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FE MODELING OF A SEISMIC ISOLATOR MADE OF HDR AND REGENERATED EPDM

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Abstract

Losses and damages induced by strong earthquakes are a dramatic reality worldwide. As a consequence, the implementation of innovative protection strategies for both existing and new constructions is of key societal importance. Elastomeric isolators are special devices for seismic isolation of structures. Typically, they are made of alternate layers of steel or fiber reinforced laminas and rubber and they are interposed between the ground and the foundation in order to increase the natural period of the structure and reduce the inertia forces to apply in case of an earthquake. This study proposes a detailed 3D FE modelling of isolators conceived for low-rise masonry buildings in developing countries, carried out through the FE software code Abaqus. The isolator under study consists of an energy dissipation core made by relatively High Damping Rubber and an external EPDM ring. In addition, in order to reduce the production cost and allow its applicability in developing countries, it presents unbonded boundary conditions. In fact, the upper and lower edges do not exhibit any bond with the supports. The main feature of such a device is the large deformability thanks to the rollover deformation and the favorably lower lateral stiffness compared to the bonded isolator.

Keywords: Base Isolation, Fiber Reinforced Elastomeric Isolator, High Damping Rubber, Regenerated EPDM, FE Analysis.

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1 INTRODUCTION

Some commercial base elastomeric isolators have been introduced in the last four decades to protect buildings from vibration and earthquake. Typically, they are constituted by several alternating layers of rubber pads and steel, interposed by two continuous pads that limit vertical deformability (Steel Reinforced Elastomeric Isolator, SREI). This system reduces the seismic demand and isolates the energy transmission of the earthquakes to the structure. A very effective seismic isolator shall satisfy the following functions: good performance under all service loads (vertical and horizontal); provide enough horizontal flexibility to reach the natural target period for the isolated structure; recentering capability after the ground motion, so that no residual horizontal displacement can downgrade the serviceability of the structure; provide an adequate level of energy dissipation (damping) to control the displacement that could damage other structural members. Fiber-reinforced elastomeric isolator (FREI) is a new type of elastomeric isolator. Instead of steel lamina, it's constituted by thin fiber layers for the vertical reinforcement. Compared with SREIs, FREIs have considerably lower weight and can be manufactured through cold vulcanization. Furthermore, FREIs can be applied to the structure in unbonded conditions without steel supports [1, 2, 3, 4, 5]. So, the isolators can be installed between the upper structure and foundation without any bonding or fastening. The advantage is related to the low production cost, that makes the device suitable for the application in developing countries. The reduced quality of the rubber material used and the unbonded condition allow their utilization only for low-rise residential masonry buildings, which are however quite widespread in developing countries. From a technical point of view, the unbonded condition results in a stable rollover lateral deformation, which reduces the horizontal stiffness and increases the efficiency of the devices. Comparing to the identical specimen but in bonded conditions, the unbonded FREIs exhibit an interesting superior performance concerning the damping [6]. This paper proposes a novel typology of base seismic isolator, Unbonded Fiber Elastomeric Isolator (UFREI), made with a core made by a relatively High Damping Rubber and reactivated Ethylene Propylene Diene Monomer (EPDM) used as ring of each pad. In this way the ageing of the device is strongly reduced. Preliminary FE results of a non-linear 3D numerical analysis carried out on a single isolator subjected to cyclic tests are presented.

2 RUBBER MECHANICAL PROPERTIES

Two rubber compounds have been considered for the design of the unbonded fiber elastomeric isolator. The first one is a relatively high damping rubber [7], and it constitutes the damping core of the isolator. This type of rubber compound, made of natural rubber (NR), guarantees a good performance in terms of energy dissipation (Figure 1), but at the same time, it is vulnerable to quick aging.

