UNIVERSITY AT BUFFALO–TAISEI CORPORATION RESEARCH PROJECT ON BRIDGE SEISMIC ISOLATION SYSTEMS

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3rd Workshop on Bridge Engineering Research in Progress
U.C. San Diego, Nov. 1992.

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SYNOPSIS

A cooperative University at Buffalo-Taisei Corporation research project on bridge seismic isolation systems started in June 1991 and will continue until May 1993. The objectives of the project are: to produce a class of passive sliding seismic isolation systems for bridges, to provide experimental verification of the systems by large scale shake table testing, to develop analytical techniques for interpretation of the experimental results, to develop design procedures for sliding bridge isolation systems and to disseminate the results to the engineering community and bridge authorities. A later phase will concentrate on in-situ determination of isolation system properties and on the implementation of the technology.

INTRODUCTION

Bridge seismic isolation systems in the United States and New Zealand have been so far entirely based on elastomeric bearings. In contrast, Italian engineers have been using for over fifteen years sliding bearings in bridge seismic isolation applications. A notable example of such application is the Mortaiolo Viaduct which consists of about 400 spans (total length of 19.2 km) and is supported by multi-directional sliding bearings with additional hysteretic dampers.

Several experimental studies on seismic isolation systems for building applications have been reported. For bridge applications, only three studies have been conducted: one at U.C. Berkeley with elastomeric systems, one at U. Buffalo with sliding systems and a recent one at the Public Works Research Institute, Japan with elastomeric systems. These studies concentrated on the response of the isolation system and, thus, utilized rigid models without due regard to the flexibility and possible inelastic behavior of the bridge substructure. These effects were analytically investigated by the authors and found to result in additional isolation system displacement.

Some of the constraints in these past experimental studies have been relaxed in the described research project.

BRIDGE MODEL AND ISOLATION SYSTEMS

A quarter length scale bridge model was designed. It is shown in Figure 1 on the shake table. The design called for the following characteristics in prototype scale: period of free vibration when the deck is pinned to both piers = 0.5 secs, period of free vibration of each pier in cantilever position = 0.2 secs, deck length to pier height ratio = 4 and deck weight to single pier weight = 1/15. These characteristics may be regarded as typical of highway bridges. The model could represent a portion of a multi-span bridge between expansion joints or a two-span bridge with one pier (the other pier could be braced longitudinally to represent a stiff abutment) or a single span bridge (both piers braced longitudinally).

The model had a deck weight of 143 kN with each pier weighing 9 kN. The specified dynamic characteristics were experimentally confirmed. The deck was supported by four sliding bearings placed 4.9 m apart in the longitudinal direction. The bearings were characterized by their coefficient of friction at high velocity of sliding, μ: low friction, $\mu = 0.06$, medium friction, $\mu = 0.11$ and high friction, $\mu = 0.16$. It should be noted that the coefficient of friction at low velocity of sliding is only a fraction of these values.

Restoring force was provided by various means. First, spherically shaped sliding bearings (known as FPS bearings) were used to provide restoring and frictional forces within a compact unit. Flat sliding bearings were combined with devices, placed in-between the deck and the pier, to provide restoring force and additional energy dissipation capacity. These devices were in the form of: a) arc-shaped rubber elements between a moving central rod and a cylindrical housing, b) wire rope springs, c) fluid spring-damper devices and d) fluid viscous dampers. The latter two devices have been previously used in military applications and they represented the state-of-the-art in hydraulic technology.

The isolation systems were designed to exhibit fail-safe characteristics. For example, the rubber devices had essentially linear elastic behavior to displacements of about 35 mm, beyond which they exhibited increasing stiffness to a maximum displacement of 50 mm.

The restoring force capability of the various systems was varied within a range. In terms of period, calculated from the deck weight and stiffness of the restoring force devices, the range in the scale of the experiment was 1.2 to 2.4 secs.

Furthermore, lubricated bearings together with mild steel hysteretic dampers were used in a configuration similar to the one used in the aforementioned Mortaiio Viaduct in Italy. This system could not provide restoring force but could limit the transmission of force to the substructure to 20% of the deck weight.

SAMPLE RESULTS

Approximately, 800 tests were conducted involving three bridge configurations and fifteen isolation system configurations. The excitation consisted of recorded earthquakes and simulated motions compatible with CalTrans spectra and Japanese level 1 and 2 bridge design spectra.

