Seismic Analysis of Steel Structures Using Friction Dampers

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Abstract. In modern seismic design, damping devices are used to increase the capacity of structures to dissipate energy. This paper evaluates the efficiency of using a passive friction damper system in a structure compared with typical structures and the influence of the damper’s capacity on the structural response. The analysis concludes that dampers with lower capacity slip more times during earthquake than dampers with bigger capacity but the acceleration result increases.

1. Introduction

Recent earthquakes have shown that the ductile design of structures, even in developed countries, leads to substantial degradation of structures as result of seismic action.

If the energy induced in the structure by the earthquake action can be controlled or can be mechanically dissipated by devices independent of the structure, the building’s seismic response is improved, thus substantially decreasing the potential damage. [1]. Therefore, there are two methods for the seismic design of structures [2]:

- Conventional method: the traditional method to resist lateral force by increasing the design capacity and stiffness e.g. shear wall, braced frames or moment resisting frames;
- Nonconventional method: based on the reduction of seismic demand instead of increasing capacity e.g. base isolation, dampers.

Passive control devices have been successfully used to reduce the dynamic response of structures subjected to earthquake. Friction devices have been used as a component of these dampers because they present high energy dissipation potential at a low cost and are easy to install and maintain [3]. Several friction devices have been tested experimentally – Pall (1982) [4], Fitzgerald (1989) [5], Aiken (1990) [6], Constantinou (1991) [7], Grigorian, (1993) [8], Nimbus et al (1993) [9], Dorka (1998) [10], Mualla (2000) [3] and some of these have been implemented in buildings around the world.

This article presents the benefits resulting from using frictional dampers to improve the seismic response of structures.

2. Experiment description

A nonlinear dynamic time-history analysis was used for evaluating the behaviour of structures equipped with friction dampers. This type of analysis shows the response of the structure during seismic action. Dampers were modelled given their hysteretic characteristics, as is shown in figure 1.
Four design scenarios were taken into consideration: unbraced structure in figure 2, centric brace structure in figure 3, eccentric brace structure in figure 4 and frictionally damped structure in figure 5. Friction dampers from figure 6 were modelled as nonlinear elements – plastic (Wen). The program ETABS 17.0.1 (2018) was used to assess the response of a 2-D structural steel frame.

**Figure 1.** Resultant elasto-plastic behaviour of friction damper in brace [11].

**Figure 2.** Unbraced structure.

**Figure 3.** Centric brace structure.

**Figure 4.** Eccentric brace structure.

**Figure 5.** Frictionally damped structure.
The general characteristics of the structures are listed below:

- The distance between columns is 6 m;
- The first level is 4.5 m high, while the rest of the levels are 3.5 m;
- The material is Steel S355;
- The response in all versions of this structure was created using the seismic action of the 1977 Vrancea earthquake (figure 7).

The structure’s response is in terms of top roof maximum displacement, story drift, story displacement, story acceleration, variation of dissipated energy.

The fundamental period of the centric brace structure is lower than the unbraced and eccentric structures but bigger than the frictionally damped structure.
Story displacement is the absolute value under action of the lateral forces. The maximum displacement of the damped structure is 3.75 times smaller than the unbraced structure. Even if the structure has a centric brace, the displacement is bigger than frictionally damped structure, as shown in figure 8.

The smallest top displacements are for the structure equipped with 150 kN dampers, figure 10, but the maximum values of acceleration are larger than the structure equipped with 50 kN dampers, figure 11.

Story drift is the displacement difference between two consecutive stories divided by the height of that story.

The story drifts can provide useful information for story damage assessments. The story drifts in the frictionally damped structure are the lowest, as shown in figure 9.

This means that using dampers in structures improves the response in terms of maximum story displacement, story drifts, top displacement and top acceleration.
During the seismic action, the damper with a 50 kN capacity, figure 12, slips more than the damper with a 150 kN capacity, figure 13.

Figures 14 and 15 show the energy components in a nonlinear time-history analysis. The input energy is greater in the structure equipped with the 50 kN friction damper than the other structure with a 150 kN damper. The dissipated energy is lower for the structure with 50 kN damper than the structure with 150 kN damper. Even though both structures have the same design, applying a different capacity for dampers can significantly change the result in terms of top displacement, top acceleration and dissipated energy.
Figure 12. Hysteretic curve for a brace at ground floor - Damper with slip load 50 kN.

Figure 13. Hysteretic curve for a brace at ground floor - Damper with slip load 150 kN.
4. Conclusions

The dynamic nonlinear time-history analysis shows that using dampers in structures improves the response in terms of maximum story displacement, story drifts, top displacement and top acceleration.

It is evident that dampers with lower capacities slip more times during earthquakes than dampers with bigger capacities, but the resulting acceleration increases.

Given their relative independence of the environmental conditions, the friction dampers are a viable alternative to enhance the structure’s capacity to dissipate energy.

Figure 14. The dissipated energy for a damper with slip load 50 kN.

Figure 15. The dissipated energy for a damper with slip load 150 kN.
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