

This paper presents a cost-efficiency solution in order to upgrade the seismic performance of an existing middle-rise steel framed building, located in down-town Montreal and converted from an industrial building into a condominium (Figure 1). Furthermore, this study was extended in order to emphasize the influences of ground condition (site class) and the effect of seismic hazard defined for eastern and western Canada, as well as the influence of building height.

The main requirement for this study was to minimize the cost of investment in the rehabilitation of existing structural members, without strengthening columns and foundations. To satisfy the seismic retrofit requirements without interrupting the structural integrity and strength, it was proposed to increase the hysteretic damping into the building in order to move energy dissipation out of the nonductile primary steel framed structure. In this respect, energy dissipation devices consisted of series of steel plates, were proposed. Pall friction dampers used in this study possess large rectangular hysteresis loops with negligible fade and are able to enhance the seismic performance of the structure.

The skeleton of the existing 10-storey structure, completed in 1929 and designed to carry gravity and wind loads only, is a nonductile steel moment frame with concrete slabs. The rehabilitation proposal consisted of incorporating Pall friction dampers with one-way diagonal braces connected to existing frame members (Figure 2), largely improved the overall stiffness and damping of the retrofitted system. In order to spread the energy dissipated by the friction devices at all stories, dampers were staggered and the flexibility of the bracing was considered by controlling the ratio between the bracing stiffness and the structural stiffness of each floor. The ratio between the design slip force of damper and the tensile force developed into the brace when the un-damped stiffened system was subjected to seismic excitation was also considered. However, adding stiffness to the existing building may increase the floor acceleration. In this regard, the following parameters are analyzed: the minimum required number of friction dampers per floor; the optimum design slip force of dampers; the minimum amount of stiffness that should be added at each floor in such a way that the stiffness at the floor above is less or equal to the stiffness at the floor below; the floor acceleration; and interstorey drift. Several linear and nonlinear time history dynamic analyses were performed in order to calibrate the aforementioned parameters. For this study the value of interstorey drift is chosen as the drift performance target imposed to be less than $0.01h_s$ (where h_s = interstorey height) in order to reduce the damage to the building brick facades.

The influence of ground condition and the seismic hazard for eastern and western Canada, i.e. Montreal and Victoria (B.C.) are emphasized by considering the building location on very dense soil (site class C) and on stiff soil (site class D). It is mentioned that the seismic provisions in the NBCC 2005 are based on the 2% in 50 years seismic hazard values. The effect of building height is discussed through two case studies (5-storey and a 10-storey steel framed building).

Although the structural Commentary J of National Building Code of Canada (NBCC 2005) permits the use of friction dampers for seismic control of building, it does not include any comprehensive design procedures for designing structures with a damping system. The quasi-static design procedure given in NBCC 2005 is ductility based and does not explicitly apply to friction-damped buildings. In this context FEMA 356 (Prestandard for the Seismic Rehabilitation of Buildings) provides the most comprehensive specifications and has been adopted for this study.

It has been found that adding damped staggered braces to existing structures do not change the lateral oscillation pattern of the primary structure; the storey drift is substantially reduced; and the storey displacement history depends on the frequency content of ground motions. Also, by minimizing the elastic strain energy, the forces acting on the gravity structural system are considerably reduced.

In conclusion, friction dampers are found to be an economic solution for upgrading the seismic performance of steel moment frame structures, even for a flexible building. This innovative solution responds well in terms of cost efficiency, design flexibility and speedy construction.



Fig. 1 Building facades



Figure 2 One-way diagonal brace with Pall friction damper