

Mitigating Artesian Water Flow by Pressure Grouting on U.S. 101 in San Jose, California

KEN JACKURA AND ED GRAF

Severe wet weather cycles in northern California during the winters of 1981 to 1982 and 1982 to 1983 created near-historic high groundwater levels in at least one area of San Jose where a depressed portion of U.S. Route 101 exists. The high groundwater level induced artesian flow onto U.S. 101 in excess of 1,100 gal/min. The flow led to piping of fines from underneath the freeway, slab uplift in excess of 10 in., and buoyancy of an underground water storage vault. Installation of temporary dewatering wells and implementation of an effective grouting program and chemically grouted structure tie-down anchors stabilized the area without shutting down traffic.

Over the past 30 years, the California Department of Transportation (Caltrans) has designed and constructed a number of depressed freeways through urban areas to balance cut and fill, reduce its visual impact, lower costs, provide for cross-traffic flow on unelevated bridge overcrossings, and more recently reduce traffic noise. High groundwater tables required special design and construction techniques to prevent buoyancy of underground structures and to mitigate the impact of seepage pressures on slopes and the roadway.

Discussed in this paper are problems associated with a rising groundwater pressure within a confined aquifer lying immediately below a depressed section of U.S. 101 in San Jose, California. The aquifer pressure head was low before construction and had been low for years due to below-normal rainfall, heavy agricultural pumping, and domestic water needs. Since 1970, increased urbanization and receding agricultural development have resulted in less shallow groundwater withdrawal. Coupling this with the heavy rains of 1981 to 1983, groundwater levels and the recharging of the confined aquifer are approaching a historic high.

Problems in the depressed section became apparent in early March 1983 when Caltrans' maintenance crews noticed water spouts emanating from around the median timber posts separating the northbound and southbound lanes. These water spouts, estimated at 3 ft high, were distracting motorists and affecting travel.

A 10- to 12-in. slab uplift in the southbound concrete pavement was also observed and water was streaming from around a pump house adjacent to the southbound lanes. Further investigation revealed buoyancy of an underground storm-water collection box and washing of fines.

The immediate problems to be solved were

1. Lowering the water table,
2. Sealing the upward flow of water where an impervious soil barrier above the aquifer had been pierced,

3. Anchoring buried structures to resist imminent flotation, and

4. Filling of voids caused by the washing of fines from under and around the buried structures.

In addition to these immediate problems, this section of U.S. 101 is the major north-south corridor feeding the San Francisco and Silicon Valley areas and is located in a highly urbanized district. Closing only one of its six lanes would cause a backup during midday and an intolerable situation during commuting hours. One of the underground structures, a concrete cistern, was completely under all of the southbound lanes. Quick installation of five dewatering wells followed by pressure grouting and structure tie-down anchors resulted in stabilizing the areas without shutting down traffic.

PROJECT LOCATION AND GEOLOGY

The limits of the depressed section, which is located at the northern end of the city of San Jose at the junction of U.S. 101 and State Route 17, are shown in Figure 1. Original ground elevation was 53 ft, whereas finished grade elevation within the depressed portion is 33 ft, a finished cut of about 20 ft below adjacent ground.

Geologically the site lies within the Santa Clara Valley, which is a large structural trough extending from Hollister (south of San Jose) to San Francisco (north of San Jose). Unconsolidated alluvial and bay deposits of clay, sand, and gravel fill this trough and make up the valley floor. The subject site area is bounded on the east and west by the Coyote River and the Guadalupe River, respectively. During their historical development, layers of sand and gravel and then finer-grained materials were laid in alternating sequence to form confined water-bearing aquifers.

Four distinct aquifers lie below the site. The upper or most shallow aquifer, which is of primary concern in this project, is approximately 30 ft thick and starts at a depth of about 40 ft below original ground surface. Sediments overlying the aquifer in this area are impervious and are composed of clays and clay-silt mixtures.

Underlying this upper aquifer are three others at depths of about 150, 350, and 550 ft. All are significant water-bearing strata. The aquifers are separated by impervious boundaries of clays, mixtures of clay, silts, sands, and cobbles. A generalized cross section of the subsurface conditions is shown in Figure 2. The illustration has no scale, but provides a general idea of the underground conditions showing water transport and recharge behavior. Recharge of the aquifer systems is primarily through the Santa Clara formation lying west of the site. Some recharge is also developed through infiltration and is most predominant in the uppermost aquifer.

