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Case Study On The Soft-First-Story Buildings Strengthened By Confined Concrete Columns

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ABSTRACT

Generally, pilotis buildings are not safe against earthquake as people might expect. However, the technique of confined concrete to columns and beams of pilotis story will give an approach of solution, it yields a stable large ductility of such 1/20～1/15 of story drift angle.

In this study, response properties of 10 stories of pilotis buildings for 25, 50 and 75 Kine ground motions are investigated, analyzed, and sufficiently illustrated what safe responses are..

1. INTRODUCTION

Since many of pilotis buildings suffered great damages during the Hyogoken Nanbu Earthquake (Great Hanshin Earthquake), it is generally evaluated that pilotis buildings are not safe enough. But due to its merit of usability and convenience, pilotis structure is widely used for apartment and office buildings. Actually, the real reason that resulted in serious damages in the Hyogoken Nanbu Earthquake is that the horizontal reinforcing bars of RC column were inadequate. Because confined concrete columns, has a secure capability against great deformation. i. That is, many reinforcing bars with circular or a square shape that will be effectively against plastic transform, has a secure capability against great deformation, this enhanced pilotis story can be used as a seismic base isolation. In this case,, the upper stories can be managed with non-damage state, and the building can be recovered by only reinforcing the pilotis story as designed plan, even in major earthquake. Moreover, the pilotis story can well utilize space well.

This research is focus on analyses about various stiffness ratios of the building carries out

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elasto-plastic based on a confined concrete column with sufficient deformation capability, and this paper reports the case study on the earthquake resistance.

2. THE DRAWING OF ANALYSES BUILDINGS

The typical floor-framing plan of a building is shown in Fig.1, and the framing elevation of span direction is shown in Fig.2. The apartment is assumed with 10 stories of reinforced concrete structure, and the buildings are divided into two categories. I.e. the first story is pilotis, which was named as case 1, as well as first to second stories are pilotis, which was named as case 2. The span direction is toward the shear walls except for a pilotis story, and ridge direction is pure rigid-frame construction for every stories. The height of pilotis story is 4.5m and others are 3.0m. The sectional size of the column used for a pilotis story can be adjusted as a parameter of case study (Refer to Table–2). The sectional size of common part except the column of pilotis story is shown in Table -1. A pilotis story is assumed to as stores. Live load is based on the 85th article of the Japanese Building Code. Used materials are shown below.

<Supposed Materials> Concrete: 1---2 stories: Fc36; 3---6 stories: F33; 7---10 stories: F30

