SEISMIC RESPONSE OF MULTISTORY BUILDING STRUCTURES WITH FLEXIBLE FLOOR DIAPHRAGMS

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SUMMARY

An efficient model for three-dimensional analysis of multistory structures with flexible floor diaphragms is proposed in this paper. Three-dimensional analysis of a building structure using a finite element model requires tedious input data preparation, longer computation time, and larger computer memory. The model proposed in this study is developed by assembling a series of two-dimensional resisting systems and is considered to overcome the shortcomings of a three-dimensional finite element model without deteriorating the accuracy of analysis results. Static and dynamic analysis results obtained using the proposed model are in excellent agreement with those obtained using three-dimensional finite element models in terms of displacements, periods, and mode shapes. Effects of floor diaphragm flexibility on seismic response of multistory building structures are investigated.

INTRODUCTION

The assumption of rigid floor diaphragm is valid in most cases of simplified analyses of building structures. However, there are situations where the floor diaphragms can not be considered as rigid. The in-plane floor flexibility is particulary significant for buildings with a high aspect ratio of floors, with stiff end walls and with plans in the shape of the letters L, T, V, etc. Thus, the flexibility of floors is significant in the analysis of this type of building structures.

Shepherd and Donald [5] studied the effect of floor flexibility in two-story buildings using a lumped-mass approach. They insisted that the neglect of in-plane floor flexibility did not change the dynamic properties significantly. Blume and Jhaveri [1] have analysed a single-story building for several values of the roof aspect ratio using a lumped-mass approach and have shown that the effect of floor flexibility could be significant for buildings with stiff end walls. Ostrom and Hurt [4] modelled the floors by beams

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and columns or walls by springs and the analysis of the resulting system was performed approximately using the Rayleigh-Ritz technique.

The objective of this study is to develop an efficient model for the analysis of building structures with flexible floor diaphragms and to investigate effects of flexibility of floor diaphragms on seismic response of multistory building structures.

SIMPLIFIED ANALYSIS MODEL

Analysis of multistory building structure with flexible floor diaphragms can be performed using a three-dimensional finite element model which provides very accurate response predictions. However the use of finite element models is not very efficient in terms of computation time and memory size required. An effort was made in this study to develop an efficient model with much less degrees of freedom without significant deterioration of accuracy in the analysis results. A multistory building structure shown in Fig. 1 is considered as an assemblage of components such as two-dimensional lateral force resisting systems and floor systems as illustrated in Fig. 2.

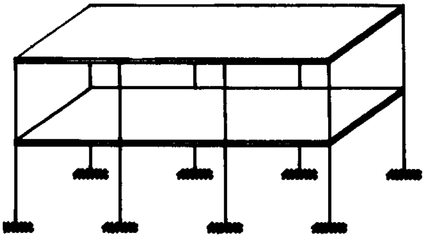


Fig 1. A multistory building structure

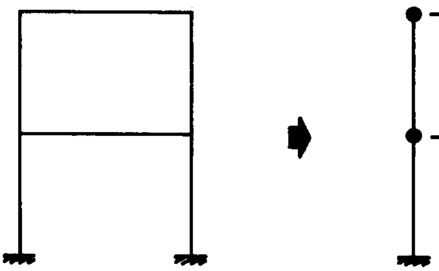


Fig 3. Reduction of a plan frame

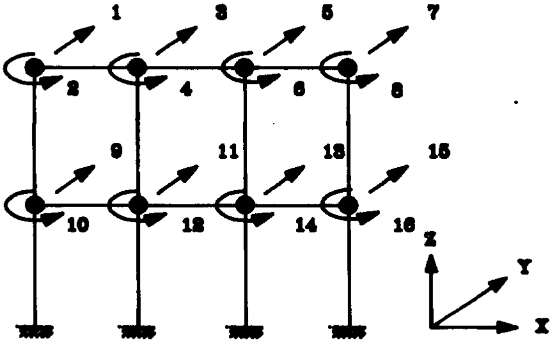


Fig 4. Assembled analysis model and degrees of freedom

A two-dimensional resisting system which can be a plane frame with or without stiffening elements such as shear walls or braces is reduced to a stick model with one degree of freedom per floor in horizontal direction as shown in Fig. 3. Degrees of freedom for vertical displacements and rotations are eliminated using the story-by-story static condensation procedure.

