

A STUDY ON DAMPING CHARACTERISTICS OF SHELL AND SPATIAL STRUCTURES — DAMPING RATIOS OF A CYLINDRICAL SHELL—

K. Shingu¹, Y. Aoki², T. Irie³, K. Mitsui⁴, K. Ogawa⁵, F. Nanaumi⁶

SUMMARY

Impact vibration experiments, microtremor observations, and rope-cut experiments on a cylindrical shell constructed at the entrance of the gymnasium at Funabashi campus, Nihon University were carried out, and the data obtained by measurements under experimental modes using the RD method were evaluated. Then the difference in damping ratio in light of the difference in experimental methods and modes were considered. Further past measurement data on shell and spatial structures were arranged, those with the newly obtained experimental data were compared, and the results of the comparisons were analyzed, thereby clarifying the damping characteristics of shell and spatial structures.

INTRODUCTION

Damping plays a very important part in vibration phenomena. Since the damping is, however, due to many factors, it is generally difficult to determine the theoretical damping ratio . Damping ratios for structures having ordinary shapes have been examined based on a large quantity of actual measurement data. Accordingly, as long as the displacement amplitude is small, it has become possible to roughly infer the damping ratio of an ordinary shaped structure from its size, material, and so on.¹⁾ In contrast, since the number of shell and spatial structures actually available for experiments is much less than that of ordinary shaped structures, measurements of shell and spatial structures are more difficult than those of ordinary shaped structures are also difficult, there have been very little measurement data available for shell and spatial structures^{2), 3)}. Although these drawbacks may have impeded the progress of the studies of shell and spatial structures, the reason that the damping ratios are adopted in the design and construction of aseismatic shell and spatial structures has been left unclear to date. In this study, damping vibration experiments were carried out on one of actual shell and spatial structures in order to clarify the damping

¹ Professor, Dr., Dept. of Oceanic Architecture and Engineering, Nihon University

² Associate Professor, Dr., Dept. of Precision Machinery Engineering, Nihon University

³ Assistant Professor, Dr., Dept. of Precision Machinery Engineering, Nihon University

⁴ Associate Professor, Dr., Dept. of Mathematical Information Engineering, Nihon University

⁵ Professor, Dr., Dept. of Mechanical Engineering, Nihon University

⁶ Haseko Corporation

characteristics involved in shell and spatial structures and also to make a data base for use in vibration analysis.

OBJECTIVE STRUCTURE

Photo 1 is a front view of the objective structure used for the experiment. Figs. 1 and 2 are the roof plan and elevation of the objective structure, respectively.



Photo 1 Objective structure (Front view)



Fig.1 Roof plan



ANALYTICAL AND EXPERIMENTAL METHODS

In order to make use of the experimental results in data processing analysis, the finite element method (ANSYS) was used for natural vibration analysis.

Three experiments, that is, impact vibration experiment using an impact hammer, microtremor observation, and rope-cut experiment were carried out. After acquiring the experimental data, the modal analysis was conducted using a VIBRANT-GEN to examine the damping ratio in each vibration mode.

Impact vibration experiment

The objective structure was vibrated by impulse through the use of an impact hammer⁴⁾. The acceleration response was input to a personal computer from an accelerometer through an amplifier and a FFT analyzer. The impact point was made to be the center of the structure, the measurements were taken at a total of 40 points at A1 through H5 (Fig. 3).

Single-axis acceleration pickups are used and installed it vertically. Impulses were applied to the structure in the vertical direction. The experiments were carried out outdoors. Therefore, in the acquisition of data, and averaging it, measurement data while referring to the coherence function were selected in order to examine the reliability of the resultant data.

Concerning the amount of data, we estimated it to such an extent that the coherence function would be stable (around 10 to 20 sets of data). After filtering out the data through the band pass filter, we calculated the logarithmic damping ratio from obtained free vibration waveforms.





