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The latest status of research on damping characteristics of shell and spatial structures in Japan

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Abstract

Damping is one of the important parameters about vibration phenomena of shell and spatial structures. However, damping of the structures is not as clear as stiffness and mass of the structures. It is impossible to evaluate damping ratios by theory or to know ones in advance from the structural system because there are so many factors around and in the structures, for example, those are the shapes, materials, sizes, ground conditions, support condition of the structures, and by the seismic forces or wind foreces and so on. The study of damping ratio evaluation of shell and spatial structures has been conducted by Professor I. Tatemichi at Meisei University and members of Shingu Laboratory at Nihon University until now. In this paper, damping ratios and characteristics of shell and spatial structures have been analyzed using 55 data of damping ratios of the structures built in Japan. We tried to search data in another contries, but to our regret, we could not find the data of damping ratios of shell and spatial structures in another contries. Therfore, the data of damping ratios of shell and spatail structures results to only the data in Japan.

Keywords: scales and materials, database, vibration tests, evaluation of damping ratios, evaluation methods, relationships between span and damping ratio, relationships between rise and damping ratio, damping ratio's dependency by the scale of the structure, effect of nonstructural elements to damping ratio

1. Introduction

Damping is of great importance in dealing with vibration problems in buildings and architecture. However, due to the large number of factors involved, it is currently not possible to obtain a theoretical evaluation of the damping ratios of structures. Accurate estimates of the damping ratio at the design stage make understanding the dynamic behavior of the structure possible, and with effective use of inherent vibration properties of the structure, it is possible to reduce stresses in the structural members, to reduce construction costs and to make related energy savings. Also, with the greater emphasis on earthquake countermeasures since the Great Hanshin-Awaji Earthquake (The Southern Hyogo Prefecture Earthquake, 1995) and The Great East Japan Earthquake (The Tohoku-Chiho Taiheiyo-Oki Earthquake, 2011), response prediction of a building has taken on great importance, and there is an urgent need to improve the accurate estimation of damping ratios.

In recent years, the expansion of databases of multi-story buildings has begun to make rough estimates of damping ratios based on size, construction and materials possible. However, for shell and spatial structures the relative lack of absolute quantifiers, coupled with the difficulty of taking real

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measurements, means there is very little real data available. Shell and spatial structures hold a lot of people and are widely used as emergency refuges in the event of disasters. Therefore, there is a pressing social need for more research to improve accuracy of damping ratios of structures, and further dynamic behavior of the structures. With this in mind, experimental measurements and analyses of several shell and spatial structures have been carried out by Professor I. Tatemichi (Meisei University) and Shingu Laboratory at Nihon University, and a database has been constructed with the goal of improving our understanding of their damping characteristics.

2. Objects of Evaluation of Damping Ratios

Reference research on damping evaluation of shell and spatial structures was carried out based on references in Japan and other countries, and the data base of damping ratios of 55 shell and spatial structures has been made [1],[2],[3],[4]. Before we had obtaied the 55 structures, we tried to search the data in another country, but we could not find the data of damping ratios of shell and spatial structures in another country. Therfore, the data of damping ratios of shell and spatail structures results to only the data in Japan.

The conditions of adoptation of shell and spatial structures in the data base are as follows.

1) The span of the object is eaqual to or over 10m.
2) The structural kind of the object is needed to be written in a report or a paper. If there is no description of the structural kind of the object, the data is not listed in this paper.
3) Both the measurement method of vibration and evaluation method of damping ratios are needed to be written in a report or a paper.

Scales and materials of shell and spatial structures in the data base are shown in Figure1.

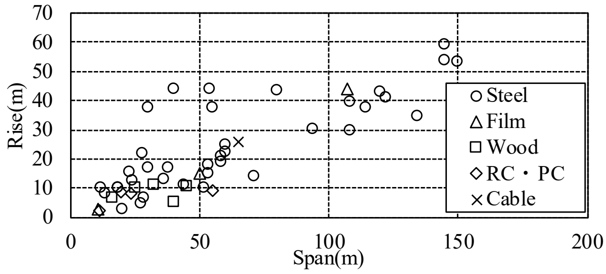

Figure 1: Scales and materials of shell and spatial structures in the database

It is understand from Figure 1 that the scale of the structures whose spans are 10.7m-150.0m and whose rises are 2.9m-59.0m.

