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ENHANCED SEISMIC LATERAL LOAD DISTRIBUTION IN CONTINUOUS SPAN BRIDGES FITTED WITH VISCOELASTIC DEVICES

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ABSTRACT

Seismic safety of a continuous span bridge could be enhanced by distributing the large inertial forces among the supporting piers. A new viscoelastic device, which is of a simple cylinder-piston assembly packed with silicone putty compound, enables lateral loads to be transmitted to piers supporting movable bearings of a bridge during earthquakes. The device was first tested for its cyclic mechanical behavior with different piston sizes and different silicone compounds as well as the effect of imperfect packing. Test results have shown that the device can provide for various design amenabilities with desired load-transmitting frequency and desired load-distribution ratios among the piers. A simple-span bridge model fitted with the viscoelastic device was then tested, and the effectiveness of the device in distributing seismic lateral loads to the piers has been shown.

KEYWORDS

Seismic Lateral Load Distribution, Viscoelastic Device, Silicone Putty, Span Fall-off Restrainer, Damper-Stopper, Seismic Retrofit

INTRODUCTION

Many bridges suffered damages during strong earthquakes due to the concentration of large forces on just a few load-resisting elements, i.e., piers and substructures supporting fixed bearing supports. On the other hand, piers supporting movable supports remained undamaged but simply let the girders fall off during large displacements, resulting in catastrophic collapse of bridges. Early retrofitting programs to prevent span fall-off in both the U.S. and Japan had put priorities on the development and installation of hinge and joint restrainers. However, recent bridge failures during the 1994 Northridge earthquake has reported several bridge damages retrofitted with cable restrainers. Likewise, several span fall-off restrainers were found to be badly broken due to the 1995 Hyogo Nanbu Earthquake. One simple reason is that restrainers are not designed to improve seismic resistance of the total bridge, but simply to hold on the girders that are about to be displaced off the supports.

It has been generally accepted that a better solution would be to distribute the lateral forces among the piers. Offering several advantages primarily in performance and maintenance, a new viscoelastic device has been developed which will enable the earthquake lateral forces to be distributed among the piers. The newly developed device has been tested for its cyclic mechanical behavior as well as its effectiveness in a simple span bridge model. Results are presented in this paper.

A NEW VISCOELASTIC DEVICE FOR SEISMIC LATERAL LOAD DISTRIBUTION

A few devices (e.g., rubber bearings, oil dampers, viscous shear dampers, ...) have been developed for seismic lateral load distribution with each offering several advantages and disadvantages in various aspects of performance, maintenance, reliability, and simplicity in construction as well as in design. The main objective of this research is to develop a device with similar functions, but possessing robustness that can better withstand adverse conditions and requiring minimum maintenance.

Offering several advantages primarily in performance and maintenance, a new viscoelastic device has been developed consisting of a piston inside a cylinder housing filled with silicone putty compound. The device uses a simple piston-cylinder unit (Fig. 1) similar in construction to oil damper and lead-extrusion damper.

Unlike the other damper-stopper devices, the new device is mechanically simple and has no bypass valves nor other appendages that might malfunction or be rendered nonfunctional during severe shakings. Silicone putty is a polymer material that readily deforms under slowly applied pressure, but becomes rigid when subjected to shock or impact loads.

