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FRICTION DAMPERS FOR SEISMIC CONTROL OF AMBULATORY CARE CENTER, SHARP MEMORIAL HOSPITAL, SAN DIEGO, CA

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SUMMARY

The new Ambulatory Care Center, built in 2003, provides extensive medical services, including surgery. The complex consists of two separate four-story buildings. The steel frame construction was adopted for cost efficiency, design flexibility and speedy construction. The structures were designed to meet 1997 UBC and 1998 California Code requirements for Seismic Zone 4. Pall Friction Dampers in steel bracing were incorporated in moment-resisting frames to resist lateral seismic forces. The results of nonlinear analysis show that the use of Pall friction dampers resulted in an economical performance-based design.

INTRODUCTION

The new Ambulatory Care Center (ACC) is located in San Diego, California (Figure 1). The ACC building provides extensive medical services, including surgery The ACC complex consists of two four-story buildings, East Wing and West Wing. The East Wing and West Wing buildings measure about 100 feet x 150 feet and 120 feet x 85 feet, respectively. The wings are connected in two places by a pedestrian bridge and an elevator lobby. The steel frame construction was adopted for cost efficiency, design flexibility and speedy construction. The floors are concrete fill over steel deck. The foundations are spread footings. Analytical models of the two wings are shown in Figures 2 and 3.

As the hospital buildings are of post-disaster importance, performance-based design criteria was adopted. The introduction of supplemental damping was considered to be an ideal solution for control of seismic forces. The use of two types of dampers was studied - friction dampers and viscous dampers.

The viscous dampers are velocity dependent. The forces exerted by the damper are different for different earthquake records. The friction dampers are independent of velocity. The hysteresis loop of viscous damper is elliptical compared to rectangular for friction damper (Figure 4). For a given maximum force, the area of hysteresis loop (energy dissipation or damping) of viscous damper is about 70% of that for friction damper i.e. 7 friction dampers will achieve the same damping as 10 viscous dampers of a given force. Conversely, for a given number and damping value, the forces exerted by friction dampers are only

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70% of those for viscous dampers. This leads to significant savings in cost of dampers, bracing, connections, columns, and foundations.

Figure 1. View of Ambulatory Care Center, Sharp Memorial Hospital.

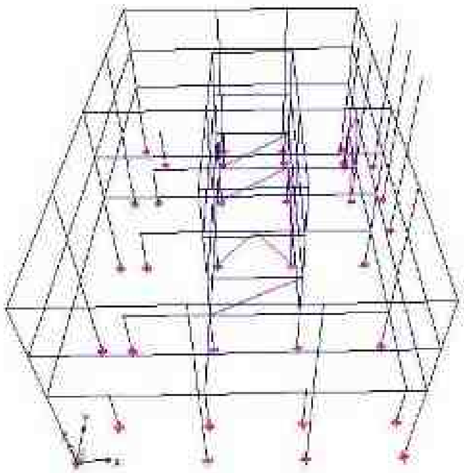


Figure 2. East Wing, 3-dimensional analytical model of building

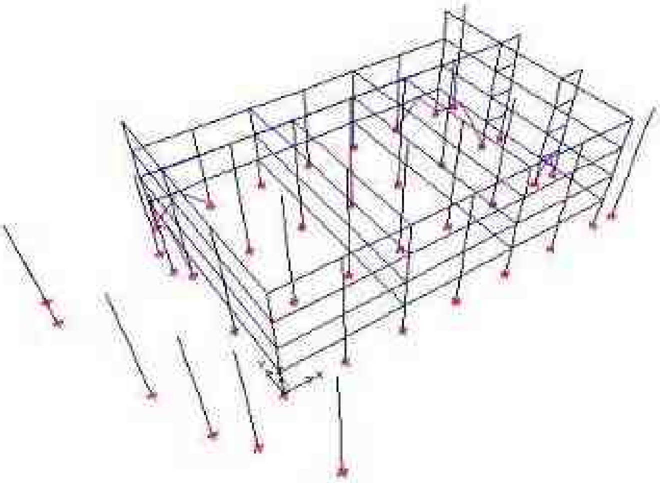
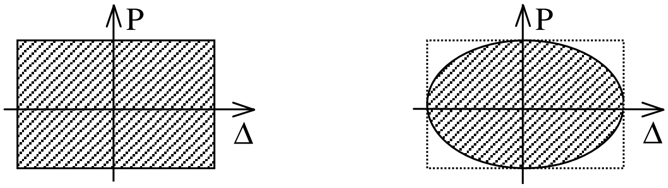


