DAMPING OF BRIDGE STRUCTURES

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The quantitative estimation of damping effect is necessitated, when the dynamic response of a structure to such a time-dependent external force as gusty wind, earthquake, or rolling stock on it, is to be obtained. However, it is said impossible to estimate the overall damping of a structure theoretically and one is forced to know it empirically. The present paper is concerned with the damping of bridge superstructure within its elastic range, and consists of the following three parts to contribute the above-mentioned requirement. The authors should like to place special emphasis on Part III in which many data of the logarithmic decrements measured so far with the actual bridge structures in Japan and other countries, were collected and analyzed.

Part I. Concepts of Structural Damping

The followings are the conventional equations of motion for a beam where internal damping exists,

$$m\frac{\partial^2 y}{\partial t^2} + 2\kappa m\frac{\partial y}{\partial t} + EI\frac{\partial^4 y}{\partial x^4} = f(x,t) \qquad \cdots\cdots(1)$$

$$m\frac{\partial^2 y}{\partial t^2} + r_i\frac{\partial^5 y}{\partial t\,\partial x^4} + EI\frac{\partial^4 y}{\partial x^4} = f(x,t) \qquad \cdots\cdots(2)$$

$$m\frac{\partial^2 y}{\partial t^2} + EIe^{2bi}\frac{\partial^4 y}{\partial x^4} = f(x,t) \qquad \cdots\cdots(3)$$

where y is the deflection, m the mass per unit span-length, EI the flexural rigidity of the beam, $f(x,t)$ the external force, and κ, r_i , b are the constants related to the damping effect.

From Eq. (1) seen in the book by C. E. Inglis, the logarithmic decrement for n-th mode is obtained as

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$$\delta_n = \frac{2\pi\kappa}{\omega_n} \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

in which ω_n is the natural circular frequency. If κ is assumed constant in Eq. (4), the higher the mode is, the smaller the value of δ_n. According to the experimental results obtained by the authors from a model test, it seems to be $m^2\kappa \fallingdotseq$ constant. Consequently, the damping force in Eq. (1) is inversely proportional to the mass of a beam.

On the other hand, the logarithmic decrement from Eq. (2), in which the damping force is assumed to be proportional to strain velocity, is

$$\delta_n = \gamma_i \pi \omega_n \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (5)$$

If γ_i is a const, δ_n will become very large in the higher modes of vibration. However, the model tests conducted by the authors reveals that δ_n decreases gradually with increasing order of mode and seems to approach a constant value for the extremely higher modes.

Eq. (3) based on the concept of complex damping leads to a constant decrement independently on mass nor mode, but this fact was not observed in the author's model tests.

Part II. Experimental Study of Bolted Joints

For the purpose of knowing the effect of the existence and the rigidity of a joint, the magnitude of strain amplitudes and the presence of intervened elasto-plastic material upon the damping characteristics, the static and dynamic experiments of cantilever steel beams having I-shaped section with or without a bolted joints in it were carried out.

The rigidity of the joint was defined by

$$S = k\,N\,T \cdots\cdots\cdots\cdots\cdots\cdots (6)$$

where N is the number of bolts, T is the torque applied to a bolt, and k is a constant.

The free vibration tests of the beam demonstrated the following facts:

1) In a specimen with a bolted joint, the logarithmic decrement δ could be considered as almost constant for small amplitudes, while δ rapidly increases when the amplitude exceeds a certain value as seen in Fig. 1. This transition amplitude increases if the rigidity of joint is augmented.

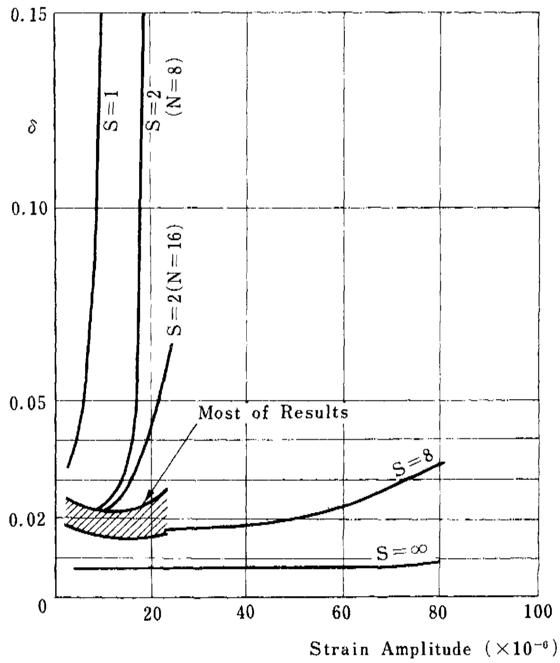


Fig. 1. Amplitude—Logarithmic Decrement

2) Fig. 2 shows that the δ values of a beam with a bolted joint decrease with increasing rigidity of the joint and consequently with increasing frequencies. However, as far as the joint is present, these δ values will be never smaller than about the double of that for a specimen without any joint.

