Stress Analysis in a Flexible Slider of a Friction Pendulum with Variable Curvature

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Abstract: - Implementation of friction pendulums having the sliding surface profile based on a polynomial function of superior order implies development of flexible sliders, able to maintain permanently the contact to the sliding surface with variable curvature. The paper present some types of sliding surfaces belonging to the concave plate of a seismic isolation system, which permit a greater flexibility in controlling the oscillations of the isolated structure, together with an innovative slider, designed to fulfill all new demands specific to this surfaces. The FEM analysis highlights the capability of the slider to perform with high reliability level under static loads due isolated structure and dynamic loads produced by earthquakes.

Key-Words: - friction pendulum, polynomial surfaces, finite element method, stress analysis, earthquake

1 Introduction

During earthquakes, a structure maintains its integrity if effective isolation systems are integrated in that structure. The most advantageous solution is to limit the transfer of energy from the ground to the structure, which means to dissipate this energy [1].

For this reason, the actual tendency is the use of the friction pendulums; these are passive devices capable to sustain significant loads and to assure the control of oscillating structures [2].

Friction pendulums can be classified, according to the number of sliding surfaces, in mono-armature or multi-armature, the sliding surfaces usually being cylindrical or spherical, some times also conical [2] and [3]. These classical friction pendulum bearings provide just pairs of parameters defining the dynamic behavior of isolated structures, namely the radius of curvature R and friction coefficient μ.

A new seismic isolator, called a variable curvature friction pendulum system, was introduced in [4]. The difference between the variable curvature friction pendulum system and the friction pendulum system is that the isolator's radii can be lengthened with the increase of the isolator displacement. Other authors introduced in [5] and [6] a variable curvature friction pendulum system with the sliding surface based on an ellipse.

The authors of this paper propos a new approach consisting in the implementation of friction pendulums having the sliding surface profile based on a polynomial function of superior order. This seismic isolation system permits, for each surface, a greater flexibility in controlling the oscillations of the upper structure, in terms of displacements or dissipated energy, by using three parameters to control the force-displacement relation. Namely, these parameters are the friction coefficient μ, and two characteristic values of the curve on which the sliding surface is constructed [7].

Opposite to classical systems, where the contact between the slider and the sliding surface assured almost uniformly distributed contact stress even for metallic components, the new devices make use of an elastomeric element between the slider and the sliding surface [8]. A quasi-uniform pressure distribution on the sliding surface can be obtained in this way, the static and dynamic analyses performed using the FEM confirmed that the use of such an element is suitable for this purpose [7]. However, for important changes in surface's curvature a gap between the slider and the sliding surface can appear, so that new concepts regarding the slider's flexible element have to be introduced, in order to overcome this problem. In this paper the authors present the behavior of a modular elastomeric element, with increased flexibility, proper to be used even for friction pendulums with important curvature variations.

2 Geometry of the sliding surface of friction pendulums having variable curvature

For the friction pendulum with the sliding surface generated by polynomial functions we consider the equation of the curve that generates the sliding surface as [8]:

$$y = a \cdot |u|^b \tag{1}$$

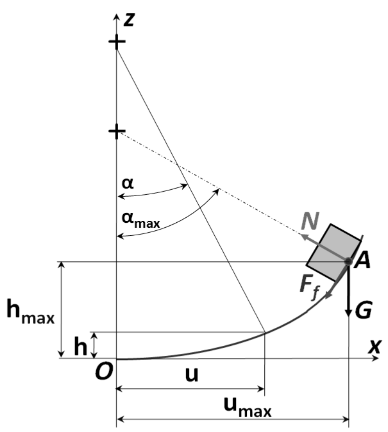

Figure 1 Friction pendulum scheme with polynomial sliding surface

Norms limit the value of the angle to $\alpha_{\max} \approx 36^\circ$, having as consequence the limitation of maximum displacement $u_{\max}$. The maximum values of displacement corroborated with height $h_{\max}$, for the polynomial functions having *b=2*, *b*=2.5 and *b*=4 and different values of *a,* are presented in the table below. To simplify calculations, we consider further only the positive *Ox* axis, i.e. positive values of *u*, because the curve is symmetrical to the vertical *Oz* axis.

