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Effective Stiffness and Period of Friction Bearing Devices with one Concave Sliding Surface for Different Load Conditions

The friction pendulum system is a passive earthquake device used for a seismic isolation of buildings, bridges and other types of structures; their purpose is to protect, control and limit the energy transfer from the soil to the structure and fully dissipate seismic energy. In the paper we determine the stiffness and effective period of the friction pendulum system with one sliding surface for different levels of horizontal load.

***Keywords**: earthquake isolation, friction pendulum, structural integrity, stiffness*

1. Introduction

Seismic isolation devices such as friction pendulum have two important properties comparing with other insulating devices: the structures have a greater stability and assure restoration forces due to the sliding surface shape [1]. For these reasons friction pendulums are increasingly used comparing to other types of insulators, being involved for seismic protection of a wide range of structure types. Being a passive device, the friction pendulum preserve its properties for long time, therefore it needs insignificant maintenance operations.

The fundamental principle of base isolation using friction pendulum is to change the building's response in a manner that it takes not over the ground motion, so that the transmitted horizontal forces are drastically diminished; the ideal system would consist in a total separation between the ground and foundation [2]. Opposite to this, for bridges the friction pendulum is placed on the top of the pillar, permitting a relative displacement between the superstructure and the pillar. In this way the bending moments in the pillar are diminished and the collapse risk is avoided.

2. Analytical considerations

The forces acting on the slider are: the vertical load *G*, witch acts at the pivot point; the horizontal force *F* transmitted through the top of the bearing and acting on the bottom part of the slider; the friction force F_f, acting on the sliding interface; the normal force *N*, acting on the sliding interface (shown off-center of the slider so that moment equilibrium is satisfied) and friction traction along the spherical surface of the slider.

Equilibrium of the slider in the vertical and horizontal direction gives [3]:

$$G - N \cos\theta + F_f \sin\theta = 0 \tag{1}$$

$$F - N \sin\theta - F_f \cos\theta = 0 \tag{2}$$

By geometry:

$$x = (R - h)\sin\theta \tag{3}$$

where *x* is the horizontal and *h* is the vertical displacement respectively (figure 1).

The expression of the horizontal force results by combining equations (1), (2) and (3), as:

$$F = \frac{G \cdot x}{(R - h)\cos\theta} + \frac{F_f}{\cos\theta} \tag{4}$$

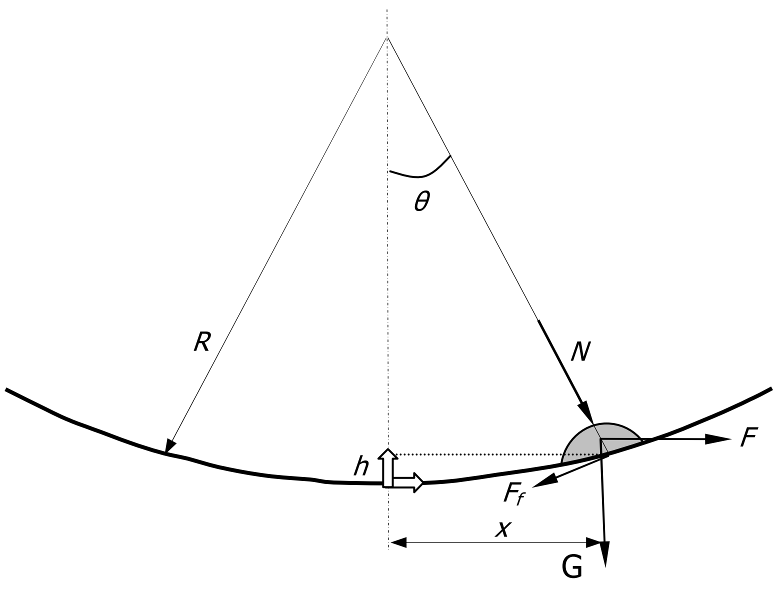

Figure 1. Forces acting on the friction pendulum

Equations (1) to (4) can be simplified when angle θ is small, so that $\cos\theta \approx 1$, $\sin\theta \approx \theta$ to give:

$$F = \frac{G \cdot x}{R - h} + F_f \tag{5}$$

For vertical displacements of less than $0.2R$, equation (5) becomes [4]:

$$F = \frac{G \cdot x}{R - h} + sgn(\dot{x}) \cdot G \cdot \mu \tag{6}$$

where $\dot{x}$ is the horizontal velocity and μ the friction coefficient.