A finite element developed for analysis of frames with shear walls(W12 element) is used for a two-dimensional resisting system with shear walls [3] [6]. A floor system which interconnects

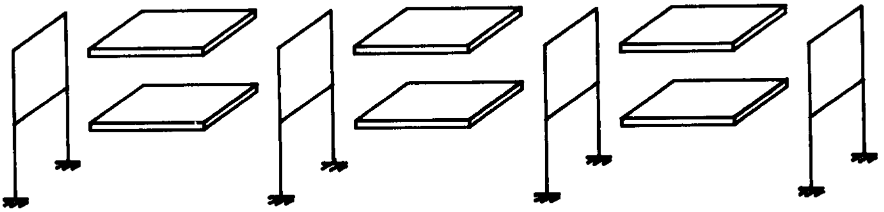


Fig 2. A multistory building structure decomposed to two-dimensional resisting systems and floor systems

two adjacent two-dimensional resisting systems at each floor level is modelled as a stiff beam with flexural and shear deformations [2]. Reduced stick models and stiff beams are assembled to obtain a simplified model for analysis of a multistory building structure with flexible floor diaphragms. The stiffness matrix of a simplified model is obtained by superposing condensed stiffness matrices of two-dimensional resisting systems and stiffness matrices of stiff beams. The assembled model and degrees of freedom are illustrates in Fig. 4. Lumped mass matrix is used for dynamic analysis of a simplified model.

PERFORMANCE OF THE PROPOSED MODEL

A two-story building structure shown in Fig. 1 is used as the prototype of example structures for assessment of the performance of the proposed model. The prototype is modified to obtain three A-type example structures as shown in Fig. 5 A1, A2, and A3 with different aspect ratio by varying the span in x-direction to 6m, 12m, and 18m respectively to assess the performance of the proposed model for different floor aspect ratio.

Shear walls are added at both ends of A-type example structures to obtain B-type example structures as shown in Fig. 6 B1, B2 and B3 for assessment of the performance of the proposed model with larger floor deformations.

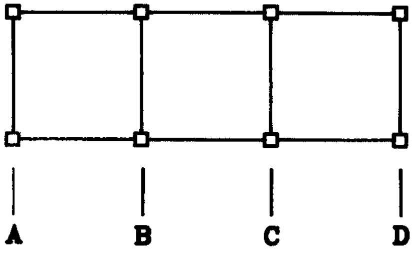


Fig 5. Plan of A-type structure

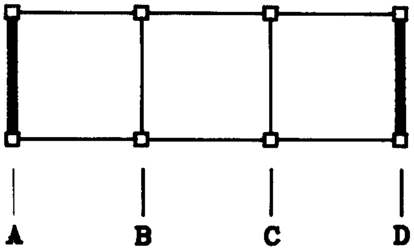


Fig 6. Plan of B-type structure

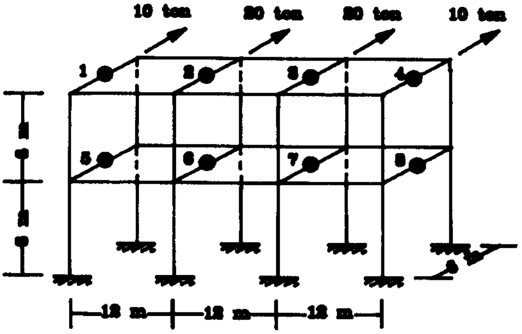


Fig 7. Loading system used for static analysis

Static and dynamic analyses are performed for six example structures using the proposed model and three-dimensional finite element models. A computer code FF3D was developed for analysis of the proposed model and the computer code SAP Ⅳ was employed for analyses of finite element models. Analysis results obtained using FF3D are in excellent agreement with those obtained using SAP Ⅳ in terms of displacements, periods, and mode shapes for all of six example structures. Floor displacements for example structures A2 and B2 due to the static loading system illustrated in Fig. 7 are shown in Figs. 8 and 9 respectively. When floor deformation is significantly large, such as in the case of B2, slight disagreement between floor displacements predicted by the proposed model and three-dimensional finite element models is observed. Natural periods of structures A2 and B2 are listed in Tables 1 and 2 for the first three modes. Corresponding mode shapes are shown in Figs. 10 and 11. Solid lines in Figs. 8, 9, 10 and 11 represent values from three--

dimensional finite element analysis while broken lines are used to plot those from the proposed model.