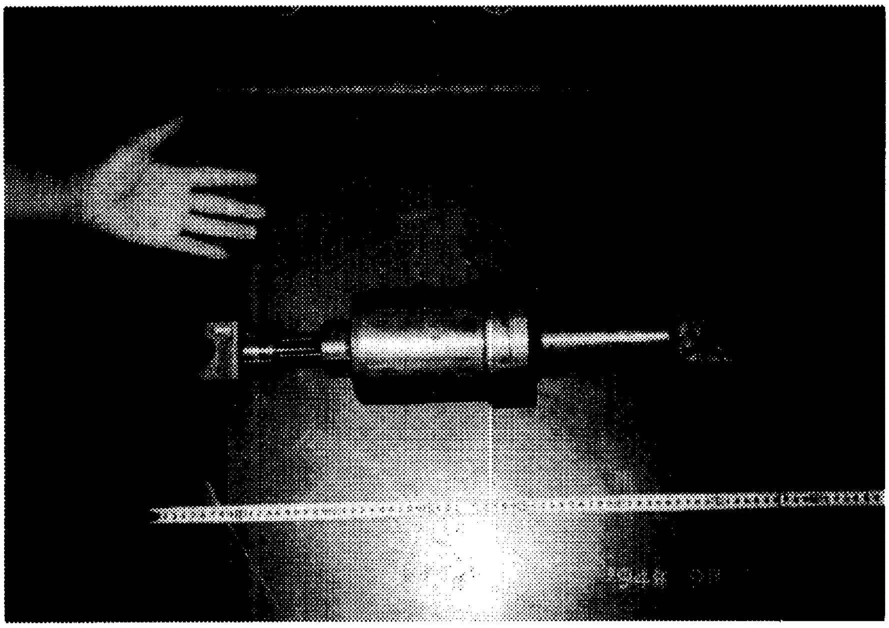

Fig. 1 A New Viscoelastic Load Transmission Device

The silicone putty is vacuum-packed into the piston-cylinder housing. Under applied loads, the putty compound is squeezed from one end of the cylinder to the other end through openings around or through the piston. With properly designed orifice opening and size of piston and cylinder, desired values of damping and stiffening can be obtained for the range of loading amplitudes and frequencies. The device is designed to be attached to the underside of the girder near a movable support and the top of the pier. In such an arrangement, it allows movement of the movable support during ambient temperature gradients, but will fix the girder-pier connection during shock or earthquake loadings and thereby transmitting a share of the lateral load to the piers with movable supports (Fig. 2). Such devices are particularly suitable for seismic retrofit of simple span bridges and in newly constructed long-span bridges.

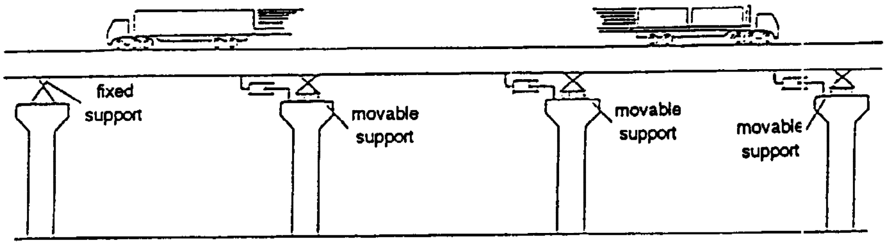

Fig. 2 A Continuous Girder Bridge with Load Transmission Devices

Similar devices called STU had been used to relieve increasing traction and braking loads in the viaducts carrying London's Docklands Light Railway [Pritchard 1989], but no tests have been conducted on its seismic performance nor data on its mechanical behavior available. In developing these devices for use in structures under earthquake loadings, studies and tests were made in different 'flow' properties of silicone compounds and the piston-cylinder assembly.

CYCLIC MECHANICAL BEHAVIOR OF THE VISCOELASTIC DEVICE

Preliminary objective is to investigate the basic mechanical behavior of prototype devices under cyclic loads. From these results, suitable putty compounds and piston-cylinder designs are evaluated and improvements are made to obtain the desired device performance. A 10-tonf capacity has been fabricated and subjected of repeated cycles of force-controlled and displacement-controlled loadings with different amplitudes and frequencies using the test setup shown in Fig. 3.

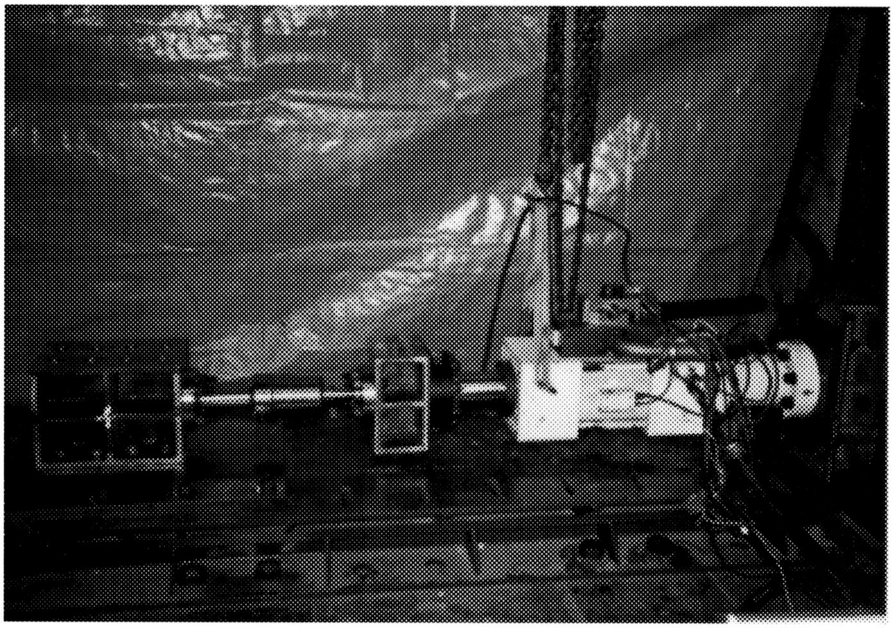

Fig. 3 Device Test Setup

The device was first tested under force-controlled loading under different frequencies (0.001 Hz to about 5. Hz). Load-deformation characteristics are shown in Fig. 4.

