DEPARTMENT OF THE ARMY
TULSA DISTRICT, CORPS OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121

October 5, 1984

REPLY TO
ATTENTION OF:

Engineering/Geotechnical

Mr. G. Lear
Chief, Structural and Geotechnical
Engineering Branch
Mail Stop P-214
Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Lear:

Reference Interagency Agreement Number NRC-03-82-102, Task Work Order No. 4.

As outlined in the referenced agreement, we are submitting our geotechnical report on the adequacy of the foundation soils for the Palo Verde Nuclear Generating Station.

Sincerely,

Donald R. Henderson

Weldon M. Gamel
Chief, Engineering Division

Enclosure

Copy Furnished:

DAEN-CWE-SS/Pritchett

GEOTECHNICAL ENGINEERING CASE REVIEW

Synopsis. A geotechnical engineering case review of a potential foundation deficiency at the Palo Verde Nuclear Generating Station was performed by the Tulsa District Corps of Engineers. The potential deficiency resulted when several temporary water lines buried in foundation soils broke and eroded fill beneath and around several structures. An extensive investigation and evaluation was performed by the licensee (Arizona Public Service Company). Based on a review of this work the Corps has concluded that the measures taken by the licensee in evaluation of the potential problem are reasonable and adequate. It was further concluded that the pipe breaks did not significantly affect the soils supporting Category 1 structures.

Introduction. This report presents the results of the Corps of Engineers' geotechnical review of various documents describing potential foundation problems resulting from broken water lines buried in the foundation soils of the Palo Verde Nuclear Generating Station (PVNGS), Phoenix, Arizona. The review also included a site visit and a meeting with key personnel involved with the problem and resulting investigation. Inclosure 1 is a complete list of documents provided for review. These documents contain detailed descriptions of the potential problem, the procedures used for its evaluation, as well as the applicant's conclusions and remedial treatment. The following paragraphs provide a summary of the information presented in these documents along with the Corps of Engineers' comments.

Description of Potential Problem. Several temporary water lines that run through the backfill at PVNGS Units 1, 2 and 3 developed leaks which resulted in erosion of an estimated 2 to 3 cubic yards of fill at Units 1 and 2. At Unit 3 the leakage consisted of clear water with no erosion occurring at the time the leakage was discovered. A negligible amount of soil was noted at the seepage exit point but the leakage continued to flow clear until the water line was shut off. The leaks were detected in September 1981, January 1980 and December 1981 for Units 1, 2 and 3, respectively. The exit point for the leakage and soil erosion at units 1 and 2 was into the seismic gap and dead space between the Auxiliary and Control Buildings while the exit point for the leakage at Unit 3 was into the equipment hatch near the southwest corner of the Auxiliary Building. In each case the primary concern under evaluation was the ability of the backfill affected by the pipe leaks to properly support critical structures. Detailed descriptions of the potential problem at each unit can be found in Documents Number 7, 14 and 17 listed on Inclosure 1.

Site Visit and Meeting. A site visit was made on the morning of August 22, 1984 to inspect the areas in each of the three units where water leakage was known to occur. Following the site visit a meeting was held with key personnel involved with the problem and its investigation. The purpose of the site visit and meeting was to obtain a better understanding of the potential problem. Inclosure 2 is a summary of the site visit and meeting with both the agenda and list of attendees attached. Included with the agenda is a list of questions and comments based on the Corps of Engineers preliminary review of the available documents. Also included was a list of additional reports requested by the Corps of Engineers for their review. The information requested

included geology, soils and foundation design data. Document Number 18 of Inclosure 1 contained the requested information. The Corps had several comments and questions prior to the site visit that were based on a preliminary review of the information submitted. Some of the comments are discussed in the site visit report (Inclosure 2). Those not discussed in Inclosure 2 are listed below:

Comment: During the grouting program it is noted that the largest excess grout take occurred at Unit 3. No eroded fill materials were observed at the reported exit point. Undetected piping may have occurred. What are the potential consequences of undetected erosion of fill in this and other areas?

Response: The fill placement procedures were designed to eliminate the possibility of a subterranean channel developing that could permit large quantities of soil washing out. In addition, the character of the natural soils, against which the backfill is placed, is such that fill could not erode into these materials. The possibility of a leak large enough to transport soil in quantities significant enough to impact foundation conditions yet remain undetected is inconceivable.