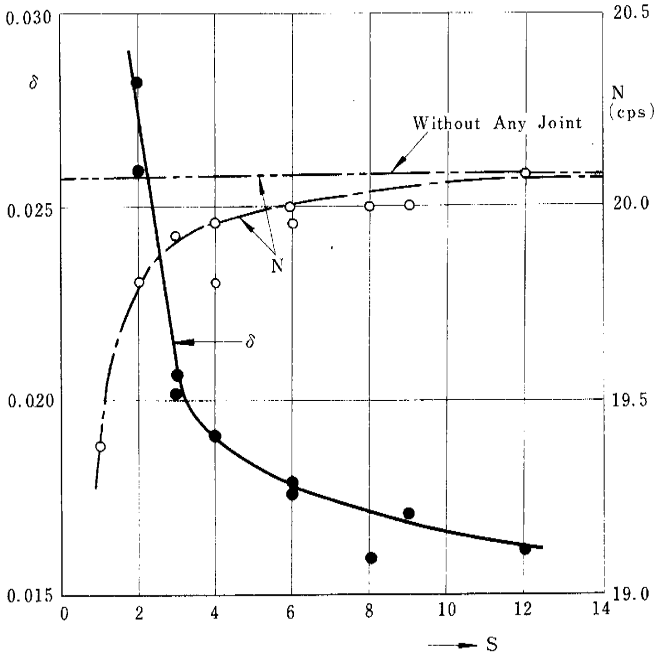


Fig. 2. Rigidity of Joint (S)—Frequency (N), Damping (δ)

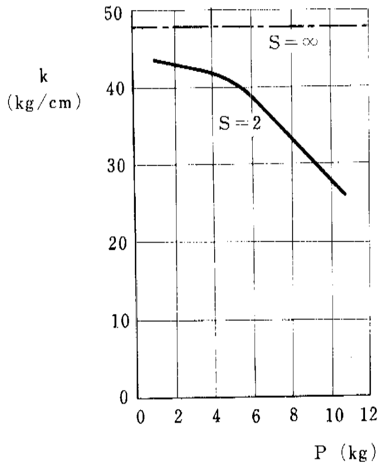
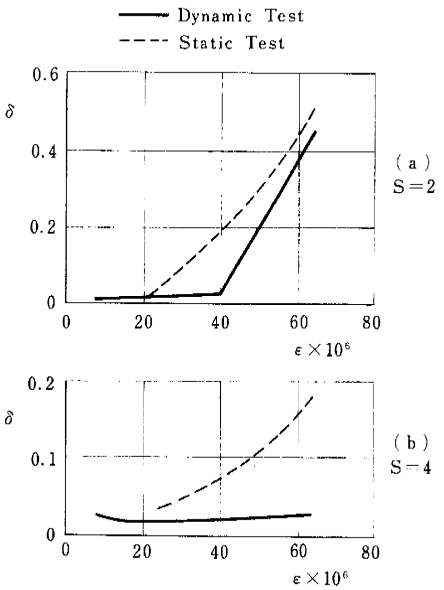


Fig. 3.
Change in Overall Rigidity of Beam (k) due to Load Amplitude (P)



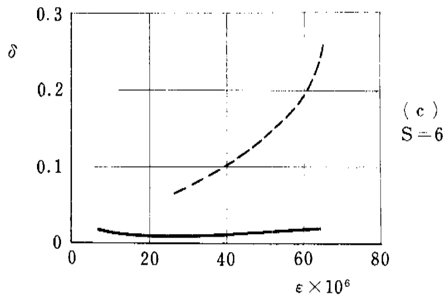


Fig. 4. Comparison of Logarithmic Decrements (δ) obtained from Vibration Test and Hysteresis Loop (ε : strain amplitude)

3) The existence of elasto-plastic material inserted between flange and splice plates did not affect the frequencies and decrements in this experiment.

The hysteresis loops for the specimens were obtained by conducting the static cyclic loading test. These indicate a softening-type curve, and the overall rigidity of a beam gradually decreases with increasing amplitudes as shown in Fig. 3. The logarithmic decrements δ_s calculated from the hysteresis loops mentioned above are compared with the δ value obtained from the free vibration tests (Fig. 4). The former rapidly increases with increasing amplitudes and is much larger than the latter, especially for large amplitudes and large rigidity. It seems to be such a mechanism that the slip at joint can not follow the velocity of motion in this case.

