(7.21)

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(7.22)

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ns in which the structural
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d f_v is in kg/cm^2

d f_v is in ksi

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height of deep beams are
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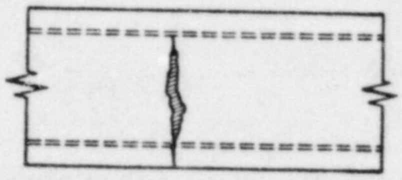

FIGURE 7.16. Cracks in deep member without longitudinal reinforcement along the lateral faces.

Although no reinforcement of this sort is needed in the direction of x when $x \leq 150$ cm (5 ft), common experience speaks of inclined cracks near the supports of beams having little or no web reinforcement even when computations indicate the presence of shearing stresses far below those which the unaided concrete in the web should be able to take. These cracks can be recognized because their widths increase with shrinkage. The cracks develop chiefly through a combination of shrinkage and diagonal tension; consequently, longitudinal reinforcement at intermediate elevations of the beam is only mildly effective in controlling the cracks. It may be advisable to supply vertical stirrups as well, designed in accordance with Eqs. (7.21) or (7.22) after letting x tend to infinity. The same applies to the design of ties in columns that may be subjected to appreciable shearing forces.[107]

This author recognizes and warns that a judgement solely based on mathematical analysis resuts may lead to problems.

Trustworthy correlations exist between the cement and water contents of concrete and its shrinkage strains under given atmospheric conditions and for given aggregates (see Chapter 3). The fact that relative humidity and the exact composition of the aggregates are unknown at the design stage makes this a random variable in structural design and it should be treated accordingly.

In principle, a more rational approach would be desirable to compute the optimum amount of reinforcement as a function of predicted shrinkage and other imposed deformations, rather than adopting a specified minimum percentage. But the initial investment at stake is very small and the change in total utility is negligible in most cases. Hence, it is hardly worth going through such an analysis except in the design of special structures for which cracking would be especially objectionable and its control especially costly. In most practical instances it suffices to follow code requirements and use the minimum slump compatible with ease in casting, resorting to revibration or the use of special cements or admixtures where a more drastic reduction in cracking is desired.

7.19 TEMPERATURE CHANGES

7.19.1 General

Effects of temperature changes, as those of shrinkage, can be included in calculations as imposed deformations. In the same manner as shrinkage, *Enclosure IV*

Control of Cracking in Mass Concrete Dams

by Walter H. Price

*ACI Honorary member **Walter H. Price** is a consulting engineer, Laguna Hills, California. His prior experience includes 30 years with the U.S. Bureau of Reclamation; American Cement Corp. as technical services director, then vice-president of the Pacific Southwest Region and president of American Cement's Philippine Rock Products division. He is the author of numerous technical papers and the recipient of many awards including: U.S. Department of Interior Distinguished Service Citation; ACI's Henry L. Kennedy Award, the Wason Medal for the Most Meritorious Paper, and the H. C. Turner Medal. He is a member of ACI committees 207, and 210. He is a past-president of ACI and has served on the Board of Direction.*

This article covers the development of construction practices during the past 67 years for the control of cracking in massive concrete dams which has led to the use of special cements, pozzolans, air-entraining admixtures, water-reducing admixtures, controlled mixing and placing of concrete, precooling of materials, and post-cooling of concrete after placing in the dam. The importance of low cement contents is stressed and methods for accomplishing the low contents are discussed. The necessity of rigid control of aggregate gradings, moisture in the sand, batching of the ingredients, mixing and placing of the fresh concrete, and protection of the hardened concrete from rapid temperature changes are also discussed. It does not cover the use of roller-compacted concrete for the construction of concrete dams

Keywords: admixtures; aggregate shape and textures; air-entraining agents; cement content; compressive strength; concrete construction; **cracking (fracturing)**; **dams**; fly ash; formwork (construction); hydration; **mass concrete**; mixture proportioning; placing; pozzolans; shrinkage; temperature control; thermal properties; volume change.

INTRODUCTION

Mass concrete is defined as "any large volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of cement and attendant volume change to minimize cracking."

The most important characteristic of mass concrete that differentiates its behavior from that of structural concrete is its thermal behavior. Mass concrete structures are, typically, structures having large dimensions. These large dimensions in a material whose thermal properties allow only slow movement of heat mean that heat trapped within a mass concrete structure can only escape slowly unless aided artificially. For instance, the laws of heat transfer tell us that heat can escape from a body inversely as the square of its least dimension. Consider a number of walls made of average concrete containing 300 kg/m^3 (505 lb/yd^3) of cement and exposed to cooler air on both faces. For a wall 15 cm (6 in.) thick, 95 percent of the heat in the concrete will be lost to the air in 1½ hr. For a 1.5 m (5 ft) thick wall, this same amount of heat would be lost in a week. For a 15 m (50 ft) thick wall, it would take 2 years to dissipate 95 percent of the heat. For a 150 m (500 ft) thick wall, it would take 200 years to dissipate 95 percent of the heat. Since change of temperature results in change of volume, and when restrained in change of tensile stress, very thin structures are relatively free from thermal cracking. However, the temperature rise in mass concrete resulting from the hydration of the cement is nearly adiabatic and must be dealt with in mass concrete structures.

Cement is the essential ingredient of concrete that develops the undesirable heat, and the less that is used the better, from this standpoint. Mass concrete, because of its large dimensions, can accommodate large aggregate graded up to 150 mm (6 in.) in size. This large maximum-sized aggregate permits a reduction in cement content of the concrete with no reduction in strength for strengths below 300 kg/cm^2 (4250 psi).

The primary requirement involved in mass concrete construction is that the completed structure is a monolithic mass that is free from cracks, particularly in the direction parallel to the axis of the dam, so that stress conditions developed in the loaded dam are essentially as calculated. Consequently, methods and rates of concrete placing, mix proportions, temperature control, and special treatment during construction are considered from this viewpoint.

HISTORY

Arrowrock Dam, which was completed in 1915, was the first concrete dam of any magnitude

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

In the Matter of	)	
	)	
LOUISIANA POWER AND LIGHT COMPANY	)	Docket No. 50-382
	)	
(Waterford Steam Electric Station Unit 3)	)	

SUPPLEMENTAL AFFIDAVIT OF JAMES P. KNIGHT

Q.1 Please state your name, title and by whom you are employed.

A.1 My name is James P. Knight. I am employed by the U. S. Nuclear Regulatory Commission as Assistant Director for Components and Structures Engineering, Division of Engineering, Office of Nuclear Reactor Regulation. A copy of my professional qualifications is attached to my previous affidavit, filed on August 7, 1984.

Q.2 Please describe the nature of your duties in this capacity.

A.2 I am responsible for the review and evaluation of design criteria to ensure the integrity of structures, systems and mechanical components, including the dynamic analyses and testing of safety related structures, systems and components, the geological, geotechnical and seismological characteristics of reactor sites, the seismic design bases, criteria for protection against the dynamic effects associated with natural environmental loads and postulated failures of fluid systems for nuclear facilities, and the stability of soils and foundation systems. I am responsible for the direction of the Mechanical Engineering Branch, the Structural and Geotechnical Engineering Branch, the Geosciences Branch and the Equipment Qualification Branch.

