Constant Acceleration of Superstructures
A Concept of Seismic Isolation

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ABSTRACT

In a study on seismic vulnerability of bridges and highway systems at the Multidisciplinary Center for Earthquake Engineering Research Center (MCEER) sponsored by the US Federal Highway Administration (FHWA), a special task has been dedicated to the development of a new seismic isolation system for highway bridges. This paper describes the progress of this research task accomplished to date with the emphasis given to the special property of the roller isolation systems that can limit the acceleration of the superstructure to within 0.25g under any possible seismic excitations while reduce the bearing displacement simultaneously.

Within the context of the theme of task committee B, this paper addresses the working mechanism of the roller isolation bearing and some of its design principles with respect to "Next Generation Building and Infrastructure Systems."

KEYWORDS: constant acceleration; reduced bearing displacement, seismic isolation

1. INTRODUCTION

1.1 Motivation

The development of a new type of seismic isolation bearing for highway bridges was motivated by the following issues.

1.1.1 Acceleration

The major purpose for seismic isolation is to reduce the acceleration of superstructures. Generally, it is preferred to keep the acceleration below about 0.25g (250gal). However, existing isolation bearings generally cannot reduce the acceleration to a level below 0.3g. For example, when ground excitation is relatively large, the acceleration will increase accordingly.

1.1.2 Displacement

When ground displacement is large, the bearing displacement for the existing devices can be quite large. Attempts to regulate bearing displacement may have a direct adverse affect on the acceleration level. For example, many bearings have been designed to allow a displacement of 15" or less. If the ground displacement is larger than 15", which is likely to happen, we must consider using larger damping is usually to regulate bearing the displacement. This added damping will make the reduction of the acceleration difficult.

1.1.3 Physical size

The dimensions of isolation bearing systems are important, especially when they are to be used in bridge retrofitting. In addition to the height of bearings, the horizontal dimensions are also important considerations because there are often space limitations and there is always a desire for simplicity in installation with lower cost.

1.2 Objectives

The objectives for the development of the roller isolation system are:

1. To provide a new bearing system that restricts acceleration to 0.2-0.25g or lower, even when ground excitation is quite large.

2. Using relatively small bearings to accommodate large bearing displacement.

3. To provide a bearing with dimensions suitable for retrofitting of existing bridges and is relatively inexpensive to manufacture and maintain.

2. BASIC MECHANISM

The basic mechanism of the roller isolation bearing is shown in the conceptual drawing in Figure 1.

The horizontal acceleration is mainly determined by the angle of the slope. That is, despite the magnitude of the ground acceleration, the acceleration of superstructure, a_r, can be written as:

$$a_r = \alpha \, g \qquad (1)$$

Since the angle of the slope is quite small, around 1.5^o to 2.5^o, the acceleration contributed by the bearing can be as small as 0.03 to 0.05 g. Even with an overdamped setup, (say the damping effect is around 0.05-0.10g), the total lateral acceleration can still be smaller than 0.15g.

3. TYPICAL TEST RESULTS

In order to prove the theoretical design of the roller bearing, several experimental studies were conducted. Figures 2 and 3 demonstrate the experimental results, taken from the first prototype bearing. Note that the slope angle is 4.5^o. For the second prototype bearing, an angle of less than 2^o was used. Figures 4 and 5 show selected test results of the acceleration and the base shear respectively from the experiments conducted in the University of Nevada at Reno (UNR) in 2003, using a down-scaled Caltran bridge model.

Since the acceleration level is deterministic and can be quite small, very large damping can be used to reduce the bearing displacement without unduly increasing acceleration.

Figure 6 shows the displacement of the roller bearing system tested at UNR. (Note that, the test is a down-scaled test, so the displacement should be multiplied by a factor of 2.5 if full scaled model is used).

From these test data, it is seen first, the goal of design a predetermined level of acceleration for superstructure is achieved. The experimental acceleration is low and is a constant, despite of the level of ground motions.

