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STUDY ON A SEISMIC ISOLATION METHOD SUITABLE FOR AN ARCHITECTURAL MONUMENT

Junior Teaching Assist. Fanel SCHEAUA, PhD.c. Eng.
Assist. Prof. Florin NEDELCUT, PhD. Eng.
"Dunarea de Jos" University of Galati

ABSTRACT

The research presented in this scientific paper investigates an adaptive seismic isolation system meant to protect architectural monuments structures subjected to a variety of seismic ground motions. This scientific paper presents a solution that is adequate for the seismic isolation of a small building or a man-made monument, having height and side of the base less than 10 meters. This paper concentrates on the analysis and experimental implementation of an adaptive isolation system for an architectural monument represented by the statue of Ovidius in Constanta (Romania). The solution proposed by the authors is one of a composed type. The isolation system consists of sliding isolation bearings in combination with a central fluid viscous damper device. In order to acquire a good seismic isolation and due to the symmetry in the vertical diametric plane, the chosen solution consists of four sliding bearings (friction pendulum type), located in the corners of the base support. Additionally, the monument is attached to the upper plate of the base support through a dissipative hydraulic element. This one has the role of insulating the monument against the normal movement of soil, mostly due to location of the monument in a public square, accessible to road traffic. The results of the research have revealed a favorable characteristic of this isolation system. The proposed system is therefore capable of simultaneously limiting the response of both sliding base isolation system and superstructure, for a large variety of seismic ground motions.

KEYWORDS: seismic isolation, friction pendulum, sliding bearings, fluid viscous damper, CFD

1. INTRODUCTION

Conventional seismic design based on ductility of structures is generally not acceptable for certain structures that must remain stable during and after earthquakes, for example for historical monuments. One approach to protect such structures involves installation of special seismic devices that ensure the essential elastic behavior of the structure during a major seismic excitation. A seismic isolation system may be used to decouple the structure from the ground motion while a supplemental damping system may be used to absorb a portion of the energy transferred into the structure. The research presented in this scientific paper investigates an adaptive seismic isolation system meant to protect architectural monuments structures subjected to a variety of seismic ground motions.

2. AIMS

This scientific paper presents a solution that is adequate for the seismic isolation of a small building or a man-made monument, having height and side of the base less than 10 meters. The seismic isolation system solution proposed by the authors is of a composed type.

This paper concentrates on the analysis and implementation of an adaptive hybrid isolation system for an architectural monument represented by the statue of Ovidius in Constanţa - Romania[1].

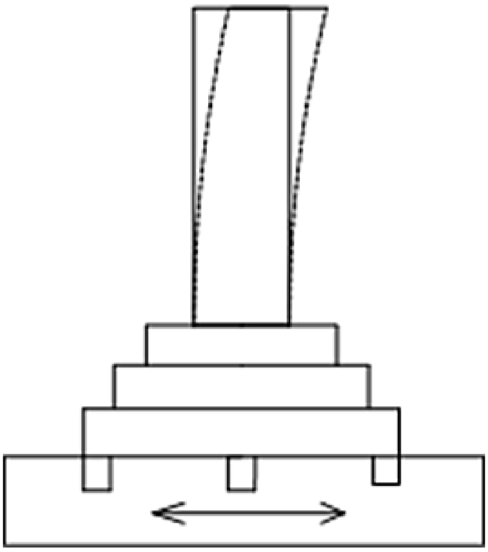
Fig. 1 - The statue of Ovidius in Constanţa

3. BACKGROUND

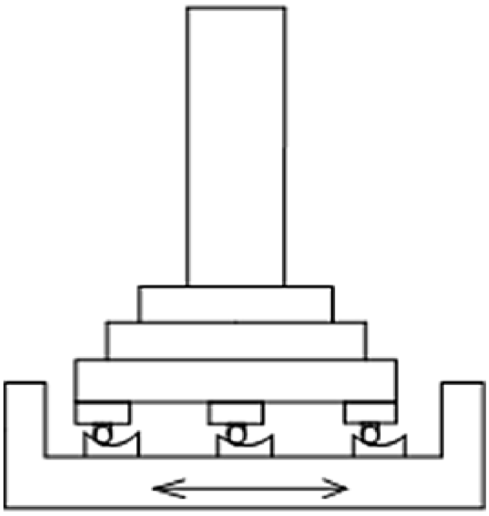
Normally, building vibration of walls and floors ranges from 3 Hz to 100 Hz. The magnitude of vibration in this range may be detrimental to structures, floors and ceilings. Building vibration damage usually occurs from 8 Hz at 0.1 mm to 100 Hz at 0.01 mm.

