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SEISMIC CONTROL OF FEDERAL ELECTRONICS RESEARCH BUILDING, OTTAWA

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SUMMARY

The Federal Electronic Research building was designed and built in 1993. In 2003, an additional storey was added to the existing structure. This building houses very sensitive instrumentation and expensive equipment. As well, it was of vital importance to the client to safeguard the storage of valuable scientific data and to provide operational continuity in the event of a major earthquake. This led to the use of an innovative yet cost effective technology. Introduction of supplemental damping in conjunction with appropriate stiffness was the chosen solution. Incorporating Pall Friction Dampers in steel bracing achieved this.

INTRODUCTION

The Federal Electronic Research building is located in Ottawa, Canada's capital (Figure 1). It was designed by the department of Public Works & Government Services Canada and built in 1993. In 2003, an additional storey was added. The three-storey building is of concrete frame construction with one basement. The foundations are on spread footings. This building houses very sensitive instrumentation and expensive equipment. Besides, it was of vital importance to the client to safeguard the storage of valuable scientific data and to provide operational continuity in the event of a major earthquake. The client expected a higher level of performance than the minimum specified in the building code.

The design criteria stipulated in most building codes, including the National Building Code of Canada (NBCC), are based on the philosophy of designing buildings to resist moderate earthquakes without considerable damage and to resist larger earthquakes without collapsing. The main emphasis is on life safety. In general, reliance for survival is placed on the ductility of the building to dispel energy while undergoing large inelastic deformations causing bending, twisting and cracking. This assumes permanent damage, repair costs of which could be economically as significant as the collapse of the building.

In the past, the minimum design provisions of the building codes were adequate for most buildings. In modern buildings, circumventing collapse alone is not enough. The cost of finishes, sensitive instrumentation and electronically stored data are more valuable than the cost of the structure itself. These

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must be safeguarded. The problems created by dependence on ductility can be mitigated if a large portion of the seismic energy can be dissipated mechanically, independent of the principal structure.

With the emergence of friction dampers, it has become economically feasible to substantially control the damage to a structure and its contents. Unlike concrete shearwalls, the friction-damped bracing is not required to be vertically over each other. This also gives more freedom in space planning. The plan of the first storey is shown in Figure 2. The friction dampers have been installed in cross bracing and single diagonal bracing as required. Architectural planning influenced the location and the type of bracing used. For instance, diagonal bracing allowed for doorways to be easily accommodated. A typical detail of a friction damper in cross bracing is shown in Figure 2. The plan of the building and locations of the friction-damped braces are shown in Figures 3 and 4, respectively. This building won the Ottawa Architectural Design Prize.

The results of analysis, design procedure, cost benefits and construction details of the chosen structural system will be discussed. A brief discussion on friction dampers is also included so that its application can be better appreciated.

Figure 1. Partial View of Federal Electronic Research Building.

During installation Finished view

Figure 2. Pall Friction Damper in cross bracing.