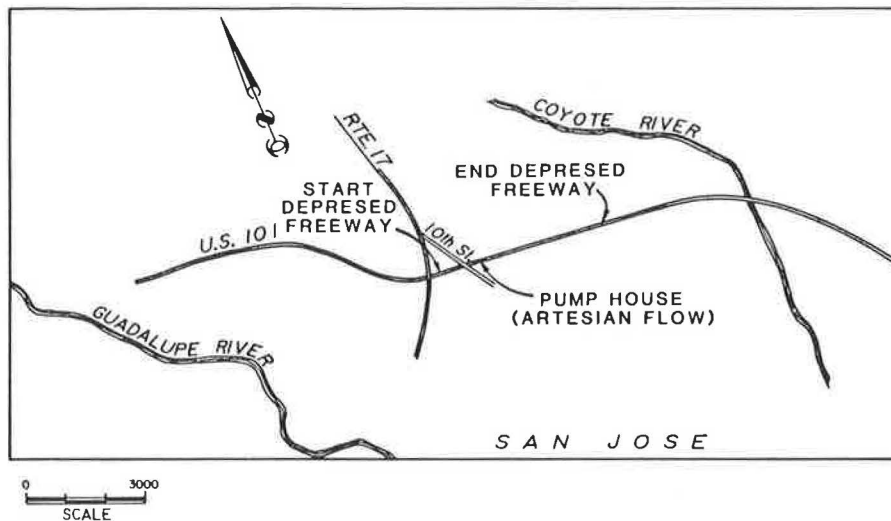


FIGURE 1 Plan map for a portion of U.S. 101 in San Jose showing location of artesian flow.

Original Construction

The depressed highway section of U.S. 101 was constructed over a 1½-year period ending in July 1960. The original contract called for widening old State Route 68 (now U.S. 101) to freeway standards for a distance of about 3 mi. A pump house, storm water storage box (cistern), one major interchange, a number of overcrossings, and reconstruction of old State Route 69 (now State Route 17) crossing U.S. 101 were part of the contract. The depressed section is 1 mi long.

Borings conducted in the early 1950s revealed silts and clays to a depth of 40 ft within the major portion of the depressed section, as illustrated on the profile map (Figure 3).

A perched static water table during that time was at elevation +43 ft, about 11 ft above finished profile grade in the depressed area. Groundwater studies conducted in the mid-1950s indicated that lateral drainage into the depressed freeway would be

from 1,500 to 3,000 gal/min (gpm). Most of this water would be coming from the depressed portion of the freeway where a 2- to 7-ft-thick clayey silty sand layer exists near elevation +36. Due to the rather slow draining nature of the soils, freeway design incorporating interceptor trenches along both sides of the freeway and a pervious 2-ft-thick sand blanket over the bottom of the cut was considered adequate to intercept and transport the perched groundwater.

Collected groundwater and storm water runoff was to be handled by a pump house and a 50-ft × 50-ft × 8-ft-high cistern as shown in Figure 4. Uplift pressures on the pump house and cistern were developed on the assumption that the phreatic line would be no higher than 2 ft below the finished profile grade elevation of 31 ft. Hence, buoyancy of these features was predicated on that assumption.

Pump house construction began before freeway excavation by excavating within the confines of sheet pilings. Pile sheet tip