Figure 3. West Wing, 3-dimensional analytical model of building



Friction damper

Viscous damper

Figure 4. Comparison of hysteresis loops of different dampers

A friction-damped structure is an engineered structure in which the forces exerted are constant for all earthquake records, design basis earthquake (DBE) or maximum considered earthquake (MCE). This is a great technical and economic advantage over viscous dampers in which forces are much higher at MCE level. Another attractive feature of friction dampers is that they offer stiffness in conjunction with supplemental damping. While supplemental damping is beneficial in reducing the earthquake forces and amplitudes of vibration, added stiffness is beneficial for stability.

Analyses were carried out with both types of dampers. The seismic performance was better with the use of friction dampers. Moreover, the friction damper solution was more economical, almost half the cost of viscous dampers. Based on architectural considerations, the friction dampers were used in single diagonal and chevron bracing. A typical chevron brace with two friction dampers at the apex is shown in Figure 5.

This paper discusses the results of seismic analyses and design procedure of the ACC Buildings. A brief review on conventional code philosophy and friction dampers has also been included so that the use of the novel structural solution can be better appreciated.

Figure 5. Typical Chevron brace with two friction dampers at the apex (during construction)

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 a series of steel plates specially treated to develop very 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 a structural property. Also, within a variation of ± 20% of slip load, the seismic response is not significantly affected. After the earthquake, the 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], Filiatrault [5].

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 to 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 through 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 the dampers 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.

Friction dampers have found many applications in concrete and steel buildings. They have been used in both new construction and seismic retrofit of existing buildings, Pall [7-10,16,22], 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 using Pall Friction Dampers. 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 a 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

In the past few years, several guidelines for 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, the 1997 UBC and 1998 California Building Code requirements for Seismic Zone 4, served as basis for the analysis and design of the ACC Buildings.

The Guidelines require that a structure with energy dissipating devices be evaluated for response to two levels of ground shaking - DBE and MCE. The DBE is an event with a 10% probability of exceedance in 50 years, while the MCE represents a severe ground motion with a probability of exceedance 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 the 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 in 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 site specific time-history records developed by the project geotechnical engineers were used. The earthquake record that provided maximum response and was used for the design (Figures 6 and 7). 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.

Several iterations were made to determine the optimum slip loads of friction dampers to achieve minimum seismic response. A total of 22 friction dampers of slip loads from 100-330 kip were used.

DISCUSSION OF RESULTS

1. Time-history deflections at the top of buildings are shown in Figures 8 and 9. Maximum defection at the roof is 3.41 inches (H/200) for the East Wing and 2.51 inches (H/265) for the West Wing. The maximum story drift was about 1%. 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, 0.049 and 0.067 inches in the East Wing and West Wing, respectively.
2. Time-history damper deformations are shown in Figures 10 and 11. After the earthquake, the dampers nearly return to their original alignment.