Comment: No discussion of settlement of equipment hatch or potential loss of support under this structure or adjacent wing of the Auxiliary Building at Unit 3 was provided. Explain why these items were not discussed, considering the leakage that exited into the settlement hatch and the possibilities of undetected erosion.

Response: The equipment hatch is a non-critical structure in which excessive settlement will cause no safety problems. The safety related Auxiliary Building on the other hand was analyzed with the conservative assumption of total loss of support under a 20 x 35 foot area at the corner nearest the leak. These items are discussed in detail in APS Final Report-DER 81-55 which was provided at the meeting.

Geotechnical Investigations.

General. Geotechnical investigations were conducted by Bechtel Construction and Ertec Western, Inc. under direction of Bechtel Engineering. The purpose of the investigations was to locate the source of the water leaks and to assess the condition of the backfill affected by the leaks. The investigations consisted of:

- Pressure tests of the water lines

- Hand probing behind the seismic gap cover plate in Unit 1

- Cone Penetrometer Tests (CPT) and "undisturbed" soil sampling between the Auxiliary and Control Buildings in Units 1 and 2

- Laboratory testing on selected samples to determine moisture content, density, and grain size characteristics of backfill

- Review of in-place moisture-density test data obtained during fill placement in the areas of interest

- Review of structural settlement records.

Pressure Tests. The results of the pressure tests are summarized in Table 1 of Document Number 8, Inclosure 1. All temporary water lines were tested for leaks. Packers were used to determine location of the leak where bends in the pipe did not preclude their use. Manometer testing was used on sloping water lines to determine the elevation of the leak. It is noted that the exit point for each of the various leaks was the closest opening to all of the known or suspected leakage points.

Hand Probing. The probing behind the seismic gap cover plate showed no voids or soft zones in the one small area tested. This showed that any damage which may have occurred was limited in area.

Cone Penetrometer Tests. Cone Penetrometer Tests (CPT) were confined to the dead space between the Auxiliary and Control Buildings where the condition of backfill could be investigated without coring through foundation slabs. At both units the CPT's disclosed the presence of zones of low-strength backfill soils beneath the axis of the dead space. Undisturbed sampling was undertaken adjacent to the CPT locations to evaluate the nature of the low strength zones.

Laboratory Tests. Results of the laboratory testing on recovered samples indicated that the density of soils within the low strength zones was substantially lower than densities measured during fill placement. Similarly, the moisture contents of sampled soils was consistently higher than those measured during fill placement.

Construction Control Records. The fill placement records were reviewed to assess the condition of the backfill prior to the pipe leaks. Specifications required backfill to be compacted to dry densities in excess of 95 percent of maximum (ASTM D-1557). Compliance with these specifications was verified by in-place density testing at a frequency of one test per 100 cubic yards in Unit 1 and one test per 55 cubic yards in Units 2 and 3. All failing tests required the fill to be replaced or reworked until the specified densities were obtained. In open areas, the fill was compacted using heavy vibratory rollers. In confined areas and within 2 feet of structural walls, compaction was accomplished using hand-operated plate compacters (wackers). Pogo sticks were used to a very limited extent, usually to compact fill around pipelines. In the areas of concern (beneath the foundations of the Control Building and wing section of the Auxiliary Building) the great majority of fill was compacted by heavy vibratory rollers.

Structural Settlement Records. Settlement records of critical structures in all three units show no significant trends that could be attributed to

weakening of foundation soils due to pipe leaks. The maximum increase in total settlement recorded from the time of the pipe breaks until early 1984 was 0.3 inches for structures whose construction was completed before the pipe breaks occurred. Structures that were still under construction experienced slightly more settlement because of the additional construction. In all cases, however, post construction total settlements were well below the nominal design limit of 1.5 inches. Furthermore, the settlements for all structures appear to have stabilized and remain within tolerable limits.

Licensee Evaluation. The licensee in their approach to the problem chose to consider the worst possible case and assume the pipe leaks had caused total loss of support under a conservatively large area of the wing of the Auxiliary Building closest to the pipe break and then perform a stability analysis to determine what effect this assumption makes. The area assumed to have lost complete soil support was a 20- by 35-foot strip. The 20-foot width was taken from the outside south edge of the Auxiliary Building. The farthest northward pipe leak was a distance of 6'4" from that south edge under the wing of the Auxiliary Building. The affected area was assumed to extend two to three feet beyond the pipe location. Therefore, for the reanalysis to be conservative, a value of twice this distance was used, or after rounding up, 20 feet. The 35-foot dimension was taken as the nominal total length of the wing of the Auxiliary Building. The reanalysis conservatively assumed that all resulting loads caused by loss of support under this area would be carried by the outer wall acting as a corbel. The results of the reanalysis show the amount of reinforcing steel provided in the wall is adequate to resist all loads within design allowable stresses, even under seismic loading.