Fig. 4 Points of observation (Microtremor observation)

Microtremor observation

In the measurement system for the microtremor observation, accelerometers were attached to the structure at all times to measure the vertical microtremor of the structure in all cases. Measurements were taken at a total of 56 points at A1 through H7 (Fig. 4). Damping ratios by using the RD method were computed. In order to apply the RD method, good data were selected.

Rope-cut experiment

The measurement system for rope-cut experiment was designed as follows. Accelerometers were attached to the objective structure, a load was suspended with a rope from the part shown in red in Fig. 5, and then the rope was cut to give the structure a free vibration, thereby measuring the acceleration caused by the free vibration.

A total of 7 measurement points were set up at E1 through E7 (Fig. 5). In acquiring measurement data, the measurement was executed 10 times at each measurement point. In the damping evaluation method, a band-pass filter was applied to the measurement data in the frequency band centering in the neighborhood of the natural frequency in order to obtain a free vibration waveform. The logarithmic damping ratio was then obtained from the acquired free vibration waveform.



Fig. 5 Measurement points and loading point (Rope-cut experiment)

NATURAL VIBRATION BY FEM AND EXPERIMENT

Natural vibration analysis by FEM

Table 1 shows the results of the natural vibration analysis of the structure using the finite element method as a reference for the measurement data analysis. Since the cylindrical shell used as the experimental object is a steel structure, its material constants used for the finite element analysis were as follows.

Young's modulus: 2.1×10^{6} kgf/cm² Poisson's ratio: 0.3 Mass density: 7.9×10^{-6} kgf •sec²/cm⁴

Order	Natural frequency (Hz)	
1st	6.86	
2nd	8.93	
3rd	11.13	
4th	12.19	

Table 1 Natural frequency by FEM



Fig. 6 Second mode by FEM (8.93Hz)



Fig. 7 Third mode by FEM (11.13Hz)

Modal analysis by impact vibration experiment

The results of the natural vibration analysis by using the frequency response function obtained from the impact vibration experiment are shown in Table 2, Figs. 8 and 9, respectively.

Order	Natural frequency (Hz)		
1st			
2nd	9.75		
3rd	10.70		
4th			

Table 2 Natural frequency by experiment



Fig. 8 2nd mode by experiment



Fig. 9 3rd mode by experiment

DAMPING RATIOS BY EXPERIMENTS

Impact vibration experiment

As an example of the measurement results averaged ten times, the input waveform of an impact hammer hitting the center of the structure is shown in Fig. 10, the temporal change of the acceleration response at the measurement point E3 (Fig.3) in Fig. 11, and the temporal change of the damping waveforms at the measurement point E3 after applying the band-pass filtering in Fig. 12, respectively.



Fig. 12 Damping waveform at E3 after applying band-pass filtering

The experimental results of the natural vibration analysis for the second vibration mode was in good agreement with the theoretical results by FEM, whereas the experimental results of the natural vibration

analysis for the third vibration mode was relatively close to the theoretical results, though far from agreement.

The experimental results were analyzed for the second and third vibration modes.

Damping ratios by Impact vibration experiment

Table 3 below shows the averaged damping ratios of the entire objective structure obtained from the impact vibration experiment for the second and third vibration modes.

Order	Damping ratio (%)		
1st			
2nd	2.3		
3rd	2.4		

 Table 3 Damping ratios by Impact vibration experiment

Microtremor observation

As an example of the measurement data obtained from microtremor observation, the temporal change of acceleration at the measurement point E4 (Fig. 4) is shown in Fig. 13.



Fig. 13 Temporal change of acceleration at measurement point E4

Applicable frequency range for the RD method was set up both in the neighborhood of a second natural frequency of 9.75Hz and in the neighborhood of a third natural frequency of 10.70Hz.

As an example, the damping frequency waveform derived by applying the RD method to the observation point E4 is shown in Fig. 14. This waveform was obtained by applying the band-pass filter to the damping vibration in the neighborhood of natural frequency 9.75Hz at sampling intervals of 1/512sec.