Second, with proper damping, the goal of regulating bearing displacement is also achieved.

4. THEORY ON FIXED ACCELERATION LEVEL OF SUPERSTRUCTURES

Among many features of the roller bearing, the most important one is its ability to keep the acceleration level of the superstructure at fixed value. If no damping is added, the value of the peak acceleration is only affected by the angle of the rolling slope, instead of any amount of the ground excitations (equation 1). In fact, the level can be designed as low as 0.03-0.05g, (30-50 gal).

We therefore can have sufficient room to add damping equivalent to 0.15- 0.2g, if the total acceleration of the superstructure is designed to be 0.2-0.25g, (200 -250 gal). Such an amount of damping is quite large so that the entire system will become overdamped (the equivalent damping ratio is considerably above 100%). The resulted bearing displacement will be notably reduced, comparing to underdamped systems, whose equivalent damping ratios are usually in the range of 20-40%.

In the above, we have shown that the experimental results exhibited the performance of the prototype bearing systems. In the following, equation (1) is proven analytically.

In Figure 7, the horizontal acceleration hg can be decomposed into two components. One is acting along the slope, which has an angle α

with respect to the horizontal line. This component is given by hg cos α. This component will affect the roller acceleration through friction force. Denoted the rolling friction coefficient by μ_r . Therefore, the corresponding acceleration, denoted by a_{r1}, is:

$$a_{r1} = \mu_r \, hg \cos^2\alpha \qquad (2)$$

Note that, the rolling friction coefficient μ_r is about 0.1%. Therefore, even if the ground acceleration is as high as 4g (h =4), a_{r1} will be smaller than 0.4% g (4gal), which can be ignored.

The second component is perpendicular to the sloped surface, whose magnitude is hg sin α. This component can be further decomposed vertically and horizontally. The horizontal component, denoted by a_{r2}, can be expressed as

$$a_{r2} = hg \sin^2\alpha \quad \approx \alpha^2 hg \qquad (3)$$

Since α is a small angle, say, $2^0 - 4^0$, then α^2 will be about 0.5%. If the ground horizontal acceleration is as high as 4g, then, the level of a_{r2} will be about 0.02g, (20gal), which can also be ignored.

Furthermore, the vertical component a_{rv}, will have the value

$$a_{rv} = hg \cos\alpha \sin\alpha \qquad (4)$$

Its influence on the horizontal acceleration through the rolling friction will be one order smaller than a_{r1}, which can also be ignored.

In addition, the vertical component, a_{rv} , caused by the ground horizontal acceleration, hg , is several percent of hg. Since α is a small number, the discomfort due to the horizontal motion can be notably smaller than that caused by the ground vertical acceleration.

5. CONCLUSIONS: APPLICATION TO NEXT GENERATION BRIDGE AND INFRASTRUCTURE SYSTEM

The roller isolation bearing for highway bridges has been further modified for isolation of buildings and building contents against strong earthquake ground motions. Primary tests have been carried out with very good results.
One of the major concerns for the application of the roller bearing is to regulate possible large bearing displacements, which can happen when the ground displacement becomes large, such as in the near field.

Generally speaking, the controls of the absolute acceleration of the superstructure and the relative bearing displacement are contradicting issues. When certain measures (e.g., using larger damping) are used to regulate the bearing displacement, the acceleration level will be increased (e.g. Kelly, 1999; Hall, 2000) .

For conventional isolation systems, the acceleration level of the superstructure is actually uncertain, because the seismic excitations are random. In additions, the capability of reducing the acceleration of conventional bearings is also limited. As mentioned before, under large earthquake excitations, it is difficult to limit the acceleration level to within 0.3g, (e.g. Constantinou, 2001; AASHTO, 2000). In such cases, there is little latitude for a designer to add damping to further reduce the bearing displacement.