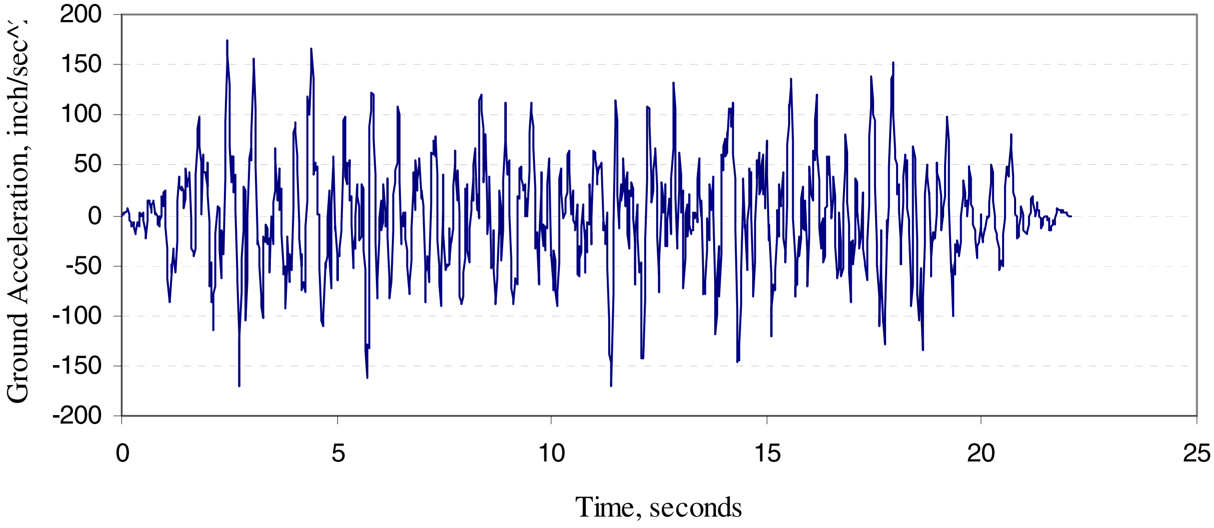


Figure 6. East Wing – Time history of earthquake record in x and y directions.

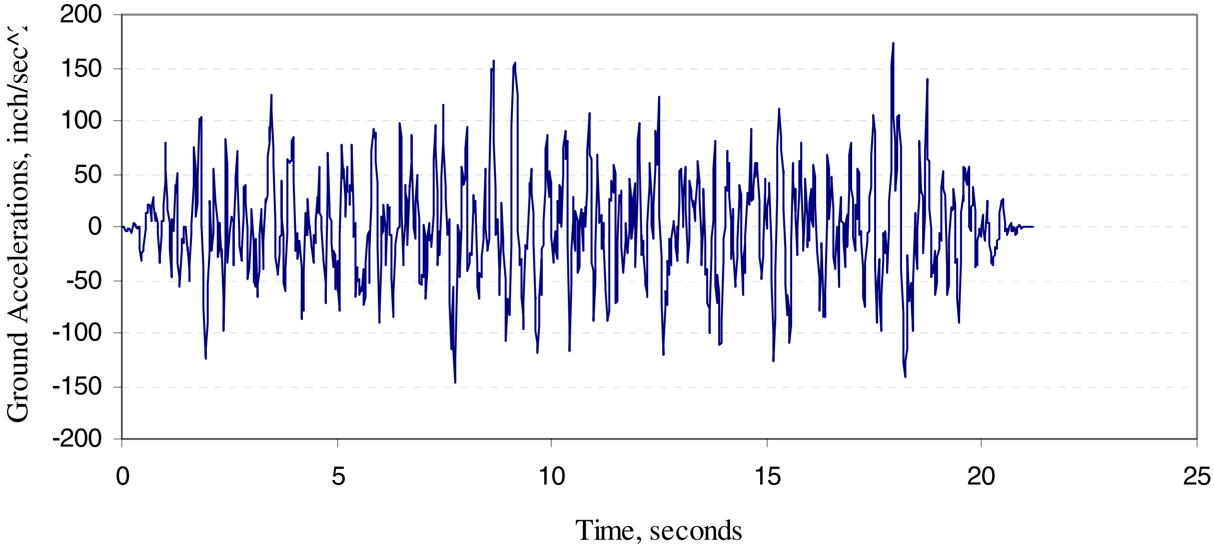


Figure 7. West Wing – Time history of earthquake record in x and y directions.