Q.3 Please describe your continued involvement with Waterford base mat-related issues since your affidavit of August 7, 1984.

A.3 In my capacity as Assistant Director for Components & Structures Engineering I have continued to superv se the overall staff review effort related to the engineering evaluation of the adequacy of the base mat at Waterford Unit No. 3 to perform the required safety functions under all design basis loading conditions. It is my responsibility to formulate the staff position considering the contributions of other members of the staff and our consultants; and after approval of that position by higher management to represent the staff position as required. I have continued to meet as necessary with members of the staff and our consultants Dr. Morris Reich, Head of the Structural Analysis Division of Brookhaven National Laboratory (BNL) and Professors Charles Miller and Carl Costantino of the City University of New York working in conjunction with BNL. In addition, I have participated in, and in most cases chaired, all the meetings with the applicant and its contractors (EBASCO, and Muenow and Associates Inc.)

Q.4 What ' the purpose of this affidavit?

A.4 The purpose of this affidavit is to describe the evaluation and conclusions of the NRC staff, concerning the design adequacy and structural integrity of the foundation base mat at Waterford Unit 3 in light of activities that have taken place since the staff's August 7, 1984 filing with the Atomic Safety and Licensing Appeal Board. Specifically, this affidavit addresses the completion of the Non-Destructive Testing (NDT) program and the filing of a final NDT report by the applicant. In addition, this affidavit provides the staff's response to the additional views of Dr. John Ma, which are being provided herewith at the Appeal Board's request. Also, the Staff is transmitting herewith as Attachment 1, the comments of Dr. John Chen of the staff; those comments are briefly addressed in this affidavit. The views of Drs. Ma and Chen are also addressed in the affidavit and accompanying Addendum, of Drs. Reich, Miller and Constantino, which is also being submitted at this time.

Q.5 Please summarize the status of the staff review as of August 7, 1984?

A.5 In our August 7, 1984 affidavit, the staff, with the aid of our consultants from the Structural Analysis Division of the Brookhaven National Laboratory (BNL), concluded that the cracking that had been observed in the Waterford base mat (both visual observation and preliminary results of the NDT) was unlikely to effect the safety of the Waterford facility. In the evaluation leading to this conclusion BNL performed some independent analyses for the staff utilizing data taken from the design analyses performed for the applicant by its Architect/Engineer, EBASCO, and by a consultant, Harstead Engineering Associates, Inc. (HEA). These materials were used in conjunction with independent analyses performed by BNL to address the most likely cause of the observed cracking and the impact of that cracking on both the calculated stress levels and dynamic response of the base mat. Based on review of the BNL analyses and evaluation of preliminary NDT data, the staff concluded that the cracks located on the top surface of the base mat would be expected to have occurred due to differential settlement induced by the imposition of dead loads (weight of the mat and partially completed structures) and other construction activities acting alone or in conjunction with previously existing thermal and shrinkage effects. These conclusions applied to the cracking both internal and external to the shield wall. In addition, the likelihood of diagonal tension failure in the base mat was evaluated and shown by analyses to be highly unlikely, a conclusion which was supported by the NDT results. Cracks in vertical walls were also evaluated and determined most probably to have been caused by thermal and shrinkage effects that occurred after the concrete was placed with some effect also due to differential settlement of the base mat. This was also corroborated by the NDT study.

In its August 1984, filing, the staff further concluded that the base mat cracks were unlikely to be significant from a safety standpoint under either normal operating loads or seismic design basis loads. Based on a review of the computer analyses performed by EBASCO and HEA, and on independent analyses performed by BNL, the staff concluded that the applicant's design appropriately considered the loads which the completed nuclear island would be expected to experience. In particular, the analyses performed by BNL demonstrated that the base mat of the completed plant is under high compressive loads largely due to lateral side soil pressures. The analyses further confirmed that these high compressive loads remain operative during all design basis seismic events. Since the compressive loads were sufficient to assure the cracks remained tightly closed during seisimc excitation, the staff concluded that the dynamic response of the base mat and supported structures would remain essentially unchanged and therefore would not adversely effect the function of Seismic Category I structures, systems and equipment.

Q.6 Has BNL indicated that they wish to change any of their conclusions contained in their July 18, 1984 report?

A.6 Yes, in one respect. BNL has indicated that one statement of conclusion in the July 18, 1984 report did not accurately reflect the content of their report and should be revised. The effect of this change is to delete item (ii) from Conclusion (c) page 26 of the July 18, 1984 BNL report:

> "the computed dead weight output data can be used to explain the pattern of cracking that has appeared on the top surface of the mat. The cracks that appear probably occurred after construction of much of the superstructure but before placement of all of the backfill and restoration of the ground water to its natural level. Growth of the cracks would then have been constrained by subsequent backfill soil and water pressures",

and to replace that conclusion with:

> "The observed cracks developed on the top surface of the mat during the construction phase and were most probably caused by differential settlement induced by the dead loads acting alone or by dead loads acting on the mat already cracked by normal thermal and/or shrinkage effects".

This matter is discussed in BNL Addendum 2 at pages 2-3.

Q.7 Please respond to the Appeal Board's comment concerning "why the cracks were not discovered before May 1983", and its comment that "the cracking as explained by BNL's analyses should have been considered and therefore more evident prior to placement of the backfill" (ALAB-786 at 12).

A.7 The staff is unable to respond to these comments other than to state that, "to the best of our information and belief, base mat cracking outside the RCB ring wall was not observed by NRC inspectors during the period in question". The staff presented this matter for response by the applicant on October 19, 1984. The applicant's response was provided by letter of October 26, 1984, a copy of which was forwarded to the Appeal Board by the applicant on October 29, 1984. Further discussion of this matter is provided in the affidavit of Dennis M. Crutchfield which is being submitted herewith.

Q.8 Has the NDT program been completed for the Waterford base mat?

A.8 Yes, the actual field work was completed in September 1984 and the applicant submitted its report, Nondestructive Test Evaluation of Base Mat Concrete Waterford No. 3, Louisiana Power and Light Co. (NDT final report), prepared by Muenow and Associates, Inc., on October 26, 1984.

Q.9 Please describe the means by which the staff proceeded to evaluate the information listed in Answer 6 above?

