VIBRATION TEST AND SIMULATION ANALYSIS OF HIGHRISE BUILDING WITH V-SHAPED FRAMING PLAN

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SUMMARY

This paper presents a forced vibration test and simulation analysis of a highrise building having a unique framing plan. The response behaviors excited by a vibrator were simulated using a three-dimensional frame analysis computer program. In the simulation analysis, the rigidities of non-structural walls such as steel fiber reinforced concrete wall, glass wool gypsum board, exterior aluminium curtain wall and so on, are taken into account in addition to the structural frame and the shear walls. It results that there was a good approximation between the resonance periods and mode shapes by the computation and those by the observation.

INTRODUCTION

This 40 story highrise hotel has a notched V-shape floor plan as shown in Fig.1. In the earthquake-resistant design of the building (ref.1), a great effort was made to grasp accurately the complex stresses and deformations due to the three-dimensional effects, by using the three-dimensional frame analysis computer program "FAPP IV", which had been previously developed by the authors. Especially, in the case that the earthquake acts in the X direction, the torsional deformations are inevitable. Therefore, the framing system and the arrangement of the slitted shear walls (ref.2) were determined by a feed-back dynamic design method (ref.3), most suitable to these characteristics.

A forced vibration test was conducted in April 1982 prior to the completion of construction, in order to actually grasp the three-dimensional behaviors which had been forecasted, and the test results were simulated by computer calculation.

OUTLINE OF BUILDING STRUCTURE

The wide spread lower part of this building, below the 5th floor, is composed of reinforced concrete structure, steel composite reinforced concrete structure and thick shear walls, so that the rigidity of this part is much higher than that of the highrise tower portion.

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The typical floor of the tower is as shown in Fig.1 and each story height is 3.2 meters. The framing system consists of rectangular steel frame with 4m x 4m grid plan as a unit. The columns are composed of 400mm series H-shaped steel and the girders are 500mm series H-shaped steel. The slitted shear walls of reinforced concrete are distributed to the center core part and the two wing parts.

FORCED VIBRATION TEST

Testing Method

As shown in Fig.1 and Fig.2, a vibrator with maximum exciting force of 3 tons was installed on the 39th floor to cause the building to vibrate in stationary sinusoidal wave. The structure was excited in the X and Y direction independently. On the roof floor measuring apparatuses were set at three points A, B and C, and on the B2, 3rd, 10th, 18th, 25th and 39th floor the apparatuses were placed at two points A and B, where A was in the center core and B and C were in the wing sides (Fig.1). The measured response data were processed by MIK system (ref.4) to which the correlation technique was applied, to obtain the resonance periods and mode shapes.

Test Results

The resonance periods and damping factors, which were derived from the resonance curves, are shown in the upper row in Table 1. The resonance mode shapes are shown in Fig.4 ∿ Fig.7. From the test results, the following properties are clarified.

(1) Each floor slab is rigid in the horizontal plane.

(2) For the X direction excitation, the combined modes of sway X and torsional rotation Φ are observed. The fundamental resonance period is 3.28sec with the rotation center in the center core. The second resonance period is 2.17sec with the rotation center in the wing side.

(3) For the Y direction excitation, the pure Y sway modes only are observed. The fundamental resonance period is 2.82sec.

(4) The resonance periods obtained from the vibration test are 65 ∿ 80% of the natural periods calculated in the analysis of the earthquake-resistant design.

(5) Each modal damping factor of about 1% is obtained from the resonance curves.

SIMULATION ANALYSIS

By substituting the structure for an analytical model as in the same way as in the design analysis, the three-dimensional behaviors observed in the vibration test were simulated using the aforementioned computer program "FAPP Ⅳ".

Analytical Model and Equation of Motion

As the lower part of the building is very rigid as mentioned above, it is assumed that the structure is fixed at the 5th floor level, and the 36-story tower portion is expressed as the analytical model in which the masses are concentrated at the floor levels.

