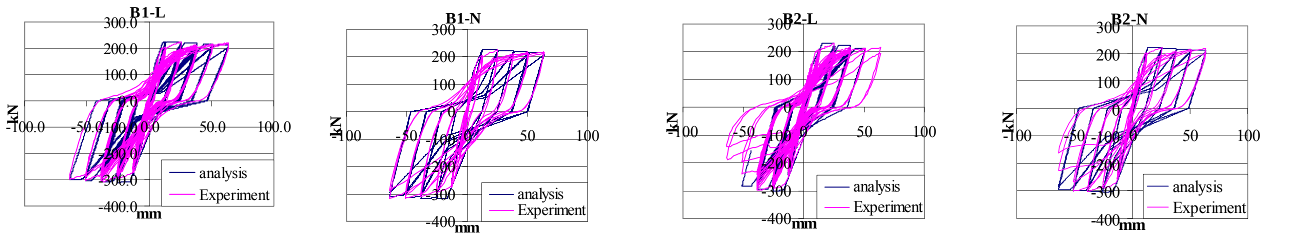


Figure 6 Hysteresis model for the Beam

The hysteresis model of the beam as given in Figure 6 is governed by the parameters R1, R2, R3 and Sy. The unloading stiffness k_r is governed by the parameter R1. The slip stiffness k_s is governed by the parameter R2. The strength degradation depends on the parameter R3. The constructed trilinear skeleton model is adopted in this model and analysis was done for all the specimens by adopting the same load which is applied in the experiment. The governing parameters were optimized in this analysis by fitting the hysteresis obtained from analysis with the hysteresis obtained from experiment. The fitted hysteresis and the optimized parameters are shown in Figure 7. This beam element model is proposed for further analysis of the model building

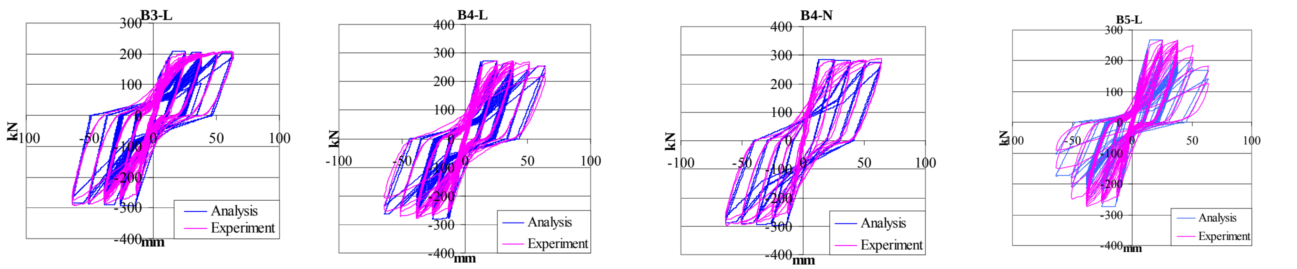


Sy	R1	R2	R3
-0.01	0.3	0.7	0.005

Sy	R1	R2	R3
-0.01	0.1	0.5	0.005

Sy	R1	R2	R3
-0.03	0.05	0.5	0.005

Sy	R1	R2	R3
-0.01	0.1	0.4	0.005



Sy	R1	R2	R3
-0.01	0.1	0.5	0.01

Sy	R1	R2	R3
-0.03	0.4	0.5	0.01

Sy	R1	R2	R3
-0.01	0.4	0.5	0.01

Sy	R1	R2	R3
0.1	0.6	0.5	0.01

Figure 7 Hysteresis fitting

Formation of element model for column:

The column is divided into nine subsections as shown in Figure 8 and the nonlinear spring in each subsection also shown in the figure. The subsections from 1to 8 consist of both steel and concrete springs and the 9^{th} subsection consists only of concrete. The hysteresis models of steel and concrete are shown in Figures 9 and 10.