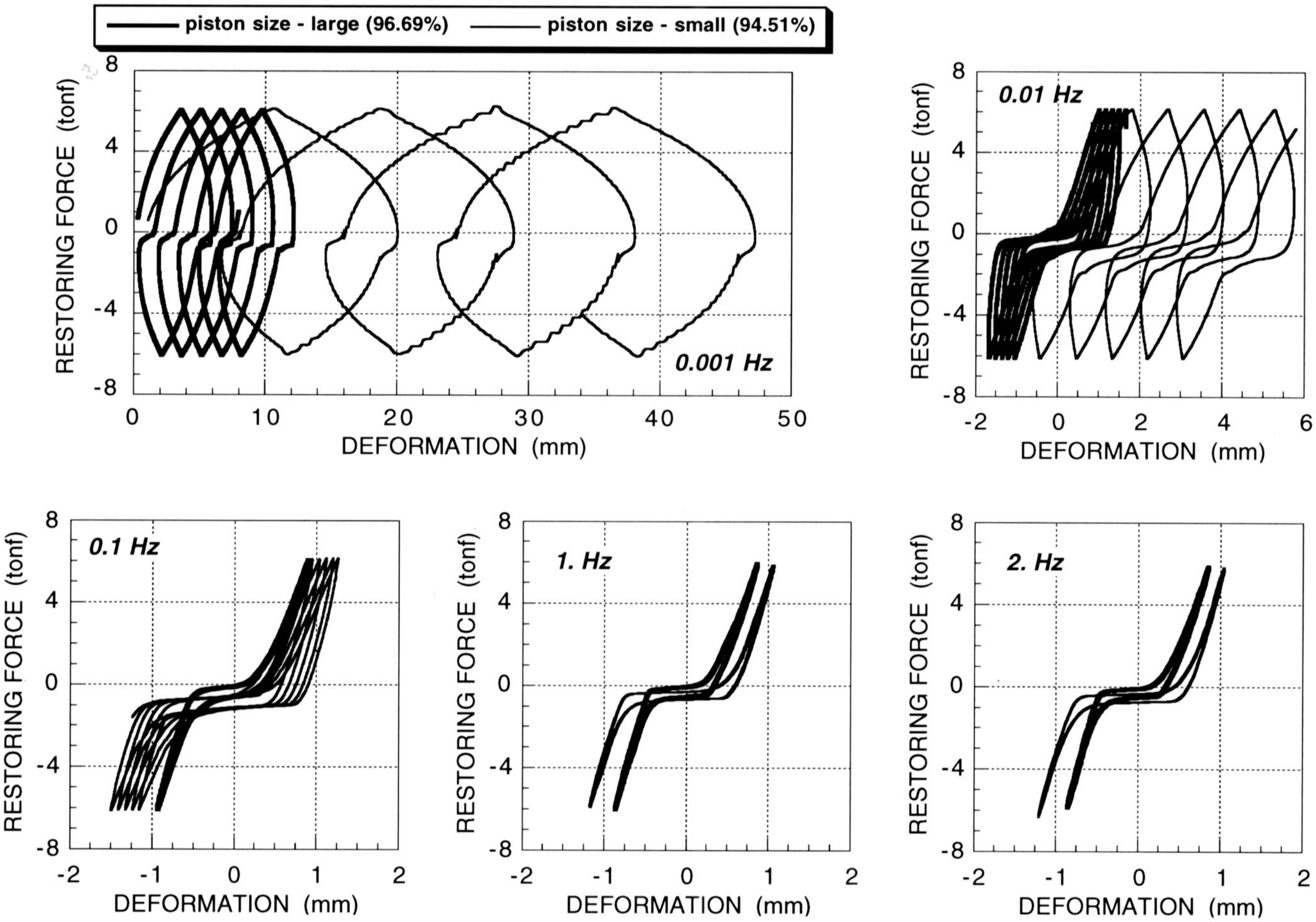

Fig. 4 Comparison of Load-Deformation Behavior of Device with Different Piston Sizes

It can be observed that the silicone putty readily allows deformation with significant hysteretic damping under low frequencies. Hystereses in Fig. 4 plotted with bold lines is for a device with a relatively bigger piston (smaller orifice) and relatively harder putty. Stiffening effect is exhibited at about 0.1 Hz. Beyond 0.1 Hz, no remarkable changes in the load-deformation behavior can be observed. That is above 0.1 Hz, the silicone putty has acted as almost a rigid body and stiffness is provided by the load-deformation characteristics of the end rod of the cylinder and the piston.

