Structural Report

San Mateo Medical Center

Water Tank & Tower Study

For
County of San Mateo
Department of Public Works
30 Tower Road, San Mateo, CA 94402

By
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December 7th, 2011
KPW Project 11C237
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A. EXECUTIVE SUMMARY

This report addresses the existing 40,000 gal water tower tank and structure located at the southwest corner of the San Mateo Medical Center (SMMC). The scope of this report includes:

- Qualitative Structural Assessment of the existing water tank structure
- Two alternative schemes to retrofit the existing structure but retaining the existing tank
- One scheme to replace the existing structure and tank

The report emphasizes the structural implications and requirements and provides a conceptual schedule and cost estimate for the various schemes.

The existing water tank acts as a 24 hour reserve storage water tank to serve the needs of the administrative wing of the SMMC. It acts an emergency water supply in the event that normal water supply is interrupted. It was reported, but not confirmed, that the supply line from the tank could be looped into the hospital if needed. If connected to the hospital function, the tank and structure would fall under OSHPD jurisdiction, and be subject to full structural compliance with current code. The existing structure and tank, reportedly not connected to the hospital functions, is under no jurisdictional requirement to be structurally upgraded.

The existing structure was constructed circa 1938 and consists of a 24 ft high cast-in-place concrete moment frame tower structure. The water tank is a steel, cylindrical tank, fastened to the top of the concrete support frame. No existing documentation is reportedly available. The tank/structure is located on a hillside and is in an area of high seismic risk. A soils report was not conducted or provided for review in preparation of this report.

The existing structure was designed and constructed before seismic codes had been well established in California and well before hospitals were under FDD/OSHPD (Facilities Development Division, Office of Statewide Health Planning and Development) jurisdiction. The existing structure is structurally inadequate, suffering significant deterioration, and is significantly inadequate structurally by failing to meet strength, stiffness, ductility or stability requirements.

The deficiencies described in greater detail in this report suggest that the structure would not meet current OSHPD standards of construction, and would not remain functional in the event of a major earthquake.
The two retrofit schemes presented herein include:

1. Installation of new steel braced frames
2. Installation of new Fiber Reinforced Polymer (FRP) around the existing concrete tower columns and beams

Both options would also require repair of the existing concrete spalling as well as strengthening of the existing foundation. The existing water tank would remain with either option.

The replacement scheme presented herein includes one new 100,000 gal useable water tank on a new concrete mat slab foundation (with the same location as the existing structure) and would require demolition and removal of the existing structure/tank but would preserve the existing nearby trees, which provide an aesthetic screening for the tank structure.

Note that the retrofit options alone would not bring the structure into compliance with OSHPD standards. The new replacement option could provide greater reserve capacity, would be OSHPD compliant, allowing the tank to serve the OSHPD jurisdiction functions of the campus as well.

This report has been prepared by

KPW Structural Engineers, Inc.

John K Westphal, SE 4575
Principal
November 29, 2011
B. ASSESSMENT REPORT

1.0 Introduction, Scope of Study

The purpose of this report is to address the structural adequacy of the existing water tank structure and provide two alternative retrofit options and one alternative new replacement structure and tank option. The structural performance level of the two retrofit and new replacement solutions should be designed to a minimum "Life-Safety" Level, while the new replacement solution should be designed to a higher level using an Importance factor of 1.5 and designed to satisfy OSHPD requirements. A site review of the existing structure was conducted, including field measurements and documentation of the existing condition. A testing and inspection agency was retained to pothole excavate around the existing footings to determine the size and reinforcement of the existing foundation and columns.

A qualitative discussion regarding the structural deficiencies of the existing structure is presented herein. Two concept retrofit solutions with concept sketches are provided. The retrofit solutions address protection of the existing concrete and reinforcing steel as required for prevention of further deterioration and long-term functioning of the structure. A concept replacement solution with concept sketches is also provided.

Due to access limitations, and as directed by the County, an analysis of the integrity of the tank and anchorage is not part of the scope for this project.

A comparison of each of the concept designs is provided in terms of construction cost estimate and construction duration in section 6.0.

2.0 Description of Existing Structure & Site

The existing tower structure was reportedly constructed circa 1938. The base structure has an approximate 20 ft x 20 ft footprint and consists of cast-in-place concrete moment frames in each direction. There are four 20"x20" concrete columns, sloping inward, reinforced with 2 - 1" square deformed vertical bars at each corner (8 bars per column) and 3/8" smooth wire ties spaced at 8" OC. Each column acts as a moment frame column for both orthogonal planes. Existing moment frame beams at the top and mid-height are approximately 18" wide x 24" deep and 16" wide x 18" deep respectively.

