DEVELOPMENT OF DESIGN MANUAL FOR SLIDING SEISMIC ISOLATION SYSTEMS FOR BRIDGES

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Abstract

PWRI has conducted two years joint research program in 2004-2005 fiscal year on the “Development of Sliding Seismic Isolation Systems for Bridges.” This program was made with 8 private companies including consulting firms and bearing makers. In the program, various research has been made including loading test of sliding bearings, shake table test of bridge models and numerical analyses. As a result of the program, the “Design Manual for Sliding Seismic Isolation Systems for Bridges” has been published. This paper presents the outlines of the research program and the developed design manual.

Introduction

The seismic isolation bridges using rubber type bearings as lead rubber bearings and high damping rubber bearings have been specified from 1996 Japan Road Association (JRA) design specifications, and have been constructed in particular after the 1995 Kobe Earthquake. However, this type of seismic isolation bridge has limitation of applicable sites and structural configurations depending on soil conditions including liquefaction effect, natural period, and others. Since the rubber bearings have functions as vertical and horizontal supports as well as a function of absorption of rotation displacement which is caused by live loads at the same time, the rubber bearing generally tends to be large in size and then sometimes loses the cost effectiveness. Also, it is necessary to absorb relatively large displacement at the bearings, so the designs of deck end space and expansion joints are also one of the important design points in the isolation design..

Recently, a function separated bearing in which vertical and horizontal forces are supported by different bearings such as sliding bearing and rubber buffer as shown in **Fig. 1**, have been developed and have began to be used in practical. The sliding bearing can ideally isolate the superstructure from substructures. When appropriate design is made considering the friction effect of sliding bearings, the equal or better isolation effect can be expected than usual isolation design using rubber type bearings. When the sliding bearing, which generally has much higher vertical support capacity, is used, the bearing size can be decreased comparing with the rubber type bearings. However, the effectiveness of the characteristics of sliding bearings and the performance of sliding seismic isolation bridges had not yet verified and then the practical design method has not yet established.

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Based on these background in the above, PWRI has conducted two years joint research program in 2004-2005 fiscal year on the “Development of Sliding Seismic Isolation Systems for Bridges” with 8 private companies including consulting firms and bearing makers. In the program, various research has been made including a series of loading test of sliding bearings, shake table test of bridge models and the numerical analyses. As a result of the program, the Design Manual for Sliding Seismic Isolation Systems for Bridges was developed. This paper presents the outlines of the research program and developed design manual. In the manual, design fundamentals, design model, performance verification method, and testing methods to verify the characteristics of isolation devices, and design details are specified. The loading tests and shake table tests conducted in the program, and the design examples, are also shown in the manual as references.

It should be noted here that the developed manual is written as a format of standard, but they are not the standard to be followed and just research outcomes.

Research Issues on Joint Research

In the program, the followings were the research points and issues.

(1) Development of Design Model of Sliding Seismic Isolation Systems
  1) Performance Requirement to Sliding Isolation Devices
  2) Verification of Performance and Dependency of Sliding Bearings
  3) Design Model of Sliding Bearings and Rubber Buffer
(2) Development of Performance Verification Methods of Sliding Seismic Isolation Bridges
  1) Verification of Effects of Earthquake response Characteristics of Sliding Seismic Isolation Bridges (including Effect of Vertical Ground Motion)
  2) Design Method and Design Details of Sliding Seismic Isolation Bridges
(3) Development of Design Manuals

These issues have been categorized into two parts, Design WG and Device WG, and have been studied jointly.

Design Manual

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The developed design manual consists of two parts. One is the design guidelines and the other is the related information including the tested data, design model and design examples. Attached is the table of contents of the manual.

Modeling of Sliding Isolation Devices

In the program, 4 types of isolation devices as shown in **Table 1** were studied. The sliding bearings with high, medium and low friction characteristics depending on used materials were studied. These sliding bearings are generally used with natural rubber bearings or energy absorption rubber bearings such as lead rubber bearings. The dynamic and static characteristics were studied through a series of loading tests of sliding bearings. **Fig. 2** shows typical force-displacement characteristics of the sliding bearing. Depending on the sliding material, the force-displacement characteristics show a hand drum shape or a square shape.

Figs. 3-5 show some of the tested data on the dependency of friction coefficient of sliding bearings on the surface pressure, loading velocity and temperature. The friction coefficient depends on surface pressure and velocity. In general, the friction coefficient decreases with the increase of surface pressure and the higher friction bearing has larger dependency on the surface pressure and velocity. The temperature dependency is not significant in the range of -20 to +40C.

