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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MAY 01 1984

MEMORANDUM FOR: George Lear, Chief
Structural and Geotechnical Engineering Branch
Division of Engineering

THRU: Lyman Heller, Leader
Geotechnical Engineering Section
Structural and Geotechnical Engineering Branch
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FROM: John T. Chen, Geotechnical Engineer
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SUBJECT: GEOTECHNICAL ENGINEERING SAFETY EVALUATION WATERFORD NO. 3 LOUISIANA POWER AND LIGHT COMPANY

References:

1. Safety Evaluation Report (SER) Related to the Operation of Waterford Steam Electric Station, Unit No. 3 (NUREG-0787, July 1981) (2.5.4);
2. Letter from the Applicant to the NRC Staff dated June 24, 1981 (Subject: Response to SER Open Item 49, "Reevaluate Foundation Mat for Changes in Value of Subgrade Modulus");
3. Harstead Associates, Inc., Waterford III SES Analysis of Cracks and Water Seepage in Foundation Mat, Report No. 8304-1, September 19, 1983;
4. Amended and Supplemental Motion to Reopen Contention 22, December 12, 1983, Atomic Safety and Licensing Appeal Board
5. Nonconformance Report W3-5997, Clam Shell Filter Blanket Under the Nuclear Island, LP&L, June 23, 1983.
6. Draft Responses to NRC's Question on Waterford 3 Basemat, March 26, 1984

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The geotechnical engineering evaluation report is attached for your use. This report was prepared based on information obtained during meetings held on March 21, 26 and 27, site visit on March 27, and review of above references.

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WATERFORD NO. 3

1. INTRODUCTION

The safety class structures at Waterford are supported on a continuous mat 270 feet wide, 380 feet long and 12 feet thick. The mat has been designed and constructed using the "compensated" or "floating" foundation concept in which the applied loads on the foundation soil, the Pleistocene clay, have been controlled so that the effective insitu stresses remain essentially the same as the stresses existing before construction. In this way, the overall settlements of the foundation soil are controlled.

In July 1977, a number of east-west oriented cracks were discovered at the top of the mat beneath the containment structure. Weeping water was reported to be low and not enough to form a sheen but enough to show the cracks and to moisten surrounding concrete. Epoxy grout was used to seal all the observed cracks in the mat inside the containment structure.

In May 1983, new cracks and accompanying weeping water were discovered in the base mat outside the containment structure. Some of those cracks were found that extended to vertical walls by an NRC investigation team in March, 1984.

This report summarizes the results of NRC's geotechnical engineering evaluation of the causes which may be responsible for the observed cracking. This report, also, addresses the present foundation conditions and anticipated future behavior of the mat.

2. SUBSURFACE CONDITONS

Subsurface conditions at the site were investigated between 1970 and 1972. 64 soil test borings, 50 to 500 feet deep, were drilled. A general description of the subsurface conditions is presented in the attached Table 2.6 of the Waterford SER.

Extensive laboratory tests were performed on selected soil samples. Significant soil characteristics are presented in Table 2.6.

3. CONSTRUCTION SEQUENCE

The construction steps involved were:

a) Groundwater control:

Groundwater levels in the plant area were controlled during construction from 1972 to 1978 by pumping from 216 shallow wells and 34 deep wells around the perimeter of the plant area. The well tips were located at El. -40 feet for shallow wells and El. -95 feet for deep wells. From November 1972 to November 1974, dewatering was stopped and about 10 feet of standing water accumulated in the excavation. In January 1977, 12 additional wells were installed around the foundation mat area to provide additional groundwater control beneath the mat.

The groundwater level was raised in a controlled pattern in late 1977 by 12 recharge wells, located near the edge of the foundation mat with tips in the shell filter blanket. Additional groundwater recharging was achieved by watering the backfill. By the end of 1979, the ground-

water was raised to normal level ranging from El. +3 to E. +12.

b) EXCAVATION:

The excavation, about 60 feet below the original grade to El. -47, was done in four phases:

Phase I, grade to El. -5, April to July 1972

Phase II, El. -5 to El. -22, January to June 1975

Phase III, El. -22 to E. -40, April to August 1975

Phase IV, El. -40 to El. -48, October 1975 to March 1976

Turbine building, grade to El. -40, January to March 1977

Phase IV excavation, cut into the upper Pleistocene clay from El. -40 to El. -48, was made in six strips, starting with a 120 ft-wide strip across the center of the common mat, and following the alternating strips north and south of the center strip.

c) Backfill and concrete placement:

After each strip was excavated, the filter cloth, the shell filter layer and the concrete mat were constructed as soon as possible so as to reload the foundation soils and minimize heave. Marafi filter cloth was placed over the Pleistocene clay before the shell layer was placed. The shell filter layer, about a foot thick, was compacted by a vibratory roller for 10 passes.

