JAN 31 1985

NOTE TO: Sherwin E. Turk
Deputy Assistant Chief Hearing Counsel, OELD

FROM: John S. Ma, Structural Engineer
Structural and Geotechnical Engineering Branch
Division of Engineering, NRR

SUBJECT: COMMENTS ON THE APPLICANT'S RESPONSE TO STAFF AFFIDAVITS FILED IN THE WATERFORD PROCEEDING

This is in response to your request of January 11, 1985 on the subject matter. My comments on the Applicant's response (Churchill, Ehasz, and Holley) are as follows:

1. The Applicant stated that my concern of the seismic response was based on the assumption that "the crack is wide and there is no contact between concrete surfaces across a crack" is a misinterpretation of my December 10, 1984 affidavit (Churchill, page 10, and Ehasz affidavit, pages 7 and 8). What stated in my affidavit is that "The actual shear stiffness of the cracked mat lies in between a condition of an uncracked section and a total separation at the crack without any friction force" (page 17, lines 15 through 17). The actual shear stiffness of the cracked mat is bounded by these two conditions, with an uncracked section as the upper bound and a cracked section of total separation at the crack surfaces as the lower bound.

2. It has been the Applicant's analytical approach that the mat was assumed uncracked and the compressive force provided by backfill soil and water pressures was not relied upon for the stability of the mat. Because of this approach, the compressive force during earthquakes was not calculated by a detailed dynamic analysis. It now appears that the Applicant wants to make a major change of its original approach for mat design to a new condition that requires the compressive force provided by backfill soil and water pressures to prevent the extensive cracks from opening up during earthquakes in order to preserve the safety function of the mat. This new approach was briefly suggested in the August 3, 1984 addendum to BNL report, but the submittal of this new approach by the Applicant was not known to me until now. Therefore, the Applicant's charge that I ignored or inexplicably did not address the presence of the compressive force provided by backfill soil and water pressures was incorrect (Churchill, pages 10 and 11). My evaluation of the Applicant's new approach is described below.

   a. Shear Capacity

   Using the Applicant's data provided in Attachment 1, and equation 7 in Attachment 2, to Mr. Ehasz's affidavit, there is only a 3.4% increase in shear capacity of the cracked mat during an earthquake

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when backfill soil and water pressures are included in comparison with the original assumption that the pressures were neglected. Therefore, what was considered as "a very substantial compression force..." (Ehasz affidavit, Attachment 1, page 20) only has an insignificant effect on the increase of shear capacity of the cracked mat.

b. Shear Stiffness (Rigidity)

The shear stiffness of the cracked mat either with or without backfill soil and water pressures was not provided by the Applicant. The Applicant's submittal does not contain enough information for me to calculate the contribution of backfill soil and water pressures on the shear stiffness of the cracked mat. Therefore, the increase of shear stiffness of the cracked mat due to backfill soil and water pressures is unknown.

c. Dynamic Analysis of the Cracked Mat

The response (displacement, rotation, stress, and strain) of the cracked mat and its super-structures including piping and equipments is a function of the shear stiffness of the cracked mat. Without the shear stiffness, structural responses cannot be calculated. Since the Applicant has not performed a dynamic analysis for the cracked mat, how can the Applicant conclude that the dynamic response of the basemat will not be significantly affected by the cracks (Churchill, page 11, Ehasz affidavit, page 8, Holley affidavit, pages 10 and 11). The Applicant's conclusion was not supported by dynamic analyses, but was based on its judgments.

d. Judgments

During a meeting with Messrs. J. P. Knight, S. E. Turk, P. T. Kuo on August 6, 1984 in Mr. Knight's office, I told Mr. Knight that "if a through crack across the width of the mat was assumed as BNL did, the cracked mat and the super-structures including piping and equipments would behave differently from the uncracked mat during earthquakes. However, the magnitude of the differences is not yet known. Because I specialized in reinforced concrete and not in structural dynamics, I had consulted with Drs. S. P. Chan and P. T. Kuo, both of whom specialized in structural dynamics, to see if they could tell the magnitude of differences between the cracked and uncracked mats. Both expressed the opinion that the cracked mat would behave differently from the uncracked mat, but they could not tell how much the difference would be." I urged Mr. Knight to verify with Dr. Kuo. Mr. Knight did and Dr. Kuo confirmed his opinion as stated above.

During this review, I again seeked Dr. Chan's opinion on January 17, 1985 (Dr. Kuo was on travel and unavailable). He said that it is very difficult to predict the stress conditions of both uncracked and cracked basemats during earthquakes without really doing the calculation and analyses. Therefore, he could not comment on the magnitude of differences between both cases.

While I respect the Applicant's judgment, I also have a great respect in the judgment and competence of Drs. Chan and Kuo. Under this circumstance, I believe that it is the Applicant's responsibility to demonstrate quantitatively by dynamic analysis that its judgment is correct.

3. A very important new information, the maximum crack width in the mat is now believed to be 0.015 inch instead of 0.007 inch, was only casually mentioned at one place (Holley's affidavit, page 6, the last sentence). The 0.007 inch was the maximum crack width that Muenow's NDT revealed in October 1984. The Applicant did not address the impact of this new information nor discuss the possible corrective actions. The new maximum crack width has exceeded the limit of 0.013 inch set by ACI Building Code and the limit of 0.012 inch recommended by ACI Committee 224. The Applicant should submit its evaluation report on the impact of this important new information.

