03 Jun 1993, 10:30 am - 12:30 pm

An Unsuccessful Urban Deep Excavation in Soft Soils

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Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 5.15

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SYNOPSIS This case history presents, from a geotechnical engineer's viewpoint, various technical, budgetary, coordination, staffing and "hidden agenda" issues that contributed to poor performance of a shored deep excavation in soft soils. The anticipated and actual construction procedures are discussed and compared. In addition, approaches to stabilize significant movements of the shoring, and the methodology needed to justify a satisfactory future performance of a pile foundation system that was speculated to be damaged are discussed. By highlighting these issues, it is hoped geotechnical engineers will anticipate and better deal with the issues under their influence, understand issues over which they may not have control, and appreciate the need for mutual understanding and cooperation by members of the design team.

INTRODUCTION

Design and construction of a deep excavation in soft soils within an urban setting is a very difficult task that requires the cooperation and understanding of geotechnical issues by the design team, contractor and owner. One deep excavation made in San Francisco in the late 1980's resulted in significant movement of shoring, distress to adjacent streets, loss of usable building space, significant delay to the construction schedule, increased costs, suspicion of future performance of the foundation system, and, finally, litigation. This paper discusses this case history from a geotechnical engineer's viewpoint, highlighting the issues involved that may have contributed to the final unsatisfactory outcome. Many of these issues are generally not apparent to the geotechnical engineer until it's too late, while others are beyond the engineer's control. These issues include:

- Poor initial design review;
- Poor communication between the geotechnical engineer and the owner/contractor concerning budgets, areas of responsibility and construction methods;
- Accelerated construction schedule;
- Errors in construction which took significant effort to correct;
- Inexperienced contractor, subcontractors, and owner;
- Unusual owner relationship between developer, design professional and contractor;
- Least cost approach to design;
- The use of "second tier" staff for supervision during night shift; and
- Difference between acceptable movements and failure.

The above issues are in addition to the technical issues that may ave had an impact on the cause of the shoring movement, and the npact on the foundation system. These issues include:

- Slope stability of excavations in Bay Mud;
- The impact of disturbance to the earth berm shoring retention system;
- Improper excavation techniques;
- The impact of lateral soil movement on a pile foundation system;
- Verification of the reliability of the foundation system; and
- The problems with using a larger than normal follower to drive the piles.

Both the non-technical and technical issues listed above are discussed in the following sections of this case history as either distinct issues or incorporated within the description of the actual construction procedures.