The load-deformation curves under two cases of displacement-controlled loading are shown in the plots in Fig. 5. It can be observed that load induced (from about 5. tonf for 5 Hz case) is significantly reduced (to less than 0.7 tonf for 0.001 Hz case) when subjected to slowly applied loads. Under service loads due to temperature changes, a displacement-controlled cyclic loading with a period of 24 hours simulating daily temperature change or a period of one year for annual temperature change would have induced almost no load resistance at all. In other words, the device does not interfere with the normal functioning of the movable bearings in relieving stresses due to elongation and contraction of the girders resulting from ambient temperature changes.

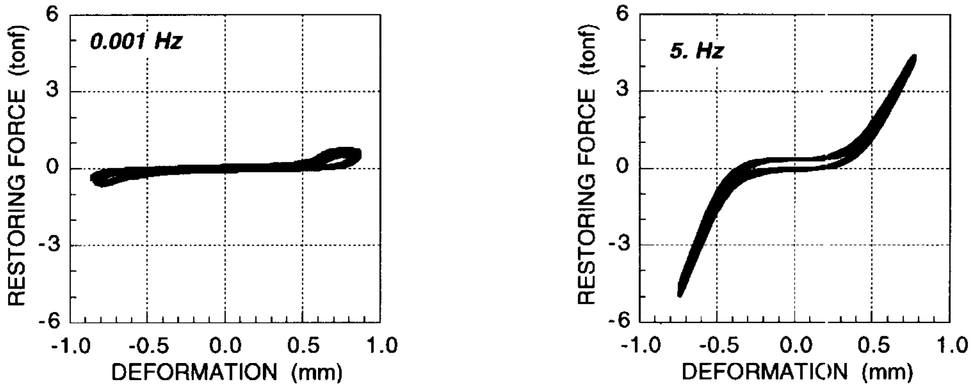

Fig. 5 Load-Deformation Behavior Under Displacement-Controlled Cyclic Loading

In order to investigate the effect of orifice sizes, the same device was then fitted with a smaller piston which would permit easier passage of the putty when squeezed. Results are shown in the hystereses plotted witth the thinner lines in Fig. 4. It can be observed that the piston was easier displaced inside the putty-filled cylinder and stiffening was initiated at a much higher frequency of about 1. Hz. Thus, the desired frequency at which stiffening is initiated to allow lateral load transmission may be set with the appropriate piston size.

Silicone putty compounds can be manufactured with different 'flow' properties. A 'softer' putty was packed into the device with the larger piston and its load-deformation hystereses (plotted with thinner lines in Fig. 6) are compared with the previous case of a 'harder' putty. It can be observed that the piston was easier displaced inside the putty-filled cylinder and stiffening was initiated at about 0.2 Hz. Thus, the desired frequency at which stiffening is initiated to allow lateral load transmission may be set with the appropriate rheological property of the silicone putty. In order to take advantage of this property, further investigation in rheological properties of putty compounds using appropriate tests [Ward and Hadley 1993] is needed to relate the material properties to the mechanical properties of the intended device.

It can be observed that slip-type behavior in the vicinity of the low load range in the load-deformation curves. This type of slip hysteresis is not desirable in that effective load transmission is not achieved within this interval. While it is not possible to ascertain at this stage all the exact causes of this slip, undoubtedly imperfect packing is one factor. This was investigated by testing the device filled with a proportion (90%) less than the maximum putty content to fill fully. Hystereses plotted with thinner lines in Fig. 7 shows the load-deformation behavior of a device with intentionally imperfect packing. A wide slip of constant width can be seen in all the hystereses.

The test results have shown that the new viscoelastic device can provide for various design amenabilities with desired load-transmitting frequency and desired load-distribution ratios among the piers. Proper characterization of the device configuration and the silicone putty properties should be the next important step in the investigation in order to better quantify the device performance.