The concrete mat was poured in 28 separate blocks from December 1975 to 1976. Each block had a thickness about 12 feet and an area which varied from 2000 to 5000 square feet. The construction of the superstructure was started in May 1977 with all concrete work completed in December 1980.

Backfill material of clean sand, was placed below El. +17 around the nuclear plant island structure from August 1976 to October 1978.

4. EVALUATION

The plant was designed to give a net reduction, by about 200 psf, of the applied effective soil loading at foundation level. Before construction began, the initial effective overburden pressure at foundation level was was 3300 psf; after construction was completed the final effective static loading of the plant and backfill was 3100 psf. Therefore, the future settlement of the completed plant would be negligible.

During construction, the insitu vertical stresses were controlled by lowering the groundwater level simultaneously with the excavating of soils. The lowering of the groundwater level would give an increase in effective overburden pressure which compensated for the soil removed. Later as structural loads were applied, the groundwater level was raised to reduce the effective overburden pressure and compensate for the structural loading. By this technique, the differential settlement of the foundation soil would be reduced and its effects on structures would be minimized.

The construction procedures are generally sound. However, the control of insitu vertical effective stresses and groundwater levels was quite difficult because of the subsurface soil conditions. Numerous construction difficulties, encountered during construction, may have contributed directly or indirectly to the observed cracking of the foundation mat. Those construction problems included:

a) Dewatering:

As discussed in 3(a) above, the tips of the dewatering wells were located at El. -40 ft., in the recent alluvium stratum, for shallow wells and at El. -95 ft, in the silty sand layer, for deep wells. The silty sand layer is an identified aquifer at the site. Because of the very low permeability of the upper Pleistocene clay, those wells did not completely lower the groundwater level in the foundatin soils to below El. -48, as evidenced by some of the piezometric readings. Locally, those high groundwater conditons appear to have caused soil disturbance, mud spurt, standing water in some area of the excavation and difficulties in compaction of the shell blanket.

b) Variable foundation soil conditions:

The foundation mat was founded on the upper Pleistocene clay. These clays were considered to be fairly uniform and over-consolidated in the design and construction of the mat. However, within the boundary of the foundation mat, the pen[illegible]ty and the compressibility of the clay layer varied significantly from one location to another as evid-

enced by the results of the piezometric and heave monitoring during construction. The measured heave at various location was 2 to 4 times the anticipated maximum heave used in the mat design; this indicates that the differential settlements of the mat would be greater than anticipated.

c) Variable degrees of compaction in the six shell filter strips: The compaction procedures were selected based on the results of a test fill program. However, due to the variability of the supporting soil and groundwater conditions, the degree of compaction in these shell filter strips varied widely, from 80 to 98 percent. Filter strip number 1, 97.5 feet long and 270 feet wide, was compacted to an average of 95 percent. Filter strip number 2, 58.5 feet long and located immediately north of strip number 1, was compacted to an average of 80 percent. Shell filter was placed in standing water in the west half of strip number 2. A mud spurt area of about 120 sq. ft. occurred in strip number 2 during compaction. Filter strip number 4, 48.5 feet long, was compacted to 98 percent.

These variable degrees of shell compaction reflect the condition of the foundation soils. Settlements of the mat due to uniform structural loads would vary significantly; strip number 2 would settle more than strip number 1 while strip number 4 would settle less. Thus, differential settlements would be experienced by structures founded over different strips. The resulting differential settlement may induce

bending stresses in the mat and cause east-west oriented cracking in the foundation mat.

d) Foundation mat construction:

As discussed in 3(c), the foundation mat was constructed in 28 blocks with a thickness of 12 feet and an area which varied from 2000 to 5000 square feet. The load due to pouring of the first block of concrete caused an immediate settlement about 3/4 of an inch and, later, some additional consolidation settlement. When the second and third blocks were poured adjacent to the first block, differential settlements between the blocks were observed. This type of settlement pattern occurred for all later constructed blocks. These differential settlement may have induced some residual stresses in the concrete and may have caused concrete cracking.

e) Significant hydrostatic pressure change:

During the construction of the concrete mat and superstructures, the groundwater levels were changed significantly three times, ranging from 20 to 30 feet. These changes in hydrostatic pressure changed the effective stresses in the foundation soils and caused movements of the foundation soils and the concrete mat. Because of the non-uniform nature of the foundation soils, differential movements within the mat would be expected. These differential movements may have induced strain in the concrete when it was still in the process of curing.