Based on these loading tests, the nonlinear friction model was proposed for the sliding bearings. Eq. (1) shows the proposed model.

$$\mu(\sigma,v)=\mu'(\sigma)\left(1-e^{-Dv}\right)+\mu''(\sigma)e^{-Dv} \tag{1}$$

Where,

σ: Surface Pressure

v: Velocity

$\mu(\sigma,v)$: Dynamic Friction Coefficient considering the effect of Surface Pressure and Velocity

$\mu'(\sigma)=A\,\sigma^{B}$: Dynamic Friction Coefficient in High Speed Loading

$\mu''(\sigma)=C\,\sigma^{B}$: Dynamic Friction Coefficient in Low Speed Loading

A - D: Constants depending on Materials

Sliding Isolation Mechanisms and Verification of Design Method

Figs. 6-7 show the shake table test to verify the sliding isolation mechanisms and the design models. **Fig. 6** shows the model consisted of superstructure and sliding isolation devices. Four sliding isolation bearings were placed at the 4 corners and two rubber buffers were placed at the both ends. The reactions at each sliding bearing were measured using 3-directional load cells. The model was excited by sinusoidal waves and earthquake ground motion. The test points were the behavior the friction of sliding bearings and uplift effect by vertical ground motion. Regarding the vertical excitation, the behavior of the model with low and mid friction type sliding bearings were not affected by the vertical motion but that of the model with high friction type sliding bearing were affected. **Fig. 7** shows the model consisted of superstructure, sliding isolation devices and reinforced concrete column. The nonlinear interaction between isolation devices and the column were studied.

The proposed design models were verified through the simulation analyses of these shake table test results.

Acknowledgments

The joint research program has conducted with Kozo Keikau Engineering Inc., Pacific Consultants Co., Ltd., Yachiyo Engineering Co., Ltd., Oiles Corporation, Kawaguchi Co., Ltd., Sankyo Oilless Co., Ltd., Nippon Chuzo Co., Ltd., and BBM Co., Ltd. The authors wish to appreciate all of the members in the program for their hard work to in perform the program.

References

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PWRI and 8 Private Companies (2005), "Report on Development of Sliding Seismic Isolation Systems for Bridges," *PWRI Report of Joint Research Program, No.320*, Public Works Research Institute, Japan, (in Japanese).

Japan Road Association (ed.) (2002). "*Specifications for Highway Bridges, Part V: Seismic Design*"

Attached Material

Design Manual for Sliding Seismic Isolation Systems for Bridges
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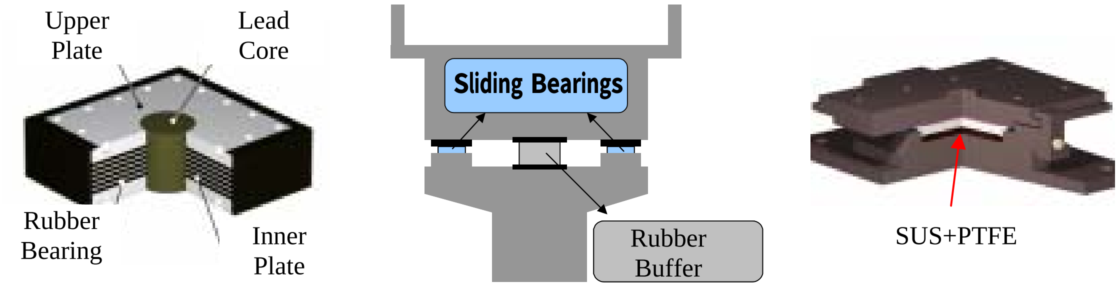
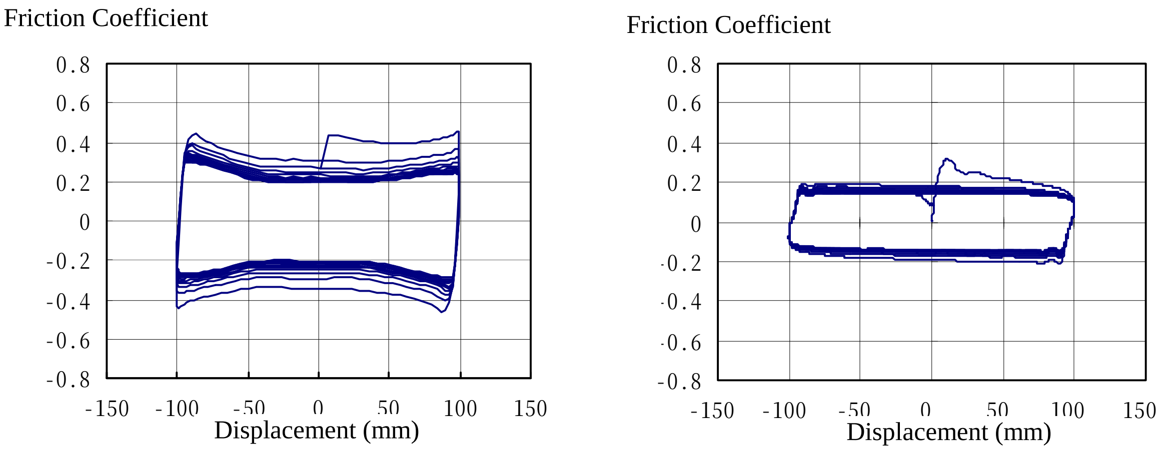
(in Japanese)