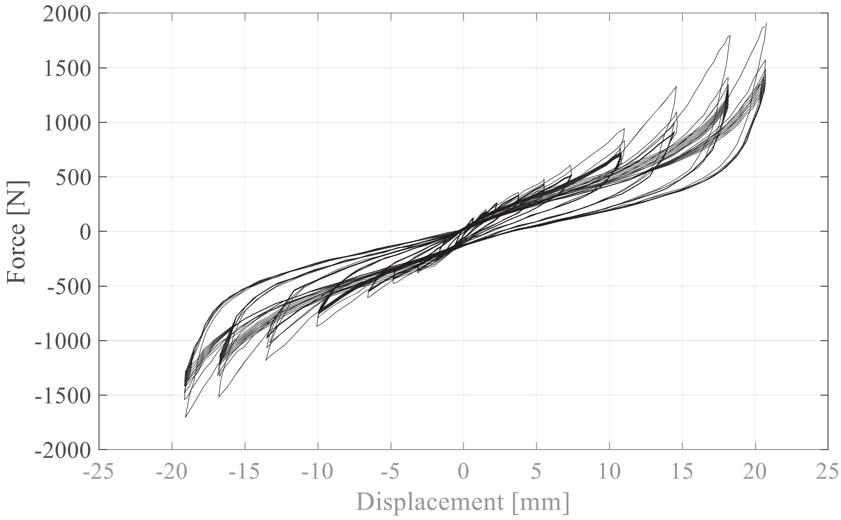
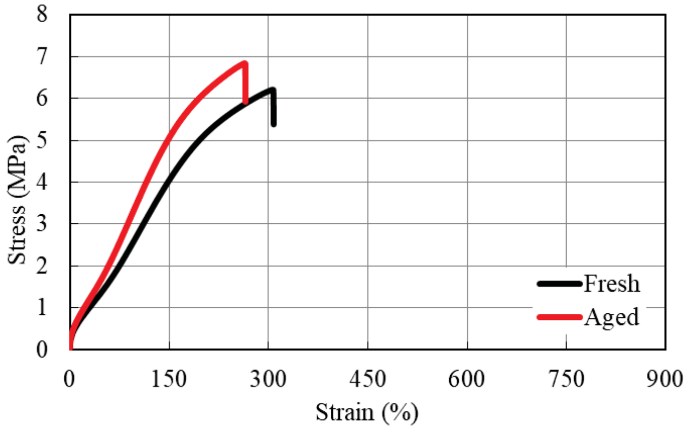
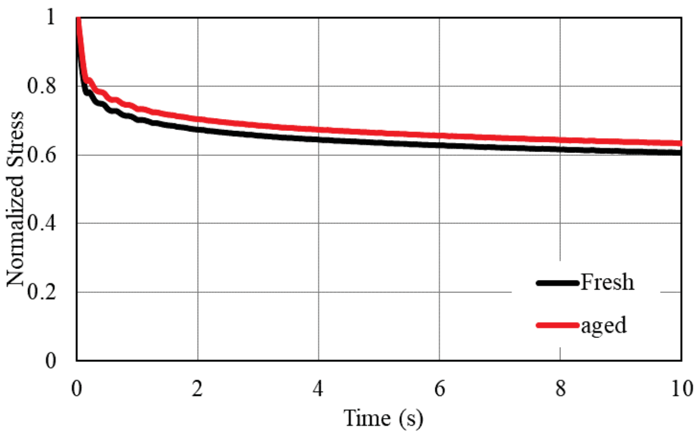


Figure 1: Hysteretic curves for different deformation levels of High Damping Rubber [7]

To protect the HDR, it has been considered a second rubber compound used as ring for each pad, namely a reactivated EPDM made with 2/3 of regenerated rubber and 1/3 of virgin rubber [8, 9, 10] which shows good performances even under aging effects (Figure 2). In Figure 3 it's possible to see the single rubber pad, made of an EPDM frame (Green) with a thickness of 5 mm, and the core (65x65 mm^2) of HDR (Red).



a)



b)

Figure 2: Stretch-stress (a) and relaxation curves (b) of reactivated EPDM, before and after aging [9]

