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FUNDAMENTAL STUDY ON RELIABILITY-BASED DESIGN OF BRIDGE WITH SLIDING TYPE BASE-ISOLATION SYSTEM

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ABSTRACT

The influence of variation of physical properties such as frictional coefficient on the dispersion of dynamic response of bridge with sliding type base-isolation system is discussed. It is also investigated whether the reduction of pier size is possible or not at the design stage of sliding type base-isolated bridge.

KEYWORDS

Bridge; base-isolation; sliding type bearing; dynamic behavior; reliability-based design; Monte Carlo simulation

INTRODUCTION

The bridge with sliding type base-isolation system which is composed of sliding bearings and rubber restoring force devices has been proposed(Okamoto *et al*,1995a). The advantageous points of this type of base-isolated bridge are as follows; 1)the response of bridge decreases as a result of large energy dissipation through the sliding bearing and this leads to the considerable reduction of shear force of pier; 2)the resonant excitation is unlikely to occur because of the large energy dissipation of the sliding system. And these characteristics have been confirmed based on experimental and analytical studies(Okamoto *et al* 1995a and b).

In case that the reliability-based concept may be applied to the design of the bridge with sliding type base-isolation system, however, the influence of variation of physical properties regarding to the sliding bearing and the rubber restoring force device on the dispersion of the dynamic response during earthquake should be considered. Specifically speaking, frictional coefficient of sliding bearing material and horizontal stiffness of rubber restoring force device should be treated as random variables.

On the other hand, although the reduction of shear force which acts on the top of pier leads to the lower construction cost, the decrease of the size of pier may cause the larger response because of the lower stiffness of pier. Therefore, it is important to investigate whether the reduction of pier size is possible or not at the design stage of sliding type base-isolated bridge.

The purpose of this study is to discuss how the variation of frictional coefficient of sliding bearing and horizontal stiffness of rubber restoring force device may influence on the dispersion of dynamic response of bridge. The Monte Carlo simulation method is adopted in this discussion. It is also discussed how many percents the size of pier can be reduced in case that sliding type isolation system is installed.

OUTLINE OF SLIDING TYPE BASE–ISOLATION BRIDGE

The bridge with sliding type base–isolation system is composed of sliding bearings and rubber restoring force devices as shown in Fig. 1. Each sliding bearing is constructed mainly from Teflon sheet and stainless steel plate. The function of rubber restoring force device is to restrict the relative displacement between bridge deck and pier during earthquake to an allowable limit.

The experimental work to obtain information of the frictional properties of Teflon–stainless steel interfaces was conducted (Mokha *et al*, 1988). And it has been revealed that only the relation between frictional coefficient and sliding velocity as shown in Fig. 2 should be considered in the dynamic analysis (Okamoto *et al*, 1995b). Experimental result about the property of restoring force of rubber devices has been also obtained as shown in Fig. 3.

ANALYTICAL MODEL

The analytical model adopted in this study is a lumped mass model with a sliding element, a linear spring and a viscous damper as shown in Fig. 4. The sliding element is modeled as a non–linear spring element expressed by Eq. (1) which is obtained from Fig. 2.