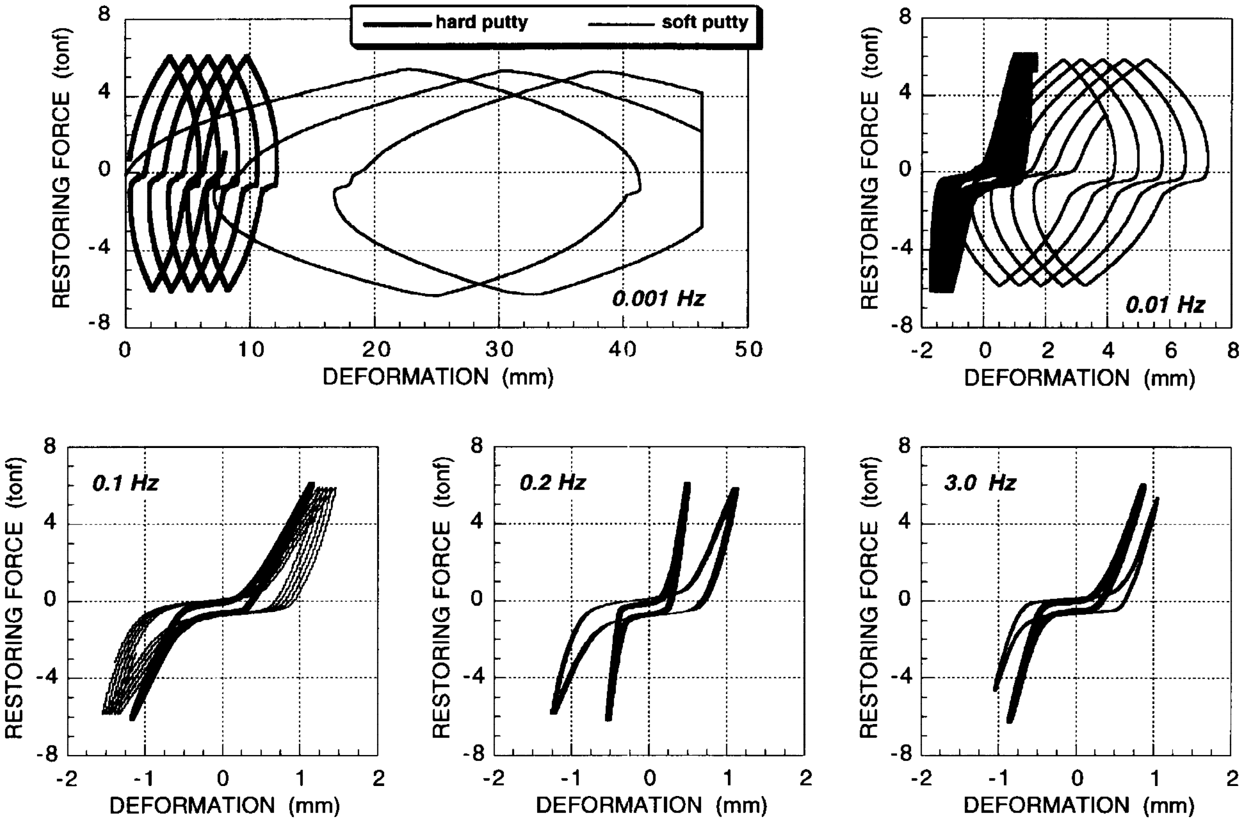

Fig. 6 Comparison of Load-Deformation Behavior of Device with Different Putty Properties

