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Seismic response control in structures via damage modelling of hysteretic energy dissipative devices

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Abstract

Dissipative energy methods are widely used to protect the structures and, therefore, to provide safety to users of these in the presence of seismic phenomena. Hysteretic energy dissipative devices (HEDD) are a subclass of these methods presenting a lower cost compared with semi-passive and active control methods.

The aim of this paper is to present a numerical algorithm for modelling HEDD as an effective and robust system control for the seismic response in multistory buildings. The algorithm is based in a continuum damage model in the framework of a large strain elasto-plastic model characterizing the plasticity and degradation of these yielding damper plates.

The algorithm, from a continuum damage model, is extended to a plane-stress finite element model to achieve the mechanical response of the damping plate itself. The conclusions are drawn upon energy criterion – the ratio of the hysteretic energy to input energy is compared for different structural configurations.

The model establishes an easy methodology to evaluate different configurations of dissipative joints through the structure, increasing the energy damping ability of the system by the optimum placement of the plates and minimizing the effects caused in the structure by seismic events.

Keywords: Hysteretic energy dissipative devices, damage model, plasticity, seismic response control.

1 Introduction

Energy dissipation-based methods have been used widely, as several other methods, to protect the integrity of structures under seismic solicitations. The importance of these methods are that there are a large set of options with high efficient response and a relatively low cost – such is the case of passive energy dissipation methods. Even though, it is of high importance to research and to develop new and more efficient methods, in terms of cost and the mechanical response, to present feasible alternatives in developing countries.

HEDD are a contribution to passive energy dissipation methods. In recent years, the application of them has been studied experimentally and by numerical approaches to reduce the magnitude of the effects caused in the structure by seismic excitations ([1], [2]). Other works have been focused on the design of energy dissipators to know the amount of devices needed for a structure ([3], [4]). These investigations are based on the information obtained from a seismic capacity curve, which shows the maximum shear force that appears in the building, so that the real response that this structure will have when incorporating the proposed dissipaters is not known.

On the importance of being able to characterize and comprehend how HEDD work in a given structure, this work focuses on the numerical modelling of the devices, in terms of a Continuum Damage Model (CDM), with the aim of characterizing the efficiency of the dissipators to absorb energy per their plastic strains according their position in the structure.

2 Numerical algorithm

The proposed algorithm is based in the theory of CDM; since HEDD help to mitigate the effects generated in the structure by the plastic strains that are generated in these by the large deformation given during dynamic loads caused by an earthquake, the CDM is formulated in a elasto-plastic framework. An isotropic damage model allows us to characterize the nonlinear behaviour through a single internal scalar variable known as damage, d .

Considering the damage in the material, in function of the history of total strains, the constitutive equation for an isotropic damage model is given by

$$\boldsymbol{\sigma} = (1-d)\mathbb{C}:\boldsymbol{\varepsilon} \tag{1}$$

where $\mathbb{C}$ is the isotropic elastic tensor and $\boldsymbol{\varepsilon}$ is the strain tensor defined as a free variable. A damage criterion to characterize the state of degradation in the material is formulated in terms of the stress space

$$f(\boldsymbol{\sigma}, r) = \mathbf{G}(\boldsymbol{\sigma}) - q(r) \leq 0 \tag{2}$$

where $\mathbf{G}(\boldsymbol{\sigma})$ is a norm in the stress space and $q(r)$ a hardening variable for controlling the evolution of the elastic domain. The evolution laws for the damage threshold and the damage variable are set by the loading/unloading conditions fulfilled in terms of the Kuhn-Tucker relations

$$\dot{r} \geq 0; \quad f(\boldsymbol{\sigma}, r) \leq 0; \quad \dot{\mu} f(\boldsymbol{\sigma}, r) = 0 \tag{3}$$

