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COMPRESSIVE BEHAVIOUR OF A CIRCULAR UNBONDED FIBER-REINFORCED ELASTOMERIC ISOLATOR (UFREI)

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Abstract

Steel-reinforced elastomeric isolator (SREI) is the most used method of seismic isolation. It consists of several rubber pads interspersed with steel laminas for vertical reinforcement. Since these devices are generally too expensive due to the need to introduce thick connection steel plates and the high energy consumed for manufacturing, they are unsuitable for ordinary residential masonry buildings. Fiber-reinforced elastomeric isolator (FREI) is a new type of elastomeric device. Instead of steel lamina, thin fiber layers are used. Compared with SREIs, FREIs have considerably lower weight and can be manufactured through cold vulcanization. They can be applied to the structure in several ways: bonded (traditional), un-bonded, and partially bonded. In unbonded conditions (UFREI), the isolators can be installed between the upper structure and foundation without any bonding or fastening, reducing costs hugely. Furthermore, the dissipation energy without steel supports improves thanks to the shear load transferred through the friction generated between the isolator and the structure surfaces. This study presents an experimental investigation into the compressive behavior of a circular UFREI. The device has been subjected to standard and cyclic compression tests considering different vertical pressures. Results, evaluated in terms of vertical stiffness and vertical frequency, provide insight into the UFREI potential for practical applications.

Keywords: Base Isolation, Fiber-Reinforced Elastomeric Isolator, High-Damping Rubber, Unbonded application, Compression Behaviour

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1 INTRODUCTION

Elastomeric isolators are special devices for the seismic isolation of structures. They are designed to reduce the seismic forces transmitted to the structure, thus increasing its overall stability and safety. Fiber-Reinforced Elastomeric Isolators (FREIs) are a recent development in the field of seismic isolation [1–3], offering several advantages over traditional Steel-Reinforced Elastomeric Isolators (SREIs). Compared with SREIs, FREIs have considerably lower weight and can be manufactured through cold vulcanization. They can be applied to the structure in several ways: bonded (traditional)[4], unbonded [5–8], and partially bonded [9,10]. In unbonded conditions (UFREI), the isolators can be installed between the upper structure and foundation without bonding or fastening, reducing costs hugely. Furthermore, the dissipation energy without steel supports improves thanks to the shear load transferred through the friction generated between the isolator and the structure surfaces. FREIs are made of rubber pads interspersed with thin fiber layers, such as fiberglass or carbon fiber, to increase their stiffness and vertical load-bearing capacity. However, the fiber reinforcement leads to a minor vertical stiffness compared to the reinforcing steel plates, which can affect FREI behavior in seismic isolation. This can be mitigated with appropriate design, ensuring adequate vertical stiffness for the specific application.

This paper presents an experimental study of the vertical behavior of UFREI. The device, designed by the authors for the installation at the base of low-rise masonry buildings in developing countries, has been subjected to compression tests, varying the vertical pressure. The aim is to evaluate the impact of vertical loads on the final compressive behavior of the UFREI evaluated in terms of vertical stiffness and vertical frequency.

2 CIRCULAR UNBONDED FIBER-REINFORCED ELASTOMERIC ISOLATOR MADE OF HIGH-DAMPING RUBBER

The isolator under investigation is a circular device with a base of 200 mm, a height equal to 67 mm (h), and is constituted by 15 rubber pads 4 mm thick (T_r), interspersed by 14 fiber fabrics layers 0.5 mm thick (T_f). Figure 1 and Table 1 show a summary of the main geometrical characteristics and the structural application.

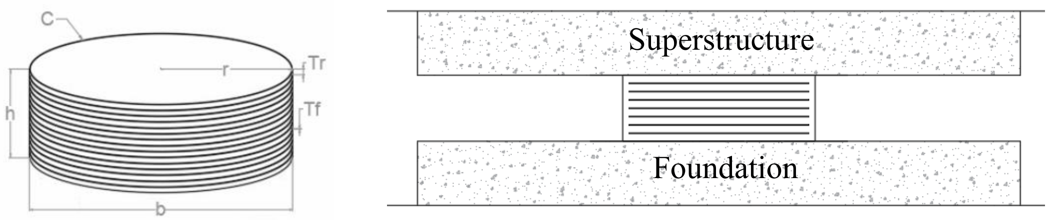
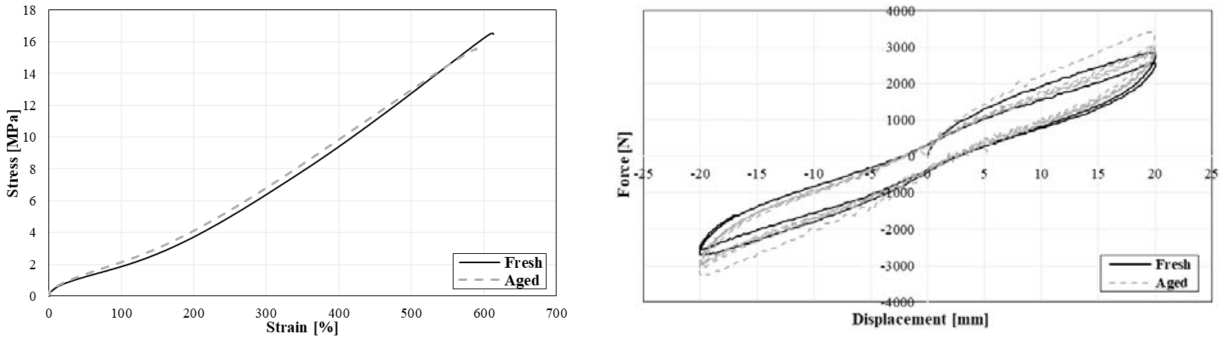


