Seismic Retrofit of the Tower of Hope – Preservation of a Masterwork of Mid-Century Modernism

Bryan Seamer, S.E., Director
Daniel Wang, S.E., Director
LPA, Inc.
Irvine, CA

Abstract

Richard Neutra's iconic Tower of Hope on the Christ Cathedral (formerly "Crystal Cathedral") campus in Garden Grove, California has been an important Orange County landmark since it was built in 1968. The thirteen-story tower – the tallest building in Orange County when it was built – has been called an "overlooked masterwork in Neutra's oeuvre" by architectural historians.

Like many concrete buildings built prior to the 1971 Sylmar Earthquake in California, the Tower of Hope's concrete frames lack the ductility needed to safely dissipate seismic energy. After acquiring the Crystal Cathedral campus in 2012 the Roman Catholic Diocese of Orange undertook a comprehensive renovation and seismic retrofit project to provide 21st century seismic resilience to the historic tower. This challenging seismic retrofit and renovation project was completed in 2015. The retrofit work included the installation of fluid viscous dampers on the second through fifth floors of the tower in combination with fiber-reinforced polymer strengthening of targeted concrete columns and walls.

This paper focuses on two challenges unique to the Tower of Hope. First, it was imperative that the retrofit design respect the historically significant mid-century modernist architecture, preserving those features that were emblematic of that period of significance. Seismic retrofit construction was limited to areas that didn't affect Neutra's open floor plate design aesthetic or lessen the inside-outside connectivity of each of the spaces. This openness was particularly challenging to preserve in the glass-walled first floor lobby where seismic forces are at their most intense. The second unique challenge was the large damper connection forces that had to be developed into the existing cast-in-place concrete frames without damaging the existing steel rebar. The strategies described by the authors are generally applicable to other historic buildings from the mid-century modernist movement and to the use of fluid viscous dampers to retrofit concrete frames.

Background

Built in 1968, the Tower of Hope was the final piece of the four-building campus that formed the original home to Reverend Robert H. Schuller's growing Reformed Church of America congregation in Garden Grove, California. Designed by famed international architect Richard Neutra, the Tower of Hope joined Neutra's Arboretum worship hall and the Large and Small Galleries to create an enclosed garden courtyard at the heart of the campus. The Tower was originally planned to be a low-lying companion to the other low-profile buildings on the site but was ultimately reconceived as a slender vertical tower with 28,000 square feet of offices and classrooms in thirteen stories. The Tower of Hope along with the other three Neutra-designed buildings on the Christ Cathedral campus are recognized by architectural historians as important examples of mid-century modernism as well as works in Neutra's celebrated portfolio.

Reverend Schuller's ministry grew dramatically during the 1970s and 1980s as his televised "Hour of Power" became synonymous with televangelism and his campus grew to include Philip Johnson's landmark glass-and-steel clad Crystal Cathedral directly to the north of the Tower of Hope.

In 2012, the Roman Catholic Diocese of Orange purchased the former Crystal Cathedral campus including the Tower of Hope from Reverend Schuller to serve as its long-planned diocesan cathedral. The Diocese immediately begin a program of modernization and renovation of all of the buildings on the newly re-named Christ Cathedral campus. From the beginning the fate of the Tower of Hope was in doubt. During the Diocese's acquisition due diligence process in the Fall of 2011, a seismic assessment suggested that the Tower of Hope was the most vulnerable building on the Cathedral campus. While the Diocese recognized the Tower's architectural and cultural significance, it decided that the safety of its large parish population must ultimately take precedence. It was at that time that contingency plans were made to demolish the Tower of Hope and replace it with a modern office building in case a viable seismic retrofit solution could not be devised.

Building Description

The Tower of Hope was originally built to house offices and classrooms supporting Reverend Schuller's growing Reformed Church of America. The tower consists of thirteen occupied stories with a double-high volume thirteenth story that houses the famed Chapel in the Sky and its panoramic views of Orange County. The building footprint is very small by modern office building standards, 58'-4" in the longitudinal direction and 32'-2" in the transverse direction. With less than 1,900 gross square feet of space per floor the building configuration is more akin to a series of stacked rooms than a traditionally subdivided office building. The floor to floor height is typically 11'4" with the 13'8" first floor and the 25'3" high thirteenth floor chapel serving as exceptions. The roof height is approximately 162'above grade. An interstitial floor above the thirteenth floor houses a machine room above the building's two elevators on the west side of the tower.

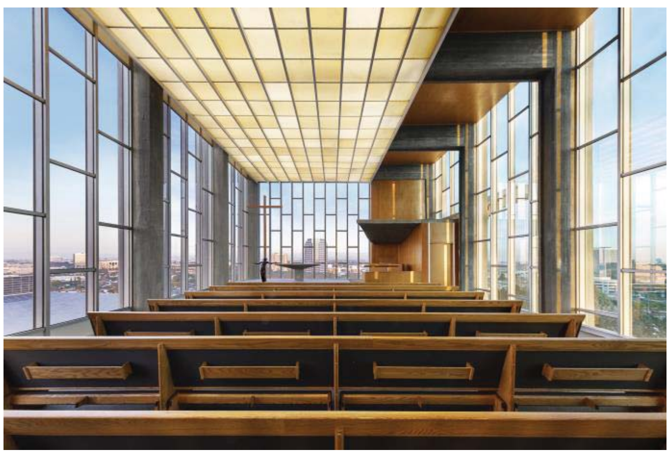

Figure 1 – The Tower of Hope's 13th floor Chapel in the Sky offers 360° views of Orange County.

The structural system of the tower is entirely cast-in-place concrete. Floor construction typically consists of 4 ½" concrete slabs spanning between 27" deep concrete beams spaced at 11'-0" on center. The beams are not isotropic along their length, the width varying from 20" at each end to 12" at mid-span. These main beams span north to south across the 32'-2" dimension providing completely open column-free floors. Perimeter concrete columns are rectangular 16" by 28" on the south side and trapezoidal 16" by 42" on the north side of the tower. Column reinforcing consists of tightly confined circular cores with more widely tied perimeter longitudinal bars forming the finished shapes of the columns.

