THE ANALYSIS OF EARTHQUAKE RESISTANCE IN HIGH BUILDINGS

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ABSTRACT

Based on the model tests, the dynamic tests of full-scale structures and theoretical analysis, a practical method to calculate the vibration of tall shear wall structures is presented. The shear wall structure is idealized as a variable thickness cantilever beam with bending and shear deformations. By means of the finite element method, the free vibration of tall shear wall structures is calculated in this paper. According to the theory of the response spectrum the seismic loads are calculated as well.

INTRODUCTION

The reinforced concrete shear wall has been widely used as a main structural member in high buildings, because there are many excellent features: it is easy in construction particularly for mechanization of construction, it needs less steel and has bigger lateral stiffness. Owing to its complex space system the precise analysis is difficult. The experiments and theoretical researches of shear wall were presented by R. Rosman and A. Coull (Ref.1,2). The shear wall also was analysed by A.C.Heidebrecht with V.Z.Vlasov's theory of thin-walled elastic beams (Ref.3). The two-dimensional finite element method was used for dynamic analysis of shear wall by T.Harrison (Ref.4). It is difficult to use the exact method in design owing to the boundary conditions. Hence, a reasonably simplified method is necessary.

Based on the model tests, the dynamic tests of full-scale structures and theoretical analysis, we present a practical method to analyse the vibration of tall shear wall structures.

According to the theory of the response spectrum, we have calculated the seismic loads of two buildings. The effect of the number of mode shapes on the bending moments and shears has been analysed.

FREE VIBRATION OF SHEAR WALL

There are many holes in the transverse section of tall shear wall buildings. Usually the width of corridor is about 1.5 - 2 m, the

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height of the connecting beam 0.4-0.8 m, and the area ratio of the hole to the shear wall about 10-15%. For simplicity, it is assumed that two pieces of shear wall can be analysed as a whole section. In order to prove that the assumption is correct, a model test is proceeded. The perspex model prepared for a 18-story structure consists of three shear walls (Fig, 1). The model dimension is about 1/40 that of Guangzhou Hotel. Some gages are put on the wall of the 5th floor to measure its strain. The strain curve of the model is shown in Fig.2. The curve is antisymmetric and the zero point of the strain is near the edge of corridor. So the effect of corridor is negligible and we can regard two pieces of shear wall as a whole section.

According to the model tests and the dynamic tests of the full-scale structures, the mode shape of shear wall structures is like that obtained from calculation in consideration of the bending effect and the shear effect, but the major effect is the bending deformation (Fig.3). For a 20-30 story building, the height-width ratio is about 4→5. The effect of the shear deformation must be considered for the higher mode shapes.

As mentioned above, the shear wall structure is idealized as a variable thickness cantilever beam with bending and shear deformations when we calculate the free vibration of shear wall structure in the transverse direction (Ref.5). The finite element method is used to calculate the free vibration of shear wall structure (Ref.6).

The equation of motion for the elastic system without damping is

$$\underline{M}\,\ddot{\underline{U}} + \underline{K}\,\underline{U} = 0 \qquad (1)$$

where

$\underline{M}$ the mass matrix of the structure

$\underline{K}$ the stiffness matrix of the structure

$\ddot{\underline{U}}$ the general acceleration vector of the nodes

$\underline{U}$ the general displacement vector of the nodes

From Equ. 1 we obtain eigenvalue equation

$$(\underline{K} - \omega^2 \underline{M})\ \underline{U}o = 0 \qquad (2)$$

where

ω the natural frequency of the structure

$\underline{U}o$ the mode shape of the structure

The stiffness matrix for a prismatic bar with shear deformation is

$$K = \frac{EI}{(1+C)L^3} \begin{bmatrix} 12 & -6L & -12 & -6L \\ & (4+C)L^2 & 6L & (2-C)L^2 \\ \text{SYM.} & & 12 & 6L \\ & & & (4+C)L^2 \end{bmatrix} \qquad (3)$$

The mass matrix for a prismatic bar is

$$\underline{m} = \frac{\bar{m}L}{420} \begin{bmatrix} 156 & -22L & 54 & 13L \\ & 4L^2 & -13L & -3L^2 \\ \text{SYML} & & 156 & 22L \\ & & & 4L^2 \end{bmatrix} \qquad (4)$$

where

$$C = \frac{12EI}{GFL^2}$$

E modulus of elasticity,

G shear modulus,

I bending moment of inertia,

L length,

F effective shear area,

$\bar{m}$ mass per, unit length.

