Cover page

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Seismic Upgrades to an Existing 180 MGD Water Treatment Plant near the San Andreas Fault

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ABSTRACT

The Harry Tracy Water Treatment Plant (HTWTP), capable of supplying 180 million gallons per day (mgd), is a critical component of the Hetch Hetchy Regional Water System that serves 2.6 million people in the San Francisco Bay Area. In 2002, the San Francisco Public Utilities Commission (SFPUC) launched the $4.8 billion Water System Improvement Program (WSIP) to provide improvements to meet level of service (LOS) goals established for seismic and delivery reliability, water quality and water supply. Under WSIP, the HTWTP Long Term Improvements Project (LTIP) was implemented to upgrade the existing plant to allow delivery of a minimum of 140 mgd within 24 hours after a major earthquake on the San Andreas Fault, located less than 1,000 feet away. Although the close proximity of the fault presented significant design challenges, the greatest project challenges related to two previously-unidentified traces of the Serra Fault that crosses the property. The identification of these traces resulted in the abandonment of two existing treated water reservoirs, and replacement with an 11-million gallon (MG) treated water reservoir (TWR), designed to resist high vertical and lateral seismic forces. The $278 million project was dedicated in 2015, marking the completion of four years of construction.

INTRODUCTION AND PROJECT DESCRIPTION

The Hetch Hetchy Regional Water System serves on average 260 mgd of drinking water to 2.6 million people in the San Francisco Bay Area, home to some of the world's largest technology corporations. The system is critical to the economic viability of the area and the public health and safety of the region's population. Built in the early 1900s, it is considered by many to be an engineering marvel for its great efficiency and the high-quality water it delivers. The system, shown in Figure 1, is supplied by pristine snowmelt accumulated in Yosemite National Park and stored in the Hetch Hetchy Reservoir, and carries water 167 miles across California—all via gravity. Although the system has performed extremely well for nearly a century, it is vulnerable to seismic events as it crosses three of the United States' most active faults: the San Andreas, Hayward, and Calaveras Faults. In 2008, the United States Geological Survey (USGS) predicted a 63 percent chance that a major earthquake could strike one of those three faults in the next 30 years [1].

Water System Improvement Program (WSIP) and Level of Service (LOS) Goals

In 2002, recognizing the need for major upgrades to the aging water system, the SFPUC initiated the WSIP to ensure water delivery following a major earthquake in the San Francisco Bay Area. The WSIP is a $4.8 billion multi-year program including 83 projects over seven counties—from the Sierra mountain range to the City of San Francisco. The WSIP includes a wide variety of improvements such as upgrades to and addition of new water treatment, transmission (pipelines, tunnels, pump stations), and storage (dams, reservoirs, tanks) facilities. It is the largest capital program ever undertaken by the SFPUC, and one of the largest water capital improvement programs in the United States (U.S.).

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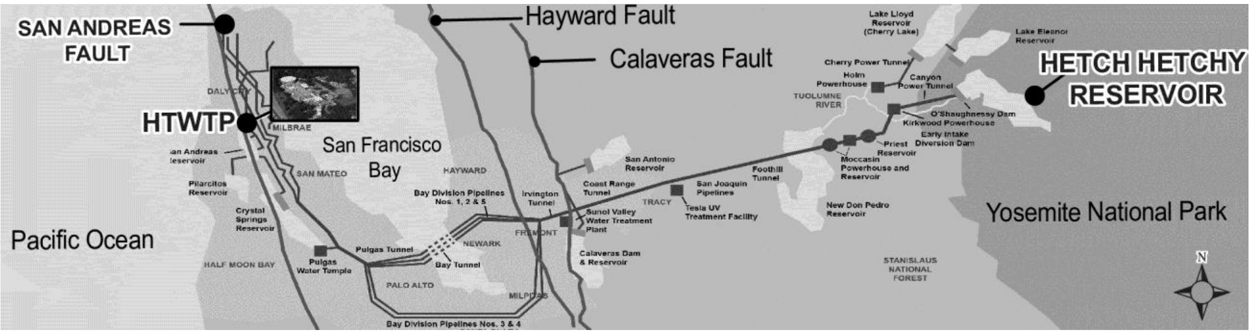

Figure 1: Hetch Hetchy Regional Water System

The overall scope of the WSIP was developed to meet four types of LOS goals: seismic reliability, delivery reliability, water quality, and water supply. The goals establish specific performance criteria for the system, and also provide quantifiable means to define and rank projects and select design criteria. The seismic reliability LOS goal category establishes the required delivery capability of the system following a major seismic event. Specifically, it requires delivery of basic service (average winter-month usage) within 24 hours following a pre-determined event on any of the three aforementioned active faults. It also specifies that facilities must be restored to meet the system's average-day demand within 30 days of such an event.

