THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XIV MECHANICHAL ENGINEERING, ISSN 1224-5615
2011

SEISMIC BASE ISOLATION OF STRUCTURES USING FRICTION PENDULUM BEARINGS

Assist. drd. eng. Fanel SCHEAUA
"Dunarea de Jos" University of Galati

ABSTRACT

Base isolation systems have become a significant element to enhance reliability during an earthquake. One type of base isolation system is Friction Pendulum Bearing in which the superstructure is isolated from the foundation using specially designed concave surfaces and bearings to allow swayunder its own natural period during the seismic events. Friction Pendulum Bearings are seismic isolation systems that have been as a kind of bridge, and building retrofit in numerous cases around the world. To assess their impact on structure performance, models are needed to capture the behavior of these highly nonlinear elements.

KEYWORDS*:* seismic isolation, base isolation, friction pendulum bearing

1. INTRODUCTION

In the past decades, earthquake resistant design of building structures has been based on a ductility design concept. The performances of the intended ductile structures during major earthquakes have proved to be unsatisfactory and below expectation. To enhance structural safety and integrity against severe earthquakes, more effective and reliable techniques for seismic isolation design of structures based on structural control concepts are desired. Among the structural control schemes developed, seismic base isolation is one of the most promising alternatives. It can be adopted for new structures as well as the retrofit of existing buildings and bridges.

A significant amount of the past research in the area of base isolation has focused on the use of frictional elements to concentrate flexibility of the structural system and to add damping to the isolated structure. The simplest sliding system device is a pure-friction system without any restoring force. The system supporting a relatively rigid superstructure is very effective for a wide range of frequency input and transmits a limited earthquake force equal to the maximum limiting frictional force.

Seismic isolation can be an effective tool for the earthquake resistant design of structures that can be used in both new construction and retrofit. Architectural innovations are encouraged by the enhanced structural response achieved through seismic isolation.

2. CONCEPT OF FRICTION PENDULUM BEARING

Friction Pendulum Bearings work on the same principle as a simple pendulum. When activated during an earthquake, the articulated slider moves along the concave surface causing the structure to move in small simple harmonic motions, as illustrated in Fig 1.

Similar to a simple pendulum, the bearings increase the structures natural period by causing the building to slide along the concave inner surface of the bearing. The bearings filter out the imparting earthquake forces through the frictional interface. This frictional interface also generates a dynamic friction force that acts as a damping system in the event of an earthquake. This lateral displacement greatly reduces the forces transmitted to the structure even during eight strong magnitude earthquakes. This type of system also possesses a re-centering capability, which allows the structure to center itself, if any displacement is occurred during a seismic event due to the concave surface of the bearings and gravity.

Friction dampers have high potential and low cost. Their main problems deal with friction coefficients and normal force: the friction static and dynamic coefficients must have values as close as possible and they should not depend on velocity, on the environment, on the long time periods when the two touching surfaces do not move; the normal force should not vary in their lifetime.

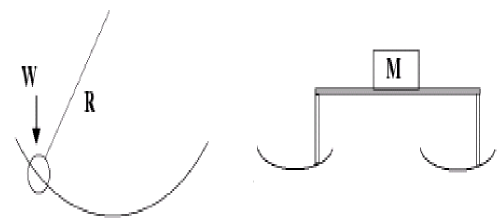

Fig. 1. Concept of sliding pendulum motion

The Friction Pendulum Bearing is a seismic isolation system, with a mechanism based on its concave geometry and surface friction properties. The supported structure is administered into a pendulum motion as the housing plate simultaneously glides on the concave dish and dissipates hysteretic energy via friction. Seismic isolation bearings are structural joints that are installed between a structure and its foundation support columns. The purpose is to minimize damage caused by large lateral displacements observed during earthquakes.

The friction pendulum bearing provides strength and stability. Its properties are not affected by aging or temperature. The bearing's low profile, high strength, and high vertical stiffness reduce installation costs. These bearings offer versatile properties which can satisfy the diverse requirements of buildings, bridges and industrial facilities.

3. MECHANICAL PROPERTIES OF FRICTION PENDULUM BEARINGS

Friction Pendulum Bearings (FPB), as shown in Fig. 2, are made up of a dense chrome over steel concave surface in contact with an articulated friction slider and free to slide during lateral displacements

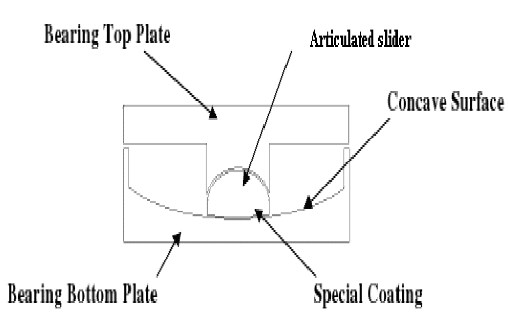

Fig. 2. Cross-section of a friction pendulum bearing

The bearing prototype is basically composed of the following components:

- bearing base plate, this plate is fixed to the structure at one side and has a concave surface on the other side to allow the bearing rotation; the concave rotation surface is realized by inserting in the base plate a disk of an innovative sliding material, called Xlide, patented by ALGA to minimize the friction due to the rotation.

