FRICTION DAMPERS FOR SEISMIC UPGRADE OF A 14-STORY PATIENT TOWER WITH A 36-FOOT TALL SOFT-STORY

Dihong Shao, P.E., S.E. [1]
Avtar Pall, PH.D. P.E. [2]
Bharat Soli, P.E., S.E. [3]

ABSTRACT

The 14-story tower is a 1970's concrete shear wall building located in the greater Seattle area. Between the top of its podium (level-3) and level-5, all interior shear wall cores are supported by rectangular concrete columns located at corners of these cores; all exterior concrete shear walls stop at level-5 and are supported by concrete columns. This creates a 2-story soft-story. The lateral resistant system of the soft-story is composed of multi-strand post-tensioned "X" braces between the adjacent columns that support the interior shear wall cores.

Studies indicated that such a soft-story would result in service disruptions after a 10%-50 year seismic event. Various seismic upgrade schemes were evaluated. The scheme with supplemental damping offered substantial cost savings on the foundation work. Long bracing prompted the use of tension-only cross-braces with friction dampers at the brace intersection. With the implementation of this upgrade, FEMA356 structural immediate-occupancy performance level is achieved and soft-story story drift is reduced in half.

This paper describes the design implementation and construction of this seismic upgrade.

Introduction

The patient tower, designed and constructed in the 1970s, is a 14-story concrete building with a rigid 2-story concrete podium. The lateral system of the tower is composed of interior concrete shear wall cores and curved exterior concrete shear 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 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. The lateral resistant system of the soft-story is composed of multi-strand post-

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[1] Principal, Andersen Bjornstad Kane Jacobs Inc., Seattle, Washington
[2] Principal, Pall Dynamics Limited, Montreal, Canada
[3] Senior Principal, Andersen Bjornstad Kane Jacobs, Inc., Seattle, Washington

tensioned “X” tension braces between the adjacent columns that support the interior shear wall cores.

Studies indicated that such a soft-story would result in structural damages and service disruptions after a 10%-50 year seismic event. Various seismic upgrade schemes were evaluated. The scheme with supplemental damping offered substantial cost savings on the foundation work. Long bracing prompted the use of tension-only cross-braces with friction dampers at the brace intersection. Twelve (12) cross-brace friction damper bays are created in the soft-story by coupling adjacent 36” diameter concrete columns. FEMA356 structural immediate-occupancy performance level is achieved by providing two (2) 200-kip cross-brace friction dampers at each of the twelve (12) bays. Prototype dampers were designed, built, and tested to ensure their performance. Damper fabrication was completed and damper installation is being completed as this paper is being written. This paper describes the use of cross-brace friction dampers for the seismic upgrade in the 36-foot tall soft-story of this patient tower.

Building Description

The patient tower was designed and constructed in the 1970s. 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 flyer for the ACI Centennial Celebration in 2004 that was widely published in numerous architectural and engineering magazines (Figure-1).

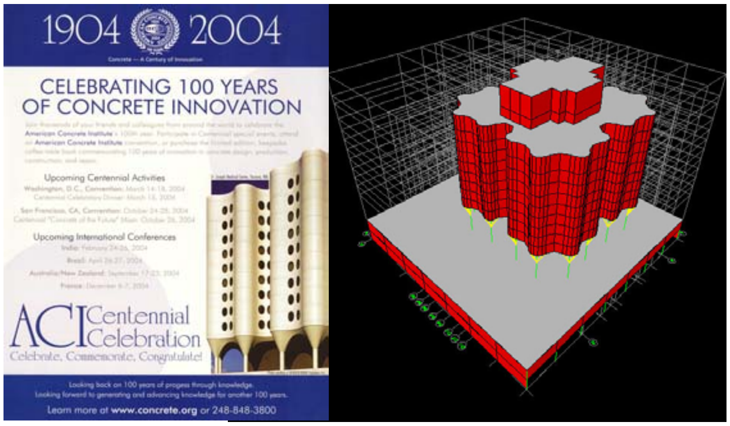

Figure-1. A Well-Celebrated Concrete Building

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’-0” and 238’-0”, respectively, in both directions. The typical floor-to-floor height is 11’-0” with the exception of floor-to-floor height between Level-3 and Level-5, which is 18’-0”. See Figure-1 and Figure-2.