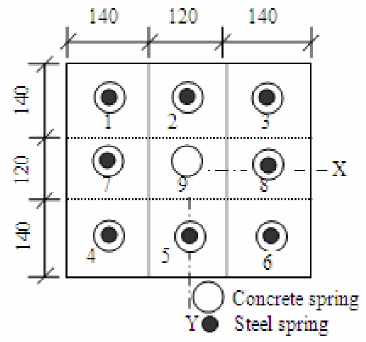


Figure 8 Multi spring model

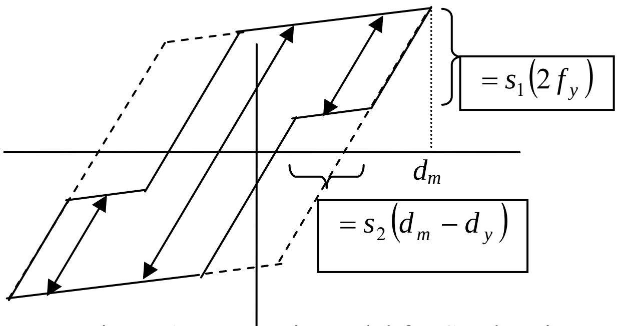
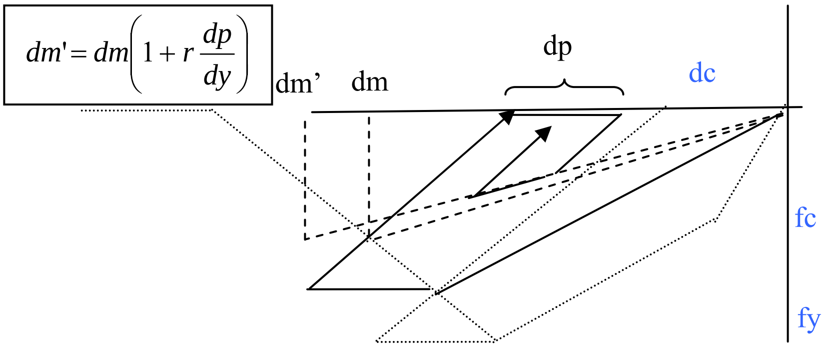


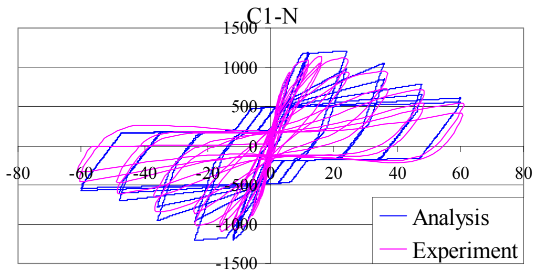
Figure 9 Hysteresis model for Steel spring

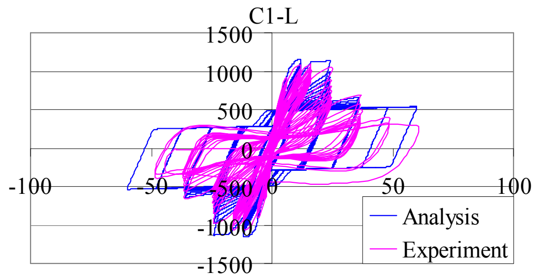
S1 is the factor control the unloading stiffness and the factor S2 controls the slip stiffness. The other parameters controls the column models are given as follows.



Ps - Factor to control the initial stiffness.
ay - Factor to control yield displacement.
Ku/Ko - Degradation Ratio of concrete
fc/fy(s)–ratio of crack &yielding force-steel
fc/fy(c)-ratio of crack and yielding force concrete

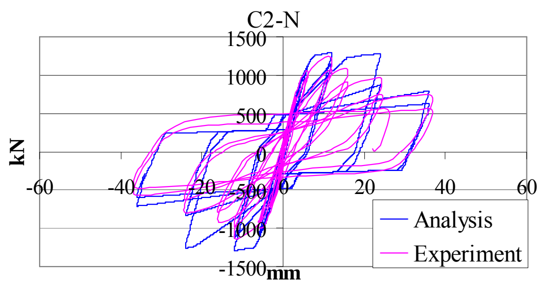
Figure 10 Trilinear hysteresis model for concrete spring