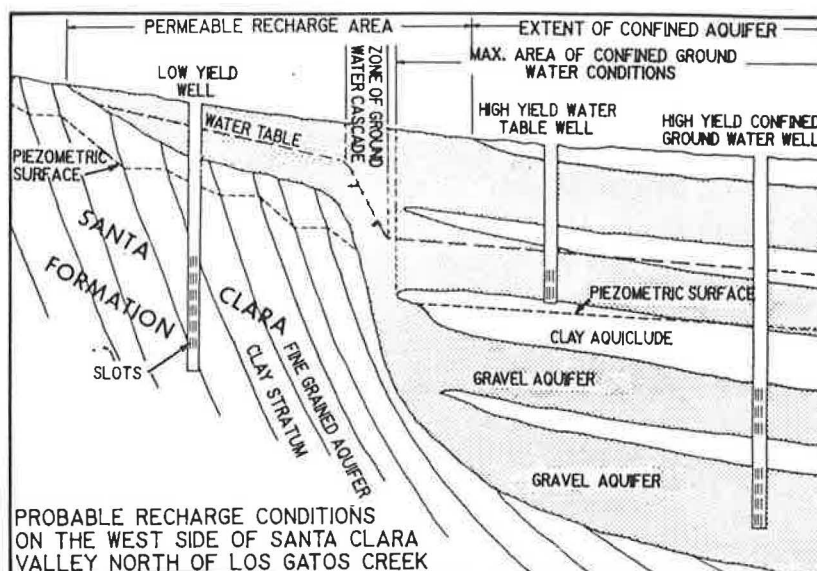


FIGURE 2 Generalized soil cross section of northwestern San Jose area showing aquifers and predominant method of natural recharge through the Santa Clara formation.

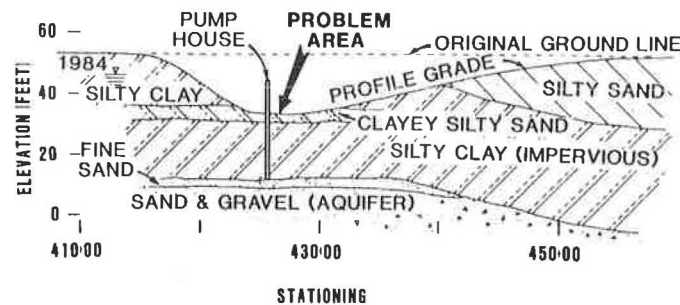


FIGURE 3 U.S. 101 profile of grade and soil types between Stations 410 and 460.

elevation was about 10+ ft or near the contact of a 3-ft fine sand layer lying immediately above the sand and gravel aquifer. Freeway excavation proceeded simultaneously with construction of the pump house.

Following full freeway excavation, construction of the cistern began. Material was excavated to elevation +21 ft (about 12 ft below grade) for construction of the cistern. This left about 9 ft of impervious material above the aquifer, but as this excavation was directly connected to the pump house excavation, it essentially punctured the impervious material.

Only minor sump pumping was necessary to maintain a water-free working platform in the excavations for the pump house and cistern. A stable working platform was constructed by placing a 6- to 12-in.-perimeter crushed-gravel base at the bottom of the excavations.

After the construction of the pump house and cistern, a clean pea-gravel backfill was used to fill the approximate 2- to 3-ft space between soil and structure.

Artesian flow

In the early spring of 1983, maintenance crews noticed 3-ft-high water spouts emanating from around several timber median posts separating the northbound and southbound lanes of U.S. 101. Further investigation revealed a bubble type of slab uplift of about 10 to 12 in. over several hundred feet of the southbound lanes and occurring in the area overlying the underground cistern.

Believing that a water main had burst, Caltrans workers contacted city maintenance personnel for verification, while

other Caltrans crews started relieving the hydrostatic pressure by trenching along the southbound lane shoulder. Trenching produced immediate relief of the slab uplift pressure by releasing large water flows estimated in excess of 1,000 gpm (Figure 5). Simultaneously, several workers descended into the cistern for inspection. Water flows into the cistern from the original drainage system were negligible and the crews decided to core into the 18-in. thick concrete walls to help relieve the large surface flows. Sixteen 2-in.-diameter core holes were drilled during the next several days; each hole produced large streams of water estimated at between 50 to 100 gpm.

Because of the high velocities of the discharging water, another problem developed rapidly: scouring of fines from beneath the pavement and, presumably, beneath the pump house and cistern. Two days after the initial trenching to relieve the slab uplift pressure had been conducted, pavement sag started developing in the inner two fast lanes of the northbound traffic flow and the southbound fast lane. During the following 4 weeks, in excess of 190 tons of asphalt concrete had to be placed over the sagging area, resembling a trough approximately 20 ft wide \times 80 ft long.