The Control Building is the only other Category 1 structure near the pipe breaks and it is beyond the points where leakage occurred and where the leaking water finally exited. It is difficult to conceive of any soil movement from the direction of this building. Also there is no evidence to suggest that the soil directly beneath the Control Building has experienced any erosion. However, it can be postulated that the projection of an angular zone of loading from the north edge of the Control Building would intercept a zone affected by the leaks. The affect of this zone on the total stability of the Control Building is considered to be negligible since the area of reduced soil density compared to the total area of the Control Building foundation is small. Additionally, from a review of settlement data no abnormal settlement has been noted for the Control Building.

The settlement records for all the buildings within the complex also show no abnormal settlement. This fact combined with the results of the stability analysis described above convinced the licensee that no remedial action other than grouting all temporary pipelines was necessary.

Corps of Engineers Evaluation. The licensee has done a thorough job of investigating the potential problem and documenting the results of his studies. The information presented above is but a brief summary of the principal features from the documents submitted for review. The Corps of Engineers is in general agreement with the licensee on the overall adequacy of the foundation soils and offers the following comments in support of this opinion.

The great majority of the backfill was compacted with heavy vibratory compaction equipment that will produce a uniformly compacted fill when the soil is placed in horizontal lifts not to exceed 9 inches as specified. The average "as placed" relative compaction was about 98 percent maximum density (ASTM D-1557) with no tests showing less than 95 percent. The frequency of quality assurance testing was adequate. The compaction procedures combined with the frequency of quality assurance testing makes it very unlikely that any significant areas of low density fill existed in machine compacted zones prior to the pipe breaks. The backfill materials classified as silty sands with less than 30 percent silt and design tests on these materials showed that saturation would have negligible effect on the strength or compressibility of the fill when placed at no less than 95% maximum density.

The hand compaction equipment used to compact fill around pipelines and within 2 feet of structural walls is more likely to produce zones to fill with low density but these areas would represent a negligible amount of fill. The location of the hand compacted zones which is generally along the sides and between buildings is another factor that reduces the potential effect these zones could have on the structures which are supported almost exclusively on fill compacted with heavy vibratory equipment.

The most probable location of the seepage paths is another factor that minimizes the potential problems that could result from the pipe leaks. The most probable seepage paths for the leakage in each case are along the pipes themselves and along the wall of the Auxiliary Building. This is due to the fact that water will follow the path of least resistance which will most likely by found along the pipelines and along the walls of the Auxiliary Buildings where the backfill was compacted with hand equipment. In each case, zones of hand compacted soils existed in practically unbroken lengths from the pipe breaks to the exit point for the leakage. Since the great majority of these areas are along the sides of Catagory 1 structures rather than under the foundation, the saturation of these soils would have negligible effect on these structures.

The dense condition of the fill compacted with heavy vibratory equipment would prevent any significant amount of flow through these soils except where hydraulic fracturing may have occurred. Hydraulic fracturing of soil occurs when the water pressure within the soil exceeds the minor prinicpal stresses within the soil. Again, the soils most likely to experience hydraulic fracturing would be the hand compacted fills since they would be expected to have lower stresses. If hydraulic fracturing did occur in the dense machine compacted fill, it would have occurred relatively close to the point of the pipe break because the water pressure would quickly dissipate as the flow distance increased from the point of the pipe break. Any damage to the fill due to hydraulic fracturing would be limited to a small zone along the fracture which is most likely to be a vertical crack due to the usual orientation of the minor prinicpal stresses. Since all temporary pipelines

were relatively close to the walls of the Auxiliary Buildings, it is probable that the great majority of the seepage path for each leak remained almost exclusively within the hand compacted fill zones. Likewise, all soil erosion that occurred would have taken place within these zones. The mechanics of soil erosion (piping) is such that it begins at the point of exit and progresses back toward the source of the leak. It would be expected that most of the soil that eroded into the seismic gap and dead space between the Auxiliary and Control Building came from near the exit points with very little if any soil eroding from under Category 1 structures. Based primarily on the reasons listed above it is very unlikely that any significant amount of soil under a Category 1 structure was affected by the pipe breaks.