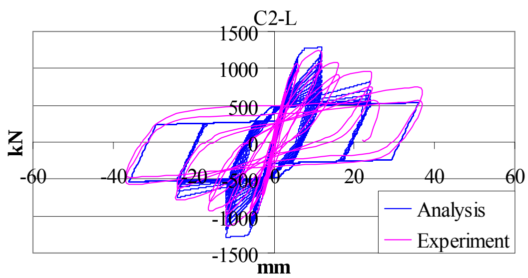




P_s	a_y	F_c/f_y(s)	F_c/f_y(c)	K_u/K_0	R	S_1	S_2
0.1	0.3	0.7	0.6	-0.02	0.1	0.7	0.7

P_s	a_y	F_c/f_y(s)	F_c/f_y (c)	K_u/K_0	R	S_1	S_2
0.07	0.3	0.55	0.55	-0.01	0.03	0.8	0.8





P_s	a_y	F_c/f_y (s)	F_c/f_y (c)	K_u/K_0	R	S_1	S_2
0.06	0.5	0.8	0.8	-0.01	0.1	0.8	0.8

P_s	a_y	F_c/f_y (s)	F_c/f_y (c)	K_u/K_0	R	S_1	S_2
0.05	0.4	0.8	0.8	-0.01	0.05	0.8	0.8

Figure 11 Hysteresis fitting for column

Figure 10 shows the tri linear hysteresis model for concrete spring. The strength degradation of the concrete due to cyclic loading is included in the model. The cyclic loading applied in the experiment is taken for the model analysis of the column specimens. The controlling parameters were optimized by fitting the hysteresis arrived from this analysis and the hysteresis arrived from the experiment. The optimized parameters and hysteresis are shown in the Figure 11.

PERFORMANCE EVALUATION AND RESULTS

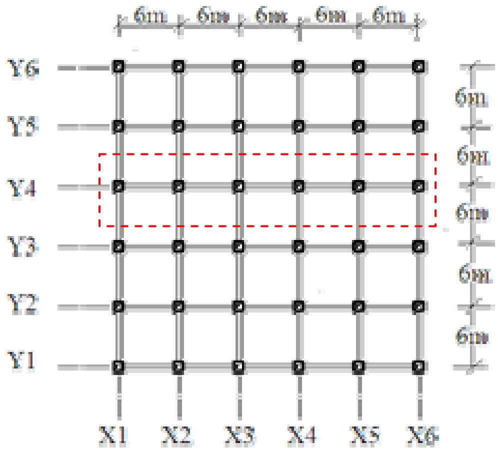


Figure 12 Plan of the building

A 36 story RC highrise building located in Tokyo is selected as a model building. The plan of the building is shown in Figure 12. The 3D model of the building was developed in the STERA 3D software and it was found that the dynamic analysis of 3D model takes more time to complete the analysis. So it was decided to form 2-D model to overcome this time constraint with the same characteristics as that of the 3-D model. So the 2D model is used for further analysis

Input Ground motions:
The ground motions given in Table 2 are selected as input ground motion for the dynamic analysis of the model building

Table 2 Input Ground Motions

Earthquake	Type of earthquake	Characteristics
El Centro 50 Kine	Famous and Design earthquake	1940 El Centro earthquake NS component. PGA 505cm/sec2 and PGV 50 cm/sec
BCJ-L2	Design earthquake.	Artificial wave developed by Building Centre of Japan (level 2), PGA 355 cm/sec2, PGV 50 cm/sec
Sannomaru	Long period ground motion	Artificial wave simulated for Tokai-Tonankai earthquake in Nagoya city
Osaka	Long period ground motion	Artificial wave simulated for Nankai earthquake in Osaka city

Results:
The performance of the model building was studied and the response of the building under various ground motions is given in Table 3. It is seen that the story drift ratio obtained from various earthquake for the model building are within the design limit of 1/100 except for the Sannomaru earthquake. The max story drift obtained for the Sannomaru earthquake at 11^{th} floor is 1/73 which exceeds the design limit of 1/100.