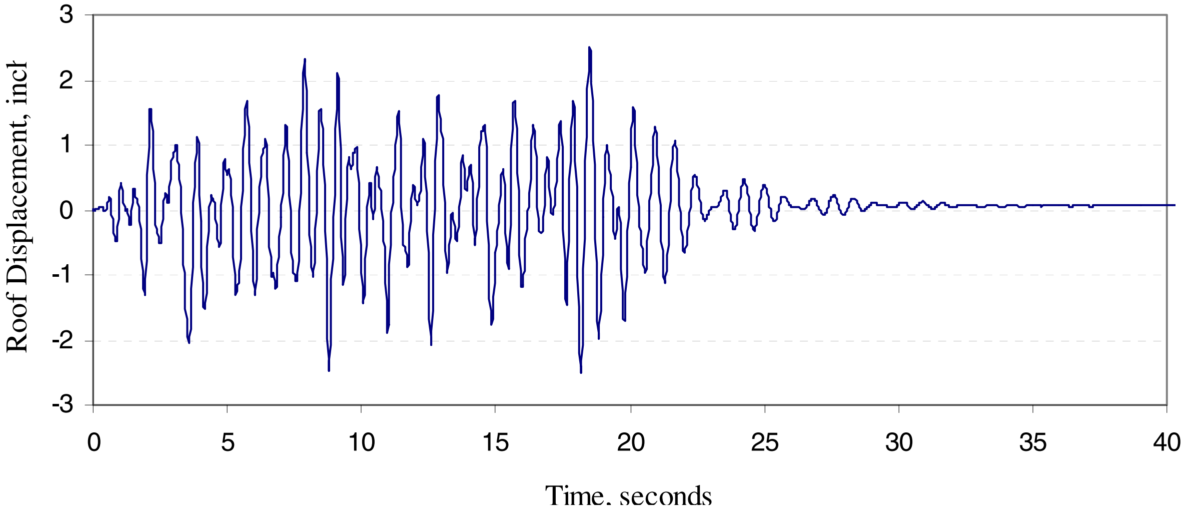


Figure 8. East Wing – Time history of displacement at roof in y direction.

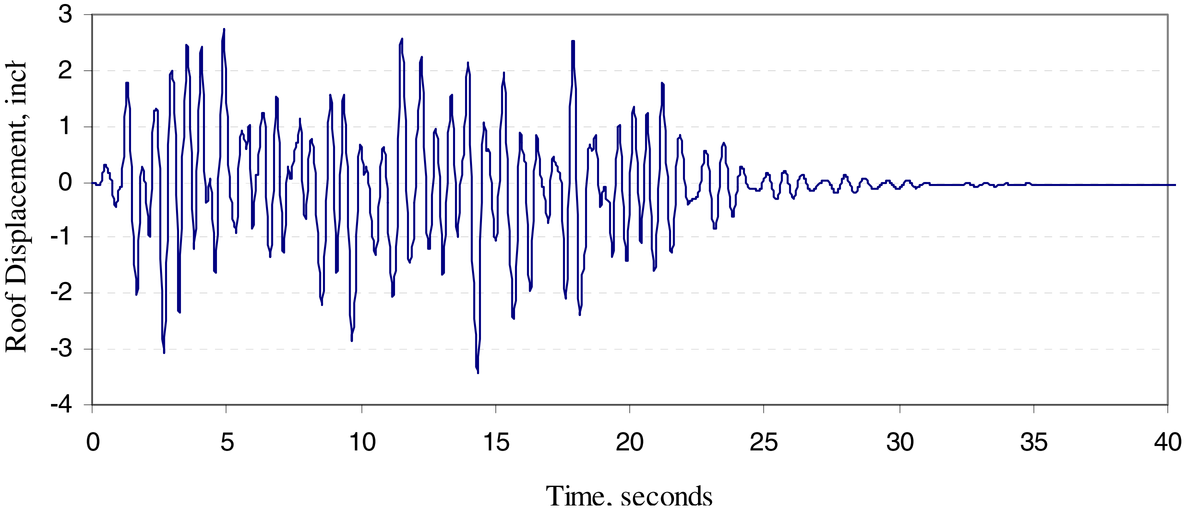


Figure 9. West Wing – Time history of displacement at roof in x direction.