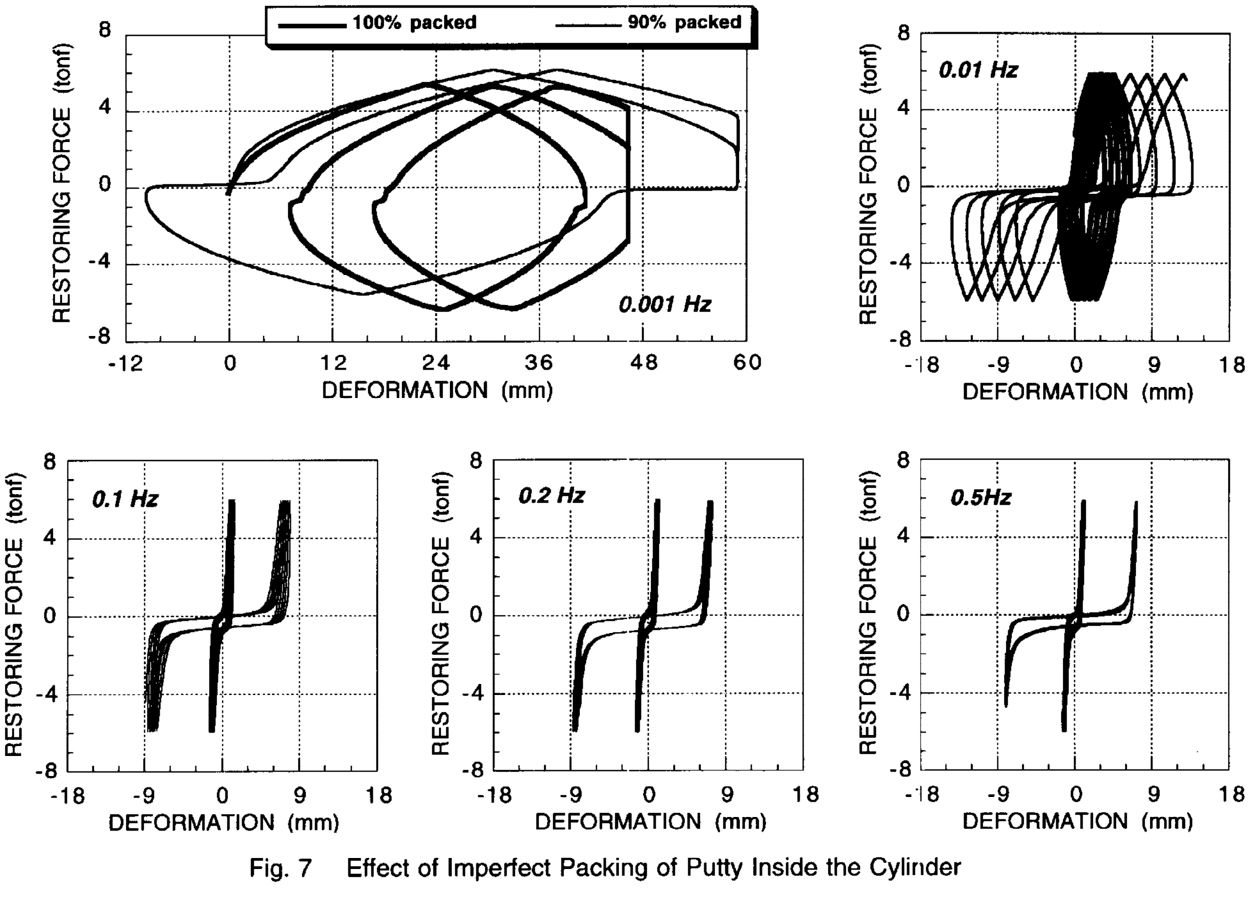

Fig. 7 Effect of Imperfect Packing of Putty Inside the Cylinder

TEST OF BRIDGE MODEL FITTED WITH THE LOAD-DISTRIBUTION DEVICE

A simple-span bridge model fitted with the viscoelastic device was next tested. The test setup is shown in Fig. 8. The piers are of identical steel section, and part of the lateral load applied through the girder can be transmitted to the pier supporting the movable bearing through the viscoelastic device and thereby effecting load distribution between the two piers. Without the device, only a small amount of lateral load could be transmitted to the pier with movable bearing through friction of the roller support. The pier supporting the fixed bearing would take almost all of the lateral load.

In the tests, displacements of the piers were measured with displacement transducers. Likewise, the piston movement of the device was monitored through a displacement transducer attacted to the shaft. In addition, a load cell was attached to the end of the device connecting to the pier supporting the movable bearing to measure the amount of load transmitted. With the new viscoelastic device attached, the bridge model was subjected to cyclic loadings with increasing loading frequencies. Test results for loading frequencies of 0.001 Hz and 1. Hz are shown in Figs. 9 and 10.

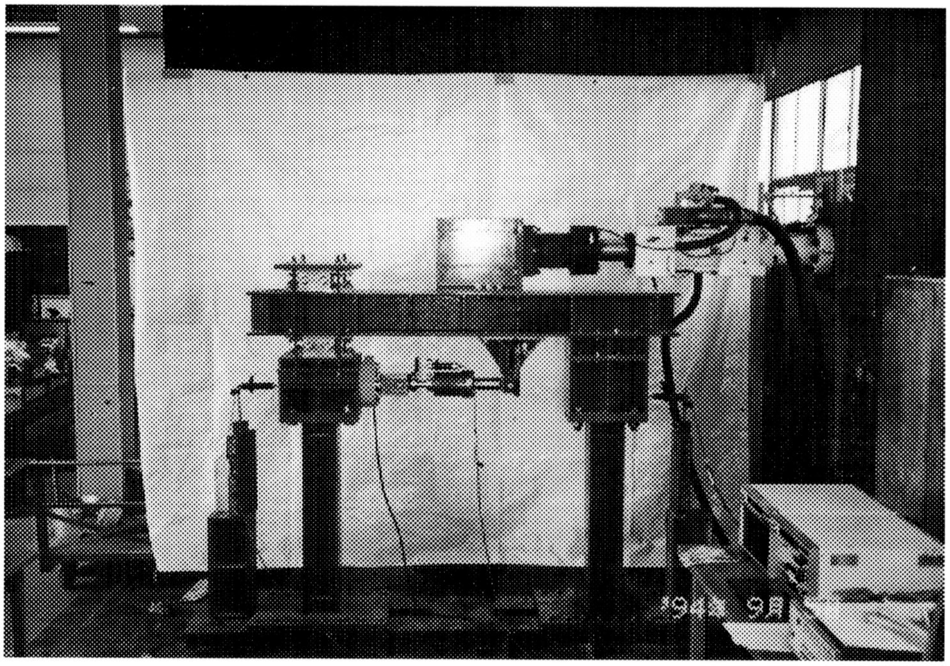

Fig. 8 Bridge Model Test Setup

For slowly applied loads, the device barely offered any resistance and moved along with the girder and the pier with the fixed bearing as can be seen in the displacement time history in Fig. 9, whereas it can also be observed that the pier supporting the movable bearing was only displaced slightly except for a small amount transferred through friction and also due to rotational restraint of the device joints. For loads due to daily and annual temperature changes, it can be considered that the device does not interfere with the normal functioning of the movable bearing in relieving stresses due to temperature effects.