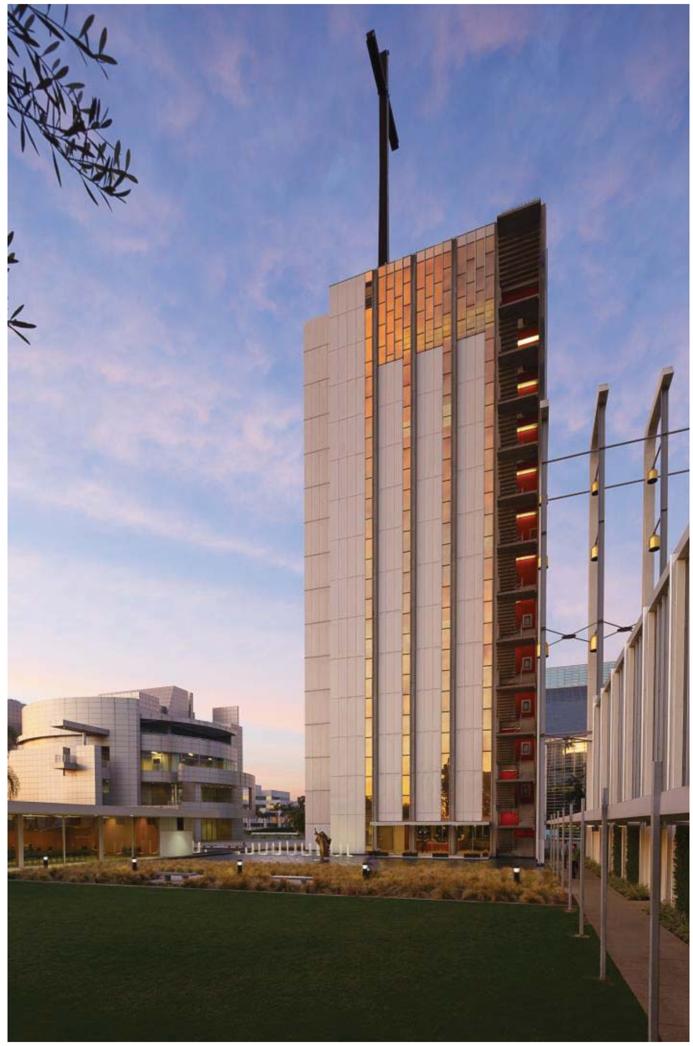

Figure 2 – Tower of Hope South Elevation.

Figure 3 – Erection of the steel cross on the roof of the Tower of Hope in 1968. (Richard and Dion Neutra Paper Archives, 1925-1970).

The foundation of the building is a Raymond step-tapered pile system with pile caps tied to each other with reinforced concrete grade beams. The Raymond pile system, developed by Alfred E. Raymond in 1893, consists of a series of helically-corrugated cylindrical steel shells driven into the soil in 8' to 16' lengths. Each subsequent shell is wider than the shell below it so the diameter of the pile is tapered along its length. The steel shells are filled with concrete as the shell-driving process advances into the soil to form a steel-concrete composite pile.

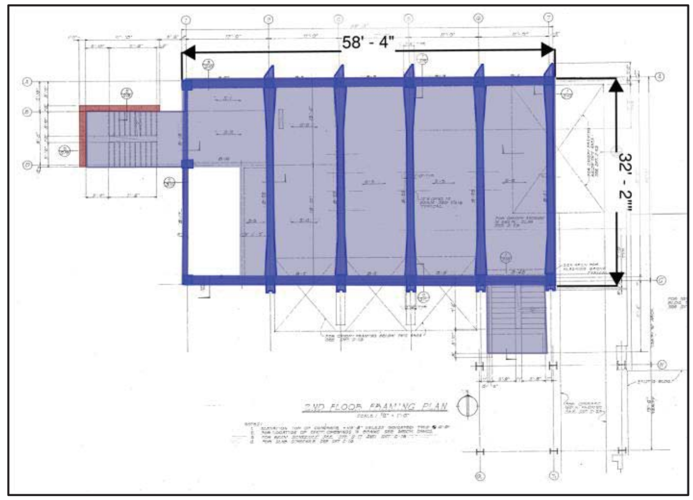

Figure 4 – Typical floor plan showing locations of concrete moment frames (in blue) and concrete shear walls (in red).

Several building elements extend out from the tower footprint. An enclosed interior stair tower extends from the northwestern corner of the main tower. With 12" thick concrete walls on two sides the cast-in-place concrete stair ties into each main floor diaphragm via an 8'4" wide 6" thick concrete slab. At the southeast corner of the main building a second exterior stair cantilevers thrillingly from the tower. This column-free stair is cantilevered almost 12' from the main floor slabs with post-tensioned tendons. Thin architectural steel cables at 5" on center enclose two sides of the vertigo-inducing stair but do not serve as structural hangers for the far landing. One of the most prominent features of the building is illuminated steel cross that soars to 88' above the roof of the tower.

The lateral force resisting system of the tower consists of concrete moment frames formed by the perimeter columns and beams and the main transverse interior beams. Supplemental lateral force resistance is provided by the two 12" thick concrete walls that are on the north and west sides of the northwest stair tower. The location of these shear walls, far from the main tower's center of mass, and the lack of a similarly rigid element on the other side of the tower result in a torsional response of the tower when loaded in the north-south direction.