Caltrans geologists and geotechnical engineers reviewed the site immediately after the maintenance superintendent warned them about the seriousness of the situation. After reviewing early site plans and construction cross sections along with the soil profile, it soon became apparent that the pump-house construction of 1960 passed through the impervious clay stratum and bottomed out on the sand layer immediately overlying the sand and gravel aquifer stratum. Since construction in 1960 and the 20 plus years following produced no flowing water, it was concluded that this sand and gravel aquifer later became

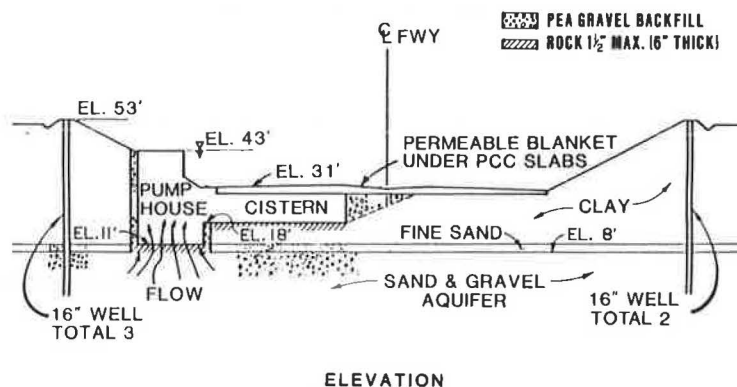


FIGURE 4 San Jose 10th Street Pump House, U.S. 101 (looking north).



FIGURE 5 Temporary repair of shoulder where a relief trench was cut to allow the water to flow from the highway subgrade.

charged to a pressure head that in 1983 was 12 ft above freeway grade.

After reaching some critical pressure head, possibly 5 to 8 ft above freeway grade, piping of the fine sand layer overlying the sand and gravel aquifer into the clean gravel backfill developed opening channels for large water flows to the surface (see Figure 4). Inducing quick release of the pressure head at the surface aggravated the scouring action of the sand blanket just beneath the pavement and resulted in the further undermining of the pump house and cistern.

Dewatering

Once the water source flow was assessed, plans were made to develop several wells at freeway grade and to use the cistern and pump house for water storage and removal. These plans were quickly abandoned after a futile attempt was made to bucket-auger a 12-in.-diameter well to the aquifer from freeway grade. Artesian pressure had to be resisted by a heavy drill mud that was difficult to work together with further complications arising from normal drilling problems.

Subsequently, plans were made to install wells on both sides of the freeway at dike (original ground) level. Initially only two wells were planned, one on each side of the freeway. Holes were augered with a 36-in.-diameter bucket to a depth of 40 ft and cased with a 30-in. corrugated metal pipe with the annular space backfilled with concrete. Following this, a 16-in.-diameter 45-slot (0.045-in. openings) stainless-steel well screen was placed. Well-screen length was 30 ft and the screen was positioned within the limits of the aquifer. Gravel packing around the screen consisted of No. 6 \times No. 12 Monterey sand (Figure 6). Gravel pack and well-screen size used were the responsibility of the experienced well-drilling contractor.

Soil borings made by Caltrans before the well drilling indicated the aquifer was made up of the least 60 percent gravel with less than 10 percent minus No. 200 sieve sizes. Sampling techniques limited the maximum material size to 2 in.; hence, larger sampling diameters would have undoubtedly yielded a higher gravel percentage. Figure 6 shows the gradation of the aquifer and the No. 6 \times No. 12 Monterey sand used as gravel pack.

Wells were developed by jetting with water and back flushing. Peak discharge flows were a disappointing 500 to 700 gpm per well that soon leveled off to about 400 to 600 gpm. Renewed back flushing increased the flow to earlier, peak values but, after 2 or 3 days pumping, it again leveled off to the lower flows.

Drawdown characteristics were measured over a period of

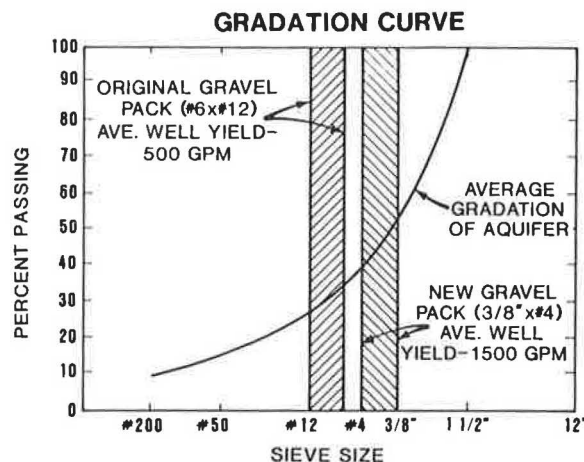


FIGURE 6 Gradation averages of aquifer and gravel packs. Original gravel pack incorporated 0.045-in. slotted screen; new gravel pack incorporated 0.100-in. slotted screen.

several weeks and indicated an approximate 5-ft drawdown at 100 ft under a combined pumping rate of 1,000 gpm (Figure 7). Because the wells were located approximately 110 ft from freeway centerline, a combined long-term pumping rate of at least 3,000 gpm was estimated to develop a theoretical 15-ft drawdown at centerline. A 15-ft drawdown was considered about the minimum required for an economic grouting program.