Harry Tracy Water Treatment Plant (HTWTP) Long Term Improvements Project (LTIP)

The HTWTP is a 180 mgd peak-capacity surface water treatment plant located in an unincorporated area of San Mateo County, near the Cities of San Bruno and Millbrae. The HTWTP delivers water stored in the Crystal Springs and San Andreas Reservoirs to over one million people on the San Francisco Peninsula. It is also the only source providing emergency water to the San Francisco Peninsula. HTWTP was originally constructed in 1972 (and originally named the San Andreas Water Treatment Plant), with major expansions in 1988 and 1990. The HTWTP is a direct filtration plant with pre-ozonation: raw water undergoes pre-ozonation, flocculation, filtration, and disinfection via chloramination before entering the system.

The HTWTP is a critical component of the Hetch Hetchy Regional Water System and therefore the $278 million HTWTP LTIP was developed as an important part of the WSIP. The primary objective of the HTWTP LTIP was to identify and upgrade specific deficiencies at the plant that restricted it from sustaining operations to meet the defined LOS goals.

LOS Goals for the HTWTP LTIP. Under the "*WSIP System Assessment for LOS Objectives*" [2], performance measures were outlined for the HTWTP LTIP with regard to water quality and seismic and delivery reliability required for HTWTP. The LOS goals for the HTWTP LTIP are twofold:

- <u>Delivery Reliability Goal</u>: Provide net water production of 140 mgd for a minimum of 60 days under typical water quality conditions. Typical water quality conditions are defined as a raw water turbidity of 10 NTU or less and less than 2 million algae cells per cubic meter. The treatment plant will be required to produce more than 140 mgd to account for in-plant uses (i.e., filter backwashing). Counting in-plant water uses, the total sustained treatment capacity is 153 mgd.
- <u>Seismic Reliability Goal</u>: Increase seismic reliability of new and modified facilities to sustain limited damage following a major earthquake and be able to deliver 140 mgd within 24 hours of such an earthquake. The specified major earthquake is an approximate magnitude 7.9 earthquake on the San Andreas Fault, which is considered a Basic Safety Earthquake (BSE)-2 event (an 84th percentile deterministic Maximum Considered Earthquake [MCE]) for existing facilities as specified in the American Society of Civil Engineers (ASCE) Standard 41, and the MCE specified in the 2007 California Building Code (CBC) for new facilities.

Summary of HTWTP LTIP Improvements. The HTWTP LTIP included major treatment process changes as well as substantive site improvements, all constructed to withstand earthquakes and meet the LOS goals previously described. Capital improvements of water treatment plant facilities were also included in the project due to scheduling constraints, construction cost efficiencies, impending facility needs, and anticipated reduction in near- and long-term operational disruptions.

The original design of treatment process improvements for the LTIP, as outlined in the 2008 Conceptual Engineering Report (CER) [3], included replacement of a raw water pump and ozone generation equipment; conversion of the ozone system from a combination air/oxygen gas feed to oxygen-only gas feed system; five new filters; a second parallel backwash system; spent washwater clarification modifications; a new solids dewatering system; and new calcium thiosulfate and polymer filter aid chemical systems. The project also included major site improvements, including structural strengthening of key structures with identified seismic weaknesses, such as the 8- and 6.5-MG reservoirs, as well as modifications to selected major pipelines to allow interior repair access.

The HTWTP is located between the Holocene-Active San Andreas and Serra Faults, as shown in Figure 2. Although the close proximity of the San Andreas Fault presented significant design challenges due to high seismic forces, the greatest project challenges of the HTWTP LTIP design were related to the presence of two previously unidentified traces of the lesser-known Serra Fault that cross the HTWTP property and are capable of movement in conjunction with an earthquake on the San Andreas Fault.

Geologic and geotechnical work performed as part of the CER phase of design included a study of two faults on the HTWTP property as well as an investigation of slope stability at and around the 8- and 6.5-MG reservoirs and two washwater clarification basins. The results of these investigations determined the need for additional treatment plant improvements to the LTIP to meet the LOS goals. These additional areas of improvement included retrofit of large-diameter transmission pipelines within the boundaries of fault traces; installation of seismic isolation valves to protect residential and school properties; and modifications to the design of new filters to avoid intersecting a fault trace. Most significant was the abandonment of two existing treated water reservoirs due to unacceptable ground deformations in the hillside below the foundations. These reservoirs were replaced with an 11-MG treated water reservoir (TWR) on the opposite side of the plant from the fault traces.

Seismic upgrades to the Plant were designed to essential facility seismic standards and included structural retrofits where necessary. Essential facility seismic standards were determined by interpreting codes and standards specific for HTWTP, using the General Seismic Requirements for Design of New Facilities and Upgrade of Existing Facilities Revision 1, December 22, 2008 [4, 5, 6] as a basis for determination.