A.9 The staff consultants, BNL and Mr. Robert E. Philleo, were requested to review the final NDT report and to determine what change, if any, the information contained in this report caused in their previous conclusions in this matter. Also, BNL was requested to review the EBASCO report and to explore by independent calculations the effect of in-structure base mat response to the cracking, to perform a small experimental program to demonstrate the likely effect of the base mat cracks upon the strength of the mat especially with respect to shear stiffness. In the course of this review meetings were held with the applicant, information was requested and provided and pertinent documents issued, as follows:

October 26, 1984	LP&L transmits Rev. 0 of EBASCO Summary Evaluation of Structural Significance of Basemat Non-Destructive Testing Results by Muenow & Assoc.
November 2, 1984	Meeting held in Bethesda, MD with the applicant to discuss Muenow and EBASCO reports
November 7, 1984	LP&L transmits Appendix No. 5 to Muenow Report (final NDT report) which contains additional information on interface between mat and fill concrete and
	LP&L transmits Rev. 1 of EBASCO summary evaluation of structural significance of basemat non-destructive testing results
November 10, 1984	Robert E. Philleo transmits Detailed Comments on Non-Destructive Test Evaluation of Base Mat Concrete Waterford No. 3 by Muenow and Associates Inc. (final NDT report)
November 13, 1984	LP&L transmits Appendix No. 6 to Muenow Report which contains "best estimate/conservative" crack profiles

November 20, 1984	Meeting held in Bethesda, MD. with the applicant to discuss revisions/addenda to final NDT and EBASCO reports
November 28, 1984	LP&L transmits Rev. 2 of EBASCO summary evaluation of structural significance of basemat non-destructive testing results
November 30, 1984	LP&L transmits additional design/analysis information regarding foundation basemat in response to request by Dr. J. S. Ma. and
December 4, 1984	Meeting held in Bethesda, MD. (BNL, John Ma, John Chen, other NRC staff) to discuss differing views.
December 7, 1984	LP&L transmits commitments to conduct a monitoring surveillance program and conduct confirmatory analyses and
December 14, 1984	BNL transmits Addendum No. 2 to its report of July 18, 1984

Concurrently, members of the civil/structural allegation review team were conducting further on-site audits with regard to the documentation necessary to demonstrate that the backfill soils had been properly placed and adequately consolidated. On information and belief, it is my understanding that the allegation review team has concluded that the necessary documentation for the backfill soils is available and adequate to demonstrate the acceptability of the soil. Further details in this regard are presented in the affidavit of Robert E. Shewmaker, which is being filed herewith.

Q.10 Did any of the documents filed with the staff since August 7, 1984 contain information which was different than that understood by the staff at the time its affidavits of August 7, 1984 were filed?

xA.10 Yes, in some respects. As a basis for our conclusions presented in my August 7, 1984 affidavit (at pp. 19-20) the following major characteristics of the cracks in the Waterford base mat were noted:

a) All of the cracks were vertical.

b) The E-W cracks exterior to the shield wall ran from the shield wall to the side walls. The depths of these cracks varied in an undulating manner from several feet (2' to 4') to as much as 9 to 10 feet.

c) Based upon preliminary data, three primary E-W cracks are located under the RCB. Two of these appeared to connect to the E-W cracks exterior to the shield wall. The specific depth contours of these cracks were currently unknown, although initial information indicated that they maybe similar to those in (b) above.

d) Cracks emanating in a radial direction from the shield wall were not as deep nor as continuous as the E-W cracks.

e) All of the basematt cracks are tightly closed. This observation is based upon the measured characteristics of the reflected signal.

Based on our review of the final NDT report the only changes in the above conclusions are as follows:

1) In the E-W direction, outside the RCB more details on crack depth have been developed. Cracks J, L, and P (see NDT report for location) on the west side, and Fe, Le and Ke on the east side, are almost uniformly deep with the cracks extending approximately to the bottom steel. The remaining cracks vary in depth as previously described.

2) While two cracks under the RCB were originally identified as connecting to the external RCB cracks, it appears that seven major cracks exist under the RCB with 3 of these matching the three deep external cracks, (5 matches J and Fe, 7 matches L and Le, and 1 matches P and Ke). Of the remaining four, three appear to match shallow external cracks, while one crack (No. 3) terminates under the RCB.

Q.11 Describe the staff evaluation and conclusions with respect to its review of the final NDT report.

A.11 As indicated in response to Question 7 above, the staff requested a critique of the final NDT report from consultants BNL and an independent consulting engineer, Mr. Robert E. Philleo. Also, as discussed below, BNL participated in an additional meeting with the applicant and the principal investigator on the NDT program, Mr. Richard Muenow. This meeting was held to further explore Mr. Muenow's testing techniques and interpretation techniques, in light of data presented in the final NDT report, and his conclusions drawn on the basis of those data.

In their initial review of the final NDT report, BNL found several areas that required clarification, specifically:

(1) The data was interpreted in terms of "likely" crack patterns. However, the method by which the "likely" crack patterns were deduced from the data was not clearly presented.

(2) The accuracy for measurements made using the 60° sensor was not clear and no description was provided with regard to the accuracy of crack width measurements.

(3) There was an inadequate description of the detection and measurement techniques employed.

On November 2, 1984, a meeting was held at Bethesda, MD. attended by the applicant (accompanied by EBASCO and Mr. Muenow), the staff (including myself and Drs. Ma and Chen), and BNL. During the course of that meeting Mr. Muenow described in some detail his approach to overcoming many of the difficulties experienced in employing the pulse echo technique utilized in the Waterford base mat NDT for the data gathered with both the 45° sensor and the 60° sensor.

In assessing the significance that should be given to the 60° data, i.e., the data defining the cracks under the RCB, BNL questioned the impact that the fill concrete on top of the mat might have if the sound waves passed into the fill concrete rather than reflecting from the top surface of the mat as intended. Subsequent to the meeting of November 2, 1984 the applicant retained Mr. Muenow to perform additional testing that would examine the bond between the fill concrete and the surface of the mat. If a good bond was not present, the staff and BNL would be satisfied that the presence of the fill concrete did not interfere with the data being gathered. Mr. Muenow performed the necessary tests, and the results were reported in Appendix No. 5 to the final NDT report dated November 7, 1984. These test results demonstrated that the fill concrete was not bonded to the mat and the question was therefore resolved satisfactorily.

Upon completion of the November 2, 1984 meeting, the applicant was asked to provide a more detailed description of the methodology used to obtain and reduce the 60° data. This information was proprietary to Mr. Muenow. Subsequent to this request and after further review of the 60° data presented in the final report and further discussions between staff and BNL, this request was rescinded. The basis for rescinding the request lay in our conclusion that the information would have little bearing on our findings with regard to the 60° data -- i.e., despite some indication that the cracks under the RCB were discontinuous and perhaps not as deep in some areas as first indicated, prudent engineering practice in light of the uncertainties fundamental to obtaining the 60° data required that the cracks under the RCB be considered to be uniformly deep, and that three of these line up with the known deep cracks outside to the RCB. This, in conjunction with the need to assure adequate protection for Mr. Muenow's proprietary information, led us to conclude that this further information was not required at this time.

The applicant was also requested to prepare "best estimate" and "worst possible crack maps" showing both location and depth. Particular emphasis was placed by the staff on the requirement that these maps be developed based on Mr. Muenow's best judgement in which he would fully integrate the data and observations he made during the full range of his NDT activities at Waterford. These crack maps were subsequently provided and, upon review, there appeared to be some inconsistencies between these maps and the data in the final NDT report. In addition, apparent inconsistencies within the data made it to ascertain a direct correlation between the data and the graphic elevation drawings of the crack depths prepared by Mr. Muenow. Based on our discussions with Mr. Muenow we are satisfied that the elevation drawings adequately represent the data, consistent with Mr. Muenow's best judgement and expertise.