Mechanical vibration sources are of many types such as machinery, water, air handling, transportation, electrical, hydraulic, man-made and earthquakes. Tall buildings greater than 100 m, which are shaken by winds, have a natural frequency ranging from 0.1 Hz to 5 Hz.

The isolation system proposed by the authors of this study for isolation of an architectural monument - Ovidius statue in Constanta, is represented by a combination of sliding bearings with supplemental fluid viscous dampers.



a) Conventional structure



b) Seismic isolated structure

Fig. 2 Comparative behavior of a building structure with a friction pendulum bearing seismic isolation system

A conventional structure experiences deformations within each level of the structure and amplified accelerations at upper level. In contrast, isolated structures experience deformation primarily at the base of the structure within the isolation system and the accelerations are relatively uniform over the height.

[1] Publius Ovidius Naso, known as Ovidius, was a roman poet who is traditionally ranked alongside Virgilius and Horatius as one of the three canonic poets of Latin literature. As Ovidius spent the last years of his life and literary work in what is now Romania, Romanian people have adopted him as the first Romanian poet and placed him in the Pantheon of Romanian national heroes. Also, a commemorative statue has been built for him in the Romanian city of Tomis (contemporary Constanţa).

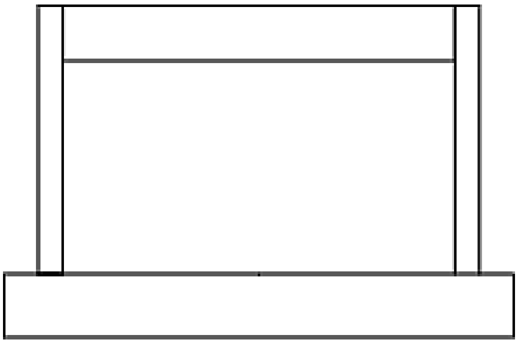


Fig. 3 Natural damping of a structural system

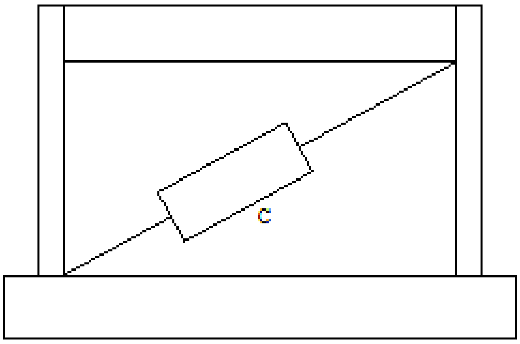


Fig. 4 Added damping of a structural system

The natural damping coefficient, ξ, may be considered as a structural property and it is dependent on system mass, stiffness and inherent energy dissipation mechanisms.

$$\xi_{natural} = 0.5 \div 7\%$$

For added damping, ξ is a structural property dependent on system mass, stiffness and the added damping coefficient, *C*:

$$\xi_{added} = 10 \div 30\%$$

The major effect of seismic isolation system is to increase the natural period which reduces the acceleration and thus the force demand over the structure. In terms of energy, the isolation system shifts the fundamental period of the structure away from the strongest components in the earthquake ground motion, thus reducing the amount of energy transferred into the structure. The energy transmitted to the structure is largely dissipated by efficient energy dissipation mechanisms within the isolation system devices.