EFFECTS OF FLOOR FLEXIBILITY

Structures A2 and B2 used previously for assessment of the performance of the porposed model are modified to obtain structures F2 and W2 by increasing the number of spans from three to four. Structures F5, F10, W10 are obtained by increasing the number of stories of F2 and W2 structures from two to five or ten. Effects of floor diaphragm flexibility on seismic response of multistory building structures are investigated using the proposed model for these example structures.

(a) Static Analysis Results

Static lateral loads of UBC type are applied to six example structures. Floor flexibility effect are assessed in terms of floor deformation rate (D) defined as follows;

$$D = \frac{\delta_{max}-\delta_{min}}{\delta_R}$$

where δ_{max} and δ_{min} are maximum and minimum lateral displacements in a floor and δ_R is lateral floor displacement obtained assuming floors as rigid diaphragms. Floor deformation rates for six structures are listed in Table 3. Floor deformation rates are significantly larger in structures with stiff end walls such as W-type structures W2, W5 and W10. Effects of floor flexibility are reduced as the number of stories are increased and less significant in upper floors in a structure. Lateral displacement of six structures due to lateral loads of UBC type are shown in Figs 12 and 13.

(b) Dynamic Analysis Results

Effects of floor flexibility on seismic response of multistory building structures can be predicted

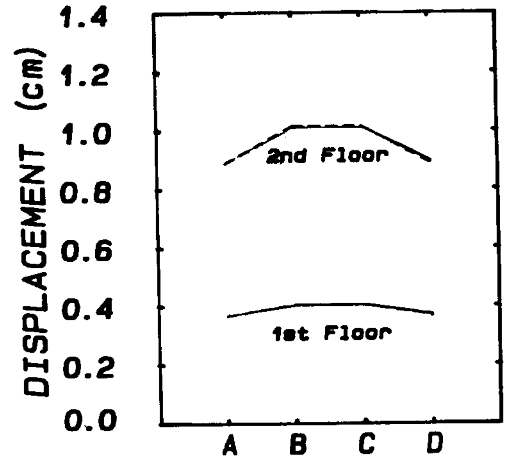


Fig 8. Lateral displacements of A2 structure due to static load

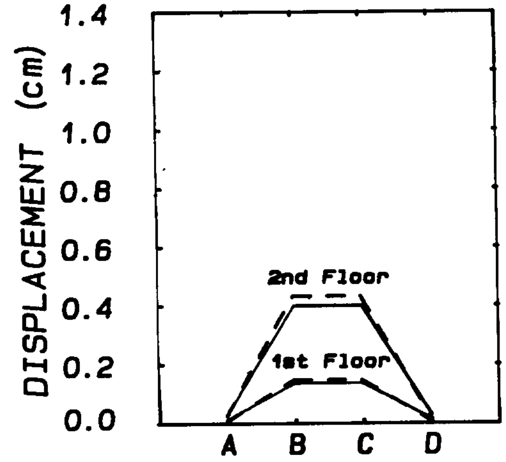


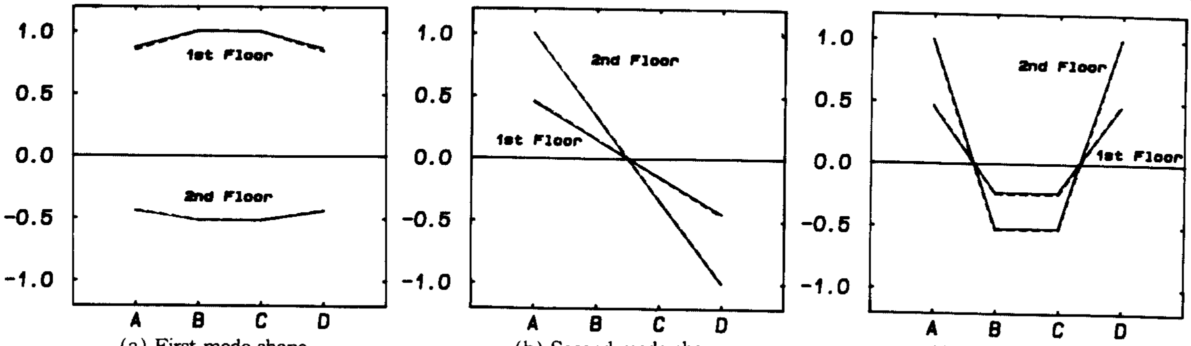
Fig 9. Lateral displacements of B2' structure due to static load