As indicated above, Mr. Robert E. Philleo, a consultant to the staff, also reviewed the final NDT report. Mr. Philleo noted difficulty in interpreting the data presented to reach Mr. Muenow's conclusions. Among these dififculties, Mr. Philleo noted some inconsistencies in numerical values used to reduce the 45° data and lack of a definitive explanation as to the engineering judgement applied in drawing the crack profiles. Similarly, Mr. Philleo noted several problems in understanding the process by which the 60° data has been reduced and interpreted in numerous instances. Mr. Philleo observed that the data interpreted in a context that is known fully only to Mr. Muenow. See letter from Robert Philleo to Dennis Crutchfield, at 1, a copy of which is attached as Attachment 2 hereto.

As Mr. Philleo notes in his cover letter to Mr. Crutchfield, Mr. Muenow's technique is proprietary and few, if any, of the practitioners have been as successful as he in applying pulse echo testing. The staff, Mr. Philleo, and BNL agree that Mr. Muenow's approach is based on sound physical principles and should give reliable results under circumstances, such as are associated with the examination of visible cracks at Waterford. In contrast to the basic soundness of the technique is the considerable difficulty persons other than Mr. Muenow have in obtaining meaningful and reproducible results. Nevertheless Mr. Muenow's success in identifying various types of discontinuities in concrete structures has been demonstrated on several occasions by drilling cores and examining subsurface concrete. This successful track record and his obvious command of the technology demonstrated to the staff and BNL during both the site visit and meetings at Bethesda lead us to conclude that the NDT data can be accepted as a significant element of information in defining cracks existing in the Waterford base mat. Although in the final analysis the interpretation of the data is almost fully dependent on the skills of Mr. Muenow, this approach represents the best available technology appropriate for physical investigation of the Waterford cracking.

Q.12 Should the NDT results for both visible and non-visible cracks be given equal weight as a reliable characterization of the detected cracks?

A.12 No. The results from the examination of the visible base mat cracks provide reasonable information as to the length, depth and orientation of the cracks (BNL Addendum 2 page 6), whereas the results from the examination of cracks underneath the RCB, which are not visible to the examiner on the surface, are considerably less reliable particularly in terms of defining crack depth.

The visible cracks were examined using a 45° transducer and an examination scheme based on both the source and the receiver being placed in a known distance from the crack as expressed on the surface of the mat. In addition to the important advantage of starting from a known location on the surface and then tracking the crack depth in relatively small steps, this procedure typically required only one reflection off the bottom of the base mat before the signal reached the sensing transducer. Thus minimizing the chance of anomalies in the recorded signal.

The cracks beneath the RCB were examined using a 60° transducer. The sound waves entered the mat at an unknown distance from the crack, and both the incident and reflected wave bounced off the bottom and top surface of the mat several times with resultant diffraction at each reflection and consequent reduction in signal quality.

Based on their observation of the process in the field at Waterford, and their further discussions with Mr. Muenow, BNL concluded that Muenow's interpretation of the 45° data can be accepted with reasonable confidence as a good characterization of the cracking identified outside of the RCB, for crack orientation (vertical) and crack depth. In addition, the results of the ultrasonic testing can be accepted with reasonable confidence for estimating crack width and for demonstrating that there are no significant voids in the concrete based on the successful application of this technique by Mr. Muenow in situations where his findings have been confirmed by physical examination.

The NDT results also should be viewed in light of an understanding of the most probable loading history experienced by the base mat. That history, as portrayed by Ebasco, and the independent analyses performed by BNL provide a strong rationale for the vertical orientation of the cracks described by Muenow.

Q.13 Describe the staff evaluation and conclusions with respect to the review of the EBASCO report, "Summary Evaluation of Structural Significance of Base Mat Non-Destructive Testing Results". (EBASCO report)

A.13 The staff requested that their consultant, BNL, evaluate the Ebasco report and provide their view on its adequacy. In the course of this review the staff and BNL met with the applicant and Ebasco on two occasions (November 2, 1984 and November 20, 1984). Following each of these meetings Ebasco agreed to make certain revisions in their report and those revisions in turn were received and evaluated by BNL.

In the initial review of the EBASCO report several questions arose with regard to the methodology employed by Ebasco in their evaluation of the significance of the cracking. Ebasco had employed a concept of averaging, wherein cracks were grouped into families and several averages were compounded to reach a measure of the significance of the cracking. Evaluation of the cracking in this manner led to apparent inconsistencies with the data presented in the final NDT report and did not appear to the staff or BNL to be a useful approach.

In addition, the report contained several conclusions concerning the state of stress during and following the formation of the cracks that did not appear justified based on our review of the construction history. A list of the specific questions generated as a result of BNL's review of the initial report is contained in Addendum 2 to the BNL Report, attached to the December 17, 1984 affidavit of Drs. Reich, Miller and Costantino.

At the November 2, 1984 meeting the above questions were discussed with the applicant and Ebasco. In the course of those discussions the staff and BNL reached agreement with Ebasco that the concept of grouping families of cracks would not be useful for the staff's assessment of the adequacy of the mat. Ebasco indicated that the groupings by families was in their view useful for obtaining an overview of the mat cracking. Ebasco also discussed their use of optical methods to obtain crack width measurements for cracks internal to the RCB in 1977. With regard to its previous contention that the upper reinforcement steel had not exceeded the yield strength of the steel during the formation of the cracks, EBASCO agreed that the steel may have reached yield stress some time before the closing of the cracks. In that context EBASCO also agreed that the BNL scenario for formation of the cracks was reasonable. Based on these agreements the applicant agreed to provide an enlarged Section 6 of the Ebasco summary report and to specifically address shear behavior in the mat, especially shear slip along the mat.

These agreements were documented in Revision 1 to the Ebasco summary report dated November 7, 1984. Based on our review of Revision 1 the staff and BNL concluded that the agreements reached in the November 2, 1984 meeting had been adequately documented. In addition, the staff and BNL concluded that a significant addition to understanding of the effect of the cracks at the Waterford Unit 3 plant had been provided by means of an EBASCO evaluation of the shear friction capacity of the mat. Utilizing an approach acceptable to the staff and BNL, EBASCO calculated that the shear capacity of the cracked mat is 1.9 times the shear demand. This computation of shear friction capacity did not take into account the compressive forces due to lateral soil and water pressures acting on the side walls. These compressive forces would further increase the mat's shear friction capacity (BNL Addendum 2 at 13).

