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ABSTRACT

At the La Rosita Power Plant site in Mexicali, Mexico, a 3-m thick layer of loose very fine sandy silt was encountered at about 7.5 m depth.. Settlement calculations performed for the heavier (150 to 200 kPa) settlement sensitive structures indicated values of up to 65 mm, compared to an allowable settlement of 50 mm.

During the design of the base plant, various options for limiting settlement were reviewed. Based on a cost and schedule review, jet grouting of the loose silt layer was chosen. The predicted post-grouting foundation settlement was approximately 35 to 40 mm. During construction of the base plant, the owner elected to add an additional unit on an adjacent site that had very similar subsurface conditions. The same ground modification options were again considered for this expansion unit. However, this time removal of a portion of the upper clayey soils and replacement with compacted structural fill materials was chosen as the best option. Computations indicated that removal to a depth of 3 m would reduce the predicted settlement to less than 50mm.

Measured settlements on both sites (base plant with jet grouting and expansion plant with soil replacement) were well within predicted limits. A comparison of the settlements showed that the soil replacement was slightly more effective than the jet grouting in these circumstances.

One meter of structural fill was required under all structures to prevent shrink-swell of the upper clayey soils. During the jet grouting operation at the base plant, the jet grout spoil materials were used in lieu of structural fill under the cooling tower foundation. At the expansion site, the cooling towers were supported on 1 m of structural fill since no jet grout spoils were available. The measured settlements of these two structures were almost identical, confirming that the jet grouting spoils produced an excellent fill material when properly handled.

INTRODUCTION

The La Rosita Power Plant Project, located in Mexicali, Mexico, was selected as the primary site for a new combined cycle power project. The project initially consisted of three gas turbine units, each with a heat recovery steam generator (HRSG), and a single steam turbine. The total output capacity of the plant when completed would be 760-megawatt. Later, during the initial construction period, a decision was made to expand the project to add an additional combined cycle plant to the adjacent site. This paper describes the details of the site investigation for the two plants, the resulting geotechnical design for the project, and the performance of the foundations during and after construction. A comparison is made of background and the performance of the two different foundation concepts used for the original base plant and for the expansion project.

DETAILS OF POWER PLANT SITE

Site Location and Description

The site is located in Las Palmas, west of the City of Mexicali, Baja California, Mexico, north of km 12 on the Federal Highway Mexicali-Tijuana. At the time of the investigation the proposed project site consisted of a rectangular-shaped lot with an area of 24.53 hectares (60.8 acres). The lot was previously used for agricultural purposes, as were the adjacent surrounding properties. The site is relatively flat, with a slope of 0.07 % from south to north and 0.09 % east to west. The average elevation is 1.69 m above mean sea level.

Geologic And Tectonic Setting

The site is located at the western end of Mexicali Valley, an active seismic region in the southern Salton Trough and Lower Colorado Delta. The Mexicali Valley is flanked by the Chocolate Mountains to the northeast and the Sierra Cucapa to the southwest. Mexicali is located in the paleo-floodplain of the Colorado River, which prior to 1901 shifted back and forth between the Salton Sea and the Gulf of California. Ground elevation in the Mexicali area is near sea level, with a very low regional gradient slope to the northwest.

Geologic faults, tectonic folds and earthquakes represent active tectonics in this region. These tectonic effects are primarily a result of tectonic plate interaction along the margin of the North American and Pacific tectonics plates. Most of the displacements between these two plates occur along the San Andreas Fault and associated major faults, such as the San Jacinto, Imperial, Cerro Prieto, Laguna Salada and Elsinore faults.

The Mexicali Valley was originated as grabben filled with continental sediments deposited by the Colorado River; the Sierra Cucapa is a tectonic lift located at the west of the grabben.

Local Geology and Seismicity

The site is located in a portion of the Mexicali Valley basin that experienced episodic flooding from the Colorado River and occasional submergence beneath ancient Lake Cahuilla. The soils are generally flat-lying lacustrine, deltaic and fluvial deposits. These materials are latest Holocene in age, and appear to record only the past several hundred to several thousand years of depositional history of the basin.

The Mexicali Valley is designated as Zone D in the Seismic Regionalization for the Mexican Republic (Regionalización Sísmica de la República Mexicana), Manual de Obras Civiles. The Comisión Federal de Electricidad, 1993, has also characterized this region as an area of frequent earthquakes of high magnitude. The design earthquake for the site has a 0.42g peak ground acceleration.

SITE INVESTIGATION

A detailed field investigation was performed at the site in August 2000. Subsurface conditions were explored by drilling 34 boreholes to depths ranging from 5 to 30 m beneath existing grade. Drilling was conducted using mud rotary methodology. Altogether, 490 split-spoon samples and 46 undisturbed 3- and 4-in. diameter Shelby tube samples were obtained.

