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Some Empirical Facts on Damping of Bridges

Quelques données empiriques sur l'amortissement des ponts

Einige empirische Tatsachen über Dämpfung von Brücken

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1. INTRODUCTION

In the dynamic analysis of bridges, the structural damping has been treated as linear within the elastic range of structure. Therefore, the hysteretic damping is scarcely taken into account with bridge structures. Another important feature of the damping of bridge is the difference in its characteristics between superstructures and substructures. The damping values for piers are widely scattered as those for buildings, while those for bridge superstructures fall within a relatively narrow range of low values [1].

The present contribution consists of two parts: one deals with the empirical facts extracted from the vibration measurements with existing bridges and another is the report of two model tests which were conducted to obtain some qualitative natures of the damping of bridge superstructures. The former is a kind of supplement to the previous paper [2] by two of the present authors. The accumulation of experimental data of damping is mostly necessitated for the more reliable dynamic analysis of structures, because the damping of structures should be relied upon empirical estimation.

2. VIBRATION DAMPING OF EXISTING BRIDGES

2.1 Vertical Vibration of Bridge Superstructures

Early experimental studies on the damping of bridges were made mostly for the vertical vibrations of superstructures in order to gather information on the impact effect of moving vehicles. Most of the available results are the damping of the fundamental mode of vibration. However, data from several recent tests seem to indicate that damping factors (or logarithmic decrement) associated with higher modes of vibration are of the same order as that of the fundamental mode. Though material damping of concrete is at least several times greater than that of steel, at present it is difficult to obtain any definite relation between the damping and the material used for bridge superstructure. This seems to suggest that the damping of bridge superstructure is mostly governed by the energy dissipation at joints, joint interfaces and supports. By plotting damping against span length it was found that the damping values of bridge superstructures with span lengths less than 40 m show larger scatter than those with span lengths greater than 40 m and that the former are greater than the latter on the average [2]. This tendency can be seen in Fig. 1 in which data for suspension and cable-stayed bridges are shown separately from other types of bridges. Damping values of different modes of vibration were counted as independent data and those for torsional as well as vertical vibrations were included for the case of suspension and cable-stayed bridges. Simple averaging gives damping factor h = 0.016 (logarithmic decrement δ = 0.102) for spans less than 40 m, h = 0.013 (δ = 0.084) for spans greater than 40 m, and h = 0.009 (δ = 0.058) for suspension and cable-stayed bridges. Fig. 2 shows the damping values of suspension and cable-stayed bridges versus their span lengths. The values are generally in a narrow range, h = 0.003 to 0.013 (δ = 0.02 to 0.08), except for several cases. Though only estimated values are available for suspension bridges with longer span lengths, they also fall in the range mentioned above. A value of δ = 0.03 is adopted for the structural damping of the suspended structures of long-span suspension bridges in Japan for the aerodynamic stability analysis.