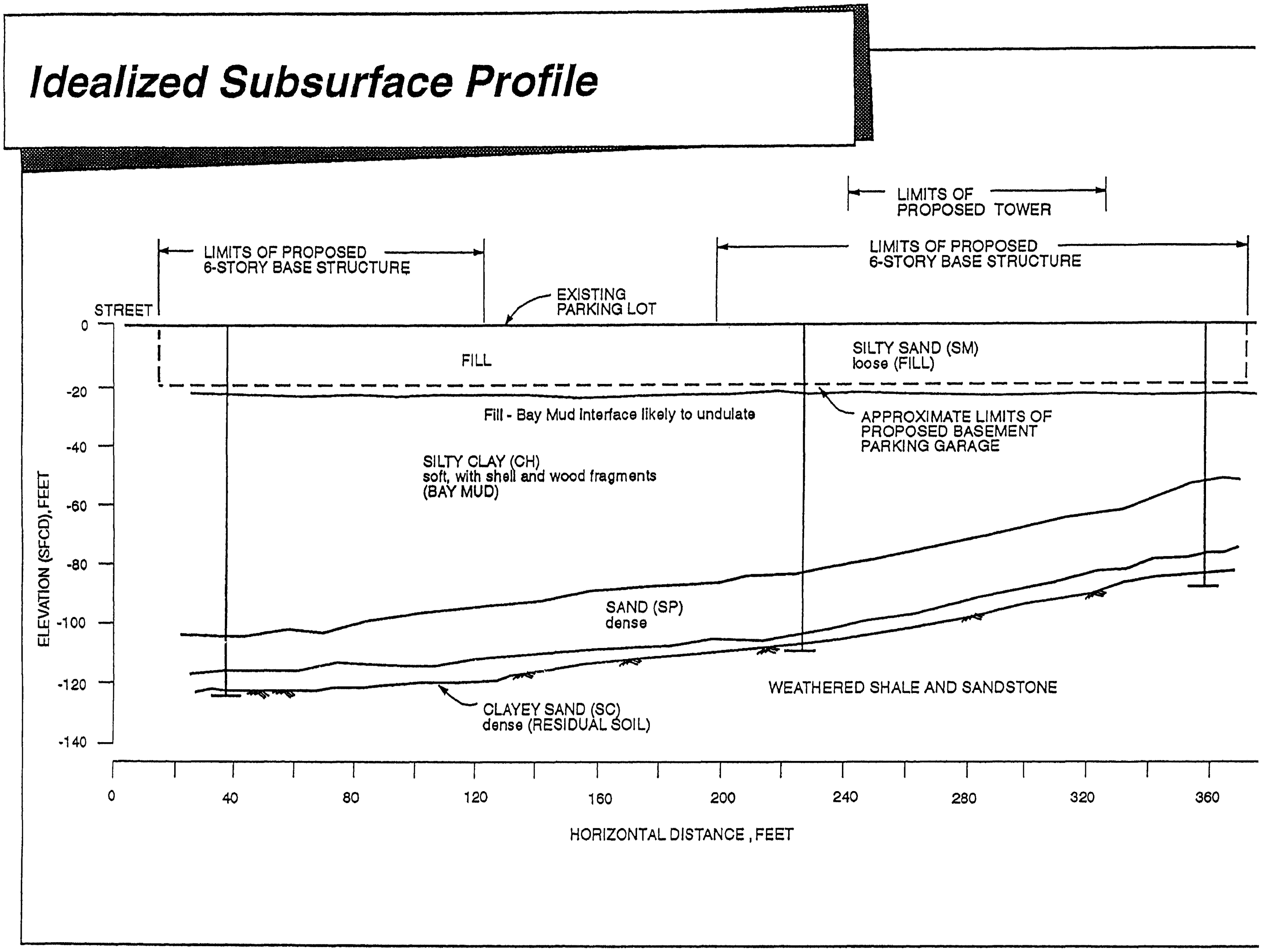
PROJECT DESCRIPTION

The project consisted of the construction of a mixed used high-rise that includes retail and residential covering half of a large city block in the South of Market section of Downtown San Francisco. The structure includes a six-story base structure 220 by 275 feet in plan with an additional two levels of basement extending below grade. Two 19 story residential towers were constructed above the base. The base structure and towers are all of reinforced concrete construction, with interior and exterior columns carrying loads on the order of 3,000 and 1,100 kips, respectively.

The area of San Francisco in which the project is located is land reclaimed from San Francisco Bay. In the late 1800's, the waterfront areas of San Francisco were diked off from the Bay by seawalls, and sand and rubble fill was placed landward of the walls to provide developable land. The fill was generally uncompacted and, consequently, remains loose even today. At the project site the fill varies from approximately 10 to 25 feet thick, and is underlain by about 60 to 80 feet of compressible marine clay known locally as Bay Mud. Bedrock consists of interbedded weak shale and hard sandstone found at depths ranging from about 90 to 120 feet below the ground surface. Groundwater at the site fluctuates with the tide, but is generally on the order of 10 feet below the ground surface. An idealized subsurface profile is shown on Figure 1.