Assuming that each floor slab is rigid in the horizontal plane, the equation of motion as for the displacements u, v and the rotation angle ϕ at the center of gravity becomes as the following.

$$\begin{pmatrix} M & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & J \end{pmatrix} \begin{pmatrix} \ddot{u} \\ \ddot{v} \\ \ddot{\phi} \end{pmatrix} + \begin{pmatrix} C_{XX} & 0 & C_{X\Phi} \\ 0 & C_{YY} & 0 \\ C_{\Phi X} & 0 & C_{\Phi\Phi} \end{pmatrix} \begin{pmatrix} \dot{u} \\ \dot{v} \\ \dot{\phi} \end{pmatrix} + \begin{pmatrix} K_{XX} & 0 & K_{X\Phi} \\ 0 & K_{YY} & 0 \\ K_{\Phi X} & 0 & K_{\Phi\Phi} \end{pmatrix} \begin{pmatrix} u \\ v \\ \phi \end{pmatrix} = m_0 r \omega^2 \begin{pmatrix} P_X \\ P_Y \\ P_\Phi \end{pmatrix} e^{i\omega t}$$

where M and J are mass matrix and rotational inertia matrix, C is damping matrix, K is stiffness matrix, $m_0 r$ is unbalanced moment of vibrator and (P_X, P_Y, P_Φ) is a vector that indicates the excitation direction.

Mass and Rotational Inertia

The masses are calculated based on the progress condition of construction at the time of the vibration test. The center of gravity is assumed to be at the center of the given floor plan. The rotational inertia is calculated from the polar moment of inertia about the center of gravity. The total mass of the 36-story tower portion under the vibration test, was about 29,000 tons and corresponds to 90% of the actual mass after the completion.

Damping

Assuming that each modal damping factor is 1% from the test results, the equivalent damping matrix can be calculated.

Stiffness of Structure

In this hotel, it is noted that the non-structural walls such as steel fiber reinforced concrete wall, glass wool gypsum board, exterior aluminium curtain wall and so on (Fig.3) are sealed carefully at the floor slabs, at the columns and at the girders for the purpose of sound proofing. And the rigidities of these elements are considered to have an effect of increasing the rigidity of the entire structure, under slight tremor condition as produced by the vibration test.

In this case, these non-structural elements are taken into account as shear elements in "FAPP Ⅳ" , in addition to the structural frame and the slitted shear walls which are considered as low stress level. In evaluating these additional rigidities, the experimental results against the lateral forces are first referred to, and after several trials of eigenvalue analyses of the structure the final evaluation is determined as shown in Table 2.

It results that the rigidities of the non-structural walls are about 20% of the total rigidities of the building in both X and Y direction.

Comparison between Computed and Tested Results

The resonance periods obtained by simulation analysis are shown in Table 1 comparing with the test results. And the resonance mode shapes are also shown in Fig.4 ∿ Fig.7.

It is obvious from the comparison that the analytical results are sufficiently approximated to the test results, except that a slight difference can be seen in the second resonance in the X direction.

CONCLUSION

The three-dimensional response under vibration test can be well simulated by the same modelling and the same analytical method as adopted in the design analysis, incorporating the rigidities of non-structural elements. The rigidities of these elements are about 20% of the total rigidity of the building in the simulation analysis.

The non-structural elements are considered to have no effect of additional rigidity against a severe earthquake, which is expected to be clarified through the earthquake observations and researches after this.