Roller bearings, on the other hand, can have the advantage of providing rather small level of acceleration. More importantly, the acceleration level is a fixed number. This gives designer more flexibility to increase the damping. Generally, the entire system is often designed to be overdamped so that the bearing displacement can be further reduced.

Therefore, the type of seismic isolation bearings, together with larger damping, can be applied at locations where both the ground displacement and acceleration are historically very large.

6. ACKNOWLEDGEMENT

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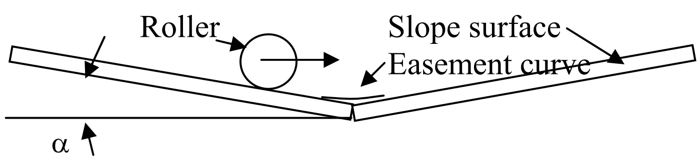

Figure 1. Conceptual assembly of bearing

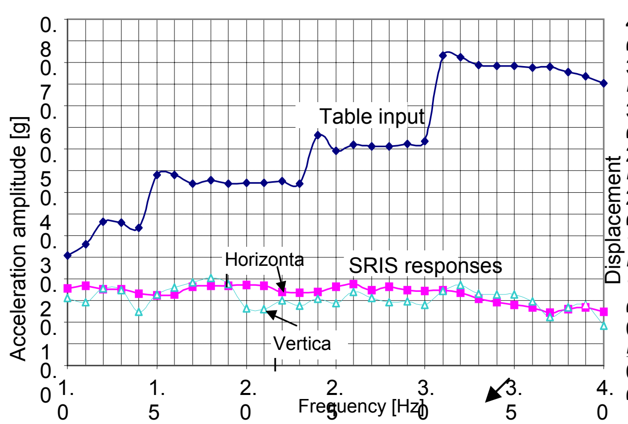

Figure 2. Acceleration level under sweep sine test

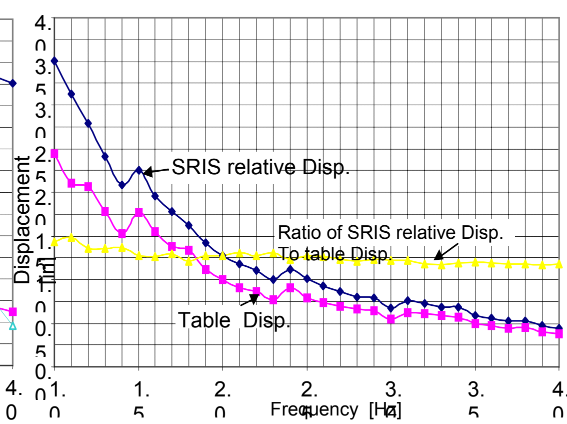

Figure 3. Displacement under sweep sine test

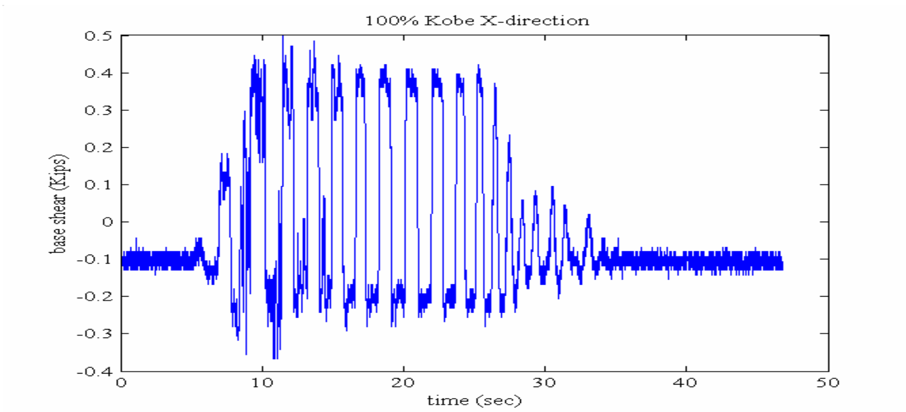

Figure 4. Acceleration levels under earthquake excitation

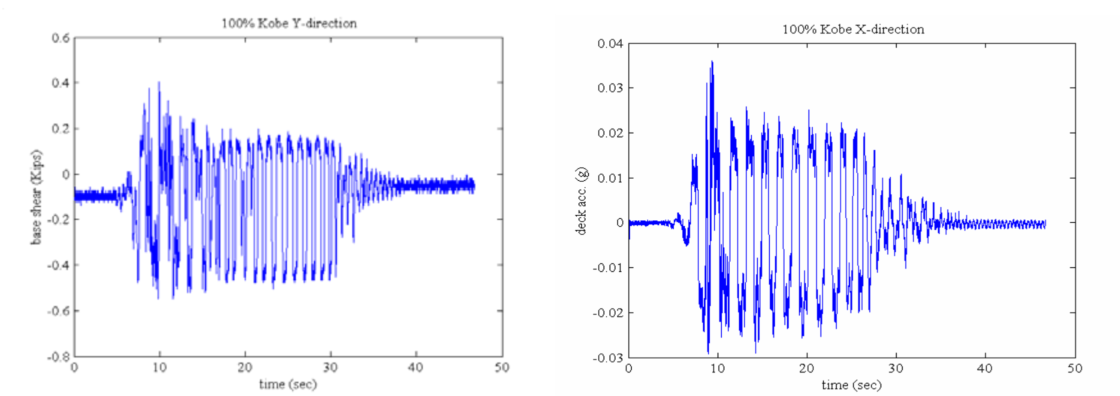

Figure 5. Base shears under earthquake excitation

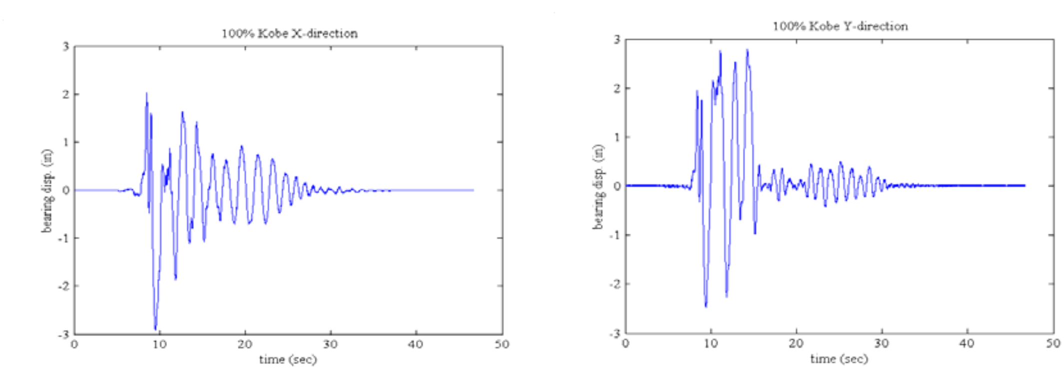

Figure 6. Bearing displacement under sweep sine excitation

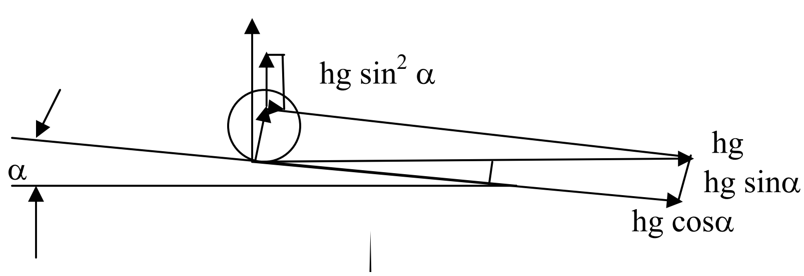

Figure 7. Acceleration distributions