The excavation required to construct the two level basement was about 28 feet deep and extended below the fill at the site and into the Bay Mud. The groundwater level is approximately 18 feet above the base of the excavation. To support the large column loads, and resist the hydrostatic uplift due to the groundwater, the foundation for the

Figure 1
Idealized Subsurface profile



development is a pile supported mat. The mat is two and one-half feet thick except at pile caps where it is typically five feet. Piles are 12 and 14-inch square precast prestressed concrete ranging in length from about 70 to 110 feet. The total number of piles driven for the project was about 1100. Each pile was designed to be driven to bedrock and to support 130 tons of combined dead and live loads.

ANTICIPATED CONSTRUCTION PROCEDURES

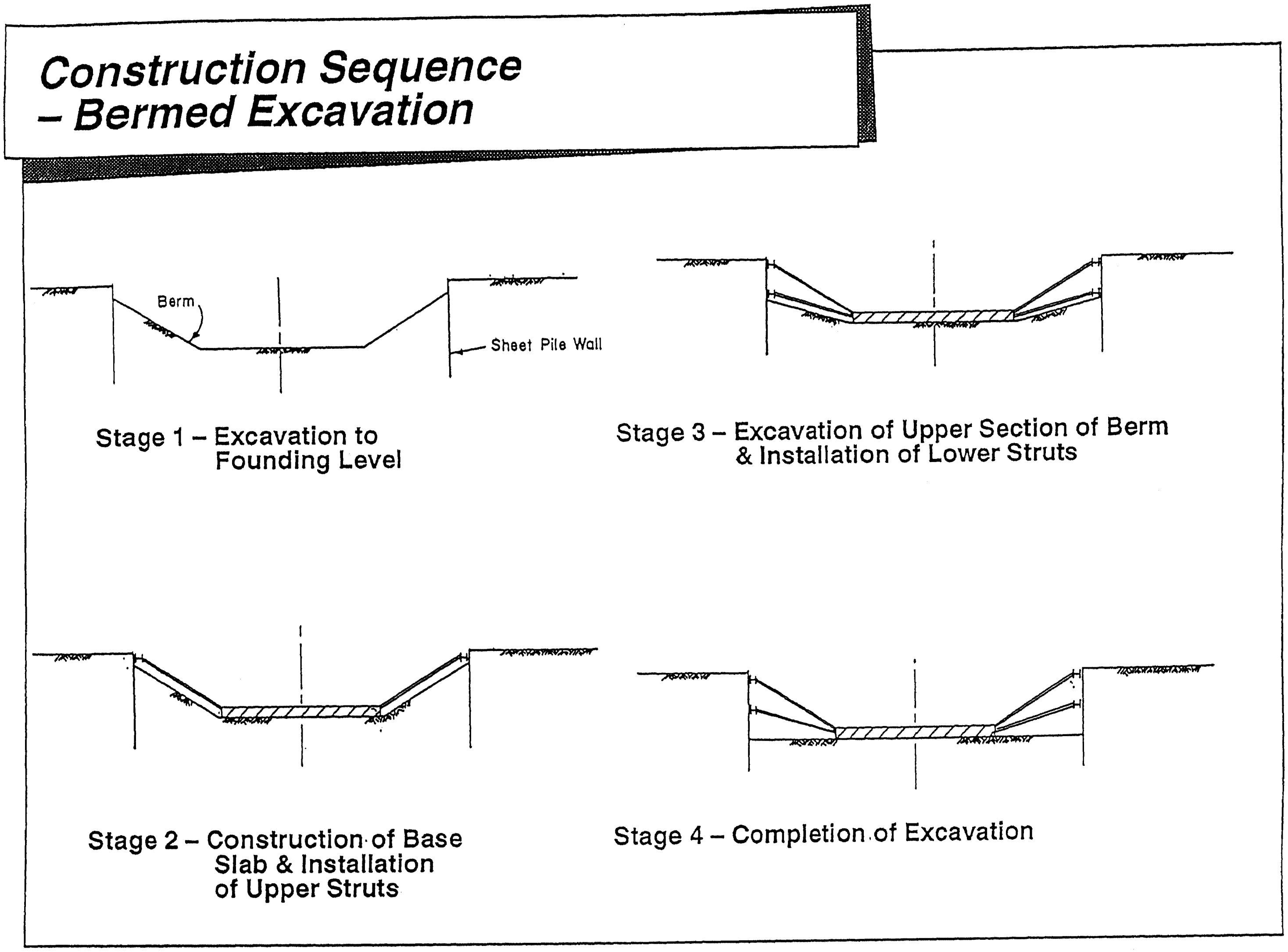
Construction of the basement required a deep shoring system. To reduce the amount of dewatering, the structural engineer suggested that a braced sheet pile shoring system be used. The system was designed by an experienced shoring designer, using lateral earth parameters presented in the original soils report for the project. Following the initial design of the system, the owner requested a redesign due to cost constraints. As a result, the lateral earth pressures were reviewed by the geotechnical engineer, and higher passive pressures were provided as a result of adding a friction angle to the cohesion properties of the Bay Mud. The redesign of the shoring system, which resulted in hundreds of thousands of dollars in savings, consisted of braced sheet piles, approximately 50 feet long, with two levels of internal braces (struts). The design and sequencing of the shoring installation was closely tied to the installation of the pile foundation. The sequencing consisted of:

1. Drive the sheet piles around the site perimeter;
2. Excavate to a depth of 6 feet to install the upper waler for shoring system and install precast concrete piles to supp foundation loads;
3. Following internal dewatering, excavate a 1 to 1 (horizo to vertical) sloped berm from the depth of 6 feet to bottom of the mat grade;
4. Construct central portion of the mat covering approximat one-half of the center of the basement;
5. Install the first row of internal braces;
6. Excavate berm to approximately 10 feet above the bottom the mat grade and install the second row of braces; and
7. Excavate remainder of berm to reach final grade.

The excavation sequences are illustrated on Figure 2 below.

Prior to installation of the sheet piles, the geotechnical engin reviewed the shoring design in accordance with the City of S

Figure 2
Bermed Excavation Construction Sequence



Francisco's requirements for the excavation permit application. The purpose of the review was to evaluate whether the soil parameters used in the design were in accordance with those recommended by the geotechnical engineer. The shoring review was performed by a staff engineer who, because of the firm's literal interpretation of the purpose of the review, did not extend his review beyond soil parameters. The inclination of the berm slope, the depth of the shoring to prevent heaving, and the construction stages were not checked for stability. The shoring designer indicated that movement of the shoring system would generally be limited to about 2 inches, and that would be tolerable for the adjacent streets and underground utilities.

The above outlined construction procedures required that the piles to support the building be driven at a grade approximately 22 feet above the design pile cut-off grade. Concerns were expressed by the geotechnical engineer that driving piles from this height above the design pile cut-off grade would: 1) require the use of a longer than normal follower that would make it difficult to evaluate final performance of the pile; and 2) increase the potential for pile damage. Pile damage was a concern because many of the piles were expected to extend above the design pile cut-off grade because of variations in the bearing strata, and damage to the piles may occur during the excavation stage to reach design subgrade. The owner and contractor ignored the engineer's concern and elected to drive the foundation piles from the grade initially indicated. In order to address the concern regarding the performance of the pile using the follower, during the indicator pile program (which aids in estimating production pile lengths), the piles were driven with the anticipated length of follower, and at two locations, extra long piles were driven next to piles driven with the follower in order to evaluate the difference in pile driving with and without the follower. It was found that the energy dissipation associated with the use of the follower was equivalent to about 8 blows per foot with a Delmag D36-23 diesel pile hammer.

A concern was also raised by the geotechnical engineer regarding the method of excavation. The concern addressed the use of steep temporary construction slopes during excavation that could result in local failure in the Bay Mud and significant lateral movements. These movements are generally are unnoticed during excavation, but based on the experience from an adjacent project, could result in significant lateral deflections of the foundation piles before they are incorporated into the structure.