In addition to the computation of shear friction capacity EBASCO provided a compelling argument with regard to the very minimal shear deformation (slip) across the cracks during an earthquake. In support of their argument EBASCO cited tests that were conducted (by J. P. Liable et al.) at Cornell University. The Cornell tests were specifically conducted to evaluate slip due to shear friction along a cracked surface under dynamic loading. A wide band of various crack parameters and loading were utilized (crack width, shear stress and clamping forces across a crack). The Cornell tests were run under conditions significantly more severe than those existing in the Waterford base mat, (BNL Addendum 2 at 13) i.e., wider cracks, higher shear stress and lower clamping forces. Based on these test results one must conclude that the shear slip along cracks in the Waterford base mat will be small, less than 0.01 inches (BNL Addendum 2 at 13). Such a small amount of slip indicates no significant change in either superstructure member forces or floor response spectra.

Several other matters were discussed at the November 20, 1984 meeting. These discussions were centered largely on the question of the maximum stress seen by the base mat top reinforcement steel under the flexure stresses considered to cause cracking. BNL maintained their view that flexure of the base mat during the construction phase sufficient to cause some yielding in the upper reinforcement was a major contributor to the cracking. Ebasco similarly maintained their view that thermal effects were a major contributor to the cracking and that yielding of the upper reinforcement had not necessarily occurred. Both BNL and Ebasco agreed that currently the loads on the base mat have placed the cracks in compression and will maintain them tightly closed.

Based on the agreements reached at the November 20, 1984 meeting Ebasco prepared Revision 2 to their summary report, submitted on November 27, 1984.

A matter also discussed at the November 20, 1984 meeting was the continued need for additional confirmatory calculations in light of significant factors of safety demonstrated in both the strength of the mat and the performance of the mat under dynamic loads i.e., the Cornell tests. Although the staff and BNL agreed that the information now documented in the Ebasco report provided high confidence in the adequacy of the base mat at Waterford Unit 3, the staff adhered to its position that the confirmatory calculations recommended by BNL are required to adequately define and document the state of the base mat and the present manifestation of the cracking, so as to provide a final analysis of record and to provide the baseline for implementation of the monitoring and surveillance program to be conducted throughout the lifetime of the plant.

Q.14 Please describe the additional independent calculations and testing conducted by BNL to further examine the impact of base mat cracking on the seisimc adequacy of supported structures and equipment, and the effects of the base mat cracks upon the strength of the mat particularly with respect to shear.

A.14 At the staff's direction, BNL further examined the impact of the base mat cracking on seismic adequacy by performing a dynamic analysis covering a wide range of base mat and superstructure stiffnesses and developing superstructure floor response spectra, to compare the superstructure seismic response under both cracked and uncracked base mat conditions. The superstructure floor spectra are a characterization of the seisimic motion that would occur at specific locations in the buildings supported on the base mat. The motions characterized by the floor spectra are the means of determining the loads on structures and systems as well as the motion input for qualification testing of equipment.

A simplified beam model was analyzed in both the cracked and uncracked base mat mode. This beam model, representing a 22' wide base mat strip running under the RCB in the N-S direction for the entire mat length, was placed on an elastic soil foundation with moduli similar to those used in the analyses performed by Harstead Engineering Associates Inc. (HEA). BNL had previously reviewed the HEA calculations and found them to be appropriate. The masses placed on the beam were also those given in the HEA calculations. A superstructure model representing the RCB and other ancillary structures was placed on top of the mat across the cracked zone. The base mat cracking was simulated by reducing the shear carrying capacity of the mat under the RCB to an infinitely small value, a very conservative representation since no credit would be given for shear capacity when, in fact, very substantial shear capacity has been calculated (BNL Addendum 2 at 13 EBASCO Revision 2 at 21). This model had the same mass and similar frequency characteristics to the structures in the RCB. A parametric study was performed considering both cracked, as above, and uncracked base mat shear strength, changing the frequency characteristics of the superstructure. A comparison of floor response spectra and element forces indicates that the cracked mat has little influence on the resultant responses for both horizontal and vertical earthquake inputs; in most instances differences in the spectral plots for the cracked and uncracked cases are indistinguishable (BNL Addendum 2 at D-4). The staff has reviewed and discussed these findings with BNL and has concluded that they provide a sound basis for the conclusion that the cracking of the Waterford base mat has negligible effect on the seismic adequacy of the mat or supported structures, systems or components.

To explore questions that had been raised regarding the effect the base mat cracks may have upon the strength of the mat (especially with respect to shear) and mat stiffness, BNL performed two tests. Based on the fact that the cracks of interest run straight across the mat, i.e., the effects are most likely associated with one-way bending of the mat, beams were used in the experiment. The beam reinforcement ratios were similar to the reinforcement ratios in the slab. Two identical beams were tested. The first beam was subjected to a negative bending moment causing a flexural crack originating at the top of the beam. The beam was then subjected to a positive bending moment which was increased until the ultimate moment capacity of the beam was reached. The second beam was not precracked and was only subjected to the positive moment loading. The load-deflection curves obtained during the test of the two beams were compared to provide a comparison of the beam strength and stiffness in the cracked and uncracked conditions, providing an indication of the effect the initial crack in the first beam has on the load carrying capacity of the beam and the beam stiffness.

BNL reported the following conclusions based on the data obtained from these tests:

1. When the beam is subjected to a negative bending moment (tension at the top) close to the yield and cracking moment, a deep crack occurs which penetrated close to the bottom steel. This is the type of cracking that has been observed in the base mat.

2. The ultimate capacity of the precracked beam is the same as the ultimate capacity of the uncracked beam. The capacity is slightly higher than the predicted strength. One can conclude that cracking of the mat will not adversely effect the mat strength.

3. The stiffness of the cracked beam is identical to the uncracked beam stiffness. One would therefore conclude that the base mat stiffness will not be effected by the E-W cracks.

4. The crack pattern caused by the positive bending moments applied to the precracked beam is very similar to the crack pattern in the beam which was not precracked. This also indicates that the negative moment crack has little effect on the beam when it is subjected to a positive moment.

The staff has reviewed and discussed these findings with BNL with BNL and has concluded that the tests provide a useful simulation of the behavior of the Waterford base mat with respect to cracking formed under flexure stresses, as well as a sound demonstration of the impact of tight flexure cracks on the strength and stiffness of cracked base mat section.

Q.15 Do all members of the staff who have been associated with the review of the Waterford base mat fully concur in the staff's conclusions?

A.15 No. Dr. John Ma of the NRC staff has developed separate views as to the actions necessary to assure the adequacy of the Waterford Unit 3 base mat. Dr. John Chen of the NRC staff also has separate views with regard to some geotechnical matters related to the staff's evaluation of the causative factors of the cracking.

Q.16 Please describe the circumstances surrounding Dr. Ma's participation in this matter?

A.16 As often occurs for matters arising late in the licensing process, the original reviewer who prepared the Staff's SER evaluation for Waterford concrete structures had been assigned to other matters by the time the base mat motion was filed. Accordingly, Dr. Ma was assigned by his supervisor to perform a review of the Waterford base mat, (which reviews reflected in his November 28, 1983 affidavit.

Following the submittal of his November 28, 1983 affidavit, Dr. Ma moved on to other assignments not related to Waterford.

