J. Kane
Rec'd. 4/5/82
12/85

D-R-A-F-T

TESTIMONY OF STEVE J. POULOS

CONCERNING THE REMEDIAL UNDERPINNING

OF THE

SERVICE WATER PUMP STRUCTURE

MIDLAND NUCLEAR PLANT

CONTRACT NRC-03-82-092

Revised March 30, 1982
File 81907-6
Project 81907
Geotechnical Engineers Inc. March 22, 1982

NOTE: This draft is submitted for review and is not intended for distribution outside the NRC. The figures are not included in this draft. They will be taken from the Applicant's submittals.

Q1 Please state your name and position.

A1 My name is Steve Poulos. I am a Principal of the firm Geotechnical Engineers Inc. of Winchester, Massachusetts.

Q2 Have you prepared statements on your professional qualifications?

A2 Yes. A copy of my resume is given in Attachment 1.

Q3 Please state the nature of your responsibilities with respect to the Service Water Pump Structure.

A3 The NRC has engaged Geotechnical Engineers Inc. to review the geotechnical aspects of the underpinning for the Service Water Pump Structure. We were engaged for this work on December 21, 1981.

Q4 What is the purpose of this testimony?

A4 This testimony relates to the adequacy of the geotechnical design and construction of the proposed remedial underpinning of the portion of the Service Water Pump Structure that currently is founded on fill material. The following general topics are covered:

a. A description of the underpinning scheme.

b. Comments on the adequacy of the design from the geotechnical standpoint.

c. Discussion of the construction procedures.

d. Discussion of dewatering scheme.

e. Description of monitoring during underpinning.

f. Discussion of remedial actions available if unexpected events occur.

g. Unresolved issues.

Q5 Describe the essential features of the existing foundations of the Service Water Pump Structure.

A5 The Service Water Pump Structure is located in the southeast corner of the power block area adjacent to the Cooling Pond. The structure is rectangular in shape with overall dimensions of 106 ft x 86 ft, as shown in Fig. 1. The structure is built on two levels, as shown in Fig. 2. The southerly portion, which will be referred to as the Tank, is adjacent to the Cooling Pond and is founded on hard clay or dense alluvium at El 587. The northerly portion, which will be referred to as the Pumphouse, is founded on compacted fill at El 613 and 617, 30 ft above the Tank foundation. The Tank is 86 ft by 72 ft and the Pumphouse is 86 ft by 34 ft in plan.

The overall height of the Tank is 69 ft, and the Pumphouse is 35 ft, both of which extend 22 ft above finish grade (El 634).

Q6 Why is underpinning required?

A6 Underpinning is required because the fill under the Pumphouse is considered to be much more compressible than the natural soils under the Tanks. Thus, the Pumphouse could tilt downward with respect to the Tank, particularly during an earthquake. Since this structure is very stiff, very small differential settlement between the Pumphouse and the Tank would cause large stresses at the connection between the two. By supporting the Pumphouse on a continuous concrete wall founded on the hard clay or dense alluvium, which is now the bearing stratum for the Tank, these potential differential movements and consequent stresses can be precluded.

Q7 <u>Is the Service Water Pump Structure currently being subjected to high stress levels due to settlement of the Pumphouse?</u>

A7 The stresses now in the structure are the responsibility of others. Two sets of tie rods have been installed as a temporary, precautionary measure at the roof level to tie the building together in the north-south direction. These tie rods provide a prestress to prevent tensile stresses in the concrete near the roof level as further settlement occurs prior to (and during) underpinning.

Q8 <u>Please describe the underpinning system.</u>

A8 The Pumphouse, now founded on fill, would be underpinned by a continuous vertical concrete wall that will be connected to the underside of the Pumphouse slab and will bear on the same hard clay or dense alluvium that is now the bearing stratum for the Tank. This concrete wall will be 4 ft thick and 26 to 30 ft high. In plan, it will be U-shaped. It will support the entire perimeter of the Pumphouse except for the end that connects to the Tank. The wall width on the bearing stratum will be 4 ft for the east and west walls and 6 ft along the north wall.