See Figure 1 for the tower location relative to the remainder of the campus.
Figure 1. Water Tower Site Location on SMMC Campus

The approximate elevation of the suspended reinforced concrete slab at the top of the concrete tower is 24 ft from the top of existing grade. Each beam-column connection is chamfered above and below and three concrete haunches are provided at each face of the top concrete beam to support the cantilevered portion of the slab. See Figure 2. The approximate weight of the cast-in-place concrete tower structure is 165 kips.

The structure has undergone significant deterioration over the past seven decades. Spalling was observed at the underside of the slab and the face of some of the columns.
Figure 2. Southwest View of Upper half of Existing Tower
Note the areas of concrete spalling at the underside of the existing slab.

Figure 3. Southwest View of Lower half of Existing Tower.
Note the area of concrete delamination at the front column.

The approximate 40,000 gallon water tank is a steel, cylindrical tank with an approximate diameter of 22 ft and approximate height of 15 ft, secured to the top of the concrete support frame. No existing documentation is reportedly available. The estimated weight of a fully loaded water tank is 385 kips.

Figure 4. Inside view of typical column base.

A Site survey was undertaken by Applied Materials & Engineering. Based on the site investigation letter “Water Tower Footing Investigation” completed by Applied
Materials & Engineering, dated October 18th, 2011, the existing foundation system for the structure consists of 12” wide x 18” deep continuous reinforced concrete grade beams interconnected between columns. Each existing column is supported by an existing 5'-0” x 5'-0” x 2'-0” deep unreinforced concrete footing that bears on the existing soil, which consists of sandy clay.

The tower structure is located on a sloping hillside adjacent to W 34th Avenue, and up the hill from a small campus parking lot. It is partially surrounded by several eucalyptus trees, ranging in diameter from 18” to 42”. They are mature trees and act to partially screen the tank from the public. See Figure 11.

Seismic hazards resulting from effects of an earthquake may include ground shaking, liquefaction, lateral spreading, dynamic settlement, fault ground rupture and fault creep, and tsunamis and seiches, although the site may not necessarily be impacted by all of these potential seismic hazards. The existing tower and tank structure are located on a site that will likely experience severe ground shaking from a major earthquake originating from the major Bay Area faults, particularly the nearby San Andreas Fault (2 miles from the site), Hayward fault (17 miles from the site), or Calaveras fault (23 miles from the site). The potential for fault ground rupture and fault creep hazards is relatively high. Based on the Liquefaction Susceptibility maps from the United States Geological Survey (USGS) site, compiled from Knudsen and others, 2000, and Witter and others, 2005, the site has low to moderate liquefaction susceptibility. See Figure 5 for the location of the site on this susceptibility map. It is recommended, however, that a more detailed evaluation be completed, such as geotechnical borings, to confirm liquefaction potential (which is characterized by the presence of loose granular soil below the water table).

The Working Group on California Earthquake Probabilities (WG99) has estimated that there is a 15 percent probability of at least one magnitude 6.7 or greater earthquake before 2030 along the Peninsula segment of the San Andreas Fault (USGS, 1999), and a 27 percent probability of at least one magnitude 6.7 or greater earthquake before 2030 along the Southern segment of the Hayward Fault (USGS, 2003).

Based on the site’s seismicity, KPW’s site review of the existing structure and the aforementioned investigation letter regarding the existing foundation system, the existing structure is anticipated to experience moderate to severe structural damage in a strong seismic event.
Figure 4. Site Location Relative to Known Active Faults

Figure 5. Site Location on USGS Liquefaction Susceptibility Map
3.0 Condition & Performance of Existing Structure

There are several significant structural concerns with the existing tower structure relative to its seismic resistance, detailing, and anticipated performance. A number of these concerns are based on the fact that the structure was constructed prior to the development of seismic standards and codes, and standards of practice that assure construction quality. They include the following:

a. The concrete moment frame elements and connections do not have adequate ductility to resist the lateral forces and anticipated displacements through flexural and shear deformations of the frame beams and columns during multiple cycles of strong earthquake ground motions without significant degradation, loss of stiffness or strength.

b. The controlling parameters for concrete moment frame designs are typically frame stiffness and strength of beam members for load combinations including both gravity and seismic forces. The existing columns, beams and grade beams are not adequately sized to meet story drift limits specified by the building code, which are a function of both occupancy category and redundancy factor;

c. The beams, columns, and joints are not proportioned and detailed adequately such that the beams will yield before the columns, which could result in a non-ductile yielding mechanism and possible catastrophic collapse of the entire structure during a moderate or major seismic event. The existing columns and beams are under-reinforced for flexural loads.