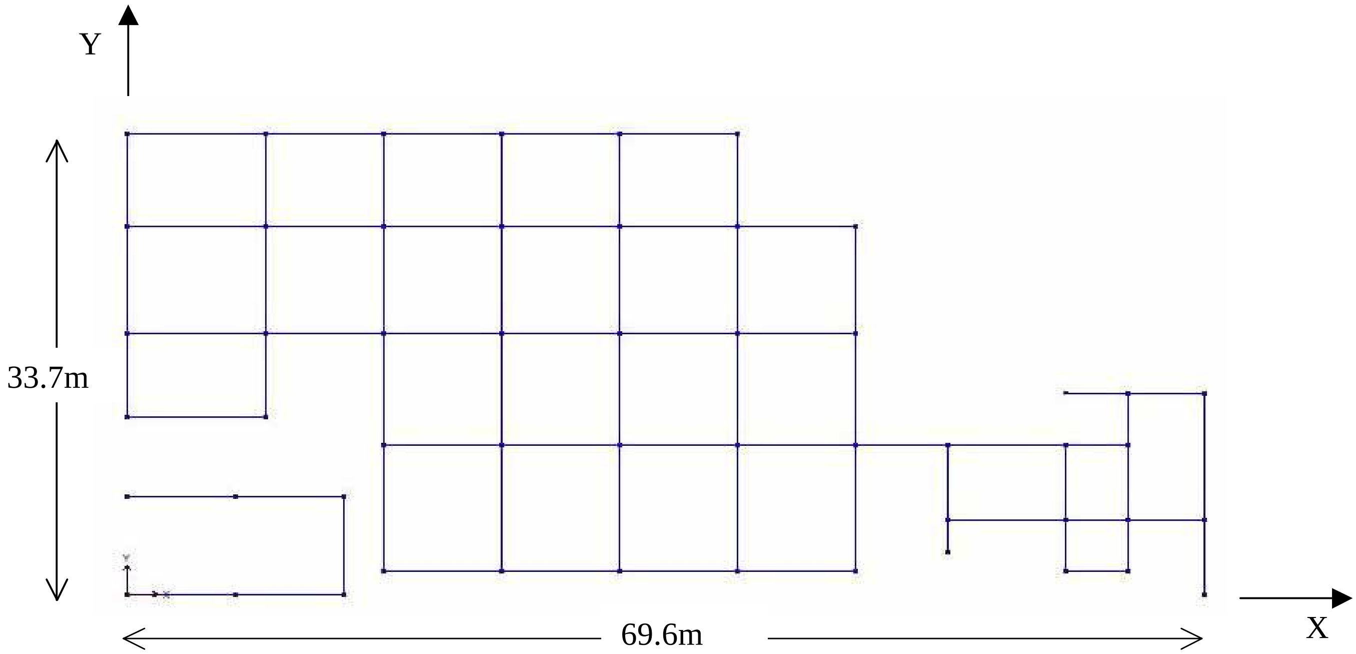

Figure 3. Plan View of First Floor, Analytical Model.