Figure 1: Design (a) and structural application (b) of UFREI200.

H	b	C	A	T_r	T_f	n°rubber layers	n°fiber laminas	T_{rtot}	T_{ftot}	R=b/h	S_1=A/(C*Tr)
[mm]	[mm]	[mm]	[mm^2]	[mm]	[mm]	[-]	[-]	[mm]	[mm]	[-]	[-]
67	200	628.32	31415.9	4	0.5	15	14	60	7	2.98	12.50

Table 1: Geometrical characteristics of the circular UFREI200.

A high rubber composition (good durability) made of a Natural Rubber and Ethylene Propylene Diene Monomer (NR-EDPM) blend has been used to produce UFREIs. The rubber has been first chemically characterized with a rheometer test and then mechanically through several experimental tests, such as tensile test, tear-resistance test, compression set, accelerated air oven aging, hardness measurement, and cyclic shear test according to UNI EN 15129, European code for anti-seismic devices. The rubber compound has met the minimum requirements of the code for high-damping rubber for elastomeric isolators. Results are shown in Figure 2, Table 2, Table 3, and Table 4.



(a) (b)

Figure 2: NR-EPDM uniaxial tensile test (B) and cyclic shear test (C) before and after aging.

Density	Hardness	Tensile Strenght at break	Elongation at break	Young Modulus	Tear Resistance
[g/cm^3]	[IRHD]	[MPa]	[%]	[MPa]	[kN/m]
1.129	59.98	16.06	613.0	1.63	22.84

Table 2: NR-EPDM mechanical and physical properties.

Accelerated air oven aging			Compression Set
Δ H	Δ TS_{break}	Δ E_{break}	
[IRHD]	[%]	[%]	[%]
1.00	-4.51	-9.51	35

Table 3: NR-EPDM mechanical properties after accelerated aging and compression set.

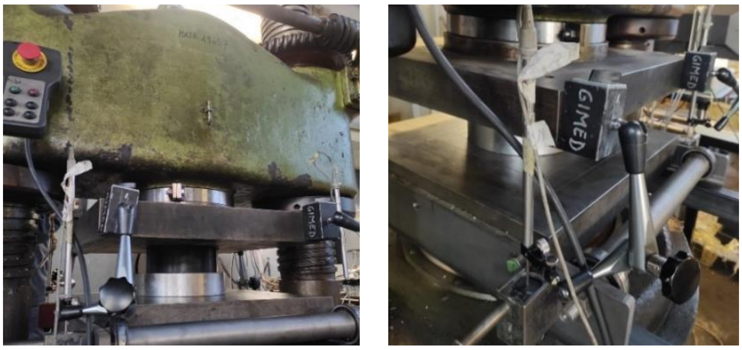
Fresh		Aged		Frequency				Temperature							
ξ	G Modulus	Δξ	ΔG	0.1Hz		2.0 Hz		40°C		0°C		(-10°C)		(-15°C)	
				Δξ	ΔG	Δξ	ΔG	Δξ	ΔG	Δξ	ΔG	Δξ	ΔG	Δξ	ΔG
[%]	[MPa]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
8.38	0.77	-12	+19	+2	+1	+4	-6	+10	-15	+12	+30	+29	+47	+45	+68

Table 4: Shear test results.

3 COMPRESSION TESTS

3.1 Standard shear test

Standard compression tets measure the compression UFREI when subjected to increasing vertical load. The maximum compressive load is applied to the bearing located at the center of the testing platen (Figure 3a) and released before any measurements are taken. After this preloading, the maximum compressive load is applied progressively with a minimum of five increments at a rate of 5±0.5 MPa/min. To conduct this study, three types of tests have been considered, varying the maximum compressive load. Pressures equal to 1 MPa, 2 MPa, and 3 MPa have been considered. The aim was to evaluate the UFREI compression behavior under expected working pressures (structural applications). With 4 Linear Variable Displacement Transducers (LVDT) located at the four corners of the testing platen (Figure 3b), the deflection has been recorded at 1/3 of the maximum load and at the maximum load.



