DAMPING CHARACTERISTICS OF R.C. HIGHRISE CHIMNEY BASED ON EARTHQUAKE MOTION MEASUREMENT

by

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SUMMARY

Authors have been doing earthquake motion measurement on 150m R.C. highrise chimney supported by steel piles driven into soft reclaimed subsoil by strong motion accelographs. 10 records were observed in about two years. Out of them, 5 records are analyzed on vibration characteristics, particularly damping characteristics of the R.C. highrise chimney. And the important characteristics of the damping of the chimney are made clear. The constant modal damping type of h_i=0.02 is suitable to this chimney and the base rotational damping factor is h=0.05∿0.10.

PREFACE

Many reports on vibration characteristics of R.C. highrise chimney by measurements of microtremor, free vibration and forced vibration tests have been made public, but reports based on natural earthquake motion measurements are few. In particular, the informations about the long period structure of this kind supported by piles are very few.

Since June 1977, authors have been measuring the seismic behavior of 150m R.C. highrise chimney supported by piles driven into soft reclaimed subsoil near Tokyo, JAPAN by servo-type strong motion accelograms.

Until today, 10 records are observed in which are included disastrous earthquakes of NEAR IZU-OSHIMA and OFF COAST OF MIYAGI both in 1978. In this report, 5 records of them are analyzed on vibration characteristics, particularly damping of the chimney.

SOIL AND STRUCTURE

Soil Soil composition and N-value are shown in Fig.1. Between GL and GL-5m are sand and silt where N-values are almost 0, between GL-5 and GL-14m is sand where N-values are 15∿50, between GL-14 and GL-34m are sandwitched sand and silt where N-values are 0∿15, between GL-34 and GL-37m is dense sand where N-values are over 50 between GL-37 and GL-41m is soft clay where N-values are 7, below GL-41m is dense sand where N-values are over 50.

Structure The chimney is 150m high, 13m in diameter at the bottom, 6m at the top, 50cm thick at the bottom and 18cm at the top. The footing shape is an octagon whose diagonal size is 28.2m, under which 96 steel piles of 40cm in diameter having been driven into the dense sand below GL-41m where N-value is over 50. R.C. outer-tube weighs 2920 ton, steel inner-tube weighs 141 ton, footing weighs 166 ton.

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MEASUREMENT SYSTEM AND RECORDS

Measurement system As shown in Fig.1, three pairs of horizontal pick-ups were set at the top (point A), middle (point B) and base (point C) of the chimney, and vertical pick-ups were set at point C and other two points D and E on the base. Recorders were set on the base. The gain and phase characteristics of the pick-up are shown in Fig.2 and Fig.3. They are flat between 0.1 Hz and 10 Hz. Recorder is FM cassette type. The start condition of the recorder is set as 2.5 gal in vertical motion. The measurement range is 1∿80 gal, and if the acceleration exceeds 80 gal, automatic attenuator change the range to 12∿1000 gal.

Observed records Since setting the seismograph up to June 1979, 10 earthquakes were observed. 5 good records among them are shown in Tab.1.

Maximum acceleration amplitude The maximum accelerations of horizontal components are shown in Tab.2. The maximum acceleration of C is 4∿24 gal, that of B is 6∿56 gal and that of A is 20∿120 gal. For example observed record of earthquake C06 which broke out in south west of Ibaragi located to the north-east of Tokyo is shown in Fig.4.

Maximum acceleration ratio Tab.3 shows the maximum acceleration ratio of the top and the middle of the chimney to the base. The maximum acceleration ratios of the top are 3.7∿6.4 in the direction X and 3.7∿7.7 in the direction Y, which are quite similar values. The ratio at the middle are 0.6∿1.3 in the direction X and 1.7∿3.9 in the direction Y, which are quite different each other.
The average and standard deviations of the maximum acceleration ratios are shown in Fig.5. On an average, the value of the top is 5 in direction X and 5.3 in direction Y, and the value of the middle is 0.9 in direction X and 2.7 in direction Y. In general a chimney is considered to be simmetrical, but really different behavior can be seen between in the direction X and Y It seems that the opening and intake flue cause these difference.