Fig. 14 Damping frequency waveform obtained by the RD method

Damping ratios by microtremor observation

Table 4 shows the damping ratio of the entire objective structure obtained as a result of the microtremor observations. In addition, it shows the number of times the arithmetic mean was obtained by observing the

microtremor 1,000 times at each observation point and by taking 56,000 small samples for each vibration mode.

Order	Damping ratio (%)		
1st			
2nd	2.2		
3rd	2.3		

Table 4 Damping ratios by microtremor observation

Rope-cut experiment

As an example of measurement data in the rope-cut experiment, Fig. 15 shows the temporal change of acceleration at measurement point E4 (Refer to Fig. 5) when the objective structure is loaded with 50kgf at E4. Fig. 16 shows the temporal change of the acceleration after band-pass treatment.



Fig. 15 Temporal change of the acceleration at E4 (rope-cut experiment)



Fig. 16 Temporal change of the acceleration at E4 after the band-pass treatment (rope-cut experiment)

Damping ratios by rope-cut experiment

Table 5 shows the averaged damping ratio obtained from the rope-cut experiments for each load applied to the structure. Fig. 17 shows the relationship between the loading weight and the damping ratio in the second vibration mode, and Fig. 18 the relationship between the loading weight and the damping ratio in the third vibration mode.

Load	2nd	3rd	Load	2nd	3rd
(kgf)	Damping ratio (%)	Damping ratio (%)	(kgf)	Damping ratio (%)	Damping ratio (%)
10	2.0	1.2	70	1.5	2.2
20	2.0	1.5	80	2.5	2.1
30	1.5	2.0	90	2.1	2.1
40	2.0	1.4	100	1.3	2.3
50	2.0	2.2	Ave.	1.9	1.9
60	2.1	1.8			

Table 5 Damping ratios by rope-cut experiment



Fig. 17 Damping ratio for each loading weight (2nd mode)



Fig. 18 Damping ratio for each loading weight (3rd mode)

COMPARISON OF EXPERIMENTAL DATA WITH PAST MEASUREMENT DATA

The experimental data described so far was compared with past measurement data. Like ordinary structures, shell and spatial structures also do not have specific constant damping characteristics. Their damping characteristics are considered to change with various factors. It is expected that their particular damping characteristics can be clarified by replacing as much vibration measurement data as possible with various parameters.

Based on the material where vibration measurement data has been taken and arranged so far (provided by Dr. Tatemichi), we compared the objective structures with ordinary structures to clarify the specific nature of the vibration measurement data.

Results of experimental natural frequencies

Fig. 19 is a graph where only clear analytical and measurement values of natural frequencies are compared (Circles in red on the graph represent the objective structures used in this study.). Likewise, Fig. 20 is a graph showing the relationship between the span and the natural frequency, and Fig. 21 a graph showing the relationship between the measured natural frequencies and the damping ratios. Fig. 21 proves that there is a tendency that as the frequency increases, the damping ratio decreases. Moreover, since the analytical result proves that the first natural frequency is very close to that in the second, only the second natural frequencies were plotted for convenience's sake.



Fig. 19 Relationship between analytical and experimental frequencies



Fig. 20 Relationship between natural frequency and span

Results of damping ratios

Comparison of the damping ratios obtained from the experiments with past measured damping ratios in Fig. 22.

However, since considering individual structures, the required quantity of measurement data is obviously insufficient, it is necessary to accumulate more measurement data.



Fig. 21 The relationship between the measured natural frequencies and the damping ratios



Fig. 22 Span and first damping ratios

CONCLUSIONS

- 1) Damping ratios obtained from the impact vibration experiment, microtremor observation, and rope-cut experiment were all limited to around 2% for both the second and third vibration modes.
- 2) Since the second and third frequencies are close to each other, those damping ratios also showed nearly the same values.
- 3) Very little amplitude dependence of the objective structure in the second vibration mode was observed, whereas in the third vibration mode, such a tendency was observed as the damping ratio increased with an increase in loading weight.

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