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HIGHTECH SEISMIC DESIGN OF LE NOUVEL EUROPA, MONTREAL

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SUMMARY

Le Europa is a luxury condominium building complex and consists of two ten-storey concrete frame buildings with two basement levels. The two buildings are interconnected at every level with two bridges. The developer opted for higher performance standards than specified in the building code. Introduction of supplemental damping in conjunction with appropriate stiffness was the chosen solution for seismic control. This was economically achieved by replacing expensive concrete shearwalls with Pall Friction dampers in steel bracing.

INTRODUCTION

Nouvel Europa is a luxury condominium building complex located in Old Montreal, close vicinity of Montreal Harbour (Figure 1). The complex consists of two ten-storey concrete frame buildings with two basement levels (Figure 2). The two buildings are interconnected at every level with two bridges. The ground floor is basically a commercial place and at upper levels it has 56 large ultra modern condominiums. The architects wanted a remarkable flexibility in interior planning in order to accommodate each client's preferences. The complex presents a new concept of good living and incorporates latest construction materials for the comfort and safety of its occupants. The developer opted for higher performance standards than specified in the building code.

Conventional concrete shearwalls are very rigid and attract higher ground accelerations during an earthquake, causing higher inertial forces on the structure. Supplemental damping in conjunction with appropriate stiffness offered an innovative solution for the seismic control of this building. This was achieved by incorporating Pall Friction Dampers in steel bracing. As soon as the structure undergoes small deformations, the friction dampers are activated and start dissipating energy. Since the dampers dissipate a major portion of the seismic energy, the forces exerted on the structure are considerably reduced. In contrast to shearwalls, the friction-damped bracing need not be vertically continuous. This aspect was particularly appealing to the project architects as it offered great flexibility in space planning. Since the damped bracing do not carry gravity load, they do not need to go down through the basement to the foundation. This allows more open space for car parking in the basement. At the ground floor level, the

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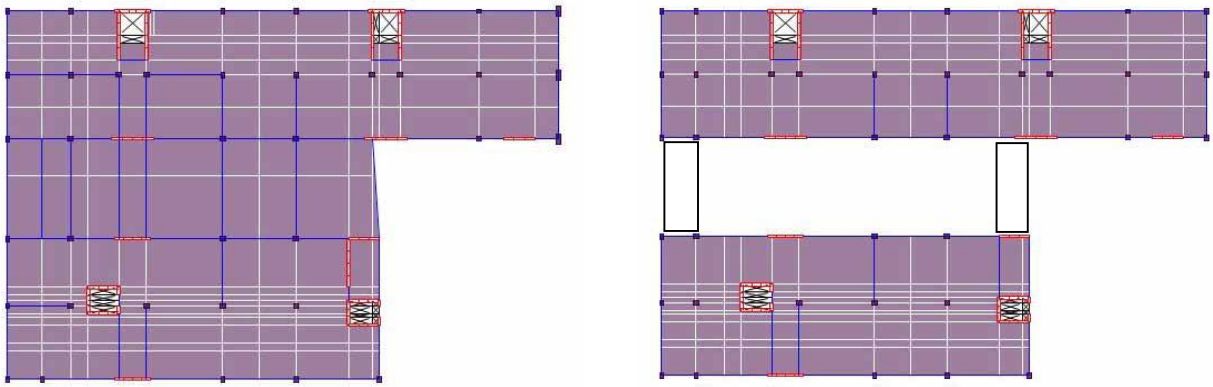
lateral shear from the bracing is transferred through the rigid floor diaphragm to the perimeter retaining walls of the basement.

A total of 57 friction dampers of 600 kN slip load capacity were installed in single diagonal steel bracing. Location of bracing can be seen in the computer model in Figure 3. Typical friction damper in a single diagonal is shown in Figure 4.

This paper describes the design criteria, seismic analysis and its results. A brief review on Pall Friction Dampers has also been included so that its practical application can be better appreciated.

Figure 1. View of Le Nouvelle Europa.



Ground floor plan Typical floor plan

Figure 2. Floor plans of analytical model.