Part III. Damping of the Superstructure of Bridges

The authors collected and analyzed the values of logarithmic decrement δ for many bridges, the reports of which have been published so far. The number of the data totals 108, among which 40 simple girder bridges, 19 cantilever bridges, 17 contineous bridges, 6 arch bridges and 26 suspension bridges are involved. The main conclusions of the study are summarized as follows:

1) In Fig. 5 the δ values are plotted against the span-length of bridges. Generally speaking, the δ values for the long span bridges having the span-length of more than 40 m lie in a relatively narrow range, that is δ = 0.02 - 0.11, independently upon the span-length nor the type of structure. On the other hand, the δ values for short spans are scattered a lot depending upon the type of structure. Accordingly, it will be said that the internal damping is dominant in short span bridges, while the energy dissipation at supports and the atmospheric resistance will be of importance for the dampening effect in long span structures.

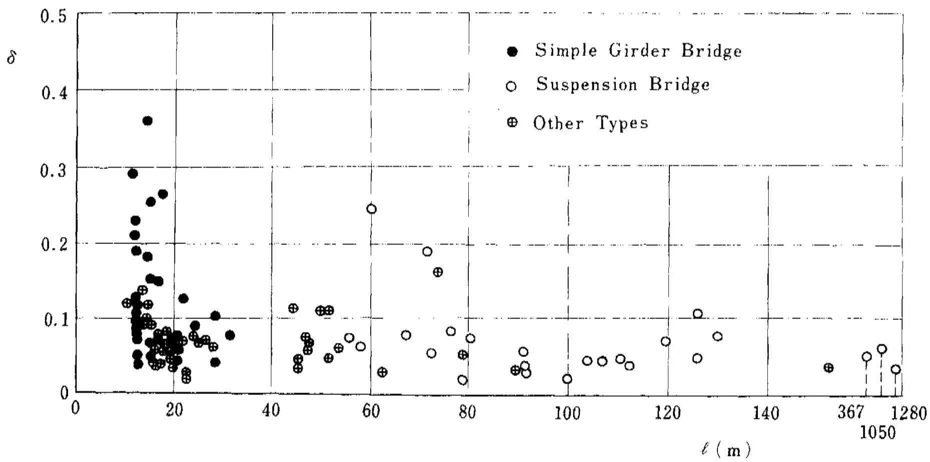


Fig. 5. Span—Logarithmic Decrement

2) The relation between the δ values and the type of structures is illustrated in Fig. 6. The cantilever bridges are considered to have very low damping capacity compared

with other types, judging from the fact that those measurements were made have a relatively short span as seen in Fig. 7.

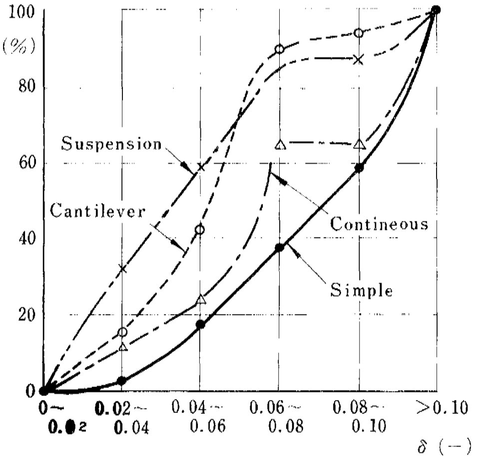


Fig. 6. Accumlative Distribution of Total Data according to Logarithmic Decrement

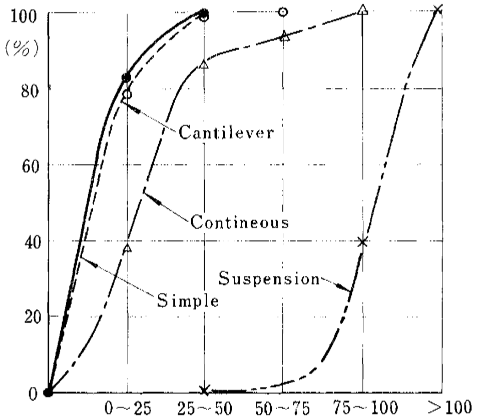


Fig. 7. Accumlative Distribution of Total Data according to Span-length

3) The suspension bridges, besides a few exceptions, have low damping value, δ = 0.02 - 0.08, independently on their span-length and types of stiffening frame.

4) The difference of damping nature in steel bridges and concrete bridges is not definitely observed. In steel bridges, the damping for plate girder bridges are generally low as compared with other types of girder bridges, and prestressed concrete bridges have lower δ values than reinforced concrete bridge.

5) Rivetted or bolted structures have approximately the twice dampening effect as that in welded structures.

6) In the rigid frame structures which have the monolythic substructure, the weaker the foundation is, the larger its dampening effect.

7) The relation between the values of logarithmic decrement and the magnitude of amplitude is not definite. However, for long span bridges, the δ values will increase with increasing amplitudes owing to the effect of atmospheric resistance and the friction at supports.

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