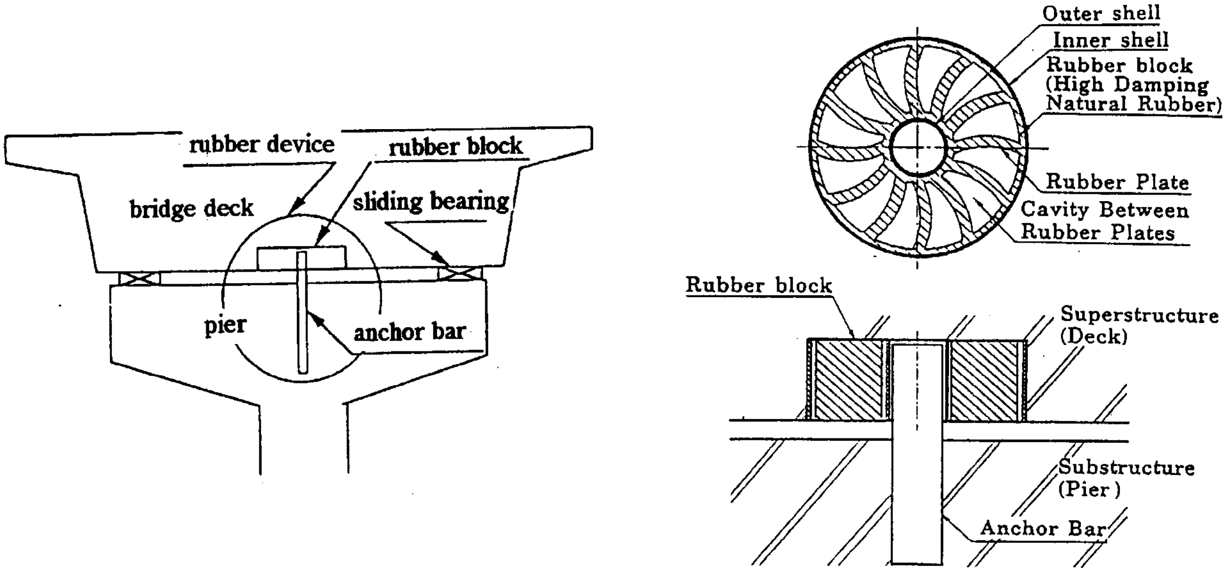


Fig. 1. Schematic diagram of sliding type base–isolation system

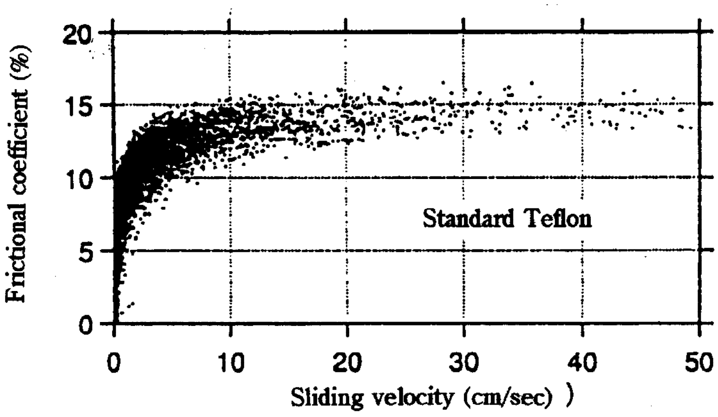


Fig. 2. Relation between frictional coefficient and sliding velocity

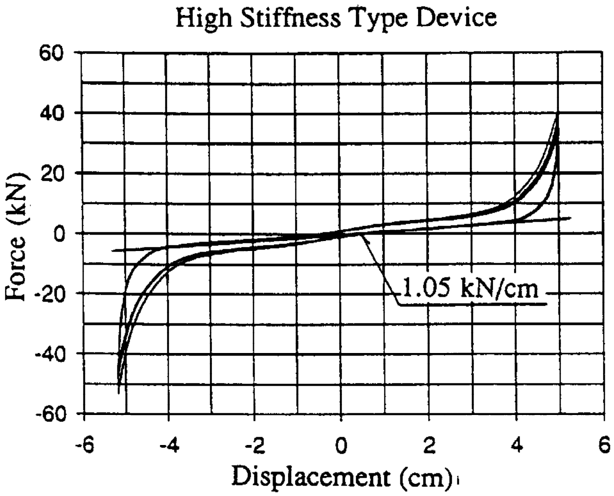


Fig. 3. Experimental result about the property of restoring force of rubber device

$$\mu = 0.14 - 0.075 \exp(-0.4v) \tag{1}$$

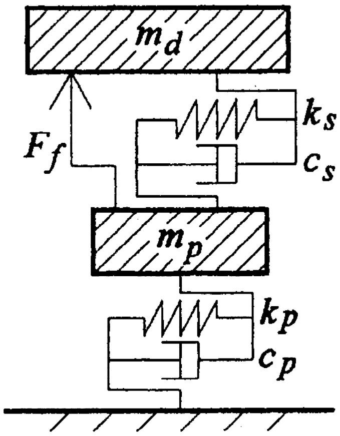
where μ : frictional coefficient of Teflon–stainless steel interface
v : relative velocity between bridge deck and pier

The restoring force is given by Eq. (2) as shown below.

