NATURAL PERIODS OF A TALL SHEAR WALL BUILDING

by

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SYNOPSIS

The natural periods of translational vibration of a tall reinforced concrete shear wall building were measured experimentally and computed analytically. Good agreement was obtained for fundamental period values. The critical damping ratios for low amplitudes of motion were also obtained experimentally.

INTRODUCTION

A large number of reinforced concrete buildings utilizing shear walls to resist lateral loads have been constructed in the city of Honolulu within the past decade. A study has been underway at the University of Hawaii to measure the natural periods and other vibrational properties of these structures. The measured periods are then compared with periods computed from mathematical models of these buildings, to determine the validity of the assumptions under which these models are formulated. This paper summarizes the results of an investigation of one of these buildings. This particular building was chosen because of its height and its relative symmetry of cross section.

BUILDING DETAILS

The building investigated, shown in Figure 1, has 37 stories and rises to a total height of 327 feet. It is supported on a slab footing laid on a basalt rock foundation. The floor to ceiling height of the first floor is 12 feet, and the height of all subsequent floors is 8 feet. All floor slabs are 6 inches thick. The building is 75 feet square in cross section. Rigidity in the North-South direction is furnished by five pairs of shear walls, two pairs of which are coupled together with two pairs of smaller shear walls by connecting beams. In the East-West direction, lateral stiffness is provided primarily by three pairs of shear walls rigidly coupled by stiff connecting beams. A typical cross section is shown in Figure 2, with the connecting beams indicated by dotted lines.

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Two stairwells are located at opposite ends of the building in the East-West direction, and an elevator shaft is located slightly off the center of the cross section. It can be seen that the building is almost symmetrical in plan.

EXPERIMENTAL MEASUREMENTS

In order to measure the motion of the building, two horizontal component Electrotech Model EV-17-H geophones, with calibrated natural periods of 1.00 second, were connected to Electrotech SPA-1-3 short period amplifiers. The damping factor of the geophones was 0.6. The amplifiers had a built in low pass filter system with settings possible at 5,7,10,13,17,23, and 30 Hertz. The output from the amplifiers was recorder on a two channel, hot pen Model 321 Sanborn Chart Recorder.

When recording the fundamental translational modes of vibration, the filter was set at 5 Hertz and very low gain was used. For the higher modes, the filter was set at 10, 13, and 17 Hertz. Three periods were identified in the North-South direction, but only two periods were clearly discernible in the East-West direction.

Readings were taken at the 37th(top) floor, and also on the 19th floor. On each of these floors, two horizontal geophones were placed in the hallway near the center of the cross section of the building, in perpendicular directions. One measured motion in the North-South direction, while the other measured motion in the East-West direction.

Both ambient and man-excited vibrations were recorded. Ambient records were taken under both low and moderate wind conditions. Figure 3 shows a portion of a record taken under ambient conditions. In addition, when the wind velocity was very small, it was possible to man-excite the structure into vibrating in two almost pure modes in both directions. In this way it was possible to estimate the critical damping ratios for these modes by the logarithmic damping method. Portions of such records are shown in Figure 4 for the North-South direction, and Figure 5 for the East-West direction. An interesting phenomenon that was noticed during these measurements was that the second mode of vibration in the North-South direction tended to be strongly excited whenever an elevator was set in motion.

MATHEMATICAL MODEL

Because the shear walls in both directions were rigidly coupled by stiff connecting beams, the entire building was modeled as a cantilever beam. The masses were lumped at each floor level. For purposes of estimating the stiffness properties of this beam model, it was assumed that each element was capable of being deformed in both flexure and in shear. An equivalent moment of inertia and an equivalent transverse shear area, corrected by the shape factor, was computed for each beam segment connecting consecutive masses from detail drawings furnished by the consulting structural engineer. The modulus of elasticity E was estimated from the recommended ACI formula $E = 33\,w^{1.5}\sqrt{f'_c}$, where w is the weight density and f'_c is the concrete compressive strength. The shear modulus G was assumed given by $G = 0.44\ E$. The mass, section, and material properties were used as input into a computer program, and the first three natural periods were computed for both directions.

COMPARISON OF RESULTS

From an analysis of the chart recordings, the natural periods of translational vibration were measured to be 1.52 , 0.42 , and 0.21 seconds in the North-South direction and 1.41 and 0.36 seconds in the East-West direction, respectively. The third period in the East-West direction was not measured. The computed periods obtained from the computer analysis were 1.56 , 0.36 and 0.24 seconds for the North-South direction, and 1.46 , 0.33 , and 0.23 seconds for the East-West direction. A comparison of the measured and computed values is shown in Table 1.

The critical damping ratios were estimated to be 1.0 % to 1.1 % for the fundamental mode, and 1.2 % to 1.4 % in the second mode in the North-South direction. For the East-West direction, the ratios were estimated to be 1.1 % to 1.2 % for the fundamental mode, and 1.2 % to 1.5% for the second mode.

