5/21/84

Geotechnical Engineering Evaluation

of Concrete Cracking in the Basemat

Waterford No. 3

John T. Chen, Geotechnical Engineer

## 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 concrete mat was poured in 28 separate blocks from Dec. 1975 to May 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 Dec. 1980.

In July 1977, a number of east-west oriented cracks were discovered at the top of the mat within the ringwall for the containment structure (Ref. 3 & 4). Weeping water was reported to be low and just 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 ringwall.

In May 1983, new cracks (not reported in 1977) and accompanying weeping water were discovered in the base mat outside the containment structure (Ref. 3). Some of those cracks were found to extend to vertical walls and to extend up those walls by an NRC investigation team (Lear, Ma, Jeng and Chen) in March, 1984.

This evaluation of the geotechnical engineering related causes which may have contributed to the observed cracking presents foundation conditions and anticipated future behavior of the mat and was based on the review of the referenced documents, field observation, and meetings held with the applicant on March 23 and 27, 1984. Other possible causes of the observed cracks are discussed elsewhere (Ref. 8). The subsurface conditions and significant soil characteristics were presented in the Waterford SER Section 2.5.4.1. The construction sequence was presented in SER Section 2.5.4.2.

## 2. EVALUATION

The plant, as stated in Reference 1, was designed to give a net reduction, by about 200 psf, of the applied effective soil loading at foundation level (El.-48 ft.). Before construction began, the initial effective overburden pressure at foundation level 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 should be negligible. The ultimate bearing capacity was calculated to be 15,000 psf, thus, there is no potential for bearing type failure and the bearing capacity is adequate.

During construction, the insitu vertical stresses were controlled by lowering the groundwater level simultaneously with the

excavation 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 total and 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 the subsurface soil conditions were somewhat different than anticipated. Numerous construction difficulties, encountered during construction, may have caused some differential settlements which may have contributed directly or indirectly to the observed cracking of the foundation mat; those difficulties encountered during construction included:

(a) Dewatering:

As discussed in Waterford SER Section 2.5.4.2 (Ref. 1), 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, all the wells did not completely lower the groundwater level in the

foundation soils to below El. -48, as evidenced by some of the piezometric readings (Ref. 6). Locally, those high groundwater conditions appear to have caused soil disturbance, mud spurt, standing water in some area of the excavation and difficulties in compaction of the shell blanket (Ref. 5).

(b) Variable foundation soil conditions:

The foundation mat was founded at elevation-47 on the upper Pleistocene clay. These clays were considered to be fairly uniform and over-consolidated in the design and construction of the mat (Ref. 1 & 7). However, within the boundary of the foundation mat, the permeability and the compressibility of the clay layer varied significantly from one location to another as evidenced by the results of the piezometric and heave monitoring during construction (Ref. 6). The measured heave at various locations was 2 to 4 times the anticipated maximum heave used in the mat design; this indicates that the differential settlements of the mat during construction would be greater than anticipated and the induced stresses might be significant enough to cause concrete cracking.

(c) Variable degrees of compaction in the six clam shell filter strips:

The compaction procedures, using a vibratory roller for 10

passes, were selected based on the results of a test fill program (Ref. 1 & 5). However, due to the variability of the supporting soil and groundwater conditions, despite occasional greater effort up to 40 passes, the degree of compaction achieved in these shell filter strips varied widely, from 80 to 98 percent (Ref. 5). Compaction of fill (shells) over a spongy subgrade is more difficult than over a solid subgrade. 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. All filter strips were to be 1 foot in thickness.

These variable degrees of shell compaction reflect the condition and consolidation of the underlying foundation soils indicating that the subgrade moduli varied among these strips. Settlements of the mat due to uniform structural loads would be expected to vary accordingly; strip number 2 would be expected to settle more than strip number 1 while strip number 4 would settle less. The resulting differential settlement may have induced bending stresses in the mat and caused

east-west oriented cracking in the newly placed foundation mat. Subsequently, differential settlements would be experienced by the superstructure founded over different strips with variable soil properties and rates of consolidation.