- articulated slider bearing that is convex and in contact with the concave surface contains the special alloy, allows the bearing movement;

- bearing top plate that is connected up to the superstructure and at the bottom with the articulated slider bearing, allows the bearing movement;

The period of the bearing is selected simply by choosing the radius of curvature of the concave surface. When the earthquake forces are below the friction force level, a Friction Pendulum supported structure responds like a conventionally supported structure, at its non-isolated period of vibration. Once the friction force level is exceeded, the structure responds at its isolated period, with the dynamic response and damping controlled by the bearing properties.

During an earthquake, the articulated slider within the bearing slide along the concave surface, causing the supported structure to move with gentle pendulum motions.

The articulated slider is coated with self-lubricating composite liner (Teflon).

These devices are specially designed for each facility based on the load capacity requirements, earthquake displacement capacity, soil conditions, and the size of the structure being supported. Bearings can be designed to accommodate different magnitudes of displacement by simply adjusting the curvature and diameter of the bearing surface. Typically Friction Pendulum bearings measure 90 *cm* in diameter, 20 *cm* high, and weigh 900 *kg*. Bearings can vary from the typical 90 *cm* diameter bearing to the world's largest bearing constructed for the Benicia-Martinez Bridge, which measures 3.96 *m* in diameter. The Friction Pendulum Bearings used in the Benicia-Martinez Bridge in the San Francisco Bay Area, weigh 18 *t* each and can displace up to 135 *cm*. The shiny surface on the inside of the bearing is the dense chrome which reduces the friction between the articulated slider and the concave surface to allow for lateral displacement when ground shaking occurs.

In a multi-modal linear analysis, to characterize a device's dissipative capacity, the equivalent damping coefficient ξ is used which is related to the dissipative efficiency.

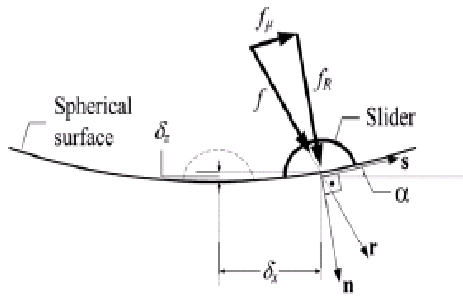

Fig. 3. Deflections and forces acting on the slider surface

Characteristics of the FPB pertaining to durability under severe environmental conditions, reduced height, and insensitivity to the frequency content of the ground motions, make it a viable option for structure seismic isolation. The behavior of the FPB is strongly nonlinear and involves the coupling of multiple components of the dynamic response, posing challenges for those attempting to model their response.

The normal force, N, acting on the FPB is inherent in both resisting force components, f_μ and f_R, of the response.

Modeling the vertical response of the FPB with a gap element allows simultaneously the monitoring of the variations in the N and capturing the effects of uplift and impact in the FPB.

The coefficient of friction, μ, in addition to the material properties of the surface, were found to be primarily a function of δ and N.

4. MODELING ASPECTS FOR FRICTION PENDULUM BEARING

The main modeling aspects of the response of the FPB are:

- the normal force *(N)*;
- the coefficient of friction *(μ)*;
- the in-plane bi-directional sliding interaction;
- large deformation effects *(P–Δ)*.

The response of the FPB is typically modeled by a simplified bilinear force–deformation relationship.

The two components of the intrinsec forces of the FPB consist of the pendulum motion of the mass, f_R , and the friction between the mass and the sliding surface, f_μ. Assuming small deformations, the unidirectional force–deformation response of the FPB is:

$$f = N\,\mu\,sgn(\delta) + \frac{N}{R}\delta \qquad (1)$$

$$f_R = \frac{N}{R}\delta\,;\; f_\mu = N\,\mu\,sgn(\dot{\delta}); \qquad (2)$$

where N is the normal force acting on the sliding surface, R is the radius of the concave surface, δ is the sliding deformation, δ is the sliding velocity, and *sgn(δ)* is the signum function, i.e., equal to *+1*, or *−1* depending on whether δ is negative or positive, respectively.

The fundamental parameters for the device design are the following:

- Isolated structure period
- Horizontal stiffness of the device
- Transmitted horizontal force

The movement of the slider generates a dynamic friction force that provides the required damping for absorbing the energy of the earthquake.