Reinforcement: Main reinforcement: SD390; Hoop or stirrup: SD295 or SD345

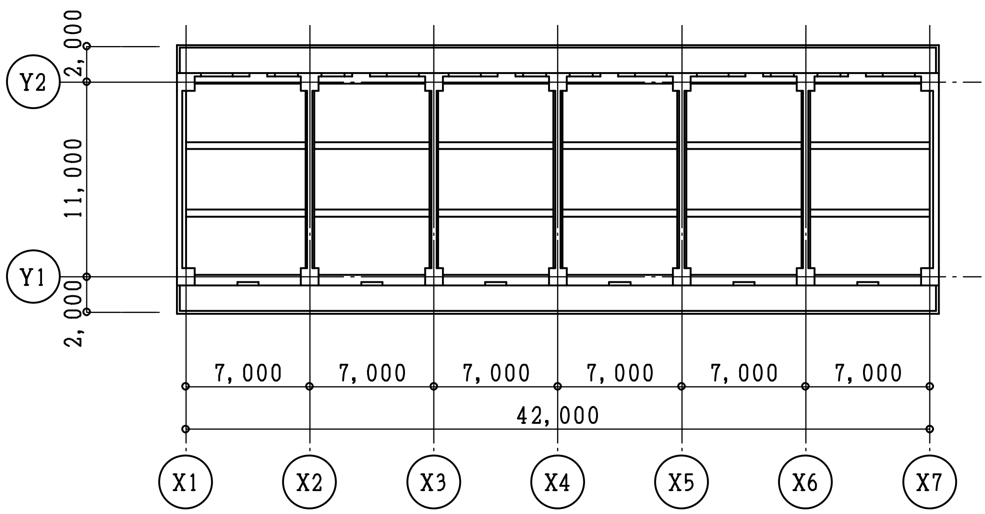


Fig.1 the typical floor-framing plan of a building

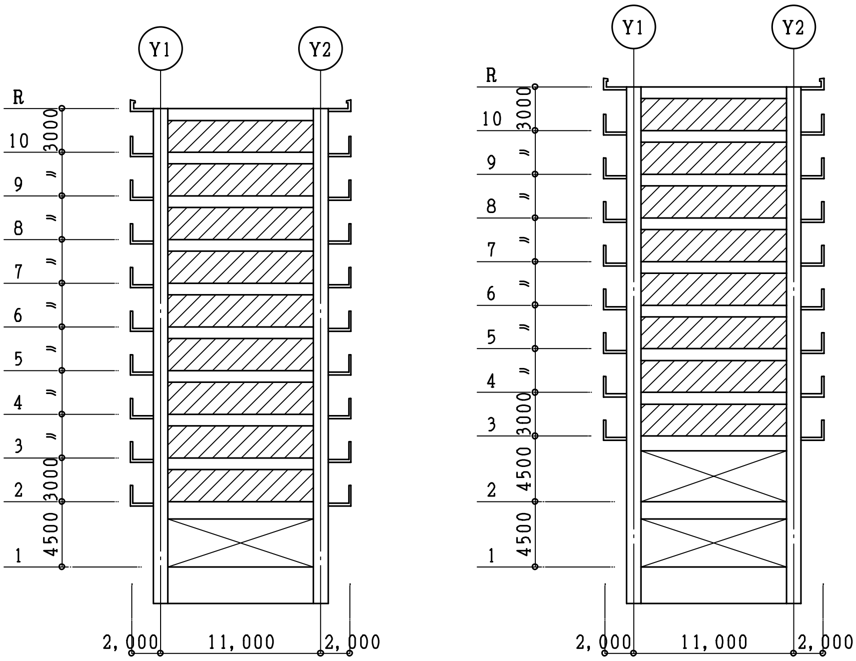


Fig.2 framing elevation of span direction

Table-1 The sectional size of common part (except the column of pilotis story)

Part/Case	Case 1	Case 2
Column (BxD)	Each story: 1000x1000	Main beam ： For span direction 600x1200(3F) 600x1200(2F) For ridge direction 500x900(3F) Others: as same as Case 1
Main beam (bxD)	Span direction: 500x750(RF)--- 600x1100(2F) Ridge direction: 400x700(R---3F) 500x900(2F)	
Wall	Shear wall: t=200 Others: t=165	
Slab	Each story: t=200	

3. THE OUTLINE OF CASE STUDY

3.1 The examination plan of the basic model

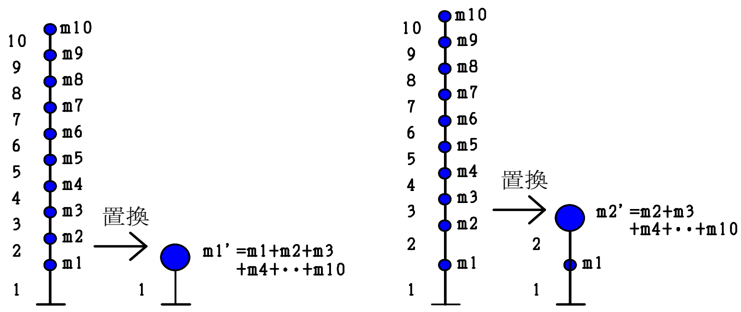
Case studies are carried out by earthquake response analyses, and the equivalent shear model is applied. The given analysis method, direct integral calculus, step-by-step integration has been taken as the Newmark- β method. A skeleton curve is considered as Tri-linear, and suppose the hysteresis characteristics be the modified Takeda model, which the decrease in stiffness ratio as $\gamma=0.4$ after unloading. Moreover, the foundation is considered as fixation.

3.2 The examination plan of the reduced lumped mass system

The analysis model is given as follows: the continuous shear wall of 10 stories is packed into one story. A case study is performed by using the same analysis method described in the section 3.1. Simplified to make it easier, the summarized method neglects the height of the reduced stories is adopted (shown in Fig.3). Namely, in case 1, the simple sum of the mass of 10 stories system is transposed to one mass, while hysteresis characteristics is, as well as that of the first story, in 10 stories system. In case 2, the hypothesis is that the hysteresis characteristics of the first to second stories, the mass sum of the second to upper stories is transposed to the mass of the second story, as well as the mass of the first story be the same.