Photo 1: Spherical concreate shell (Positive Gaussian curvature)

Some photos of shell and spataial strucures in the data base carried out by Shingu Laboratry are shown in Photo 1- Photo 3. Photo 1 is a planetarium (Chiba, Japan) whose span is 23.2m and the rise is 8.11m.

Photo 2: Conical steel framed shell (Zero Gaussian curvature)

Photo 2 is a sports center (Chiba, Japan) whose span is 68m.

Photo 3: Hyperbolic paraboloidal steel framed shell (Negative Gaussian curvature)

Photo 3 is a martial arts gymnasium (Chiba, Japan) whose sizes are 44m x 44m.

Photo 4 shows the servo velocity detectors for microtremor measurement and so on. It is possible to measure velocities in the three directions at the measurement points of the structures. This is an example of the measurement equipment.

Photo 4 : Servo velocity detectors for microtremor measurement and so on

Vibration tests for evaluation of damping ratios, and evaluation methods of damping ratios in the data base are shown in Figure 2 and in Figure 3, respectively.

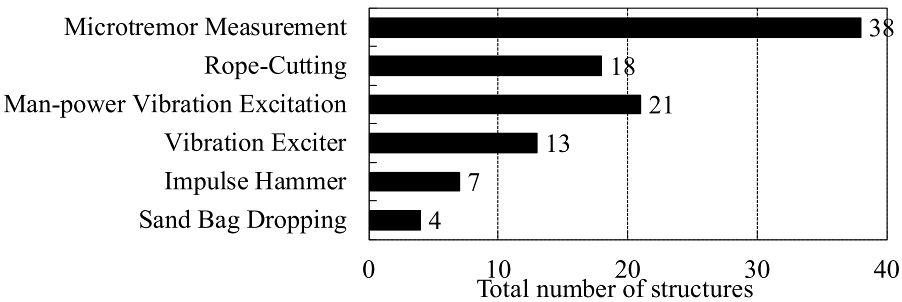

Figure 2: Vibration tests for evaluation of damping ratios

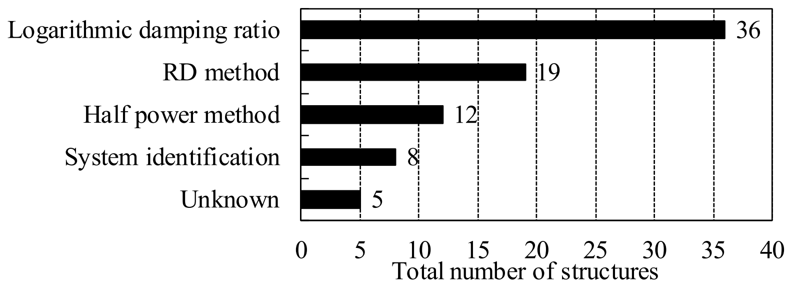

Figure 3: Evaluation methods of damping ratios

3. Results of Estimation of Damping Ratios

Damping ratio's dependency by the scale, vibration amplitude and frequency of shell and spatial structures are considered from the results of damping ratio evaluation of 55 shell and spatial structures.

3.1. Damping ratio's dependency by the scale of the structure

When estimating damping ratios of a multi-story structure, damping ratios had been proposed as the parameter of the scale of the structure in the book [5]. Therefore, the estimated damping ratios of shell and spatial structures were made with the span or the rise of the shell and spatial structures as parameters.