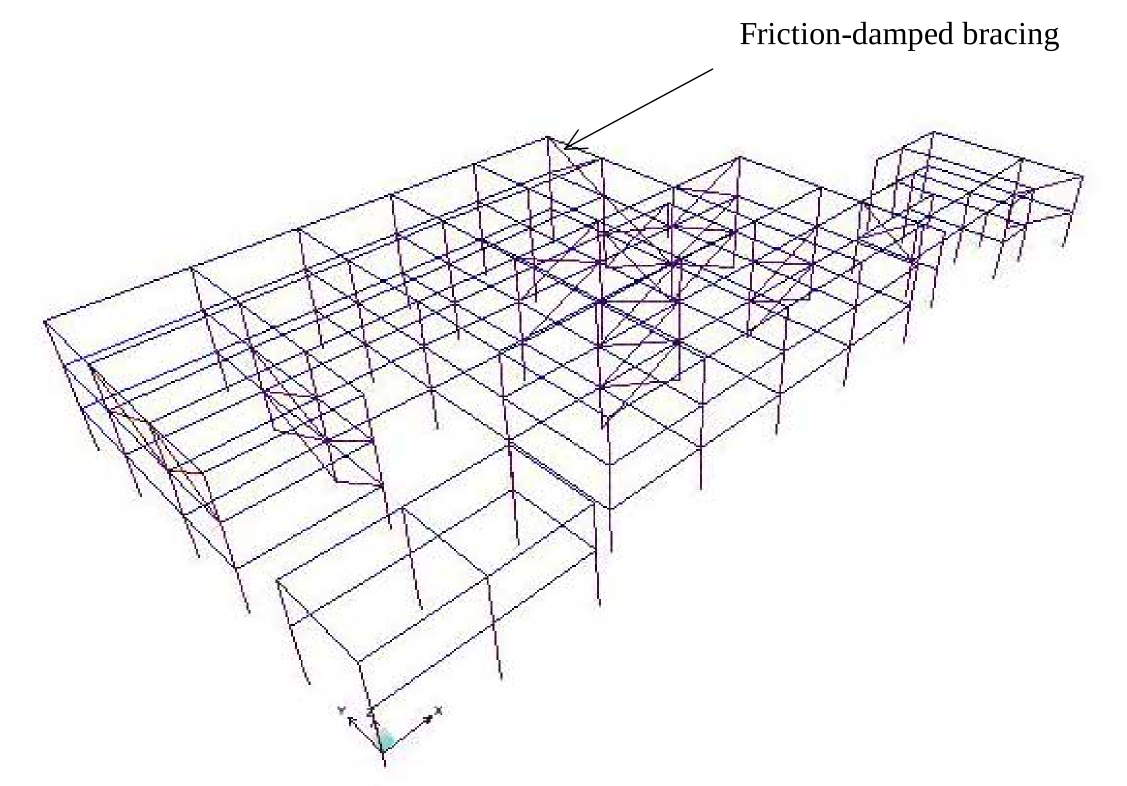

Figure 4. Three Dimensional Analytical Model.

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. In late seventies, the principle of friction brake inspired the development of friction dampers, Pall et al. [8-11]. Similar to automobiles, the motion of vibrating building can be slowed down by dissipating energy in friction. Several types of friction dampers have been developed, Pall et al. [11]. For frame buildings, these are available for tension cross bracing, single diagonal bracing, chevron bracing, and friction connectors at expansion joints to avoid pounding.

Pall friction dampers are simple and foolproof in construction and inexpensive in cost. They consist of series of steel plates specially treated to develop most reliable friction. The plates are clamped together with high strength steel bolts. Friction dampers are designed not to slip during wind. During severe seismic excitations, friction dampers slip at a predetermined optimum load before yielding occurs in other structural members and dissipate a major portion of the seismic energy. Another feature of friction damped buildings is that their natural period varies with the amplitude of vibration. Hence the phenomenon of resonance is avoided. After the earthquake, the building returns to its near original alignment under the spring action of an elastic structure.

These particular friction dampers have successfully gone through rigorous proof testing on shake tables in Canada and the United States. In 1985, a three-storey frame equipped with friction dampers was tested on a shake table at the University of British Columbia, Vancouver, Cherry et al. [3]. Even an earthquake record with a peak acceleration of 0.9g did not cause any damage to friction damped braced frame, while the conventional frames were severely damaged at lower seismic levels. In 1987, a nine storey three bay frame, equipped with friction dampers, was tested on a shake table at the Earthquake Engineering Research Center of the University of California at Berkeley, Kelly et al. [7]. All members of the friction damped frame remained elastic for 0.84g acceleration, while the moment-resisting frame would have yielded at about 0.3g acceleration.

Friction dampers possess large rectangular hysteresis loops, similar to an ideal elasto-plastic behavior, with negligible fade over several cycles of reversals Pall et al. [9], Filiatrault et al. [3]. Unlike viscous or visco-elastic devices, the performance of friction dampers is independent of temperature and velocity. For a given force and displacement in a damper, the energy dissipation of friction damper is the largest compared to other damping devices (Figure 6). Therefore, fewer friction dampers are required to provide a given amount of supplemental damping. Unlike other devices, the maximum force in a friction damper is pre-defined and remains the same for any future ground motion. Therefore, the design of bracing and connections is simple and economical. There is nothing to yield and damage, or leak. Thus, they do not need regular inspection, maintenance, repair or replacement before and after the earthquake. These friction dampers are also compact in design and can be easily hidden within drywall partitions. The friction dampers meet high standard of quality control. Before delivery to site, each damper is load tested to ensure proper slip load.