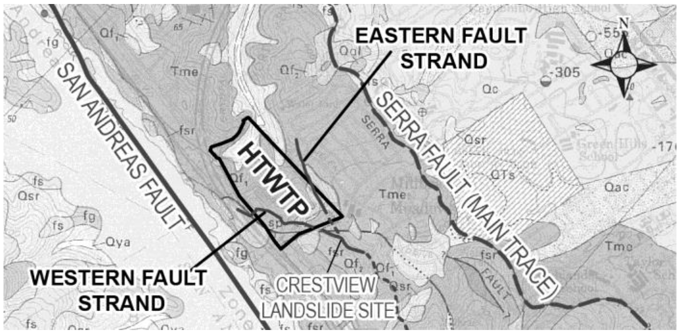

Figure 2: Faults near the HTWTP

GEOTECHNICAL INVESTIGATION

The project’s seismic challenges stemmed from the treatment plant’s location within the seismically active San Francisco Bay Region and the close proximity (approximately 1,000 feet) to the San Andreas Fault. This active fault governed the determination of seismic criteria (including seismic response spectra and design accelerations) for structural analyses and improvements, and studies of slope stability and risk of seismically-induced landslides. The seismic design loads determined from the site-specific seismic requirements were much higher than the design loads of the existing facilities designed between the late 1960s and early 2000s.

As part of the CER [3], a geotechnical study of two fault strands on the HTWTP property was conducted. There are two known fault strands on the HTWTP property, termed the Eastern and Western Faults—also known as “Serra Faults” as they may be branches of the Serra Fault passing through nearby City of Millbrae. Figure 3 shows the locations of the Eastern and Western Faults. Both faults slope under the main HTWTP facilities at steep angles and deemed capable of movement in conjunction with an earthquake on the San Andreas Fault.

Eastern Fault

The Eastern Fault has been only relatively recently identified on the HTWTP property. Estimated horizontal displacements from movement on this fault range from 6 inches (475-year return period San Andreas Fault earthquake) to 11 inches (2,475-year return period San Andreas Fault earthquake) and vertical displacements are approximately 2 inches (475-year return period San Andreas Fault earthquake) to 3 inches (2,475-year return period San Andreas Fault earthquake). Implications of this fault for the HTWTP LTIP are noted below:

- A portion of the 60-inch San Andreas No. 3 Raw Water pipeline adjoins the Eastern Fault area and is possibly susceptible to damage from the movement of off-site landslides. Residential and school properties are downhill of this pipeline and this pipeline could release large volumes of water from San Andreas Reservoir if ruptured. This could create life safety and property damage hazards depending upon the amount and duration of water release.
- The 60-inch Sunset Branch (Treated Water) pipeline crosses this fault and has important facilities directly over the fault zone. This pipeline also passes through an off-site landslide area from the 1970s, expected to be susceptible to movement from earthquakes. Residential and school properties adjoin this pipeline and this pipeline could release large volumes of water from the water transmission system if ruptured.

Western Fault

The Western Fault has been typically interpreted as inactive (last movement 20,000 to 5,300,000 years ago) based upon geometry and slip direction. This secondary fault is considered capable of some slip during a major earthquake because it represents a pre-existing plane of weakness.

Estimated horizontal displacements from this fault are approximately 2 inches (475-year return period San Andreas Fault earthquake) to 4 inches (2,475-year return period San Andreas Fault earthquake) and vertical displacement estimates are approximately 1 inch (475-year to 2,475-year return period San Andreas Fault earthquakes).

Although the SFPUC General Seismic Requirements [4] do not specifically require special measures for secondary inactive faults, implications of this fault on the existing and proposed facilities include:

- The five new media filters could not be located at the previously planned expansion location since they would have been astride the Western Fault, and were therefore moved to the existing (unused) sedimentation basin footprint.