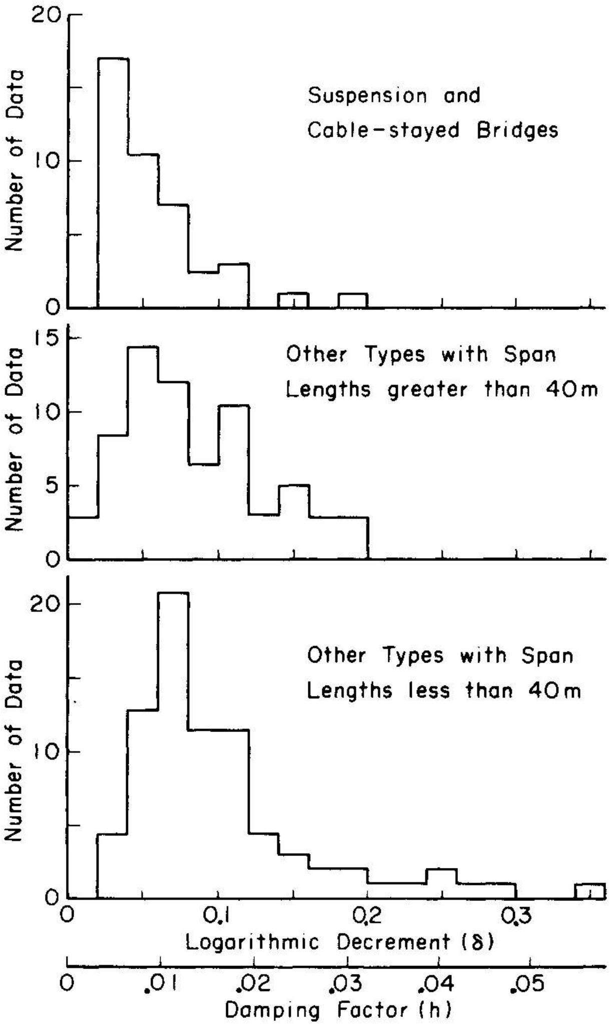

Fig. 1 Distribution of Damping Values of Bridge Superstructures

2.2 Torsional Vibration of Bridge Superstructures

The damping value for torsional vibration has been believed to be generally higher than that for bending vibration in the same structure. In suspension bridges and cable-stayed girder bridges, however, the logarithmic decrements for both vibrations are found comparable each other [3], the data for other types of structure having short and medium span length are not available though.

2.3 Horizontal Vibration of Whole Bridge System

In the earthquake resistant design of bridge structures, the dynamic behaviors of a whole bridge system in horizontal directions play the most important role. In last fifteen years in Japan, a number of dynamic tests were carried out for bridge foundations, piers, and completed bridges. Emphasis in these tests were placed on the investigation of horizontal dynamic behaviors both in lateral and in longitudinal directions. Most of these tests were performed by using vibration generator mounted on a structure.

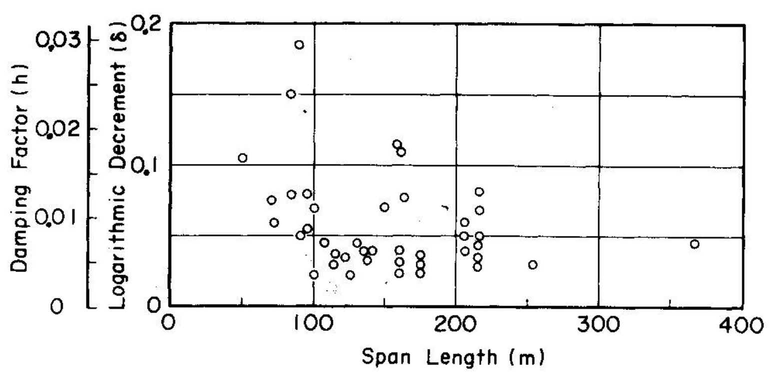

Fig. 2 Damping of Suspension and Cable-stayed Bridges vs. Span Length

In Fig. 3 are shown damping

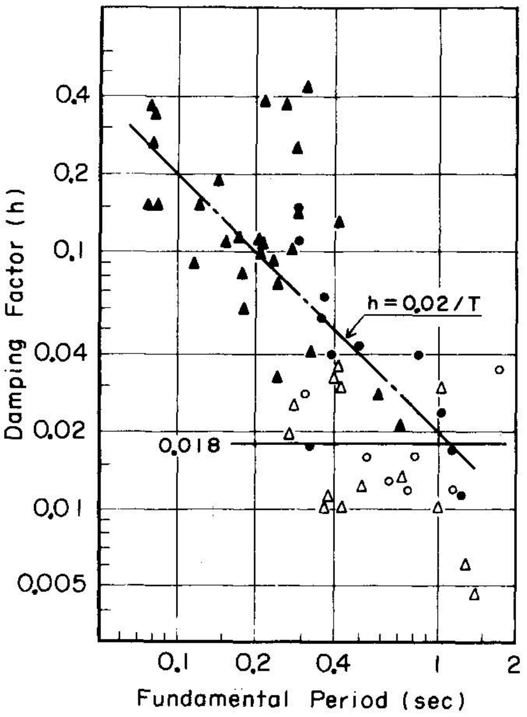

Fig. 3 Relation between Damping and Natural Period for Horizontal Fundamental Mode of Vibration (▲: Foundations and ordinary piers, ●: Bridges and ordinary piers, △: Tall piers with height greater than 25 m, ○: Bridges on tall piers)