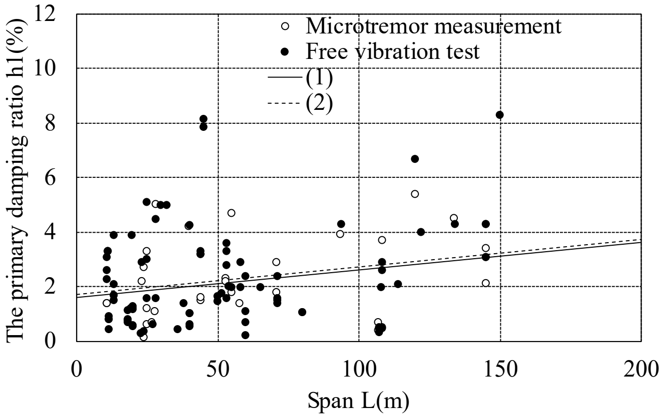

Figure 4: Relationships between span L and primary damping ratio h_1

The relationship between span L and primary damping ratio h_1 is shown in Figure 4, and also the relationships of two kinds are presented in eqs. (1) and (2). These equations are obtained by using the least-squares method.

Relationships between span L(m) and primary damping ratio h_1:

Microtremor measurement: $h_1=0.01L+1.61$ (1)

Free vibration test: $h_1=0.01L+1.72$ (2)

The following equation (3) is obtained as the averaged value of eqs. (1) and (2).

$$h_1=0.01L+1.67 \quad (3)$$

The relationship between rise H and primary damping ratio h_1 is shown in Figure 5, and also the relationships of two kinds are written in eqs. (4) and (5). These equations are also obtained by using the least-squares method.

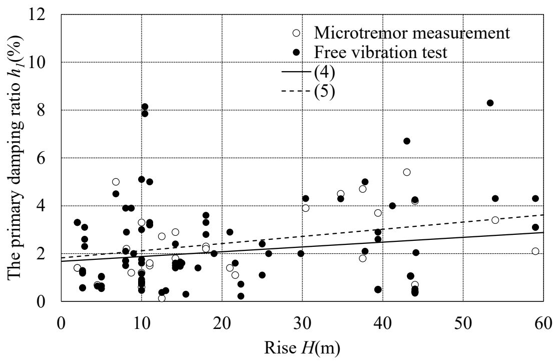

Figure 5: Relationships between rise H and primary damping ratio h_1

Relationships between rise H(m) and primary damping ratio h_1:

Microtremor measurement: $h_1=0.02H+1.68$ (4)

Free vibration test: $h_1=0.03H+1.82$ (5)

The following equation (6) is obtained as the averaged value of above equations.

$$h_1=0.025H+1.75 \quad (6)$$

3.2. Damping ratio's dependency by amplitude of vibration

It is shown in the database that the damping ratio measured by a microtremor is smaller than free vibration experiment through man-power vibration excitation or rope-cutting in the case of the same structure. Therfore, damping ratios which were obtained from microtremor measurment and free vibration experiment are shown in Figure 6 and the values are compared.

The comparison of Figure 6 showed that, despite the structural material, the damping ratios from the vibration experiments tended to be large than those microtremor measurment.

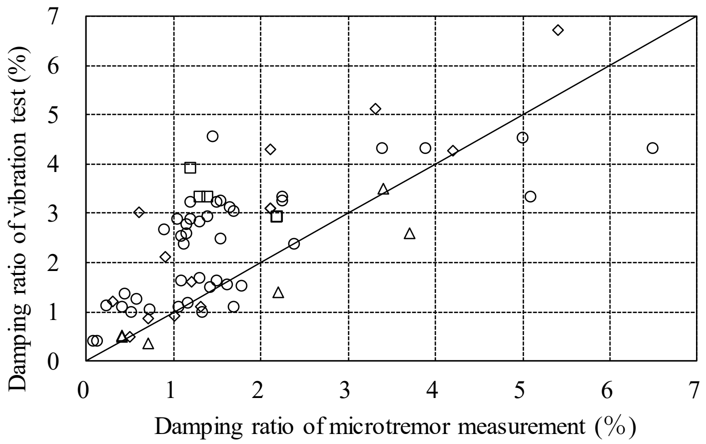

Figure 6: Amplitude dependency of damping ratios

3.3. Damping ratio's dependency by frequency

In the case of multi-story buildings, stiffness propotinal type damping ratios are often used [2]. Therefore, the correlation between natural frequency measurements and damping ratios of shell and spatial structures has led to the study of the freqency dependance of damping ratios.