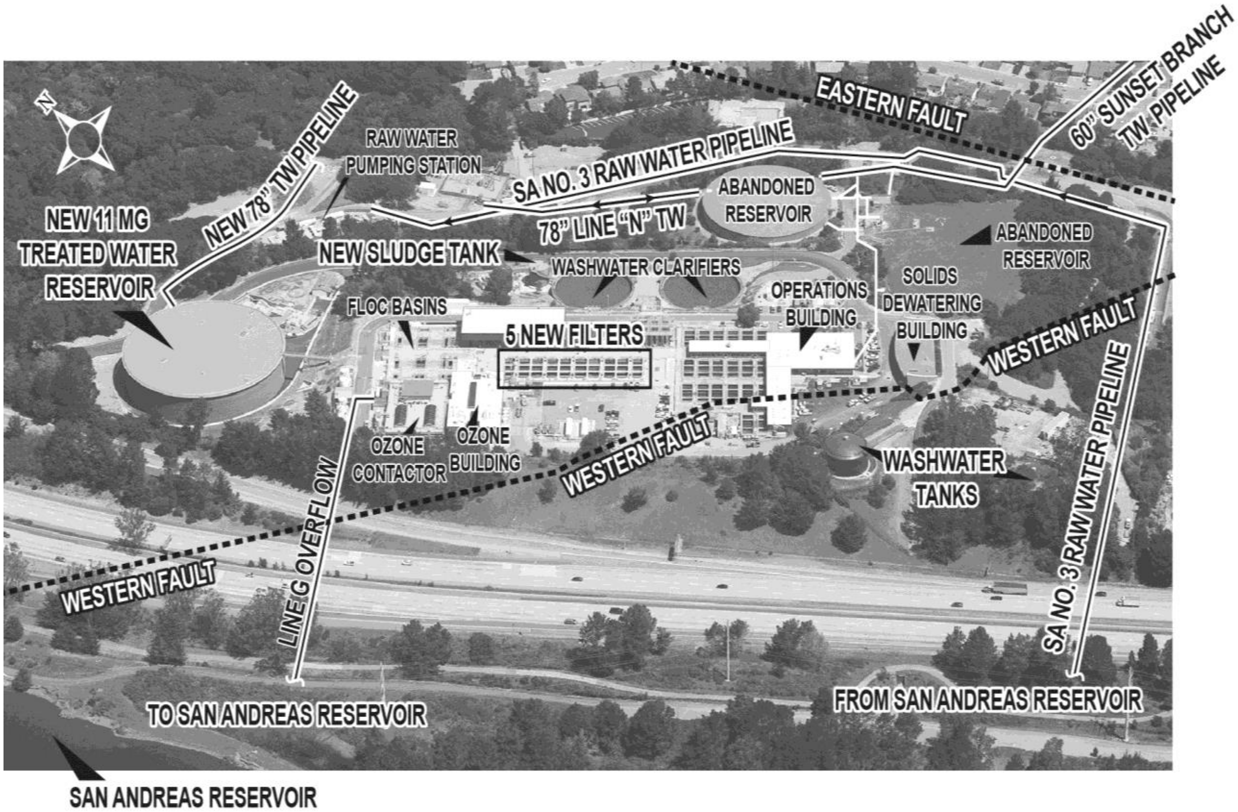

Figure 3: HTWTP Site Plan showing Eastern and Western Faults

- Serious damage of the existing water conduits, channels, and filters could take place if estimated fault displacement occurs and structures do not maintain their integrity at the displacement. Rupturing of certain channels and conduits could flood the filter galleries and take the HTWTP out of service for months.
- The 72-inch San Andreas No. 3 Raw Water pipeline crosses the Western Fault near its tunnel portal. A ground displacement at this location presents of risk of damage and possible pipeline rupture. Failure of this raw water pipeline could drain a significant volume of San Andreas Reservoir toward residential and school properties.

Slope Stability Analysis

A dynamic slope stability analysis [7] identified the need for slope improvements to reduce potential displacements from the MCE/ BSE-2 event. Study implications included:

- Portions of the fabricated and natural slopes adjoining the existing 8- and 6.5-MG reservoirs could experience landslides or deformations. Deformation could be relatively minor (i.e., surface cracking) or major (i.e., where landslides damage the reservoir structures, downhill pipelines, roads, and other facilities). It is also possible that reservoir water could be released, compounding the potential damage and hazard.
- Portions of the fabricated slopes adjoining the washwater clarifiers and main plant access road could experience landslides. Although deformations could be relatively minor in some cases, others could be major (e.g., landslides that damage structures and pipelines, releases of large volumes of water causing cascading damage to utilities, access, and other structures).
- Landslides or slope displacements put the adjoining treated and raw water pipelines at risk for rupture and compounding failures.

- Measures to increase the slope stability surrounding the existing reservoirs and washwater clarifiers and to reduce the potential for pipeline damage were required. Measures included drilled micropiles, piers or caissons, tie-backs, rock anchors, and other means to reduce displacements.

Fault Rupture Hazard Assessment of New TWR Site

The nearby San Andreas and Serra Faults and secondary Eastern and Western Faults constitute a fault surface-rupture hazard during large earthquakes on the San Andreas Fault. Therefore, although the HTWTP is outside the California State Alquist-Priolo Earthquake Fault Zone (A-P Zone) for the San Andreas Fault, it was determined that a site-specific fault rupture hazard investigation should be performed for the proposed improvements to the site to minimize the surface-fault rupture hazard from possible secondary faults.

Specifically, the rupture hazard investigation was performed to evaluate the proposed location for the new TWR—designed to replace the existing 8- and 6.5-MG reservoirs that were at risk for landslides or deformations as previously described. Although previous investigations had determined the proposed TWR site was located about 200- and 800-feet from the Western and Eastern Faults, respectively, the presence or absence of additional secondary faults had not yet been determined. A rupture hazard assessment was therefore performed to evaluate the presence and displacement potential of minor shears and shear zones that may underlie the TWR site within the Merced Formation sandstone, as suggested by similar features previously identified in the direct vicinity of the TWR site. The following are conclusions and recommendations resulting from this assessment:

- The known primary and secondary faults on or near the HTWTP do not constitute a rupture hazard to the proposed TWR site.
- The rupture hazard from secondary faults within the TWR footprint is very low.
- The proposed TWR footprint overlies individual shears and minor shear zones within Merced Formation sandstone and minor conglomerate. Such minor shears can be assumed to underlie the entire site and cannot be avoided.
- The rupture hazard associated with the minor shears is low, but it is possible that they can accommodate minor secondary (sympathetic) movement during or following a large earthquake on the San Andreas Fault.