Seismic Vulnerabilities

When the Diocese of Orange purchased the Christ Cathedral campus in 2012 the due diligence phase of the real estate transaction identified the Tower of Hope as a building of elevated seismic risk due to its age and concrete moment frame construction. The seismic vulnerabilities associated with non-ductile concrete frames and the risk they pose to buildings of this age and construction type are well-known. As part of a campus wide modernization and renovation program the Diocese solicited the services of several structural engineers, including Irvine-based integrated design firm LPA, Inc., to perform a detailed evaluation of the Tower of Hope. This initial assessment comprised three basic steps: data collection, seismic screening, and identification of potential deficiencies.

A common challenge with assessment and retrofit of buildings of this age is that original construction documents are not often available. This potential challenge is amplified in a concrete building because direct observation of the steel reinforcing is impossible and non-destructive testing methods are time-consuming and not always accurate. This challenge was largely bypassed on the Tower of Hope retrofit project, however, because the building is an important piece of architectural history and the design team had incredible access to original sources of information on the design and construction of the building.

For the Tower of Hope project these issues were avoided entirely due to the careful preservation of Richard Neutra's records by architectural historians at the "Richard and Dion Neutra papers, 1925-1970" archive at the Charles E. Young Research Library on the campus of UCLA. This archive holds nearly comprehensive documentation on the design and construction of the Tower of Hope. Complete construction drawings by Richard and Dion Neutra, Architects and Associates and J. Kinoshita & Associates Consulting Structural Engineers dated May 15, 1966 proved to be instrumental in understanding the construction of the Tower. In addition to original construction documents, the design team was able to review meeting minutes, correspondences, construction RFIs, submittals, and crucially, inspection and testing reports. The availability of original concrete testing reports was important for two reasons. First, it gave the design team confidence in the as-built compressive strength of the concrete. This confidence is directly applied analytically in the form of a knowledge factor, κ, that is a part of the seismic retrofit provisions of ASCE Standard 41-06. The most important discovery during the design team's review of Neutra's project records was the fact that during construction the contractor decided to use 4,000 psi concrete in lieu of the 3,000 psi concrete called for in the structural. This change is not insignificant in relation to the seismic performance of the building as is discussed further below.

The initial seismic assessment of the Tower of Hope was based on a "Tier 1 Screening" as described in ASCE Standard 31-03 "Seismic Evaluation of Existing Buildings." This process consists of a series of quick checks to identify potential vulnerabilities that warrant more detailed study. The prescriptive checklist of potential vulnerabilities was supplemented by a detailed review of the construction documents by experienced structural engineers to identify potentially brittle concrete details and other system-wide vulnerabilities.

Several serious deficiencies were identified during the screening phase, most of them related to non-ductile detailing of the concrete frames:

- <u>Inadequate confinement of column reinforcing</u>. The central core of each columns is confined with a tight spiral of #4 bars at a 2" on center. However, the remainder of the vertical bars, including those at the perimeter of the column that are potentially most effective in resisting flexural forces is confined with #3 ties spaced at 12" on center.

- <u>Short splices in column vertical bars</u>. Typical column splices are 30 bar diameters.

- <u>Vertical column bars are not fully developed into the foundation.</u>

- <u>Frame beam longitudinal bars not fully developed into frame columns.</u> In multiple locations not all of the longitudinal bars are fully developed into the columns due to 90-degree hooks that don't extend far enough into the columns or bottom bars that don't have hooks at all.

- <u>Torsional irregularity.</u> The stair tower at the northeast corner is enclosed with 12" thick concrete walls while the much larger main tower is a moment-resisting space frame. The difference in lateral stiffness of these two systems leads to a torsional response and induces amplified seismic forces in the outer frames and the relatively narrow portion of floor slab that ties the stair tower to the rest of the structure.

Taken in total these deficiencies – particularly those related to non-ductile concrete detailing – represent a serious risk to the building despite a seismic-force resisting system that is otherwise relatively well-proportioned and redundant for a building of this size.

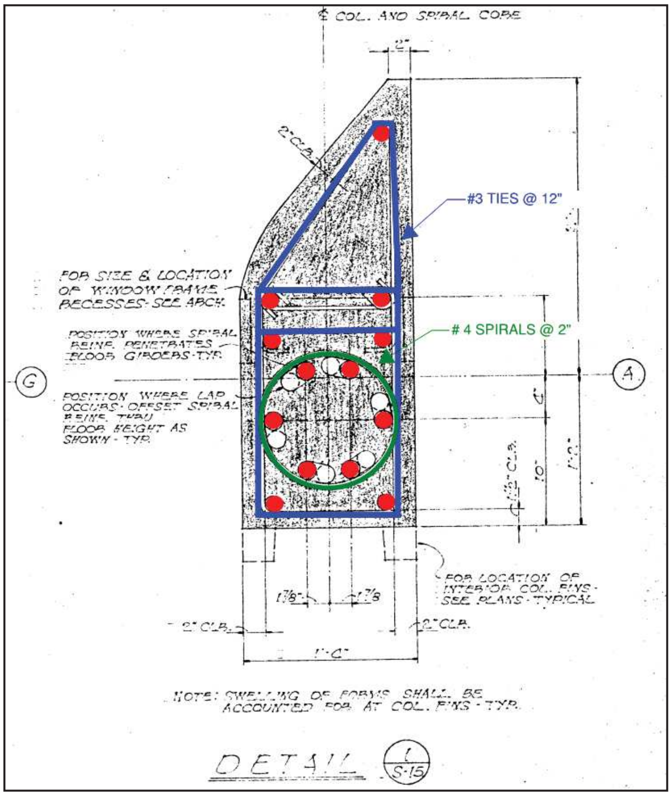

Figure 5 – Typical column reinforcing detail.