In the case of a symmetric model, tension-compression, the norm in the stress space is given by

$$\mathbf{G}(\boldsymbol{\sigma}) = (\boldsymbol{\varepsilon}:\mathbb{C}:\boldsymbol{\varepsilon})^{1/2} \tag{4}$$

The plastic condition is set by a von Mises criterion, where the yield surface is set as

$$F(\sigma) \equiv \frac{1}{\sqrt{2}}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2]^{\frac{1}{2}} - \sigma_e = 0 \tag{5}$$

where σ_1, σ_2 and σ_3 are the eigenvalues of the stress tensor. In a plane stress condition, equation (5) reduces to

$$F(\sigma) \equiv \frac{1}{\sqrt{2}}[(\sigma_1 - \sigma_2)^2 + (\sigma_2)^2 + (\sigma_1)^2]^{\frac{1}{2}} - \sigma_e = 0 \tag{6}$$

3 Numerical modelling of braced frame structure with HEDD

The classification of HEDD rises based on the yielding mechanisms that they present, see **错误！未找到引用源。**. Hysteretic steel dampers of flexural yielding type withstand shear forces and bending moments under both in plane and normal plane bending. For this work, it is modelled a X-ADAS steel damper, in a plane arrangement, formed by steel plates united, each other, by rigid stops in both ends and a localized weak zone at the middle of the plate.

A set of different structural configurations were proposed as a case of study, shown in Figure 1. The main structure consists in a five-story two-bays two-dimensional model. The clearing of the bays is 6m and the height for each level is proposed of 4m. To contrast the efficiency of the hysteretic steel plate dampers three cases are proposed: structure without any lateral reinforcement, Figure 1(a); structure with braced frames (BF), Figure 1(b); and structure with the X-ADAS steel dampers as passive dissipative devices located at the nodes of the BF, Figure 1(c). Mechanical and physical properties of the elements are given in Table 1.

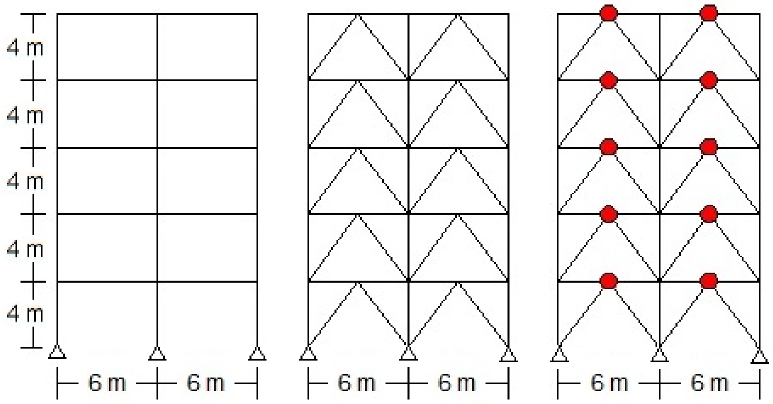

Figure 1. Structural configurations to evaluate: a) structure without lateral reinforcement, b) braced frame structure, c) hysteretic steel plate dampers.

Table 1. Mechanical and physical properties of structural elements.

	Young Modulus (kg/cm^2)	Shear Modulus (kg/cm^2)	Area (cm^2)	Moment Inertia (cm^4)
Columns	2100000	807692	231	66180.8
Beams	2100000	807692	231	66180.8
BF	2100000	807692	11.3	86.2

The input excitation is given by the Kobe '95 earthquake date, which its accelerogram is present in Figure 2.

