STUDY ON THE EFFECT OF A SIMPLE FRICTION PENDULUM RADIUS ON THE RESPONSE OF ISOLATED STRUCTURES

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Abstract: *The paper presents a study regarding the effect of the simple friction pendulum radius on the behavior of isolated structures equipped with this kind of device. A model created in SolidWorks is employed in the research to find out the structural behavior. The excitation, ensured by a simulated shaking table, follows a harmonic displacement. The study revealed the frequency at which the chosen friction pendulums assure efficient isolation. Also, it revealed the frequency domain in which the displacement of the structure is important.*
Keywords: *friction pendulum, structural isolation, Simulation, SolidWorks, Motion*

1. INTRODUCTION

Earthquakes take place if a relative displacement along the Earth's crust fractures happens. The resulting shaking of the soil affects large regions around the epicenter, which may harm the built environment and lead to loss of human lives. Some Romania regions present a high risk because of to the seismic activity that originates from the Vrancea source [1]-[3]. Solutions to reduce the effect of the ground motion are nowadays available [4]-[6]. Insertion of elastomeric devices between the ground and the protected structure is one of them [7]. Description of these devices, consisting of natural rubber [8], lead rubber [9] or hybrid lead rubber bearings [10], can be found in the literature. Also, models of such devices describing specific behavior are available [11]-[12]. Other seismic isolation devices, introduced in 1985, are friction pendulums (FP). Until now, a lot of advanced FP bearing types were developed and optimized. Among these solutions, we can mention the simple, double and triple friction pendulum [13]-[17].

2. MATERIALS AND METHODS

The test structure, presented in figure 1, is generated in *SolidWorks* as an assembly with three parts: 1 - the structure with the dimensions 1200x400x200 mm; 2 - the base plate with the dimensions 600x200x10 mm as a reference; 3 - the shaking plate with the dimensions 600x200x10 mm reproducing the ground motion. The simulation was made in *SolidWorks Motion*, for the following conditions:

- the base plate is fixed;
- the shaking plate is moved on the X direction with a *Linear Motor* that imposes displacement with the following parameter: Oscillating motion, Max Displacement 10 mm, Frequency f = 1 Hz, Shift 0 grd;
- a *SolidBody Contact* with friction is imposed between the bottoms side of the structure made from acrylic material and cylindrical surface of the shaking plate made from steel (greasy) material. The following properties are imposed by *SolidWorks Motion* for the dynamic and static friction coefficients μ_D and μ_S, respectively the dynamic and static velocity coefficient ν_D and ν_S. These are: μ_D=0.05 and ν_D=10.16 mm/s^2 respectively μ_S=0.08 and ν_s=0. 1 mm/s^2;
- the gravitational acceleration g=9806.65 mm/s^2 oriented in Y direction;
- the time of analyze is imposed as 30 s;
- the radius of the sliding surface extruded from the shaking plate was modified in the range 110 ÷ 960 mm, with a 50 mm step.

An image comprising these settings is presented in figure 2. The system has a natural frequency f_n which can be calculated using the mathematical relation:

$$f_n = 2\pi\sqrt{\frac{g}{R}} \quad (1)$$

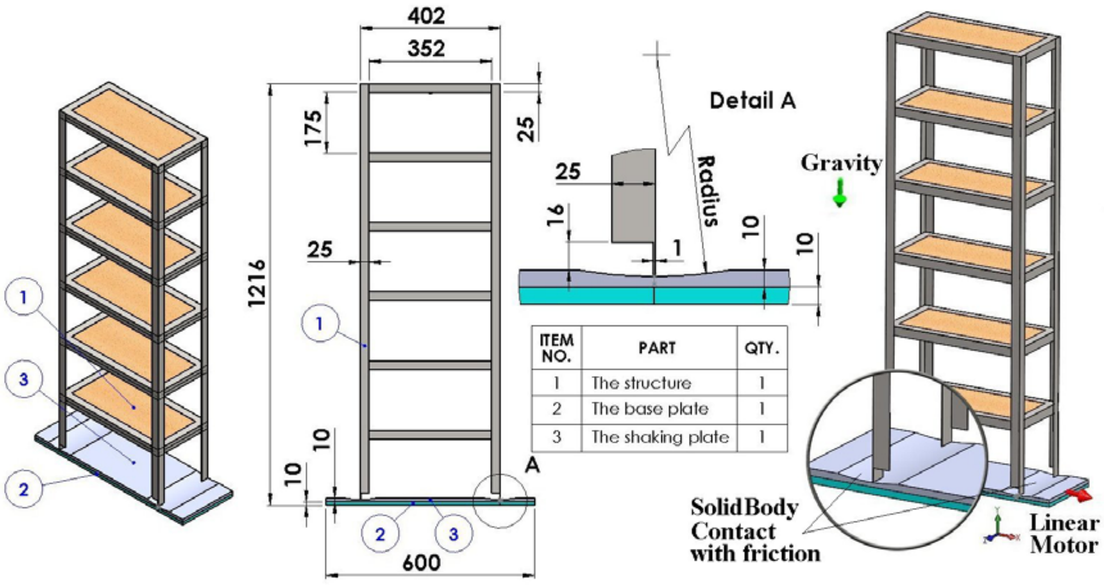

Figure 1: The test structure

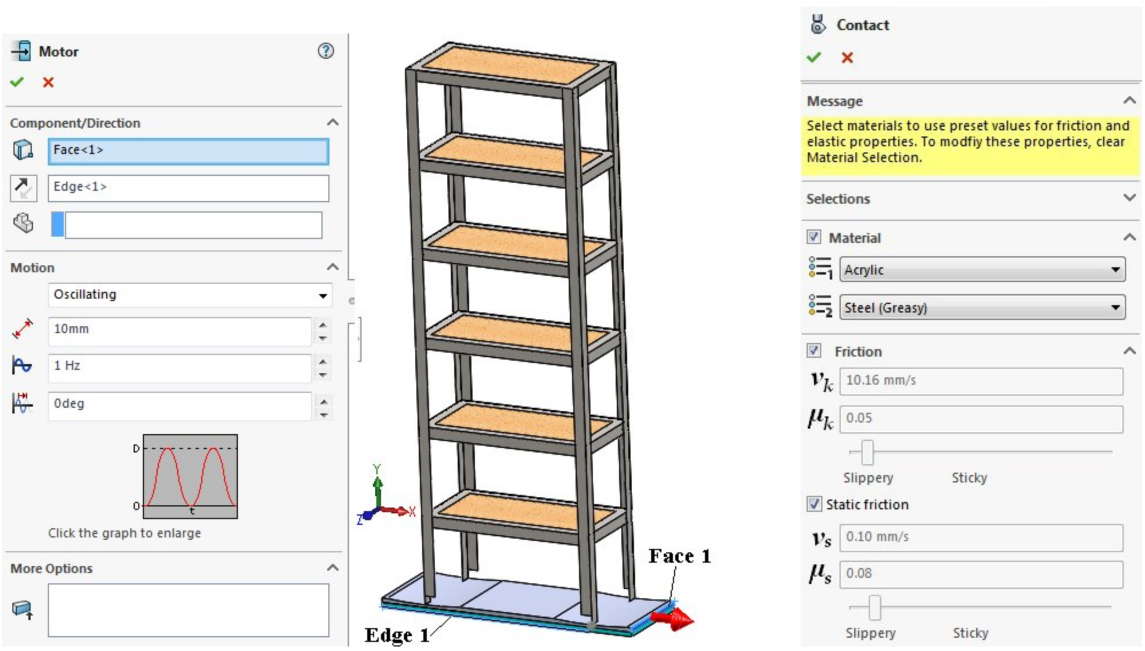

Figure 2: The Linear Motor

The aim of the study is to identify the friction pendulum's radius which the natural frequencies ensures an efficient base isolation.