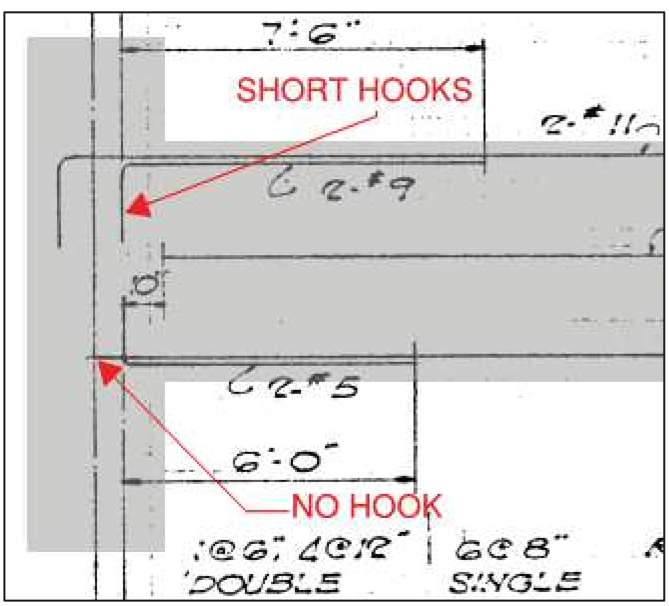

Figure 6 – Representative beam to column joint detail.

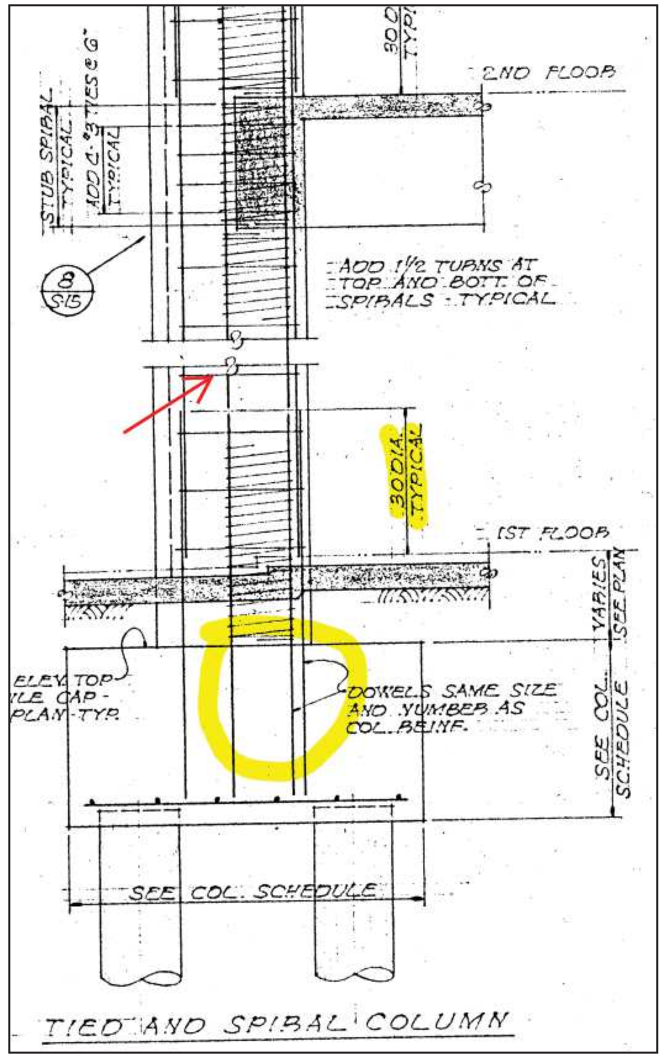

Figure 7 – Original construction drawing showing column to pile cap connection, column bar lap length and column tie configuration

Seismic Retrofit Constraints

The Roman Catholic Diocese of Orange approached the renovation and retrofit project with the safety of its large congregation and staff as the main priority but knew that preserving the Tower of Hope would be challenging for several reasons. As a historically significant work by one of the masters of the modern architecture movement preservation of Neutra's original design aesthetic through the retrofit process was essential. To ensure that the historic architecture was maintained and celebrated through the renovation project Barbara Lamprecht, an architectural historian and expert in the works of Richard Neutra joined the design team. With her guidance, LPA's team of architects and structural engineers designed renovation and retrofit measures that were true to the architectural period of significance. Specifically, the inside-outside connectivity between the glass-walled lobby and the fountain and garden to the south and entrance to the east needed to be maintained. This dictum essentially precluded the addition of new lateral-force resisting elements at the perimeter of the first floor - the location where such elements would be most effective.

The Tower along with the former Crystal Cathedral campus is also an important part of the history of Orange County, CA. The Diocese chose to preserve the top floor Chapel-in-the-Sky and Rev. Robert Schuller's private office on the twelfth floor in recognition of the building's regional historical significance.

Figure 8 – Glass-walled lobby looking west.

Figure 9 – Southern view from lobby to courtyard and fountain.

Another factor limiting the placement of new seismic load resisting elements is the very small floor plates. At only 32 feet wide by 58 feet long the usable square footage of each floor is very valuable. Any new walls or braced frames in the interior of the building would make space planning a major challenge and make it nearly impossible to design fully open floors. Further, because the Diocese's program included a combination of entirely open floorplan classrooms, subdivided office floors, a television studio, a chapel and the open-plan lobby there were no common walls at the interior of the building that stacked from floor to floor.

Another major constraint to designing an effective seismic retrofit strategy was cost-related. Due to site soil conditions the Tower of Hope is supported by deep pile foundations. A traditional retrofit design that adds significant lateral stiffness to the tower would lead to increased foundation loads and the need for new piles. Construction of any new piles, while technically possible beneath the existing building, proved to prohibitively expensive. The exterior glazing and cladding of the tower also needed to be preserved both because of the historic aesthetic and because of the cost needed to replace it. Any seismic retrofit design would need to be able to be built without replacing or damaging the glass.

These constraints when taken together form a set of seismic design criteria that severely limited the possible retrofit options.