ACTUAL CONSTRUCTION PROCEDURES AND RESULTS

Following removal of the existing asphalt parking lot at the site, the sheet piles for the shoring system were driven. The driving of the sheet piles resulted in densification of the loose sand fills at the site, with corresponding settlement of the adjacent streets of approximately 6 to 12 inches, with some initial minor cracking. The initial excavation was then made, but was increased from 6 to 8 feet in depth by the contractor for easier installation of the perimeter waler. During this initial excavation, the top of existing wood piles were encountered that were speculated to be part of an old wharf. These piles were determined by the contractor to interfere with the installation of the new concrete foundation piles for the building, and as a result the owner agreed to their removal. Over 300 piles were removed, most within about 60 feet of one side of the shoring. The shoring designer requested that the holes resulting from the extraction of the wood piles be filled with sand or grout. During removal of the wood piles, the contractor found that filling of the holes was not practical without expensive equipment and chose to forego the backfilling without notifying the shoring designer. Throughout this period of time, the geotechnical engineer was not aware of any work occurring at the site.

After the initial excavation was made, the wood piles extracted, and the area regraded to allow for access by the pile driving rig, the production piles were driven under the observation of the geotechnical engineer. Because of the proximity of the site to the financial district of San Francisco, all pile driving had to be performed at night, which resulted in "second tier" management by the contractor. During pile driving, the amount of penetration into the bedrock to achieve adequate support was found to vary significantly, even in the same pile cap. Differences of up to about 10 feet in a 15 by 15 foot pile cap were found. This resulted in a large number of piles with the tops above the design pile cut-off grade.

During production pile driving, the portion of the sheet pile shoring adjacent to where the wood piles had been removed, was found to have moved several inches toward the excavation. These movements were larger than anticipated at this stage of construction. It was decided to monitor the movements of the shoring system on a weekly basis.

Following production pile driving, excavation began without prior review of the operation by the geotechnical engineer, as required by the project specifications, and without notification to the geotechnical engineer. When approximately one-half of the excavation for the central mat was completed, the geotechnical engineer noticed, during an unrelated site visit, that near vertical temporary cut slopes of up to 15 feet in height had been made in the fill and Bay Mud, counter to the original recommendations by the engineer. There was a concern that lateral movements could have an impact on the piles that extended above the design pile cut-off grade. The excavation operation was stopped, and procedures were changed to perform the excavation more uniformly across the site. During the excavation, movement of the shoring adjacent to the location where the wood piles were pulled continued to occur. At one point, a maximum rate of about 1/8 inch in a 24 hour period was measured. These movements were additionally impacted by the contractor creating steeper than designed inclinations at the toe of the berm slope, and insufficient dewatering of the interior of the site which resulted in constant water infiltration. The insufficient dewatering caused the near fluid Bay Mud to flow into the excavation where exposed in the berm. This created additional instability during the excavation process.

Because of concerns of the impact on the schedule of emergency remediation, measures to address the movements were not implemented until after the shoring had moved about 10 inches into the excavation. The measures implemented included decreasing the inclination of the berm slope from approximately 1-1/2 to 1 (horizontal to vertical) to between 3 and 4 to 1. This measure was found to significantly slow the rate of movement, but did not eliminate it. As a result of using this scheme, the lateral extent of the berm increased and the plan size of the central mat had to be reduced, which resulted in longer internal bracing (struts). During the remainder of the excavation, the contractor many times ignored the concerns of the geotechnical engineer concerning the precarious balance that had been achieved by the remediation scheme, and elected to make near vertical notches in the earth berm to construct tower cranes and to install dewatering sumps, stockpiled mate and soil at the top of steepen slopes, and excavated in the str behind the shoring where diagonal corner bracing was located, a which resulted in additional movements. Ultimately, the maxin shoring movement was over 18 inches, which resulted in the los usable basement space and distress to adjacent streets and utilities.