The results of rupture hazard assessment suggested the TWR design accommodate 1 to 2 inches net, including 0.5- to 1-inch vertical displacement within the footprint on individual shears or shear zones, with no more than two shears or shear zones spaced at approximately 100-foot intervals being capable of such displacements. Thus, given a proposed 240-foot tank diameter, a major (i.e., BSE-2 or 2,475-year) event may produce one to two individual displacements of 2 inches net and 1-inch vertical each beneath the TWR, for a total cumulative offset of 4 inches net and 2 inches vertical [8].

OVERVIEW OF HTWTP LTIP UPGRADES

As noted above, the purpose of the HTWTP LTIP was to upgrade the HTWTP to meet the delivery and seismic reliability LOS goals, which required major treatment process upgrades as well as substantial site improvements. In order to meet the LOS goals, not only was new and existing equipment installed and retrofit to withstand earthquakes (hardening and bracing of existing equipment and structures), but significant redundancy was built into HTWTP processes. For example, HTWTP includes 15 filters, two parallel washwater systems, six megawatts of standby power, and an emergency chlorination system, allowing for chlorination of untreated San Andreas Reservoir water in the event of a major disaster and the need to send untreated water through the transmission system. Additional design and construction challenges stemmed from the requirement to keep the plant operational during construction. Only six major outages were allowed during the four years of construction, typically, between October and March of each year with outages ranging from 4 to 10 weeks.

The HTWTP LTIP improvements modified the treatment process for functional, seismic strengthening, and reliability reasons and included the following upgrades [9]:

- Raw Water Pump Station: Addition or replacement of variable frequency drives for six raw water pumps (45 and 15 mgd pumps).
- Ozone System: Replacement of liquid oxygen storage tanks, vaporizers, ozone generation and destruction equipment. Conversion of the ozone system from a combination air/oxygen gas feed to oxygen-only gas feed system.
- Filters: Addition of five gravity, dual media filters for a total of 15 filters; with new applied water channel, filtered water conduit, Filter Effluent Chamber, and blower room.
- Washwater Supply: Addition of second 0.5 MG washwater storage tank and replacement of existing 0.5 MG washwater storage tank.
- Washwater Treatment: Conversion of two existing washwater clarifiers to serve as washwater equalization basins. Addition of four Parkson high-rate clarifiers; second sludge storage tank and associated pumps; centrifuge dewatering equipment and conveyor system.
- Treated Water Reservoir: One new 11 MG TWR with associated piping and chemical application mixing. Keeping the system as gravity-fed, with equivalent hydraulic head as the existing system, drove the TWR site selection.
- Chemical Systems: New caustic soda, sodium hypochlorite, aqua ammonia, calcium thiosulfate, washwater ferric chloride, washwater polymer, hydrofluosilicic acid, and filter aid polymer chemical facilities. Replacement of existing chemical tanks for higher seismically reliable storage tanks.
- Emergency Chlorination: Emergency chlorination facility to allow for chlorination of untreated San Andreas Reservoir water in the event of a major disaster and the need to send untreated water through the transmission system.
- Pipelines: Replacement of major portions of on-site raw and treated water transmission pipelines for seismic reliability.
- Electrical: All new main switchgear and electrical service equipment in the Standby Power Building. An additional 2-megawatt diesel-engine driven electrical generator. Wide-ranging infrastructure improvements across the site for electrical and instrumentation service, SCADA, piping, pumping, and HVAC purposes.
- Structural: Structural strengthening of the Operations Building complex, Ozone Building, Ozone Destruct Room, Ozone Contactor Structure, inlet water channels, the overflow junction box, and valve vault.
- Site Improvements: Micropiles to strengthen the hillside beside the washwater equalization basins and sludge storage tanks; drilled piers to support the retaining wall system along the Standby Power Building.
- Existing equipment/pipe/conduit/duct support evaluations and strengthening.

Seismic Performance Category

Seismic criteria were developed for the LTIP based on importance factors to either: (1) ensure restoration to a level of service consistent with adopted post-earthquake goals within 24 hours for primary facilities; or (2) experience damage but retain the capability to restore service within 30 days for secondary facilities. Therefore, all structures at the HTWTP were classified as either Seismic Performance Category (SPC) II (equivalent to the 2007 CBC Occupancy Category III) or SPC III (equivalent to Occupancy Category IV).

- SPC II: The performance goal of the SPC II classification is to provide life safety protection against earthquakes likely to affect the site. Therefore, structures classified as SPC II may experience damage but should be capable of restoration to service within 30 days.
- SPC III: The performance goal of the SPC III classification is to provide life safety protection against earthquakes likely to affect the site, but includes reasonable expectations of post-earthquake operability of SPC III classified facilities. Therefore, structures classified as SPC III should be capable of restoration to a level of service consistent with adopted post-earthquake level of service goals within 24 hours.

DESCRIPTION OF SELECT KEY IMPROVEMENTS

Descriptions of improvements to the Operations Building Complex, large diameter transmission pipelines and the new TWR follow.