As an example, Figure 2 shows the 5%-damped spectra of the Japanese level 2 motions for ground conditions 1 (stiff soil) to 3(deep alluvium). One should note the substantial spectral acceleration values in the period range of 2 to 5 secs. The difficulties in achieving effective isolation with such motions are apparent. If a design calls for an isolation system force of 0.3 W, W = deck weight, and the system is capable of delivering an effective damping of 30% of critical, then according to AASHTO, the system should have an effective period of at least 4 secs for the ground condition 3 motion. Bearing displacement would have been around 1200 mm. Apparently, such a design is impractical.

Herein, we restrict the presentation of results to few cases which demonstrate that it is possible to provide effective isolation for severe excitations as those depicted in the spectra of Figure 2. In these tests the utilized bearings were of high friction. It is important to restate that friction is velocity dependent. The coefficient of friction varies from a low value at very slow sliding velocity (as in thermal motion) to a considerably higher value at large velocity of sliding (as in seismic motion). The high friction bearings utilized in these tests had a friction coefficient varying between the values of 0.06 and 0.16.

In the tests with the rubber restoring force devices, an attempt was made to provide effective isolation while maintaining bearing displacements below the limit of 50 mm (or 200 mm in prototype scale). Such low bearing displacements would require short expansion joints with a number of associated benefits. The rubber devices could provide an isolation system period of about 1.4 secs (or 2.8 secs in prototype scale).

Figure 3a shows the recorded response (in terms of only the isolation system hysteresis loop) of the system with two flexible piers in the Japanese level 2, ground condition 1 (stiff soil) motion. Bearing displacements exceeded the limit of linear behavior of the restoring force devices and the displacement restraint mechanism was activated. This resulted in an isolation system force of 0.46 times the deck weight and a pier shear force (see Table 1) of 0.50 times the weight carried by the pier. This represents the shear force used in the design of the piers (design based on applicable steel specifications without allowance for increased allowable stresses). Testing with motions compatible with the spectra of ground conditions 2 and 3 were not carried out.

Subsequently, the system was modified by the addition of fluid viscous dampers. These devices behaved essentially as linear viscous dashpots with a combined damping constant of 62 N-sec/mm. The recorded response of the system is shown in Figure 3b and summarized in Table 1. Evidently, the use of fluid dampers caused a marked reduction of the isolation system force and pier shear force and reduced bearing displacements.

Table 1: Summary of Experimental Results (Length Scale = 4)

System	Excitation	Peak Bearing Displ. (mm)	Base Shear/Weight	Pier Shear/Weight	Pier Displ. (mm)
High Friction, Rubber Device	Japanese, Level 2 G.C. 1	49.3	0.46	0.50	7.2
High Friction, Rubber Device, Fluid Damper	Japanese, Level 2 G.C. 1	40.0	0.28	0,33	5.5
High Friction, Rubber Device, Fluid Damper	Japanese, Level 2 G.C 2	38.1	0.31	0.36	5.8
High Friction, Rubber Device, Fluid Damper	Japanese, Level 2 G.C. 3	36.9	0.30	0.35	5.6

Moreover, tests with the system containing fluid dampers were conducted with the Japanese ground conditions 2 and 3 motions (deep alluvium soil). The response is summarized in Table 1 and depicted in Figure 3c (case of ground condition 3). Very interestingly, the response is only marginally affected by the characteristics of the excitation. The input motion for ground condition 3 consisted of ten major cycles of ground displacement over a duration of 50 secs. Figure 3c demonstrates the excellent energy dissipative characteristics of the system over a large number of cycles.

The effectiveness of the isolation system may be determined by comparison of the results of Table 1 to the response of the non-isolated bridge. Based on the spectra of Figure 2, and for elastic behavior (period equal to 0.5 secs), the pier shear force in the non-isolated bridge would have been between 70% and 100% of the deck's weight.

In conclusion, we note that is possible to provide effective bridge seismic isolation for strong, long period seismic motions while allowing modest bearing displacements. This requires highly energy dissipating systems which can be produced by combining frictional and viscous elements.

SUMMARY

The initial phase of the U.Buffalo-Taisei Corp. research project, on the development and testing of a class of seismic sliding bridge isolation systems, is now completed. Work is currently in progress on the interpretation of the results and development of design procedures. A subsequent phase will concentrate on in-situ testing procedures and implementation.

ACKNOWLEDGEMENTS

Financial support is provided by Taisei Corp., NCEER, Earthquake Protection Systems, CA, SVP, NJ, Taylor Devices, NY and ALGA, Italy.