$$F = a_1 x + a_2 x^3 + a_3 x^5 + a_4 x^7 \tag{2}$$

where F : restoring force caused by rubber device
x : relative displacement between bridge deck and pier
a_1 : constant = 1.36×10^{-2}
a_2 : constant = 1.45×10^{-5}
a_3 : constant = -2.42×10^{-8}
a_4 : constant = 1.05×10^{-11}

Eq. (2) is estimated from Fig. 3. The analytical model described above is the same as that adopted in Okamoto's study (1995 b).



m_d : lumped mass of bridge deck
m_p : lumped mass of pier
k_p : stiffness of pier
c_p : damping constant of pier
k_s : stiffness of rubber device
c_s : damping constant of rubber device
F_f : friction force (= $\mu \cdot m_d \cdot g$)
μ : frictional coefficient

Fig. 4. Analytical model of bridge with sliding type base–isolation system

The above two physical properties should be considered as random variables in case that reliability–based design concept is applied to the design of bridge with sliding type base–isolation system. Therefore friction coefficient and restoring force of rubber device (i.e. stiffness of rubber device) are assumed to be normally–distributed random variables whose mean values are given by Eq. (1) and Eq. (2), respectively. The values of coefficient of variation (designated COV afterwards) of each variable are changed from 0.1 to 0.5 parametrically. Other values such as damping coefficients of rubber device and pier and stiffness of pier are assumed to be constant.

For convenience, these two random variables are generated by Monte Carlo simulation method and the dynamic response of bridge is obtained by using these two values. The number of repetitions of simulation is 500 because the results became stable when it becomes greater than 200. The analytical model is subjected to the El Centro(NS) earthquake wave.

INFLUENCE OF VARIATION OF PHYSICAL PROPERTIES

As an example of the calculation results, the coefficient of variation of dynamic response of shear force which acts on the top of pier from bridge deck is shown in Fig. 5. In this figure, horizontal axis represents the value of COV of frictional coefficient and restoring force of rubber device. The vertical axis shows the value of COV of calculated shear force. Broken line , dotted one and solid one correspond to the following cases, respectively;

broken line : the case that only friction coefficient is assumed to be a random variable
dotted line : the case that only stiffness of rubber device is assumed to be a random variable
solid line : the case that both friction coefficient and stiffness of rubber device are assumed to be random variables.

From Fig. 5, it can be found that the value of COV of shear force is at most 0.092 and is considerably smaller than the values of COV of physical properties. Although not shown in figures or tables, approximately the same results have been obtained regarding to the dynamic responses of deck acceleration, pier acceleration, and relative displacement between deck and pier.

These results indicate that the influence of the variation of frictional coefficient and stiffness of rubber device on the scatter of response is negligible.