During the excavation process, it was uncertain as to what im the movement of the shoring would have on the foundation piles the building. Following excavation for the central mat, most o piles nearest the location from where the wood piles were extra were found to be 4 to 19 inches off design location, wit preponderance of mislocations away from the shoring. mislocation could have been the result of lateral movement of shoring or the earth berm during excavation, errors made in original pile location layout, piles inadvertently driven off loca (especially with the use of a long follower, which made vi tracking impossible), or a combination of these. It was determ that only the lateral movement scenario would have a signifi impact on the future performance of the structure, since the could be either broken or overstressed laterally. As a result, va attempts were made to verify the adequacy of the piles to suppor design vertical and lateral loads. The first attempt was based o assumption that any pile that had been elastically deflected by movement would possess sufficient strain energy to bounce ba freed by removal of soil on the tension side. A large diameter a was used to remove the soil from the tension side, but due to plastic nature of the Bay Mud at design pile cut-off grade, this approach proved inconclusive. Sonic testing of the piles also pr to be inclusive. Finally, two vertical and lateral pile load tests performed, using the adjacent piles for reactions. These tests sh the piles were capable of supporting at least 150 percent o vertical design load. It was concluded that the piles are capab supporting the design loads as long as the pile caps and assoc mat are sufficiently reinforced to evenly distribute the design l In this way a single pile defect, if any existed, would only ha minimal effect on the mat as a whole.

After completion of the project, legal action was brought b owner against the geotechnical engineer and the shoring designe material and delay costs, estimated to be approximately six mi dollars. The engineers cross-filed against the contractor. The was settled out of court, with the terms not disclosed.

ISSUES

In reviewing the construction of the project, the problems occurred were found to result from many issues, with no spe issue easily identified as the main source of the problems. T issues include technical, budgetary, coordination, staffing, "hidden agenda" issues not initially understood by some of the de consultants. These issues are discussed below.

A unique characteristic of the project was the partnership that m up its ownership. The development was owned by a lim partnership consisting of a developer, the general contractor for project, and one of the a design engineering company, along numerous minority partners. The make-up of this partnership not apparent to the geotechnical engineer at the outset of the proj and became known to him only after difficulties arose in which contractor was at odds with the geotechnical engineer regar appropriate solutions. In instances where this occurred, contractor would, on occasion, invoke his position as an owne reject decisions which were unfavorable to him. Because of this usual relationship between owner/designer/contractor did not alv exist. Decisions affecting the contractor's work were difficul discuss with the ownership partners, and criticisms of procedure quality of work were sometimes rejected outright. In general, t was a perception by the contractor/owner and that he knew bes the project regardless of the criticisms or recommendations prese by consultants. This attitude contributed to problems with excava and shoring techniques, and hindered implementation of solutions

Review by the geotechnical engineer of the shoring system performed by a staff engineer relatively inexperienced in this typ excavation. Although the review fulfilled "the intent" of the review, a more in-depth review would have revealed that the design inclination of the berm slope was probably too steep for the Bay Mud conditions at the site, that the depth of shoring below the bottom of the excavation was probably not sufficient to avoid heave, and the stability of the shoring during the various stages were not sufficient to limit movements to the originally anticipated 2 inches. In short, the shoring design was not overly conservative and was very sensitive to errors in installation and any unanticipated conditions. However, since movement began at a stage of excavation before the above items could have significantly impacted the stability of the excavation, it is unknown what influence they would have had on the ultimate performance of the shoring if other things had not gone awry.

There was no pre-construction meeting to discuss the soil report or procedures for excavation recommended in the report. Essential recommendations given by the geotechnical engineer had been omitted from the construction documents either through oversight or as cost cutting measures. Specific recommendations regarding excavation procedures were omitted. Recommendations for backfilling of voids created by the removal of timber piles were dispensed with because of costs. During the initial stages of construction it was apparent, in hindsight, the trend the contractors attitude would take toward the consultants and their recommendations. Recommendations were selectively implemented and changed, including the depth of initial excavation, which was increased.