The underpinning wall will be connected to the underside of the slab with bolts that will be tightened to create a shear connection. The southerly ends of the east and west walls will be connected to the Tank by reinforcing rods that are grouted into the existing structure along the vertical interface.

The total bearing area of the new wall will be 756 ft^2 and the allowable bearing pressure on the bearing stratum (with a factor of safety of 3) is 17 ksf. The highest bearing pressure at any point along the underpinning wall is 17 ksf, except that during an earthquake that causes stresses 1.5 times as high as the safe shutdown earthquake, the highest bearing pressure reaches 26 ksf. The factor of safety is 2 during this earthquake. The average bearing pressure, assuming that the underpinning wall supports the entire Pumphouse, is 5600/756 = 7.4 ksf.

Q9 Please provide a brief evaluation of this underpinning system, vis-a-vis other available remedial measures.

A9 Some of the possible underpinning methods and their disadvantages relative to the proposed system are given below.

No underpinning - Continued settlement of the fill due to its own weight and the superimposed weight of the Pumphouse, particularly due to earthquake shaking, would cause the Pumphouse to be cantilevered from the Tank. For this condition yield stresses may develop in the concrete in the roof. Because the structure is very stiff, very small settlements are needed to cause the cantilevered condition.

Piles or caissons - Past experience shows that it is very difficult to design a seismic connection between piles or caissons and a heavy building, even if the piles or caissons are installed before construction of the building. To install piles adjacent to an existing heavy building and to construct a safe seismic connection is even more difficult. To drill piles or caissons through the thick, heavily reinforced base slab would mean cutting many of the existing reinforcing rcds. This option could be used but is more complicated and, hence, less secure than the proposed system.

External ties - A system of vertical, horizontal, and diagonal ties could be used to prestress the structure and the connection between the Pumphouse and Tank could be strengthened to allow the Pumphouse to act as a cantilever safely. Since the structure is complete and equipment is installed, it would greatly delay the schedule of work to use this approach. Also, the appearance of permanent external ties would not inspire confidence in the safety of the structure.

Grouting - Much of the soil of which the compacted fill is composed is too fine-grained for adequate grouting.

Grout Jacking - One could lift the Pumphouse by injecting grout under pressure just beneath the slab. This procedure would have to be repeated after earthquakes and every few years during the early years of the life of the building, because creep settlements of the fill would continue. This solution could lead to costly shutdowns in the future when power is being generated.

Ground Freezing - The compacted fill could be frozen in place and maintained frozen for the life of the structure. This solution would require continuous freezing throughout the life of the structure, but would be fail-safe in the sense that a long period would be available to repair the freezing system if it broke down. During first freezing the heave could cause high enough upward stresses on the base slab to damage the structure. This technique has not been tried and would be questionable for use in this case.

<u>Continuous Underpinning Wall</u> - The proposed wall is costly. However, by connecting it with bolts to the existing structure at many locations and founding it on the same bearing stratum as the Tank, the entire structure, for practical purposes, is as secure as it would have been if constructed with deep continuous footings originally.

Q10 <u>What are the most critical geotechnical aspects of the design of this underpinning?</u>

A10 <u>First</u>, one mus_ ensure that a bearing stratum is reached which is at least as firm as the bearing stratum for the Tanks.

<u>Second</u>, the structure must be carefully designed to accommodate seismic loading, particularly the connections between the underpinning wall and the adjoining structure and the horizontal sliding resistance of the entire structure. The response of the structure during an earthquake is given in the testimony of Dr. Paul Hadala.

<u>Third</u>, the construction must be carried out in such a manner as to avoid damage to the structure and the bearing stratum during underpinning and due to long-term settlements.

Q11 <u>What data are available to you about the foundation materials upon which you base your testimony?</u>

A11 The available data on foundation materials at the site are covered in the testimony of Mr. Hari Singh.