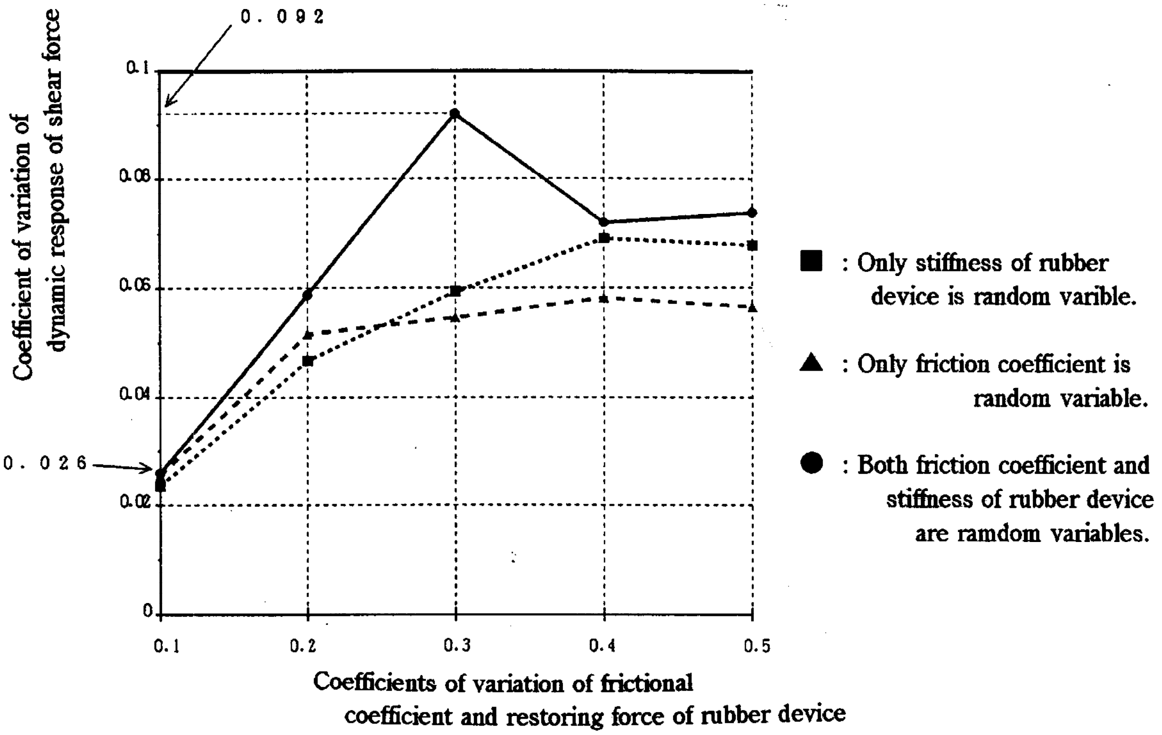


Fig. 5. Coefficient of variation of dynamic response of shear force vs. coefficients of variation of frictional coefficient and restoring force of rubber device

INVESTIGATION OF REDUCTION OF PIER SIZE

In the design of bridge pier based on Japanese Specification for Highway Bridges (Japan Road Association, 1990) (designated JSHB afterwards), shear force which acts on the top of pier from deck under earthquake motion is one of the principal loads. As this shear force is reduced if the sliding type base-isolation system is installed in the bridge, the construction cost of pier with base-isolation system may decrease. However, the decrease of the pier size may cause the larger response because of the lower stiffness of pier.

In order to investigate whether the reduction of pier size is possible or not at the design stage of sliding type base-isolated

