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FRICTION DAMPERS FOR SEISMIC UPGRADE OF PATIENT TOWER ST. JOSEPH HOSPITAL, TACOMA, WA

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ABSTRACT

The 14-story Patient Tower, built in the 1970s, is a concrete shear wall building. The interior and exterior shear walls are supported on concrete columns. This creates a 36 foot high soft-story. Studies conducted in 2004 indicated that such a soft-story would result in service disruptions after a seismic event.

Various seismic upgrade schemes were evaluated. The scheme with supplemental damping offered substantial cost savings on the foundation work. Long bracing in soft-story prompted the use of tension-only cross-braces with Pall friction dampers at the brace intersection. With the implementation of this upgrade, the story drift was reduced to half and FEMA356 structural immediate-occupancy performance level was achieved. The seismic upgrade was completed in 2005.

Introduction

The Patient Tower, designed and constructed in the 1970s, is located in Tacoma in the greater Seattle area (Fig. 1). It has been a well-received and celebrated concrete building in the concrete industry ever since it was built. In fact, it was featured in the ACI Centennial Celebration in 2004 that was widely published in numerous architectural and engineering magazines

The tower has a total of fourteen (14) stories, including a 2-story podium. The tower and podium have an out-to-out dimension of 136' and 238'. The typical floor-to-floor height is 11' with the exception of between Level-3 and Level-5, which is 18' each.

The tower floors are constructed with 15" thick flat concrete slabs. The flat slab at each floor is supported by the 10" thick perimeter curved concrete walls and the interior concrete shear wall cores. The podium floors are constructed with waffle slabs using 4 ½" slabs over 14" deep 4' square pans. The waffle slabs are supported by 24" square concrete columns at 34' on center each way outside of the tower footprint, sixteen (16) 36" diameter concrete columns that support the tower perimeter curved concrete walls, and podium interior and perimeter 12" thick concrete shear walls. Combined with the tower interior shear wall cores this creates a very stiff concrete box podium between Level-1 and Level-3. All walls and columns are supported by strip or pad concrete footings with the allowable soil bearing capacity of 12 ksf.

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Figure 1. Existing Building.

Figure 2. Existing Building Soft-Story.

The lateral system of the tower is composed of 10” thick interior concrete shear wall cores and 10” thick curved exterior concrete walls. Between the top of the podium (level-3) and level-5, all interior shear wall cores are transferred to rectangular concrete columns located at the corners of these cores; the curved exterior concrete shear walls stop at level-5 and are supported by sixteen (16) 36” diameter concrete columns. This creates a 2-story 36-foot tall soft-story (Fig. 2). The lateral resistant system of the soft-story is composed of eight (8) bays of multi-strand post-tensioned “X” tension braces between the adjacent columns that support the interior shear wall cores with four (4) bays in each direction. Each brace is composed of thirty-six (36) 0.6” diameter post-tensioned strands in three (3) tendons that were tensioned at 50-kips per tendon with a total post-tension force of 150-kips in each brace. This unique lateral system was developed with the intent to prolong the building periods and thus reduce the seismic forces imposed onto this very heavy concrete tower. This concept of prolonged period is now widely used in base-isolation systems.