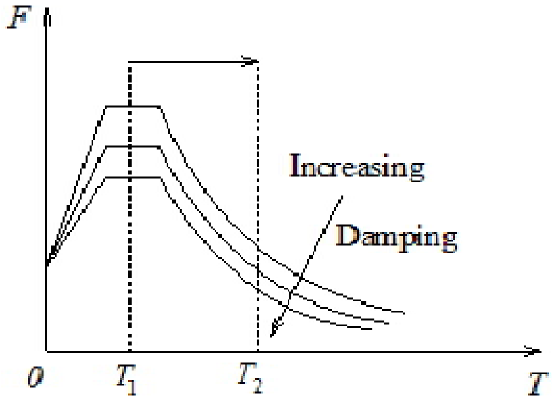


Fig. 5 Increasing the vibration period of the structure is reducing the base shear

F - shear force [N];

T_1 - vibration period for a structural system without isolation devices [s];

T_2 - vibration period for a structural system with isolation devices [s];

D - displacement demand [m].

The effect of using seismic isolation devices is illustrated in Fig. 5, where it may be observed that an increase of the structure period of vibration from T_1 to T_2 has as immediate effect a decrease in value of the shear force with each level of the isolation devices used for seismic isolation. The major effect of seismic isolation is to increase the natural period, T, consequently increasing the displacement demand, *D*. The displacement is shifted from the superstructure to the isolation system. An increase of period of the isolated structure inevitably increases displacements demand as it is shown in Fig. 6.

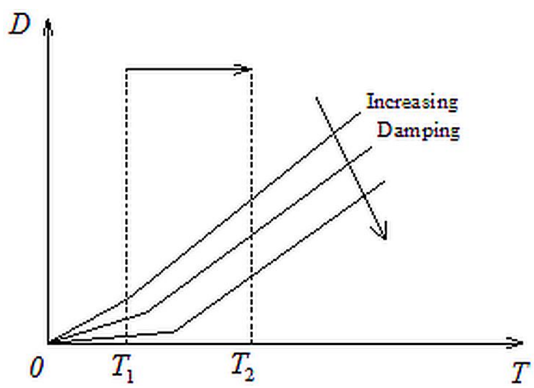


Fig. 6 The immediate effect of a seismic isolation system for three different damping levels

4. FRICTION PENDULUM™ BEARING AS PART OF THE ISOLATION SYSTEM

Friction Pendulum™ Bearing typically utilizes either spherical or flat sliding surfaces.

Single Pendulum bearing is a simple and reliable isolation system, but it maintains constant the friction, the lateral stiffness, and the dynamic period of the building movements for all levels of earthquake motion and displacements.

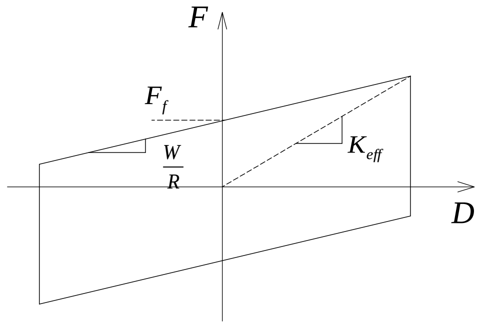


Fig. 7 Idealized sliding bearing hysteresis loop

This design is providing a very small horizontal stiffness to the sliding bearings while they are able to support large vertical load.

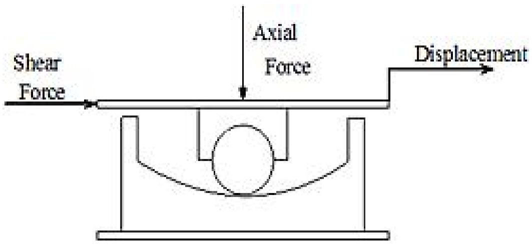


Fig. 8 Model of Friction Pendulum™ sliding bearing

The sliding bearing that utilizes a spherical surface is the most widespread sliding seismic isolation bearing in use within the United States and Japan and the number of seismically isolated buildings supported by sliding bearings is increasing constantly.

The lateral resistance of a sliding bearing is determined by applying a lateral load to the bearing and determining the resisting forces.

The equation (1) shown below is obtained when establishing equilibrium in both the vertical and horizontal directions and neglecting higher order terms.

$$F = \frac{W}{R} D + \mu W \operatorname{sgn}\left(\dot{D}\right) \qquad (1)$$

where:
F- lateral force [N];
W- load [N];
R- radius of the concave surface [m];
μ - coefficient of friction;
D - displacement [m];
$\dot{D}$- velocity [ms^{-1}].