WAVE ANALYSIS

Fourier spectrum analysis To make clear period characteristics of the chimney in seismic motion, Fourier spectrum ratio of the top to the base are investigated. For example, the Fourier spectrum ratios in earthquake C06 are shown in Fig.6. As shown in Fig.6, the first predominant peak, the second, the third and the fourth come out clearly, and the predominant periods in X and Y directions are almost same, and peaks at the second period are higher than the others. Tab.4 shows the predominant periods from the first mode to the fifth mode in Fourier spectrum ratios of 5 earthquake records in Tab.1. The predominant periods of the transfer functions of 5 earthquake records are almost same at each mode, and the periods in the direction X are the same values as those in the direction Y. The value of each predominant periods is 3 sec in the first mode, 0.7 sec in the second mode, 0.3 sec in the third mode and 0.2 sec in the fourth mode. From the vertical motion of three points (C,D,E) on the base, the acceleration of rocking-motions in the direction X and Y calculated and those Fourier spectra are investigated. Fig.7 shows these results. The frequency characteristics of the rotational motion is similar in both direction X and Y. In particular, 0.72 sec is most predominant in each graphs. This period is coinside with the second predominant periods of the chimney obtained from the analysis of horizontal components. It should be noted that the second mode has a great influence on the rocking motion of this chimney in the acceleration order.

MODELING OF R.C. CHIMNEY

Three kinds of models are considered for the analysis of the chimney, base fixed model, rocking model and sway-rocking model. Tab.5 shows the natural periods of these models. The chimney is modeled as lumped mass system. The stiffness matrix is calculated assuming Young's modulus as 2.1×10^5 kg/cm^2 and considering the bending and shear deflection. The rocking spring is calculated from the axial stiffness of the steel piles, and the sway spring is calculated supposing the piles are supported by lateral springs of soil distributed along the pile axis. The natural periods of model show good agreement with observed results. Only a little deviation, which is seen in the first and second mode, might be caused by the assumption of the Young's modulus of concrete and by neglect of inner steel tube and intake steel flue.

MODAL DAMPING FACTOR OF THE CHIMNEY

Depending upon the observed results, the modal damping factors are obtained through spectrum fitting method with the rocking model. The results of the spectrum fitting method, for earthquake C06 are shown in Fig.8. In this Fig.8 the solid line shows the transfer function of observed record, and the broken line shows the transfer function of the rocking model. The modal damping factors obtained by the spectrum fitting method with 5 earthquakes, their average and standard deviation are shown in Tab.6. The modal damping factors in the first mode are deviated, but the modal damping factors from the second to the fifth coherent and reliable. In Fig.9 the relation between the predominant periods and the modal damping factors is shown. The modal damping factors shows the constant tendency between 0.02 and 0.04 in the higher mode except the second mode. The modal damping characteristics of the R.C. chimney is not frequency-propotional type.

EARTHQUAKE SIMULATION OF THE VARIOUS TYPES OF DAMPING

The viscous damping factor of the base rotation is assumed 0.10 referring to Yamahara's wave reactance theory. The modal damping of the chimney are assumed three types, frequency-propotional type of h_1=0.02, Rayleigh type of h_1=h_2=0.02, constant type of h_i=0.02. By combining structual and base rotational damping of Tab.7 three rocking models are made and calculated the maximum response accelerations of the top and the middle by inputting the observed record (C06). Comparison of these results in Tab.8 with the observed values shows that the Rayleigh type or constant type damping is suitable for this model and the frequency propotional type seems to be overestimated the damping.