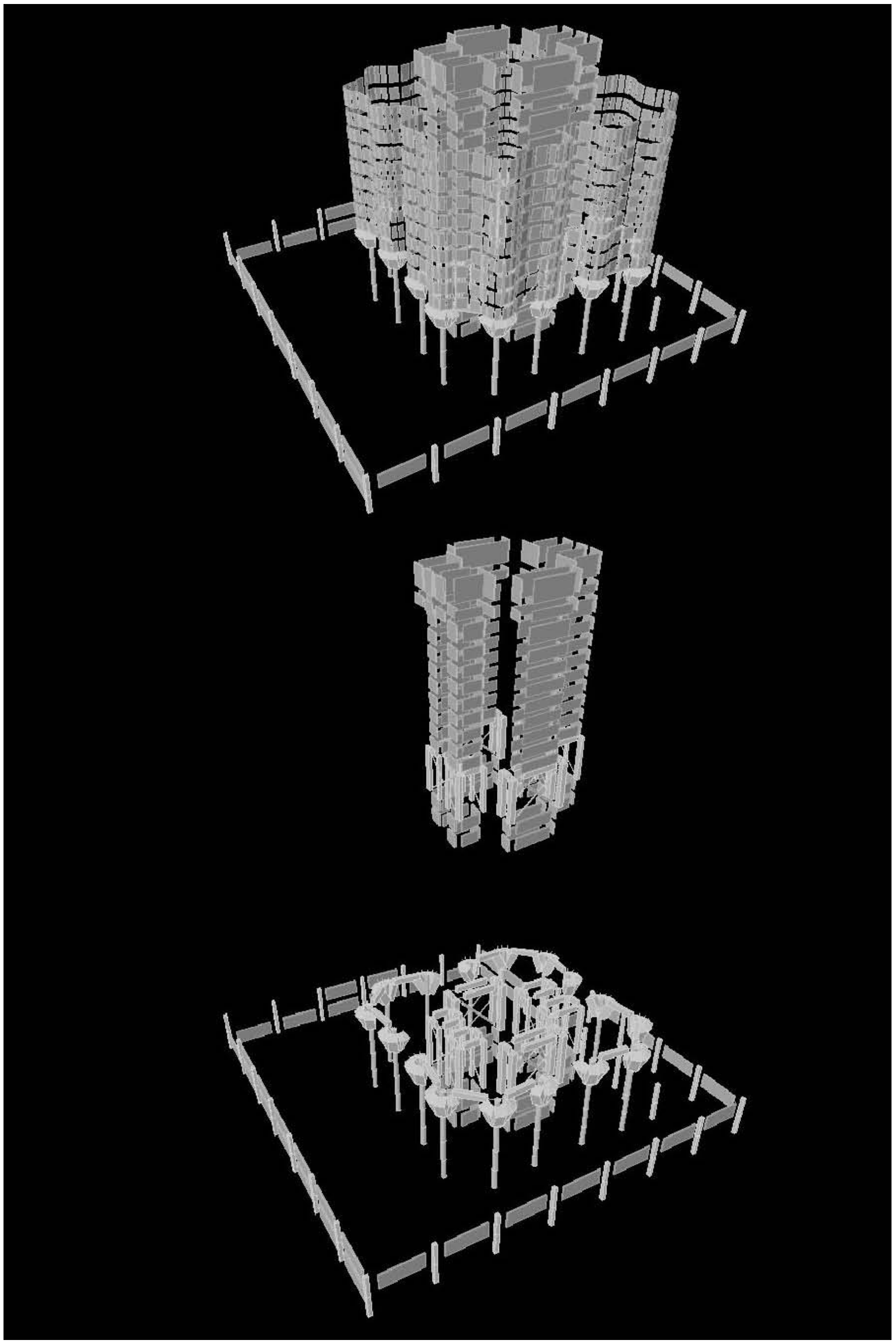

Figure 3. Lateral System.

Fig. 3 (top) shows the entire building lateral system; Fig. 3 (middle) shows the full extent of tower concrete cores from Level-1 to roof along with post-tensioned “X” tension braces at the soft-story (Level-3 to Level-5). Fig. 3 (bottom) shows the entire building lateral system below Level-5.

Design Objectives and Seismic Upgrade Methodology

Detailed dynamic studies indicated that large drifts at the soft-story would result in structural damage and service disruptions after a code-defined 10%-50 year seismic event. The primary concerns were as follows:

- The non-ductile large diameter existing concrete columns at the soft-story will suffer severe damage after repeated large lateral movements during the code-defined 10%-50 year seismic event.

- Damage to the non-structural building systems and components due to excessive story drift at the soft-story during the seismic event. This was a real concern for this building.