(d) Foundation mat construction sequence:

As stated above, from December 1975 to May 1976 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 on the subgrade due to pouring of the first block of concrete caused a measured settlement about 3/4 of an inch and, later, some additional consolidation settlement (Ref. 6 & 7). After the second and third blocks were poured adjacent to the first block, differential settlements between the top of the completed blocks were observed. This type of settlement pattern occurred for all later constructed blocks. These differential settlements may have induced some residual stresses in the concrete. If the residual stresses were large enough, they may have caused concrete cracking or may have caused preexisting cracks to expand further.

(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 (Ref. 6). 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 stresses in the concrete when it was still in the process of curing, contributing to the concrete cracking.

The plant foundation design, the "compensated" foundation concept, is a sound one. The cracks which may have been initiated due to thermal stresses or shrinkage (Ref. 8), in the foundation mat appear to have been affected significantly by the differential settlements experienced and, to a lesser degree, by superstructure loads as they were applied during construction. The differential settlements were caused mainly by the variable soil conditions, high groundwater levels, variable compaction of the shell filter strips, and foundation mat construction sequence. 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 applicant performed a detailed soil-structure interaction analysis to evaluate the effects of changes in the values of the subgrade modulus used in the design of the concrete mat (Ref. 2 &

7). However, those difficulties encountered during construction and mentioned above have not been considered in the applicant's analysis. To evaluate the potential for future cracking, the effects of differential settlements during construction should be determined so that the current state of stresses in the base mat can be better assessed. The soil shear moduli to be used in such an analysis should reflect more closely the soil conditions that existed during construction, when the foundation soil was in the process of being consolidated.

The future settlement is expected to be negligible because of the "compensated" foundation design. The results of the current settlement monitoring program show that the overall settlement of the mat has been essentially stable since 1979, with some minor movements (about ½ inch) due to seasonal groundwater level fluctuations (Ref. 6). The cracks reported in 1983 and vertical wall cracks discovered in 1984 seem to indicate that movements of the foundation mat and growth of cracks are continuing. The current settlement monitoring program reveals that the mat moves in conjunction with fluctuation of groundwater levels. Unfortunately, the scope and accuracy of the current monitoring 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 this relationship.

The scope of the applicant's current monitoring program should be expanded to collect more useful and accurate information about the differential settlements in the mat and about the precise growth of all prominent cracks. More accurate differential settlement monitoring can be achieved by installing additional monitoring points on the mat with increased monitoring accuracy. The added points can be located on the outside walls of the mat. The crack monitoring program should provide information about the development of new cracks and the propagation of the cracks, particularly those cracks that extend to the vertical walls.

3. CONCLUSION AND RECOMMENDATION

Based on the information reviewed, it is concluded that:

(a) The plant foundation design, the "compensated' foundation concept is sound and acceptable. The soil bearing capacity is adequate and the future settlement should be negligible.

(b) The east-west oriented cracks in the foundation mat and structural walls may have been caused or further aggravated by differential settlements that occurred mainly during construction.

(c) These differential settlements resulted from complicated soil conditions, high groundwater levels, variable compaction of shell filter strips and foundation mat construction sequence.

(d) Movements of the foundation mat, probably less than an inch, as the mat rises and falls in conjunction with seasonal groundwater level fluctuation will continue. In addition the cracks may be expected to continue.

(e) A more refined analysis using the soil conditions disclosed during construction should be performed to determine the effects of past and future differential settlement on the potential for cracking of the concrete mat.

(f) In order to better examine and evaluate differential settlement and possible cracking of the foundation mat, 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 monitoring program.