The principal feature of the foundation materials that is critical to design is the hard clay or dense alluvium that exists at or above the foundation level of the Tank. This stratum was overridden by a glacier perhaps 500 ft thick or greater. Apparently it was not remolded by that glacier, merely loaded vertically. Thus, the proposed bearing stratum has already been loaded for hundreds of years to a pressure that is considerably higher than the pressure that will be applied by the underpinning wall.

A second feature of the foundation conditions is the presence of groundwater and the adjacent cooling water pond that supplies the water. A carefully planned and monitored dewatering system will be required during construction. This system is covered in the testimony of Mr. Joseph Kane.

A third important aspect of the foundation soils is the character of the fill material since its behavior during underpinning will govern the amount of support removed from the Pumphouse prior to installation of new piers. Such removal will cause stresses to build up on the structure. The fill is a silty clay or silty sand, both of which are expected to have a substantial stand-up time in the tunnels and piers, so long as the site is dewatered.

Q12 How will the underpinning wall be constructed?

A12 The underpinning wall will be constructed as a series of individual vertical piers that will be connected together with shear keys and reinforcing rods.

The sequence of pier construction is shown in Fig. 4. The northwest and northeast corners of the Pumphouse will be supported first. Calculations, which have been checked by the NRC structural group, show that the structure can safely span between these corner piers, if that were to become necessary. The piers are of sufficient capacity to handle 2100 kips in each corner safely, for a total of 4200 kips. Since the Pumphouse weighs 5600 kips, the structure should be safe during construction as soon as the corner piers are in place. It is vital that the jacking loads be maintained at this stage of construction and that the structure be monitored to ensure tolerably small vertical differential movements.

After the corner piers are in place, the center piers under the north underpinning wall will be installed and the jacking load applied.

Subsequently, the remaining piers along the north, east, and west walls will be completed.

The last two piers will be those at the connection to the Tank. This connection will be made after the adjacent piers have been loaded for a long enough period that subsequent settlements are expected to be negligible. The last piers can then be installed without concern that the shear connection at the vertical interface will be stressed highly due to settlement of the adjacent pier during the period of construction.

Q13 What stages during construction are critical to the existing structure and to the proposed underpinning wall?

A13 The critical construction stages are:

1. Dewatering must be done to a level at least one foot below the excavation level. It is particularly important that dewatering be continued even during work stoppage. Contingency plans must be developed for action in the event of breakdown of the dewatering system.

2. The minimum amount of undermining of the slab must be done for installation of the corner piers and the central piers. Monitoring of movements of the structure are crucial during this period. The bracing, lagging, and the backpacking for the lagging in the tunnels must be done carefully and quickly to reduce foundation movements. If work stops, the face must be carefully braced and the dewatering must be maintained.

3. The bracing of the sides of the piers must be carried out carefully and expeditiously to reduce soil movement. If local water pockets or loose sands are encountered, "runs" of soil into the piers are possible. Contingency plans should be prepared for this situation, such as use of vertical sheeting if lagging cannot be placed, temporary flooding, or auxiliary dewatering.

4. The jacking loads must be continually maintained to ensure that the structure does not deform appreciably as settlements of the piers occur. Settlements will take place throughout construction and the load will gradually move down to the bearing stratum. Thus, absolute movements of the Pumphouse must be monitored to control the jacking loads.

5. The piers must be designed to handle at least two times the expected construction loads without excessive deflection because unexpectedly high loads could be applied to the piers, particularly the first two piers (one on each corner).

6. The bearing stratum must not be disturbed mechanically or due to groundwater inflow during construction operations. The groundwater must be lowered below the alluvium if a pier is to be founded on alluvium. If the bearing stratum is hard clay, the groundwater level need only be lowered down to the hard clay. If the hard clay is stratified with pervious layers, the groundwater level must be at least a foot below the excavated surface.

7. The dewatering system must be designed and monitored to assure that fines are not being removed during dewatering in sufficient quantity to be of concern.