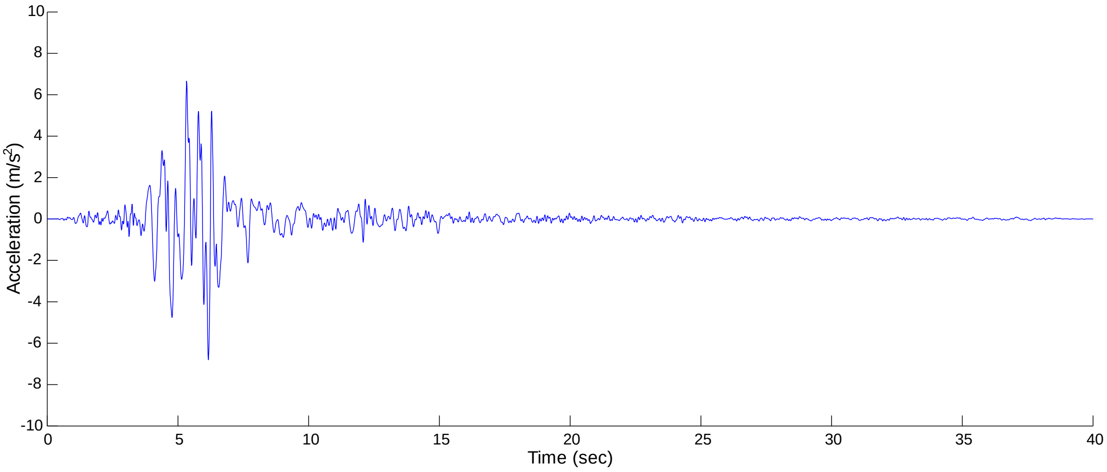

Figure 2. Accelerogram of the 1995 Kobe earthquake.

3.1. Displacement measured in structure

A control parameter to measure the efficiency of the implementation of BF and DP is in terms of the lateral displacement given in each level of the structure. Given the element properties for the structure, described in previous section, and using the accelerogram for the 1995 Kobe earthquake, the measured displacement for the fifth level, in the three cases, is displayed in **错误！未找到引用源。**. It is observed that the magnitude, at the beginning of the ground excitation for cases 2 and 3, where BF with and without DP are located, is the same. As the degradation of the plates through their yielding is reached, the displacement for case 3 grows.

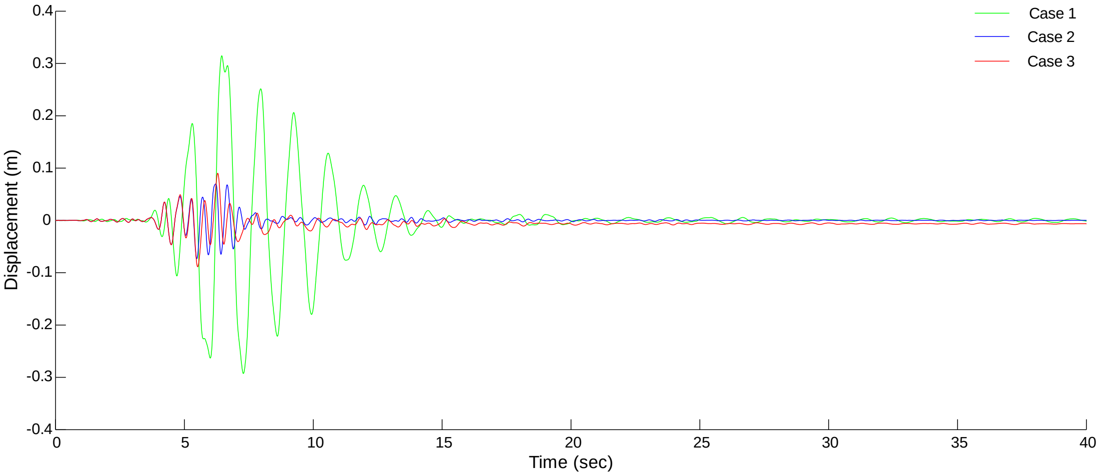

Figure 3. Displacement comparison for fifth level - case 1 to 3.

3.2. Damage at response

The damage evolution of the HEDD is shown in Figure 4 - Figure *7* for different number of devices per set in each braced frame (BF). At the beginning of the input function, the higher degree of damage is present in the upper level and with lower values for the lower ones. As the excitation continues over the structure, and the stiffest levels are the lower ones, the damage of the DP is propagated downwards.

