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Project Title: Seismic Performance of Hybrid Energy Dissipation Bays (EDBs) Equipped with Shape Memory Alloy (SMA) Connections and Steel Slit Walls

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Project Outline:

A great challenge of modern seismic engineering is to combat the drawbacks of the conventional ductility-based seismic design philosophy that may produce systems experiencing severe damages when subjected to a moderate-to-strong earthquake event. In order to enhance the seismic performance of ductile steel moment resisting frames (MRFs), the concept of the 'energy dissipation bays (EDBs)' equipped with sacrificial mechanisms was proposed. The research findings showed that a wise combination of the EDBs and the main frame of high strength steel (HSS) results in desirable 'damage-control behaviour' as inelastic damages can be restricted in the EDBs for a wide deformation range, and the EDBs also provide sufficient lateral stiffness against normal loading conditions, e.g. wind.

The plastic energy dissipation capacity and ductility of EDBs have been given high priority in the previous works. Nonetheless, rapid rehabilitation after earthquake attacks and the ability of the EDBs sustaining the energy-input are equally important. In this context, the limitation of the EDBs can be seen. In particular, welded connections between the sacrificial beams and columns were employed in the EDBs in previous works done by the P.I. and colleagues, which may complicate the post-earthquake repair work of the connection. Lopes proposed that a plasma cutter or an oxygen-acetylene torch may be required to repair the EDBs equipped with bolted shear links, as observed in a full-scale experimental investigation, making the repair work cumbersome in practical cases. Hopefully, recent research progress in seismic application of 'self-centring' concept and innovative material showed that it is possible to achieve encouraging seismic performance and rapid rehabilitation for seismic resistant systems. In particular, research works show that HSS would optimise the structural damage-evolution mode of the structure. This noteworthy feature is due to that the higher yield strength of the HSS material decouples the interdependence of strength and stiffness of the system, and the HSS members may stay in the elastic stage for a wide deformation range. On the other hand, the self-centring behaviour may be achieved using Shape Memory Alloys (SMAs), and SMA-based connections are promising candidates for energy dissipation mechanisms in the EDBs. SMA is a smart metal with two noteworthy features, namely the shape memory effect (SME) and the superelastic effect (SE). The two extraordinary characteristics enable the SMAs to recentred from the deformed shapes to the undeformed shapes either by heating (SME) or unloading (SE), as schematically. Nonetheless, due to the relatively lower Young's modulus of SMA, additional reinforcing component may be required to offer lateral stiffness of the EDB. Thus, the proposed research project focuses on the notion of a novel HSS-based EDB equipped with an innovative SMA-based connection and steel slit walls (SSWs). An overview of the novel EDB is schematically. Specifically, the SMA connection examined by the P.I. and co-workers will be installed in the developed EDB. In the connection, the SMA bolts are intended to resist the applied moment. Concurrently, the connection is equipped with HS bolts with Belleville spring (BVS) washers that connect the end-plate with the column flange in order to offer sufficient shear resistance. Note that the SMA BVS washers will eliminate potential inelastic axial deformation to be occurred in the HS bolts due to the connection moment, and concurrently provide energy dissipation accompanied with recentring capacity. To enhance the lateral stiffness of the EDBs, the proposed EDB is further enhanced by SSWs. To optimise the nonlinear behaviour of the EDB, columns and links in the EDB will be made of HSS with a nominal yield strength over 690 MPa, and inelastic actions can be locked in the SMA connection and the SSWs for a reasonable deformation range. It is also of great significance to note that due to the slit configuration of a SSW, the strength and stiffness of the EDB can be modulated with sufficient flexibility. It is believed that the proposed novel EDB would show excellent energy dissipation capacity with enhanced recentring behavior.

Objectives:

In the proposed research project, full-scale tests of subassemblies of the innovative EDBs covering a practical spectrum of parameters such as geometry of SMA connections and loading protocols will be conducted. Hysteretic behaviour and seismic resistance of the proposed EDB will be studied by conducting 1) mechanical behaviour tests of HSS material, SMA material and the SMA Belleville spring (BVS) washers; 2) cyclic test of the novel EDBs equipped with the proposed SMA-based connections and SSWs; 3) numerical investigation of the connections and the EDBs based on finite element (FE) models; 4) development of a simplified FE model for the analysis of the EDBs in steel MRFs; and 5) a preliminary design framework of steel MRFs equipped with the novel EDBs.

Expected deliverables:

Applicable methods for quantifying the hysteretic performance of the proposed EDB (e.g. elastic stiffness, ultimate resistance and hysteretic energy dissipation) will be developed, and a stepwise procedure which may be used to develop an applicable strategy of a HSS MRF equipped with the novel EDB will be proposed. The research findings will be disseminated to international research communities through journal articles and conference presentations and papers.