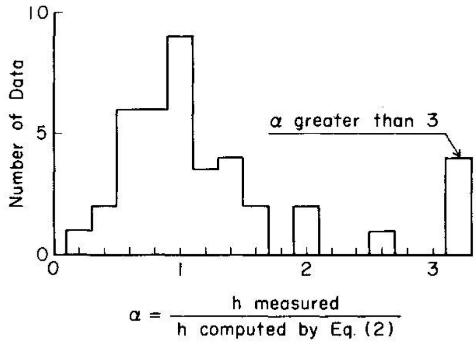

Fig. 4 Scatter of Data about the Line $h = 0.02/T$

factors of the fundamental mode of vibration for foundations, foundation-pier systems, and foundation-pier-superstructure systems. Most of the data in Fig. 3 were taken from Ref. [4] and twelve data from other sources were added. Data are divided into two groups, namely those for ordinary short piers and those for tall piers with heights greater than 25 m. There is a significant difference between the two groups of data though damping factors of bridge structures with fundamental periods longer than 0.4 sec are usually between 0.01 and 0.04 regardless of the types of piers. The least square fitting on the log-log basis for 40 data of foundations, ordinary foundation-pier and ordinary completed bridge systems gave a relation between the damping and the period as

$$h = 0.0228\ T^{-0.97} \qquad (1)$$

which confirms the usefulness of the approximate formula

$$h = 0.02/T \qquad (2)$$

proposed by Kuribayashi and Iwasaki for the estimation of damping factor of the types of structures mentioned above [4]. However, it should be noted that the deviations of actually measured values from the values calculated by Eq. (2) are often very great as shown in Fig. 4 indicating the complexed nature of damping mechanisms in actual structures. On the other hand, damping factors of tall piers and bridges on tall piers are not strongly dependent on natural periods. The simple average is $h = 0.018$ ($\delta = 0.116$) and the scatter of 20 data about the average is shown in Fig. 5.

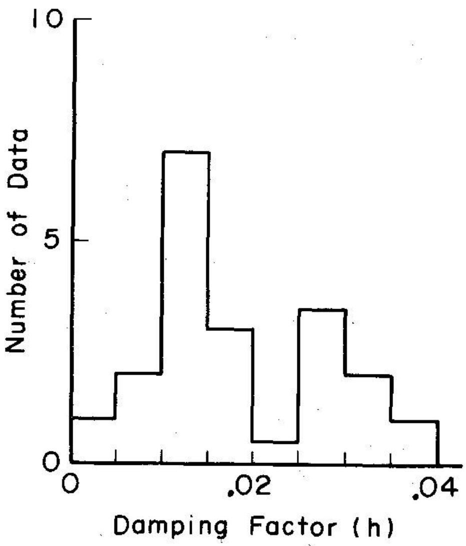

Fig. 5 Scatter of Damping Factors for Tall Piers and Bridges on Tall Piers

For the dynamic analysis of flexible structures with long fundamental natural periods, it is often necessary to assume damping of higher modes of vibration. In order to investigate the damping associated with higher modes of vibration, the ratios h_1/h_2 of damping factors of the two lowest measured modes are plotted in Fig. 6 against the ratios T_1/T_2 of the corresponding periods. It is difficult to find any definite relation between these quantities but most of the h_1/h_2 values are close to or slightly less than unity except for several cases. However, it should be borne in mind that a vibration generator cannot usually excite a mode in which deformation of the foundation in the ground dominates and for which damping may be substantially greater than the observed values.