(a) (b)

Figure 3: UFREI200 under the testing machine (a) and particular of an LVDT location (b).

3.2 Cyclic shear test

This test corresponds to Method 2 of the loading procedures for vertical testing of bearings as specified in the ISO 22762-1 standard. Here, the vertical compression commenced by monotonically loading the bearing up to the predetermined vertical load. Once the vertical load is attained, it is sustained for five seconds before being sinusoidally cycled ±20% of the applied vertical load value at a frequency of 1 Hz. Tests at three vertical pressures (1 MPa, 2 MPa, and 3 MPa) have been carried out. Deflection has been recorded for the maximum and minimum load at the third cycle.

4 RESULTS

Results (Figure 4, Figure 5, Table 5) have been evaluated in terms of compressive stiffness K_v as follows:

$$K_v = \frac{F_{z2} - F_{z1}}{v_{z2} - v_{z1}} \tag{1}$$

Where, for the standard compression test, F_{z2} and F_{z1} are, respectively, the maximum and minimum loads and v_{z2} and v_{z1} are the corresponding vertical deflection of the bearing at the same two loads. Instead, for the cyclic compression test, F_{z2} and F_{z1} are, respectively, the maximum and minimum loads and v_{z2} and v_{z1} are the corresponding vertical deflection of the bearing at the same two loads.
Subsequentially, the vertical frequency has been evaluated as follows:

$$f_v = \frac{1}{2\pi} * \sqrt{\frac{K_v * g}{P}} \tag{2}$$

where g is the acceleration due to gravity and P is the vertical load on the bearing.

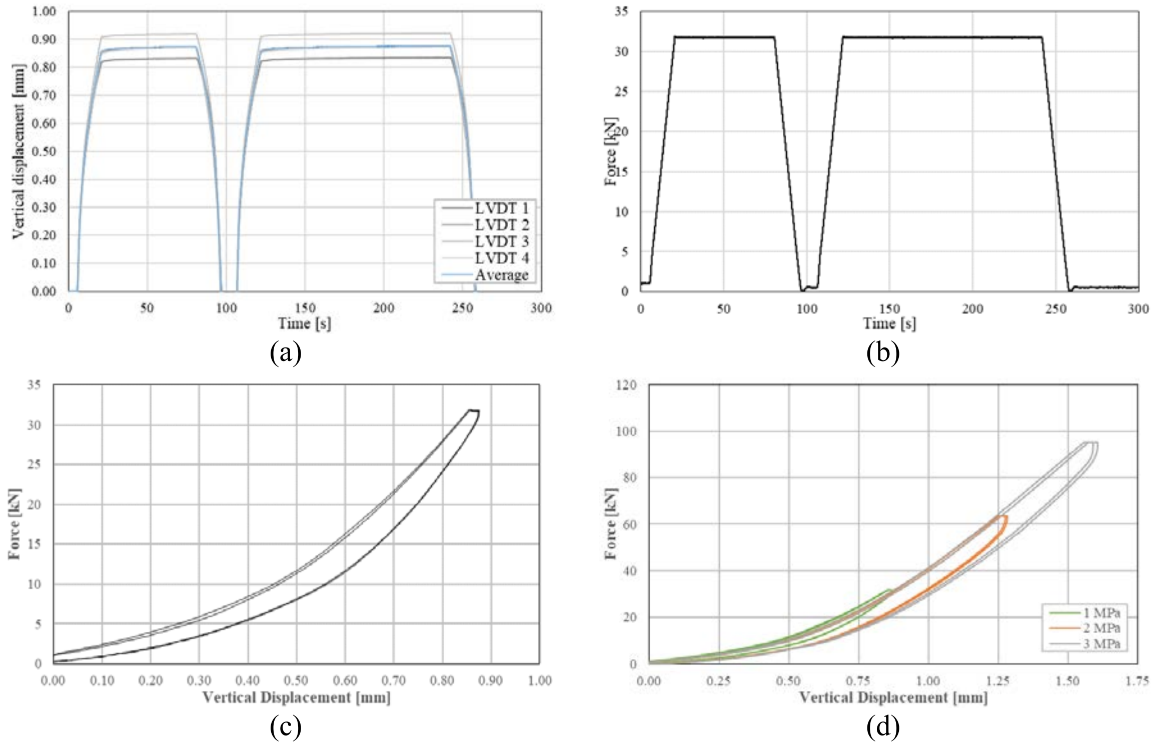


Figure 4 – Standard compression test: average LVDT (a), displacement and Load actuator (b), load-LVDT displacement (c) curves for Test 1, and load-LVDT displacement curves (d) for Test 1, Test 2, and Test 3