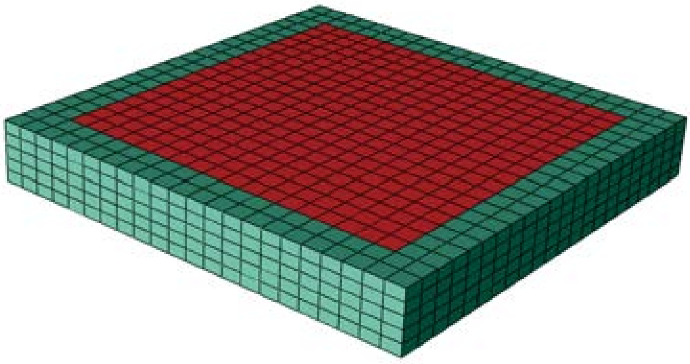


Figure 3: Rubber pad made of HDR and reactivated EPDM

3 HIGH DAMPING RUBBER BEARING

The device object of the study (Figure 4) is constituted by five pads of HDR and reactivated EPDM (10 mm thick), and four GFRP laminas (0.5 mm thick) with a square section of 75x75 mm^2. On the top and on the bottom, there are two pads of EPDM (3 mm thick) in direct contact with the superstructure and the foundation.

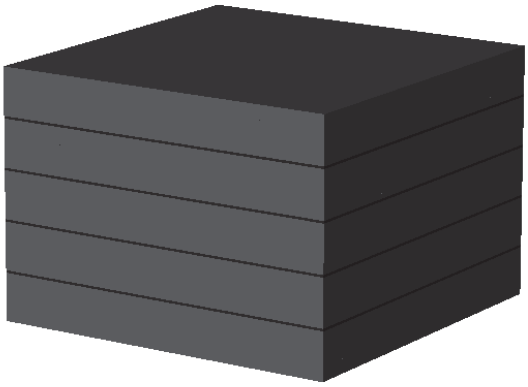


Figure 4: Design of Unbonded Fiber Elastomeric Isolator made of HDR and EPDM

4 3D FE MODEL - CYCLIC SHEAR ANALYSIS

In this section, detailed 3D FE analyses are performed on a single UFREI. In particular, the device is subjected to a 0.5 Hz cyclic horizontal displacement up to 60 mm applied at the top under a constant vertical pressure of 1 MPa.

4.1 3D FE Model

The isolator has been modeled using almost 18000 eight-node brick (C3D8RH) elements with dimensions 3.5 x 3.5 x 2 mm^3. The final mesh is shown in Figure 2. Unbonded condition has been simulated. No bonding is present between the supports and the rubber pad. So, a penalty surface-interaction model has been introduced between the two surfaces and a friction coefficient of μ=1 has been applied. On the contrary, a perfect bond using the surface-to-surface tie constraint between HDR, EPDM and GFRP has been adopted.

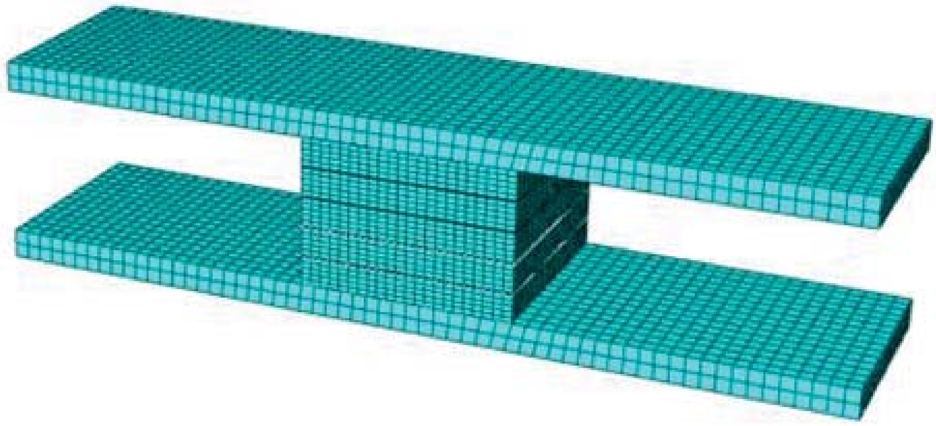


Figure 5: FE model of Unbonded Fiber Reinforce Elstomeric Isolator

4.2 Results

Effective horizontal stiffness $K_{H,eff}$ and damping ratio ξ have been evaluated on four cycles with maximum displacement equal to 15 mm, 30 mm, 50 mm, and 60 mm respectively. The computations are based on the equations (1)-(4):

$$K_{H,eff}= (F_{max}- F_{min})/(\Delta_{max}- \Delta_{min}) \tag{1}$$

$$\xi=W_d/(4\Pi W_s) \tag{2}$$

$$Ws=(1/2)*K_{H,eff}*\Delta^2_{max,ave} \tag{3}$$

$$\Delta_{max,ave}=(\Delta_{max} + \Delta_{min})/2 \tag{4}$$

Cycle	Effective horizontal stiffness $\mathbf{K_{H,eff}}$ [N mm]	Damping ratio ξ [%]
	Device cured at 130° for 40 minutes	
1°	39.69	5.60
2°	31.91	8.22
3°	22.48	11.65
4°	19.46	14.42

Table 1: Damping ratio and Effective horizontal stiffness for each cycle on the device.