5. FLUID VISCOUS DAMPER (FVD) AS PART OF THE ISOLATION SYSTEM

Hydraulic dampers may be considered as passive control devices in seismic isolation devices category.

A fluid viscous damper (FVD) may be considerred as a cylinder filled with a fluid and it operates on the principle of fluid flow through orifices. As the damper piston rod and piston head are stroked, fluid is forced to flow through orifices around and through the piston head. Hence, the fluid flows at high velocities, resulting the development of viscous friction and thus heat.

The force/velocity relationship for this type of damper may be characterized as:

$$F = C\left|\dot{D}\right|^{\alpha} \operatorname{sgn}\left(\dot{D}\right) \qquad (2)$$

where F [N] is the output force, $\dot{D}$ [ms-1] the relative velocity across the damper, C is the damping coefficient and α is a constant exponent (usually between 0.3 and 1.0). Fig. 9 presents a force-displacement sample loop for the hysteretic viscous fluid dampers and exemplifies the behavior of these velocity dependent systems.

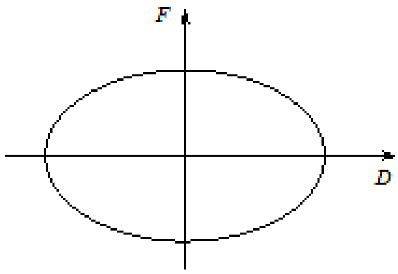


Fig. 9 Viscous fluid force-displacement loop

Usually, in order to have higher viscous friction, the stainless steel piston travels through chambers that are filled with silicone oil. The silicone oil is inert, nonflammable, nontoxic and stable for extremely long periods of time [8].

For a better damping, the chosen fluid is a high-viscosity silicone-oil type, with a viscosity of 29.1 $kgm^{-1} \cdot s^{-1}$ and a density of 970.0 kg/m^3.

The pressure difference between the two chambers cause silicone oil to flow through some orifices made in the piston head and the seismic energy is transformed into heat which dissipates to the external environment. FVDs may operate over temperature fluctuations ranging from –40°C to +70°C.

6. RESULTS AND DISCUSSION

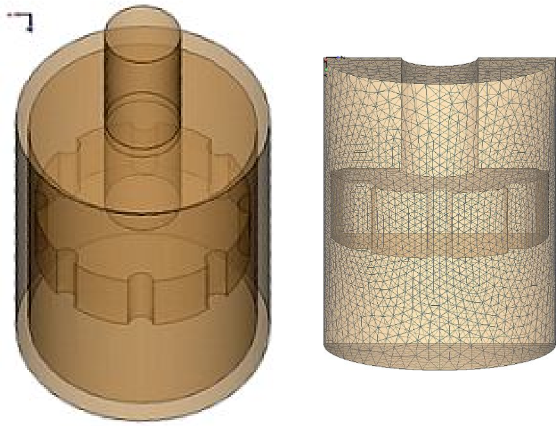
A hybrid seismic isolation system (HSIS) consists in a base isolation with friction pendulum bearings (FPB) combined with supplemental FVD, in order to offer a reliable and cost-effective approach for moderating the effects of strong ground motion.

There are limitations in the performance of hybrid isolation systems. These systems may not perform well for structures that are inclined to resist to a wide variety of earthquake ground motions. For example, when the ground motions are associated with near-field region of an earthquake, they may be quite different from the far-field region motions. Thus, the appropriate seismic isolation system design may be different for each type of ground motion.

Fig. 10 The proposed hybrid seismic isolation system (HSIS) – artistic view

And yet, when used paired with a motion damper, as the chosen fluid viscous damper is, friction pendulum bearing adapts to the earthquake motion and displacements. The smaller the displacement, the higher frequency ground motions are absorbed by the pendulum, while the movement period is shortened.

The chosen solution analysis was made with the following software: for the 3D model, the authors used SolidEdge from UGS and Microstation from Bentley, while the CFD analysis was conducted in Flowizard, software from Ansys.



a) b)

Fig. 11 a) The 3D model; b) the mesh of the fluid viscous damper (FVD)

The dimensions of the hybrid isolation system (HIS) are: 3.00 m length for each horizontal face of the foundation and 0.585 m for its height.