Friction dampers manufactured by Pall Dynamics Limited have found many applications in new construction and seismic retrofit of existing buildings, Pall et al. [12-17], Vezina et al. [23], Pasquin et al. [18-20], Godin et al. [4], Savard et al. [21], Wagner et al. [25], Deslaurier et al. [2], Balazic et al. [1], Hale et al. [5,6]. Boeing's Commercial Airplane Factory in Everett WA - world's largest building in volume has been retrofitted with these friction dampers, Vail et al. [24]. Boeing saved more than US$30 million by using this technology. The City and County of San Francisco chose Pall friction dampers for the seismic control of Moscone Convention Center as it saved them US$2.25 million compared to alternate viscous dampers, Sahai et al. [22]. To date, more than eighty buildings have already been built and several are under design or construction. For more details refer www.palldynamics.com.

NONLINEAR TIME HISTORY DYNAMIC ANALYSIS

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 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. The slippage of friction damper in an elastic brace constitutes nonlinearity. Also, the amount of energy dissipation or equivalent structural damping is proportional to the displacement. Therefore, the design of friction-damped buildings requires the use of nonlinear time-history dynamic analysis. With these analyses, the time-history response of the structure during and after an earthquake can be accurately understood.

Three-dimensional nonlinear time history dynamic analyses were carried out using the computer program DRAIN-TABS (Guendelman-Isreal and Powell 1977), developed at the University of California, Berkeley. This program consists of a series of subroutines that carry out a step by step integration of the dynamic equilibrium equations using a constant acceleration in a time step. Although several commercial programs are now available for three-dimensional nonlinear analysis, DRAIN-TABS was the only one available in 1992. 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.

Different earthquake records give different responses. Three earthquake records, which had peak horizontal velocity and peak ground acceleration falling within the ranges prescribed by NBCC for Ottawa region were used. The earthquake record, which gave the maximum response, was an artificial earthquake record generated to match the Newark-Blume-Kapur (NBK) response spectra with peak ground acceleration scaled to 0.2g. The analyses were carried out for earthquakes applied along the x-axis, y-axis and at a 45 degree angle.

Viscous damping of 5% of critical was assumed in the initial elastic stage to account for the presence of non-structural elements. Hysteretic damping due to inelastic action of the structural elements and slipping of the friction dampers is automatically taken into account by DRAIN-TABS. Interaction between axial forces and moments for columns and P-Δ effect were taken into account by including geometric stiffness based on axial force under static loads. To account for accidental eccentricity, the center of mass was shifted by 10% of the building dimension along both axes.

A series of analyses were carried out to determine the optimum slip load of the friction dampers. A total of 23 friction dampers of 300 kN slip load capacity were required to extract sufficient seismic energy to safeguard the structure and contents from damage.

The time-histories of deformation in the friction-damped bracing are shown in Figure 5. The maximum slippage in the friction damper is about 13 mm. After the earthquake, the damper nearly returns to its original alignment under the elastic action of frame. The friction dampers underwent several cycles of reversals and dissipated a large amount of seismic energy.

The time-histories of the deflections at the roof level is shown in Figure 6. The maximum drift is 35 mm. The maximum storey drift is about 0.5%, which is about 50% of that specified in NBCC for buildings of post disaster importance. At these low drifts, very little damage is expected.