Operations Building Complex

The Operations Building complex consists of several buildings, including the Operations Building, Basement, Filter Gallery, and Office and Storage Building. The complex includes the plant control room, offices, a workshop, restrooms, a laboratory, and other facilities on the ground level, in addition to a mezzanine level, and a lower level connecting the filter galleries and equipment rooms. During preliminary design it was determined various components of these buildings required seismic upgrading. For example, the small separations between the various buildings did not meet the project-specific criteria. Additionally, due to the project requirement to keep HTWTP operational during construction, replacing the existing complex with a new, seismically sound facility would not meet project schedule, and therefore retrofit of the existing building was included in the project.

To address these issues, the project included the following seismic improvements:

- Added steel wall columns and knee braces to brace masonry walls for out of plane forces.
- Added transverse and longitudinal roof collectors to engage masonry walls.
- Structurally joined the buildings by closing roof joints.
- Removed some infill walls, and removed and replaced all partition walls.
- Braced lighting fixtures and provided emergency lights.
- Replaced all exterior cladding with drift tolerant materials and replaced plaster soffit over entrance.
- Braced mechanical, electrical, and plumbing equipment as needed.
- Braced fire sprinkler piping and modified ceiling tile penetrations for sprinkler heads.

In addition to these improvements to the building itself, a buried geofoam pier wall was constructed between the Western Fault and the Operations Building complex foundation, to protect the building from movement during a seismic event. The geofoam pier wall consisted of 48-inch diameter intersecting geofoam piers buried 17 feet and extending a length of 90 feet.

Large Diameter Transmission Pipelines

During the preliminary stages of design of the HTWTP LTIP, multiple large diameter pipelines at the site were determined to be in close proximity to the Western and Eastern Faults and therefore at risk for failure during a seismic event. The 72-inch San Andreas No. 3 pipeline (SAPL3, raw water pipeline) was found to cross the Western Fault and then run parallel to Eastern Fault, and was located within a steep slope at risk for landslides in a seismic event. The 60-inch Sunset Branch (treated water) pipeline was found to cross the Eastern Fault, while the 78-inch Line 'N' (treated water) was found to run parallel to and cross the Eastern

Fault. In order to strengthen the raw and treated water pipelines, LTIP construction improvements included:

- Raw Water Pipelines: The existing 60-inch SAPL3 was abandoned and a new 72-inch raw water pipeline was installed. The pipeline was installed partially above ground on pipe saddles set on caissons and was buried for the remainder of the alignment.
- Treated Water Pipelines: A new 78-inch treated water pipe was constructed to deliver water from the new 11 MG TWR. Additionally, portions of the existing 60-inch Sunset Branch (treated water) pipeline was sliplined with 48-inch, polyurethane-lined pipe 220 feet in length. The existing Sunset Branch pipeline is a cement mortar lined and coated steel pipe. Because the original alignment included a 53 degree slope that transitioned to a 33 percent slope, an anchor block was constructed on the top and bottom of the pipeline alignment and reinforced with drilled caissons. The sliplined pipe was then installed from either end of the existing pipe (top of slope and bottom of slope) and was exposed in the middle to enable welding of the two ends of pipe together.

Treated Water Reservoir [10]

Replacing the two existing reservoirs with a new 11 MG TWR was the largest major seismic component of the LTIP. The new TWR was designed as a reservoir with an integral chlorine contact basin. The chlorine contact basin is configured as a long single-pass raceway, created as a ring outside the circular reservoir-portion of the structure, with the outside wall of the contactor being the outside wall of the TWR tank and the inside wall being the outside wall of the operational storage portion of the reservoir. The water storage reservoir is located in the center of the TWR. See Figure 4 for the components of the TWR.

A raceway contactor configuration was selected because of its hydraulic efficiency due to its superior flow path for chlorine contact effectiveness. This configuration provides a smooth flow path, given the minimal difference in inner to outer radius on such a large-diameter tank, and provides uniform contact across the flow path cross section with minimal mixing in the direction of flow. This configuration begins to approach the hydraulic design of a pipe or conduit.

The bypass piping configuration allows for the following operational configurations:

- Bypassing the entire TWR structure.
- Taking the contactor off-line while leaving the reservoir portion of the structure on-line.
- Taking the reservoir portion of the structure off-line while leaving the contactor on-line.

Filtered and chlorinated water flows into the TWR from the filter effluent chamber through a 96-inch filtered water line and is then conveyed through piping and associated valves as follows:

- Chlorinated filtered water enters the annular raceway contactor located along the perimeter of the TWR through a grated pipe opening in the TWR floor.
- The filtered water is distributed across the annular raceway cross-section through a perforated baffle wall and flows around the raceway and through a second perforated baffle wall.
- At the end of the annular raceway, the disinfected water flows over a weir, which maintains the required water level in the contactor section at all times before the water enters a pipeline. Disinfected water is delivered to the external pump mixing system for chemical mixing.
- After the chemicals disperse into the water, the chloraminated and pH-adjusted water enters the TWR storage area in the center of the structure for operational storage prior to distribution.
- Treated water flows to distribution through a new 78-inch pipeline, which includes a new 78-inch Venturi flow meter.