3. RESULTS AND DISCUSSIONS

The structure's response in terms of displacements in X direction during the 30 seconds of forced excitation are presented in figure 3, for the 18 analyzed cases, corresponding to the radius modification in the 110 ÷ 960 range with a 50 mm step. From these time-histories one can observe that the structure's displacement amplitude becomes smaller and stable as value if the R > 560 mm. In addition, the system's frequency gets stable and takes the value of the pendulum. Table 1 show the minim and maxim values of the structure calculated by *SolidWorks Motion* for the linear displacement in X direction. These values are graphically presented in figure 4.

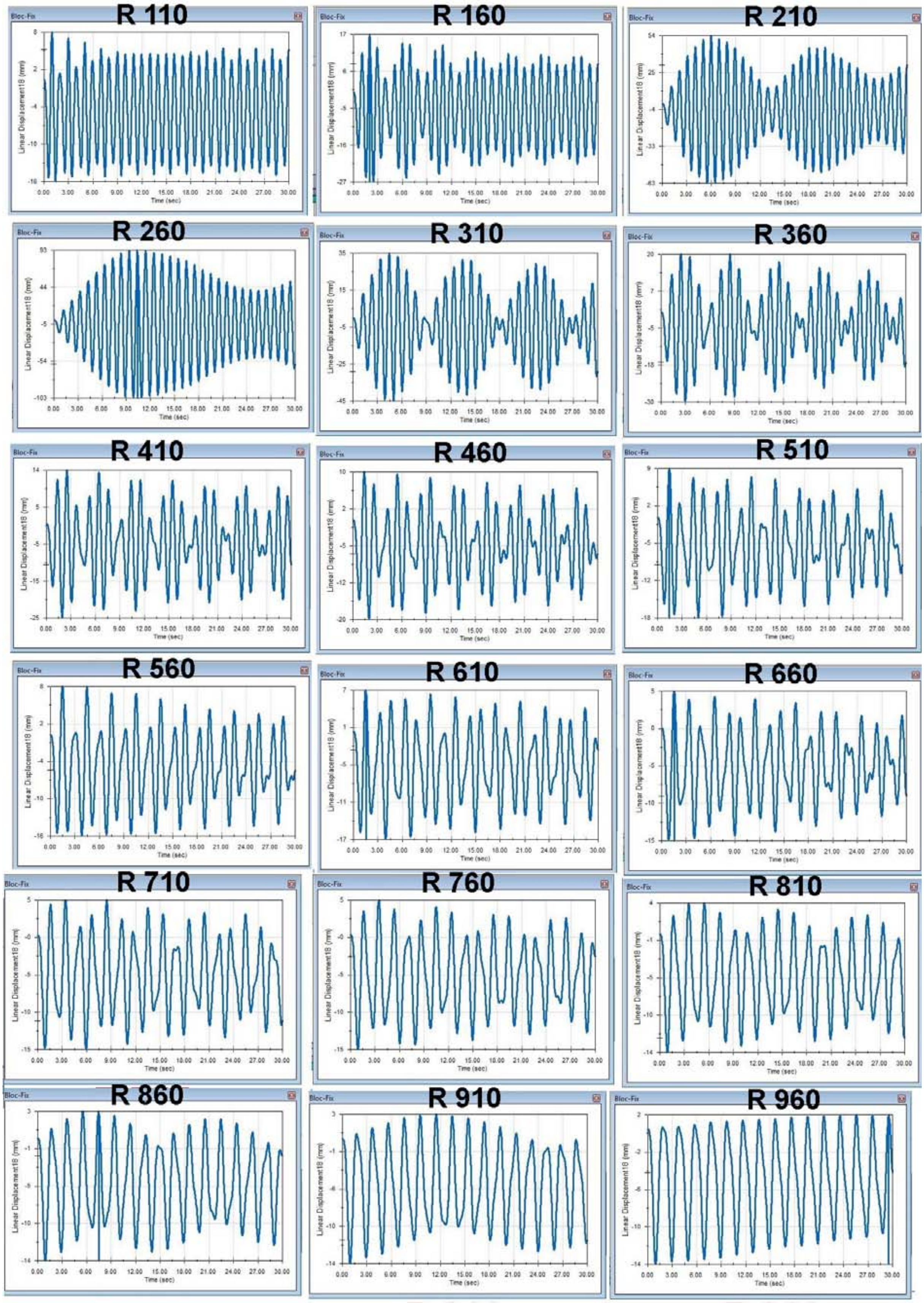

Figure 3: Response signal captured from the isolated structure for different friction pendulum radii

Table 1: Linear displacement in X direction

Radius [mm]	Min. Value [mm]	Max. Value [mm]	Radius [mm]	Min. Value [mm]	Max. Value [mm]
110	-15.92	7.54	**560**	-16.08	7.8
160	-26.53	17.26	**610**	-16.51	6.52
210	-62.57	53.79	**660**	-15.05	5.08
260	-103.29	93.35	**710**	-14.92	4.74
310	-45.31	35.47	**760**	-14.57	4.55
360	-30.36	19.61	**810**	-14.41	3.95
410	-24.63	14.23	**860**	-14.13	3.21