The horizontal force is given therefore by:

$$F = G\left[\frac{x + sgn(\dot{x})\mu\sqrt{R^2 - x^2}}{\sqrt{R^2 - x^2} - sgn(\dot{x})\mu x}\right] \tag{7}$$

The potential energy E_P accumulated by the movement of the pendulum can be expressed as the product of the weight and vertical movement, if the vertical movement is geometrically [5]:

$$h = (R - h_{max}) - (R - h_{max})\cos\theta = (R - h_{max}) \cdot (1 - \cos\theta) \tag{8}$$

$$h = (R - h_{max}) \cdot \left(1 - \sqrt{1 - \sin^2\theta}\right) \tag{9}$$

$$h = (R - h_{max}) - \sqrt{(R - h_{max})^2 - x^2} \tag{10}$$

And the potential energy has the form:

$$E_p = G\left[(R - h_{max}) - \sqrt{(R - h_{max})^2 - x^2}\right] \tag{11}$$

Simple friction pendulum can be assigned with: weight supported (vertical force) G, lateral force F, the friction coefficient μ and the maximum displacement x_{max}, reached at a lateral force:

$$F_{max} = \mu G + x_{max} \cdot \frac{G}{R} \tag{12}$$

Simple friction pendulum with elastic stiffness characterized by post-elastic stiffness k and k^* corresponds to a hysteretic bilinear model [6] and [7], presented in figure 2.

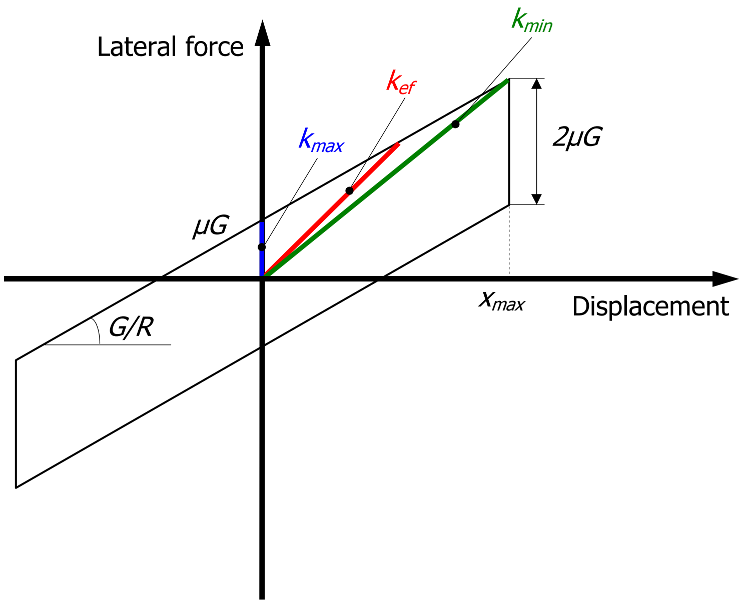

Figure 2. Characteristic load-displacement

Bilinear model based on the assumption that the normal to the sliding surface N is constant for small angles θ (taking the value of G), the friction coefficient μ is constant, and the horizontal displacements are disconnected by the orthogonal directions. Isolator deformations are small and flat on the interval [0, x_{max}], for calculating the stiffness we determined the mathematical relationship [8]:

$$k_{ef} = G\left(\frac{1}{R} + \frac{\mu}{x}\right) \tag{13}$$

By increasing the lateral force F to the maximum, k_{ef} posses a continuous decrease from the theoretical infinity (k_{max}) at a minimum (k_{min}) given by the ratio F_{max}/x_{max}.

Figure 3 show the hysteresis curves for three vertical load cases with different specifications, maintaining a steady coefficient of friction and a radius of curvature of Table 1. The effective stiffness of the isolator was determined as depending on the movement amplitude, using the equation (13), and the variation of coefficient according to the amplitude of the effective stiffness as shown in Figure 4.

Table 1 Parameters used in the simple concave friction pendulum analysis

Case	Weight G [kN]	Radius R [m]	Friction coefficient μ
1	400	5	0,03
2	300	5	0,03
3	200	5	0,03

As expected, increasing the vertical loads lead to greater dissipation energy during a complete cycle, decreased range of motion leading to lower energy dissipation.

