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Shaking table test of RC columns with a low-cost sliding pendulum system under bi-directional excitations

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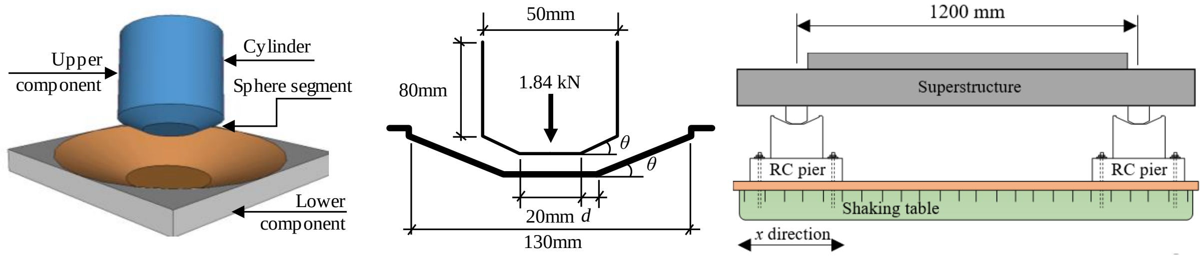
Abstract

A novel low-cost friction sliding system composed of a flat surface at the center surrounded by a spherical segment is proposed through the use of conventional steel and concrete materials. The flat-inclined surface of concrete component was fabricated using an acrylic mold created by a three-dimensional printer. The fundamental behavior of the proposed system is based on the energy dissipation by the friction generated during the sliding and the restoring force by the sphere inclination for limiting the residual displacements. Bi-directional shaking table tests are conducted to evaluate the seismic response in the longitudinal and transverse directions of a one-span bridge model. Experimental results demonstrated the effect of disintegration of frictional forces on the dynamic behavior of friction pendulum subjected to the bi-directional motions. It was observed that shear forces transmitted to the bottom of RC pier and foundation were reduced and the residual displacements of the pendulum were limited. The optimal angle of inclination and flat area were determined experimentally. Compared to the non-linear response of general RC piers due to the formation of plastic hinges, proposed system can ensure the seismic resilience of bridges even under severe earthquake excitation.

Keywords: friction sliding system, seismic resilience, shaking table test, RC bridge pier, low-cost design

1. Introduction

Current design methodology requires that RC columns fail in flexure based on capacity design concept [1]. However, the large economic losses caused by recent strong earthquakes has questioned the achievement in the capacity design concept. A novel sliding pendulum system using only concrete and steel was originally proposed in [2]. Although large decrease of accelerations was observed, the high pressure of pendulum caused damage to the concrete surface. A new type of geometry consisting of a flat area at the center with an inclined surface is proposed herein as shown in Figs. 1 (A) and (B) to develop the bi-directional properties from the original low-cost system. As evidenced in uni-directional test conducted by Igarashi et al. [3], it is expected that flat-inclined surfaces can improve seismic response of bridges.



(A) 3D flat-inclined surfaces (B) Characteristics of specimen (C) View of the shaking table

Fig. 1 – Proposed friction sliding system and the view of the shaking table

2. Shaking Table Test

The flat-inclined surface of concrete component (i.e. lower component in Fig. 1 (A)) is fabricated using an acrylic mold created by a three-dimensional printer. Shaking table test was conducted to evaluate the effectiveness of the system using a 1/33-scale model of bridge. Effect of inclination θ and distance d shown in Fig. 1 (B) on the dynamic behavior is evaluated through the bi-directional excitation using the Noto Hanto earthquake (2007). Five sets of four RC piers with θ = 4°, 7°, 11°, 18° and 25°, and d = 10 mm are fabricated. There are two sets of four RC piers with θ = 11°, one set with d = 5 mm and the other with d = 20 mm. Experimental specimens are named according to θ and d as F-4-d10, F-7-d10, F-11-d5, F-11-d10, F-11-d20, F-18-d10, and F-25-d10. The second term is used to describe θ. The third term is used to describe d on the flat surface. Fig. 1 (C) shows a view of the longitudinal (x) direction of shaking table.

3. Results and Discussions

A summary of test results is shown in Fig. 2. Relationships between the ratio of maximum acceleration of superstructure (A_{max}) to peak ground acceleration (PGA) and the ratio of residual displacements (δ_r) to maximum sliding displacement (δ_{max}) are presented. It is observed that large θ could cause large impact forces under the bi-directional motion provoking amplification of response accelerations while the low θ and large d causes large δ_r/δ_{max}. δ_r/δ_{max} shows large scatter and δ_r seems to be independent of δ_{max}. From the different values of θ and d, test results indicate that specimen with θ = 11° and d = 10 mm could reduce large accelerations with the proper δ_r, which are the main desirable design parameters to achieve seismic resilience of bridges.

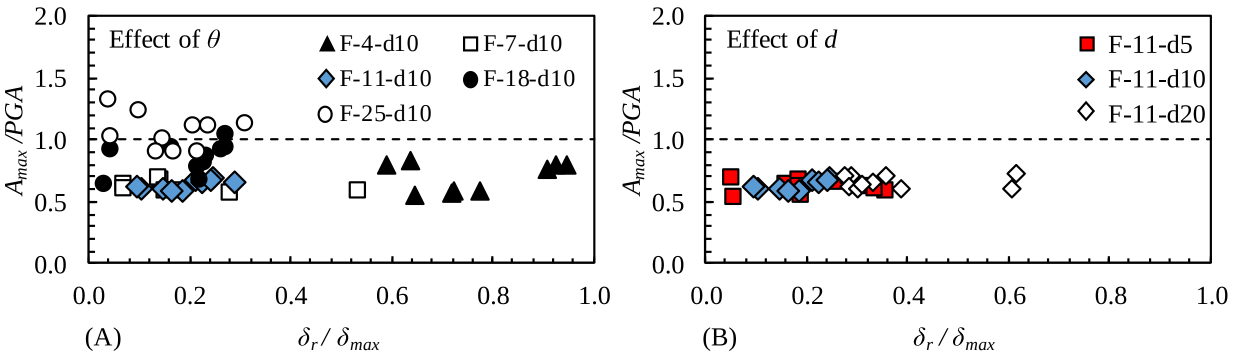


Fig. 2 – Relationship between acceleration and displacement ratio

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