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To limit forces or displacements: Collapse study of steel frames isolated by sliding bearings with and without restraining rims

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ABSTRACT

Sliding isolation bearings can provide enhanced seismic performance for both structural and non-structural components under design level earthquakes. However, the ultimate performance once the physical displacement limit is reached or exceeded has received little attention. One major difference in sliding isolation bearing designs around the world is the restraining rim design. In Europe, the code explicitly forbids any restraining rim in order to eliminate transmission of impact forces to the surrounding structure. However, in North America, sliding bearings have some form of rim to keep the inner slider from falling out of the bearing. In this study, a moment-resisting frame and a concentrically-braced frame, both isolated with sliding bearings using these two rim designs, are investigated under extreme conditions. The collapse risks of these base-isolated frames are quantified and compared. Due to the flexibility of the moment-resisting frame, the collapse margin ratios vary slightly between the rim designs with a slight benefit seen with the bearing design without rims. But for the stiff concentrically-braced frame, eliminating the restraining rim consistently results in a larger collapse margin ratio. This is because the impact force from the rim tends to impose large ductility demands on the concentrically-braced frames causing excessive yielding soon after impact. Generally, using flat rim bearings has a lower collapse probability for both isolated frames, indicating better performance.

1. Introduction

One major type of seismic isolation system, sliding bearings, consists of a slider, one or more spherical sliding surfaces, and surrounding rims. The high level of seismic performance of sliding isolation bearings under design level excitations, regardless of the specific configuration, has been extensively studied and verified [1–4]. One major concern is that sliding isolation bearings can exhibit large horizontal displacements, especially under pulse-like ground motions [5–7], which in extreme events may cause pounding against the moat wall or impact within sliding isolation bearings, potentially resulting in major yielding or collapse of the superstructure. However, most studies have not investigated the ultimate behavior of sliding isolation bearings under extreme conditions.

Pounding of base-isolated building against the moat wall has been investigated in several studies [8–10] with the finding that pounding can result in yielding of the superstructure and increase in the collapse probability. Studies on the extreme behavior of double and triple friction pendulum bearings isolated structures have been conducted by Bao et al. [11] and Becker et al. [12], respectively. However, both of these studies focus on the fully connected restraining rim design (Fig. 1, left), which is widely used in the United States but may not be representative in the other regions. In Japan the sliding isolation bearings are manufactured either with a flat rim (Fig. 1, right) or a restraining rim that is bolted on, while in Europe only flat rims are permitted for sliding isolation bearings [13]. A recent shake table test using double sliding pendulum bearings [14] demonstrated that the restraining rim designs have substantial influence on the extreme behavior of the bearings themselves. With a fully connected restraining rim, although the bearing can withstand stronger seismic excitation compared to a flat rim design, the bearings transmitted shears as large as 180% of the superstructure's weight. In real structural design, such high base shear may induce considerable yielding, potentially resulting in collapse. For the sliding isolation bearing with a flat rim design, assuming that the bearing fails once the nominal displacement capacity is exceeded may be unnecessarily conservative. In fact, in the experimental study by Bao et al. [14] the flat rim bearing achieved displacements of roughly 150% of its nominal capacity before becoming non-functional. These observations motivated the study examining and comparing the collapse risk of base-isolated frames using the two aforementioned rim designs. Although adopting a flat rim bearing design may in some instances be conceptually similar to increasing the bearing displacement capacity, if

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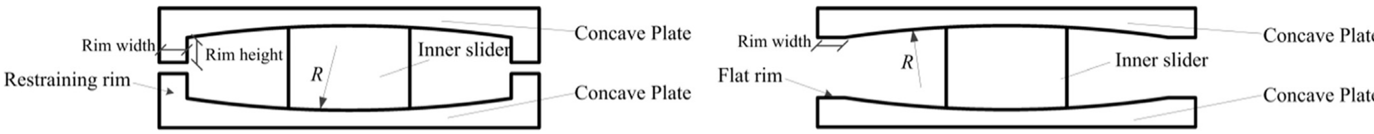

Fig. 1. Configurations of non-articulated double friction pendulums with different rim designs (left: rigid rim bearing, right: flat rime bearing).

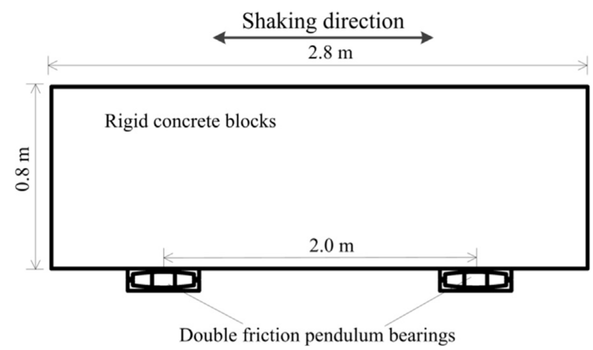

Fig. 2. Schematic drawing of experimental setup.

moat wall impact is completely avoided or isolation used mid-level, the system-level failure mechanism may change based on the bearing rim design, leaving uncertainty regarding which design results in a smaller collapse risk.