An isolated structure with decreasing weight, using a simple friction pendulum determines a decrease in the effective stiffness throughout the entire period under review. The movement is larger, the effective stiffness decreases according to the relation (13) with infinite variation when amplitude is very small and tends to G / R when the amplitude is very large.

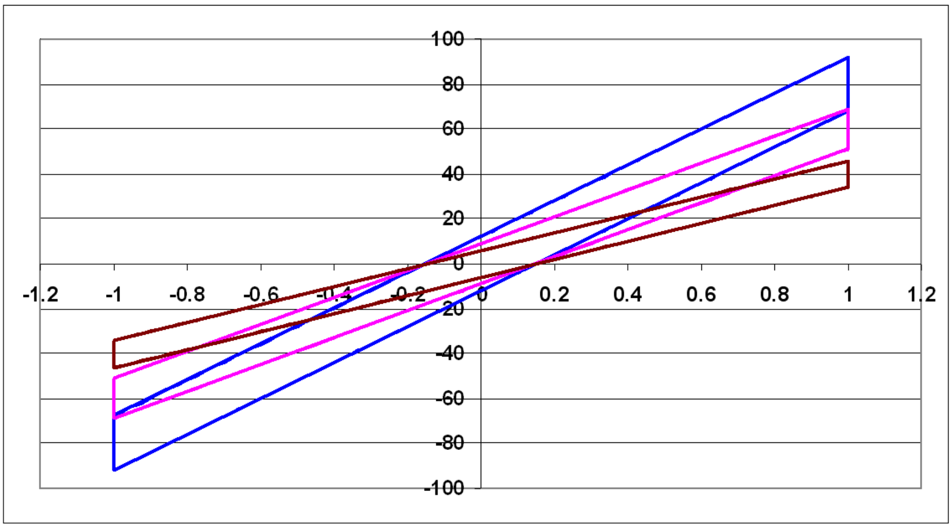

Figure 3. Hysteretic curves for three different vertical loads (G_1 = 400 kN, G_2 = 300 kN and G_3 = 200 kN)