Table 1 Standard Values of Damping Factors for Bridges

			Damping Factor (h) Average	Damping Factor (h) Minimum
Superstructures in Vertical Vibration	Suspension and Cable-Stayed Br. (Torsional Vibr. Included)		0.009	0.005
	Other Types	Span Length > 40 m	0.013	0.005
		Span Length < 40 m	0.016	0.005
Whole Bridge System in Horizontal Lateral and Longitudinal Vibr.	Bridges on Short Piers		$0.02/T$	$0.01/T$
	Bridges on Tall Piers with Height Greater Than 25 m		0.018	0.01

2.4 Standard Damping Values of Bridges

The standard damping values of bridges for engineering purposes were estimated from the results of the foregoing study and are summarized in Table 1. If a vibrational mode of a whole bridge system is known to be the one in which soil-foundation interaction effect is great, a larger damping factor may be assumed (possibly 0.1 to 0.2) for that particular mode even for bridges on tall piers.

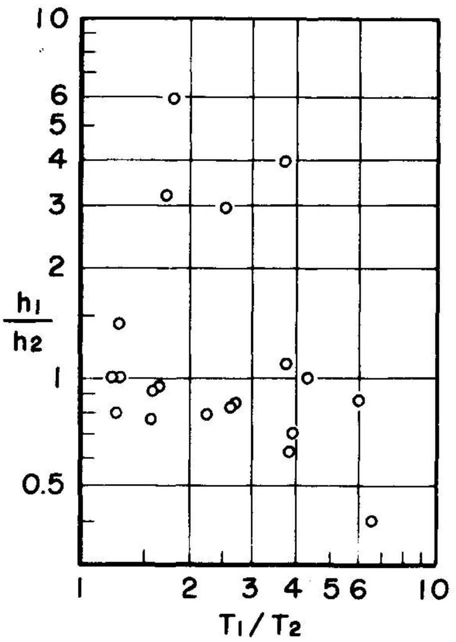

Fig. 6 Relation between h_1/h_2 and T_1/T_2

3. FINDINGS FROM MODEL TESTS

3.1 Effects of Mode, Mass and Rigidity

Aiming mainly to know the damping characteristics of very higher modes of vertical vibration, a flexible suspension bridge model having a single span length of 8 m was used in the experiment. The effects of various factors, such as mass, flexural rigidity and supporting conditions of the stiffening girder, were also investigated.

When other conditions are the same, the following findings were obtained from the experiments:

1) The effect of mode The free vibration tests were conducted up to such a higher order of mode as having eighteen nodes. As seen in an example in Fig. 7, the

logarithmic decrement tends to increase at higher modes of vibration, especially in case the rigidity is large. However, this trend is somehow contrary to the previous tests with different models [2]. It seems that the damping value is sensitive to various other structural factors, but the present result appears to give general characteristics.

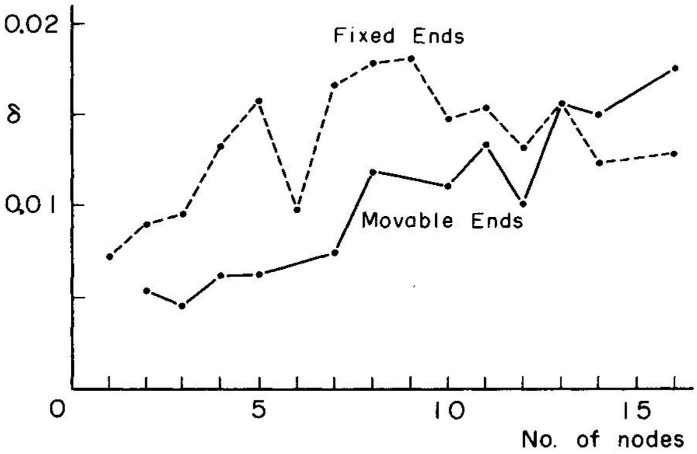

Fig. 7 Damping vs. Modes of Suspension Bridge Model

2) The effect of mass Increasing mass of the girder augments the logarithmic decrement, but quantitative analysis could not be made because of the shortage of data.

3) The effect of flexural rigidity In many cases less rigidity brought on less damping, but this tendency was not clear. The change in rigidity did not affect so much on the damping of symmetric modes and very higher modes of vibration.

4) The effect of amplitudes The damping values seem to increase with increasing amplitudes at higher modes of vibration. Judging from other data [3, 4], however, they are independent on the amplitude in the range of small displacement.