The structural system isolated period is calculated according to the following formula:

$$T = 2\pi\sqrt{\frac{R}{g}} \qquad (3)$$

with:
T = isolated structure period in second
R = sliding surface curvature radius
g = gravity acceleration
The significant parameters are::
- μ = dynamic friction coefficient;
- δ = horizontal displacement;
- W = design vertical load;
- K = device horizontal stiffness;

$$K = \frac{W}{R} \qquad (4)$$

- K_{eff} = effective device horizontal stiffness;

$$K_{eff} = \frac{H}{\delta} = (\mu + 1)\frac{W}{R} \qquad (5)$$

- H = horizontal load given by the device;

$$H = \mu W + K\delta \qquad (6)$$

- T_{eff} = effective isolated structure period;

$$T_{eff} = 2\pi\sqrt{\frac{W}{g\,K_{eff}}} \qquad (7)$$

- ξ_{eff} = effective damping of the isolation system;

$$\xi_{eff} = 2\left[\mu/(\mu+\delta)/R\right]/\pi \qquad (8)$$

The theoretical response curve is the following:

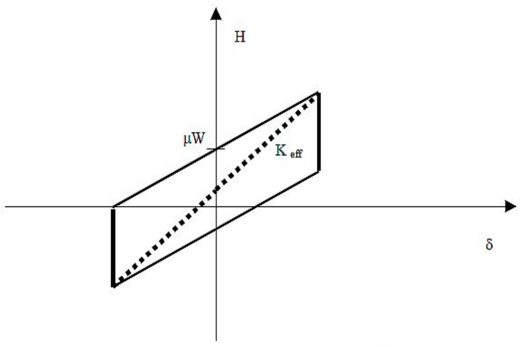

Fig. 4. Theoretical response curve of the sliding surface pendulum

Dissipative efficiency is defined as the ratio of area of the hysteretic cycle and that of the circumscribed rectangle. The coefficient of friction is dependent on the contact pressure between the Teflon and the stainless steel surface. The coefficient decreases as the pressure increased. For an effective isolation, the value of μ must be considered reasonable between *3-10 %.*

5. CONCLUDING REMARKS

The base isolation bearings with considerable lateral flexibility help in reducing the earthquake forces by changing the structure fundamental period to avoid resonance with the predominant frequency contents of the earthquakes. The sliding bearings filter out earthquake forces via the discontinuous sliding interfaces, between which the forces transmitted to the superstructure are limited by the maximum friction forces, function of earthquake intensity. The friction systems perform very well under a variety of severe earthquake loadings and are quite effective in reducing the large levels of the superstructure's acceleration without inducing large base displacements.Comparative study of different base isolation systems has shown that the response of sliding system does not vary with the frequency content of earthquake ground motion.

Friction dampers have high potential and low cost. Their main problems deal with friction coefficients and normal force: the friction static and dynamic coefficients must have values as near as possible and they should not depend on velocity, on the environment, on the long time periods when the two touching surfaces do not move; the normal force should not vary in their lifetime.

They can be utilised in both energy dissipation and re-centring, exploiting, in this way, their superelastic properties and low-fatigue resistances.

.

REFERENCES

[1] Battain M., Marioni A. , *Development of a new sliding pendulum for seismic isolation of structure,* R&D Manager, ALGA S.p.A., Milano – Italy.

[2] M. Eröz , R. DesRoches, *Bridge seismic response as a function of the Friction Pendulum System (FPS) modeling assumptions,* Engineering Structures, November, 2008.

[3] Kravchuk N., Colquhoun R., PorbahaA., *Development of a Friction Pendulum Bearing Base Isolation System,*

[4] Jangid R.S., *Optimum friction pendulum system for near-fault motion,* Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, India.

[5] Symans M. D., - *Seismic Protective Systems: Passive Energy Dissipation*. Instructional Material Complementing FEMA 451, Design Examples, 2004.

[6] Martelli, A. - *Modern Seismic Protection Systems for Civil and Industrial Structures.* SAMCO Final Report 2006, F11 Selected Paper, 2006.

[7] Naeim F., , Kelly, J. M. - *Design of Isolated Structures from Theory to Practice,* John Wiley & Sons, Inc., Canada, 1999.

[8] Ealangi, I. *Earthquake protection of buildings by seismic isolation. devices and concepts,* Technical University of Civil Engineering Bucharest.

[9] Amin, N., Mokha, A. and Fatehi, H., *Rehabilitation of the U.S. Court of Appeals Building Using Sliding Isolation System",* Proc., ATC-17-1 Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control, Applied Technology Council, San Francisco, March 1993.

[10] Zayas, V.A., Constantinou, M.C., Tsopelas, P. , Kartoum A. *Testing of Friction Pendulum Seismic Isolation Bearings for Bridges. Proceedings of the Fourth World Congress on Joint Sealing and Bearing Systems for Concrete Structures,* Sacramento, California, September 1996.

[11] Constantinou, M.C., Mokha, A.S., Reinhorn, A.M., *"Teflon Bearings in Base Isolation* American Society of Civil Engineers, 1990.