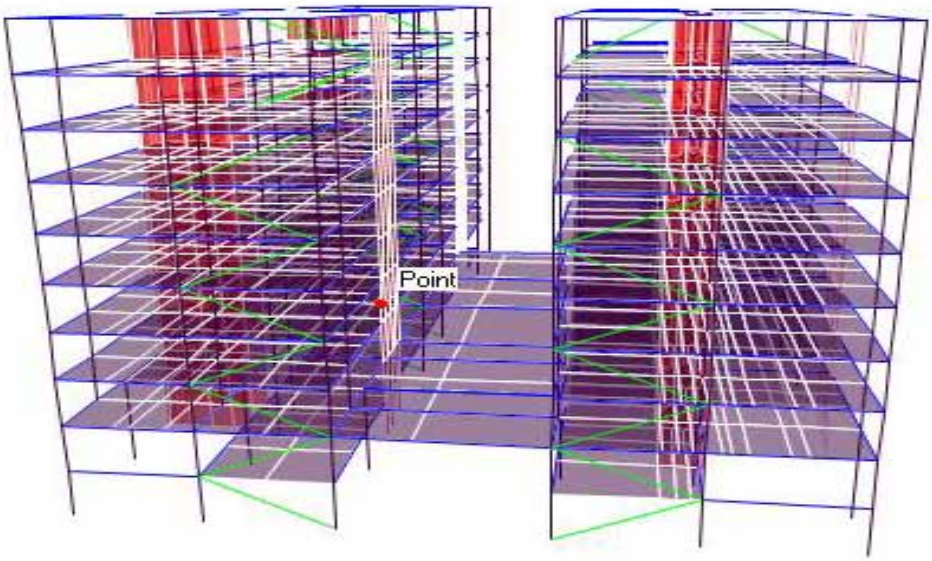


Figure 3. 3-Dimensional analytical computer model

Figure 4. Typical Pall Friction Damper in a single diagonal brace.

PALL FRICTION DAMPERS

Of all the methods available to extract kinetic energy from a moving body, the most widely adopted is undoubtedly the friction brake. It is the most effective, reliable and economical mean to dissipate energy. For centuries, mechanical engineers have successfully used this concept to control the motion of machinery and automobiles. In the late 1970's, the principle of friction brake inspired the development of friction dampers, Pall [1] and Pall [2]. Friction dampers suitable for use in tension cross bracing, single diagonal bracing, and chevron bracing, have been developed, Pall [3].

Pall friction dampers are simple and foolproof in construction and inexpensive in cost. Basically, these consist of series of steel plates specially treated to develop most reliable friction. The plates are clamped together with high strength steel bolts. Slippage is smooth without any stick-slip phenomenon. Friction dampers are designed not to slip during service loads and windstorms. During a major earthquake, they slip at a predetermined optimum load prior to yielding of structural members. By properly selecting the slip load, it is possible to 'tune' the response of the structure to an optimum value. Parametric studies have shown that the optimum slip load is independent of earthquake record and is rather a structural property. Also, within a variation of ± 20% of slip load, the seismic response is not significantly affected. After the earthquake, building returns to its near original alignment under the spring action of an elastic structure. These friction dampers possess large rectangular hysteresis loops, similar to an ideal elasto-plastic behavior, with negligible fade over several cycles of reversals, Pall [4].

These particular friction dampers have successfully gone through rigorous proof testing on shake tables in Canada and the United States. In 1985, a three-story frame equipped with friction dampers was tested on a shake table at the University of British Columbia, Vancouver Filiatrault [5]. Even an earthquake record with a peak acceleration of 0.9g did not cause any damage to the friction-damped braced frame, while the conventional frames were severely damaged at much lower seismic levels. In 1987, a nine-story three-bay frame, equipped with friction dampers, was tested on a shake table at Earthquake Engineering Research Center of the University of California at Berkeley, Kelly [6]. All members of the friction damped frame remained elastic for 0.84g acceleration, while the moment-resisting frame would have yielded.

Unlike viscous devices, the performance of friction dampers is independent of temperature and velocity. Unlike systems that dissipate energy through the process of yielding – causing permanent damage, friction dampers dissipate seismic energy in friction. The maximum force in a friction damper is well defined and remains constant for any future ground motion. Hence, the design of bracing and connections is straightforward and economical. Since they are not active during wind or service load conditions, there is no danger of failure due to fatigue. There is nothing to leak or damage. Therefore, they do not need regular inspection, maintenance, repair or replacement before and after the earthquake. Friction dampers are also very compact in design and can be easily hidden within drywall partitions. These friction dampers meet a high standard of quality control. Every damper is load tested to ensure proper slip load before it is shipped.

These friction dampers have found many applications for concrete and steel buildings. They have been used in both new construction and seismic retrofit of existing buildings, Pall [8-10,16,22], Verganelakis [7], [Vezina [9], Pasquin [11,18,19], Godin [12], Hale [13,21], Savard [14], Wagner [15], Deslaurier [17], Balazic [20], Chandra [23]. To date, more than eighty buildings have already been built and several are under design or construction. Boeing Commercial Airplane Factory at Everett– the world's largest building in volume and Boeing Development Center Buildings at Seattle have been retrofitted with these friction dampers. Compared to conventional retrofit, Boeing saved more than US$30 million in their Commercial Airplane Factory alone, Vail [24]. The City and County of San Francisco chose Pall friction dampers for seismic control of Moscone Convention Center as it saved them US$2.25 million compared to alternate viscous dampers, Sahai [25]. For more details refer www.palldynamics.com.