Table 1 Limits for displacement and height

b	a	$u_{\max}$ [m]	$h_{\max}$ [m]
2	0,242	1,501	0,545
	0,23	1,57	0,566
	0,3	1,81	0,982
2,5	0,275	1,037	0,301
	0,3	0,979	0,260
	0,25	1,1	0,348
4	0,18	1,005	0,183
	0,2	0,968	0,175
	0,15	1,06	0,189

For a circular sliding surface with the radius $R = 5$ m, for $\alpha_{\max} \approx 36^\circ$, the ultimate values are $u_{\max} = 2{,}93$ m and $h_{\max} = 0{,}948$ m.

In figure 2 we have represented a circular arc with radius $R = 5$ m with continuous line and the arcs given by equations $y = 0{,}101u^2$, $y = 0{,}101|u|^{2,5}$ and $y = 0{,}101u^4$ with dashed line, solid line and dotted line respectively.

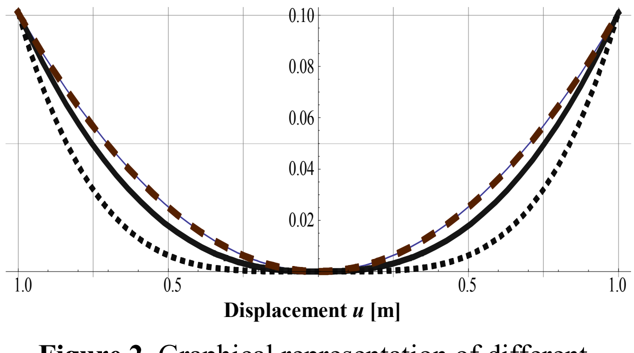

Figure 2 Graphical representation of different curves that generates the sliding surface

For limited values of u, there is a good similitude between the circular arc and the polynomial of second order; the insignificant differences are represented in figure 3.

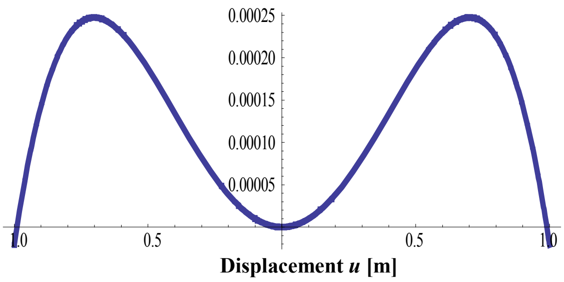

Figure 3 Differences between the circular arc and the polynomial of second order

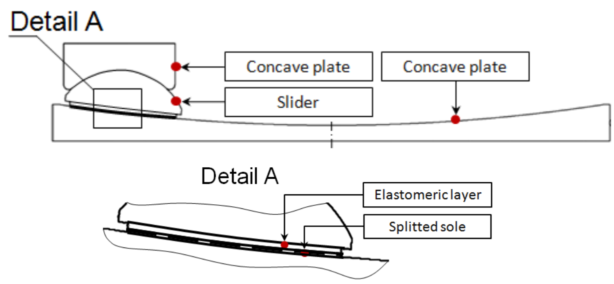

Figure 5 Friction pendulum with polynomial generated surface and splitted sole

The net advantage of these surfaces is the possibility to control the speed and consequently the kinetic and potential energy of the system. On the other hand, it is possible to calibrate the pendulum to operate for low lateral forces, if *b* from equation 1 takes high values, or opposite, to operate just for important lateral forces, if *b* take low values.

In figure 4 we present the evolution of velocities and the heights while the structure moves free from point A to point O (figure 1), on different types of sliding surfaces generated by $y = 0{,}101u^2$ (dashed line), $y = 0{,}101|u|^{2{,}5}$ (solid line), $y = 0{,}101u^4$ (dotted line) and a circular arc with the radius $R = 5$ m (thin continuous line).