The plant foundation design, the "compensated" foundation concept, is a sound one. the cracks in the foundation mat appear to have resulted mostly from the differential settlements experienced and, to a less degree, as superstructure loads were applied during construction. These differential settlements were caused mainly by the variable soil conditions, high groundwater levels, and the variable compaction of the shell filter strips and concrete mat construction procedures. The hydrostatic pressure changes, affecting the effective stress state in supporting soils, may have aggravated the growth of the cracks after the mat was completed.

The future settlement should be limited and "stable" because of the "compensated" design. However, the cracks discovered in 1983 and vertical wall cracks discovered in 1984 seem to indicate that the movements of the foundation mat and the growths of the cracks are continuing. The current settlement monitoring program provided some useful information indicating that the mat would move in conjunction with fluctuation of groundwater levels. But the scope and the accuracy of the current program, are not sufficient to provide accurate information to assess and relate the actual differential settlements to the growths of the cracks in the mat. Sensitive measurements are essential to determine the future behavior of the concrete mat.

The scope of the current monitoring program should be expanded to collect more accurate information about the differential settlements in the mat and about the precise growth of new and old cracks. The more accurate

differential settlement monitoring can be achieved by installing additional monitoring points on the mat with increased monitoring accuracy. The added points cab be located on the outside walls of the mat. The crack monitoring program whould provide information about the development of new cracks and the propagation of the cracks. Specifically, those cracks that extend to the vertical walls should be monitored. Leachate on the cracks should be cleaned out to expose the cracks. Brass pins or other means should be used to identify the extent and progression of the cracks.

5. CONCLUSION AND RECOMMENDATION

Based on the information reviewed to date and such other matters as in our judgement are pertinent, it is concluded that:

a) The plant foundation design, the "compensated" foundation concept is sound and acceptable.

b) The cracks in the foundaton mat and structural walls ~~a structural~~ were probably caused by differential settlement that occurred mainly during construction.

c) These differential settlements resulted from complicated soil conditions, high groundwater levels, compaction of shell filter strips and the concrete block construction procedures.

d) Movements of the foundation mat and the growth of the cracks will continue.

e) Seasonal groundwater level fluctuation will cause some movement of the foundation mat.

f) In order to examine and evaluate the future performance of the foundation, it is recommended that the current monitoring program be expanded to enable more accurate measurements of differential settlements and crack growths. All prominent cracks should be mapped and included in the program.

Table 2.6 Summary of subsurface soil conditions

Elevation (ft above MSL)	General description	Significant characteristics
	<u>Recent Alluvium</u>	
+13 to -40	Clay with silt and sand pockets	C = 0.5 ksf; OCR = 2.0*; recent alluvium was removed from beneath seismic Category I foundations. $k = 1.5 \times 10^{-6}$ cm/sec
	<u>Upper Pleistocene</u>	
-40 to -77	Tan and gray clay (partly fissured)	C = 1.5 ksf; OCR = 3.4; fairly uniform but with occasional silt and sand lenses. $k = 10^{-8}$ cm/sec
-77 to -92	Tan silty sand	N = 30 to 50/5 in.** Layer consistent throughout the site; Dewatering well tips located in this layer. $k = 3 \times 10^{-5}$ cm/sec
-92 to -108	Gray clay with silt lenses	C = 1.2 ksf; OCR = 1.4 Similar to the tan and gray clay at El -40 to -70
-108 to -116	Dark gray clay (organic)	C = 1.8 ksf, OCR = 1.7 Organic content 3% to 16%
-116 to -127	Gray and tan clay with sand lenses	C = 0.7 ksf; OCR = 2.0
-127 to -317	Greenish gray clay silty clay with sand lenses and layers	C = 2.0 ksf, OCR = 1.5 to 2.4 Organic content = 4% to 7% (El -197 to El -217). Sand layer generally very dense with N = 16 to 50/5 in. (El -237 to El -245).
	<u>Lower Pliestocene</u>	
-317 to -500+	Gray silty sand	N = 38 to 50/4 in.

*C = cohesion (average); OCR = over-consolidation ratio (average)
**N = standard penetration test value, blows/ft (ASTM) D-1586