COUPLED DAMPING CHARACTERISTICS OF STRUCTURE AND BASE ROTATION BY COMPLEX EIGEN-VALUE METHOD

For catching the contribution of the base rotational damping to the coupled damping, the damping of the chimney is assumed Rayleigh type of $h_1=h_2=0.02$ or constant type of $h_i=0.02$, and the base rotational viscous damping factor is parametrically changed to 0.02, 0.05 and 0.10. 6kinds of combination in Tab.9 are considered. By applying the complex eigen-value method to each model, the coupled modal damping factors are able to be obtained. The results of Rayleigh type and constant type are shown in Fig.10 and Fig.11. In Rayleigh type the coupled modal damping factors are almost similar as the base fixed modal damping factors, even if the base rotational viscous damping factor is changed. In constant type the coupled coupled modal damping factors of the medium modes are greatly influenced by changing the base rotational viscous damping factor. By comparing the modal damping factors of Fig.9 to the coupled modal damping factors of Fig.10 and Fig.11, it seems that the constant type damping of $h_i=0.02$ is suitable for this chimney and the base rotational damping factor is $0.15\sim 0.10$.

CONCLUSION

The modal damping of the structural system is not considered to be frequency-proportional type, but seems to be constant. The response accelerations in this R.C. chimney are not so influenced by base rotational damping. As for the coupled damping, the contribution of the base rotational damping is remarkable in case of constant type of chimney damping but less in case of Rayleigh type damping.

ACKNOWLEDGEMENTS

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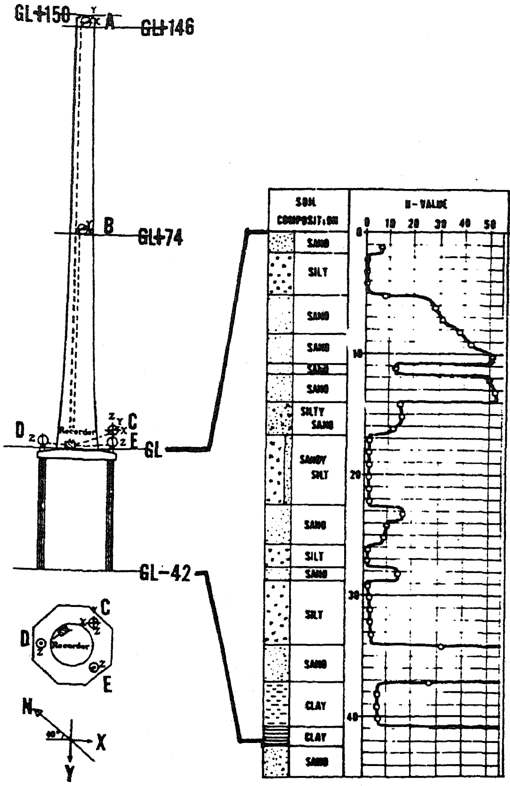

Fig.1 Location of Seismograph

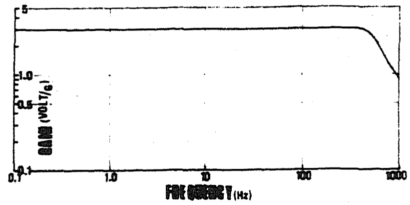

Fig.2 Gain Characteristics

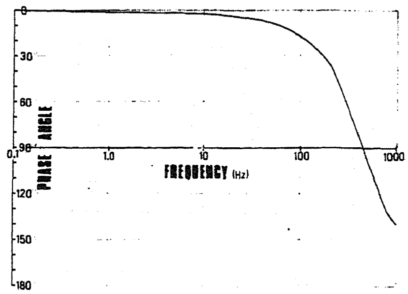

Fig.3 Phase Characteristics

Tab.1 Earthquakes used in Analysis

CODE	DATE	EPICENTER	DEPTH (KM)	DISTANCE (KM)	M
C02	1977.10.05	NORTH OF CHIBA	60	32	4.6
C04	1978.01.14	NEAR IZUOHSHIMA	0	103	7.0
C05	1978.03.07	NEAR TORISHIMA	440	500	7.8
C06	1978.03.20	S. W. OF IBARAGI	60	65	5.5
C07	1978.06.12	OFF COAST OF MIYAGI	40	350	7.4

