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Strategy for required data reduction in the practical implementation in a low-cost electronic platform of an index for damage assessment of seismic dampers

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ABSTRACT

This paper presents a strategy to reduce the number of data required for the in-situ health evaluation of hysteretic energy dampers used for seismic protection of building structures. Such an optimization is essential in order to implement in practice the numerous indices now available for damage assessment of structures in real time, in the context of Structural Health Monitoring (SHM). In general, damage indices are implemented and verified in lab systems entailing expensive and very specialized equipment, which permits the use and management of large amounts of data. For real-time field applications, low-cost embedded computers with limited calculation and data recording capacity may be used; however, they require thorough study of the influence of variables involved in the algorithms for calculation of the damage indices, with ulterior optimization and required data reduction. While the proposed strategy can be followed in broader applications and SHM techniques, the present paper focuses on its application to data coming from vibration tests carried out to evaluate damage of a particular type of hysteretic damper, the Web Plastifying Damper (WPD). The WPD was patented by the University of Granada for the passive control of structures subjected to earthquakes, through a non-parametric damage index previously developed by the authors. This study describes two steps for reducing data: (1) An in-depth study of the calculation time spent on each step of the theoretical algorithm; (2) A parametric study of the influence of key signal parameters—window length, number of windows and duration of the signal—on the damage index calculation in order to minimize the resources needed. Results show a successful optimization that permits the damage index to be calculated with the low-cost *Picocom* platform.

1. Introduction

In the last few decades, passive control has become a popular tool for protecting buildings against earthquakes and preventing or limiting the damage (plastic strains) of the main structure. A typical building structure with passive control systems consists of a main frame and a series of special energy dissipating devices (EDD), also called dampers, whose main role is to dissipate most of the energy input by the earthquake, as shown in Fig. 1. Among the different EDDs used for structural passive control, the so-called hysteretic damper is quite common. With these devices mechanical energy is dissipated by means of metal plastic deformation. The hysteretic EDD to which data the reducing strategy of this research was applied is called a *Web Plastifying Damper* (WPD). It consists of I-section steel segments assembled and installed in the structural frame with a conventional brace as shown in Fig. 1. Thus, the energy is dissipated through out-of-plane plastic strains on the web of the I-section when the frame is subjected to lateral seismic loads [1–4]. Minor or moderate earthquakes do not exhaust the energy dissipation capacity of the dampers, though they damage them. For this reason, continuous or periodic damper health evaluation is required to decide if they need to be replaced. Such evaluation should not be based on simple visual inspection; it requires the application of efficient structural health monitoring techniques, involving in-practice effective algorithms and equipment. In particular, the main requirements would be: (1) reliable algorithms to evaluate the level of damage; (2) not expensive instrumentation (as low-cost as possible); (3) fast

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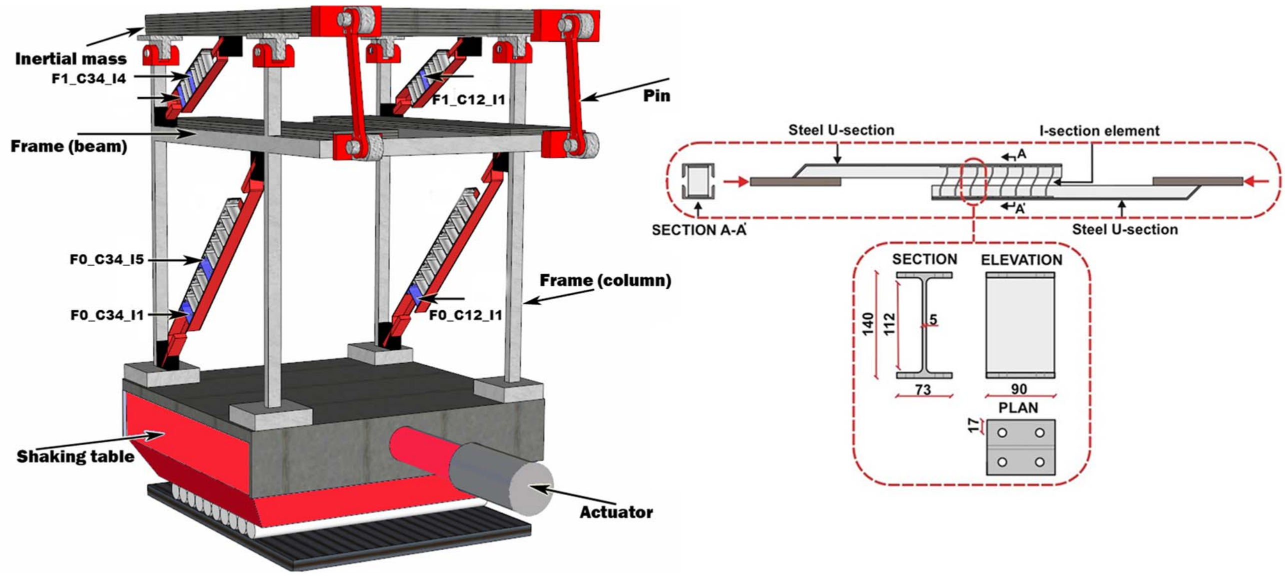