REFERENCES

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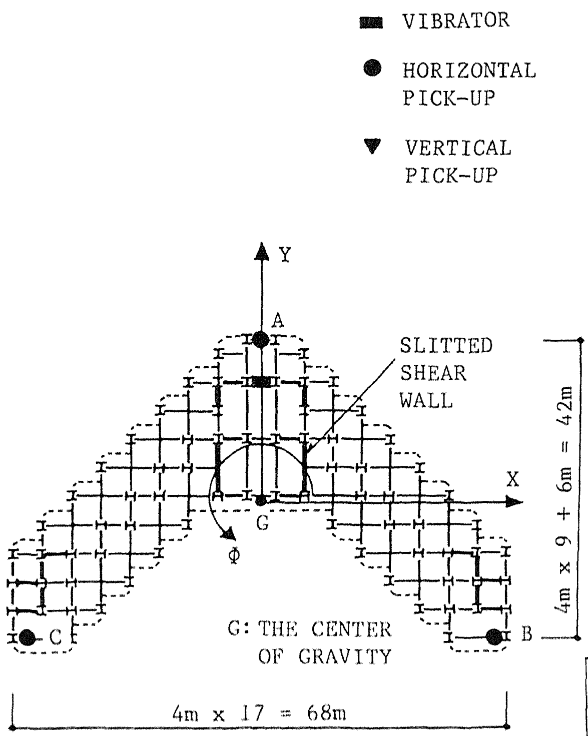

Fig.1 TYPICAL FLOOR PLAN

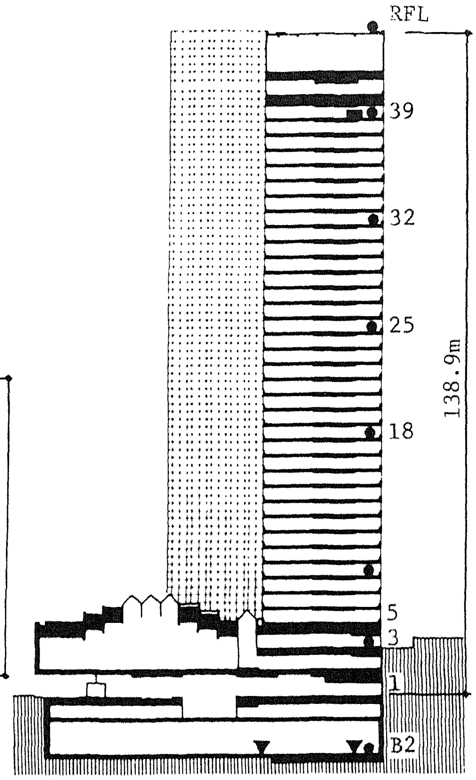

Fig.2 Y-DIRECTION SECTION

TABLE 1 RESONANCE PERIOD AND DAMPING FACTOR

OBTAINED BY	ITEM \ MODE \ DIRECTION	X 1st	X 2nd	X 3rd	X 4th	Y 1st	Y 2nd
VIBRATION TEST	RESONANCE PERIOD (sec)	3.28	2.17	0.91	0.72	2.82	0.83
	DAMPING FACTOR (%)	1.1	1.2	1.0	1.2	1.1	1.2
SIMULATION	RESONANCE PERIOD (sec)	3.24	2.38	0.98	0.74	2.80	0.83
DESIGN	NATURAL PERIOD (sec)	4.10	3.38	1.34	1.09	3.84	1.15
PREDOMINANT COMPONENT		COMBINED SWAY X and ROTATION Φ				SWAY Y ONLY	