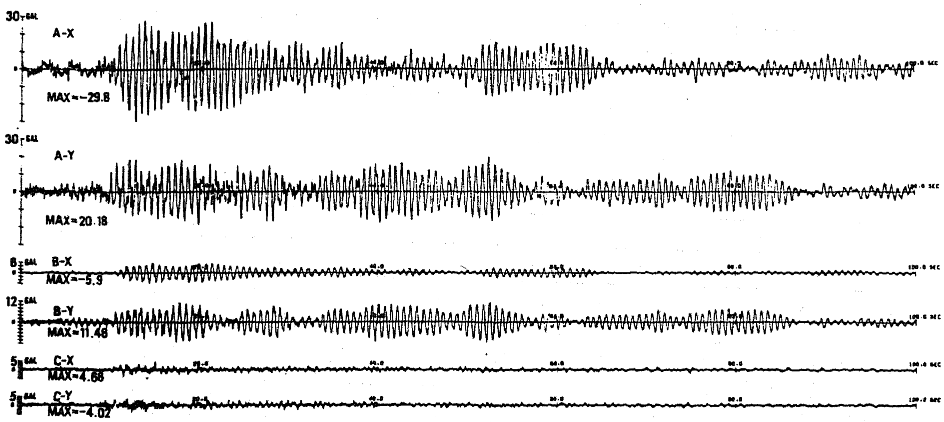

Fig.4 Observed Acceleration (C 06)

Tab.2 Observed Maximum Acceleration (gal)

	Co2		Co4		Co5		Co6		Co7	
	X	Y	X	Y	X	Y	X	Y	X	Y
C 0m	8.48	6.21	19.34	23.50	10.98	13.30	4.66	4.02	23.68	14.34
B 74m	5.65	20.76	11.52	44.02	12.42	22.82	5.90	11.46	21.14	55.92
A 146m	36.41	36.09	72.03	94.19	65.20	49.64	29.80	20.18	115.9	110.4

Tab.3 Maximum Acceleration Ratio

	CO2		CO4		CO5		CO6		CO7	
	X	Y	X	Y	X	Y	X	Y	X	Y
C (GL)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
B (74)	0.67	3.34	0.60	1.87	1.13	1.72	1.27	2.85	0.89	3.90
A (146)	4.29	5.81	3.72	4.01	5.94	3.73	6.39	5.01	4.89	7.70