Table-2 Analyses Parameters

Parameters	Case 1	Case 2
The section size of the pilotis colunm BxD (mm) (Case1: 1F) (Case2: 1 to 2F)	1500 x 1500	1600 x 1600
	1400 x 1400	1500 x 1500
	1300 x 1300	1400 x 1400
	1200 x 1200	1300 x 1300
	1100 x 1100	1200 x 1200
	1000 x 1000	1100 x 1100
	900 x 900	1000 x 1000
	800 x 800	900 x 900
	700 x 700	800 x 800
The number of main reinforcement of pilotis column (Diameter)	32, 20 (D35)	34, 24 (D35)
Input ground motion	EL CENTRO 1940 NS TAFT 1952 EW HACHINOHE 1968 NS	
The lever of input waves	25 , 50 , 75 Kine	
Damping h	0.03 , 0.05 , 0.10	



(1) Case 1 (2) Case 2

Fig.3 Modified model

3.3 The examination method of the pilotis column

In this examination, it is expected there exists a large deformation and a high axial force arise on the pilotis column. The confined reinforcement concrete column, which used as resistance performed on the pilitis story, to the large deformation and high axial force. An examination equation is shown in Eq.1, and an example of a confined reinforcement hoop is shown in Fig.-4.

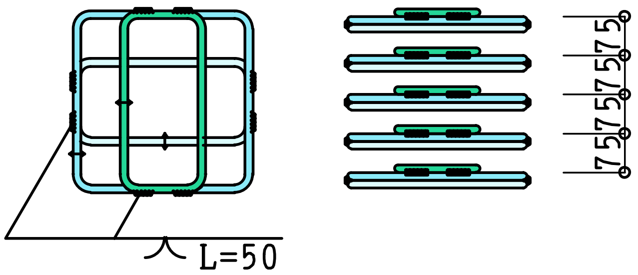


Fig.4 an example of a confined reinforcement hoop

$$p_s = 1.5 \cdot (a \cdot \eta + b) \cdot \left(\frac{Fc}{30}\right)^m \cdot \left(\frac{350}{\sigma_{try}}\right)^{\frac{2}{3}} \cdot \left(\frac{3}{5} + \frac{4}{5 \cdot n_s}\right) \cdot \left\{\left(\frac{A_g}{A_c}\right)^{\frac{3}{2}} - \frac{1}{3}\right\} \cdot \left(\frac{5}{4} \cdot \frac{S}{D} + \frac{7}{8}\right) \tag{1}$$

Here, $a = \frac{200 \cdot \theta_u}{9} + \frac{8}{9}$, $b = 10 \cdot \theta_u - \frac{5}{12}$, $m = \frac{43}{Fc} + \frac{3}{7}$

4. RESULTS OF ANALYSIS

4.1 Basic analysis

According to Section 3 of article 82 of Japanese Building Code, the stiffness ratio for elastic response is defined as below,

$$\text{stiffness ratio} = \frac{1/R_{calculated}}{\sum_{i=1}^{n}(1/R_i)/n} \tag{2}$$

Here, $R_{calculated}$: the deformation angle of calculated story for elastic response analysis
Ri: optional story
n: the number of total story

Table-3 shows the natural period and the stiffness ratio of the first story using the engenvalue analysis by changing the diameter of pilotis column in each case.

4.2 The maximum response displacement of the first story

Fig.5 displays the maximum response of the first story and the results of each case with input earthquake velocity 50Kine EL Centro 1940 (NS), with various diameter values of pilotis columns. Y-axis indicates the maximum response displacement, and X-axis indicates the stiffness ratio of the first story. The following tendencies are shown in Fig.5, i.e. the stiffness ratio becomes smaller, and the maximum displacement is larger for the first story. Compare case 1 with case 2, the maximum displacement and the influence of damping factor of case 1 are both larger.