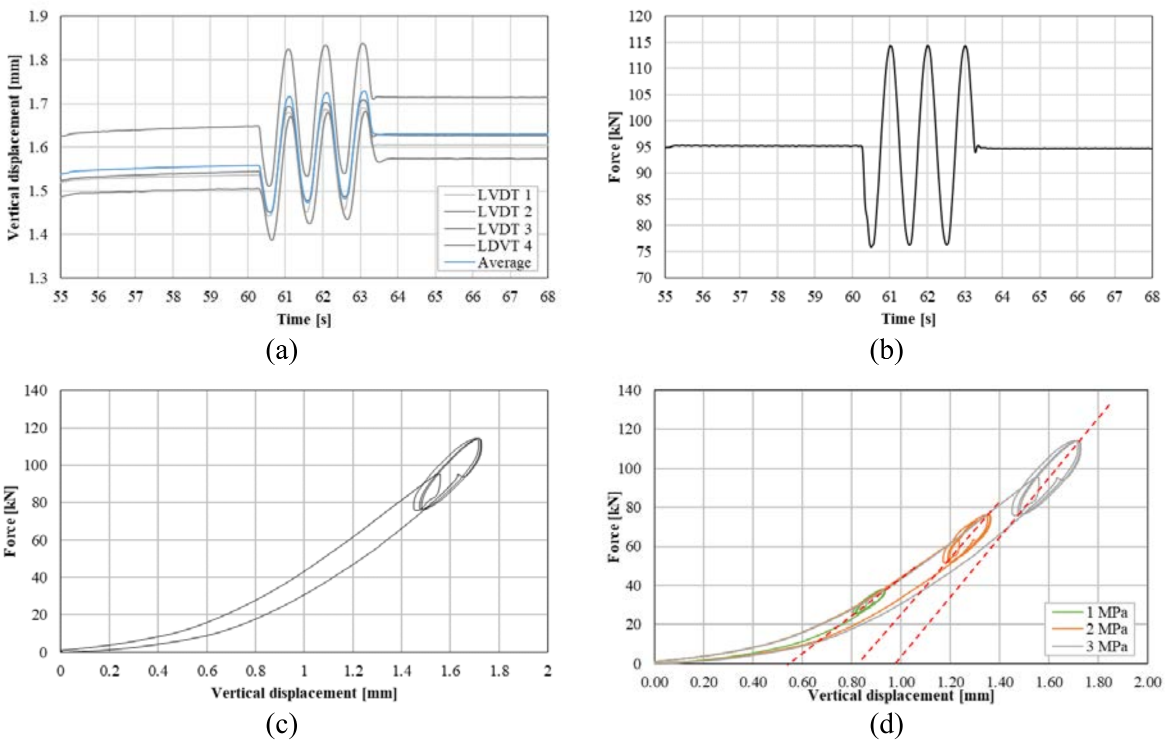


Figure 5 – Cyclic compression test: average LVDT (a), displacement and Load actuator (b), load-LVDT displacement (c) curves for Test 1, and load-LVDT displacement curves (d) for Test 1, Test 2, and Test 3

Table 5 - Compression test results

Compression test	Compressive stiffness (1 MPa)	Compressive stiffness (2 MPa)	Compressive stiffness (3 MPa)
[-]	[kN/mm]	[kN/mm]	[kN/mm]
Standard	54.66	77.55	90.07
Cyclic	113.64	140.06	144.08

Table 6 –Vertical frequency

Compression test	Vertical frequency (1 MPa)	Vertical frequency (2 MPa)	Vertical frequency (3 MPa)
[-]	[Hz]	[Hz]	[Hz]
Standard	20.68	17.42	15.33
Cyclic	29.82	23.41	19.38

5 CONCLUSIONS

Inspection of the data reveals that the vertical stiffness increases with the increase of the applied load. This increase is partially attributed to the fiber fabric reinforcement. As the vertical load is increasing, the glass fiber fabric experiences higher tension, thus straightening the fiber strands and increasing the effective fiber modulus [11]. The calculated frequency values ranged from approximately 15 to 30 Hz. This is significantly larger than the estimated base-isolated structures frequency range of 0.8–2 Hz. Therefore, rocking-induced motion is expected to be insignificant for the FREIs base-isolated structure considered in this study. Upon completion of each vertical test, the bearing was removed and inspected for any visible signs of damage. No damage was observed to have occurred in any of the tested bearings.

Further experimental tests are currently underway to investigate the device lateral response, and these results will provide additional insight into the UFREI potential for practical applications.

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