Table 1. Vibration period of A2 structure

Mode	Period(sec)	
	F F 3 D	F E M
1	0.2494	0.2492
2	0.2208	0.2233
3	0.1036	0.1082

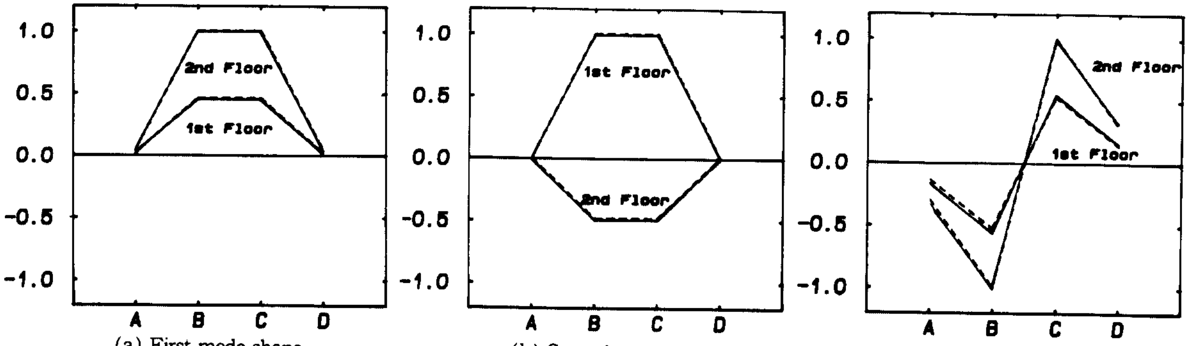
Table 2. Vibration period of B2 structure

Mode	Period(sec)	
	FF3 D	FEM
1	0.1588	0.1586
2	0.0735	0.0735
3	0.0552	0.0523



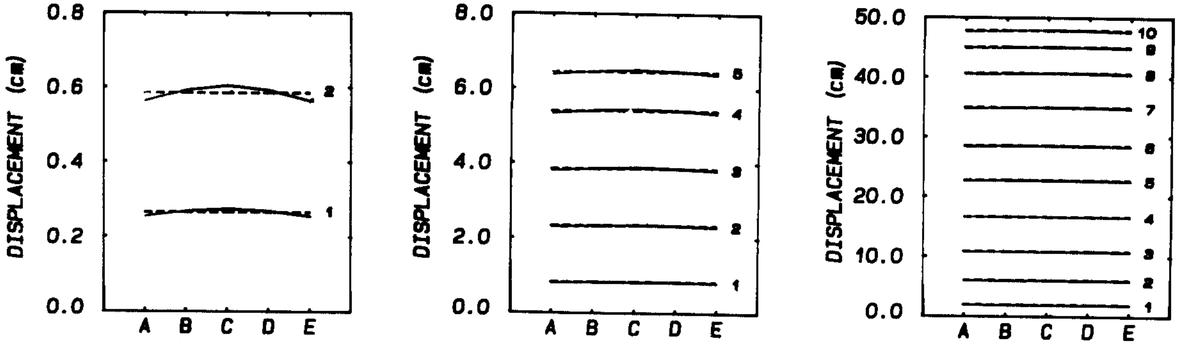
(a) First mode shape　(b) Second mode shape　(C) Third mode shape