Seismic Retrofit Design

Based on the aesthetic, historic, economic, and practical constraints the seismic retrofit strategy for the Tower of Hope was designed to meet the following objectives:

- Respect the period of architectural significance and historical context of the Tower by not adding structural elements to the first floor, twelfth floor offices of Reverend Schuller or thirteenth floor Chapel-in-the-Sky
- Limit new seismic-force resisting elements to the perimeter column lines to maximize usable interior space and allow for future flexibility.
- Avoid the need for adding new foundation elements in order to minimize construction costs.

LPA, Inc. structural engineers worked closely with the Diocese of Orange to establish the structural performance objectives for the seismic retrofit. In accordance with the voluntary seismic retrofit provisions of the 2013 California Building Code and American Society of Civil Engineers Standard 41-06, "Seismic Rehabilitation of Existing Buildings" (ASCE 41-06) the following structural performance objectives were selected:

- Life Safety performance during an earthquake having a 10% probability of exceedance in 50 years (BSE-1)
- Collapse Prevention performance during an earthquake having a 2% probability of exceedance in 50 years (BSE-2).

In order to satisfy both the practical and analytical project objectives two specialized structural components were used in tandem. First, supplemental damping was added to the building in the form of diagonally-oriented fluid viscous dampers. This served to reduce the seismic demand on the existing concrete frames without adding significant foundation forces. Second, fiber-reinforced polymer (FRP) was added to select concrete columns and walls for increased strength.

The structural design for the seismic retrofit followed the linear dynamic procedure of ASCE 41-06 using site specific time histories. The linear time history procedure was chosen for two reasons. First, the fluid viscous dampers are velocity-dependent so a time-history analysis was needed to model the effect of this supplemental damping. Because of the limited ductility of the existing concrete beams and columns these elements had very little post-elastic capacity so any effective retrofit design would necessarily result in nearly linear behaver of these elements. Because of this practical reality and for computational efficiency a linear time history analysis was performed. The concrete elements were modelled with reduced effective stiffness parameters between 30% and 70% of E_cI_g for flexure and 40% of E_cA_g for shear to account for shear, flexure, and axial behavior and rebar slip deformations per the requirements of ASCE 41-06.

The seismic analysis of the building was performed using ETABs Version 9.7 structural analysis and design software published by Computers and Structures, Inc. The finite element model was subjected to seven pairs of site-specific response spectra-scaled time histories for each of the two earthquake hazard levels. The time histories were constructed by Leighton Consulting, Inc. geotechnical engineers based on earthquake records having magnitudes between 6.0 and 7.0 at distances ranging from 10 to 20 kilometers and geologic and seismic/tectonic environments compatible to the site of the Tower of Hope. Leighton Consulting, Inc. built these site specific acceleration time histories to meet the requirements of Section 1.6.2.2 of ASCE 41-06. Because seven sets of time histories were considered in the analysis the average value of each of the maximum response parameters from each time history was used for assessing the acceptability of each structural element. Multi-directional seismic effects were taken into account by using 100% of the response parameter with a given time history applied in the X-direction combined with 30% of the response parameter with the time history applied in the Y-direction. This resulted in fourteen time history analyses for each of the two earthquake hazard levels.

The results of the time history analysis were exported to Microsoft Excel and post-processed using proprietary LPA, Inc. spreadsheets and Visual Basic macros. Each existing concrete beam, column and shear wall that resists seismic forces was checked against the ASCE 41-06, Supplement No.1 acceptability criteria for both Life Safety and Collapse Prevention performance. These acceptance criteria are based on multiple force-controlled or deformation controlled actions for each element and explicitly include consideration of stress level, rebar splice length, confining reinforcement, and development of rebar into beam-column joints. Because of the lack of ductile rebar detailing at the Tower of the Hope the acceptance criteria of many of the concrete beams and columns necessitates nearly elastic behavior.

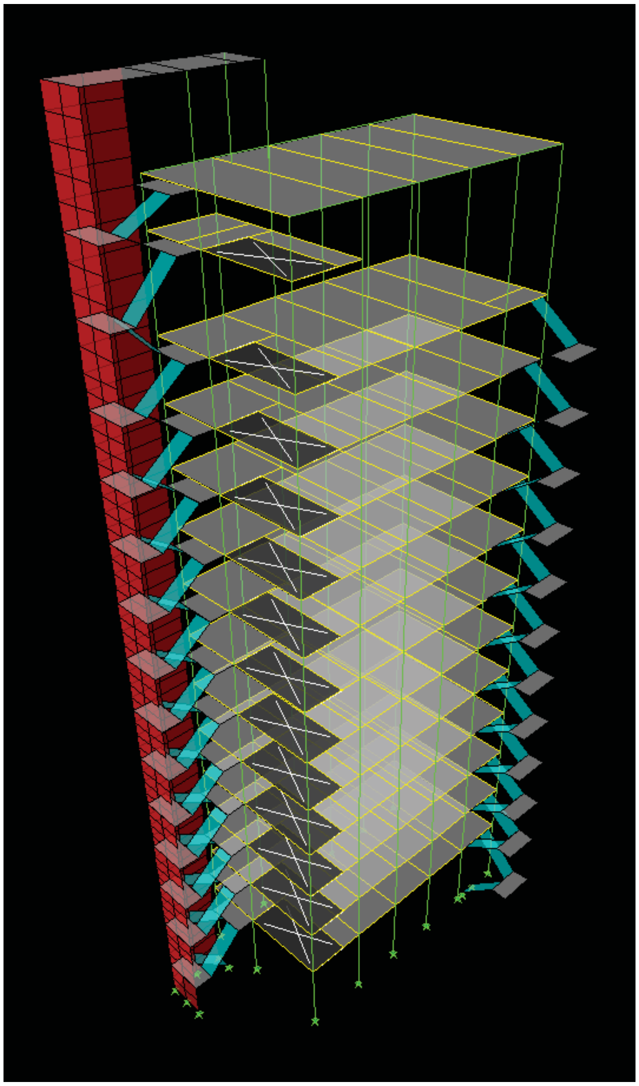

Figure 10 – ETABS model of Tower of Hope in original condition.