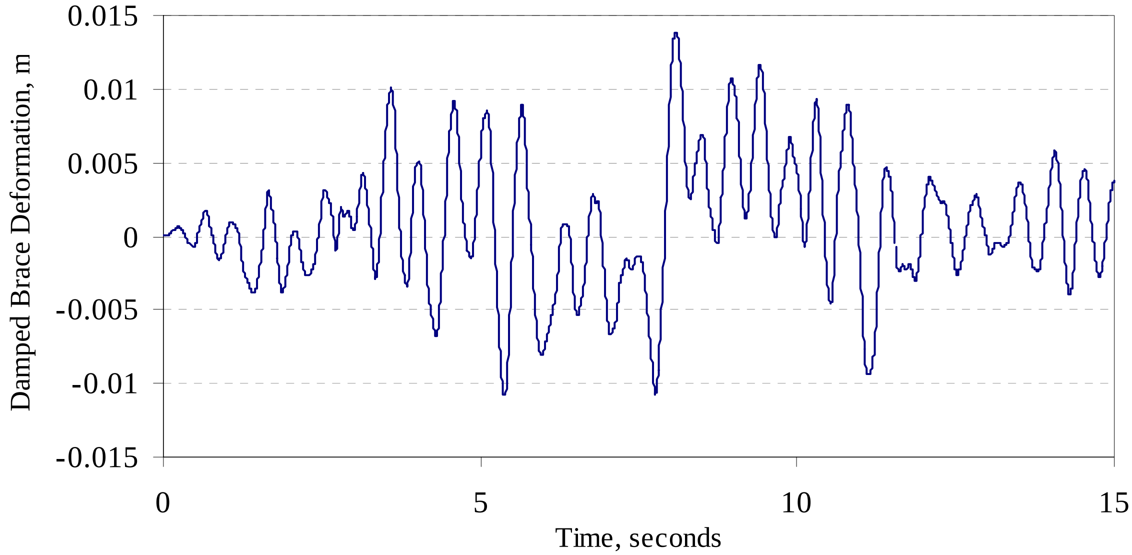

Figure 5. Time Histories of Displacements in Damped Bracing

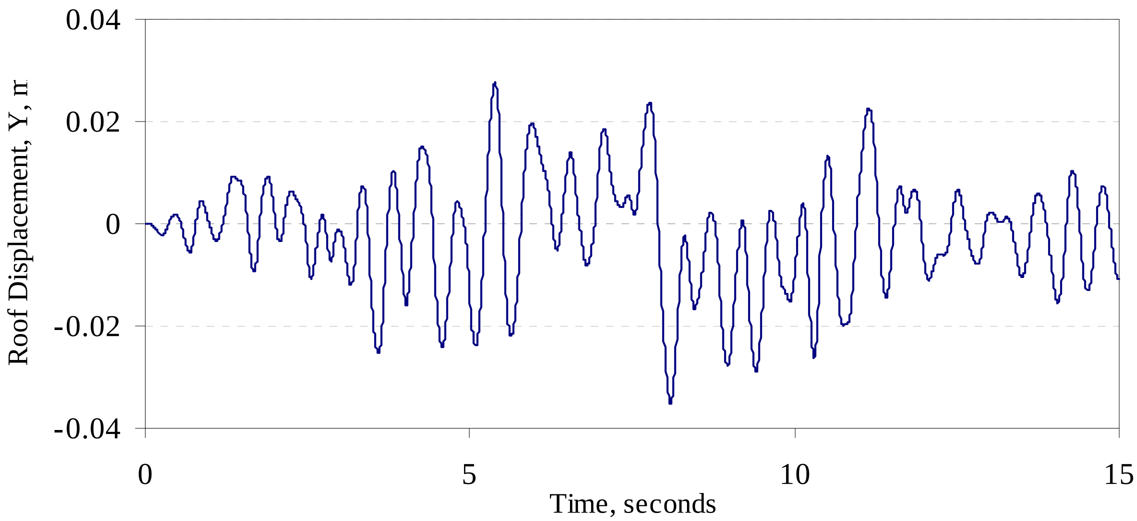

Figure 6. Time History of Deformations at Roof Level.

CONCLUSIONS

The analytical studies have shown that the friction-damped structure should perform very well in the event of a major earthquake. The seismic performance of the structure is far superior to the requirements of the building code. As the seismic forces exerted on the structure are significantly reduced, the system offers saving in initial construction cost. Besides, the life cycle cost could be significant less as damage to the building and its content is minimised. The use of friction dampers has shown to provide a practical and economical solution for the performance-based design of Federal Electronics Research building.

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