Fig 10. Three mode shapes of A2 structure



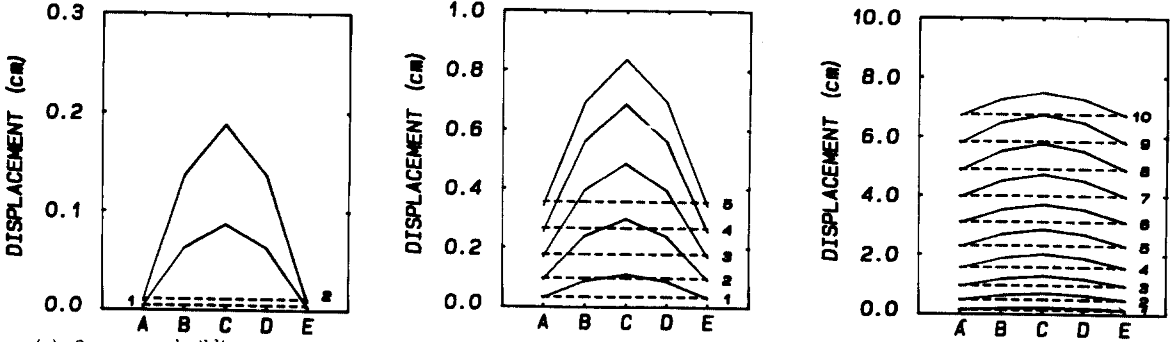
(a) First mode shape　(b) Second mode shape　(C) Third mode shape

Fig 11. Three mode shapes of B2 structure



(a) 2 - story building structure　(b) 5 - story building structure　(c) 10 - story building structure

Fig 12. Lateral displacements of F-type example structure due to UBC type loads



(a) 2 - story building structure　(b) 5 - story building structure　(c) 10 - story building structure

Fig 13. Lateral displacements of W-type example structure due to UBC type loads

Table 3. Floor deformation rates(D) for example structures

F－Type STRUCTURE			W-Type STRUCTURE		
	STORY	D		STORY	D
F2	2	0.0702	W2	2	15.2141
	1	0.0730		1	15.9885
F5	5	0.0170	W5	5	1.3903
	4	0.0166		4	1.6047
	3	0.0172		3	1.7577
	2	0.0185		2	2.0902
	1	0.0210		1	2.2894
F10	10	0.0047	W10	10	0.1149
	9	0.0045		9	0.1626
	8	0.0044		8	0.1819
	7	0.0045		7	0.1886
	6	0.0047		6	0.1912
	5	0.0049		5	0.2420
	4	0.0054		4	0.2884
	3	0.0060		3	0.3395
	2	0.0068		2	0.4680
	1	0.0079		1	0.5296

Table 4. Vibration frequencies for example structures

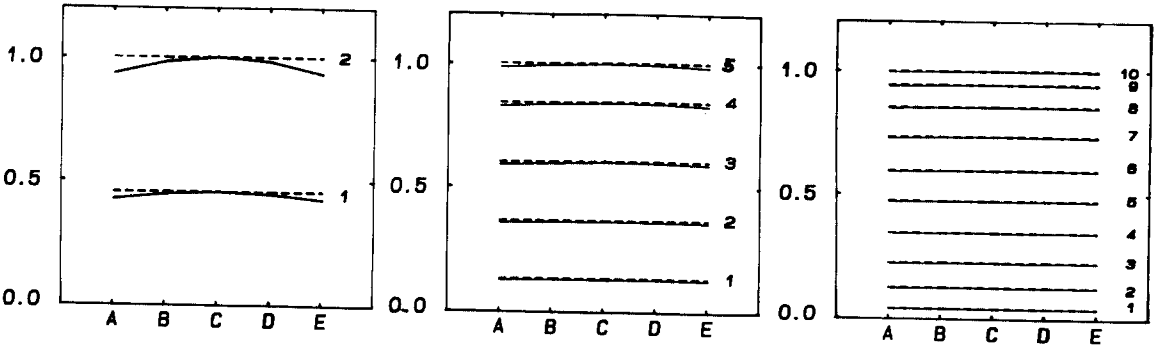
STRUCTURE	MODE	FREQUENCIES (cycle / sec)	
		FLEXIBLE FLOOR	RIGID FLOOR
F2	1	2.289	2.298
	2	2.597	2.599
	3	7.788	8.054
W2	1	4.447	15.807
	2	8.319	24.152
	3	14.310	50.315
F5	1	1.069	1.070
	2	1.206	1.206
	3	3.226	3.248
W5	1	3.265	4.567
	2	4.869	6.840
	3	6.642	18.744
F10	1	0.551	0.551
	2	0.620	0.620
	3	1.559	1.562
W10	1	1.443	1.498
	2	2.173	2.178
	3	3.788	6.972