Figure-2. Existing Building

The tower floors are constructed with 15” thick flat concrete slabs without column capitals. 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’-0” square pans. The waffle slabs are supported by 24” square concrete columns at 34’-0” 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.

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 (Figure-3). 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. The author believes that such a unique lateral system at the soft-story was invented with its intent to prolong the building periods and reduce the seismic forces imposed onto this very heavy concrete tower. This concept is now widely used with the inventions of various base-isolation systems.

Figure-3. Existing Building Soft-Story

Figure-4 (top) shows the entire building lateral system; Figure-4 (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); Figure-4 (bottom) shows the entire building lateral system below Level-5.

Seismic Concerns and Upgrade Challenges

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

1. 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.
2. Damage to the non-structural building systems and components due to excessive story drift at the soft-story during the seismic event. This issue is very well addressed by the construction industry nowadays for base-isolated buildings. However, it becomes a real concern for this building.

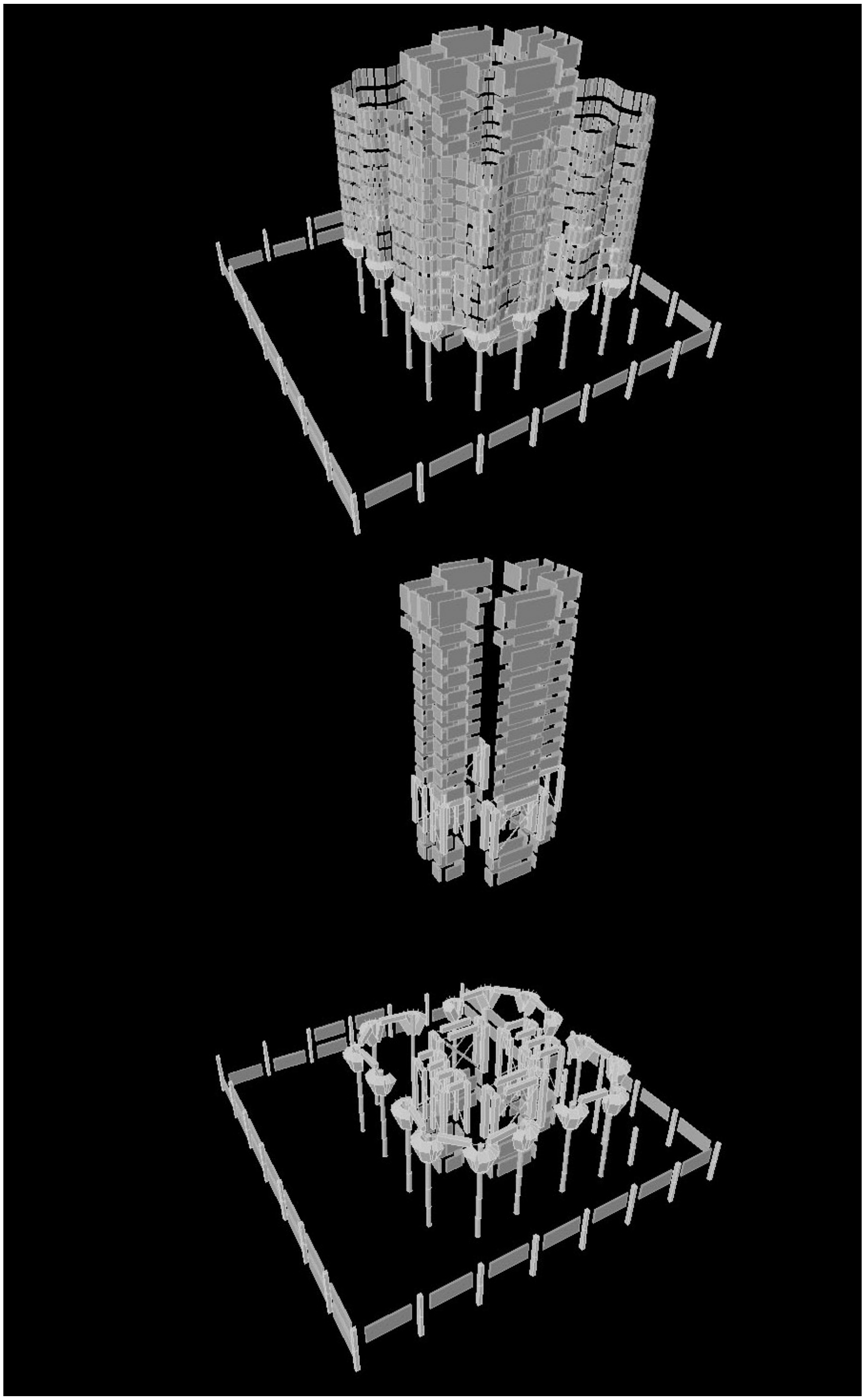

Figure-4. Lateral System

In order to minimize post-earthquake damages to the building structure and reduce building service disruptions after a seismic event, various seismic upgrade schemes to reduce or eliminate the soft-story effects 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 Cross-Brace Friction Dampers

The above-mentioned third scheme led to the consideration of using cross-brace friction dampers (Figure-5), notice pencil on the damper for scale) for the building seismic upgrade. The main advantages of using this type of damper are as follows:

1. Dampers can be strategically sized and placed to avoid foundation work.
2. Such dampers are driven by tension-only braces. Consequently, longer while smaller size braces can be used to reduce impacts to the building appearance.
3. Such dampers are cost effective compared to other damping devices, which do not have the features mentioned in item 2 above.
4. Such dampers have been widely accepted and utilized in the engineering and construction industries, especially in building seismic upgrade and retrofit projects.
5. The existing post-tensioned “X” braces provide a building re-center mechanism after a seismic event.

Figure-5. Friction Damper In the Lab Friction Dampers Installed

Based on the analyses, a total of 12 cross-brace friction damper bays will be required in the soft-story. This is achieved by coupling adjacent 36" diameter concrete columns with HSS10x6 tube "X" braces. Two (2) 200-kip cross-brace friction dampers will be required at each of the 12 bays. Dampers will be 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 footing 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 were designed, built, and tested by Pall Dynamics Inc. to ensure their performance (Figure-5 and Figure-6). Damper fabrication was completed and dampers were delivered to the site. Damper installation was completed in October of 2005.

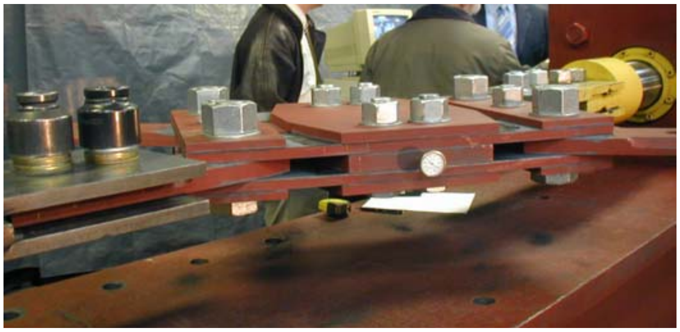

Figure -6. Friction Damper Under Testing

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:

1. 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.

2. 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.
3. 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 Figure-7 with comparison to Figure-4 (bottom).
4. 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 Figure-7 and Figure-8.
5. Concrete shear walls and shear wall footings are added along the building podium exterior to complete the podium “box”. See Figure-7 with comparison to Figure-4 (bottom).