d. Ends of columns require adequate confinement to ensure column ductility in the event of hinge formation. These hoops restrain dilation of the core concrete as it is loaded in compression, increasing the member’s strength and strain capacity. Shear reinforcement is also required to prevent shear failure prior to the development of the flexural capacity of the section. Transverse reinforcement provided in the existing columns does not meet current design practices. In one area of the column where the concrete was spalling, transverse reinforcement was observed to be ¼” smooth wire spaced at 8” OC. See Figure 6. This under-reinforcing for shear and confinement is one of the most critical structural deficiencies of the frame.

e. Flexural members are not provided with adequate confinement where plastic hinges are likely to form. These are important to ensure sufficient ductility of the members under reversible loads, to resist shear and to maintain lateral support for the main longitudinal bars;

f. Members do not have adequate strength to resist the secondary moments (P-Δ effects) that are induced due to displaced gravity loads, or to account for orthogonal effects (axial and biaxial flexural interaction);
The existing columns have undergone significant deterioration. The following observations were made at the site: Spalling of concrete at the corners of the existing concrete columns, at the underside of the slab, and corrosion of the exposed steel reinforcement. See Figures 2, 3 and 5;

h. Large air pockets were observed on the face of the existing columns, suggesting that the concrete mix during construction was of poor quality and/or poor workmanship (Concrete may not have been properly cured or vibrated during installation). See Figure 6.

i. The existing foundation grade beam and footings are not sized or reinforced appropriately to resist anticipated seismic overturning forces, resulting in instability/collapse of the entire structure due to inertial forces, shear failure of the soil or large settlement on soft soils.
Figure 6. Existing Concrete column with areas of poorly graded or deteriorated concrete.

j. Anchorage of the steel tank to the supporting slab may not have sufficient strength to resist the horizontal and tension forces due to current code seismic or wind loads on the tank (and the effects of sloshing of the stored water on the tank). If the tank is not properly fastened to the existing slab, the connection will tear out of the concrete slab and the tank will tip over and collapse;
k. The water tank, which is constructed of steel, may have undergone significant corrosion and its connections may have deteriorated over time, inhibiting its ability to retain its contents.
l. The structural capacity of the existing 70 year old tank may not be adequate to resist current code level forces. An investigation into the integrity of the tank is outside of the scope of this report, but should be evaluated prior to any retrofit work on the tower structure.

4.0 Retrofit Solutions

Several conceptual strengthening design solutions for the existing water tank concrete tower structure were considered. Some of these employ relatively conventional methods to resist seismic loads, such as construction of new steel concentrically braced frames or steel moment resisting frames (applied to each face of the existing structure), concrete shear walls constructed integrally with the existing columns, strengthening of the existing frame elements by encasing them with a jacket of reinforced concrete, and addition of an exterior buttress on each side (and each direction) of the existing structure. Strengthening the existing
beams and columns using Fiber Reinforced Polymer (FRP) products was one of the more advanced techniques considered. FRP is a carbon or glass fiber compound that exhibits exceptional tensile capacity and is externally bonded to existing concrete with an epoxy agent to achieve composite action. In concrete applications, it is commonly used to strengthen sections lacking tensile or flexural strength, or lacking confinement or shear strength. Another technique that was considered involved employing a base isolation/dampening system which would decouple the superstructure from its substructure and significantly reducing the potential seismic load on the structure.

Two of the considered retrofit solutions have been selected for a more detailed review and feasibility study based on efficiency, cost, schedule and constructability. Local repair of any of the deteriorated concrete elements (spalling of existing concrete slab and columns, cleaning of exposed/corroded reinforcement) will be necessary prior to the construction work proposed below. Other required and recommended upgrades that are independent of the retrofit of the seismic solution include: repair of the railing attachments, abatement (removal of any existing hazardous materials), repainting of the structure, and a providing a new liner in the tank to help deter deterioration.

4.1 Retrofit Solution A – Steel Braced Frame

General Description
A two-story steel Special Concentrically Braced Frame (SCBF) on each face of the existing structure with an extended concrete foundation (footing & grade beam) offers a clean and simple practical solution, with minimal work on the existing structure. Demolition work and attachment to the existing structure would be relatively straightforward. The strength and stiffness of the new steel frame would be designed to resist all of the lateral loads from the tank, the existing concrete structure, and the steel frame’s self-weight. The existing concrete frame tower structure will be prevented from significant story drift and deformation, thus limiting any further structural stresses and excessive damage.
Figure 7. Retrofit Solution A Foundation Plan
Figure 8. Retrofit Solution A Typical Frame Elevation

New Frame Members
The SCBF option would consist of four new HSS steel frames. Each frame would be completely shop fabricated, reducing cost, improving the schedule, and improving the quality. Demolition of the existing concrete haunches at the slab would be required to allow access of the beams at the top of the structure, and new steel members would be required to support the cantilevered portion of the slab. The HSS members would be attached to the existing concrete tower frame. The new frames should be hot dip galvanized for long term durability.