As a result, a decision was made to install three additional wells, two on the south side of the freeway and one on the north side. This time Caltrans engineers decided to install a 100-slot screen (0.100-in. opening) and increase the gravel pack to $\frac{3}{8}$ in. \times No. 4 (see Figure 6) to increase well yield and risk migration of fines from the aquifer.

Once these new wells were in and flushed, pumping began with significant increases in flow. The new north-side well had a long-term capacity in excess of 2,500 gpm, whereas the two south-side wells had long-term capacities of about 1,500 gpm. The belief that a significant increase in the migration of fines would occur was unfounded as pumped water indicated turbidity almost the same as that in the first two wells. With all pumps turned on, more than 5,000 gpm could now be pumped resulting in a drawdown of about 19 ft (Elevation 24) in the vicinity of the cistern. Figures 8 and 9 show the wells after installation and water discharge during pumping.

GROUTING

In order to (a) seal the primary source of water from the pump house area that connected to the aquifer, (b) shut off water flow

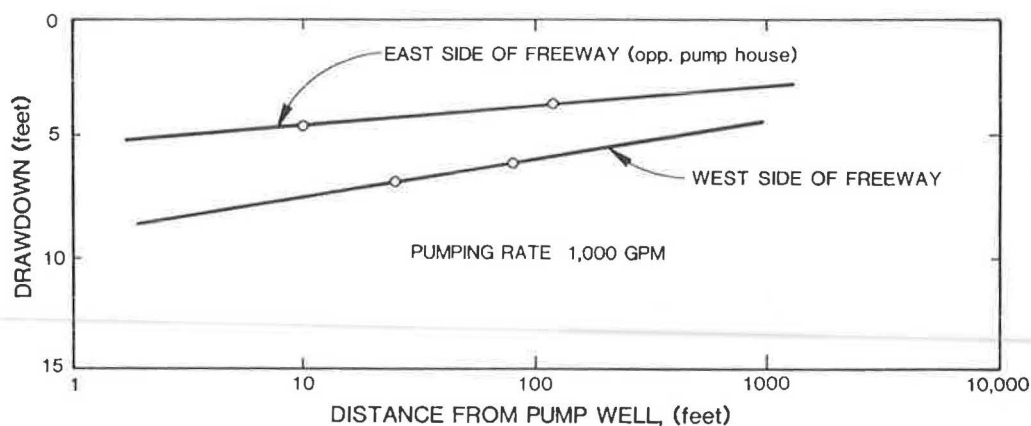


FIGURE 7 Drawdown characteristics of aquifer on east and west side of freeway. East side curve typified area drawdown when full dewatering was implemented.

in the clean gravel fill under and around the pump house and cistern, (c) fill voids created by the washing of fines, and (d) anchor the structures to resist buoyancy, a contract was let to Pressure Grout Company whose personnel worked with Caltrans to develop, implement, and modify the procedures.

Phase I grouting was to seal the perimeter of the pump house. This was accomplished from the sloping surface around the pump house using grout injection points driven to Elevation 10 (Figure 4) and staged up.



FIGURE 8 Bucket rig used in drilling wells. Upper 40 ft lined with 30-in. corrugated metal pipe and concrete backfilled. Water jet spray used for cleaning.

Phase II was to grout the pump house invert. This was accomplished by drilling through the pump house floor, setting packers (about 12 ft of groundwater head) with pipes attached that injected the grout at the base of the 2 ft of gravel fill underlying the slab. Phase III of grouting was to fill the gravel and voids under the cistern using the same techniques used in the pump house.

Phase IV was the grout filling of the gravel and voids around the perimeter of the cistern. Because of the three lanes of freeway above the cistern, this was accomplished through grout holes drilled through the walls.