Table-3 Natural period and the stiffness ratio of the frist story

Case 1			Case 2		
Diameter B=D (mm)	Natural period (s)	Stiffness ratio Rs	Diameter B=D (mm)	Natural period (s)	Stiffness ratio Rs
1500	0.302	0.772	1600	0.349	0.646
1400	0.308	0.698	1500	0.368	0.583
1300	0.320	0.622	1400	0.393	0.523
1200	0.335	0.544	1300	0.424	0.467
1100	0.356	0.467	1200	0.461	0.414
1000	0.384	0.389	1100	0.507	0.364
900	0.425	0.332	1000	0.565	0.317
800	0.483	0.271	900	0.640	0.272
700	0.569	0.210	800	0.740	0.230

4.3 The ratio of displacement for pilotis story to uppermost story

The ratio of the maximum response displacement of pilotis story to the maximum response displacement of the uppermost story is defined as displacement ratio. The variation of displacement ratio with the diameter change of pilotis column for each case is shown in Fig.6. As stiffness ratio becomes smaller, the deformation of pilotis story is larger. If the stiffness ratio is less than 0.4, then the ratio of displacement will exceed 90 percent. And the deformation will focus on the pilotis story. Although here shows only 50 Kine and h= 0.05 of EL CENTRO 1940 NS were shown here, the same tendency, was observed for other cases. Since the velocity of input ground motion as 25, 50, 75Kine respectively, the results of the distribution of the height direction for drift angle of maximum response, and the relationship between the shear force and the ratio of displacement, are shown in Fig.7-10. In these figures, the drift angle is very small compare with the pilotis story, so it turns out that the pilotis story should be one type of seismic base isolation.

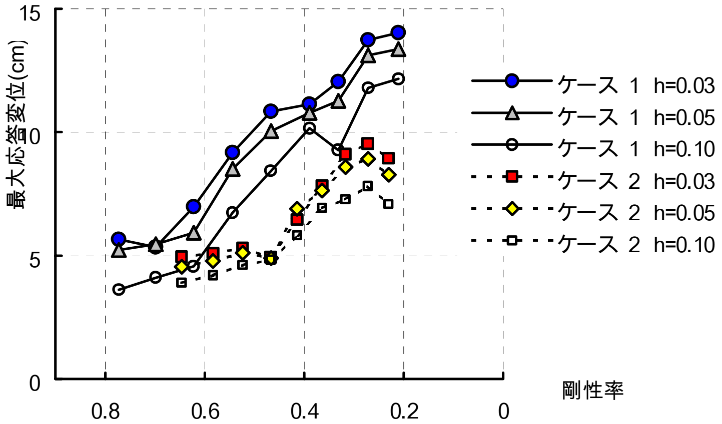


Fig.5 the maximum response of the first story

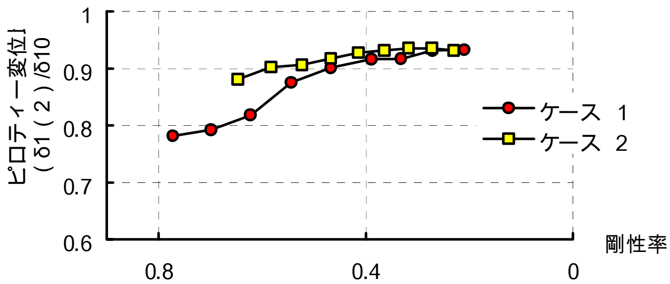


Fig.6 displacement ratio of pilotis story

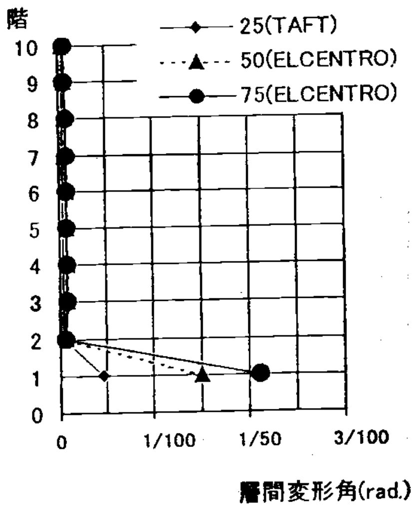


Fig. 7 drift angle of maximum response (Case 1)