In order to demonstrate the accuracy of the computation method mentioned above, the free vibration of the model and two tall buildings - Guangzhou Hotel and Baiyun Hotel has been analysed.

The main building of Guangzhou Hotel has 24 stories, 76.17m high. On its top there is an attic which has 3 stories. The main building of Baiyun Hotel has 29 stories, 103.5m high. It has a 4 story attic onits top. These two buildings are constructed with reinforced concrete shear walls. The plans of Guangzhou Hotel and Baiyun Hotel are shown in Fig. 4a and Fig. 4b respectively.

The results of natural periods of dynamic tests and our computations are listed in Table 1. From Table 1. we can see that the periods in the two results are nearly the same with each other.

The measured and calculated mode shapes of Guangzhou Hotel are shown in Fig.5. It can be seen that the calculated mode shapes are nearly the same as those obtained in the tests.

In order to compare our method with the exact method, we calculated the model of T. Harrison with our method. The natural frequencies are shown in Fig.6. It is clear that the natural frequencies which are calculated by two methods are very nearly the same as those obtained in the tests. Since we use one dimensional finite element method, our method needs small memory space and short computing time.

Table 1. Natural periods of Several buildings

Building	Method	Periods (sec)		
		T1	T2	T3
Guangzhou Hotel	Measured	0.960	0.220	0.110
	Calculated	0.962	0.220	0.103
Baiyun Hotel	Measured	1.440	0.350	0.160
	Calculated	1.662	0.345	0.153
Model	Measured	0.025	0.006	0.003
	Calculated	0.024	0.006	0.003

SEISMIC LOADS AND INTERNAL FORCES

According to the theory of response spectrum, the horizontal seismic load is

$$P_{ji} = C\,\alpha_j\,\gamma_j\,X_{ji}W_i$$

where

C: structural-related coefficient,

α_j: seismic-related coefficient of jth mode shape,

X_{ji} relative horizontal displacement at ith point of jth mode shape,

W_i: weight concentrated at ith point.

$$\gamma_j = \sum_{i=1}^{n} X_{ji} W_i \Big/ \sum_{i=1}^{n} X_{ji}^2 W_i$$

The structural internal force which is caused by horizontal seismic load is

$$S = \sqrt{\sum_j S_j^2}$$

which

S_j: structural in ternal force which is caused by horizontal seismic load, corresponding to jth mode shape.

The seismic loads and the internal forces of Guangzhou Hotel and Baiyun Hotel have been calculated, and the results are listed in Table 2. The base moments and shears computed with three mode shapes are nearly the same as those with five mode shapes. The maximum difference is only 4%.

The bending moment and shear of the shear wall in Guangzhou Hotel are shown in Fig.7.

Table 2. Internal forces at base of buildings

Number of mode shape	Guangzhou Hotel				Baiyun Hotel			
	$M_{(T-M)}$	%	$Q_{(T)}$	%	$M_{(T-M)}$	%	$Q_{(T)}$	%
1	31736	86.5	535.35	77.9	70234	97.9	913.82	63.8
2	31973	87.2	562.01	81.8	71027	99.0	1316.42	92.0
3	35183	95.9	664.14	96.7	71661	99.9	1416.91	99.0
4	35409	96.5	664.62	96.8	716 70	99.9	1429.27	99.8
5	36656	100	686.57	100	716 73	100	1430.71	100

CONCLUSION

1. When the area ratio of the hole to the shear wall is about 10-15% the two pieces of the couple shear wall can be analysed as a single solid section.
2. The bending and shear deformations must be considered when the vibration is analysed.
3. For 20-30 story building we only need to consider three mode shapes if the seismic load is calculated.