DESIGN CRITERIA

The quasi-static design procedure given in the NBCC is ductility based and does not explicitly apply to friction-damped buildings. However, structural commentary - J of the NBCC, allows the use of friction dampers for seismic control of buildings. It requires that nonlinear analysis must show that a building so

equipped will perform equally well in seismic events as the same building designed following the NBCC seismic requirements. In the past few years, various guidelines on the analysis and design procedure of passive energy dissipation devices have been developed in the U.S. The latest and most comprehensive document is the "NEHRP Guidelines for the Seismic Rehabilitation of Buildings", FEMA 356 / 357, issued in 2000. These guidelines and provisions of NBCC, served as basis for the analysis and design.

The NEHRP Guidelines require that the structure with energy dissipating devices be evaluated for response to two levels of ground shaking - a design basis earthquake (DBE) and a maximum considered earthquake (MCE). The DBE is an event with 10% probability of exceedance in 50 years, while the MCE represents a severe ground motion of probability of 2% in 50 years. Under the DBE, the structure is evaluated to ensure that the strength demands on structural elements do not exceed their capacities and that the drift in the structure is within the tolerable limits. For the MCE, the structure is evaluated to determine the maximum displacement requirement of the damping device. It is presumed that if proper ductile detailing has been followed, the structure will have sufficient reserve to resist any overstress that may occur during MCE.

NEHRP guidelines require that friction dampers are designed for 130% MCE displacements and all bracing and connections are designed for 130% of damper slip load. Variation in slip load from design value should not be more that ±15%.

NONLINEAR TIME-HISTORY DYNAMIC ANALYSIS

The movement of a friction damper in an elastic brace constitutes nonlinearity. Also, the amount of energy dissipation or equivalent structural damping is proportional to the displacement. Therefore, nonlinear time-history dynamic analysis is a more accurate procedure for the design of buildings with damping devices. With these analyses, the time-history response of the structure during and after an earthquake can be accurately understood. Several nonlinear programs are available on which friction dampers can be easily modeled. Three-dimensional nonlinear time-history dynamic analyses were carried out using the computer program ETABS. The modeling of friction dampers is very simple. Since the hysteretic loop of the damper is similar to the rectangular loop of an ideal elasto-plastic material, the slip load of the friction damper can be considered as a fictitious yield force.

Since different earthquake records, even of the same intensity, give widely varying structural responses, results obtained using a single record may not be conclusive. Therefore, three pairs of time-history records suitable for the region were used. The earthquake record that provided maximum response was used for the design (Figure 5). Analyses were carried out for ground motions simultaneously 100% along x-direction and 100% along y-direction. Viscous damping of 5% of critical was assumed in the initial elastic stage to account for the presence of non-structural elements.

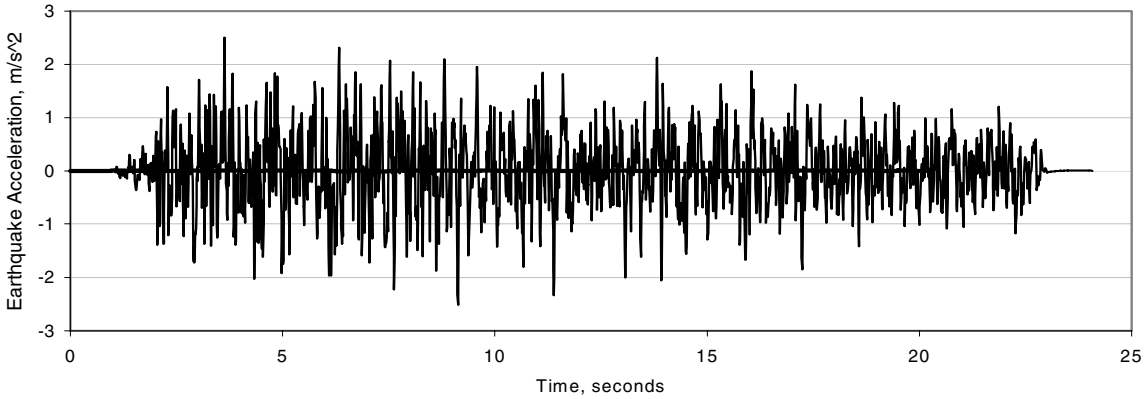


Figure 5. Time-history record of earthquake.