See Figure 8 for an elevation of the proposed steel frame, with approximate sizes for each element.
Foundation Improvements
The vertical loads on each existing spread footing due to combinations including seismic overturning result in soil bearing pressures that exceed acceptable presumptive maximum allowable load-bearing values. The size of the footing may be inadequate to prevent soil failure in the event of a moderate to severe seismic event. Furthermore, the existing footing is unreinforced and does not have sufficient shear capacity. The size of footing should be increased such that the final footing size is 11 ft square to avoid a brittle failure. This can be achieved by providing epoxy dowels and a new reinforced concrete section around the existing footing (with depth to match the existing footing).

There is a net uplift on each column due to overturning. The structure may not have sufficient weight to resist overturning nor sufficient reinforcing and detailing to develop and engage the existing 5 ft x 5 ft spread footing. This would result in collapse of the structure in the event of a high seismic event. The existing column and grade beam will need to be connected to the existing footing.

4.2 Retrofit Solution B – Strengthening of Existing Concrete Moment Frame

General Description
Strengthening the existing concrete moment frame is an alternate feasible solution. Strengthening of the existing concrete elements can be achieved by using either all FRP or a combination of FRP and concrete encasement of the beams and columns. Repair of the unsound and spalled concrete by patching with cement mortar and pressure-injection into any existing cracks will be required.
Figure 9. Retrofit Solution B Foundation Plan
Beams
Some strengthening is required at each end and midspan of the moment frame beams (both top and bottom) to address their flexural deficiencies. Additional flexural capacity can be achieved at the concrete beams by externally bonding FRP fabric around the corners of each column with an epoxy agent and extending the FRP toward the middle of the beam, approximately a third of the span. FRP will be used primarily to enhance the positive bending capacity of each existing concrete beam.

Figure 10. Retrofit Solution B Typical Frame Elevation
The beams located at the mid-height of the frame also require flexural strengthening. If FRP products are used, the fabric would wrap around the corner of each column and extend toward the middle of each beam. Confinement can be provided by wrapping the entire perimeter of each beam with FRP. Confinement or shear strengthening is most critical at a certain distance from each joint face and on both sides of any section where flexural yielding is likely to occur as a result of inelastic lateral displacements of the frame.

**Columns**
The concrete in the existing columns is not adequately confined with deformed transverse hoops to provide lateral support to the longitudinal reinforcement. These bars are generally provided to ensure that spalling of the shell concrete will not result in a loss of axial strength of the column. The most practical way to address this deficiency is to externally bond FRP fabric around the perimeter of the existing column. Although the most critical region of the column is above and below the existing beam, it is recommended that the entire length of the column be strengthened with FRP fabric to provide reasonable protection and ductility to the mid-height of columns.

**Foundation Improvements**
The vertical loads on each existing spread footing due to combinations including seismic overturning result in soil bearing pressures that exceed acceptable presumptive maximum allowable load-bearing values. Furthermore, the existing footing is unreinforced and does not have sufficient shear capacity. It is recommended that the size of footing be increased such that the final footing size is at least 10 ft square to avoid a brittle failure.

Additionally, the columns do not appear to be positively tied to the footings. A positive anchor must be made to properly engage the footing and prevent failure.
5.0 New Design

The most critical factors influencing the appropriateness of a replacement solution are (a) the short and long term demands of the water tank (which part(s) of the campus are to be served by the tank), and (b) the current budget allowance for the project, and (c) the anticipated timeline for attainment of project budget approvals for a complete replacement solution. Although it requires a significantly higher upfront cost, demolition of the existing structure and construction of a new structure compliant with OSHPD regulations will provide long-term performance, while being able to serve a greater area of the campus when an emergency arises.

Figure 11. Tower Site Plan with Surrounding Landscaping

The most simple and cost-effective replacement solution involves the construction of a reinforced concrete mat slab to support one large or two smaller sized water tanks. The advantage of a single 100,000 gal useable tank is that it and its concrete slab could be located in the same footprint as the existing tower and tank and utilize the existing trees to provide cover. See Figures 12 and 13.