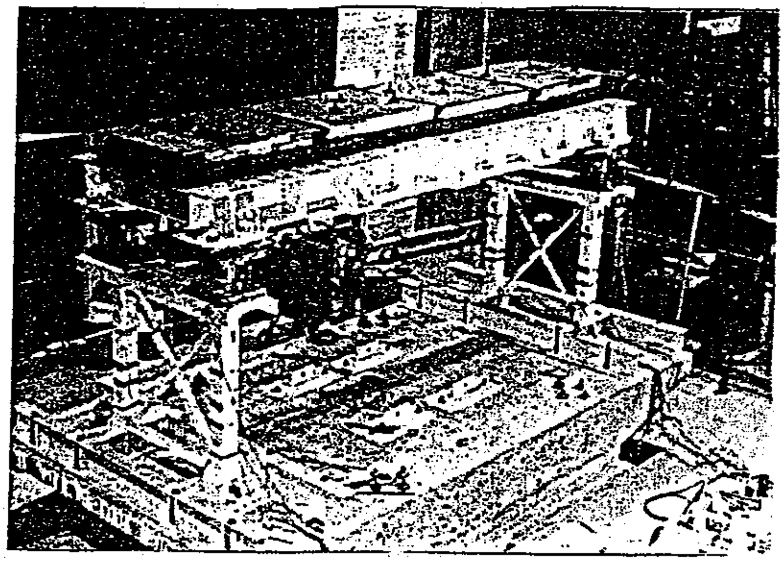


Figure 1 - View of Bridge Model on Shake Table

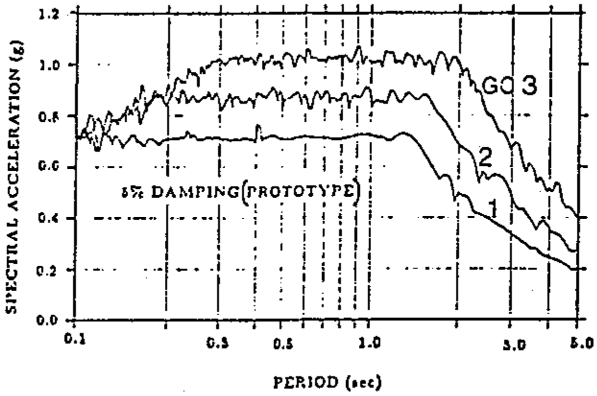


Figure 2 - Response Spectra of Japanese Level 2 Bridge Design Motions

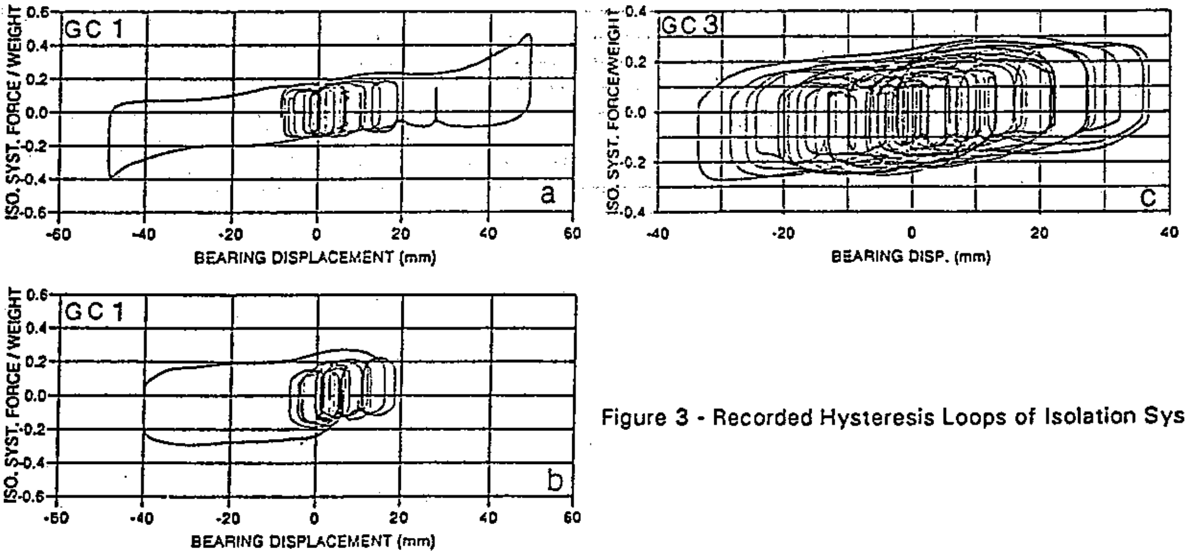
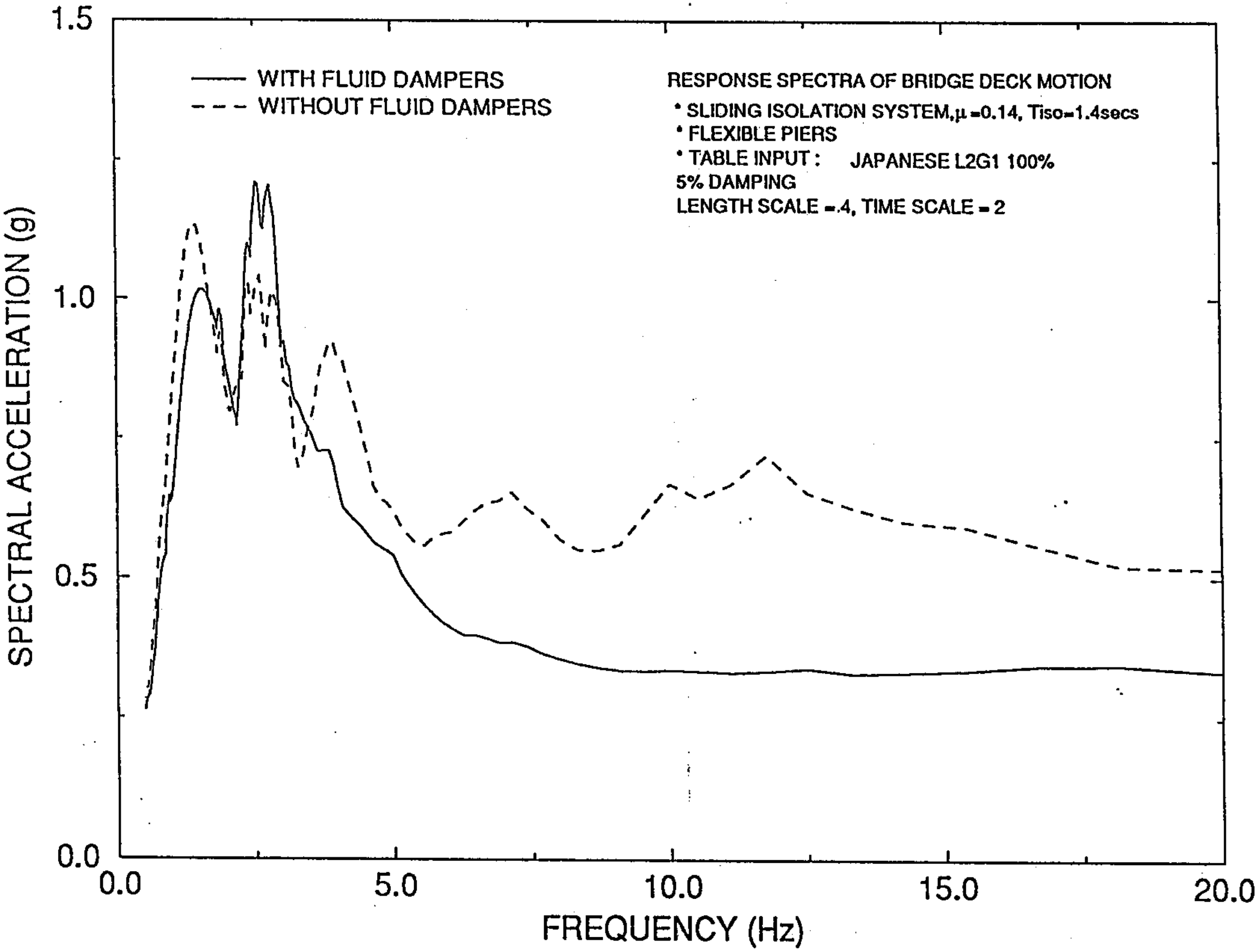


Figure 3 - Recorded Hysteresis Loops of Isolation System



1.5
1.0
0.5
0.0
SPECTRAL ACCELERATION (g)
0.0
5.0
10.0
15.0
20.0
FREQUENCY (Hz)
WITH FLUID DAMPERS
WITHOUT FLUID DAMPERS
RESPONSE SPECTRA OF BRIDGE DECK MOTION
• SLIDING ISOLATION SYSTEM,μ =0.14, Tiso=1.4secs
• FLEXIBLE PIERS
• TABLE INPUT : JAPANESE L2G1 100%
5% DAMPING
LENGTH SCALE =.4, TIME SCALE = 2