THE STATUS QUO OF DAMPING EVALUATION OF SHELL AND SPATIAL STRUCTURES IN JAPAN

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Abstract

A study of damping ratio evaluation of shell and spatial structures has been conducted by members of Architectural Institute of Japan (AIJ) mainly until now [1]. These results are newly going to be added to the book “Damping in Buildings” [2] as the contents about measurement of vibration and evaluation of damping ratios of shell and spatial structures in the new book “Damping and Vibration of Buildings” [3] that is going to be published in autum or winter in 2020.

Damping is one of the important parameters about vibration phenomina of shell and spatial structures. However, damping of the structures is not as clear as stiffness and mass of the structures. It is imposible 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 shpapes, matrials, 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 members of Shingu Laboratory at Nihon University, and members of AIJ mainly until now. In this paper, damping ratios and characteristics of shell and spatial structures have been analized using 55 data of damping ratios of the structures those located places are 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.

These results are newly going to be added to the contents about measurement and evaluation of damping ratios of shell and spatial structures in the new book “Damping and Vibration of Buildings” [3] as mentioned in the above. This paper is the introduction of one of new parts of the contents of shell and spatial structures in the several structures.

The main contents of this paper are as follows:

1) Scales and materials of shell and spatial structures in the database
2) Vibration tests for evaluation of damping ratios
3) Evaluation methods of damping ratios
4) Relationships between span and primary damping ratio
5) Relationships between rise and primary damping ratio
6) Damping ratio’s dependency by the scale of the structure
7) Damping ratio’s dependency by amplitude of vibration
8) Damping ratio’s dependency by frequency
9) Effect of nonstructural elements to damping ratio

Keywords: damping ratio; damping evaluation; shell and spatial structures; velocity; acceleration

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 estimate the damping ratios of structures theoretically. 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 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 Shingu Laboratory at Nihon University and others, 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 another country, and the data base of damping ratios of 55 shell and spatial structures has been made [4,5,6,7]. 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 Fig.1.

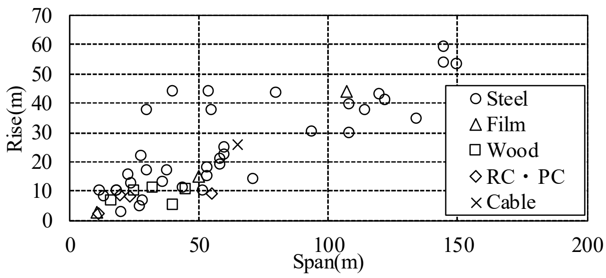

Fig. 1 – Scales and materials of shell and spatial structures in the database

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

Some photos of shell and spataial strucures in the data base carried out by Shingu Laboratry are shown in Photo 1- Photo 4.

Photo 1–Spherical concreate shell in Chiba prefecture (Planetarium, Span:23.2m, Rise:8.11m, Positive Gaussian curvature)

Photo 2–Conical steel framed shell in Chiba prefecture (Sports center, Span:68m, Zero Gaussian curvature)

Photo 3–Hyperbolic paraboloidal steel framed shell in Chiba prefecture

(Martial arts gymnasium, the Outside, 44m x 44m, Negative Gaussian curvature)

Photo 4– Hyperbolic paraboloidal steel framed shell in Chiba Prefecture
(The Inside of the Same structure of Photo 3)

Photo 5 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 5– Servo velocity detectors for microtremor measurement and so on (Shingu Laboratry)