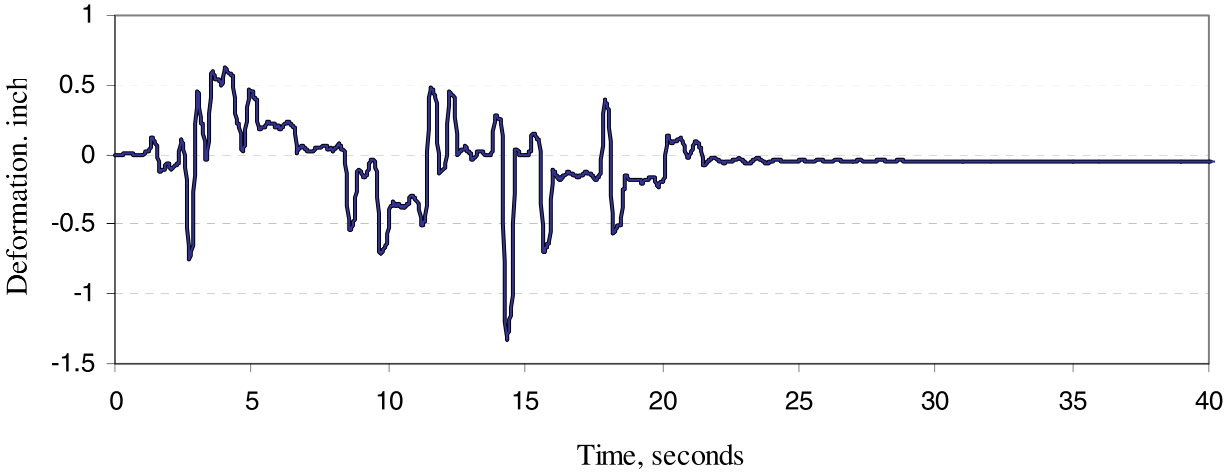


Figure 10. East Wing – Time history of deformation of damper at apex of chevron brace along y axis**.**

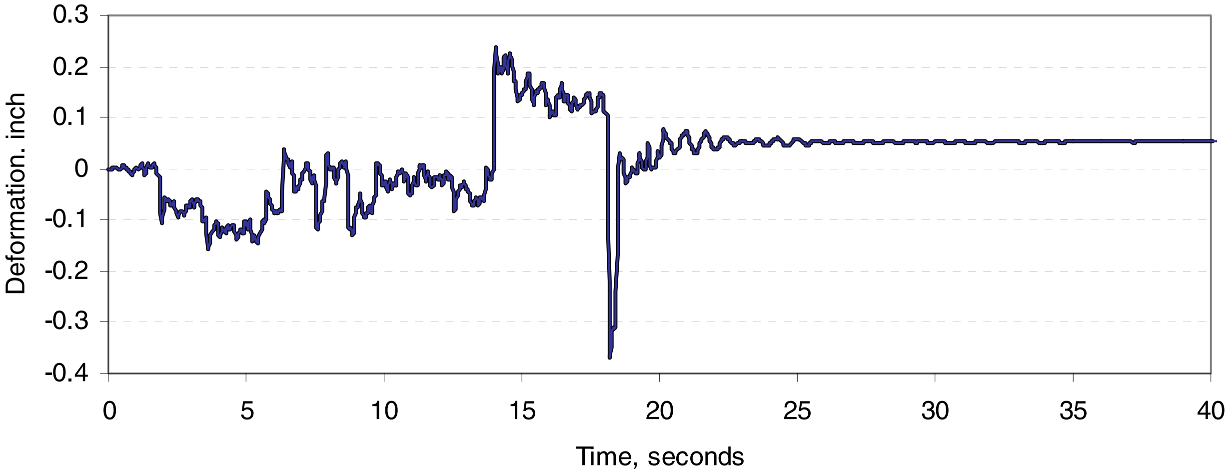


Figure 11. West Wing – Time history of deformation of single diagonal brace damper along x axis.