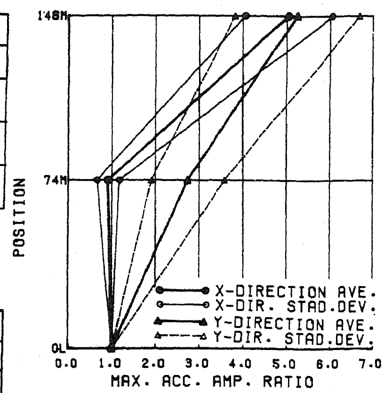

Fig.5 Max. Acc. Ratio

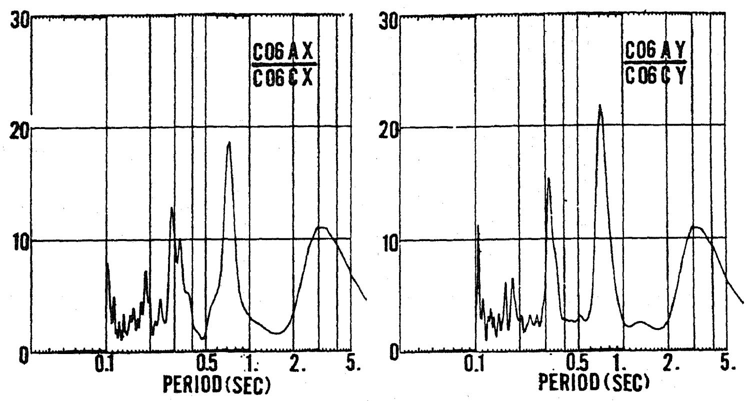

Fig.6 Fourier Spectrum Ratio

Tab.4 Predominant Period in Spectrum Ratio

	CO2		CO4		CO5		CO6		CO7		Average	S.D.
	X	Y	X	Y	X	Y	X	Y	X	Y		
1st	3.0	3.0	3.1	3.0	3.2	3.2	2.9	3.0	3.3	3.3	3.1	0.13
2nd	0.71	0.68	0.72	0.72	0.71	0.71	0.73	0.71	0.73	0.76	0.718	0.02
3rd	0.32	0.32	0.32	0.31	0.31	0.32	0.33	0.32	0.33	0.33	0.321	0.007
4th	0.17	0.18	0.21	0.20	0.18	0.18	0.19	0.18	0.19	0.19	0.187	0.015
5th	0.11	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.12	0.12	0.115	0.005

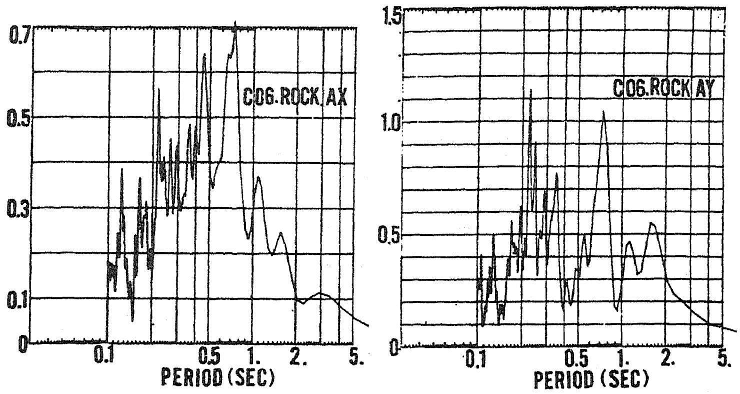

Fig.7 Fourier Spectrum of Rocking

Tab.5 Natural Period of Analysis Model (sec)

	1st	2nd	3rd	4th	5th
Base Fixed	3.488	0.759	0.331	0.190	0.122
Rocking	3.579	0.799	0.350	0.202	0.132
Sway Rocking	3.585	0.821	0.471	0.329	0.197

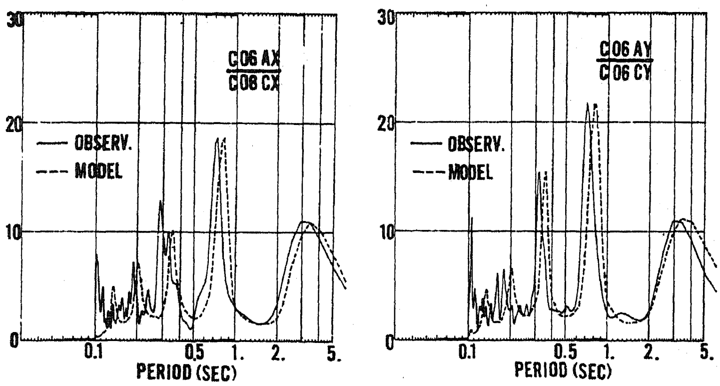

Fig.8 Spectrum Fitting

Tab.6 Modal Damping Factor of Rocking Model

Code / Mode	CO2		CO4		CO5		CO6		CO7		Average	S.D.
	X	Y	X	Y	X	Y	X	Y	X	Y		
1st	0.013	0.049	0.0	0.0	0.0	0.14	0.010	0.010	0.0	0.0	0.022	0.042
2nd	0.018	0.007	0.011	0.012	0.026	0.016	0.014	0.007	0.019	0.019	0.015	0.005
3rd	0.041	0.056	0.025	0.041	0.035	0.038	0.042	0.021	0.028	0.035	0.036	0.009
4th	0.058	0.043	0.071	0.035	0.075	0.048	0.040	0.044	0.030	0.020	0.046	0.016
5th	0.036	0.044	0.010	0.026	0.017	0.035	0.028	0.031	0.019	0.017	0.026	0.010