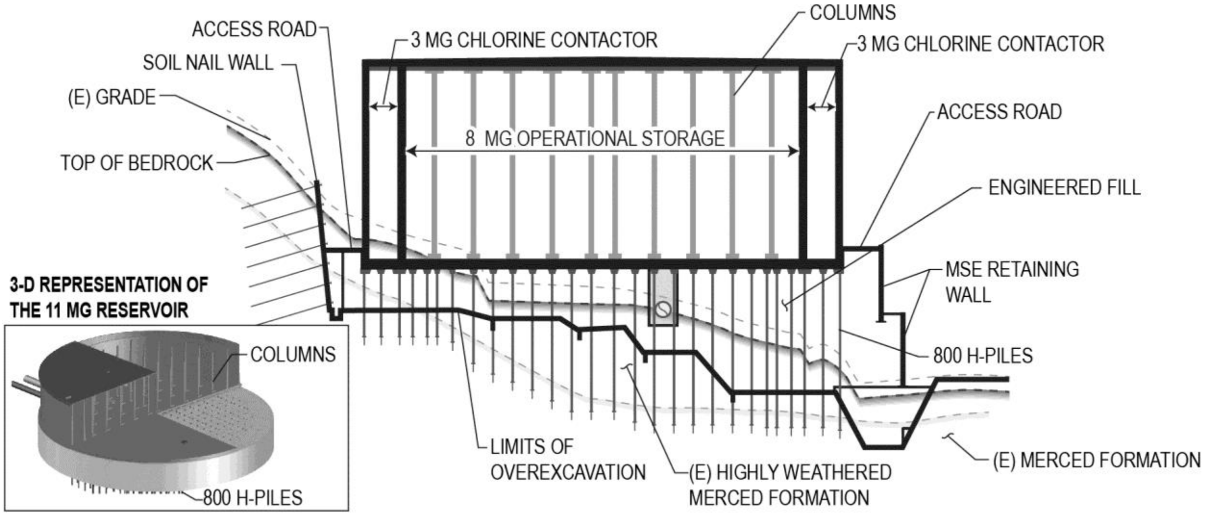

Figure 4: Treated Water Reservoir Design

Chemical additions of ammonia and caustic are assisted by an external pump mixing system for effectively mixing in the injected ammonia (to produce a chloramine residual) and caustic (for corrosion control through pH adjustment) in the chlorinated water before it enters the storage reservoir portion of the TWR.

Structural components. The 11-MG structure is circular, with an integral chlorine contact basin, an inside diameter of 240 feet, and a height of 48 feet (including 3 feet of freeboard). Its capacity is divided into 3 million gallons (MG) for the chlorine contact basin and 8 MG for operational storage. The chlorine contact basin consists of an outer annular raceway approximately 16 feet wide around the perimeter of the reservoir. Design of the reservoir included a feature for draining completely either the chlorine contact basin or operational storage basin while the remainder of the tank remains full and in service. The reservoir was constructed at a new site, with the exterior walls completely exposed for monitoring and repairs.

Foundation. The TWR was constructed on a hillside that required extensive cut to create a stepped excavation and partial engineered fill to develop the foundation pad for the reservoir, resulting in a potential for differential settlement across the cut/fill transition. A soil nail retaining wall, rising up to 65 feet tall and supported by approximately 1,000 soil nails up to 70-feet long, was constructed directly uphill of the TWR to support the cut face of the excavation. A mechanically stabilized earth (MSE) wall, located downhill of the TWR, was utilized to support the engineered fill for the tank pad and separates the reservoir from the main plant access road.

A pile-supported reinforced concrete mat slab foundation was found to be the most-economical foundation type that would address up to 4 inches of potential differential settlement due to the cut/fill transition and would also mitigate seismic settlement caused by sympathetic movement on secondary faults near the tank site. Final design of the pile-supported reinforced concrete mat slab required more than 800 steel H-piles, at approximately 10-feet on center, and driven to depths of 20 to 60 feet, including up to a depth of 12-feet into the Merced Formation bedrock unit below the overlying engineered fill. The piles were designed to support the reservoir's vertical and lateral loads, including high seismic loads. The reinforced concrete mat slab was constructed on top of the pile caps, with a gravel subgrade for an underslab drainage system. Footings for more than 80 interior columns supporting the reservoir roof were placed monolithically with the reinforced concrete mat slab.

Tank Design. The circular reservoir is a “tank within a tank,” with a strand-wound, pre-stressed, cast-in-place reinforced concrete exterior wall with vertical post-tensioned tendons and a galvanized steel diaphragm, and a conventional, cast-in-place reinforced concrete interior wall with vertical post-tensioned tendons. The interior wall separates the contactor portion from the operational storage portion of the reservoir. Internal weir walls are conventional cast-in-place reinforced concrete walls, while internal baffle walls are constructed of fiberglass reinforced plastic (FRP).