(a) Lead Rubber Bearing **(b) Sliding Isolation System** **(c) Sliding Bearing**

Fig.1 Sliding Isolation Systems



(a) Hand Drum Shape Type **(b) Square Type**

Fig.2 Examples of Force-Displacement Relation of Sliding Bearings

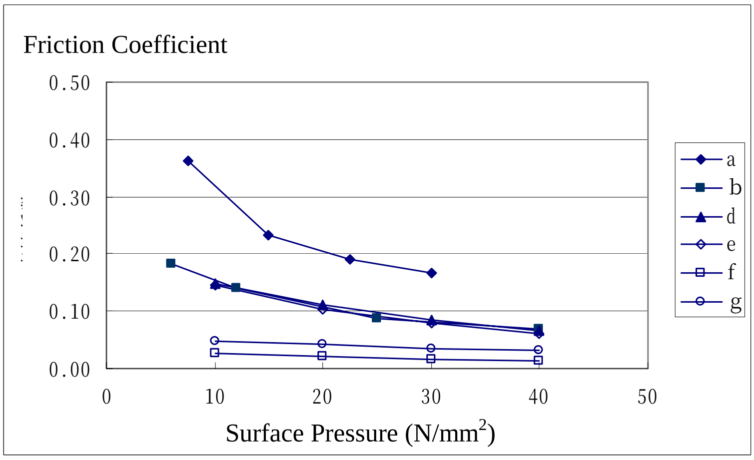


Fig.3 Dependency of Pressure on Friction Coefficient

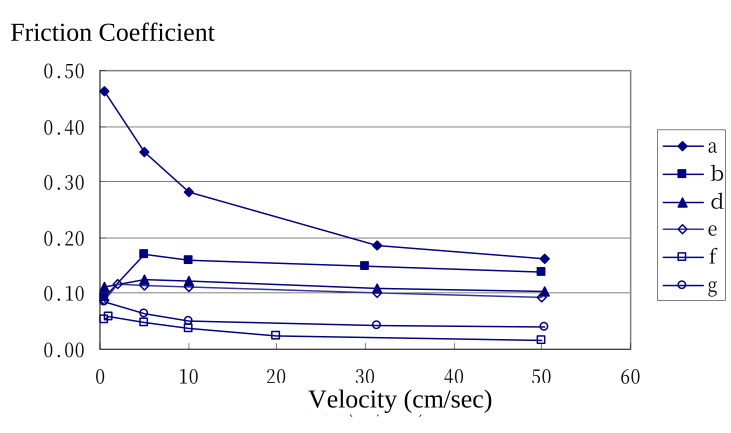


Fig.4 Dependency of Loading Velocity on Friction Coefficient

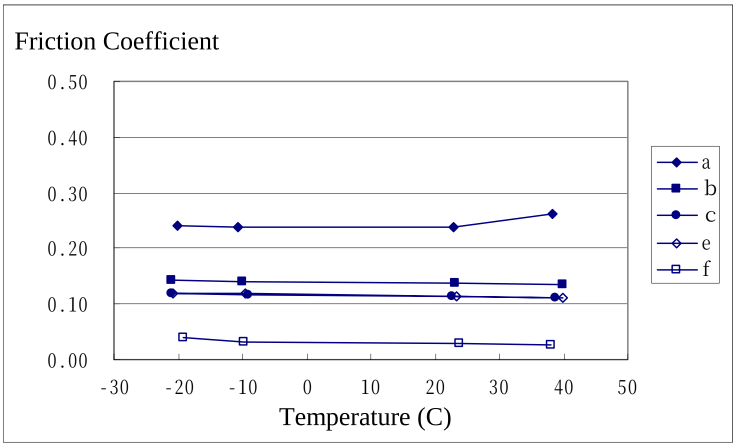


Fig.5 Dependency of Temperature on Friction Coefficient

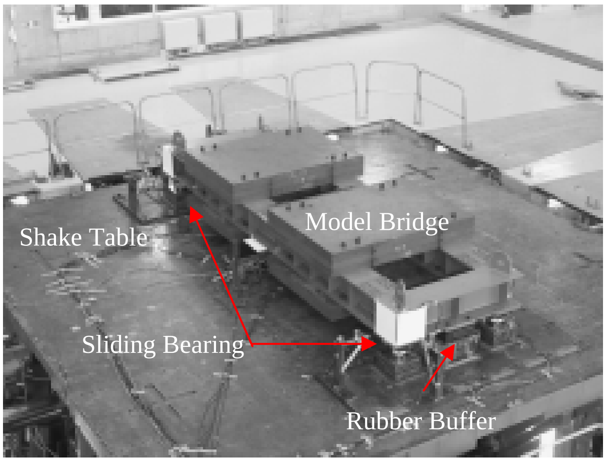


Fig.6 Shake Table Tests of Superstructure and Devices System

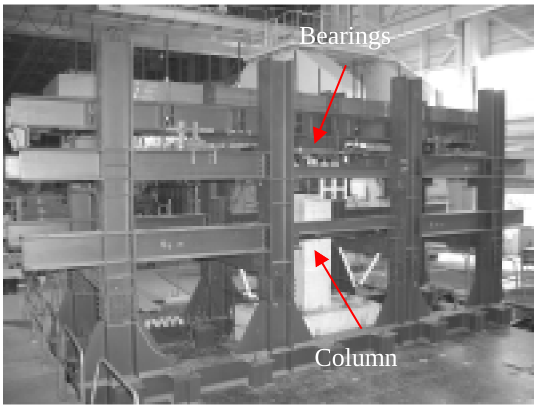