- Selected soil samples obtained from the field investigation were tested in the laboratory to evaluate classification indices and estimate relevant engineering and chemical properties.

SUBSURFACE PROFILE AND ENGINEERING PROPERTIES

The subsurface conditions consisted of approximately 1 m of organic material, 7.5 m of a medium stiff to stiff clay underlain by 2.5 to 3 m of loose to very loose very fine sandy silt, then a few meters of dense sand and then a very stiff clay layer. Based on the results of the field investigation and the laboratory-testing program the following engineering properties were determined for each of the soil layers. It was always assumed that the upper organic layer would be removed from under all foundations.

Table 1. Soil Properties

Layer	Depth	USCS	w	LL	PL	γ	c_u	ϕ
	(m)		(%)	(%)	(%)	kN/m^3	kPa	Degrees
1	1.00-8.50	CH	16-30	71	21	19.1	112	0
2	8.50-11.0	ML	19-24	NP	NP	15.7	0	25
3	11.0-15.0	SM	21	NP	NP	15.7	0	40
4	15.0-30.00	CH	19-32	72	21	19.2	139	0

FOUNDATION DESIGN CONCEPTS

Preliminary Design Concept

Prior to the start of the project, the project owner provided the logs of 3 soil borings. These borings were each conducted to a depth of 15 m, terminating in the dense sand layer. Based on these borings, the initial preliminary foundation design concept for the project was to support the heavy and settlement sensitive foundations on piles driven into the dense sand layer. The piles were designed mostly as end bearing, driven into the dense sand, with some friction along the shaft for the embedded length in the sand layer. The decision to use deep foundations was based on calculations that showed unacceptable settlements (greater than 50 mm) resulting from combined settlement in the upper clay, the underlying silt layer, and the lower clays. The calculations showed that the upper clays would behave elastically (preconsolidated) and would not act in virgin consolidation. The calculated settlements assuming virgin consolidation were about 10 times higher. It was also assumed at that stage that the dense sand layer was continuous to a much greater depth.

Final Design Concept for Base Plant

The results of the project subsurface investigation indicated that the dense sand layer was of limited thickness, and in fact in some areas was nonexistent. As a result of these changes from the original assumptions, the design concept of driving the piles into the sand layer no longer was valid. The initial revised concept was to drive the piles into the lower clay layer, changing the design from end bearing to mostly friction piles. However, in making this change, the pile length dramatically increased from about 15 m to over 20 m, increasing the cost of the piling by over 33 percent.

With the increased cost of the foundation installation, other foundation concepts were investigated, including ground improvement, removal and replacement of the upper clay layer, and surcharging the site. Initial cost estimates showed that removing the upper clay layer would not be acceptable. The schedule impacts of surcharging were also found to be unacceptable. With regard to ground improvement, design calculations showed that either treating the upper clay layer or the lower loose silt layer could reduce the settlements to acceptable levels since both were contributing equally to the overall settlement. However, since the lower silt layer had a thickness of only 2.5 to 3 m, a method that treated just the silt would be more economical than treating the upper 7.5 m of clay. Based on the above, Super-jet grouting of the silt layer was selected. In general, the program consisted of drilling down to the bottom of the silt layer into the top of the dense sand, and then injecting grout under high pressure to form and soil-cement column up to the upper clay layer, as shown below in Fig. 1. The columns would then transfer any foundation loads through this layer into the underlying sand.

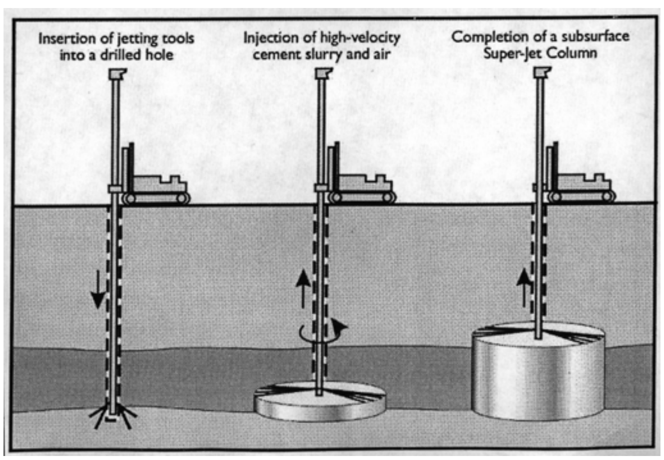

Fig. 1. Installation Details of Jet-Grouting Soil Columns (Courtesy of Hayward Baker Inc.)