3. Hysteretic loops of a typical damper in chevron bracing and single diagonal bracing are shown in Figures 12 and 13, respectively. The friction dampers have experienced several cycles of reversal and dissipated large amounts of seismic energy.
4. Time history energy input and energy dissipated are shown in Figures 14 and 15. The friction dampers in the East Wing and West Wing have dissipated 65% and 70% of the seismic energy input, respectively. Since a major portion of the energy has been dissipated, it results in overall improvement of seismic response.

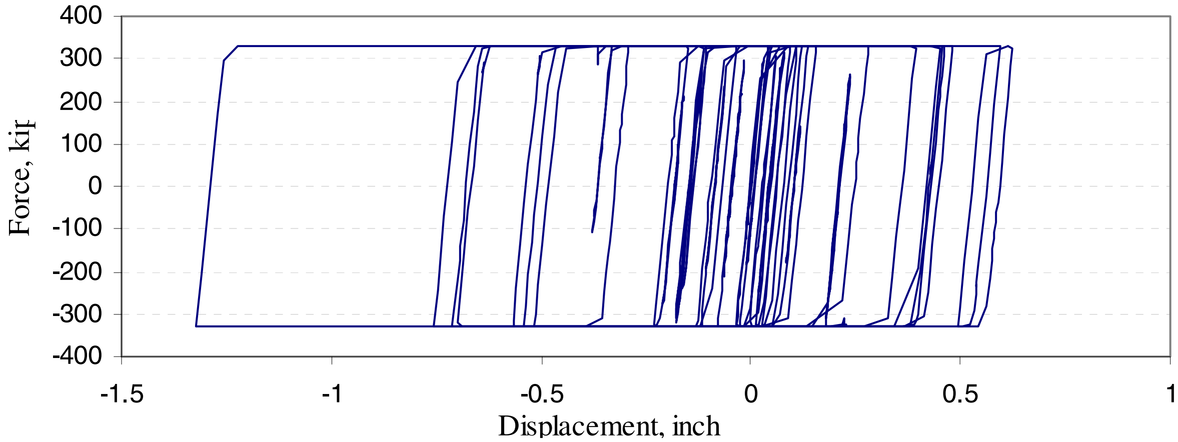


Figure 12. East Wing – Hysteretic loop of a 330 kip friction damper at apex of chevron brace.