The design of both the pre-stressed exterior and interior walls include an anchored flexible base in accordance with ACI 350.3, Type 2.3(1), to allow the tank to expand and contract during filling and draining. All reservoir walls are anchored to the foundation via reinforcing dowels and seismic cables in order to transfer seismic loads from the roof and the walls themselves to the foundation, and to prevent the reservoir from sliding off the foundation (See Figure 5). The pre-stressed exterior and interior walls, which have flexible bases, are isolated from internal concrete and baffle walls with non-flexible bases via expansion joints with waterstops and slotted connections. The exterior concrete wall and floor of the contactor are coated with an elastomeric polyurethane coating, while the internal and external walls of the reservoir is coated with a crystalline waterproofing coating system to minimize leakage and protect the concrete surfaces from the corrosive water. The pre-stressed exterior wall was placed against the galvanized steel diaphragm, which wraps around the outside face of the wall. The diaphragm lies in between the wall and the post-tensioned strands to provide additional protection for the strands against any seepage. Shotcreting via the wet-mix process was used to encapsulate the post-tensioned strands to protect them from corrosion. The concrete reservoir walls are designed to resist temperature gradients radially through the thickness of the walls.

The reinforced concrete reservoir roof is designed to be weather-tight in order to prevent leakage and contamination of the reservoir contents. It is also designed to accommodate thermal stresses from an 85 degrees Fahrenheit temperature differential. The structure of the roof is a two-way slab supported on top of the pre-stressed exterior and interior walls and more than 80 interior reinforced concrete columns at approximately 20-foot centers inside the operational storage portion of the reservoir. The roof rests on bearing pads on top of the walls and is positively connected to the top of the pre-stressed exterior wall via flexible pinned connections. For drainage, the top of the roof has a minimum slope of 1.5 percent (an approximately 22-inch difference in elevation from roof center to roof perimeter).

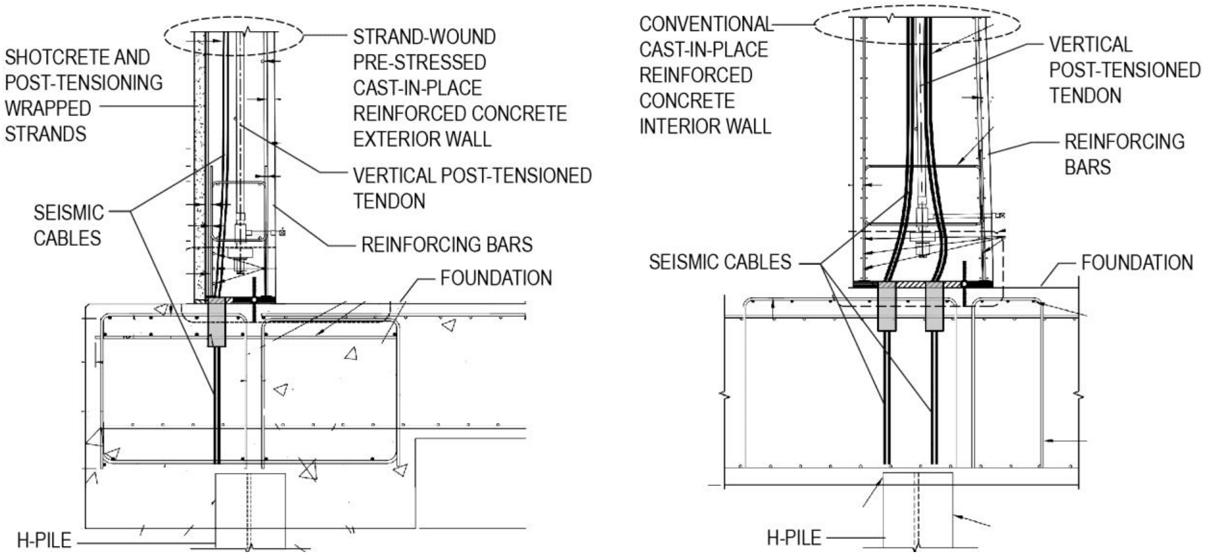

Figure 5: Connection of Exterior and Interior Walls and Foundation

Appurtenances and Underdrain. The tank appurtenances of the reservoir include the inlet, outlet, drain, and overflow piping; overflow weir; valves outside the tank; piping in the tank roof and walls for sensors and sampling; roof openings for access hatches and ventilators; and locking and safety devices. All piping is concrete-encased beneath the tank floor slab. Flexible joints are provided outside the wall footing to accommodate any movement caused by differential settlement or seismic activity. Materials and coatings utilized in the reservoir's construction satisfy the requirements of National Sanitation Foundation (NSF) 61.

The reservoir includes an underdrain system configured to collect water and detect leakage from isolated areas of the TWR. Groundwater levels may result in hydrostatic uplift under the tank; therefore the underdrain system was designed to prevent hydrostatic uplift and detect potential floor leakage.

CONCLUSION

The improvements constructed as part of the HTWTP LTIP allows the SFPUC to supply emergency water to over one million people after a seismic event on the San Francisco Peninsula. Design challenges included seismic retrofit of existing facilities and locating a new 11 MG TWR at site with limited space, near the San Andreas and Serra Faults, and with the requirement to maintain operation of the existing plant 7 days a week, 24 hours per day. The $278 million project was dedicated at a public ceremony in 2015, marking the completion of nearly four years of construction.

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