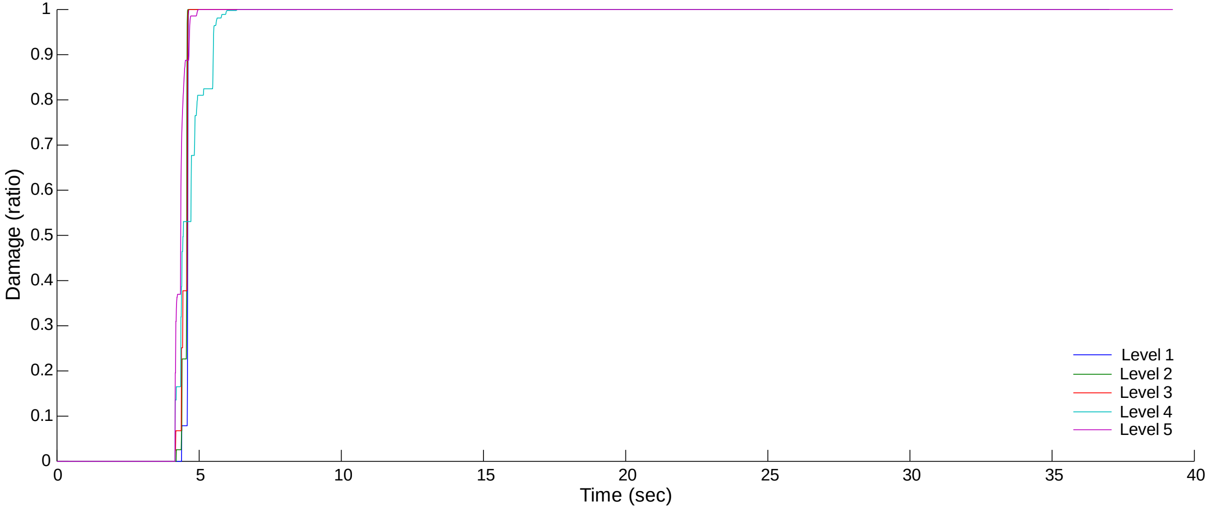

Figure 4. Evolution of damage given in set of 2 HEDD per BF.

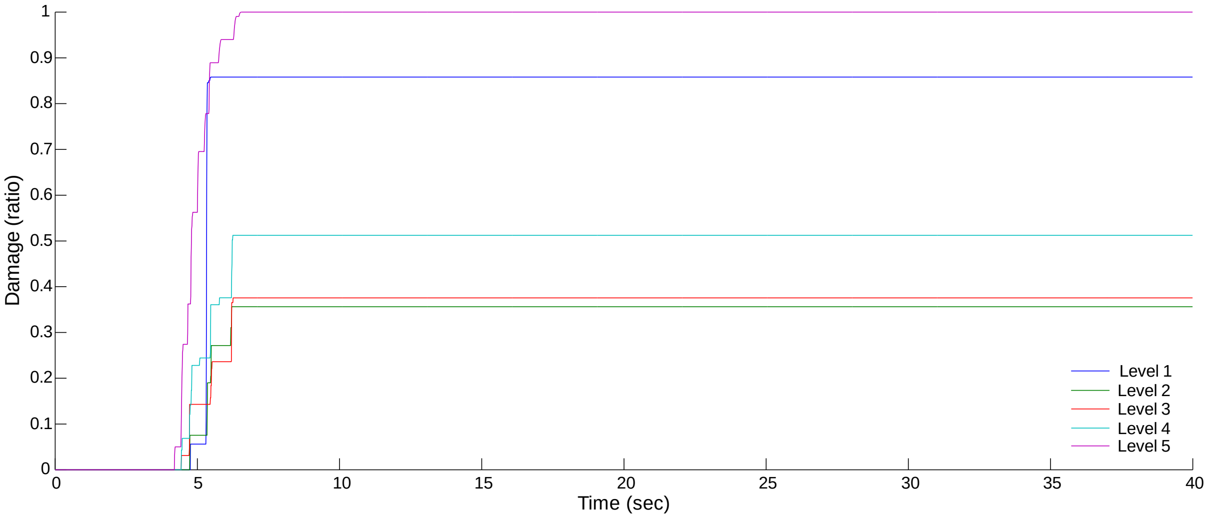

Figure 5. Evolution of damage given in set of 4 HEDD per BF.