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

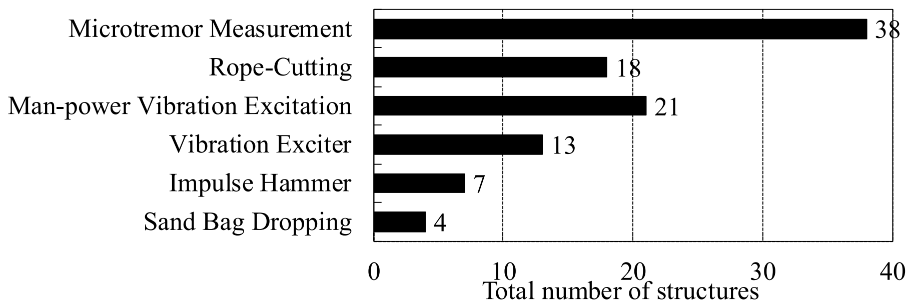

Fig. 2 – Vibration tests for evaluation of damping ratios

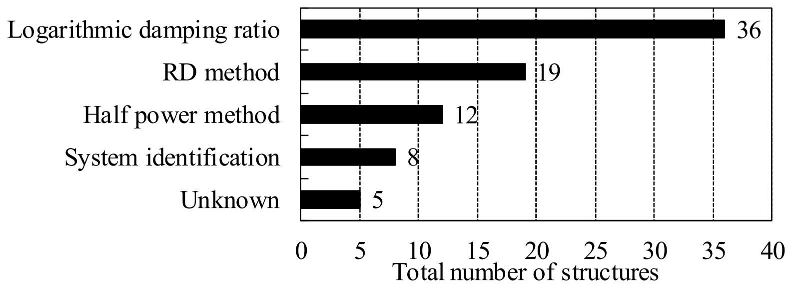

Fig. 3 – Evaluation methods of damping ratios

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

In the case of estimation damping ratios of a multi-story structure, damping ratios had been proposed as the parameter of the scale of the structure in the book [2]. Therefore, estimation damping ratios of shell and spatial structures are considered as the parameters of the span or the rise of the shell and spatial structures.

The relationship between span L and primary damping ratio h_1 is shown in Fig.4, and also the relationships between span L and primary damping ratio h_1 are shown in Eq. (1) and Eq. (2). The equations are obtained by using the least-squares method.

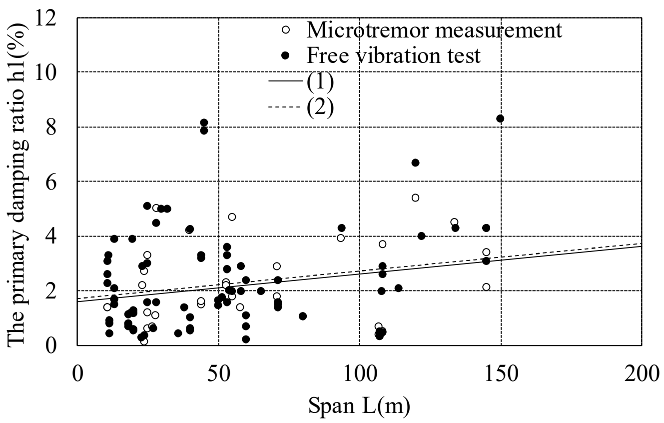

Fig. 4– Relationships between span L and primary damping ratio h_1

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 relationship between rise H and primary damping ratio h_1 is shown in Fig.5, and also the relationships between rise H and primary damping ratio h_1 are shown in Eq. (3) and Eq. (4). The equations are also obtained by using the least-squares method.

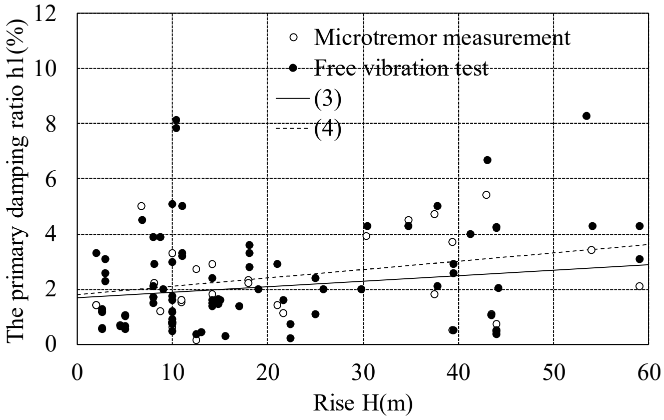

Fig. 5 – Relationships between rise H and primary damping ratio h_1

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

Microtremor measurement: $h_1=0.02H+1.68$ (3)

Free vibration test: $h_1=0.03H+1.82$ (4)

3.2 Damping ratio's dependency by amplitude of vibration

It is reported in the database that microtremor measurment those amplitude is smaller than free vibration experiment throgh man-power vibration excitation or rope-cutting in the case of the same structure. Therfore, damping ratios those were obtained from microtremor measurment and free vibration experiment are shown in Fig.6 and the values are compared.

It is understood that damping ratios through the free vibration experiment those magnitude are larger than the other have a tendency to be larger than those through microtremor measurment in spite of structural matrials from the comparison results.

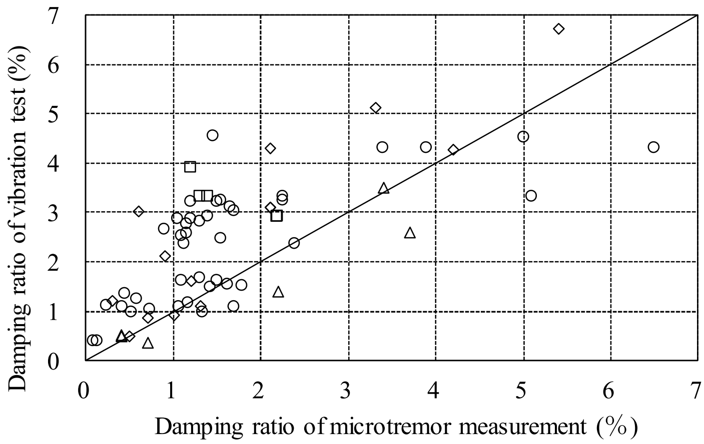

Fig. 6 – Amplitude dependency of damping ratios

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, damping ratio’s dependency by frequency has been researched by correlation between measured natural frequencies and damping ratios of shell and spatial structures.