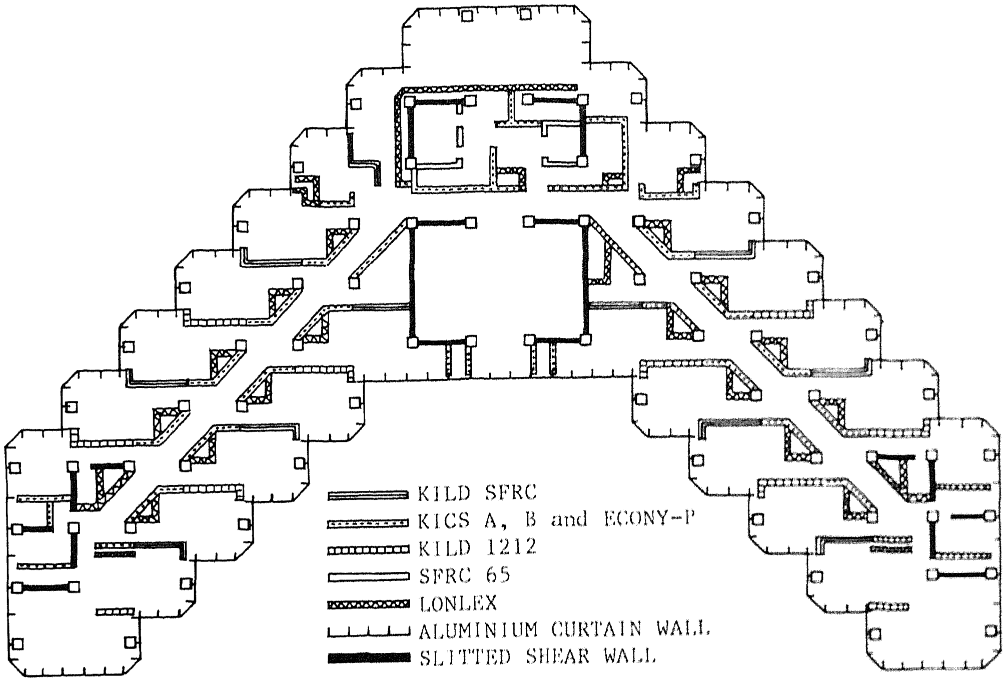

Fig.3 ARRANGEMENT OF NON-STRUCTURAL WALLS IN TYPICAL FLOOR

TABLE 2 ASSUMED SHEAR RIGIDITIES OF NON-STRUCTURAL WALLS

MEMBER		RIGIDITY (10^3t/rad·m)	TOTAL RIGIDITY (10^3t/rad)		REMARKS
			X-DIREC.	Y-DIREC.	
PARTITION WALL	KILD SFRC	0.2	8	2	GYPSUM PLASTER BOARD and STEEL FIBER REINFORCED CONCRETE
	KICS A, B and ECONY-P	0.2	24	15	ROCK WOOL MORTAR and VERMICULITE PLASTER
	KILD 1212	0.2	7	1	GYPSUM PLASTER BOARD
	SFRC 65	39.0	468	113	STEEL FIBER REINFORCED CONCRETE
	LONLEX	1.2	97	47	GLASS WOOL GYPSUM BOARD
ALUMINIUM CURTAIN WALL		0.3	42	40	