In this paper one moment-resisting frame and one concentrically-braced frame are isolated with double friction pendulum bearings, which exhibit standard bilinear hysteretic behavior. Two bearing designs are used: one with fully connected rims and one with flat rims. A comprehensive numerical model which can capture both the isolation bearing failure and inelastic superstructure behavior is used. By comparing the seismic responses using the two restraining rim designs, it is found that the stiffness of the superstructure has a profound influence on ultimate performance. For the flexible moment-resisting frame, the impact force does not significantly increase the superstructure ductility demand, resulting in similar collapse margin ratio using the two rim designs. However, for the stiff concentrically-braced frame, the impact force from the rigid restraining rims generates large ductility demand on the superstructure, resulting in a smaller collapse margin ratio compared to flat rim design. When further examining the individual record collapse margin ratios, it is concluded using the flat rim bearing has considerable beneficial effects in reducing the collapse probabilities for both isolated frames.

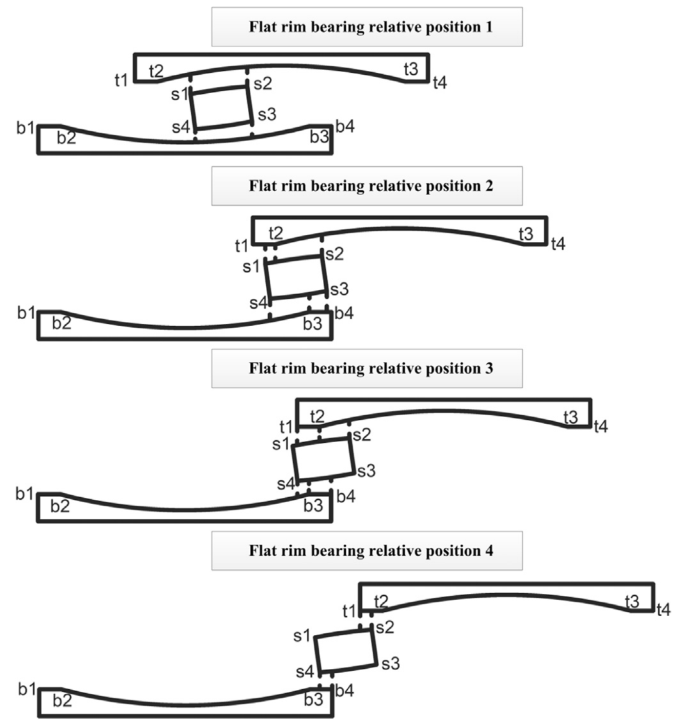

Fig. 4. Relative positions for flat rim bearing model.

2. Validation of numerical bearing models

To compare the failure with the two bearing types, it is important that the bearing model can accurately capture the extreme bearing behavior. A rigid body model capable of predicting failure for the double friction pendulum bearings follows the methodology presented by Bao et al. [11] which modifies the formulation of Sarlis and Constantinou [15]. By assuming each bearing component is rigid, the location of any point within the component can be determined from rigid

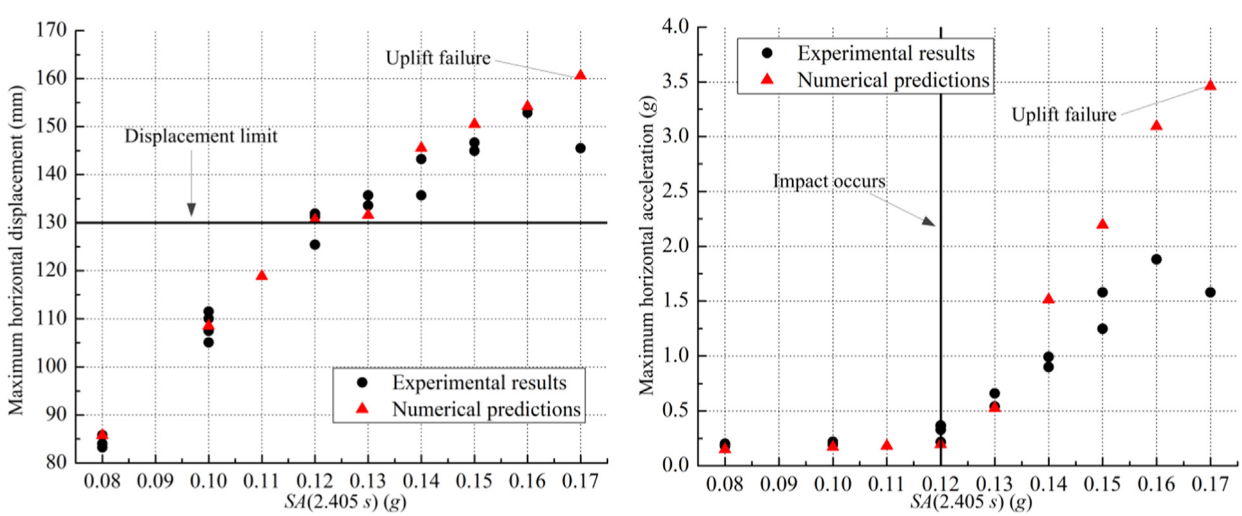

Fig. 3. Comparisons between rigid rim bearing model and experiment (left: maximum horizontal displacement; right: maximum horizontal acceleration).