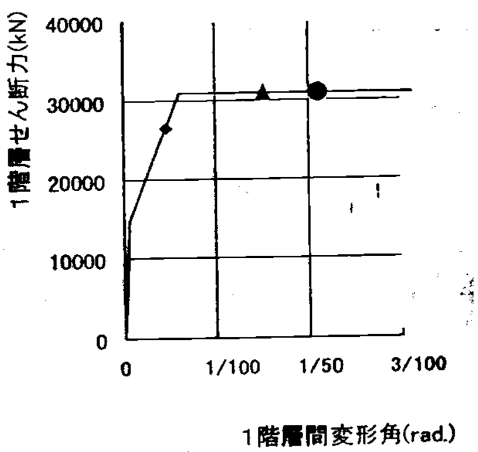
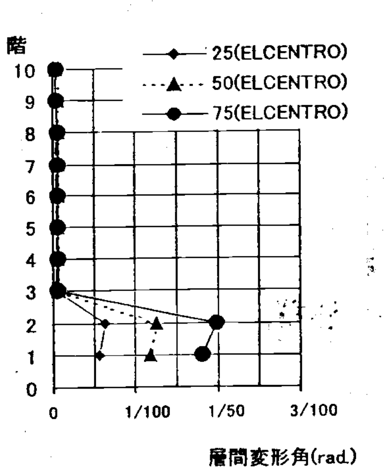


Fig.8 the relationship between the shear force and the ratio of displacement (Case 1)



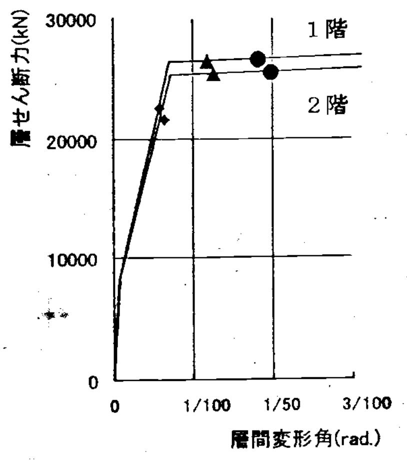
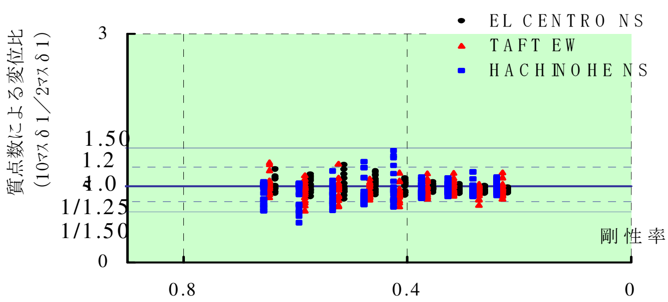


Fig. 9 drift angle of maximum response (Case 2)

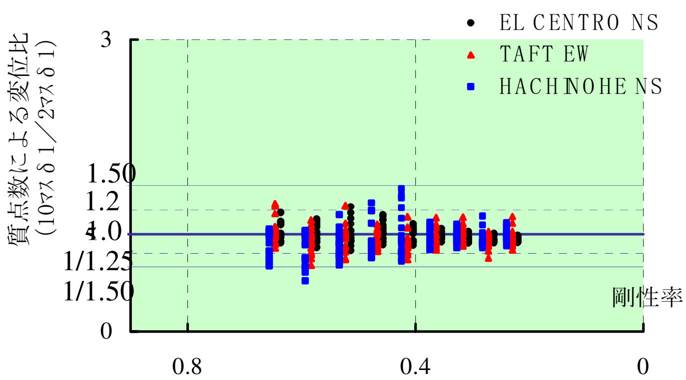
Fig.10 the relationship between the shear force and the ratio of displacement (Case 2)

4.4 Comparison of the maximum response displacement of 10 masses system with one mass system

The value, which analyses from 10 masses system is divided by the value of the modified system, is used as the ratio of displacement. The results of the maximum response displacement are shown as in Fig.11. Y-axis is the ratio of displacement, and X-axis is the stiffness ratio of first story. In these figures, the stiffness becomes smaller; the ratio of displacement will tend to approach 1. The stiffness ratio is 0.3 or less in case 1, and 0.4 or less in case 2. The ratios of displacement will converge in the range of about 1/1.25---1/1.30. This leads surely to the possibility of simplified analysis of one