The jet-grouting was performed on a grid pattern under the entire array of heavy and settlement sensitive foundations. It was calculated that the settlements under the foundations in all cases would be reduced to less than the acceptable limit of 50mm. The details of the ground improvement program for this site can be found in Bell *et al*., 2003.

Upon completion of the jet-grouting, the foundations were installed on top of the upper clay layer. In addition, due to concern of shrink-well of the upper clay layer, the upper 1 m of clay was replaced with a well-compacted sand layer. The removal of the upper clay was also considered in the calculations to help reduce the computed settlements to the acceptable levels.

Foundation Concept for Expansion Project

During the construction of the base plant, a decision was made to expand the plant to include on additional combined cycle unit on the site immediately adjacent to the north end of the base plant. The subsurface investigation for the expansion site indicated very similar soil conditions. As a result, it was initially planned to remobilize the specialty contractor to conduct the jet-grouting program for the expansion project. Again, due to cost and schedule considerations, other foundation concepts were considered, as had been done previously done for the base plant. The concept of replacing the upper clay layer or a portion of the clay layer was also further investigated. In the process, a calculation was made to determine the minimum thickness of the upper clay layer that would need to be removed to reduce the calculated settlements to just under the 50 mm level. These calculations indicated that it would be necessary to replace approximately 3 m of the clay material with a well-compacted sand material to reduce the settlement. In general, each additional meter of clay replaced with structural backfill reduced the predicted settlement by about 5 mm. Based on these recommendations; the construction of the expansion plant was performed in this manner.

FOUNDATION PERFORMANCE

Settlement Monitoring

Throughout the construction of both the base and expansion pants, settlement measurement of all foundations was conducted on a routine bases to monitor the performance of the foundations. Fig. 2 is a plot of the settlement of the Steam Turbine Generators for both plants.

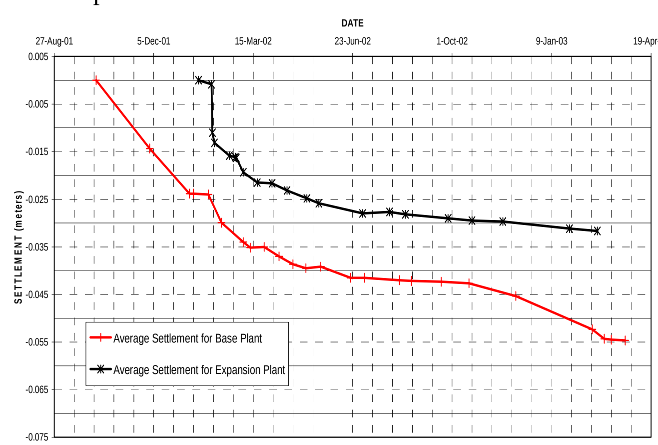

Fig. 2. Measured Settlement for Steam Turbine Generator for Base and Expansion Plants.

Observations from Settlement Readings

As can be seen from Fig. 2, the settlement of both Steam Turbine Generators generally resulted in values within the predicted and anticipated ranges. In addition, it can be seen from Fig. 2 that the settlements were almost entirely elastic with the settlement occurring with the application of the load. The initial settlement took place with the pouring of the base mat, which contributed to about 40 percent of the final foundation dead load. The second marked increase in settlement was during construction of the columns and the elevated platform for the equipment. The third notable increase in the measured settlement resulted from the placement of the equipment. At the end of equipment placement, the measured average settlement for the base plant Steam Turbine Generator was about 45 mm. This compared to the design calculated value of 50 mm. At the end of the placement of the equipment for the expansion plant, the measured average settlement for the Steam Turbine Generator was about 30mm, well within acceptable limits and significantly less than the design predicted value of 50 mm.

Normally it would be not be considered a problem or a concern that the measured foundation settlements were less than the predicted values. However, in this case the predicted settlements were used to determine the depth of undercut and replacement needed. Therefore, the over-prediction of the settlement resulted in additional cost to the project. In trying to determine the cause of the over-prediction, it was found that the major factor was an incorrect design assumption. The calculation for the steam turbine generator for the expansion plant was based on the assumption that the same piece of equipment with similar loads was being used in both plants. It was later found that the Steam Turbine Generator for the expansion project was a smaller unit with lower foundation loads. If this had been known during the design phase, the depth of the undercut could have been reduced to about 2 m, with a resulting cost saving to the project. The additional settlement of about 10 mm shown for the base plant occurred during the initial operation of the unit due to live loading and foundation vibration. Final post-operation readings for the expansion plant were not taken.