When the bridge model is subjected to higher-frequency loads (the case of 1. Hz shown in Fig. 10) or earthquake-like loads, the device would act to transmit loads to the pier with the movable bearing. It can be observed from the displacement time history in Fig. 10 that both piers are displaced equally and thereby shared in resisting the total lateral load from the girder. The device had acted to transfer about half of the load acting on the pier with the rest transferred through friction of the roller bearing.

In considering load distribution, it is necessary first to evaluate the seismic capacity of the piers. The appropriate shares of loads to be taken by the piers are related to the relative stiffnesses of the piers and the devices. Tests and analyses on the total response with the relative stiffnesses taken as parameter of investigation are needed. In addition, thorough study of the effectiveness of the device would also require an extensive study of the performance of the device under realistic earthquake excitations since the behavior of the device is very much frequency-dependent. Only performance under harmonic excitation had been conducted and presented in this study.

Lastly, it should be noted that a load-transmitting device would demand a stricter tolerance in the fabrication of the joints than a damper device. Even a slight slip or deformation in the hinges would negate the effectiveness of the device.

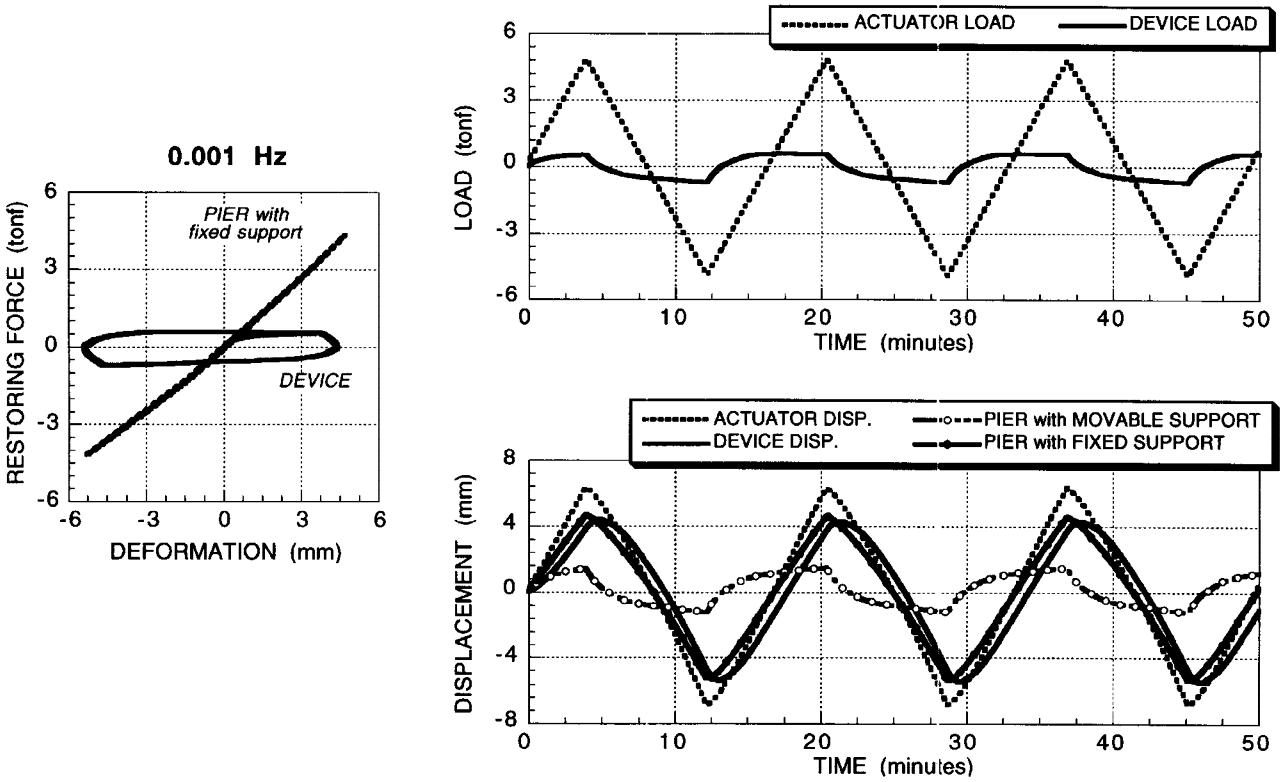

Fig. 9 Simple Span Bridge Prototype Subjected to Slowly Applied Loads (0.001 Hz)