Following the filing of a second base mat motion, the staff determined that additional staff review was necessary. Due to the complexity of the issue, the Chief of the Structural & Geotechnical Engineering Branch (SGEB), was assigned primary responsibility for conducting the review. In order to take advantage of his background, Dr. Ma was also asked to participate in this review, on an ad hoc basis. In the course of accomplishing the review, it became apparent that a level of expertise, in excess of that available within the staff would be required, particularly with respect to the evaluation of as-built concrete structures, BNL was therefore requested to assist the staff in completing this review and in particular to bring to bear the expertise and experience of Dr. Reich and Professors Miller and Costantino. In the course of Dr. Ma's participation in this process, subsequent to filing his November 28, 1983 affidavit, Dr. Ma developed several hypotheses regarding the as-built condition of the base mat at Waterford Unit 3. Initially Dr. Ma was concerned that serious voids and honeycombs might exist internal to the base mat, based on a site visit he conducted and information he had received which indicated the likelihood of concrete handling deficiencies when the base mat was poured. Thereafter, the procedures employed in the placement of the base mat concrete were reviewed by a staff consultant, Mr. Robert Philleo. Mr. Philleo concluded that the precautions taken during placement of the base mat concrete were adequate, and based on Mr. Philleo's review, Dr. Ma considered that his concerns as to construction practices had been satisfactorily resolved.

Following the site visit (at which the surface expression of the base mat and vertical wall cracks were viewed by Dr. Ma, other NRC staff members and members of the BNL staff), and review of a geotechnical report prepared by another SGEB staff member, Dr. John Chen, Dr. Ma expressed the view that there was a high likelihood that serious diagonal tension failure had occurred in the Waterford base mat. Neither Dr. Ma's immediate supervisors nor the consultants from BNL, considered that this diagonal tension failure hypothesis was soundly based and safety evaluation finding the base mat acceptable for service was prepared.

Nonetheless, in light of Dr. Ma's continued concern over the likelihood of diagonal tension failure, I decided to undertake a review of this matter.

Dr. Ma recommended that two principal steps be taken: that an NDT examination of the base mat be made to determine whether or not the planes of the crack internal to the base mat approached the 45° angle characteristic of the diagonal tension failure, and that additional analyses be performed in an attempt to evaluate the stresses during construction that would have led to the cracking. Dr. Ma recommended Muenow & Associates Inc. as being one of the few organizations that could perform this task.

The staff concluded that the NDT could provide valuable insight as to the nature and extent of the cracking in the Waterford base mat, particularly since the record at that time as to cracks may have been covered by structures on top of the base mat appeared to be ambiguous. The staff therefore prevailed upon the applicant, to proceed with the NDT, and Dr. Ma was assigned to be present during the initial testing efforts.

The preliminary and final results of the NDT performed by Muenow & Associates was unambiguous in describing the vertical orientation of the cracking in the Waterford base mat. Accordingly, Dr. Ma's concern with regard to diagonal tension failure was considered to have been satisfactorily resolved.

In addition to recommending the NDT, Dr. Ma had also recommended that additional analyses be performed considering differential settlements that may have occurred during the initial construction of the base mat. Again, the significance of such analyses were not agreed to by

Dr. Ma's immediate supervisors or by BNL. While Dr. Ma did not feel he could reach a finding without benefit of additional analyses, the staff and our consultants believed that we had reached a correct understanding of the base mat crackings impact on safety and that such analyses should properly be handled as a confirmatory matter. Dr. Ma was offered an opportunity to present a differing professional opinion in this regard, and to submit his views to the Appeal Board, at the time the Staff's affidavit were filed on August 7, 1984 but declined to do so.

Q.17 Please summarize your understanding of Dr. Ma's views expressed in his affidavit of December 12, 1984.

A.17 Dr. Ma appears to take issue with the staff's conclusions and with BNL's recommendations which form the principal bases for those conclusions, in three areas.

1. The initial causes of the cracking.

2. The acceptability of the cracking from the standpoint of dynamic response of the base mat.

3. The acceptability of the cracking from the standpoint of corrosion and durability.

With regard to the origin of the cracking, Dr. Ma appears to take issue with the conclusion that the cracks were in part the result of construction loads acting on the base mat. Although Dr. Ma offers no alternative process for the formation of the cracks, there appears to be some agreement that thermal stresses and differential settlements also played a significant role in the cracking as it exists today.

With regard to the dynamic response of the base mat, Dr. Ma does not appear to accept the BNL conclusion that the dynamic response of the base mat will not be significantly affected by the cracking, although he offers no rebuttal to the BNL finding that the crack faces are held in contact by high compressive loads due, in part, to the backfill soil and water pressures on the side walls of the base mat and supported structures. In his discussion of this matter, Dr. Ma relates his concerns regarding the differences between the design analysis assumption of a homogeneous concrete mass, and the present cracked condition of the mat. His principal concerns in this matter appear to be the possible transmission of loads through the reactor building and a change in stiffness of the as-cracked mat that, in his view, could change the seismic design bases for systems and equipment supported by the base mat. Dr. Ma offers no showing of inadequacy but discusses some of the difficulties he perceives in analyses of a cracked section.

With regard to the questions of reinforcing steel corrosion and concrete durability, Dr. Ma offers some general discussion of commonly accepted effects of corrosion on reinforcing steel, which are not related to the likelihood of corrosion at Waterford. Also, he does not provide any bases for differing from either the conclusion offered by BNL and the applicant that the cracks now existing in the base mat are tight (on the order of 7 mils), or from his initial affidavit's view of the significance of the cracking in the region of the reinforcing steel.

Dr. Ma offers some comparisons with permissible crack widths offered in the ACI 318-83 and ACI 318-71 codes, and appears to infer that the cracks at the bottom of the base mat may be significantly larger than these referenced values. However, he makes no showing of why the cracks at the bottom of the base mat should be assumed to be so much wider. In fact, if one accepts Dr. Ma's discussion concerning the adequacy of base mat design and concrete construction sequence, it must be concluded that the tensile stresses present at the bottom of the base mat throughout the construction sequence were no greater than intended, and one would not, therefore, expect the cracks to be any wider than contemplated in the design.

Q.18 Do you believe that Dr. Ma's views have been adequately considered by the Staff and BNL?

A.18 Yes. Since March 1984, Dr. Ma has offered several different hypotheses as to matters which were of concern to him with regard to the Waterford base mat. Each of Dr. Ma's concerns were given serious consideration and pursued in sufficient depth either to require specific actions to be taken by the applicant or to reach a determination that the matter was not germane to the safety of the base mat. The Staff's effort to satisfactorily address Dr. Ma's concerns is reflected, in part, in my August 7, 1984 affidavit. In particular, the concern that diagonal tension failure may have occurred (item (b) of answer 7); the relationship between basemat cracks and vertical wall cracks (item (c) of answer 7); and the concern over the effect the cracks might have on response to the base mat under seismic loads, (item (d) of answer 7), were all maters which Dr. Ma considered to require further evaluation by the staff. In a number of instances, I asked BNL to undertake particular analyses or evaluation of Dr. Ma's concerns when the BNL consultants and other NRC staff members did not consider such additional work to be necessary.