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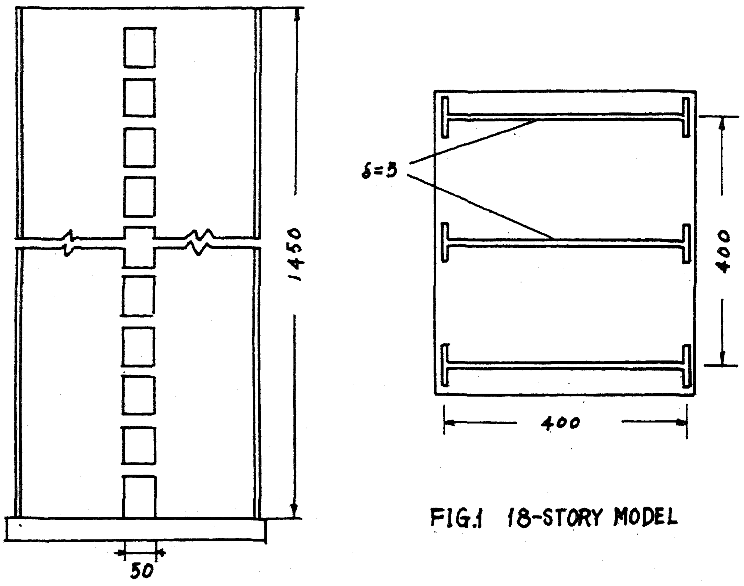