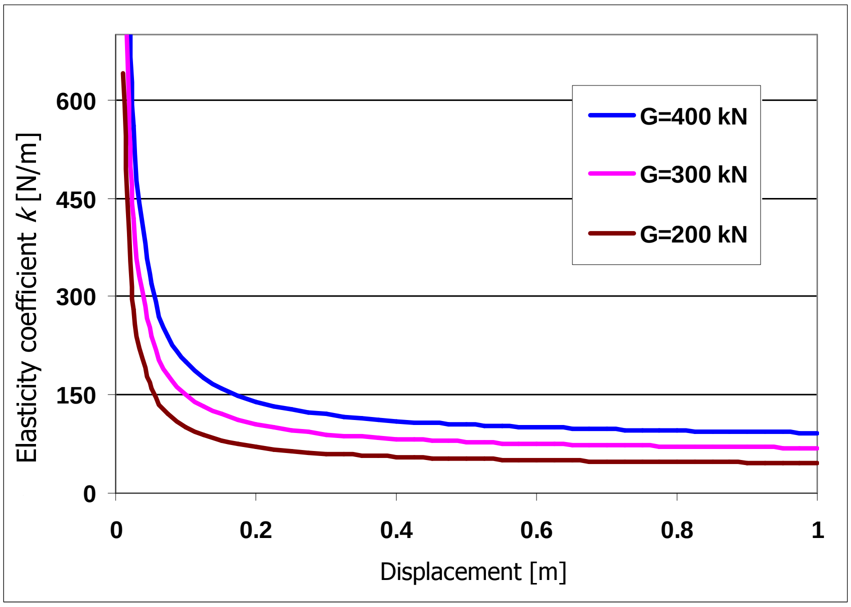

Figure 4. Effective stiffness depending on amplitude of displacement x

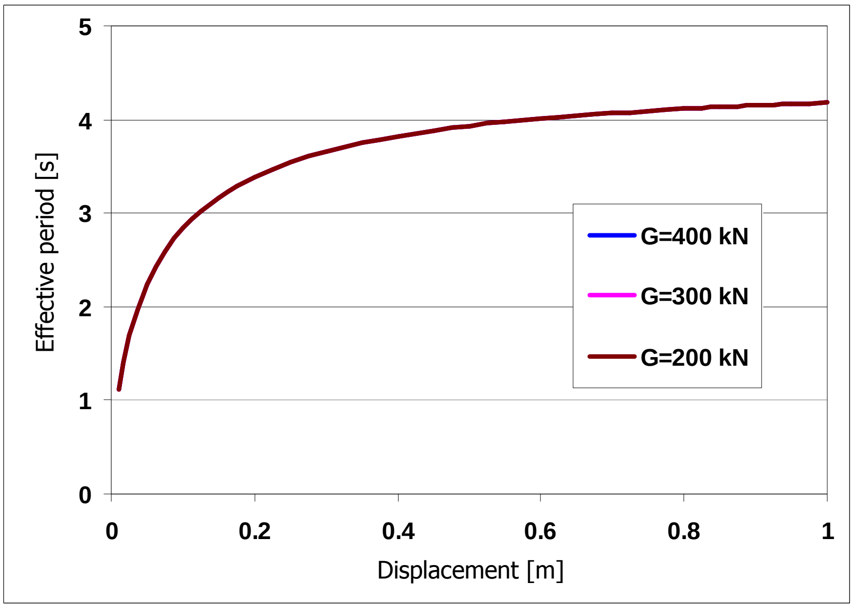

Figure 5. Actual period depending on different vertical load amplitudes

The effective period T_{ef} of the free movement can be determined using the equation as follow:

$$T_{ef} = 2\pi\sqrt{\frac{G}{k_{ef} \cdot g}} = 2\pi\sqrt{\frac{G}{G \cdot \left(\frac{1}{R} + \frac{\mu}{x}\right) \cdot g}} = 2\pi\sqrt{\frac{R \cdot x}{(x + \mu \cdot R) \cdot g}} \tag{14}$$

From figure 5 one observes that the free movement increase the period of the friction pendulum with increasing the range of motion. Vertical load does not affect the movement period.

4. Conclusion

The analysis of the dynamic behavior of a structure isolated by a simple concave friction pendulum show that the structure's weight G influences the dissipated energy; the bigger the weight, the bigger the dissipated energy. At the same time, the increase of isolated mass increases the elasticity coefficient k_{ef} for the entire displacement domain.

On the other hand, the structure's weight do not influence the isolated system's period T, irrespective to the effective ground displacement amplitude.

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References

[1] Skinner R.I., Robinson W.H., McVerry G.H., *Seismic Base Isolation*, Higher Education Higher Education Foundation, Istambul, 2002 An Introduction to Seismic Isolation, Wiley, Chichester, Anglia, 1993.

[2] Tsai C.S., Chiang T.C., Chen B.J., *Seismic behavior of MFPS isolated structure under near-fault sources and strong ground motions with long predominant periods*, The 2003 ASME Pressure Vessels and Piping Conference, Seismic Engineering, Cleveland, Ohio, U.S.A., Iulie, 2003.

[3] Constantinou M.C., *Friction Pendulum Double Concave Bearing, Technical Report*, University of Buffalo, New York, USA, 2004.

[4] Jurcău Ş.C., Gillich G.R., Iancu V., Amariei D., *Evaluation and Control of Forces Acting on Isolated Friction Pendulum*, The 3rd International Conference on Engineering mechanics, structures, engineering geology (EMESEG '10), Corfu Island, Grecia, 2010.
[5] Jurcău Ş.C., Gillich G.R., *The use of the friction pendulum bearings for isolation of the built environment*, ANCS 2009, Romanian Journal of Acoustics and Vibration, Volume VI, Reşiţa, 2009.
[6] Jangid R.S., *Seismic Response of Structures with Sliding Systems*, Journal of Seismology and Earthquake Engineering, Vol. 2, No.2, 2000.
[7] Johnson E.A., Ramallo J.C., Spencer B.F. Jr., Sain M.K., *Intelligent Base Isolation Systems*, Proc. Second World Conf. Struct. Control, pp. 367–376, Kyoto, Japan, 1999.
[8] Jurcău Ş.C., *Theoretical and Analytical Studies about Friction Anti-Seismic Devices*, PhD Thesis, Reşiţa, 2012.

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