The high water velocities through the 2-in. holes in the



FIGURE 9 Discharge from one of the wells during well development.

cistern (previously drilled to relieve water pressure from the highway pavement) scoured fines from the subgrade, the underlying silt and clay layer, and presumably from the aquifer itself, and ended up in the cistern, which acted as a settlement pond. During the pump-house grouting (Phases I and II) almost 150 yd³ of silt was removed from the cistern using a propane-powered Bobcat loader and hoisting it to the surface for transportation to a disposal site. Figure 10 shows the drilled relief holes and silt line within the cistern.

Because of the potential voids beneath the pump house, it was feared that any large decrease in the water level could result in settling of the pump house with resulting shearing of connections and supports to the cistern. At the same time, there was the concern that grout pressure could cause uplift. Using "dangerous" grout pressures (40 to 50 psi), techniques were used that essentially precluded uplift. Precise elevation monitoring was maintained during both dewatering and pressure grouting. Maximum differential movement of the pump house during both dewatering and grouting was less than 0.015 ft.

Grout mix used throughout this filling and sealing operation consisted of nine sacks of cement and three sacks of bentonite per cubic yard admixed to eliminate setting shrinkage and

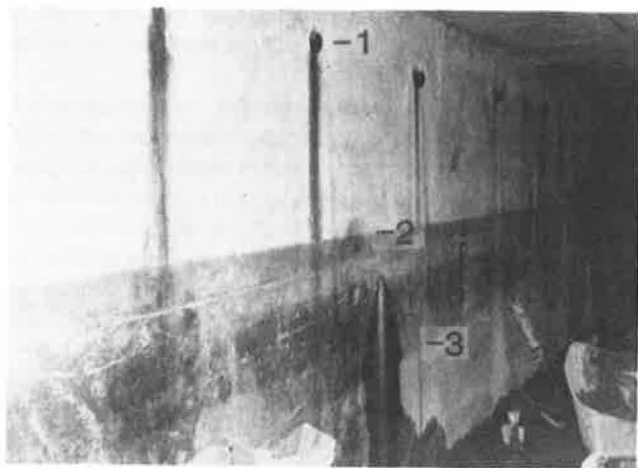


FIGURE 10 Inside 8-ft tall cistern. Note (a) drilled water pressure relief holes, (b) high water line, and (c) silt line.

yielding a full volume set. No sand was used because of potential filter plugging in the pea gravels; the goal was a complete filling of all voids.

Grout was pumped as follows:

Phase		Cubic Yards
I	Pump house perimeter	62
II	Under pump house	15
III	Under cistern	10
IV	Cistern perimeter	55

This work was completed in 4 working days.

SOIL ANCHORS

To resist buoyancy, it was assumed that the pump house and cistern would behave like a piston within the clay layer or cylinder. It was not known how effective the slurry grout seal was at depth; therefore, it was assumed that an effective seal existed only around the perimeter of each structure. Because of potentially large displacements in the soil as a result of earthquake loading breaking any bond between grout and the clay layer surrounding the structures, frictional resistance between structure and soil was conservatively assumed to be zero.

Resistance to uplift was then based on the dead weight of the structures plus any overlying soil. Uplift forces were computed on a water elevation rise to 48 ft (15 ft above freeway grade). Water elevation rises to a maximum of 53 ft (20 ft above freeway grade) were assumed as an ultimate condition. Water rises above this point would cause rupture of the overlying clay layer somewhere near freeway centerline, therefore it was considered fruitless to provide safety factors of the structures significantly higher than incipient failure of the freeway itself.

Under the design water elevation rise of 15 ft above freeway grade, 2,270 kips of resisting force was required to resist buoyancy of the cistern and 455 kips was required for the pump house. Several alternatives were evaluated to determine the best way to provide resistance to the buoyancy forces. Of the

alternatives discussed, the more practical ones, beside soil anchors, were tie-beams over the top of the cistern held down by large-diameter friction piles external to the structure; and for the pump house a girth strap with friction piles or dead weight added to the top of the structure. The soil anchors were preferred primarily because of the almost total lack of impact on the traffic flow. All the anchors could be installed from within the structures. The potential disadvantage was long-term stability due to corrosion of the pipe. However, this was of negligible concern because future freeway widening plans were no more than 10 years away and at the minimum, a new pump house was required. In addition corrosion estimates were very low for a 20-year design life based on the nonoxygenated water, pile depth, absence of chlorides and sulfates, and the highly alkaline environment of the grout around the anchors.