Q14 <u>How will the structure be monitored during construction?</u>

A14 Three deep benchmarks will be installed, two at the north end and one at the south end, to measure absolute vertical movements to 0.001 in. These benchmarks will be read for at least one week prior to start of digging below the structure to obtain baseline data. Then readings will be taken at least every four hours during the first digging under the structure and while piers at the corners and in the center (Piers 1, 2, 3, 4, 5) are constructed.

In addition, two strain gages, one on the east wall and one on the west wall near the roof level, will be installed to monitor strains in the concrete. These locations were chosen because settlement of the Pumphouse would cause the greatest movement at these zones.

Upper limits will be set on both the strains and the benchmark readings. If the limits are reached, construction will be stopped and remedial action taken to avoid further movements. Contingency plans will be prepared to cope with various possible developments and the construction sequence will be planned to ensure that safe remedial action is possible for most circumstances that can be foreseen.

Q15 <u>What alternative construction procedures are available to prevent damage to the structure if movements or strains reach the maximum allowable values during construction?</u>

A15 These remedial measures have not yet been presented to NRC by the Applicant.

Q16 <u>What steps are being taken to ensure that the bearing stratrum will not be disturbed during construction?</u>

A16 A complete dewatering system both inside and outside the proposed underpinning wall is being installed to draw the water level down to the hard clay bearing stratum. Six piezometers will be installed to monitor the groundwater level to ensure that it is below the level to which each pier is being excavated. It is essential that dewatering below the bearing stratum be done before reaching that level to avoid upflow of water and consequent disturbance to that layer.

A complete review of the groundwater conditions is given in the testimony of Mr. Joseph Kane.

The excavation in each pier will be carried out by hand, due to the small space available. Therefore, mechanical disturbance to the bearing stratum will be small. The last 12 in. of excavation will be carried out very carefully to avoid disturbance of the bearing elevation. A layer of concrete about 3 in. thick will be placed immediately after testing the bearing elevation, so that subsequent operations can be carried out without disturbance to the bearing layer.

Q17 <u>Describe the procedure for identifying the bearing stratum.</u>

A17 A geotechnical engineer who is trained and experienced will observe the bearing stratum in each pier and will map the soils as the bearing elevation is approached.

A cone penetrometer will be used to measure the resistance of the bearing stratum as a means for identifying that the appropriate layer has been reached.

A field densiy test will be made at the bottom of each pier for record purposes, and the hole will be filled with concrete.

Q18 <u>Describe the procedure for testing the bearing stratum in place.</u>

A18 The Applicant has stated that a static cone penetrometer will be used to test the hard clay bearing stratum and has presented a correlation chart between the penetrometer resistance and the allowable bearing pressure. This correlation chart is satisfactory to the NRC.

The Applicant has stated that a dynamic cone pentration test will be used to test the dense alluvium if it is used as a bearing stratum. The Applicant has been requested to submit the following additional information for review by NRC: (1) a correlation between the dynamic cone pentration and the allowable bearing capacity and (2) procedures to be used if gravel content of the dense alluvium exceeds 15% by weight.

The NRC has requested that the Applicant submit procedures for carrying out a plate load test or a pier load test on the bearing stratum near or at the first pier installed. Another plate load or pier load test should be performed if the dense alluvium is used as a bearing stratum also.

These procedures have not been reviewed by NRC to date but they pose no impediment to approving the design, so long as the procedures are reviewed and accepted prior to start of construction.

Q19 What steps will be taken if the elevation of the proposed bearing stratum changes abruptly between adjacent piers?

A19 If a subsequent pier is higher in elevation than a previously installed, adjoining pier, then the subsequent pier will be founded at the higher elevation, so long as that elevation is El 587 or lower.

If a subsequent pier is below a previous, adjacent pier by 18 in. or less, vertical sheeting will be driven adjacent to the previous pier, the soil for the subsequent pier will be excavated to the bearing stratum, and unreinforced concrete will be placed up to the bearing level of the previous pier. The remainder of the pier will be constructed using this mat of concrete as the bearing elevation.

The procedures to be used if the subsequent pier is below a previous, adjacent pier by more than 18 in. have been requested by NRC but have not been submitted.