In order to minimize post-earthquake damages to the building structure and reduce building service disruptions after a seismic event, various seismic upgrade schemes were studied. They are as follows:

1. Construct shear walls at locations where existing post-tensioned “X” tension braces are located. This will effectively reduce or eliminate the soft-story effects. However, the building foundation will have to be strengthened and enlarged. Such foundation work in an occupied building can be very costly and affect the building’s current normal function during construction. Consequently, this scheme was eliminated.

2. Construct steel braces at locations where existing post-tensioned “X” tension braces are located. This will also effectively reduce the soft-story effects. However, connections between the steel braces and existing concrete columns will be very difficult to construct due to existing post-tensioned “X” tension braces. Again, costly foundation work is also unavoidable.

3. Coupling adjacent 36” diameter columns with steel “X” braces. This will result in large size steel braces due to longer bracing length, which will affect the building appearance. Tension-only braces were considered and they are not as effective as tension-compression braces. In addition, costly foundation work is also unavoidable due to increased seismic forces caused by these braces that shorten the building periods.

Seismic Upgrade with Pall Friction Dampers

The above-mentioned third scheme led to the use of cross-brace type Pall friction dampers (Fig. 4) for the seismic upgrade. When one of the brace slips in tension, the mechanism makes the other brace to slip in opposite direction and thus eliminates buckling. In the next half cycle, the other brace is immediately ready to slip in tension. For more details, visit the website of Pall Dynamics Limited. The main advantages of using this type of damper are as follows:

- Friction damper slip load can be so selected to avoid foundation work.
- Cross brace type Pall friction dampers are activated by tension-only braces. Consequently, long and small size braces can be used to reduce impacts to the building appearance.
- Friction dampers are cost effective compared to other damping devices, which do not have the features mentioned above.
- Such dampers have been widely accepted and utilized in the engineering and construction industries, especially in building seismic upgrade and retrofit projects.
- The existing post-tensioned “X” braces provides a re-center mechanism after a seismic event.

(a) (b)

Figure 4. (a) Prototype Friction Damper and (b) Installed Friction Damper.

Based on the analyses, a total of 12 cross-brace friction damper were required in the soft-story. This was achieved by coupling adjacent 36” diameter concrete columns with HSS10x6 tube “X” braces. Two (2) 200-kip cross-brace friction dampers are attached in each of the 12 bays. Dampers are located at the intersection of these “X” braces with one on each side of the braces. Dampers were sized to avoid column footing enlargement and uplift under the code defined 10%-50 year seismic event. Dampers were also sized to reduce the soft-story drift in half.

Two (2) prototype dampers (Fig. 4), designed and fabricated by Pall Dynamics Limited, were tested for 24 cycles to ensure their performance. Every damper was tested for two cycles to ensure production quality control. Damper installation was completed in October 2005.

In order to implement the damper installation and increase the structural integrity, the following structural components were also added for various structural reasons. They are as follows:

- All sixteen (16) 36” diameter concrete columns at the soft-story are enlarged to 48” diameter along their entire length with 3/8” thick steel plate jackets and infill grout. This is to increase column ductility and to ease design difficulty for the connections between concrete columns and damper braces.
- All sixteen (16) 36” diameter concrete columns below the soft-story are enlarged to 52” diameter from the foundation up with 8” thick concrete jackets. This is to avoid the need to enlarge the existing column footings and to increase column axial load carrying capacity for the increased downward seismic forces imposed to columns due to added seismic dampers at the soft-story.
- Drag struts at the top of the building podium (Level-3, which is the bottom of damper braces) are added to allow positive load transfer between damper braces and rigid-box building podium. See Fig. 5 with comparison to Fig. 3 (bottom).
- 3-D steel trusses are added between the bottom of Level-5 floor slab and the top of damper braces to allow load transfer between Level-5 floor slab and the damper braces. This is also to avoid requiring the enlarged 36” diameter columns to transfer all the damper forces with potential shear failures. See Figs. 5 and 6.
- Concrete shear walls and shear wall footings are added along the building podium exterior to complete the podium “box”. See Fig. 5 with comparison to Fig. 3 (bottom).

