

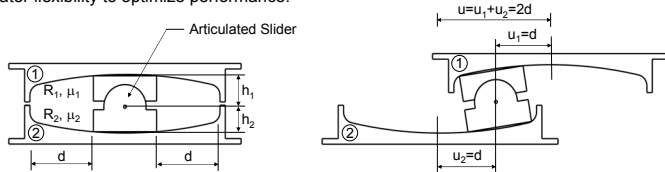
Introduction to the Double Concave Friction Pendulum Bearing

Daniel M. Fenz

Department of Civil, Structural and Environmental Engineering, University at Buffalo

INTRODUCTION

The Double Concave Friction Pendulum (DCFP) bearing is an adaptation of the well-known single concave Friction Pendulum bearing. The principal benefit of the DCFP bearing is its capacity to accommodate substantially larger displacements compared to a traditional Friction Pendulum bearing of identical plan dimensions. Moreover, there is the capability to use sliding surfaces with varying radii of curvature and coefficients of friction, offering the designer greater flexibility to optimize performance.



DCFP bearing at zero displacement (left) and at maximum displacement (right). The DCFP bearing has approximately twice the displacement capacity of a traditional Friction Pendulum bearing with identical plan dimensions.

OBJECTIVES

The goal of the initial phase of the study is to gain understanding of the fundamental behavior of the DCFP bearing. This entails development of a force-displacement relationship based on first principles that can describe behavior in configurations ranging from the simplest case of equal radii and equal friction to the most general case of unequal radii and unequal friction. This is the subject of the work presented in this poster. Future research will focus on how to fully exploit the unique hysteretic behavior offered by the DCFP bearing when concave surfaces of different radii and friction are employed with emphasis on reduction of response of secondary systems and nonstructural components.

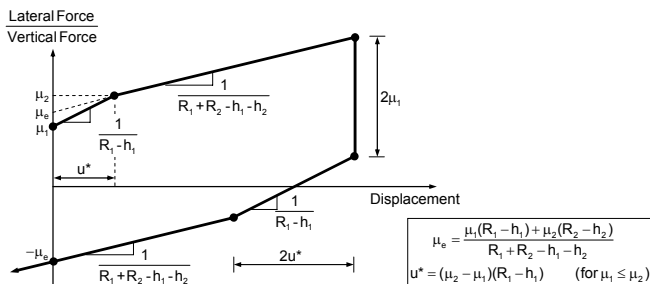
FUNDAMENTAL BEHAVIOR

To derive the force-displacement relationship for the DCFP bearing, the motions of the top and bottom surfaces are considered separately and then combined based on equilibrium and compatibility to yield the relationship for the complete bearing.

$$\begin{aligned} \textcircled{1} \quad & F_1 = \frac{W}{R_1 - h_1} u_1 + F_{f1} \quad F = F_1 = F_2 \quad F_2 = \frac{W}{R_2 - h_2} u_2 + F_{f2} \quad \textcircled{2} \\ \textcircled{3} \quad & F = \left(\frac{W}{R_1 + R_2 - h_1 - h_2} \right) u + \left(\frac{F_{f1}(R_1 - h_1) + F_{f2}(R_2 - h_2)}{R_1 + R_2 - h_1 - h_2} \right) \end{aligned}$$

Equations governing sliding on the surface of least friction, (1-2), and simultaneous sliding on both surfaces after the breakaway force on the surface of higher friction is exceeded, (3).

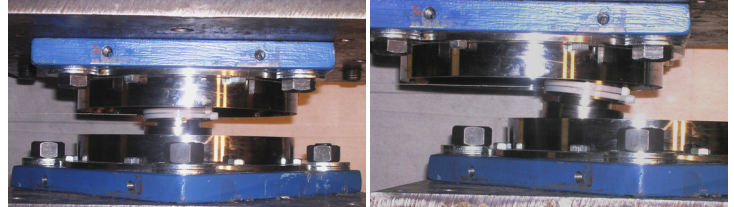
When friction is different on the upper and lower concave surfaces ($\mu_1 \neq \mu_2$), motion initiates on the surface of least friction and continues on this surface only for a distance u^* . During this sliding regime, the force-displacement relationship is governed by equation (1) if $\mu_1 < \mu_2$ or equation (2) if $\mu_2 < \mu_1$. After the displacement exceeds u^* , there is sufficient horizontal force to initiate sliding on the surface of higher friction and motion continues with simultaneous sliding on both surfaces. During this regime, the force-displacement relationship is governed by equation (3). Accordingly, the force-displacement relationship is rigid-bilinear.