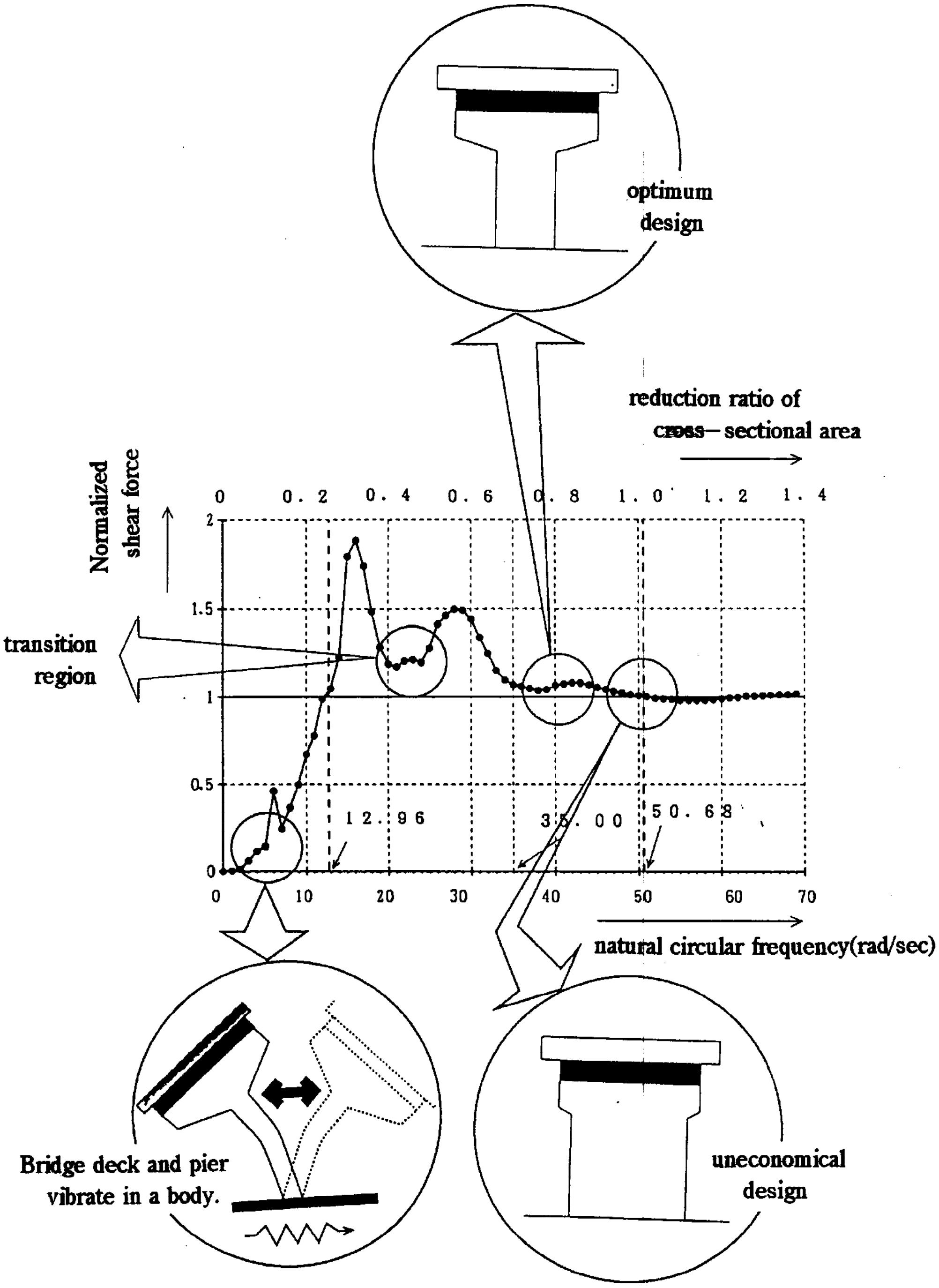


Fig. 6. Shear force which acts on the top of the pier vs. reduction ratio of cross-sectional area of bridge pier

bridge, the following attempt is made here;

- 1st step : design the reinforced concrete pier (RC pier) on which simply supported steel girder bridge deck of 20m span length without base-isolation system is set up based on JSHB;
- 2nd step : by executing the dynamic analysis where the simplified model as shown in Fig. 4 is adopted, obtain the maximum value of shear force S_{max} of the bridge with base-isolation system;
- 3rd step : changing the value of shear force arbitrarily, design the RC pier again and calculate its cross-sectional area and stiffness;
- 4th step : using the values calculated in the 3rd step, execute the dynamic analysis and obtain the maximum shear force S'_{max};
- 5th step : compare the value S'_{max} with S_{max}.

If the ratio S'_{max}/S_{max} is approximately equal to 1.0, it can be judged that the RC pier designed in the 3rd step can be adopted. That is, the reduction of construction cost of pier is possible.

Figure 6 shows the calculation results through the attempt described above. The horizontal axis represents the ratio of cross sectional area obtained in the 3rd step to that calculated in the 1st step and the vertical axis shows the ratio S'_{max}/S_{max} in Fig. 6.

From Fig. 6, it can be found that the value of S'_{max}/S_{max} is nearly equal to 1.0 if the ratio of cross-sectional area is greater than 0.7. This fact indicates that about 30% reduction of cross-sectional area is possible if the sliding type base-isolation system is set up to the simply supported bridge.

It is also found from Fig. 6 that the ratio of S'_{max}/S_{max} takes the value of greater than 1.0 if the ratio of cross-sectional area is between 0.3 and 0.7. In this region of the ratio of cross-sectional area, bridge pier itself becomes easy to vibrate because of its lower stiffness.

In the case that the ratio of cross-sectional area becomes less than 0.3, the ratio S'_{max}/S_{max} decreases rapidly. The reason may be as follows; because of considerably low stiffness of bridge pier, the relative displacement scarcely arises as illustrated in Fig. 6, that is, bridge deck and pier become to vibrate in a body.

Summarizing the above facts, it can be concluded that about 30% of the size of pier can be reduced if the sliding type base-isolation system is adopted.

CONCLUDING REMARKS

A fundamental study on reliability-based design of bridge with sliding type base-isolation system was conducted in this paper. The result has shown that the influence of the variation of frictional coefficient and horizontal stiffness of rubber device on the scatter of dynamic response is negligible. It has been also revealed that about 30% of pier size can be reduced if thesliding type base-isolation system is adopted.

As one of the future works, an attempt of dynamic analysis in which non-linear property of RC pier is considered is now being made.

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