Several iterations were made to determine the optimum slip loads of friction dampers to achieve minimum seismic response. A total of 57 friction dampers of 600 kN slip load capacity were used.

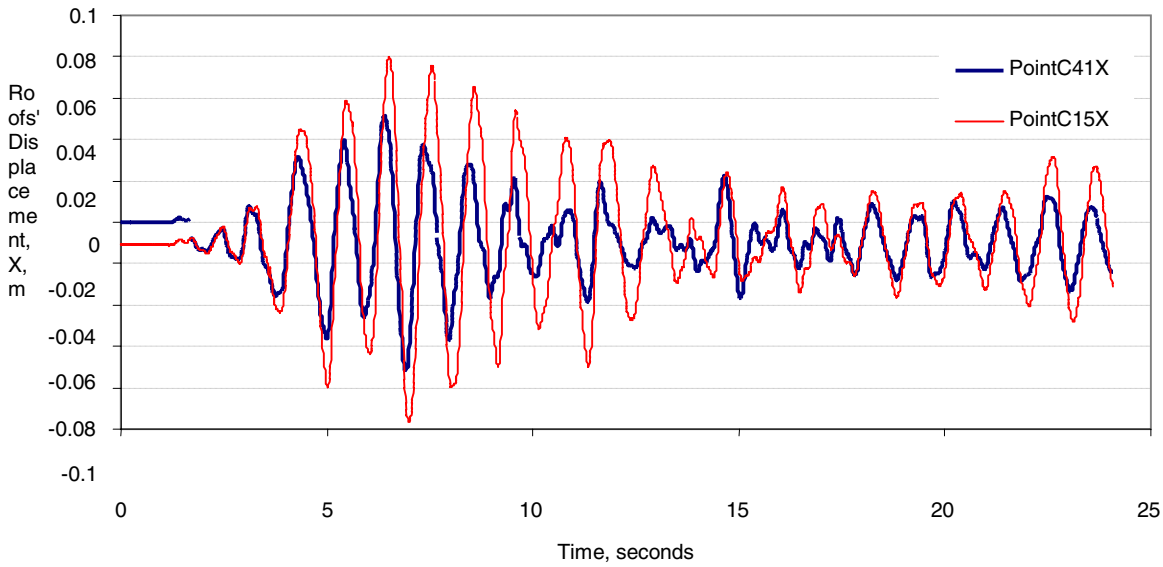
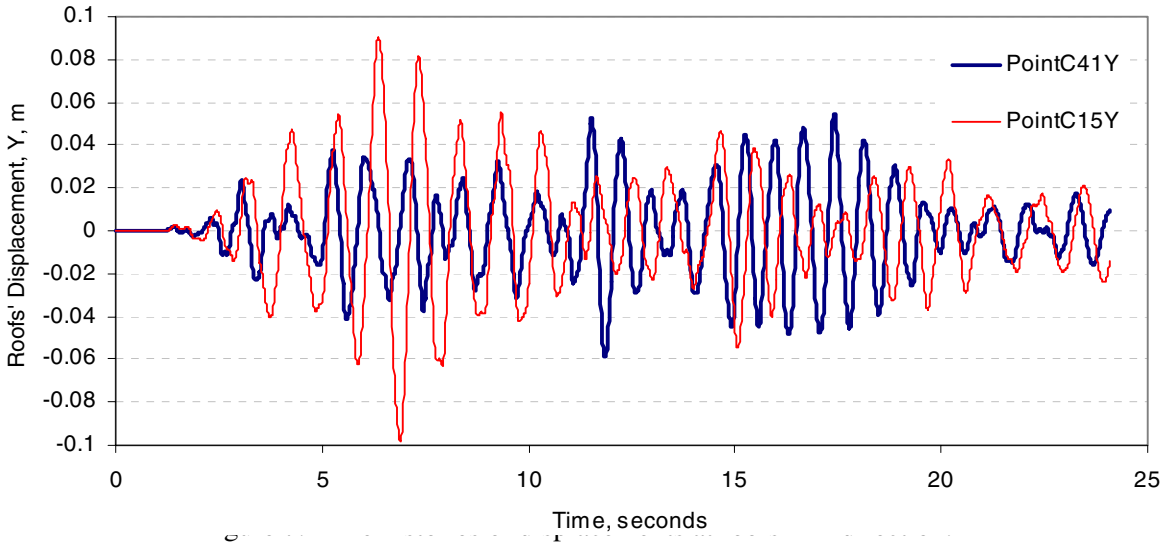


Figure 6. Time histories of displacements at roofs in y-direction..