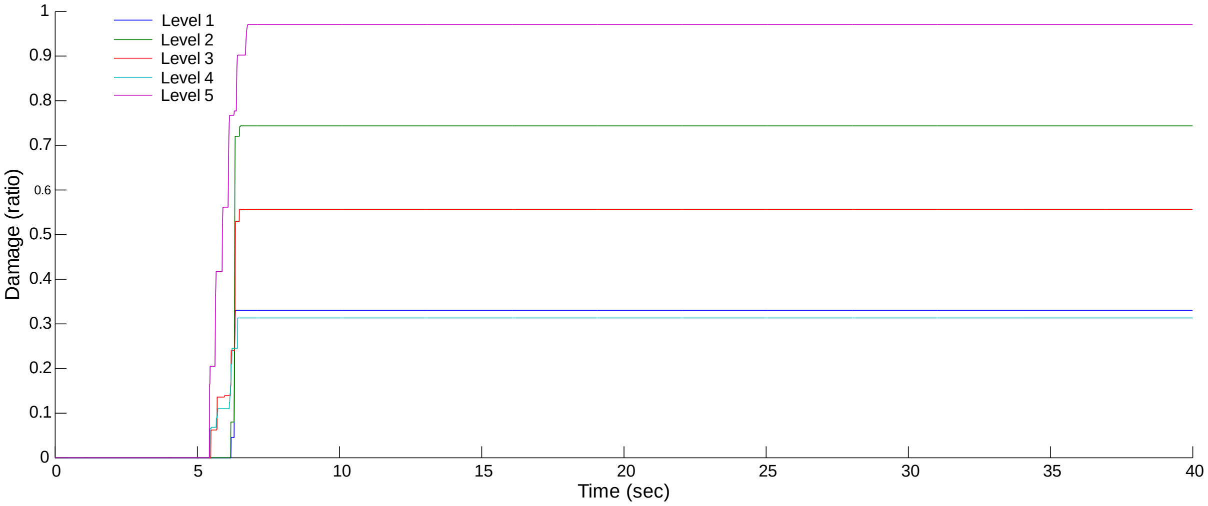

Figure 6. Evolution of damage given in set of 6 HEDD per BF.