Table 3 Max drift, displacement and ductility

Earthquake	Max Drift (cm)	Max Drift Ratio (rad)	Max displacement @ top (cm)	Max Ductility
El Centro 50 Kine	2.35@ 22F	1/134	66.1	1.47
BCJ-L2	2.59@ 19F	1/122	71.8	1.61
Sannomaru	4.41 @11F	1/73	108	3.19
Osaka	0.8 @12 F	1/400	22.8	0.48

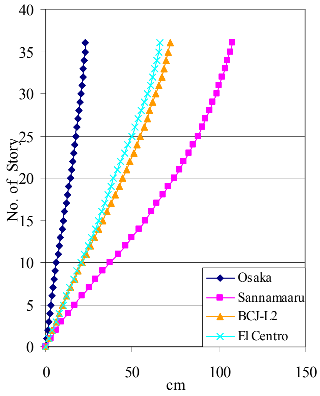


Figure 13 Story Drift

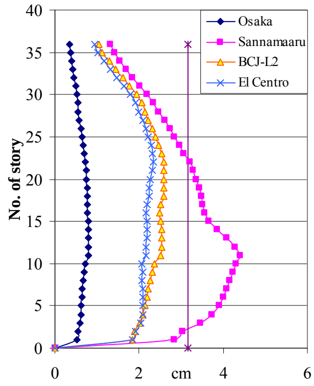


Figure 14 Max top displacement

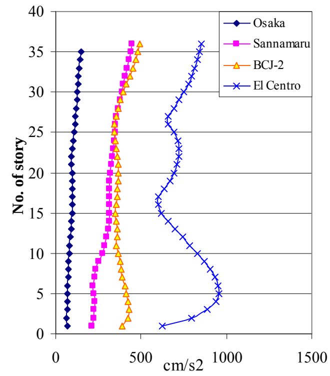


Figure 15 Max Acceleration

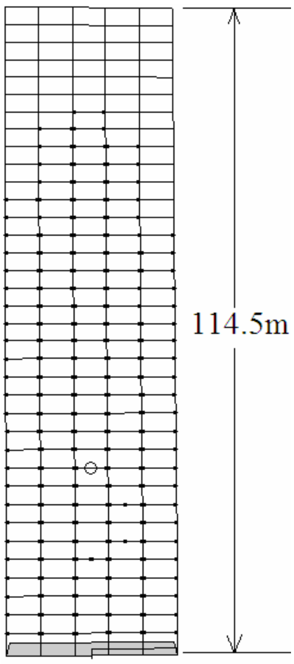


Figure 16 Distribution of hinges

The story drift distribution for each earthquake is given in Figure13. The maximum story drift is produced by the Sannomaru earthquake with the value of 4.41cm. The story drift ratio for this drift is 1/73. This is over the design safety limit of 1/100.

The maximum top story displacement given by the model building under various input ground motions is shown in Figure 14. It is also seen that highest top displacement for the model building was found under Sannomaru earthquake than the other three earthquake considered for this study. The maximum top story displacement is observed from the Sannomaru earthquake and the value is 108 cm

The distribution hinges developed due to Sannomaru earthquake is shown in Figure 16. It is estimated that 75% of beams were damaged due to Sannomaru earthquake. This study implies that the performance of model building satisfies the design standard except that under Sannomaru earthquake.

CONCLUSIONS

In this study new element models were proposed for beam and column elements based on experimental results which enable to consider the strength degradation by long period loading. Dynamic analysis of the 36 RC highrise building was conducted adopting proposed element models under long period ground motions. It was found that the performance of the building was within safety criteria of design standard except that under Sannomaru earthquake. 75% of beams damaged under Sannomaru earthquake and it may require a large amount of repair work. To avoid such severe damage, retrofitting of highrise building will be necessary.

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STERA 3D software link: http://iisee.kenken.go.jp/net/saito/stera3d/index.html