460	-19.88	9.69	**910**	-13.9	2.84
510	-18.46	9.11	**960**	-13.73	1.55

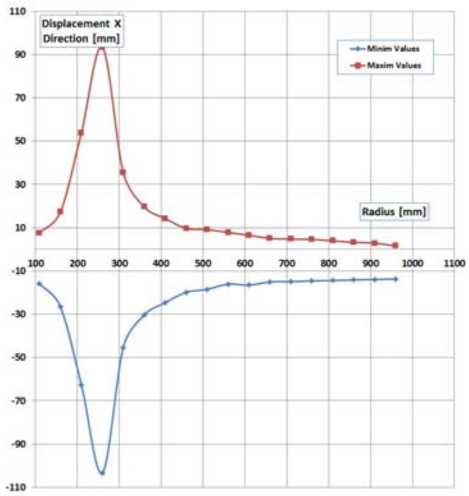

Figure 4: Maximum and minimum displacement amplitudes

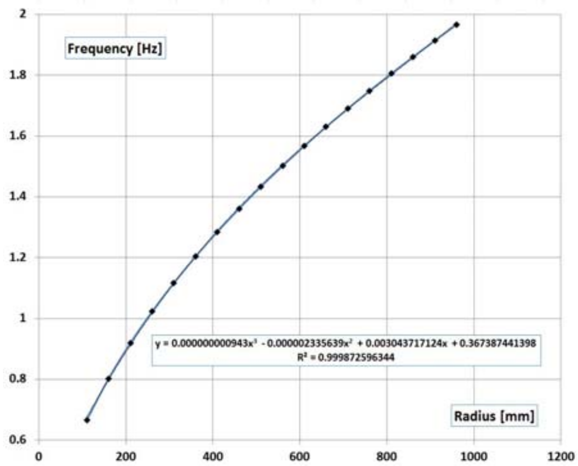

Figure 5: Frequency ratio f_n/f versus the sliding surface radius *R*

Figure 5 shows the evolution of the frequency ratio f_n/f with respect to the sliding surface radius *R*. One can observe that for the ratio $f_n/f > \sqrt{2}$ a reduced transmissibility is achieved and so the structure becomes isolated to the ground motion.

4. CONCLUSION

The papers present the response of a structure to ground excitation if isolated with friction pendulums having different radii. It was found efficient isolation is provided if the radius is bigger then 600 mm in the case of exciting the structure with an oscillation having the frequency of 1 Hz and the amplitude of 10 mm. In addition, from the response signal's time history, we observed an amplitude increase if the excitation frequency is in a narrow band around pendulum's natural frequency. Next studies will be focused on energy dissipation and the hysteretic behavior of the friction pendulum.

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