The mesh used in CFD methods is part of the specific method used to solve numerically the CFD problems. Usually, CFD methods comprise two main stages. First, the whole fluid field is divided into small elements named cells, usually of a tetrahedral type, forming a continuous tridimensional structure, named mesh. Solving the partial differential equations over the entire mesh, over a reasonable number of iterations, helps explaining the fluid flow phenomena. The mesh used in our analysis had a total of 28730 tetrahedral cells.

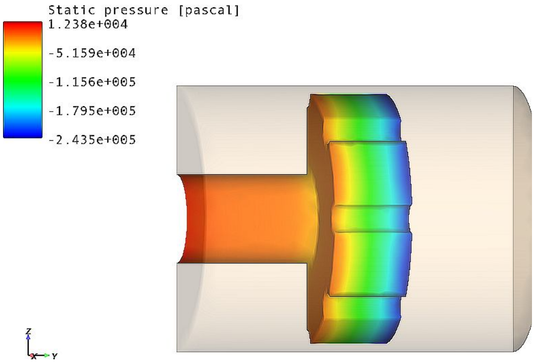
Then, with Flowizard from Ansys, as a CFD solver program, were solved the pressures and forces developed into the model of the FVD. Using the mesh in Fig. 11, the calculation completed after 89 iterations, when the solution converged to a stable one.

The analysis was made in order to evaluate the pressures, velocities and forces (Table 1) inside the FVD, for a 5Hz seismic oscillation, typical for ground movements.

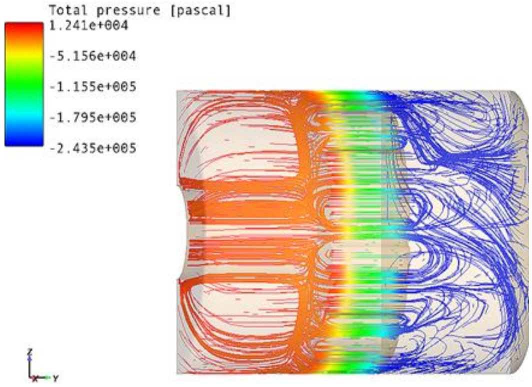
Table 1 Force (N) distribution

Boundary	**X-Component**	**Y-Component**	**Z-Component**
Cylinder	-4909.1723	-2737.4396	-1.0092873
Piston	1006.8993	2737.3864	0.99731058

Net	- 3902.273	-0.053200	-0.01197672



a) Static pressure distribution



b) Total pressure pathlines

Fig. 12 a) Static pressure distribution and b) Total pressure pathlines developed into the FVD

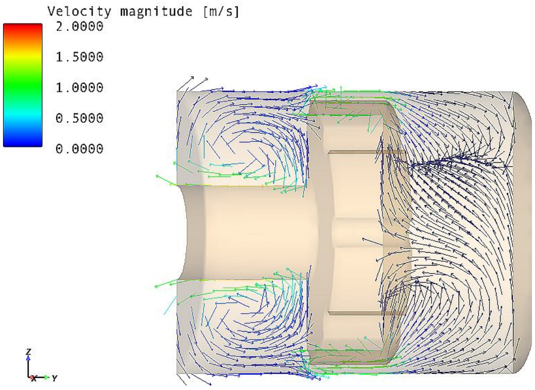


Fig. 13 Velocity magnitude of the fluid flow

7. CONCLUSIONS

When evaluating the dynamic behavior of base-isolated structures, we may highlight that:

Isolation systems are almost always nonlinear, that is why, in the preliminary design is commonly utilized an equivalent linear static analysis, using effective bearing properties.

Also, the final design should be performed using a nonlinear dynamic response analysis of the base-isolated structure.

The proposed system is more complex than FP or FVD systems used separately, but it is still capable to limit simultaneously the responses of both sliding base isolation system and superstructure, for a large variety of seismic ground motions.

Since the proposed system is a hybrid one and has a composed structure, it is therefore capable to ensure isolation for a wider range of frequencies, corresponding to patterns both of near-field and far-field regions of an earthquake.

Also, the proposed system provides isolation from vibrations which come from the city traffic, more common in the area where the monument is placed.

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