Construction of the seismic upgrade has been completed in 2005. Fig. 7 shows the before and after of the column enlargement for columns below the soft story. Figure 8 shows various stages of the damper installation including concrete column steel jacket installation and Fig. 9 shows dampers and steel braces installed.

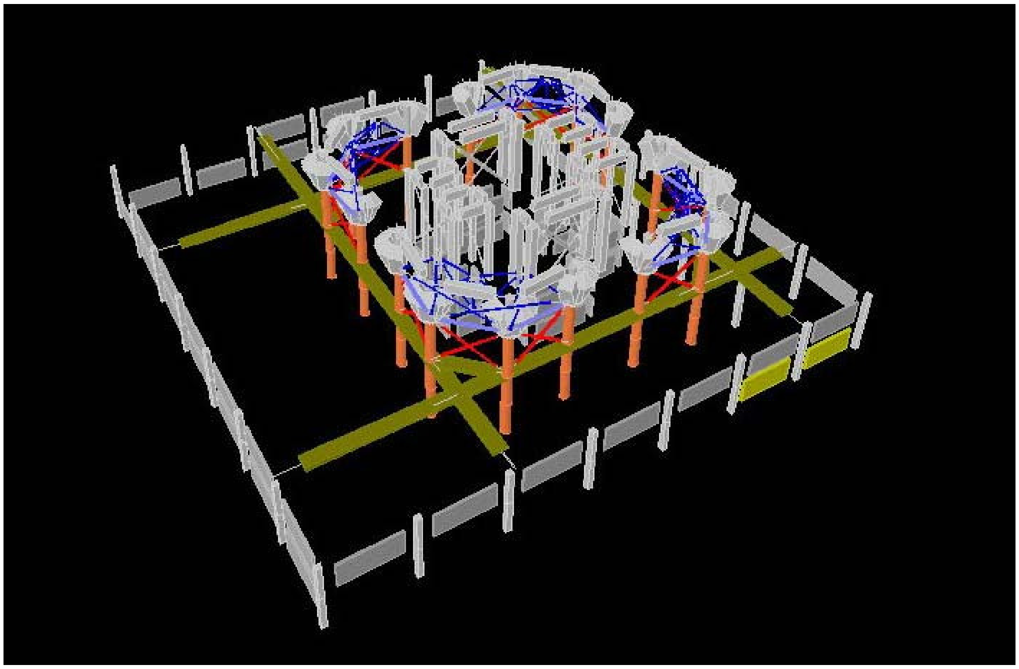

Figure 5. Drag Struts, 3-D Trusses and Damper Braces.