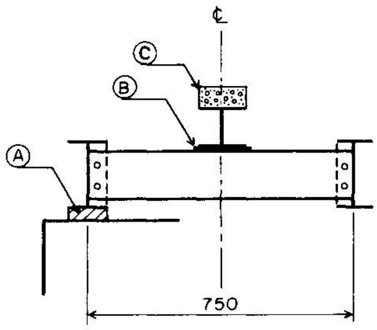

Fig. 8 Cross Section of Model Girder

5) The effect of supporting condition The Coulomb's damping due to the movement of supports is said to play an important role in long-spanned bridges. Three cases were tested: both ends movable, one end pinned and both ends pinned. Distinct differences were not observed, but the case of movable support showed larger damping values particularly at lower asymmetric modes. It must be noted that the friction at movable bearings was very small in the present model.

Table 2 Results of Girder Test

Combination of device	Log. Decrement	Efficacy*
Without any device	0.034	
(1) Rubber shoe	0.064	O
(2) Rubber slide-plate	0.070	O
(3) Concrete block movable	0.096	O
(4) Stringer movable	0.050	Δ
(1) + (2)	0.074	X
(1) + (3)	0.097	X
(1) + (4)	0.109	O
(2) + (3)	0.108	Δ
(2) + (4)	0.120	O
(3) + (4)	0.072	X
(1) + (2) + (3)	0.081	X
(1) + (2) + (4)	0.181	O
(1) + (3) + (4)	0.078	X
(2) + (3) + (4)	0.117	Δ
(1) + (2) + (3) + (4)	0.141	Δ

* O··· good, Δ··· moderate, X··· poor

3.2 Effects of Structural Assemblage

Making use of a simply-supported girder model, the section of which is as shown in Fig. 8, the effects of interface damping on the overall damping were tested. The arrangements for this purpose are as follows, referring to Fig. 8:

Ⓐ Bearings of girder Three types of supporting conditions: both ends movable, one end fixed and both ends fixed, and two kinds of bearing materials: rubber and iron plate, were compared in their combination.

Ⓑ Stringer With and without a stringer. When with it, the stringer was placed movable on the slide-plate of rubber or gunmetal attached to cross-beams, and the torque to tighten bolts connecting the stringer was also varied.

Ⓒ Concrete blocks With and without concrete blocks on the stringer. When with them, the concrete blocks were either connected or not connected with the flange of girders.

The results of free vibration tests indicate that such devices as increasing the friction between different structural parts and contributing to energy dissipation, can augment the overall damping of structure to some extent, but their combination does not always bring about the algebraic superposition of each effect. These situations are illustrated in Table 2.

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SUMMARY

The standard damping values of bridges for engineering purposes are estimated from the results of survey on existing bridges. Furthermore, two model tests were conducted to know the effects of various factors on the overall damping of superstructures. The damping values seem to be generally increased, but not so remarkably, with increasing order of modes and mass of structure. The influence of interface friction between different structural elements is also reported.

RESUME

Les valeurs d'amortissement courantes des ponts du génie civil sont estimées grâce aux résultats des expertises faites sur des ouvrages existants. De plus, on a réalisé deux essais sur modèle pour connaître les effets des différents facteurs sur l'amortissement global des superstructures. Les valeurs d'amortissement semblent généralement augmenter, suivant un ordre croissant selon le type et la masse de l'ouvrage. On montre aussi l'influence des frottements internes entre les différents éléments de la structure.

ZUSAMMENFASSUNG

Die Standardwerte für Brückendämpfung zu Ingenieurzwecken werden aus Resultaten von Beobachtungen an bestehenden Brücken geschätzt. Ferner werden zwei Modell-Versuche beigefügt zwecks Erforschung der Auswirkung verschiedener Faktoren auf die globale Dämpfung des Ueberbaus. Die Dämpfungswerte scheinen generell, jedoch nicht sehr ausgeprägt, mit zunehmender Ordnung der Schwingung und der Masse des Tragwerkes zu wachsen. Der Einfluss der inneren Reibung zwischen verschiedenen Bauteilen wird ebenfalls behandelt.