Because of deadlines related to financing and tax considerations the project was on an accelerated construction schedule. Pressure was therefore placed on fast-tracking foundation installation and basement excavation. A number of design details associated with these activities were overlooked inadvertently because of haste, and others were not implemented because they were considered too time consuming. Excavations were made in excess of the depths prescribed by the sequencing and were not properly braced when old foundations were removed below the depth of planned excavation, and other activities were carrier out without notifying the responsible consultant. Consultants were not informed either through ignorance of the contractor, or to avoid their possible objection to the procedures being used. As a result, the geotechnical engineer was often unaware of activities under his purview until after the fact, and sometimes after significant problems had arisen. This is especially true in association with the pulling of the existing wood piles, and not refilling the resulting voids. As a result of allowing the Bay Mud to squeeze into the voids created by pulling nearly 300 piles, the integrity of the earth berm to restrain the shoring was reduced. Interaction with the geotechnical engineer would have hopefully resulted in another approach that would have filled the voids, such as grouting of the voids as the piles were extracted.

The architect for the project was an out-of-town firm that did not naintain an office in the locale of the project to service it. Communications were initially handled through the contractor's uperintendent. As the project progressed, a full-time construction nanagement specialist was brought in by the ownership. However, is primary function was to control costs. As problems with work rogress arose, discussions with the project manager became more dversarial and not conducive to solving problems, especially where elays and/or additional costs were involved.

When shoring movements became excessive, rather than halt xcavation until an adequate solution could be formulated, the ontractor and construction manager insisted excavation of the site roceed and a solution be found as the work was in progress. This sulted in several attempts at arresting the movement which failed ecause of slow implementation, poor design, and changing nditions as the excavation progressed. In the end, excavation work d to be halted, portions of the site backfilled, and after days of lay, started anew with a drastically changed excavation and shoring heme.

Because of the location of the project near the financial district of n Francisco, all pile driving had to be performed at night. Other construction activities were carried out during the day. As a result, senior personnel of the general contractor were on-site during the day and the night shift was usually manned by junior or second tier staff. These people were generally inexperienced with the issues they were called upon to decide during the pile driving. The complexities of the site and the variable nature of the subsurface conditions resulted in several situations which could not be resolved on the spot by the contractors night staff. Delays were therefore incurred, usually until the next day, while the proper people were contacted and the issues resolved.

Finally, consideration should be given to assessing the difference between acceptable movements and failure. Although there were no drastic shoring failures during the project, movement of 18 inches is beyond that acceptable for this type of excavation. The process to estimate lateral movements of shoring systems are generally based on experience, rather than the use of analysis. For this project, the original estimate by the shoring designer of two inches of lateral movement was probably based on previous projects that most likely included excavations other than in Bay Mud sites. The two inch movement was probably an underestimate due to the significant amount of movement required to develop maximum passive pressure in the Bay Mud. A technical approach should be used to estimate the lateral movements of the shoring more accurately. In this way, problems within the design scheme and parameters used may be found before the system is installed.

CONCLUSIONS

It is the intent of the authors in presenting this case history to show that unsuccessful results can be caused by issues which are not specifically related to the technical aspects of design. The geotechnical engineer should be aware of these non-technical issues and their possible impact on the performance of the design. In addition, when providing technical services, consideration should be given to addressing issues other than those specifically requested by the client or governmental agencies. The overall success of geotechnical aspects of the project may depend upon details not directly the responsibility of the geotechnical engineer.

ACKNOWLEDGEMENTS

The authors would like to thank Ms. Lee Ann Julson and Ms. Theresa Bowermaster of Kleinfelder for their careful assistance in the preparation of this manuscript, and Mr. Craig Sheilds of Treadwell and Rollo for the use of the figures. The authors are also indebted to Mr. Terence Wang of Kleinfelder for his financial support.