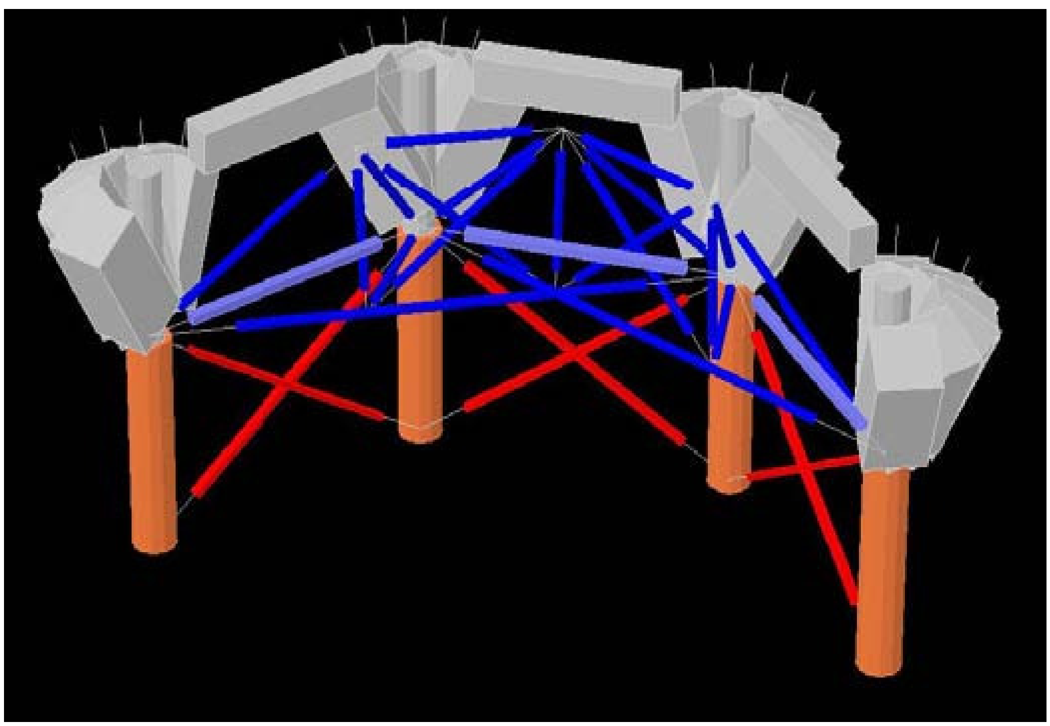

Figure-6. 3-D Trusses and Damper Braces (One Quadrant).

Figure 7. Concrete Column Enlargement Before and After.

Figure 8. Steel Jacket and Damper Installation.

Figure 9. Completed Damper Installation.

Conclusions

This paper presents a unique structural solution for the seismic upgrade of a 14-story patient tower with a 36-foot tall soft-story. Cross-brace type Pall friction dampers are utilized at the soft-story and they consequently reduced the story drift in half. The upgraded building has achieved the FEMA356 structural immediate-occupancy performance level code requirements for10%-50 year seismic event.

This unique solution has the following advantages:

- It is very cost effective and resulted in a saving of approximately $1 million on the foundation work compared to the conventional concrete shear wall seismic upgrade scheme.
- It simplifies the construction process with minimum disturbances to an occupied hospital facility during construction.
- It is aesthetically acceptable.
- It adds structural integrity and improves building life safety.
- It helps minimize post-earthquake structural and non-structural damage and reduces potential down time and repair costs after a seismic event.

Acknowledgements

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References

Hale, T., Pall, R., 2000. “Seismic Upgrade of the Freeport Water Reservoir, Sacramento, California”, Twelfth World Conference on Earthquake Engg., Auckland, New Zealand, Paper No. 269.

Kelly, J.M., Aiken, I.D., Pall, A.S.,1988. “Seismic Response of a Nine-Story Steel Frame with Friction-Damped Cross-Bracing”, Report No. UCB / EERC-88/17. Earthquake Engineering Research Center, University of California at Berkeley, p. 1-7.

Pall, A.S., Marsh, C., 1982. “Seismic Response of Friction Damped Braced Frames”, Journal of Structural Division, ASCE, St. 9, 108:1313-1323. (ASCE “Raymond Reese Research Prize 1983”).

Sahai, R., Laws, J., Chen, D., Kong, F., Castillo, F., 2000. "Performance Based Design of 4-Story Moscone Convention Center Expansion Using Steel Couple Girder Moment Resisting Frame and Friction Dampers", Proceedings, SEAOC Annual Convention, Santa Barbara, California.

Soli, B., Baerwald, D., Krebs, P., Pall, R., 2004. "Friction Dampers for Seismic Control of Ambulatory Care Center, Sharp Memorial Hospital, San Diego", Proc. 13th World Conference on Earthquake Engineering, Vancouver, Paper # 1953.

Vail, C., Hubbell, J., Pall, A., 2004. “Seismic Upgrade of the Boeing Commercial Airplane Factory at Everett, Washington”, Proc. 13th World Conference on Earthquake Engineering, Vancouver, Paper # 3207.