DISCUSSION AND CONCLUSIONS

From Table 1, there is good agreement between measured and computed values for the fundamental periods of vibration, with errors being 4 % or less. For the second periods, the errors are larger. The ratio of the fundamental period to the second period is usually an indication of the type of deformation present in a structure. For this building, the measured ratios are 3.6 for the North-South direction and 3.9 for the East-West direction. The corresponding ratios derived from computed values are 4.3 and 4.4 for the respective directions. In both directions, the measured ratios are significantly less than the computed ratios.

It appears that the beam model chosen for this building gave satisfactory results for the fundamental periods. For the higher periods, it appears that the beam model may not contain a sufficient amount of shear strain energy. The smaller values of the ratios of the fundamental to the second periods of the measured results compared to the computed results probably indicate that there was a larger proportion of shear energy of deformation in the real structure than was present in the beam computer model. The critical damping ratios are small because they were measured at very low amplitudes of vibration. Higher values of damping ratios would probably be measured if this structure could be subjected to higher levels of excitation.

ACKNOWLEDGMENTS

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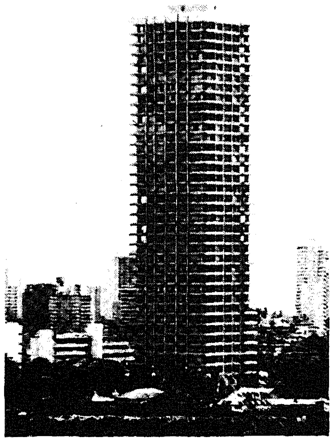


FIGURE 1
THE BUILDING STUDIED

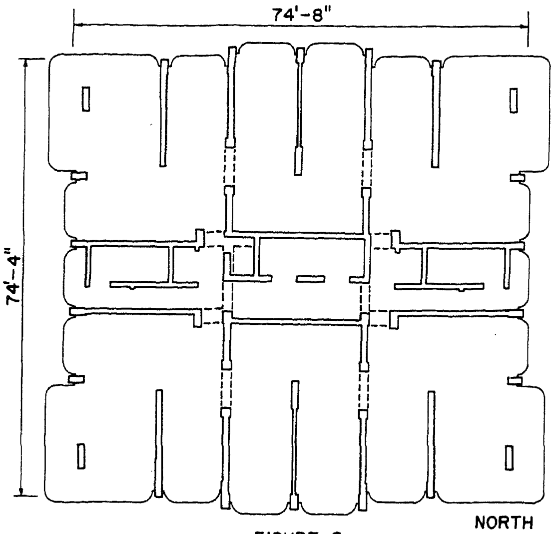
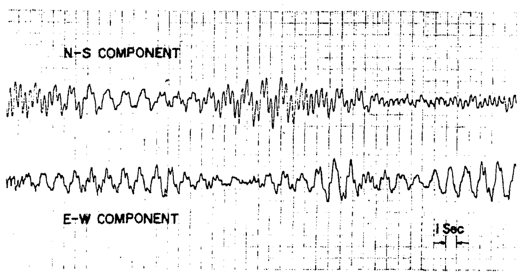
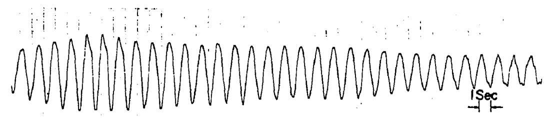


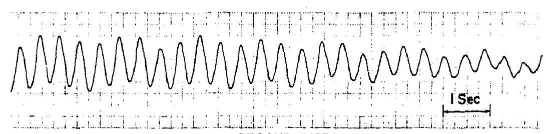
FIGURE 2
TYPICAL FLOOR FRAMING PLAN



AMBIENT RECORDS
FIGURE 3

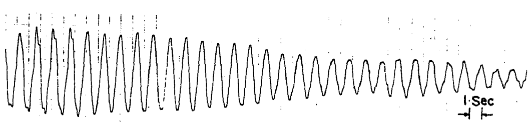


FIRST MODE

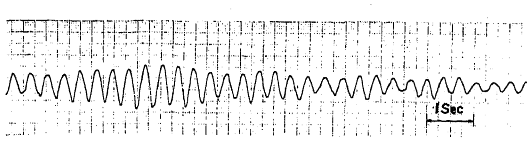


SECOND MODE

MAN-EXCITED RECORDS (N-S COMPONENT)
FIGURE 4



FIRST MODE



SECOND MODE

MAN-EXCITED RECORDS (E-W COMPONENT)
FIGURE 5

TRANSLATIONAL MODE NUMBER	EXPERIMENTAL PERIOD (SECOND)	COMPUTED PERIOD (SECOND)	PERCENT ERROR
NORTH-SOUTH			
FIRST	1.52	1.56	+ 3
SECOND	0.42	0.36	−14
THIRD	0.21	0.24	+14
EAST-WEST			
FIRST	1.41	1.46	+ 4
SECOND	0.36	0.33	− 9

TABLE 1
COMPARISON OF EXPERIMENTAL AND COMPUTED PERIODS OF VIBRATION