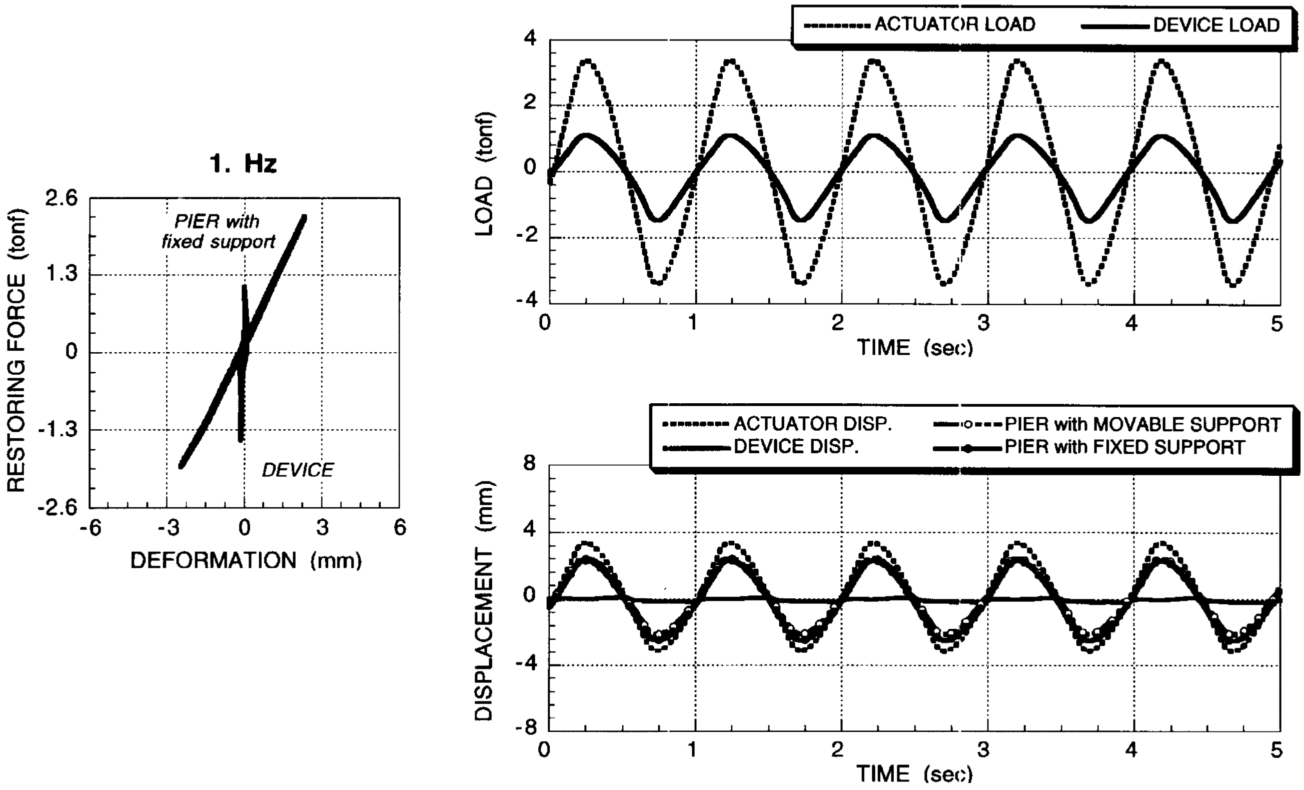

Fig. 10 Simple Span Bridge Prototype Subjected to Higher-frequency Loads (1. Hz)

SUMMARY AND CONCLUDING REMARKS

Current retrofit programs in both the U.S. and Japan have been on component retrofitting. Kawashima [1990] noted that countermeasures made only to prevent damages suffered in past earthquakes may led to failures in the next weak points in future earthquakes. For instance, due to damages suffered during the 1964 Niigata Earthquake and the San Fernando Earthquake, the first stage of seismic retrofit program had focused on the development and installation of stoppers, restrainers [Selna and Malvar, 1984], seat extension, and other devices for preventing collapse of span [Kawashima 1990]. The second stage of the retrofit program is currently focusing on the improvement of column ductility based on experiences of the 1989 Loma Prieta Earthquake, 1978 Miyagi-ken-oki Earthquake, the 1983 Nihon-kai-chubu Earthquake, and most recently the 1994 Northridge Earthquake and the 1995 Hyogo-ken Nanbu Earthquake. These component retrofitting programs had led to speculation to whether the next failure points will occur in the substructure components. Thus, there is a need to establish a retrofit program to enhance the seismic safety of the total structure. One solution would be using devices to distribute the seismic loads among the load-resisting elements.

A new viscoelastic device, made up of a simple piston-cylinder assemble and packed with stable silicone putty, is developed to enable transmission of loads to piers with movable bearings during earthquakes. Test results to obtain basic load-deformation behavior of the viscoelastic load-transmission device under cyclic loadings were conducted in which the effect of packing, piston sizes, putty flow properties were investigated. Seismic performance of the new viscoelastic device has been shown to be effective in distributing lateral loads among the piers.

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