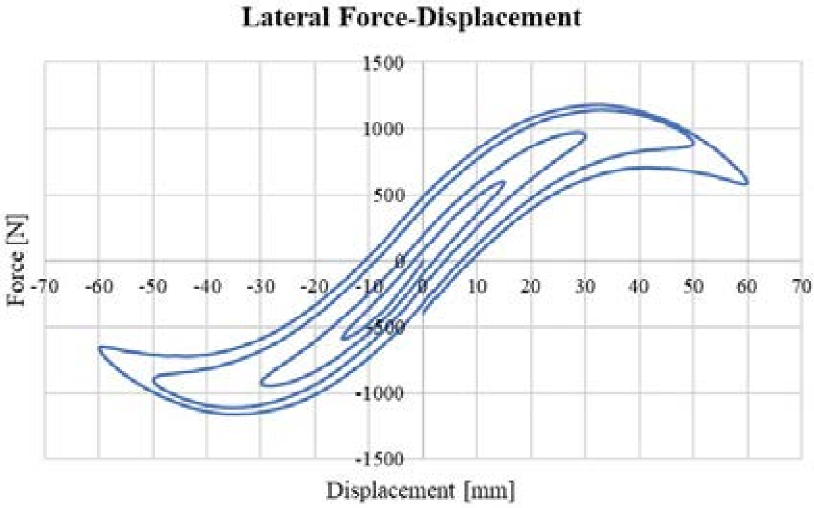


Figure 6: Lateral force-displacement curve for the unbonded FREI.

In Figure 6, the lateral force-displacement curves of the device are shown. The effective horizontal stiffness decreases from the first to the last cycle, up to the final displacement equal to 60 mm (Table 1). This is a typical characteristic of unbonded application, rollover (Figure 7), which causes a nonlinear behavior, resulting in a softening behavior.

5 CONCLUSIONS

In this paper, preliminary FE analyses on a novel typology of Unbonded Fiber Reinforced Elastomeric Isolator have been presented.

Each pad of the isolator is constituted by two rubber compounds, HDR as core and EPDM as external layer; the aim is to obtain -at low cost- a base seismic isolator with good performance in terms of damping and good durability. Subsequentially, a detailed 3D FE model of the isolator has been considered, carrying out the analyses through the FE software code Abaqus; in particular, cyclic shear tests with a maximum displacement of 60 mm have been performed. The preliminary numerical results obtained seem promising to consider this new device suitable to isolate low-rise masonry buildings in developing countries, where the low cost and the promotion of circular economy will be crucial in the future decades.

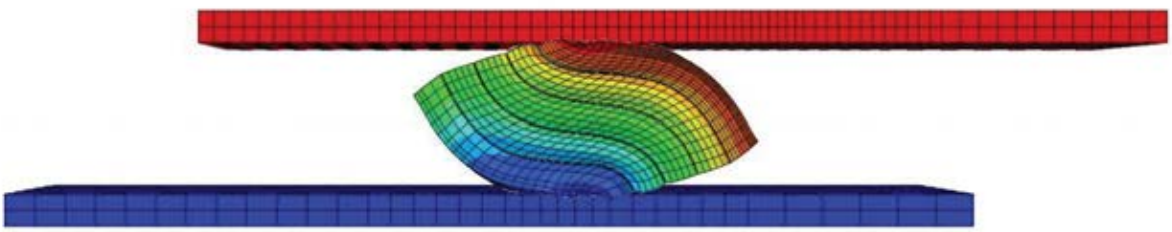


Figure 7: Typical rollover deformation due to unbonding, which causes a softening behavior

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