Q.19 Do you believe that the concerns of Dr. Chen have been adequately considered and addressed by the Staff?

A.19 Yes. As in the case of Dr. Ma's concerns, Dr. Chen's concerns were considered throughout the staff review. The four specific items (a through d) listed in answer 6 of my August 7, 1984 affidavit reflect the explicit concerns identified by Dr. Chen for Staff consideration. These concerns prompted the concern for diagonal tension failure, a concern which we are satisfied has been resolved. Dr. Chen's views were considered by BNL in their review and analyses of base mat issues although, in many instances, the BNL staff did not concur with his conclusions.

Dr. Chen has recently provided a written memorandum setting forth his current views on the Waterford base mat, a copy of which is attached to this affidavit along with an earlier report he prepared. I have requested BNL's assistance in addressing these matters.

Q20. Has the conclusion of the staff or their consultants with regard to the adequacy of the base mat at Waterford No. 3 changed in any way since the filing of the staff's August 7, 1984 affidavit?

A20. No, there has not been any change in the conclusions reached by the staff or their consultants that the base mat at Waterford Unit No. 3 is acceptable for service contingent only on an acceptable monitoring and surveillance program and confirmatory analyses. The following activities and results since the filing of the August 7, 1984 staff affidavit have confirmed that conclusion:

Activity	Finding
NDT completed	Cracks are vertical, probably discontinuous and tight

EBASCO evaluation of shear friction	Shear capacity is at least 1.9 times shear demand
EBASCO citation of dynamic shear slip tests at Cornell	Strong evidence that shear slip at Waterford will be less than .01 inches
BNL dynamic analyses comparing floor spectra developed for simulated cracked and uncracked	In structure spectra for cracked and uncracked base mat show negligible change
BNL tests of concrete beams constructed with the reinforcement ratio of the Waterford base mat	Crack characteristics identical to those described by NDT for the Waterford base mat. Load deflection curves show negligible change for cracked and uncracked specimens.

Q21. Has the applicant provided an acceptable commitment as to (a), its proposed monitoring and surveillance program and (b) the confirmatory analyses which have been required by the NRC staff?

A21. Yes. In a letter dated December 7, 1984 the applicant committed to submit, prior to exceeding 5% power, a base mat monitoring and surveillance program for NRC staff review and approval. The LP&L commitment is to provide a program that will address, at a minimum:

1. settlement of the base mat.

2. changes in ground water chemistry that could effect corrosion of reinforcing steel.

3. seasonal variation in ground water levels.

4. mapping of significant cracking in the basemat and adjacent walls.

In addition, prior to exceeding 5% power, LP&L will submit for NRC staff review and approval a detailed commitment to perform confirmatory analyses for the base mat. The commitment will address the following elements:

1. dynamic coupling between the reactor building and the base mat for seismic stresses resulting from the vertical earthquake input;

2. dynamic effects of lateral soil/water loading;

3. artificial boundary constraints infinite elements models;

4. fineness of base mat element mesh; and

5. origin of cracks in the vertical walls.

These confirmatory analyses will be submitted for review by the NRC Staff prior to restart after the first refueling cycle.

Q22. Has the Staff reached a final conclusion as to whether there are any outstanding safety issues related to the Waterford base mat?

A22. Yes. The Staff has determined that there are no outstanding safety issues at this time related to the Waterford base mat.

James P. Knight

Subscribed and sworn to before me this 17th day of December 1984.

MAXINE H. LAIEFSKY NOTARY PUBLIC MONTGOMERY COUNTY, MD.

Notary Public

My Commission Expires 7/1/86

ATTACHMENT 1

TO THE AFFIDAVIT OF JAMES P. KNIGHT

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

DEC 13 1984

NOTE FOR: [redacted] Assistant Director
for Components and Structures Engineering
Division of Engineering

FROM: J. T. Chen, Geotechnical Engineer
Structural and Geotechnical Engineering Branch
Division of Engineering

SUBJECT: WATERFORD 3 BASE MAT CRACK ASSESSMENT

I was surprised to learn that NBL acknowledged that they agreed with my assessment about the causes of the base mat cracks during the December 4 meeting. This was quite a contrast to the reception I received from them seven months ago when I presented the same findings in the meeting held at Nicholson Lane.

After the December 4 meeting, I took the liberty and reviewed the BNL's July 18 report. I have to say that, as BNL stated in the meeting, this report is consistent with their two previous reports with the same conclusion, "The cracks that appear probably occurred after construction of much of the superstructure but before placement of all of the backfill and restoration of the goundwater to its natural level. Growth of the cracks would then have been constrained by subsequent backfill soil and water pressures." However, I feel this conclusion is quite different than mine and wish to offer the following comments for your consideration:

1. BNL's conclusion was based on the review of the HEA finite element analysis results. However, the HEA analysis does not represent the actual loading conditions of the mat when the cracks were discovered.

2. No place in the BNL's reports raised the concern about the stress conditions in the mat during early stage of construction and BNL had not questioned about the validity of the soil moduli used in either HEA's or EBASCO's finite element analyses. If the soil moduli were reduced to reflect the realistic soil conditions prior to concrete pouring, similar finite element analyses results, if performed as Dr. Ma and I recommended in April, would indicate that the stresses and bending moments would be much higher then those values presented in the HEA's analysis. This would provide a positive clue that the mat might be overstressed and the cracks could have been developed on the top of the mat.

3. BNL attributed the E-W cracks inside the ring wall had the same origins as the cracks outside the shield wall. (Dead loads acting in conjunction with thermal and shrinkage effects). (BNL report p. 14). But, BNL stated that HEA computer results can not be used to explain those cracks. Another words, the stress level under 100 percent dead load was not high enough to cause the E-W cracking. If under full load, the mat will not crack; how can one conclude that under partial loading conditions (60 percent of the dead load was on the mat when cracks were discovered in 1977), the mat cracked?

4. BNL stated in the report that "....., soil settlement at the site was found to be instantaneous based on actual measured data." (BNL report p. 21). But BNL also stated that: "Long term consolidation effects can be anticipated to cause effective redistribution of loads to cause the mat to behave in a more flexible manner" (BNL report p. 14). This contradicts the previous statement. If the soil possesses long term consolidation characteristics, the settlement should not be described as instantaneous which misled the reader to overlook the importance of the consolidation effects on the mat. The applicant's submittal of the measured settlement data, clearly showed that soil settlements were not instantaneous.

5. BNL stated in the meeting that the foundation soil beneath the mat are uniform across the site based on its review of settlement measurements. However, it should be pointed out that those settlement measurements were obtained using an averaging technique and they were also influenced by the stiffness of the concrete blocks. The averaging technique could reduce the reported differential settlement to less than half of its real value. All other instrumentations installed at the site such as heave gages and piezometers clearly showed the non-uniform nature of the foundation soil conditions beneath the mat. The compaction state, placement fill in water, and mud spurt during construction served as further indicators of the non-uniform nature of soil conditions.