In reviewing all the other factors used to determine the predicted and measured settlements, it was found that the soil parameters and assumptions used in design were very reasonable, particularly the assumption that the upper clayey soil layer would perform elastically. Fig. 3 demonstrates the elasticity of the soils more dramatically during the hydro-testing of one of tanks at the La Rosita site.

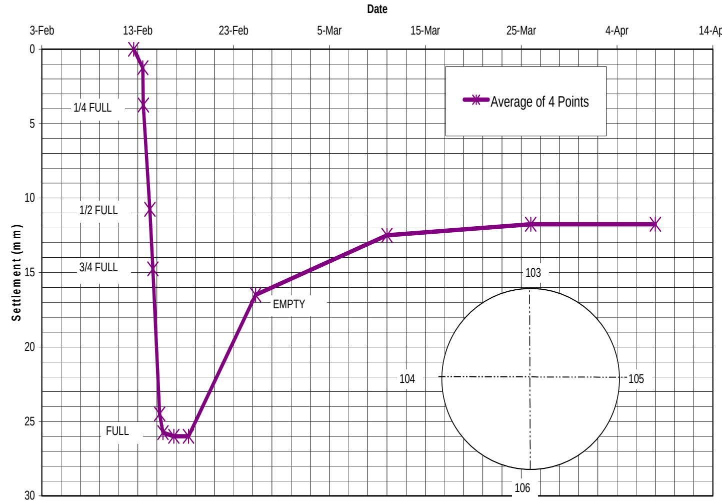

Fig. 3. Measured Settlement of Fire Water Tank

Settlement of Cooling Towers and Use of Spoil Materials

For the lightly-loaded structures, the only foundation improvement made was the removal of all organic soils and the replacement of the upper 1 m of the clayey soils with a well-compacted sand fill, which was done to protect the foundations from shrink and swell. The only difference between the base and expansion plant with regard to the cooling towers was that the fill under the cooling tower for the base plant was the spoil material generated from the grouting operation. The 1 m undercut beneath the cooling tower was excavated prior to the start of the installation of the jet-grouting. During the installation of the jet-grouting, the spoil material, which consisted mainly of grout and silt material, was allowed to sit for approximately one day, then transported to the excavated area, as shown in Fig. 4.

Fig. 4. Spoil Material From Jet-Grouting Being Loaded for Transport to Cooling Tower Foundation Area.

After moving the material to the excavated area, it was spread by a dozer, compacted and leveled using a road grader. Shown below, as Fig. 5, is the near-completed foundation pad for the cooling tower using the spoil materials.

Fig. 5. Completed Foundation Pad for Cooling Tower Foundation Using Spoil Material.

The settlement monitoring for the cooling tower for the base and expansion plant are shown below in Table 2.

Table 2. Measured Settlements for Cooling Towers

	Base Plant	Expansion Plant
Average	12 mm	10 mm
Maximum	21 mm	20 mm
Minimum	6 mm	2 mm

As can be seen from the measured settlements, the spoil material from the jet-grouting produced results nearly equal to those obtained using an imported structural fill material. It was also found from closely monitoring the settlement data from these two projects that the highest settlements under the cooling tower occurred at the location immediately adjacent to the cooling tower forebay area, where a deeper excavation was made after the foundation for the cooling tower had been poured.

CONCLUSIONS AND RECOMMENDATIONS

The two La Rosita projects offered the opportunity to use and compare different foundation alternatives and techniques to reduce the anticipated settlements to acceptable levels. This al so allowed an evaluation of the effectiveness of the two ground improvement techniques. The base plant used ground modification (jet-grouting) to improve a deeper soil layer while the expansion plant used soil replacement of a portion of the upper soil layer to accomplish the same goal. The two techniques were very different, but the results both proved favorable for both projects. The jet-grouting for the base plant was more economical than the soil replacement due to the size of the project (3 units) as where the soil replacement was more economical and could be completed in a shorter schedule for the smaller expansion plant. the In addition, the reuse of the spoil material on the base plant provided a significant cost saving in reducing the quantity of imported fill material required, and also the need for finding another method and location for disposing of the spoils.

The main conclusion and finding from these projects is that there is often more than one foundation alternative for each project. The final selection must not only consider the purpose of the foundation technique (providing a safe foundation with acceptable settlements). It must also consider the economics and availability of materials. The collection of the settlement data for these projects enabled measurement and evaluation of the effectiveness of both of the two techniques chosen.

The recommendations and lessons learned from this project showed the importance in monitoring the performance of the foundations once installed. It should always be the roll of the project geotechnical engineer to be involved with a project through construction and initial operation to confirm that the chosen foundation design not only performed as planned but also was the most effective design.

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