The final retrofit design for the Tower of Hope balanced the addition of fluid viscous dampers and FRP-strengthening of columns and walls with the goal of minimizing total construction cost. To that end, the retrofit design process was iterative with supplemental damping increased until the addition of more damping had only incremental effect on the acceptability of the existing concrete frames and shear walls. The final result was a design that included dampers added in a two-story X configuration on each of the perimeter column lines on stories two through five. After analytically experimenting with several different combinations of damper properties it was determined that dampers with a damping constant, C, of 120 kip-sec/in and a velocity exponent, α, of 0.5 was most effective for this building. These properties resulted in dampers with a maximum of 260 kips of axial force and 4” of stroke during the suite of BSE-2 time histories. A factor of safety of 2.0 against yielding and 2.5 against ultimate failure was used in the design of the damper components. Taylor Devices of North Tonawanda, NY designed and fabricated the 32 dampers for the Tower of Hope.

During the preliminary design phase of the project a review of the original Tower of Hope construction files uncovered concrete submittals and field inspection and testing reports that revealed that the as-designed 3,000 psi concrete for the superstructure was replaced with 4,000 psi concrete during construction. The design team hypothesized that this change was made to accelerate erection time as each subsequent level had to reach adequate strength before the next level up could be poured. This construction change had an initially counterintuitive effect on the retrofit design. While the high strength concrete did have more capacity than originally thought it also resulted in a more rigid structure. This added stiffness led to higher seismic forces and reduced the effectiveness of the fluid viscous dampers which generate damping to the structure proportionally to their drift-induced stroke velocity.

In its original condition, without any supplemental damping approximately one third of the existing concrete elements did not meet the seismic performance objectives required by ASCE 41-06. With damping added on levels two through five only about 6% were still deficient. These remaining deficient elements were strengthened with fiber-reinforced polymer (FRP) wrap to add flexural capacity, confinement or both.

Figure 11 – Fluid viscous dampers on the north side of the Tower of Hope.

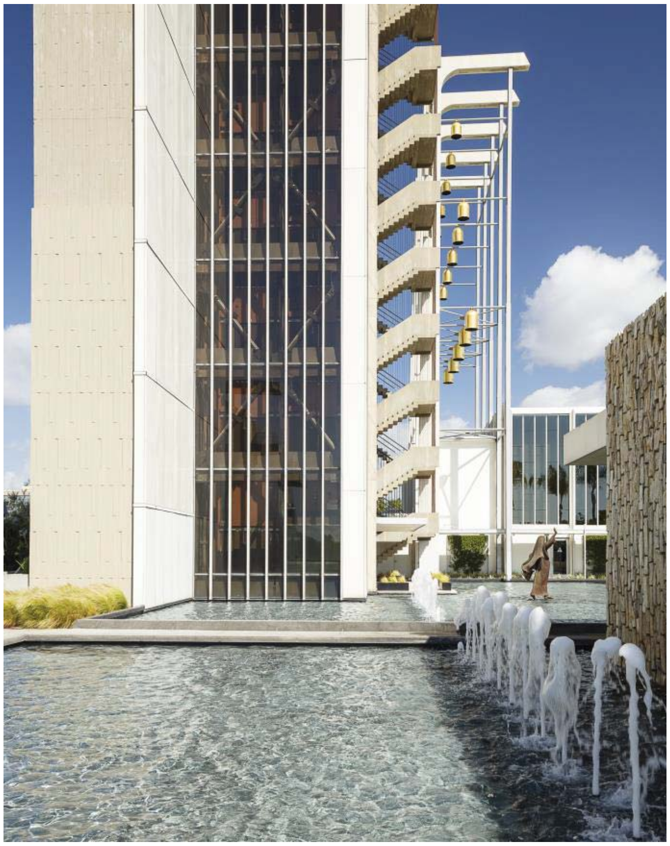

Figure 12 – West elevation of the Tower of Hope, fluid viscous dampers visible at second through fifth floors.

The Raymond Step-Tapered pile system was also evaluated using the acceptance criteria detailed in ASCE 41-06. Ultimate pile uplift, compression, and lateral capacities were derived from information found in the Raymond Pile design guide and soil properties provided by the project geotechnical engineer. This analysis demonstrated that the existing pile system met the seismic performance objectives without need for retrofit.

Figure 13 – Structural model of the Tower of Hope with dampers on second through fifth floors.

Figure 14 – Tower of Hope entrance with FRP visible on exterior face of concrete column.

Figure 15 – Column confinement FRP installation.

Seismic Retrofit Detailing and Construction

The seismic retrofit of this historically significant 1968 non-ductile concrete frame building included unique detailing challenges both structurally and architecturally.

The most challenging part of the structural design was developing the large damper forces into the existing concrete frame. The vertical component of the damper reaction was resisted by Grade 105 bolts through the existing concrete frame beams near the diagonal damper driver connection point at beam mid-span or at the beam-to-column joint. Horizontal forces were resisted with a series of Hilti KBTZ expansion anchors along the entire length of the concrete frame beams. This resulted in steel connection plates that ran the length of the floor at the perimeter of the building between columns which practically maximized the ability for the concrete frame to transfer forces into the dampers without failure of these connections.