Fig. 1. Test model with arrangement of the WPDs and I-sections installed in the 3D frame. EDD details with 8 I-section elements. Geometry and dimensions (in mm) of a particular I-section element.

performance, for real-time evaluation; and (4) easy installation and management within the building, this usually implying small size and remote wireless connections. In fact, such requirements also extend to many other fields and applications involving SHM technologies: aerospace, energy power plants and transport, industrial plants, civil engineering structures, transportation, etc. [5–7]

Some SHM techniques entail the use of sensors permanently attached to the structure that collect vibration data. The basic idea is to highlight changes in the vibration data that are induced by the damage [8–15]. Thus, if changes are properly extracted, they may be correlated with the damage level of the structure so as to evaluate it. Clearly, a great amount of data will be recorded during operation, especially during continuous monitoring. It must be reduced to calculate damage indices efficiently by means of electronic measurement equipment fulfilling requirements stated in previous paragraph [16–22].

This technology, generally referred to as the vibration technique, has been applied by our research group to evaluate damage of WPDs. The basic idea is to design smart dampers with an integrated actuator/sensor piezoelectric system attached to them; after signal analysis, it provides damper damage evaluation. To this end, a particular non-parametric algorithm in the domain frequency (DDNP) has been developed and validated. The algorithm generates an appropriate damage index (called *Area Damage Index,* ADI) shown to be very well correlated with the plastification level of damper I-sections, mechanically evaluated with the so-called index ID (see [1,2] for details).

However, ADI involves calculation of the FRF (Frequency Response Function) of vibration signals by means of the Welch approach and some additional calculations. The very high computing times make it difficult or almost impossible to implement in low-cost hardware remote platforms with limited calculation and data recording capacity. For this reason a new two-step strategy was proposed. Firstly, a deep study of the computing time spent on each step of the theoretical algorithm to calculate ADI. Secondly, with this information, a parametric study of the influence of key signal parameters on the damage index calculation, e.g. window length, number of windows and duration of the signal, to minimize the resources necessary to obtain a value similar to the one obtained with greater resources. Results demonstrate that is fully possible to extract reliable information for calculation of the ADI (that is, keep it well correlated with ID) using 90% less data, thus reducing by 81.25% the computing time. This optimization allows the algorithm to be implemented in low-cost hardware platforms such as *Picocom* from F & S Elektronik Systeme. The system with expensive and specialized equipment now available in the lab could thereby become in the future a commercial application for use in real buildings with hysteretic dampers. This application using embedded computers will make it possible to carry out vibration tests and determine the damage index of the dampers in real-time, and even by remote request.

2. Data acquisition and limitations

A reinforced concrete structure with WPDs was subjected to four seismic simulations on the shaking table of the University of Granada (Spain). Acceleration peak increased from one simulation to the next, so that four levels of damage to the dampers were considered: C100 (d0, damage 0), C200 (d1, damage 1), C300 (d2, damage 2) and C350 (d3, damage 3). Vibration tests of some I-sections of the dampers, marked in blue[1] in Fig. 1, were conducted after each simulation test. Vibration data were collected using a PI®PRYY0842 piezoelectric transducer from PI Ceramic GmbH, working as actuator attached on the center of the I-section web, and PI®PRYY + 0220 piezoelectric transducers as sensors [3,23–25]. The I-sections were excited with random white noise.

The electronic measurement system used in the lab—of high cost, size and performance—is shown in Fig. 2. It basically consists of a signal generator (CoCo80 from Crystal Instruments), a signal acquisition system (PULSE from Bruël & Kjaer), a work station, and a complex system of differential signal connections with a distribution box in order to achieve electrical noise suppression. Its maximum sample rate was 65,536 Hz. Consequently, the frequency content of the excitation signal was from 0 to 32,768 Hz. The excitation signal amplitude provided by the signal generator was 10 VRMS. This input signal was amplified by 20. Previous tests demonstrated that the results remain similar when the excitation amplitude varies from 1 V_{RMS} to 10 V_{RMS}. Data storage had no limit, so any value of window length and duration of the signal could be selected.

All electronic devices were properly connected to the grounding system; differential connections were made so that the measurement system would achieve a good performance against the electrical and environmental noises. Thus, a robust measurement system was obtained, with controlled noise conditions and high quality vibration signals.

[1] For interpretation of color in ‘Fig. 1’, the reader is referred to the web version of this article.