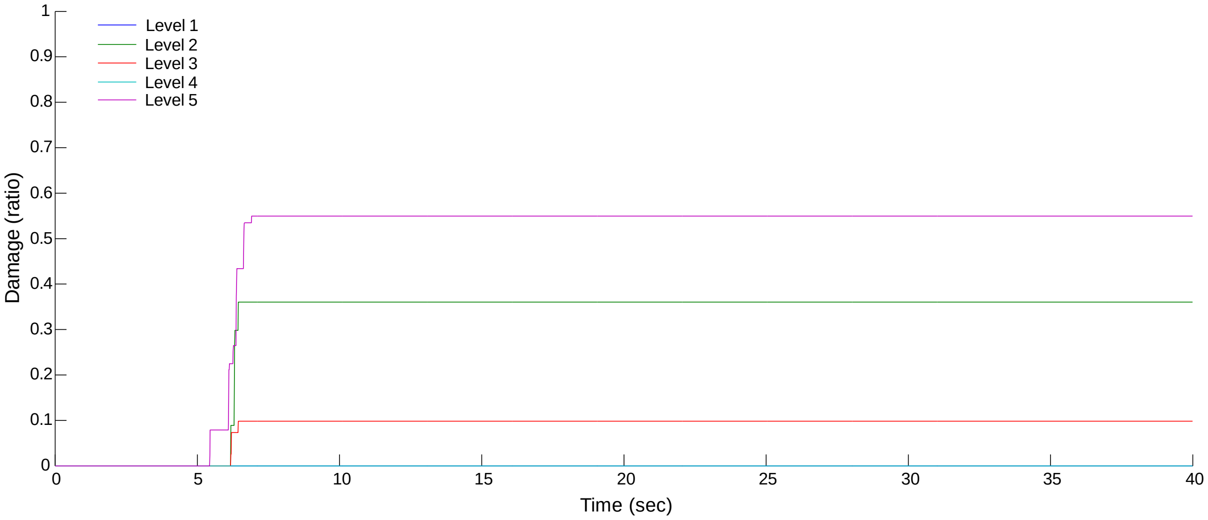

Figure 7. Evolution of damage given in set of 8 HEDD per BF.

Figure 8 shows the accumulative strain energy released. As stated, once it reaches a stationary deformation rate, the energy released is linearly computed.

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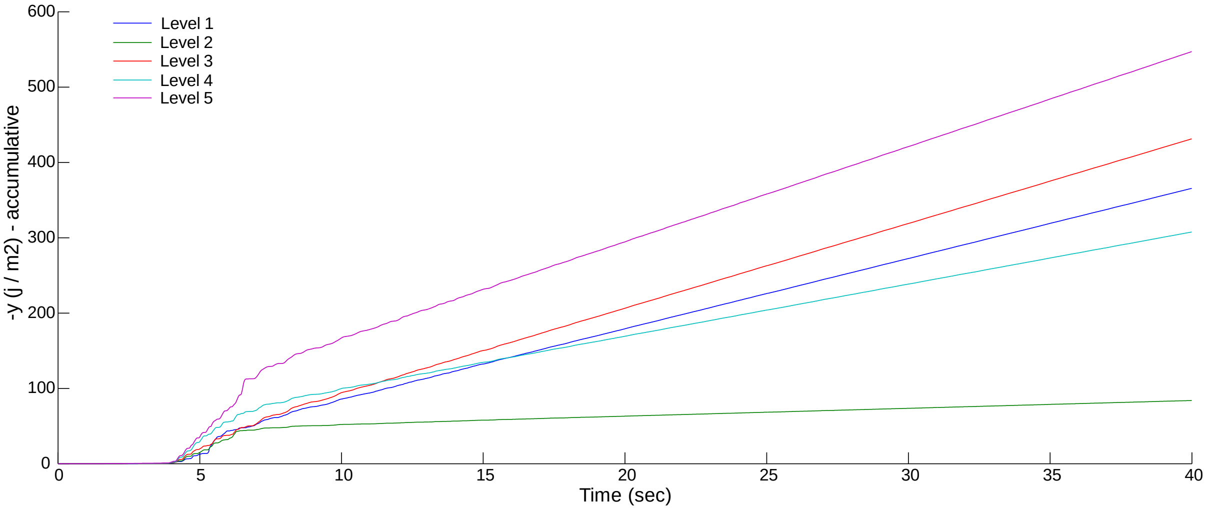

Figure 8. Accumulative strain energy released.

4 Conclusions

CDM are an alternative to FEM for modelling the behaviour of damage in elements, such DP. Satisfactory results were obtained for the modelling of a two-dimensional structure subject to sinusoidal excitation at its base. It is important, in risk assessment, to obtain at low computational cost some input of the response of the structure under seismic solicitations.

The method herein proposed allows us to have an effective numerical method to evaluate different geometrical configuration of the DP and their physical position in a structure to propose the most efficient one.

Further work is proposed to incorporate alternative yielding surfaces as well as a corroboration with FEM.

References

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