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 Fig. 7, respectvly. Althogh number of the data in this resarch 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 region. Therfore, it is understood that damping ratio of shell and spatial structures is near mass propotinal type.

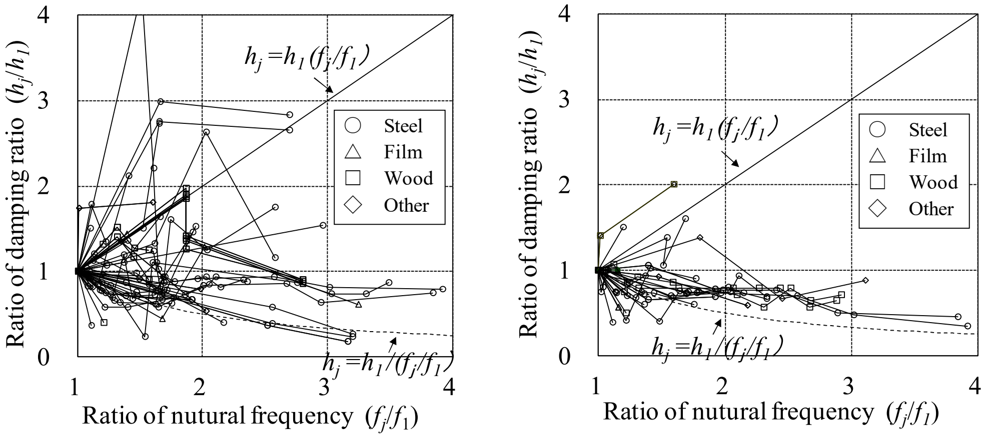

Fig. 7 – Frequency dependency of damping ratios
(Left: Microtremor measurement, Right: Free vibration test)

3.4 Effect of nonstructural elements to damping ratio

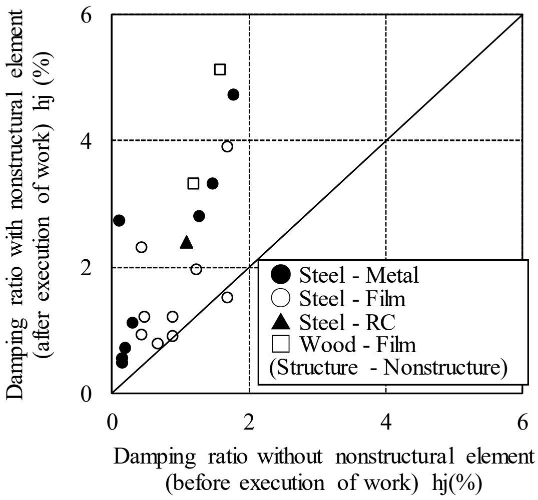

Fig. 8 –Change of damping ratios before and after execution of work

There are several papers or reports about changes of damping ratios before execution of work and those after execution of 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 Fig.8.

From the results, it is understood that the magnitude of damping ratios after execution of work are about two times of those of before execution of 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

Experimental measurements and analyses of several shell and spatial structures were carried out by Shingu Laboratory at Nihon University and others, reference research on damping evaluation of shell and spatial structures was carried out based on references in Japan, and the data base of damping ratios of 55 shell and spatial structures has been made.

1) Based on the database consisting of 55 shell and spatial structures, damping ratio evaluation of shell and spatial structures had been carried out.
2) Estimation damping ratios of shell and spatial structures have been proposed in Eq.(1) and Eq.(2) as the parameter of the spans of the structures, and as the parameter of the rises of the structures in Eq.(4) and Eq.(5).
3) There is damping ratio’s dependency by the scale of the structure.
4) There is damping ratio’s dependency by amplitude of vibration.
5) There is damping ratio’s dependency by frequency.
6) Effect of damping ratio by nonstructural elements is very large. The magnitude of damping ratios after execution of work are around two times of those of before execution of work.
7) As the constitution number of the database of shell and spatial structures is not so large, high correlation equations are not obtained yet. It is urgent work to grasp damping characteristic of the structure correctly as shell and spatial structures are often used for evacuation facilities in the case of disasters. In near future, the database is expected to be enlarged.

5. Acknowledgements

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6. References

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