The Applicant has chosen to found the piers at El 587. However, the piers at the corner of the structure and in the middle of the north wall will be founded at El 585 in an attempt to preclude the possibility that the bearing stratum of adjacent piers, which will be constructed later, will be at a lower elevation.

According to the available borings, the bearing stratum will be found at an elevation at least 5 ft above El 587. Therefore, the probability that the bearing stratum locally dips below El 587 is low. See Fig. 3.

Either the hard clay or the dense alluvium is satisfactory as bearing stratum, according to the data presented. However, the dense alluvium is more susceptible to disturbance due to inflow of groundwater. Therefore, it is vital that the groundwater level be lowered below the surface of the dense alluvium, about one foot or more, before excavation into it. Monitoring points must be established to ensure that this will be the case.

Before excavation into the hard clay, the groundwater level must be lowered down to its surface. It will be less susceptible than the dense alluvium to disturbance from water inflow unless it is stratified with pervious layers, in which case the groundwater must be at least a foot below the excavated surface at all times.

Q20 Who will be directly responsible for ensuring that the groundwater level is low enough and that the bearing stratum is adequate under each pier?

A20 The adequacy of the bearing stratum will be judged by a geotechnical engineer who is trained and experienced and who will use his classification of the soil, the results of plate or pier load tests, the results of the penetrometer test, and index properties if necessary, to decide whether the bearing stratum is satisfactory at El 585 or 587, or whether further excavation is needed. The Bechtel resident geotechnical engineer assisted by his consultant, a member of the staff of Mueser Rutledge Johnston & DiSimone will make this judgment and will have the authority to require further excavation.

The groundwater level will be evaluated by the Bechtel resident geotechnical engineer who will judge whether the level is low enouogh to proceed with excavation. He or she will have the authority to halt excavation if the groundwater is not low enough.

Q21 Are there any unresolved issues relating to the geotechnical aspects of the underpinning of the Service Water Pump Structure?

A21 As of March 20, 1982, the following issues remain unresolved:

1. The types, locations, and elevations of the groundwater monitoring devices.

2. The procedure for excavating to a level deeper than 18 in. below an adjacent pier.

3. The procedure for carrying out a plate or pier load test on the bearing stratum.

4. How the effects of gravel content in excess of 15% will be handled when judging the suitability of the bearing stratum.

5. The correlation between dynamic cone penetration resistance and allowable bearing capacity for the dense alluvium.

6. The allowable strains and settlements which, if reached, will trigger immediate evaluation or halt of construction.

7. The methods to be used for supporting the tunnel face or pier face in the event of work stoppage exceeding 8 hours.

8. The contingency plans that will be effective to stop further movement in the event that the measured strains or settlements are exceeded.

9. The procedure for handling local pockets of perched groundwater that may be encountered during tunnelling or pier construction.

10. The method and sequence of construction has not been finalized.

11. The Applicant has not documented his agreement to Q list all tunnelling and pier construction below the bottom of the slab.

12. The Applicant has not submitted a complete monitoring plan that shows instruments, monitoring accuracy, details of the strain measuring devices, monitoring frequency for critical and noncritical stages, and the trigger points for action. The NRC has requested that the Applicant consider a deep benchmark adjacent to the south end of the structure.

13. The Applicant has not documented what period he will use to develop baseline readings for the critical instruments.

14. NRC has not provided a response to the Applicant on the spring constants to be used for structural analysis.

15. Applicant has not submitted calculations for the sliding factor of safety, for the out-of-plane earth and water pressures on the underpinning wall, and justification of the sliding friction factor on the base for a seismic event.

16. Applicant has not documented the procedures for avoiding large differences in bearing elevations between adjacent piers.

17. The Applicant has not provided the expected lag between the time when an allowable movement or strain is exceeded and the time when contingency plans will go into effect.

18. The Applicant has not provided the detailed procedures for maintaining the pier loads during construction and for final transfer of load to the completed underpinning wall.