4. 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. LP&L's Draft Responses to NRC's Question on Waterford 3 Basemat, March 26, 1984;

7. Affidavit of R. Pichumani on the Stability of the Foundation Underlying the Concrete Mat at Waterford 3, Nov. 1983;

8. R. E. Philleo, Evaluation of Concrete in the Basemat, Waterford 3, May 8, 1984.

D. Lear

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

JUN 7 1984

Docket No.: 50-382

MEMORANDUM FOR: George W. Knighton, Chief
Licensing Branch No. 3
Division of Licensing

FROM: James H. Wilson, Project Manager
Licensing Branch No. 3
Division of Licensing

SUBJECT: LOUISIANA POWER AND LIGHT COMPANY MEETING

DATE & TIME: Friday, June 8, 1984
~~8:30 am~~ - 5:00 pm
12:30 pm

LOCATION: Room P-118
7920 Norfolk Avenue
Bethesda, Maryland

PURPOSE: To discuss the enclosed agenda items from Waterford 3 team efforts

PARTICIPANTS: NRC

D. Eisenhut, D. Crutchfield, J. Wilson, L. Lazo, S. Turk, L. Shao, R. Shewmaker, S. Hou, J. Harrison, et al.

LP&L

R. Leddick, D. Dobson, K. Cook, J. Cain, R. Barkhurst

James H. Wilson

James H. Wilson, Project Manager
Licensing Branch No. 3
Division of Licensing

Enclosure: As stated

cc: See next page

Note: This meeting will be transcribed.

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Note: Change in time.

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Agenda for Meeting with LP&L Concerning
- Waterford Unit 3 on June 8, 1984

I. Quality Assurance/Quality Control

a. Inspection Personnel qualifications and certifications (Mercury and Tompkins - Beckwith)
b. Safety related N1 Instrument Line Documentation
c. Instrumentation Expansion Loop Separation
d. Upgrading to NCR's of Lower Tier Corrective Actions
e. Vendor Documentation - Conditional Releases
f. Dispositioning of NCR's
g. Missing NCR's

II. Civil/Structural and Piping/Mechanical

a. Backfill Soil Densities
b. Visual Examination of Shop Welds During Hydrostatic Testing
c. Welder Certification
d. Inspector Qualifications (Jones and Fegles)
e. Cadwelding
f. Main Steamline Restraints above the Steam Generators
g. J. A. Jones Speed Letters and EIR's
h. Welding of "D" level material inside Containment

## INQUIRY TEAM

- O CONSTRUCTION MATERIAL TESTING (CMT) PERSONNEL

- O UNDERSIZED WELDS

- O SYSTEMS TRANSFERS WITHOUT ADEQUATE CLOSEOUT OF LP&L QA CONSTRUCTION WALKDOWN FINDINGS

## CIVIL/STRUCTURAL AND PIPING/MECHANICAL TEAM

- O BACKFILL SOIL DENSITY
- O CADWELDS
- O WELDING INSTRUMENTATION CABINET SUPPORT
- O INSPECTION OF SHOP WELDS DURING HYDRO-TESTS
- O STRUCTURAL INSPECTORS QUALIFICATIONS
- O INSPECTION RECORDS ON MAIN STEAMLINE RESTRAINT FRAMING
- O SPEED LETTERS AND ENGINEERING INFORMATION REQUEST (STRUCTURAL AREAS)
- O WELDS ON CONTAINMENT SPRAY PIPING SUPPORTS

## QA RECORDS REVIEW TEAM FINDINGS

- O UNQUALIFIED OR INCORRECTLY CERTIFIED QA/QC INSPECTION PERSONNEL
- O INADEQUATE OF MISSING QA DOCUMENTATION (RECORDS)
- O INADEQUATE REVIEW OF QA DOCUMENTATION
- O INADEQUATE DISPOSITION AND CLOSURE OF NONCONFORMANCE REPORTS
- O WELDER QUALIFICATION AND WELDING PROBLEMS
- O LOWER TIERED CORRECTIVE ACTION DOCUMENTS WERE NOT UPGRADED TO NONCONFORMANCE REPORTS
- O VENDOR DOCUMENTATION/CONDITIONAL RELEASE SYSTEM
- O QA PROGRAM BREAKDOWN BETWEEN EBASCO AND MERCURY COMPANY

## EI&C

- O NON-SEISMIC EQUIPMENT (Category 2) INTERFACE WITH SAFETY EQUIPMENT (Category 1) DURING SAFE SHUTDOWN EARTHQUAKE.

- O EXPANSION TYPE ANCHORS IN CONCRETE FOR CATEGORY I STRUCTURES