The installation of the critical damper to concrete frame connection bolts and expansion anchors proved equally challenging. Because the essence of the retrofit strategy was to take advantage of the capacity of the existing concrete frames it was imperative to preserve as much of that inherent capacity as possible during installation of the dampers. This meant that any connections between new steel elements and existing concrete beams and columns needed to avoid damaging existing steel rebar to the extent that was possible. While the record drawings showed sizes, quantities, and configuration of all of the column and beam reinforcing the precise location could not be determined without extensive testing in the field. Ground penetrating radar (GPR) was used extensively during construction to precisely locate the existing rebar. The design allowed for small adjustments of connection bolt locations in the field to avoid existing rebar although in several locations connections had to be reconfigured and reanalyzed during construction to allow through-bolts to snake through the existing beams without damaging their reinforcing. This resulted in highly customized connections at many of the 64 damper and driver connection locations. In order to keep the project on schedule much of the steel connection fabrication took place on site with bolt holes being drilled in plates and plates welded to braces in the field only after a viable bolt pattern had been identified and analyzed on a case-by-case basis. The contracting team of MATT construction and Saunders Commercial Seismic implemented a 24-hour work day in three 8-hr shifts, six days a week during the four-week long damper installation phase of the construction. In the end the design and construction team worked hand-in-hand to successfully install over 250 anchors and bolts.

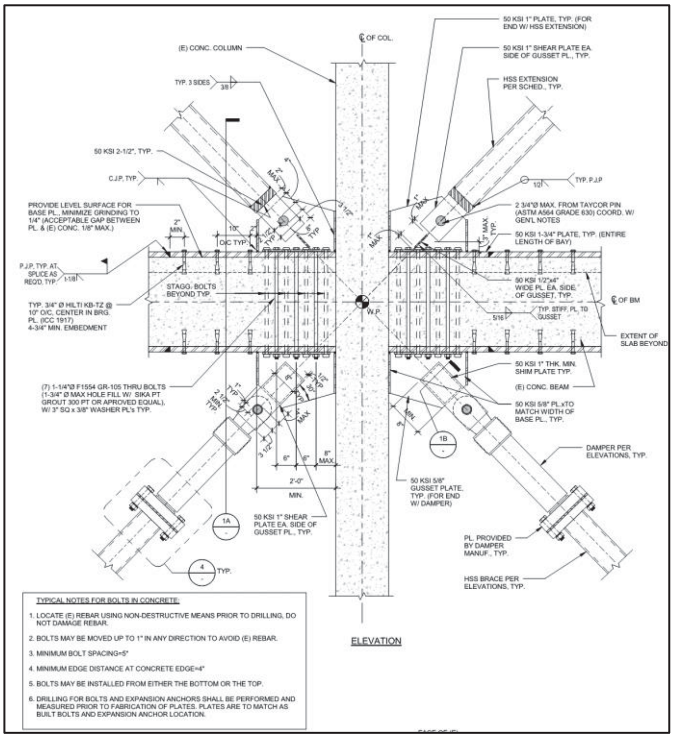

Figure 16 – Damper connection to existing concrete beam-column joint detail.

At the west side of the building the concrete frame beams are narrower than on the other three sides because of the proximity of the building's elevator shaft. This condition reduced the effectiveness of expansion anchors installed on the top surface of the beam due to reduced concrete edge distance. Because of this Grade 105 through-bolts were added through the two columns on the west side of the building. The through-bolts at both column and beam were designed to resist the combined effects of tension and shear. Because the column ties were spaced too closely to avoid damaging them when installing the through-bolts the retrofit design included the addition of confinement FRP between the connection plates and the concrete columns on this side of the tower. The sequencing and coordination between the GPR testing company, structural engineer, FRP sub-contractor and steel sub-contractor had to be carefully orchestrated to ensure that the dampers and FRP could be installed without damaging the longitudinal column and beam reinforcing.

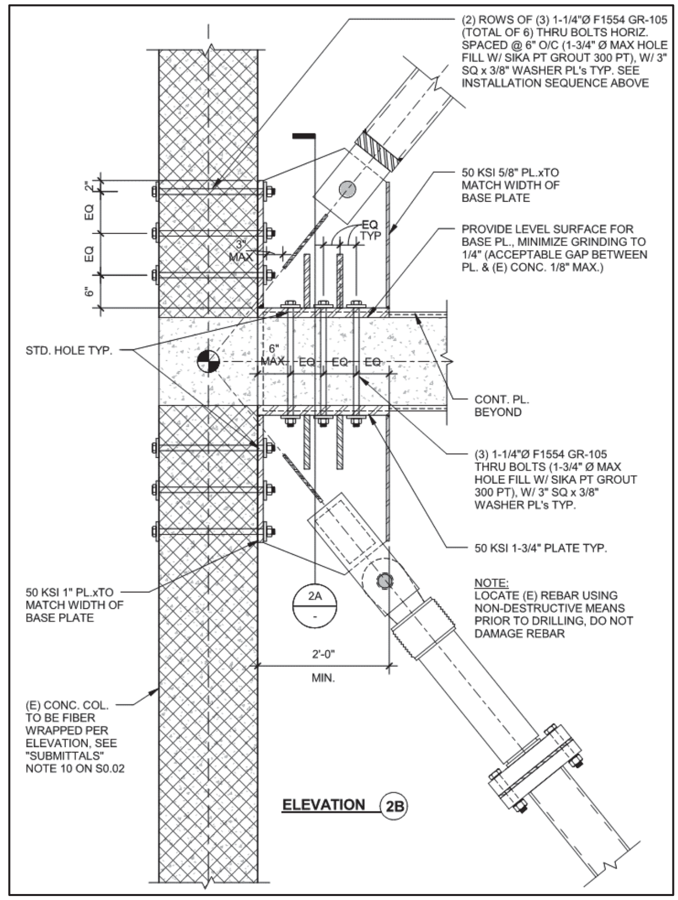

Figure 17 – Damper connection to beam and column at southern column line.

Maintaining and preserving the mid-century modernist aesthetic and the specific elements of Richard Neutra's design was as important as the structural engineering requirements of the project. While much of the FRP wrap occurred within the curtain-wall envelope of the Tower there were locations where FRP was needed on the exterior of the building as well. In order to hide the FRP yet maintain an aesthetic true to the original period of architectural significance the design team worked closely with the team's architectural historian to develop fluted 10-gage metal cladding that was differentiated from but consistent with the original Neutra design.