DISCUSSION OF RESULTS

1. Time-histories of deflections at the top of buildings are shown in Figures 6 and 7. Maximum defection at roof is 101 mm. (H/300). The maximum story drift was about 0.5%. At this low level of deformations, no damage is expected during a major earthquake. At the end of ground motion, the permanent offset at the top of the building is negligible.

2. Time-histories of damper deformations are shown in Figure 8. After the earthquake, the dampers nearly return to their original alignment.

3. Hysteretic loops of a typical damper in single diagonal bracing are shown in Figure 9. The slope in the hysteretc loop is the elastic deformation of brace. The friction dampers have experienced several cycles of reversal and dissipated large amounts of seismic energy. As major portion of the energy has been dissipated, it results in overall improvement of seismic response.

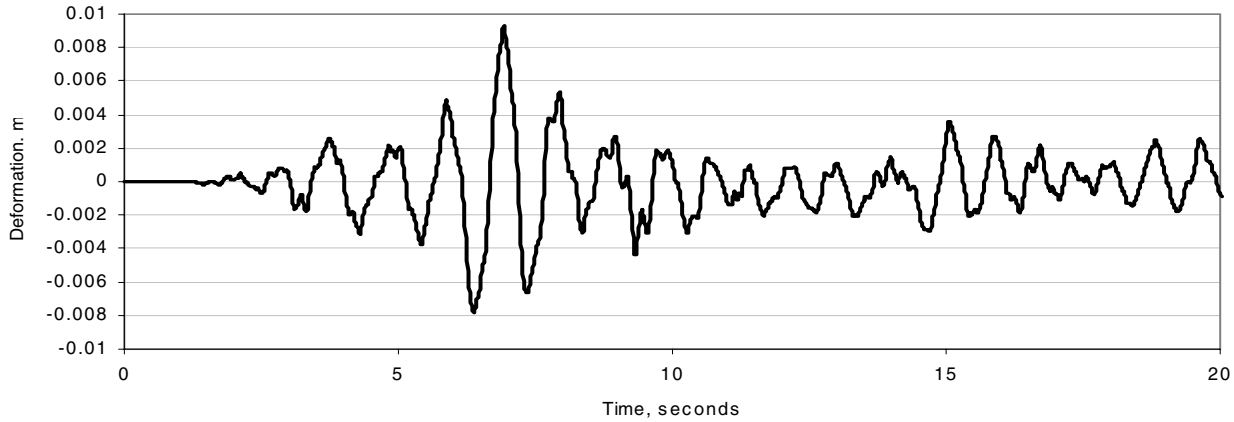


Figure 8. Time history of deformation of a damped bracing.

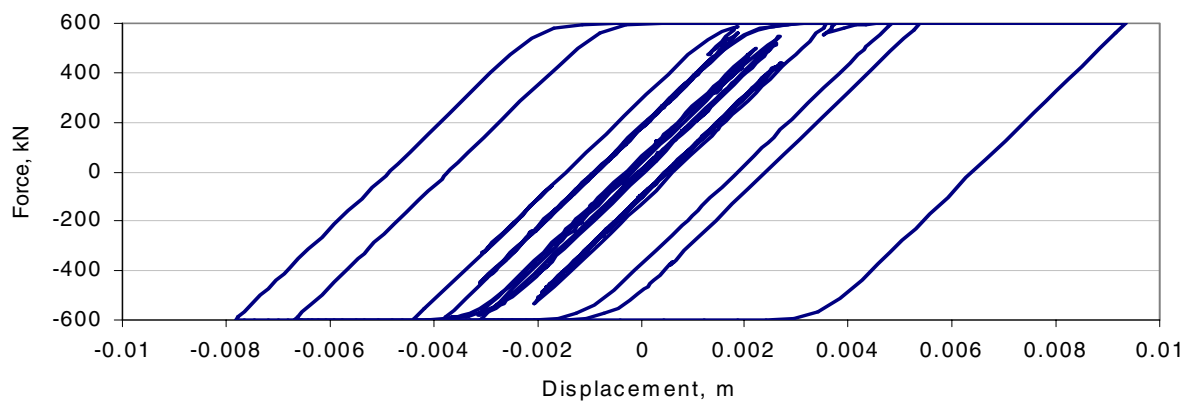


Figure 9. Hysteretic loop of a 600kN friction damper in a diagonal brace.

CONCLUSION

The use of Pall friction dampers has shown to provide a practical solution for the seismic control of the Europa building. As the friction dampers have dissipated major portion of the seismic energy, the seismic forces exerted on the structure and the story drifts are significantly reduced. Analytical studies have shown that their use has resulted in an economical performance-based design.

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