One section of pipe did pass under the wing of the Auxiliary Building but the reanalysis performed by the licensee in which total loss of support under this corner of the building was assumed is conservative considering the relatively small amount of soil that was likely affected by the pipe break. The settlement records which show no abnormal settlement after the pipe breaks lends further support to the conclusion that no significant damage to the fills supporting Category 1 structures occurred as a result of the pipe breaks.

Conclusion and Recommendations. The measures taken in evaluation of the potential problems due to the pipe breaks are reasonable and adequate and the conclusion of the geotechnical review is that the pipe breaks did not significantly affect the soils supporting Category 1 structures. This conclusion is based on the probable location of the seepage paths and the effect of potential damage on critical structures. The probable seepage paths would have concentrated potential damage to narrow pathways rather than spread through the general mass of the backfill. The pathways would be along pipe-soil and wall-soil interfaces. The only areas with any significant potential for damage to soils under a critical structure was in fill under the wings of the Auxiliary Buildings at each unit. A structural reanalysis of this building was performed assuming total loss of support under a conservatively large area and the results showed the original design would be adequate. Since this conclusion is based primarily on engineering judgement rather than actual measurement of the soil properties under the structures, it is recommended that the settlement measurements be continued throughout the life of the project with special measurements taken after any significant event such as earthquakes or structural additions.

Subject: Palo Verde Project - (50-528)
Listing of Documents Furnished to COE for Their Review
(Task No. 4, Consulting Contract NRR 82-102)

Document No.	Document No.	Document Title
1	Oct. 7, 1981	Telephone Record Sheet - G. Duckworth's notification of Bob Dodds on DER 81-35 Void in Backfill
2	Nov. 5, 1981	"Interim Rpt. - DER 81-35", 50.55(e) Potentially Reportable Deficiency Relating to a leak in Temporary Fire Protection Pipe Disturbing Backfill in Proximity of Auxiliary and Control Building (Ltr. from E. Van Brunt, Jr to Reg. V)
3	Dec. 31, 1981	Ltr w/encl. from Reg. V (B. Faulkenberry) to Ariz. Public Service Co., "NRC Inspection of Palo Verde"
4	Feb. 11, 1982	Ltr. from E. Van Brunt, Jr. to Reg. V. (Faulkenberry) on DER 81-35 status
5	May 13, 1984	Ltr w/encl. (Def. Eval. Rept.) of DER 81-35 from W.H. Wilson (Bechtel) to E. Van Brunt (ANPP)
6	May 19, 1982	"Attachment A - Geotechnical Investigations to Assess Condition of Backfill After Pipe Leaks at the Palo Verde Nuclear Generating Station"
7	May, 1982	"Engineering Evaluation of Conditions of Backfill After Pipe Leaks at the Palo Verde NGS -DEFICIENCY EVALUATION REPORT NO. 81-35
8	1982	"Grouting for Disposition of Temporary Piping at the Palo Verde Nuclear Generating Station
9	May 20, 1982	Ltr. w/encl., DER 81-35 from E. Van Brunt, Jr. to Reg. V (Bishop)
10	Oct. 13, 1982	Ltr w/encl. from D. Sternberg (Reg. V) to E. Van Brunt, Jr. on "NRC Inspection of Palo Verde"
11	April 6, 1983	Ltr. w/encl from E. Van Brunt, Jr. to Reg. V (Sternberg) on DER 81-35 w/transmittal of Rev. 1
12	Dec 3, 1983	Newspaper Article from MESA Tribune on "Palo Verde Safety Problem Alleged"

Document No.	Document No.	Document Title
13	Feb. 9, 1984	Memorandum w/Attachment from G. Lear to G. Kighton, "Request for Additional Information, Reevaluation of Degraded Backfill Under Seismic Category 1 Structures"
14	June 18, 1984	Responses to NRC Request for Additional Geotechnical Information
15	Sep 19, 1984	Summary of Meeting to Discuss Effects of Water leaks on foundation stability
16	Aug 23, 1984	Listing of Information Requested by NRC of APS on August 23, 1984 Following Site Visit-Palo Verde Project (These documents were reviewed by COE during site Visit on Aug 22, 1984)
17	Sep 29, 1982	APS Final Report - DER 81-55 Deficiency evaluation PVNGS Unit 3
18	April 1983	FSAR sections 2.5, 2A, 2B, 2E, and 2F updated through Amendment 13.