In summary, I feel that BNL's report did not take the factual information into consideration in their evaluation process. This probably led the Board to conclude that BNL raised more questions than they tried to answer them. The mechanism causing the mat to crack can be identified because the loading history of the mat and foundation soils is available. The only missing link is to transfer the loading history on the mat/soils into stress history on the mat/soils and to determine the effects of those stresses on the past and future behavior of the mat. Specifically, the cracking mechanism can be demonstrated if one would perform an analysis taking the loading history and soil conditions during early stages of construction into consideration, i.e. (a) block construction sequence induced initial tensile stresses in the mat (b) softer soil conditions induced significant high stresses and bending moments in the mat when the concrete had not developed its full strength, (c) differential settlement between construction strips #1 and #2 caused prevailing E-W oriented cracks (d) hydrostatic pressures changes in 1977 induced additional bending/tensile stresses that caused the show-up of the cracks. The stresses induced by those factors are accumulative. Any one factor may not be significant enough to cause the mat crack, but, the combined effects would show us the kind of cracks on the mat as we observed.

J. T. Chen

J. T. Chen, Geotechnical Engineer
Structural and Geotechnical
Engineering Branch
Division of Engineering

cc: R. Vollmer
D. Crutchfield
J. Scinto
S. Turk
G. Lear
L. Heller
J. Ma
J. Wilson

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 currently proposed 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.

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.

ATTACHMENT 2

TO THE AFFIDAVIT OF JAMES P. KNIGHT

TELEPHONE (703) 256-4183

ROBERT E. PHILLEO, P.E.
CONSULTING ENGINEER

7420 ANNANWOOD COURT
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November 10, 1984

Mr. Dennis Crutchfield
Assistant Director for Safety Assessment
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Office of Nuclear Reactor Regulation
United States Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Mr. Crutchfield:

As requested by Bob Shewmaker, I have reviewed in some detail the report entitled "Nondestructive Test Evaluation of Basemat Concrete, Waterford No. 3, Louisiana Power and Light Company" by Muenow and Associates, Inc.

There is no accepted standard for pulse echo testing although several organizations are working on the technique and having considerable difficulty in obtaining meaningful and reproducible results. Muenow has what is, essentially, a proprietary technique which no one else has been able to duplicate or totally comprehend. The approach is based on sound physical principles. If taken at face value, his technique has overcome the experimental difficulties of distinguishing between the desired pulse and spurious pulses and of transducer ringing. The problem of spurious pulses is dealt with in paragraph 6 on page 31 where, apparently, all pulses except the one which the operator believes is the correct one are prevented from interfering with the operation. One can only wonder if sometimes the pertinent pulse is likewise excluded. The problem of ringing is recognized in paragraph 7 on page 23, but the solution is not clear because in the same sentence it is stated that the transducers were placed both closer together and farther apart in order to overcome the problem. One of the dimensions may be in error.

Nevertheless, on several occasions Muenow's findings have been verified by drilling cores and examining subsurface concrete. These findings have given his technique a certain credibility.

It is very difficult to reach the conclusions given in the report from the data given in the report. The difficulties are documented in the attached comments. Either the engineering judgment required to interpret the data belongs to Muenow alone, or the report does not provide all the data. It appears as though he did not expect anyone to critically examine the report.

As a result of reading this report I believe we know with confidence little more than we knew before receiving the report. However, even if all the conclusions are accepted, there is nothing to cause concern about the structural performance of the basemat. All the cracks are found to be nearly vertical and are probably the result of thermal stresses formed during cooling of the concrete after the early hydration of the cement. There is no evidence of shear cracks resulting from unusual loading conditions or adverse foundation support.

I hope this evaluation is of value to you. I will be happy to discuss the matter further in whatever detail you desire.

Sincerely yours,

Robert E. Philleo

Robert E. Philleo

encl.

cc: Richard A. Lofy

DETAILED COMMENTS ON

Nondestructive Test Evaluation of Base Mat Concrete
Waterford No.3, Louisiana Power and Light Co.

by

Muenow and Associates, Inc.

Robert E. Philleo,
Consulting Engineer

In spite of its bulk, the report is incomplete or poorly explained in many places so that it is difficult to justify some of the conclusions which are reached. The following specific items are noted:

1. On page 10 it is stated that the average transit time is 71.2 microseconds per foot, rounded to 71. Throughout the report a value of about 75 apparently has been used to reduce the data.

2. The data sheets for the 45-degree transducer show a row of figures across the top which purport to be the microseconds to a crack along the surface of the basemat. The test locations are 12 inches apart, but these figures are obviously based on an 18-inch interval, which is the spacing of the test lines. All these figures appear to be in error.

3. The significance of the readings of 0 in the 45-degree tables is not explained. Sometimes they seem to be north-to-south readings where no response was received, and sometimes they seem to be south-to-north readings which were never run.

4. The asterisks on the 45-degree data sheets are not explained.

5. Although there were some readings taken in the south-to-north direction, the data have not been reduced in the report; and there is no comment as to how well the results agreed with the north-to-south readings. I checked the 7-foot test on Line No. 5 for Crack A, where a transit time of 700 microseconds is shown for the north-to-south direction and 990 microseconds for the south-to-north direction. I agree with the angle of 3.47 degrees shown in the report for the N-S direction (assuming a transit time of 75 microseconds per foot), but I get a value of 13.89 degrees for the S-N direction. This particular disagreement may be resolved by the fact that the second path intersects the crack at a lower elevation than the first, but the report is silent on this whole issue.

6. The manner in which engineering judgment was applied in drawing crack profiles based on the 45-degree data is not explained. The computer

plotted all the points, including values of zero where apparently no signal was received. Crack lines were drawn from the surface until a value of zero was approached. Non-zero values at lower elevations are dismissed as random reflections.

7. On the 60-degree transducer data sheets all the data have been massaged so that the value for every test is given as though the test location were 105 feet from the center-line of the mat rather than its actual distance. This is unfortunate. It deprives the reader of a look at the actual data, and it renders impossible an opportunity to compute the average transit time at the actual test location instead of having to use an average value measured on another portion of the basemat.

8. On the 60-degree data sheets there are some entries where distances are shown but not transit times. These are not explained.

9. There is nothing on the 60-degree data sheets to justify the manner in which cracks have been drawn, where the drawings include discontinuous segments. For example, the drawings for crack No. 6 show discontnuities in the crack, as indicated by dashed lines at test locations 65, 70, 77, 70e, and 75e in the plan drawing and at locations 60e, 65e, 70e, and 75e in the profile drawings. Presumably a discontinuity is detected when a signal fails to reflect and, therefore, fails to be detected by the receiving transducer. All the test points in the above-referenced lines, however, demonstrate a complete set of signal-return data with no anamolies in the reported data.

10. On page 32 it is stated in paragraph 7 that frequency and attenuation measurements are used to correlate continuous and/or noncontinuous reflecting surfaces. No frequency or attenuation data are given in the report. It is impossible for a reader of the report to evaluate the manner in which the author dealt with this matter.

11. To note a very minor point, the horizontal scale is in error in Drawing No. 2. It should be 1.5mm = 1 ft rather than 15mm = 1ft.