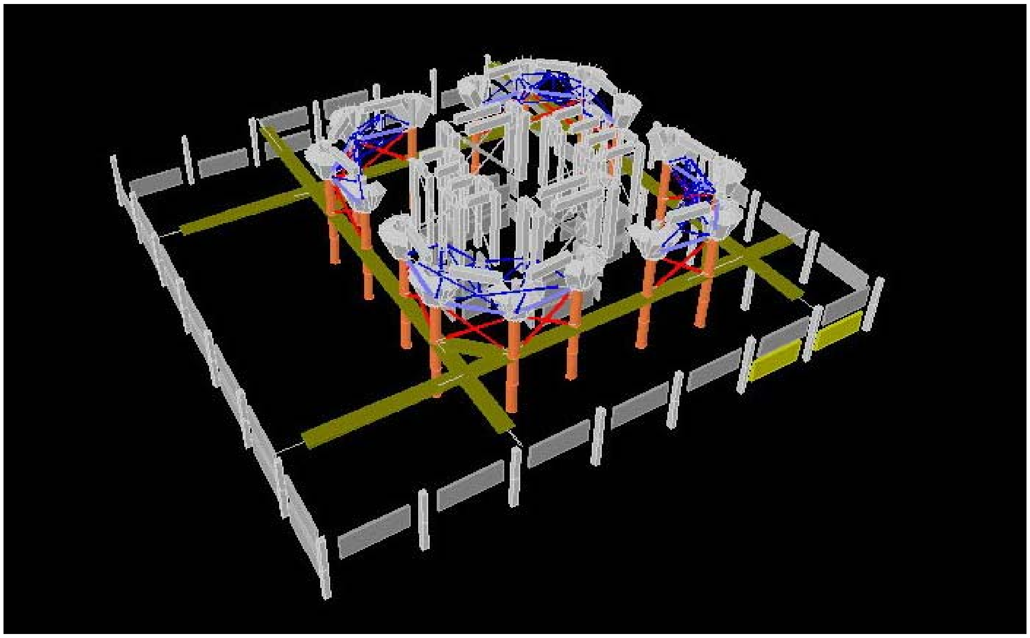

Figure-7. Drag Struts, 3-D Trusses and Damper Braces

Construction of the seismic upgrade is nearly complete. Figure 9 shows the before and after of the column enlargement for columns below the soft story. Figure 10 shows various stages of the damper installation including concrete column steel jacket installation and Figure 11 shows dampers and steel braces installed. The construction of concrete drag struts are well underway as this paper is being written.

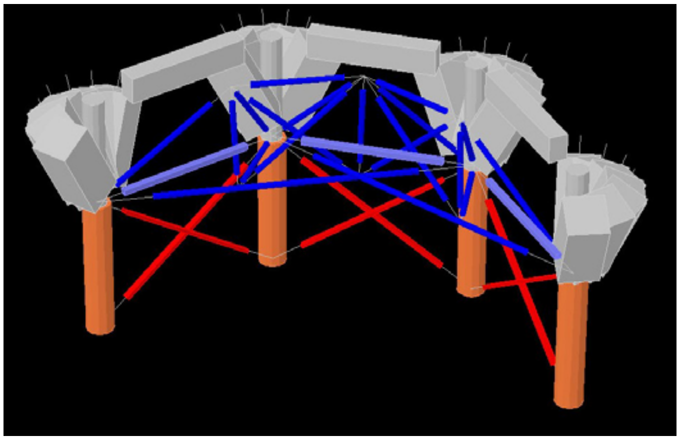

Figure-8. 3-D Trusses and Damper Braces (One Quadrant)

Figure-9. Concrete Column Enlargement Before and After

Figure-10. Steel Jacket and Damper Installation

Figure-11. Completed Damper Installation

Conclusions

This paper presents a unique solution for the seismic upgrade of a 14-story patient tower with a 36-foot tall soft-story. Cross-brace seismic dampers are utilized at the soft-story and they consequently reduce the story drift in half. The upgraded the building achieves the FEMA356 structural immediate-occupancy performance level under code defined 10%-50 year seismic event.

This unique solution has the following advantages:

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

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