FIG.1 18-STORY MODEL

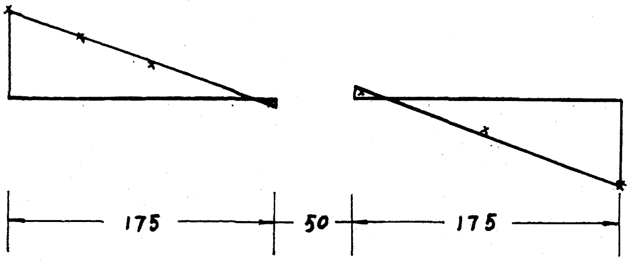

FIG.2 STRAIN DISTRIBUTION OF THE MODEL

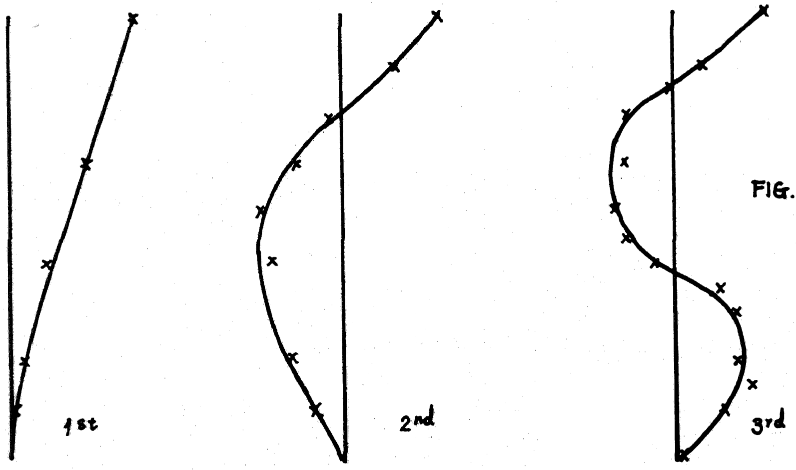

FIG.3 MODE SHAPES OF THE MODEL

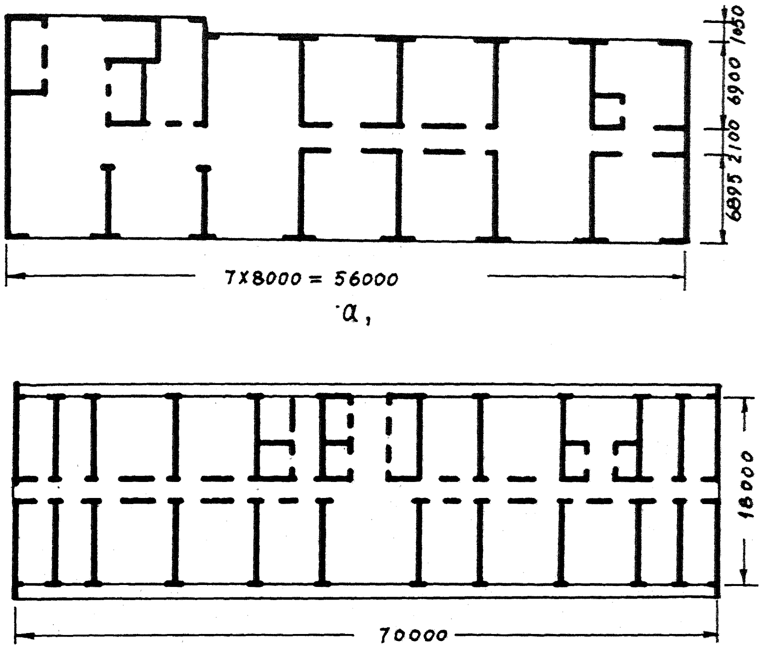

FIG.4

a. TIPICAL PLAN OF GUANGZHOU HOTEL
b. TIPICAL PLAN OF BAIYUN HOTEL

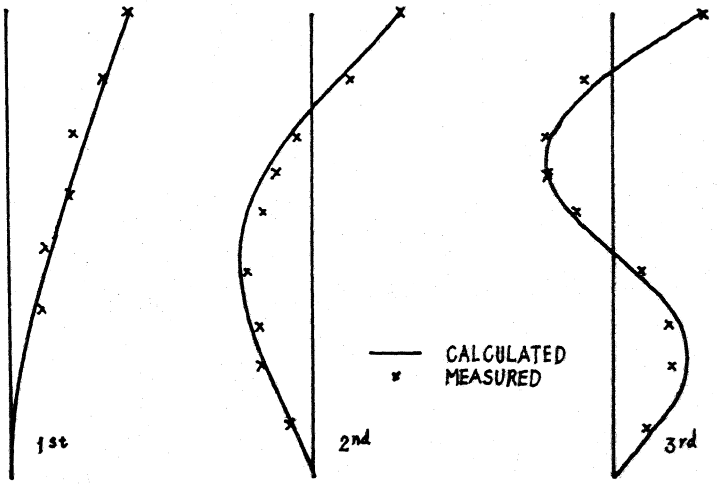

FIG.5 MODE SHAPES OF GUANGZHOU HOTEL

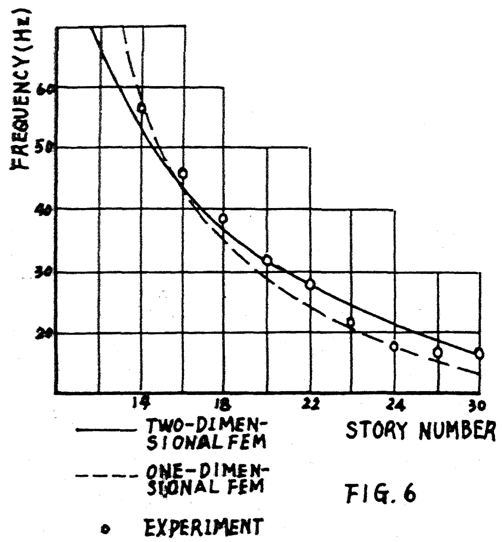

FIG. 6

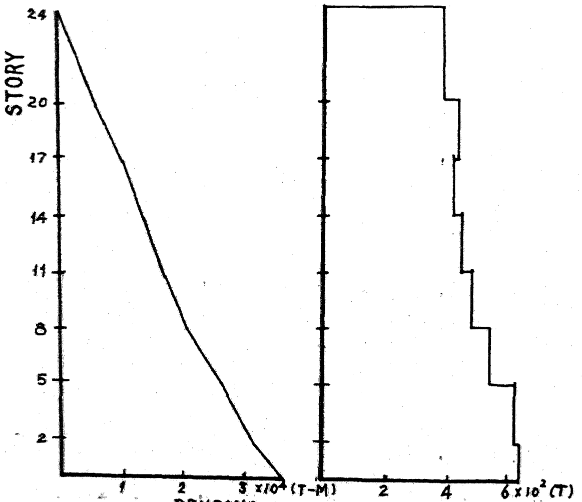

FIG.7 BENDING MOMENT AND SHEAR IN SHEAR WALL