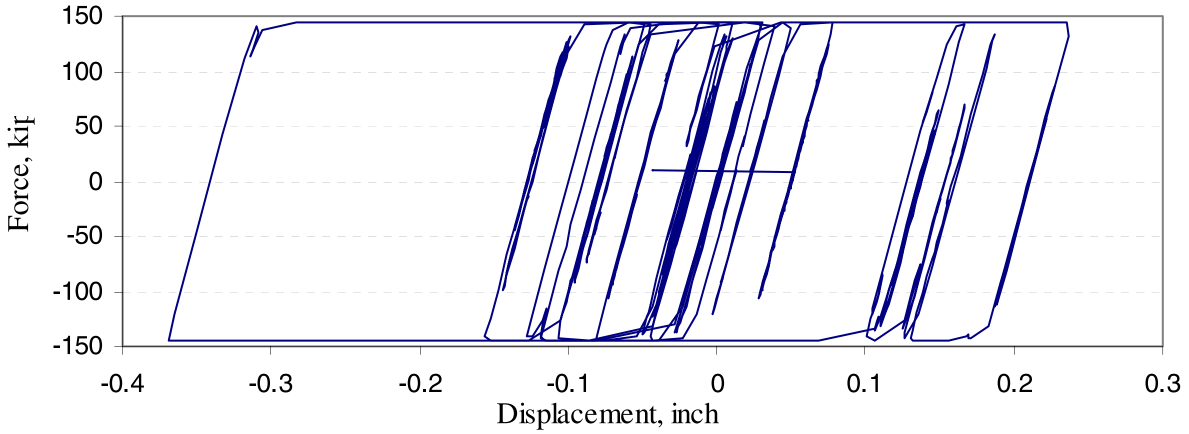


Figure 13. West Wing – Hysteretic loop of a 144 kip friction damper at bottom of single diagonal brace.

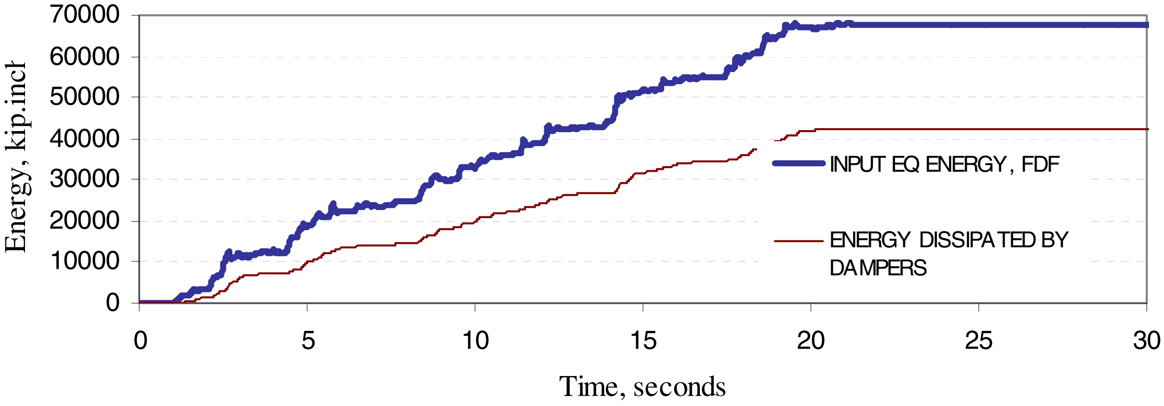


Figure 14. East Wing – Time histories of energy input and energy dissipated.

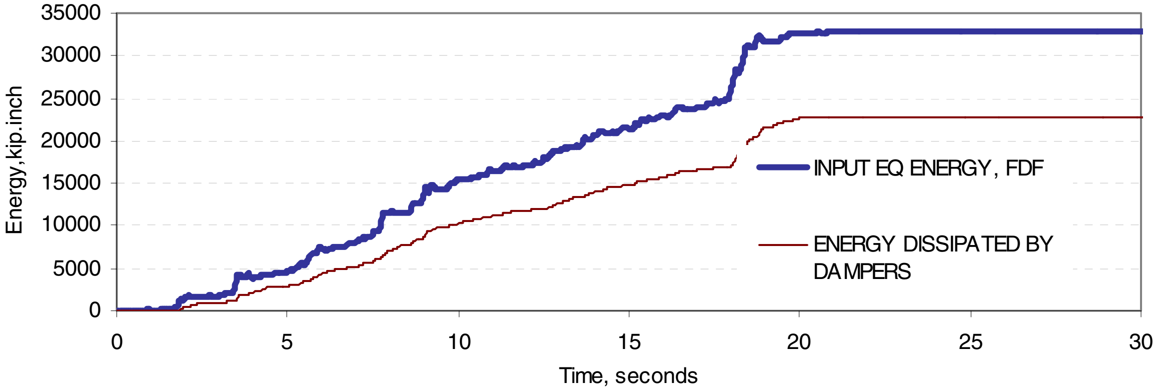


Figure 15. West Wing – Time histories of energy input and energy dissipated.

CONCLUSION

The use of Pall friction dampers has been shown to provide a practical solution for the seismic control of the ACC Buildings. Since 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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