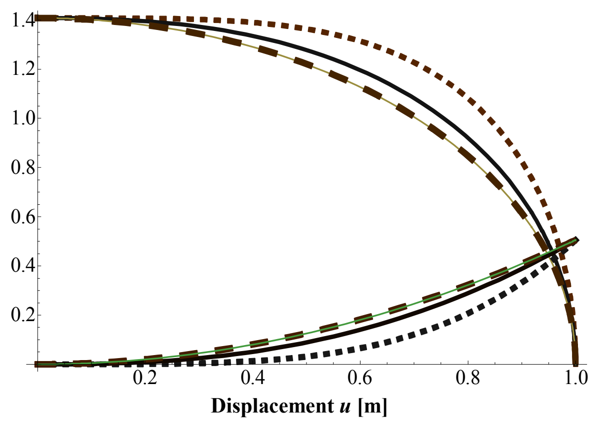

Figure 4 Evolution of the velocities and heights

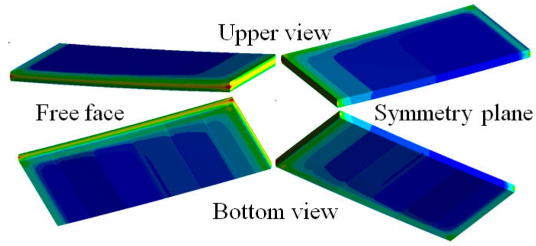

Figure 6 Normal Stress distributions in elastomeric volume

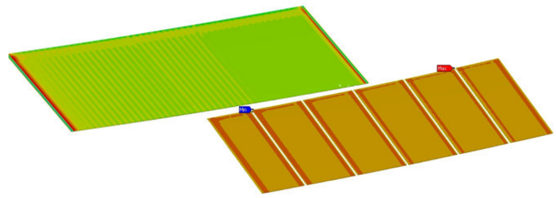

Figure 7 Normal stress distribution map in sole (simple and splitted)

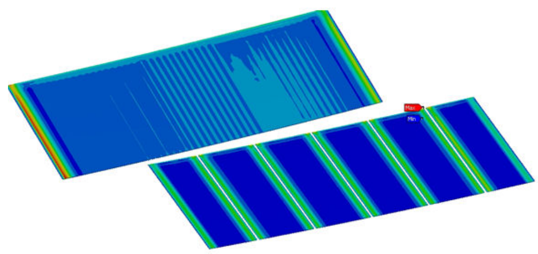

Figure 8 Von Mises Stress distribution map in sole (simple and splitted)

3 Stress analysis in slider for various load conditions

The boundary condition imposed for analysis is presented: during the first second a vertical increasing load was applied, until it reaches the weight of superstructure [9]. Afterwards, until the end of the considered time interval of 2 seconds, a predetermined course (simulating horizontal oscillation during an earthquake) was imposed [10]. Material characteristics were determined in concordance with [11].

These results prove that the splitted sole version assured a better stress distribution in order to maintain a well balanced load in the elastomeric layer. All stress values are in the allowable range. In normal operation condition this new approach represents a better choice in order to dissipate earthquake energy

4 Conclusion

For classical earthquake isolation systems the dynamic response control is limited due to the reduced number of control parameters. In order to avoid this deficiency, sliding surfaces with variable curvature are introduced. But, while for cylindrical or spherical surfaces the slider has the same shape with the concavity of the plate, for the sliding surfaces with variable curvature, an elastomeric element able to follow the changes of the curvature has to be interposed between the slider and the sliding surface.

Analyses made by means of the finite element method shown, for low curvature variance, that the normal stress values are reduced in case of use this kind of innovative earthquake isolation system; all values for stress magnitude fall in the allowable range. For higher curvature variances, the authors propose the use of a modular elastomeric element, with increased flexibility, capable to overtake important deformations.

For the innovative friction pendulum with elastomeric layer having the sole executed from a single part, normal stress value has maxima located in the ends areas, which is naturally due to additional compression in the central area designed to close the gap. Also normal stress values are greater in the posterior area of the sole.

For the variant with sole splitted in 6 (six) parts for each of the 6 pieces is revealed a reduction of normal stress average value with 20%. In the posterior zone there are no high values and normal stress value is uniform throughout the contact area. This think ensures operation without major demands of the sole.

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