

Adoption of a multi-dimensional hysteretic model to simulate the response of seismic isolation devices

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1 INTRODUCTION

Recent experimental campaigns, conducted on single full-scale seismic isolation devices as well as on scaled base-isolated three-dimensional structures, provide crucial pieces of information that permit to investigate the complex multi-axial hysteretic behavior exhibited by seismic isolators (*De Domenico et al., 2023*). Specifically, such experimental results reveal the need to employ accurate and computationally efficient hysteretic models in order to perform nonlinear dynamic analyses during design stages.

To this end, in this work, it is proposed a novel multi-dimensional hysteretic model recently formulated by the author within the framework of the general thermodynamic theory (*Vaiana, 2026*). In particular, such a phenomenological model, having a differential nature, allows for the simulation of the coupled isotropic multi-axial rate-independent hysteretic response and offers the possibility of accounting for linear kinematic and/or isotropic hardening phenomena. The validation of the proposed model is carried out experimentally.

2 PROPOSED MODEL

The proposed model is based on three basic assumptions on the size of the deformation (small deformations), the type of material (rate-independent hysteretic material with linear kinematic and/or isotropic hardening), and the properties of the body (homogeneous and isotropic body).

Moreover, it requires four material parameters, namely E_h , T_h , E_k , E_i : the first two, that is, E_h and T_h , govern the rate-independent hysteretic behavior without hardening, whereas the other two, that is, E_k and E_i control the linear kinematic and isotropic hardening, respectively.

3 EXPERIMENTAL VALIDATION

The experimental validation relies on comparing the simulated hysteretic responses with the experimental ones that characterize the behavior of an elastomeric isolator deforming after imposing two distinct infinitesimal strain histories that describe, respectively, a *cloverleaf curve* and a *Dürer folium curve* in the strain plane (*De Domenico et al., 2023*).

For this purpose, the proposed model is implemented in the computer program MATLAB R2022a and its material parameters are first accurately identified and then listed in Table 1.

Figure 1 [Figure 2] plots the experimental (black solid line) and simulated (red solid line) hysteretic responses due to the exerted cloverleaf strain curve [Dürer folium strain curve]. Specifically, Figures 1a, 1b, 1c [Figures 2a, 2b, 2c] present, in the order, the stress curves, and the hysteresis loops in the $(E_4, (T_{RR})_4)$ and $(E_5, (T_{RR})_5)$ planes.

This comparison suggests a good agreement between the experimental and simulated hysteretic responses thus making possible the experimental validation of the proposed model.

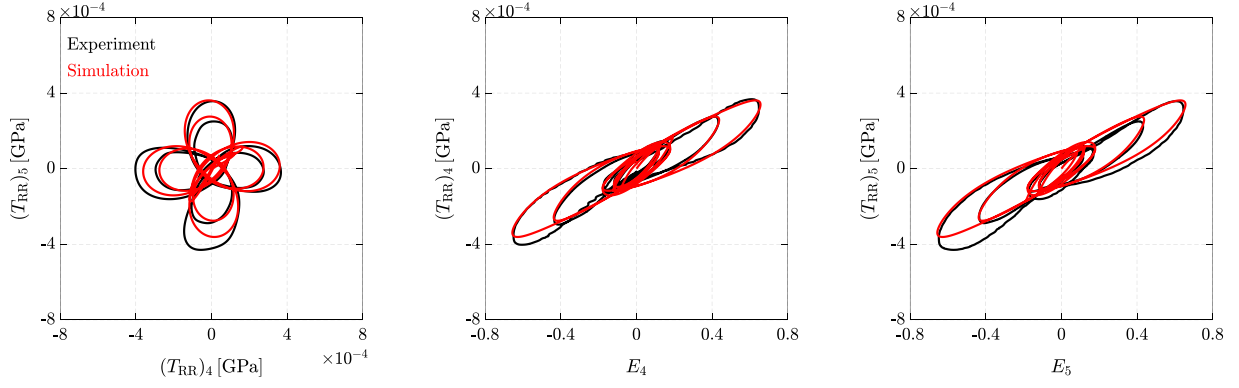


Figure 1. Experimental validation: experimental and simulated stress curves (left), experimental and simulated hysteresis loops in the $(E_4, (T_{RR})_4)$ plane (center) and $(E_5, (T_{RR})_5)$ plane (right) associated with the imposed cloverleaf strain curve.

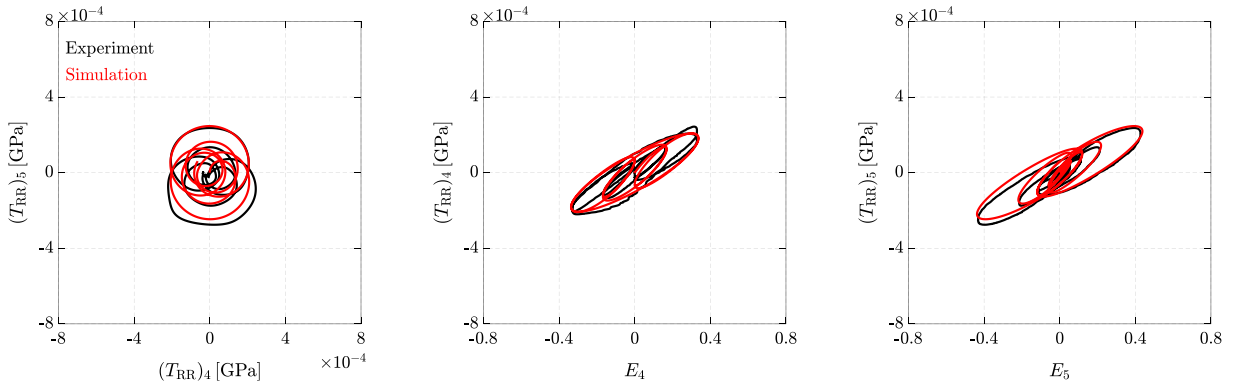


Figure 2. Experimental validation: Experimental and simulated stress curves (left), experimental and simulated hysteresis loops in the $(E_4, (T_{RR})_4)$ plane (center) and $(E_5, (T_{RR})_5)$ plane (right) associated with the imposed Dürer folium strain curve.

Table 1. Material parameters of the proposed model used to simulate the responses in Figures 1 and 2.

E_h	T_h	E_k	E_i
[GPa]	[GPa]	[GPa]	[GPa]
0.002	0.00016	0.00085	0

REFERENCES

De Domenico D., D. Losanno, N. Vaiana. (2023). Experimental tests and numerical modeling of full-scale unbonded fiber reinforced elastomeric isolators (UFREIs) under bidirectional excitation. *Engineering Structures*, 274: 115118.

Vaiana N. (2026). A multi-dimensional rate-independent hysteretic model for homogeneous, isotropic Duhem-like solids. Submitted to *Mechanical Systems and Signal Processing*.