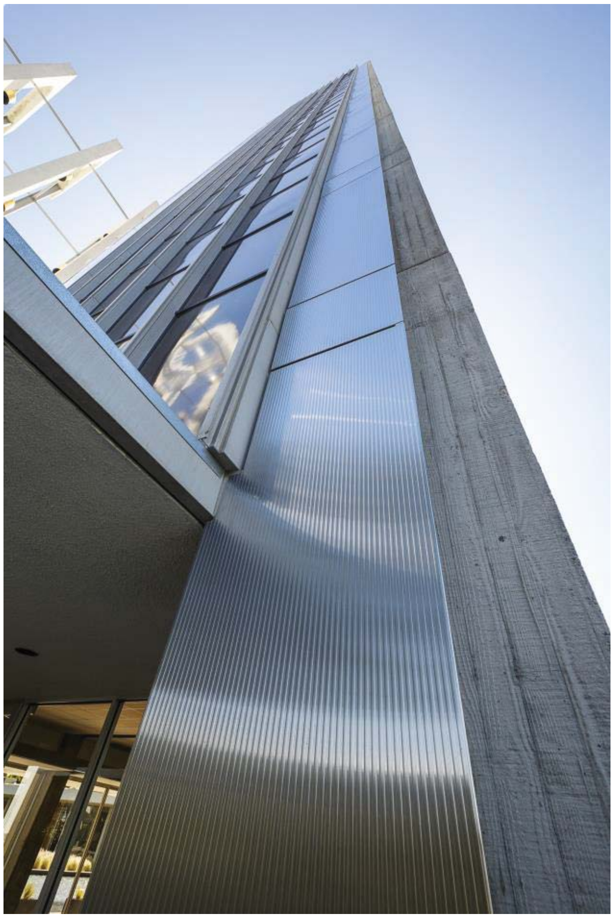

Figure 18 – Architectural metal paneling to hide FRP at column adjacent to building entrance. Reference Figure 14.

Conclusions

This paper presented a case study in performance-based seismic retrofit for a historically significant non-ductile concrete frame building using a combination of fluid viscous dampers and fiber reinforced polymer (FRP). Several of the lessons learned by the project team on this project may be broadly applicable to other projects with similar project goals and features. These general conclusions include the following:

- Respect for the features of the building that make it historically significant are important. The project team for the Tower of Hope included an architectural historian who is an expert in the works of Richard Neutra to ensure that the seismic retrofit and associated renovation work was differentiated from yet compatible with the building's period of architectural significance.

- The addition of supplemental damping to an existing structure is an effective way to significantly reduce seismic demands on the building. Fluid viscous dampers are most effective near the base of the building but need not extend through the first floor to the foundation to improve overall seismic performance of a structure.

- Seismic retrofit in a concrete building may be limited by the ability to transfer seismic forces between the existing concrete structure and strengthening elements. This limitation is particularly important when a small number of bracing elements are added because the connection capacity between new steel elements and existing concrete is relatively small.

- The Tower of Hope seismic retrofit project was successful in part because of the relatively small floor plates of the building. Each floor comprises less than 1,900 square feet of space so perimeter dampers proved effective. The supplemental damping needed to effectively retrofit the Tower of Hope resulted in approximately one damper per 500 square feet of floor area in each direction. To be more generally applicable for typical non-ductile concrete moment frame retrofit in buildings with larger floor plates it should be understood by the design team that more dampers than is architecturally practical may be needed.

- Locating and avoiding existing steel reinforcing in a large concrete frame is very challenging. While the quantity of bars may be understood by reviewing record drawings and other as-built information the exact location in the field may vary by several inches in any direction. Careful detailing to allow for flexibility during construction and thoughtful coordination and planning between the structural engineer, contractor, testing company and project inspector is essential when new steel elements are being added to an existing concrete building.

Acknowledgements

The authors would like to thank the Roman Catholic Diocese of Orange County for their commitment to preserving this iconic building and their willingness to embrace an innovative performance-based design retrofit strategy. The Diocese team was led by Rob Neal, Managing Partner of Hager Pacific Properties, and Tracy Bejotte, Chief Operating Officer of the Christ Catholic Cathedral Corporation.

The authors would also like to acknowledge the contributions of the LPA, Inc. integrated architecture and interior design team led by Jim Wirick, AIA, and Maria Louie.

Finally, the dedicated construction team led by Kevin Pitzer of MATT Construction and Amber Zamora of Saunders Commercial Seismic deserves recognition for their commitment to high quality work on this very demanding construction project.

References

ASCE, 2003, *ASCE Standard 31-03 Seismic Evaluation of Existing Buildings,* 2003, American Society of Civil Engineers, Reston, Virginia.

ASCE, 2006 *ASCE Standard 41-06 Seismic Rehabilitation of Existing Buildings w/ Supplement No. 1*, 2006, American Society of Civil Engineers, Reston, Virginia.

ACI, 2011, *Building Code Requirements for Structural Concrete (ACI 318-11)*, American Concrete Institute, Farmington Hills, Michigan.

Barbara Lamprecht, lamprecht, archiTEXTudal, personal communication, various dates.

CBSC, 2013, *California Building Code, California Code of Regulations, Title 24, Part 2, Volume 2*, California Building Standards Commission, Sacramento, California.

Computers and Structures, Inc., 2011, ETABS version 9.7 [Computer software], 2011, Berkeley, California.

Leighton Consulting, Inc., 2012, *Geotechnical Exploration for Proposed Seismic Upgrade of Tower of Hope and Arboretum Building Existing Crystal Cathedral Campus 12141 South Lewis Street Garden Grove, California*, Project No. 10021.001

Raymond International Inc., *Raymond Step-Taper Piles*, 1977, Houston, Texas.

Richard and Dion Neutra papers archive, 1925-1970, Charles E. Young Research Library, University of California, Los Angeles.