(a) Case 1



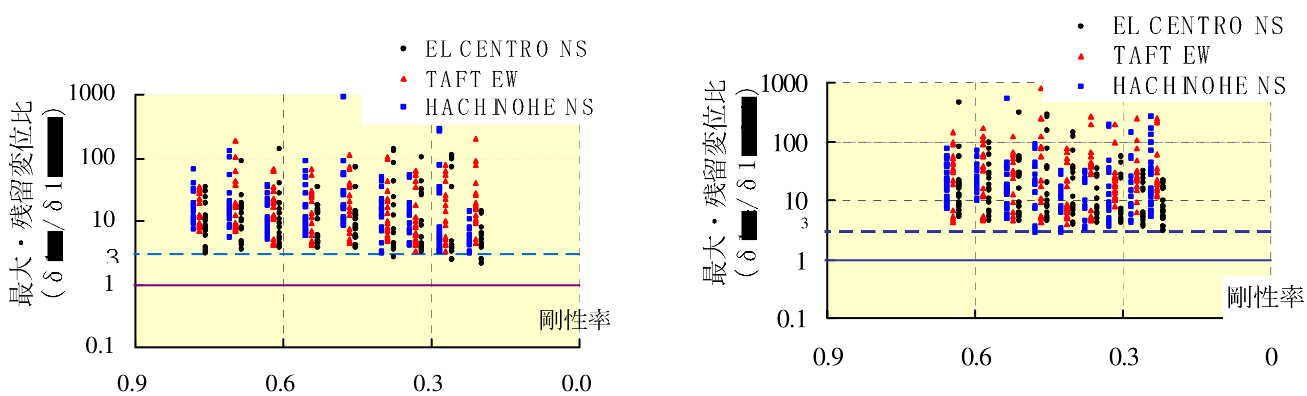
(b) Case 2

Fig.11 the maximum response displacement

mass system in seismic design, if stiffness ratio is about 0.3---0.4 of less.The analysis by the simple modified model neglects the height of upper stories when the stiffness ratio of pilotis story is small, the maximum response displacement of the pilotis story can be estimated within the limits, which is about 20 to 30 percent of errors. It means, if stiffness ratio is about 0.3 to 0.4 or less, it is analyzable by using modified model of one mass system.

4.5 Comparison of the maximum response displacement with residual displacement

In this paper, the displacement in the last step of response analysis is defined as residual displacement. During this step, the numerical value, which the maximum response displacement of the first story is divided by the residual displacement of same story, is used as the ratio of residual displacement. The result of the ratio of residual displacement is shown as in Fig. 12. Y-axis is the ratio of displacement, and X-axis is the stiffness ratio of first story. In addition, the Y-axis is expressed as a scale with logarithm. By this expressing method, the ratio of displacement is distributed widely in about 3 to100. So the residual displacement defined here is 1/3 or less tendency of the maximum displacement. Furthermore, actual residual displacement, which is the value at the time of unloading, is smaller than the value defined here. So it is considered that the ratio of the residual displacement to the maximum one becomes much smaller.



(a) Case 1

(b) Case 2

Fig.12 the ratio of residual displacement

4.6 The design of the ductile column for pilotis structures

Pitch of the hoops is calculated using Eq.1 to the drift angle of pilotis story as follows.

According to Fig. 7---10; $\theta_u = 1/50$

In design, $\theta_{uD} = \theta_u \times 1.5 = 1/30$ (1.5 is safety factor assumed .)

The ratio of axial force is; $\eta = 0.3$

∴ The hoop shown in Fig.4 is to be placed as: D13@75

5. CONCLUSION

The given study models are 2 kinds of apartments with10 stories, one has a pilotis story on the first story, and another has pilotis story on the first to second stories. Based on the above case study, the earthquake responses are analyzed as the case study for various diameters of the pilotis column. The following conclusions can be obtained by comparing these results.

(1) If the stiffness ratio of pilotis story is 0.3 to 0.4 or less, 90 percent or more of the maximum response displacement of the whole building will converge on the pilotis story.

(2) When the stiffness ratio of pilotis story is 0.3 to 0.4 or less in a simplified model of one mass system neglecting the height of upper stories, the maximum response displacement can be estimated with about 20% to 30% in error. Namely, it can be remarked that the analysis is possible by using modified one mass system.

(3) The residual displacement of pilotis story is about 1/3 or less of the maximum response displacement.

REFERENCE

1. Proceedings of JCI Symposium on Practical Approach to Ductility Base Design and Ductile of Concrete Structures, Committee report pp.176 (by K. Suzuki), Japan concrete Institute, 2001.11