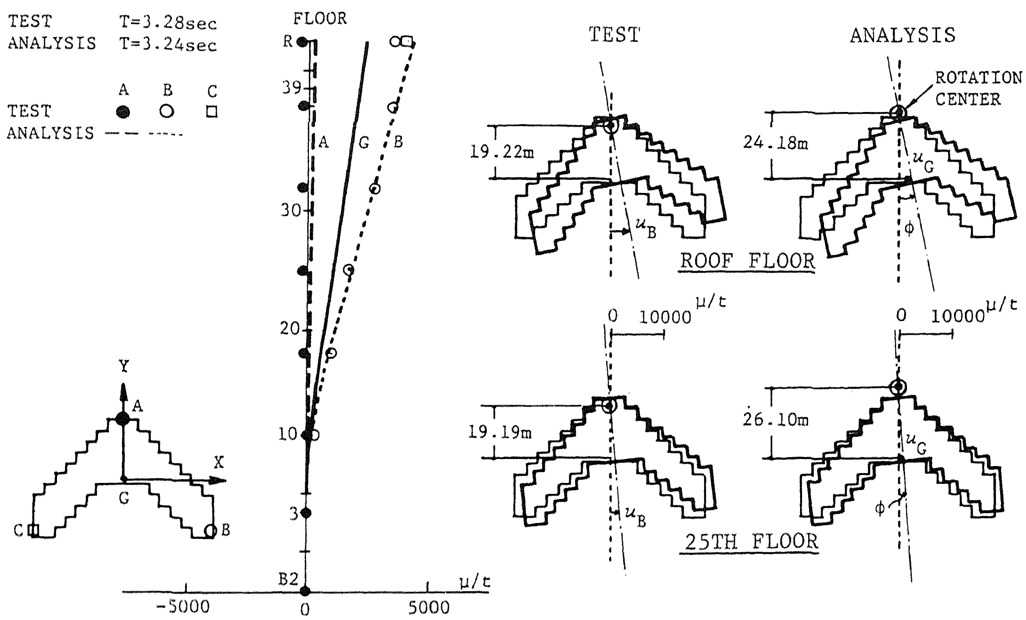

Fig.4 COMPARISON BETWEEN TESTED AND ANALYZED FUNDAMENTAL RESONANCE MODE IN X DIRECTION

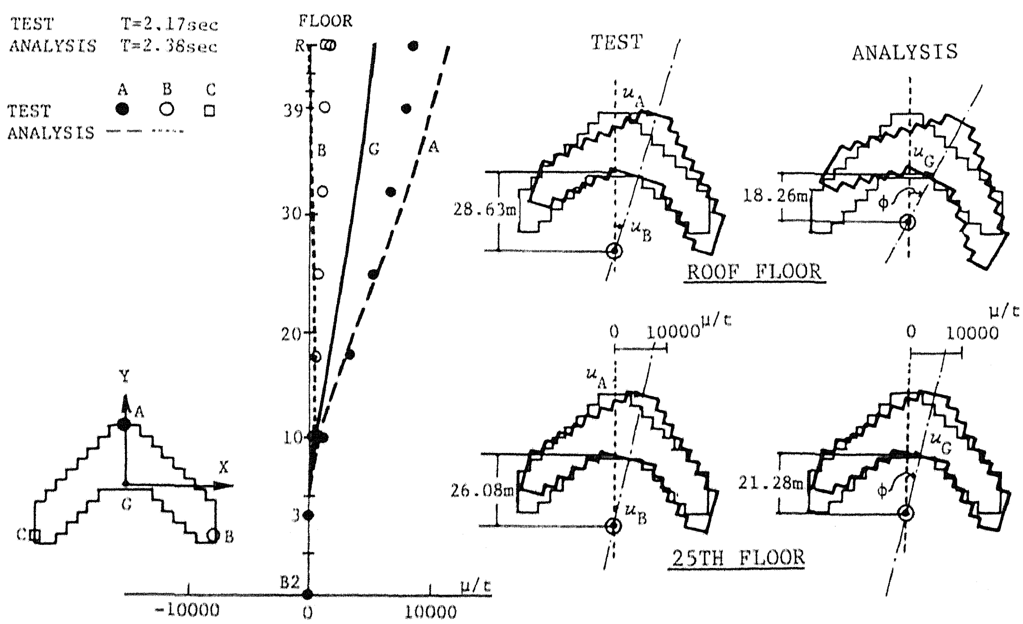

Fig.5 COMPARISON BETWEEN TESTED AND ANALYZED SECOND RESONANCE MODE IN X DIRECTION