Tab.7 Damping of Rocking Model for Response Calculation

	Structure	Base Rotation
Model 1	$h_1=0.02$ ω-proportional damping	$h_R=0.10$
Model 2	$h_1=h_2=0.02$ Rayleigh damping	$h_R=0.10$
Model 3	$hi=0.02$ constant damping	$h_R=0.10$

Tab.8 Observed Acc. and Response Calculation Acc.

	Co6X(gal)				Co6Y(gal)			
	Observed	Model 1	Model 2	Model 3	Observed	Model 1	Model 2	Model 3
A 146m	−29.8	−10.7	−18.3	−19.3	20.2	−11.0	22.6	24.3
B 74m	− 5.9	− 6.7	−10.1	−10.3	11.5	5.8	11.9	12.3
C 0m	4.66	4.66	4.66	4.66	− 4.02	− 4.02	− 4.02	− 4.02

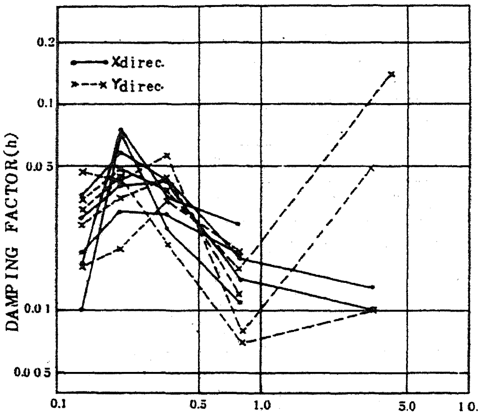

Fig.9 Damping Factor and Period

Tab.9 Damping of Rocking Model for Complex Eigen-value

	基礎回転減衰定数	筒体の減衰
Model(A)	$h_R=0.02$	$h_1=h_2=0.02$ Rayleigh damping
Model(B)	$h_R=0.05$	
Model(C)	$h_R=0.10$	
Model(D)	$h_R=0.02$	$hi=0.02$ constant damping
Model(E)	$h_R=0.05$	
Model(F)	$h_R=0.10$	

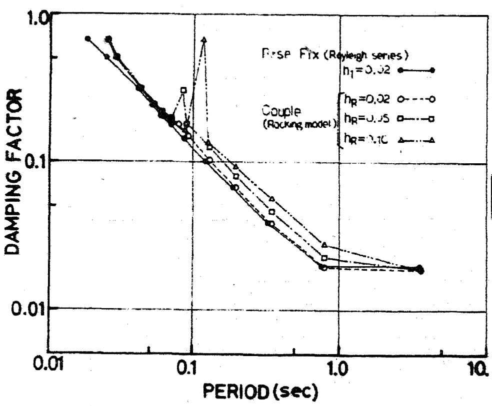

Fig.10 Coupled Damping of Rayleigh Type

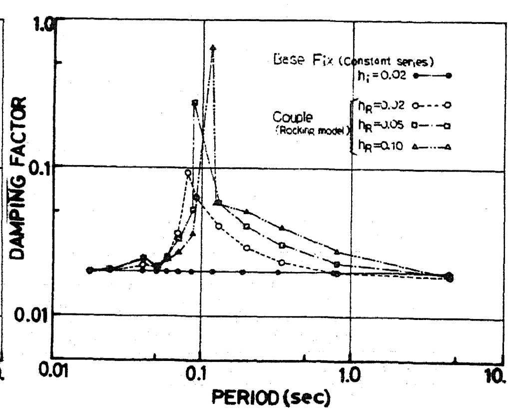

Fig.11 Coupled Damping of Constant Type