Rigid-bilinear force-displacement relationship for a DCFP bearing having concave surfaces with unequal friction. In the case of equal friction, $u^* = 0$ and the behavior collapses to the same rigid-linear behavior exhibited by traditional Friction Pendulum bearings.

CHARACTERIZATION TESTING

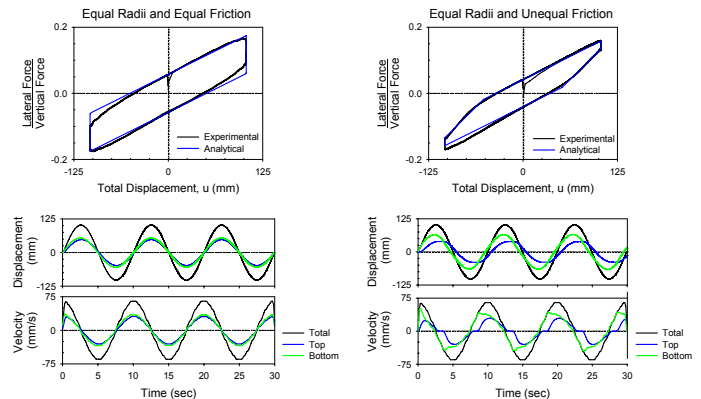
To verify the theoretical force-displacement relationship, experimental testing of a DCFP bearing having concave plates with equal radii of curvature was performed. Tests were performed in configurations in which the concave surfaces had both equal and different coefficients of friction. The latter was achieved by lubricating the bottom sliding surface.



Photographs of the DCFP bearing tested at the University at Buffalo at zero displacement (left) and at maximum displacement of 100 mm (right). The bearing has concave surfaces each with radius of curvature of 474 mm and diameter of 229 mm.

RESULTS

Experimental results are presented below and compared to the proposed theory. When friction is the same on both concave surfaces, the hysteretic behavior is rigid-linear like that of the traditional Friction Pendulum bearing. When friction is different, the behavior changes to rigid-bilinear. The analytical force-displacement relationship is shown to accurately capture the experimentally observed behavior except for the effect of the velocity dependence of the coefficient of friction. Histories of displacement and velocity confirm that simultaneous sliding occurs over the entire range of motion when friction is equal on both surfaces. When friction is different, upon initiation or reversal of motion the slider temporarily sticks on the surface with higher friction. This is demonstrated by the periods of zero velocity on the upper surface.



Hysteresis loops and histories of displacement and velocity from characterization testing.

CONCLUSIONS

- The displacement capacity of a DCFP bearing is approximately twice that of a traditional Friction Pendulum bearing with the same plan dimensions. For a given design displacement, a DCFP bearing half the size of a traditional Friction Pendulum bearing can be used.
- When surfaces with equal friction are used, there is simultaneous sliding on both surfaces over the entire range of motion, regardless of the radii of curvature. The hysteretic behavior is rigid-linear like that of the traditional Friction Pendulum bearing.
- When surfaces with unequal friction are used, upon initiation or reversal of motion, sliding occurs only on the surface of least friction for a distance u^* . When the horizontal force exceeds the breakaway force on the surface of higher friction, there is simultaneous sliding on both surfaces. The hysteretic behavior is rigid-bilinear.

ACKNOWLEDGEMENTS

Faculty advisor: Dr. Michael Constantinou
Financial Support: Multidisciplinary Center for Earthquake Engineering Research (Thrust Area 2: Seismic Retrofit of Acute Care Facilities) and Earthquake Protection Systems Inc.