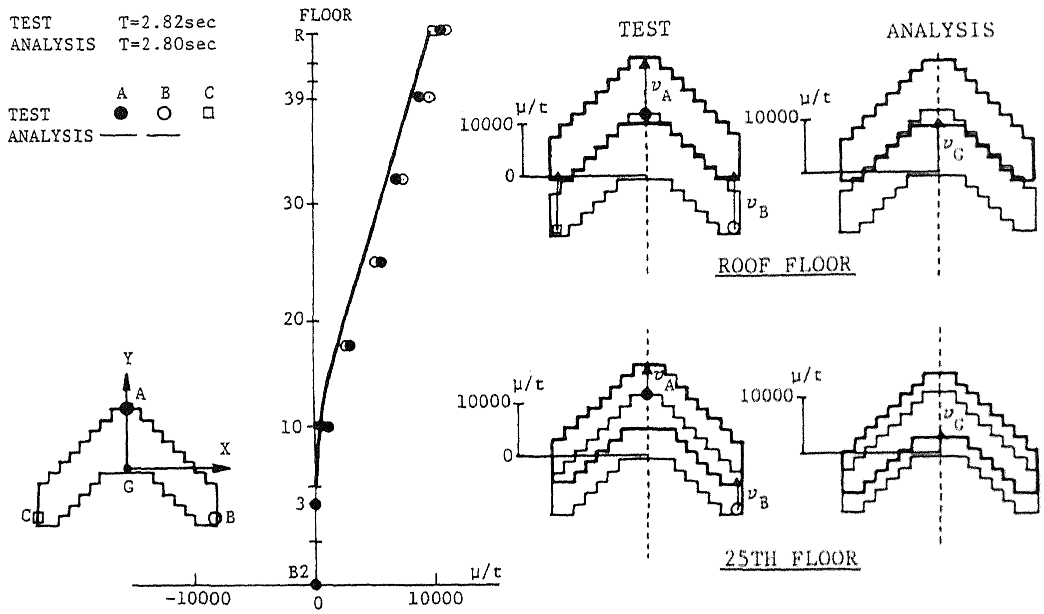

Fig.6 COMPARISON BETWEEN TESTED AND ANALYZED FUNDAMENTAL RESONANCE MODE IN Y DIRECTION

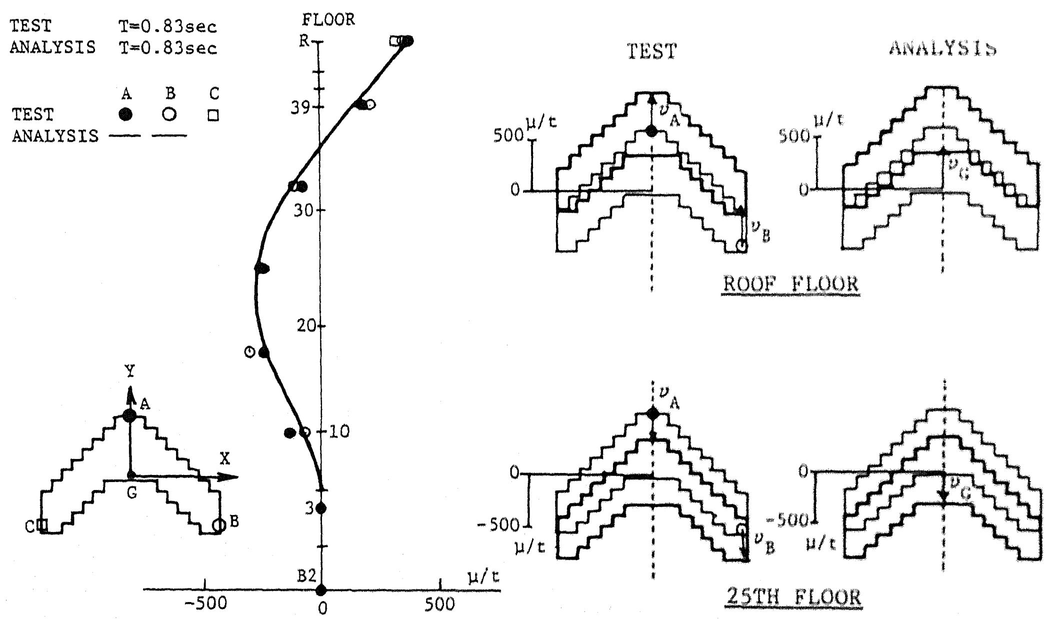

Fig.7 COMPARISON BETWEEN TESTED AND ANALYZED SECOND RESONANCE MODE IN Y DIRECTION