To determine pile tip elevation and anchor pullout resistance, soil anchors were driven into the ground at freeway surface and load tested. Soil anchors consisted of perforated 2-in.-diameter Schedule 80 steel pipe in 5-ft lengths, coupled with steel pipe sleeves (40-kip rupture). The anchors were driven by a pneumatic 90-lb pavement breaker (Figure 11) to depths of 30, 40, and 50 ft into the sand and gravel and then grouted in place. A minimum holding capacity of 30 kips was necessary, which was developed with the 50-ft penetration depth. Figure 12 shows the loading and reaction-frame apparatus used for the pullout resistance tests.



FIGURE 11 Air hammer used in driving soil anchors to depth. Location where test soil anchor is driven.

Figure 13 shows the soil anchors installed within the cistern before grouting and cutoff. Because the dewatering reduced the head, there was only a small inflow from the aquifer through these anchors. Casings were set from the top of slab to above the water table owing to the high head in the pump house, and all work progressed through the casings until the anchors were grouted.

The grout used was CemChem, a two-solution cement grout using set times of 30 to 45 sec. Longer set times would travel long distances in the gravel aquifer without benefit to the project. CemChem has the characteristics of full-volume set, no syneresis, and controllable final set times from less than 10 sec to more than an hour.

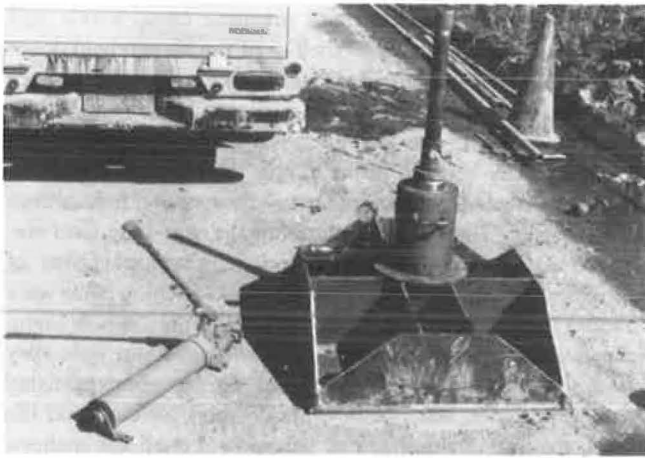


FIGURE 12 Hydraulic jack and reaction frame used for testing pile anchor capacity.

Once the technique was developed for anchor placement and grouting, the contractor began placement of the anchors within the cistern on September 7, 1985. A total of 105 soil anchors were placed within the cistern and 33 were placed within the pump house. The job was completed on November 1, 1983, 43 working days after driving the first anchor.

Design working load of each anchor was 20 kips with the ultimate estimated load between 30 and 35 kips. During the grouting process, anchors were periodically load tested for pullout capacity. Approximately 10 percent were tested with the first few indicating low pullout capacities of between 25 and 27 kips. Sandblasting the pipe and a change in the grouting procedure before placement resulted in the pullout resistance exceeding the 30-kip capacity requirement.

CONCLUSIONS

The dewatering, grouting, and soil anchor program was developed on an emergency basis. In particular, the soil anchor system had never been used before to the authors' knowledge and was an extrapolation.

In retrospect, the current problems could easily have been prevented if the pump house had not terminated on the sand layer immediately above the sand and gravel aquifer. Only a few feet of impervious material would have been sufficient to preclude piping. Alternatively, excavation of the sand layer and

recompaction of an overlying impervious material with or without a membrane seal would also have prevented the piping problem.

Future geotechnical investigations for such facilities will examine past historic peak water table elevations and design the facility accordingly unless strong evidence suggests otherwise. Caltrans has constructed a significant number of depressed sections in a variety of soil and water table conditions. In virtually every instance these facilities are trouble free as a result of the design accommodating site conditions.



FIGURE 13 Soil anchors installed in cistern before grouting and cutoff.

However, long lulls in high rainfall and the increased demand on virtually all usable water sources can produce a false sense of security, as happened in this instance. The lesson learned here is valuable and will be used as an excellent teaching guide for the future.

ACKNOWLEDGMENTS

The authors express gratitude to Dino Cassinelli and Dave Hayes of Caltrans District 4 in San Francisco for their field information and input in the preparation of this paper.