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An energy-based method for seismic retrofit of existing frames using hysteretic dampers

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ABSTRACT

This paper proposes a method for the seismic retrofitting of existing frames by adding hysteretic energy dissipating devices (EDDs). The procedure is based on the energy balance of the structure, and it is used to determine the lateral strength, the lateral stiffness and the energy dissipation capacity of the EDDs needed in each story to achieve prescribed target performance levels for a given earthquake hazard. The performance levels are governed by the maximum lateral displacement. The earthquake hazard is characterized in terms of input energy and several seismological parameters, and further takes into account the proximity of the earthquake to the source. The proposed method deals with the effect of the EDDs explicitly in terms of hysteretic energy, bypassing equivalent viscous damping approximations, and directly quantifies the cumulative damage induced in the EDDs. The validity of the method is assessed numerically through nonlinear dynamic response analyses with near-fault and far-field ground motions, as well as experimentally through dynamic shaking table tests.

1. Introduction

Energy dissipating devices (EDDs), also known as dampers, are giving rise to technology capable of minimizing interstory drift and increasing the earthquake resistance of buildings, to achieve performance-based seismic design. EDDs have been used for a decade, and continue to attract attention in the field of earthquake engineering. A main application, particularly in Europe, is in the seismic rehabilitation of buildings. Mechanisms studied and used for passive energy dissipation include metal yielding, phase transformation of metals, friction sliding, fluid orificing, and deformation of viscoelastic solids or liquids. The EDDs based on the yielding of metals—commonly known as hysteretic dampers—are among the most popular. The present study focuses on the application of hysteretic EEDs to the seismic retrofit of buildings. In order to develop cost-effective retrofit solutions, it is of paramount importance to have practical and sufficiently accurate design procedures, able to define the EDDs that satisfy target building performance levels for a given earthquake hazard.

There are important differences between new construction design and seismic retrofit design, using EDDs. When EDDs are used in new structures, the main frame can be designed to contribute to dissipating, through plastic deformations, a portion of the total energy input by the earthquake. This can relax the requirements of the EDDs (strength, stiffness, ultimate energy dissipation capacity) and lower their cost. In contrast, most existing structures were built according to past seismic codes and their energy dissipation capacity, if any, is very limited. The seismic retrofit design of such structures can therefore not rely on the contribution of the main frame to dissipate energy; the design of the dampers must guarantee that, under the design earthquake, the main structure remains "basically" within the elastic range. In new construction design of frames with EDD, the members can be easily dimensioned to accommodate the forces transferred by the EDDs, while in seismic retrofit design the strength, the stiffness and the location of the EDDs must be carefully studied in order to control torsion effects and to avoid unexpected failures in the main frame before the dampers attain their maximum strength. The design of new lateral force-resisting elements consisting of EDDs for the seismic retrofit of existing structures must consider important issues such as: (i) the connection of the EDDs with the existing frame; (ii) the compatibility of deformation with the existing lateral force-resisting or gravity load-carrying system; (iii) the extent to which the new system relieves the existing structure of load or deformation at all levels; (iv) the significance of the mass added by the EDDs, and (v) the need for extensive new foundations.

The first guidelines for the application of hysteretic EDDs to building rehabilitation are the standards developed by the Federal Emergency Management Agency (FEMA) in Reports 273, 274 [1] and 356 [2], which contain both linear and nonlinear static procedures. In the linear static procedures, the energy dissipation

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