by examining effects on changes in frequencies and mode shapes. Frequencies for first three modes of six structures F2, F5, F10, W2, W5 and W10 obtained assuming floor diaphragm as flexible or rigid are listed in Table 4. Frequencies of W－type structures are significantly reduced when floor flexibility is considered while those of F－type structures are less sensitive to floor flexibility. Frequency reduction is considered to be caused by the contribution of floor flexibility to the stiffness of structures. As the number of stories, increases frequency reduction is less significant whether floor diaphragms are flexible or rigid. First mode shapes of six structures are illustrated in Figs. 14 and 15 as top view of each floor. Significant floor flexibility effects are observed in W－type structures from the difference in mode shape with flexible floors represented by solid lines and that with rigid floors represented by broken lines. Difference in mode shapes due to floor flexibility increases is structures with less number of stories.

CONCLUSION

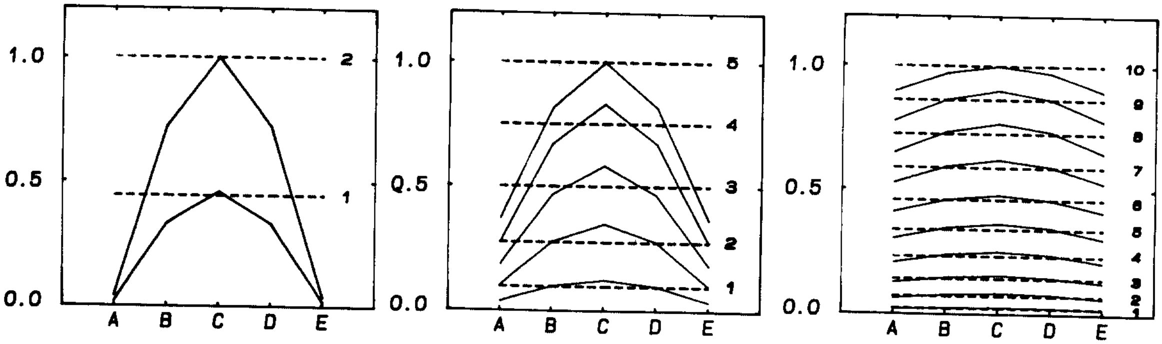
Following conclusions are drawn from comparison of analysis results obtained using the proposed model and / or finite element models for example structures.

1. The simplified model proposed in this study can be used as an efficient tool for the approximate analysis of multistory building structures with flexible floor diaphragms.
2. The use of the proposed model is so efficient in terms of computational time and memory size that three－dimensional analysis of multistory buildings can be performed even on a personal computer.
3. The effects of floor diaphragm flexibility on the response of a structure decreases as the number of stories increases.
4. Floor flexibility is less significant in structures consisting of similar lateral force resisting systems (F－type structures).



(a) 2-story building structure (b) 5-story building structure (C) 10-story building structure

Fig 14. First mode shape of F-type example structures



(a) 2-story building structure (b) 5-story building structure (C) 10-story building structure

Fig 15. First mode shape of W-type example structures

5. Floor flexibility effects on the response of a structure are reduced in upper stories.
6. Frequency reduction is induced by floor flexibility in structures with different lateral force resisting systems such as frames with stiff end walls (W-type structure).

REFERENCES

1. Blume, J.A. and Jhaveri, D., Time-History Response of Buildings with unusual Configurations, Proc, 4th word conf. earthquake eng., Santiago, Chile, 1969.
2. Cowper. G.R., The Shear Coefficient in Timoshenko's Beam Theory, Journal of Applied Mechanics, pp. 335-34, July, 1966.
3. Lee, Dong-Guen, An Efficient Element for Analysis of Frames with Shear Walls, Proc, ICES88-Atlanta, April, 1988.
4. Ostrom D.K. and Hart, G.C., In-plane Slab Deformation in Multistory Structures, Earthquake and wind Engineering Report UCLAENG-7444(EWE 74-02), University of California, Los Angels, 1974.
5. Shepherd, R. and Donald, R.A.H., The Influence of In-Plane Floor Flexibility on the Normal Mode Properties of Building, Journal of Sound and Vibration. Vol.5, No.1, pp. 29-36, 1967.
6. Weaver, W.Jr., Lee Dong-Guen and George Delbalian, Finite Elements for Shear-Walls in Multistory Frames, Journal of the Structural Division., ASCE, Vol.107, No. ST7, Proc. Technical Note, July, 1981.

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