Based on discussions with facilities, a 80,000 gallon tank (24 ft diameter x 24 ft high) or 100,000 gal tank (26 ft diameter x 30 ft high) are recommended.
Bolted steel liquid storage tanks are common in the Western United States and are considered as value engineered alternatives to field erected welded tanks. These tanks are easy to install and have factory powder coating materials inside and outside which give them chemical resistance to corrosion and superior durability. Most bolted steel tank manufacturers offer tanks that are chip and scratch resistant, solvent free and environmentally safe.

Figure 12. Replacement Solution Foundation Plan
6.0 Concept Cost Estimates and Schedule Impact

There are considerable cost differences between a retrofit solution and a complete replacement solution for the water tank tower. The steel frame proposed Retrofit Solution A can be fabricated almost entirely off-site, and be constructed within a short amount of time. See Table 1 for a matrix comparing each of the proposed solutions.
Table 1. Cost, Construction Schedule, and Benefits/Disadvantages Comparison of Proposed Solutions

<table>
<thead>
<tr>
<th>Proposed Solution</th>
<th>Estimated Construction Cost</th>
<th>Estimated Construction Duration (Working Days)</th>
<th>Pros</th>
<th>Cons</th>
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<td>Retrofit Solution A:</td>
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<td>Steel Concentrically Braced Frame</td>
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<td>78</td>
<td>- Cost Effective</td>
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<td>- Un-intrusive to (E) function</td>
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<td>- Steel fabricated off site, quick field erection</td>
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<td>- Tree cover remains intact</td>
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<td>- Steel frame limits structural drift &amp; deflection</td>
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<td>- Steel frames have minimal impact on (E) frame aesthetics</td>
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<td>- Very short tank shutdown time for liner replacement</td>
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<td>- County Jurisdiction/Approval is simple/quick</td>
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<td>- New liner will significantly increase life of (E) tank</td>
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<td>- Tank, guardrails, piping, elevated slab, and other non-tower components not updated to current code</td>
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<td>- Tank capacity unchanged</td>
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<td>- Steel requires longer lead time/fabrication</td>
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<td>$215,000</td>
<td>58</td>
<td>- Cost effective</td>
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<td>100,000 useable gal tank and new</td>
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<td>- OSHPD approval will allow structure to be used by hospital wing</td>
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<td>- 100,000 useable gallons or more, will meet SMMC goals</td>
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<td>- Tank will not exceed (E) tank height</td>
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<td>- Trees will remain</td>
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<td>- Most costly</td>
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<td>- Demolition of (E) tank/structure will take time &amp; will impact nearby residence</td>
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<td>- Different “aesthetic look”</td>
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<td>- OSHPD requirements more stringent</td>
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Qualifiers:
- Estimated construction costs do not include soft costs, such as design services, permits, special inspections, owner project management, or construction management services
- Duration does not include Bidding, Permits, Approvals
- Soils report will be required

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SMMC Water Tower & Structure Report
Nov 29, 2011
7.0 Limitations and Disclaimer

This report is presented at the request of the County of San Mateo. Its purpose is to provide a qualitative assessment regarding the structural integrity of the existing concrete water tower based on visual observations and limited structural analysis. It is limited in that as-built drawings, hidden conditions, and a geotechnical/seismic hazard report were not provided or are unknown.

The two retrofit solutions and new replacement solution presented herein are based on limited information of the existing system and discussions with the Facilities Director of the San Mateo Medical Center. The retrofit solutions presented are the efficient alternative to address the existing structural deficiencies with minimal impact to the function and operation of the existing tank.

The new replacement solution has been roughly sized based on input from Facilities. The consideration to incorporate OSHPD reviews and approvals for the new solution is based on the potential to use the new tank to feed hospital services as well.

This report is based on professional opinions, recommendations and conclusions, on generally accepted structural engineering principals, practices and observations.
8.0 Recommendations and Conclusions

The existing concrete structure is deteriorated, out-dated, not current code compliant, and represents a seismic risk and hazard.

It is recommended that the existing structure be retrofitted with one of the two retrofit solutions presented herein. As an alternate, the existing tower and tank could be demolished, and replaced in its entirety and a new higher capacity water tank could be installed in the same location on campus.

Various factors comparing the feasibility of the mitigation options, such as conceptual construction cost, construction drawings, etc., have been included in this report. Additional factors, such as operations, long term master planning, etc. will need to be considered by the Owner when selecting the appropriate solution.

This report has been prepared by

KPW Structural Engineers, Inc.

John K Westphal, SE 4575
Principal
November 29, 2011