Correlation between natural frequencies and damping ratios by microtremor measurment (whose velocity amplitude are small) and free vibration test (whose velocity amplitude are large) are shown in the Left and the Right in Figure 7, respectively. Although number of the data in this research is not so many and it is still in the improvement stage, damping ratios in the smaller frequncy region have a tendency to be larger than those in the larger frequency region. Therfore, it is understood that damping ratio of shell and spatial structures is near mass propotinal type.

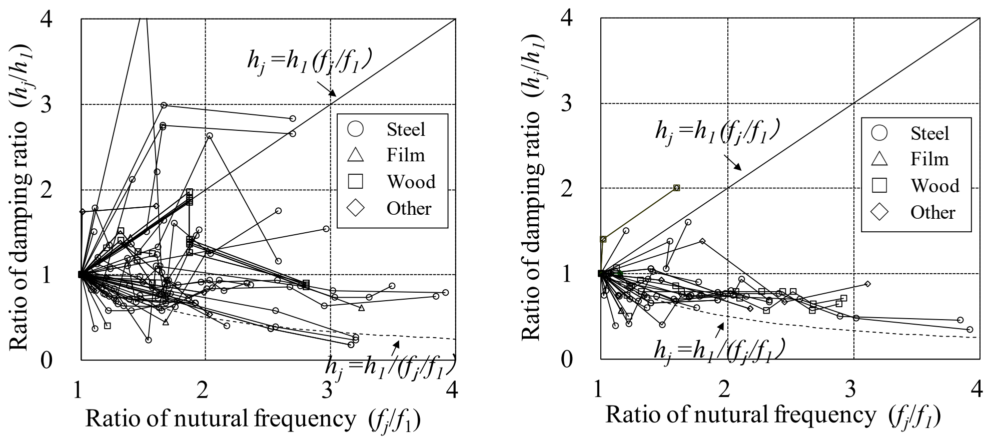

Figure 7: Frequency dependency of damping ratios
(Left: Microtremor measurement, Right: Free vibration test)

3.4. Effect of nonstructural elements to damping ratio

There are several papers or reports about variations of damping ratios before execution work and those after execution work in the data base. Therefore, comparison of damping ratios of shell and spatial structures without nonstructural elements and those with nonstructural elements is shown in Figure 8.

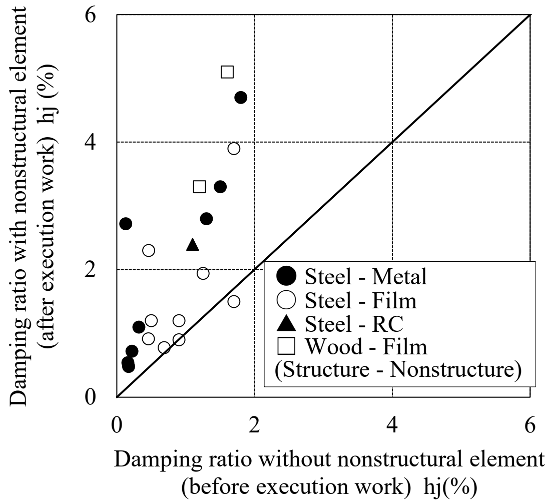

Figure 8: Change of damping ratios before and after execution work

From the results, it is understood that the magnitude of damping ratios after execution work are about two times of those of before execution work in spite of structural and nonstructural material kinds. It is understood that the effect of damping ratios by nonstructural elements is very large.

4. Conclusions

This paper is based on Reference [6], and the equations of estimation damping ratios have been newly proposed by us.

1) Two kinds of evaluation of damping ratio of shell and spatial structures have been proposed in Equation (3) as the parameter of the spans of the structures, and similarly, as the parameter of the rises of the structures in Equation (6).

   Proposed damping ratio (parameter: span(m)) $h_1=0.01L+1.67$ (3)

   Proposed damping ratio (parameter: rise(m)) $h_1=0.025H+1.75$ (6)

2) There is damping ratio's dependency by the scale of the structure.
3) There is damping ratio's dependency by amplitude of vibration.
4) There is damping ratio's dependency by frequency.
5) Effect of damping ratio by nonstructural elements is very large. The magnitude of damping ratios after execution work are around two times of those of before execution work.

Acknowledgements

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