Fig.7 Shake Table Tests

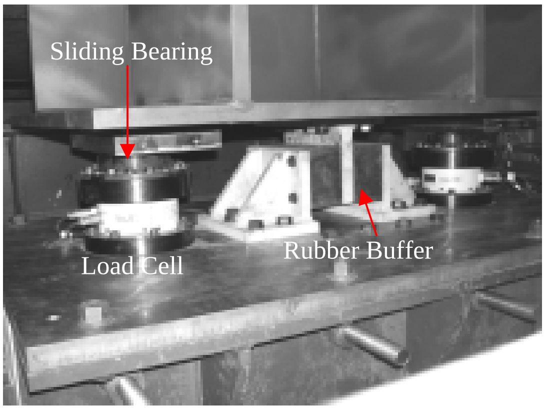
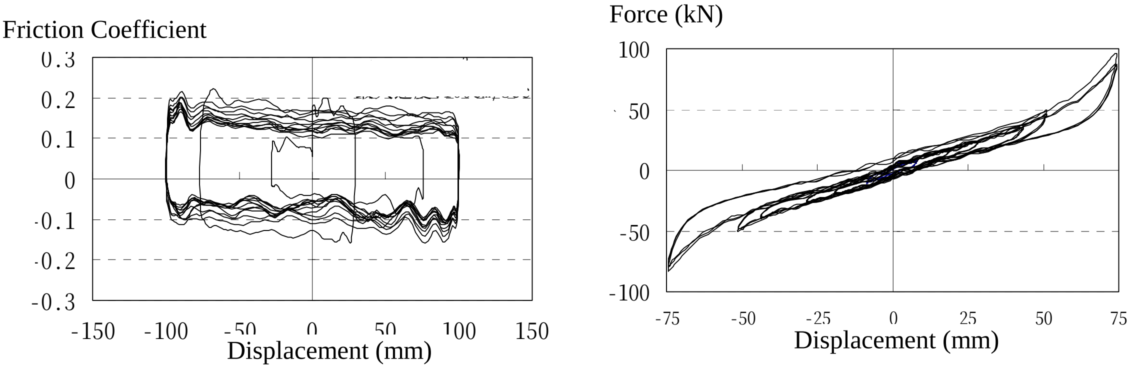


Fig.8 Sliding Isolation Systems



(a) Sliding Bearing **(b) Rubber Buffer**

Fig.9 Typical Force-Displacement Relation of Devices for Shake Table Tests

Table 1 Sliding Isolation Devices studied in the Joint Research

Friction Type	Sliding Material		Target Friction Coefficient (Surface Pressure N/mm^2)	Rubber Buffer
Mid	PTFE	SUS (Mirror Finish to No.3 and Better)	0.1-0.15 (12-20N/mm^2)	Combination with 1) Rubber Bearing 2) Lead Rubber Bearing
High	Sintered Steel	SUS (No.2 and Better)	0.25 (15N/mm^2)	
Low	AFRP	SUS (Fluorocarbon Resin Coating)	0.05 (20N/mm^2)	