Laboratory testing results have indicated that the shear stiffness of a crack section is influenced by many factors, such as test methods, the amount of reinforcing steel across the crack surfaces and its distribution along the depth of the crack section, and size effect. Nevertheless, test data have confirmed that the crack width is the most important factor influencing the shear stiffness. The pictorial test data in Enclosure 1 present a good indication of the amount of reduction in shear stiffness versus crack widths with other factors being kept constant. The test data have also negated the Applicant's claim that "...there is [the crack's result] no change in the rigidity [stiffness] of the mat and no effect upon the dynamic response of the basemat to the earthquake." (Ehasz's affidavit, Attachment 1, page 23).

4. The applicant seems to argue that the temperature induced cracking problem is not a concern at Waterford because the basemat is not an unreinforced mass dam (Ehasz's affidavit, page 7, and Holley's affidavit, pages 12 and 13). The following excerpt from "Control of Cracking in Concrete Structures" reported by ACI Committee 224, published in October 1980, clearly stated that temperature induced cracking should be considered and prevented in mass concrete of steam power plants and building foundations.

"Chapter 7 - Control of cracking in mass concrete

7.1 - Introduction

Temperature induced cracking in a large mass of concrete can be prevented if proper measures are taken to reduce the amount and rate of temperature change. Measures commonly used include precooling, post-cooling or a combination of the two, and more recently, thermal insulation has been used to protect exposed surfaces. The degree of temperature control necessary to prevent cracking varies greatly with such factors as the location, the height and thickness of the structure, the character of the aggregate, the properties of the concrete and the external restraints. Although a large amount of the data for this chapter has been obtained by experience gained from the use of mass concrete in dams, it applies equally well in mass concrete used in other structures such as steam power plants, powerhouses, bridge and building foundations, navigation locks, etc...."

The applicability to steam power plants and building foundations, which are reinforced concrete, is specifically mentioned in the above quotation.

Regarding the unusual depth of cracks in the mat, the Applicant rationalized that the thermal stress could have resulted in substantial concrete tensile stresses (on the order of several hundred psi) in the mat (Ehasz's affidavit, Attachment 1, page 12). However, the Applicant did not say whether this substantial tensile stress was greater than the concrete cracking strength of about 355 psi due to axial tension (not bending). Therefore, it is not known whether the thermal stress alone had cracked the concrete mat. Section 7.3 "Determination of temperatures and tensile strains" of the above quoted report may be used for analysis to determine the magnitude of tensile strains and stresses in the concrete mat.

Before the extensive cracking in both length and depth in the mat was revealed in October 1984, the Applicant had stated that "there is no direct evidence, nor is it reasonable to assume, that vertical through-cracks have occurred...." and "the formation of vertical or near vertical through-cracks would imply an occurrence of shear failure in the mat concrcte" (Enclosure 2, Attachment 1, pages 1 and 2). Now, the "hypothetical" condition has been verified by NDT, but the Applicant is mute on its own previous conclusion of shear failure, and altered its conclusion to the opposite. The Applicant should provide technical reasons for the change of conclusion.

5. According to Mr. Ehasz's affidavit, pages 9 and 10, the corrosion problem to reinforcing steel bars was the only subject studied and the study was performed in terms of chemical tests alone before September 1983. The sole consideration of steel corrosion might have been sufficient then when the cracks were thought to be very shallow and limited. Due to the extensive cracking now existing in the mat, a broader consideration of durability appears to be warranted. Steel corrosion in terms of chemical effects may still be the leading concern in the durability consideration. Nevertheless, the potential problems resulting from wet-dry, and thermal cycles, and other factors on the extensive crack surfaces and reinforcing bars should now be considered. Since the concrete deterioration in the mat cannot be detected visually, it is prudent to consult or involve a concrete material science specialist during the process of developing a monitoring program for the operating text specification.

6. On pages 11 through 13 of Mr. Ehasz's affidavit, it concluded that the differential settlement was the primary cause of basemat cracking and cited the apparent mistake of BNL by neglecting it and advanced its own scenario on the sequence of basemat cracking. BNL's mistake was fundamental and obvious because it used an unrepresentative analysis to explain that the sequence of basemat cracking that occurred during construction. The sequence of basemat cracking in Ehasz's affidavit might be considered as a logical one, if the data he used were correct. However, Dr. Chen has provided information concerning the validity of the data interpretation that

led to the convexity of basemat during construction claimed by Mr. Ehasz (Chen's memo to S. E. Turk, January 23, 1985).

Therefore, the current understanding of the basemat cracking is that the major contributing factor to the cracking may have been identified, but the magnitude of each individual factor has not yet been calculated.

Conclusion

The extensive cracking in both length and depth including many through-cracks in the Waterford 3 basemat is not a normal crack pattern in accordance with its design. These cracks are formed in planes nearly across the whole width of the mat and they present a potential for failure during earthquakes and for concrete durability problems. Even the Applicant had acknowledged prior to NDT testing that the through-cracks would imply an occurrence of shear failure in the mat concrete.

The precise causes and sequence of basemat cracking are not yet known because no analysis has been performed to demonstrate such an occurrence. The available data seem to indicate that cracking is still in progress (Chen's memo to S. E. Turk, dated January 23, 1985).

Dynamic analysis has not been performed by the Applicant to assess whether the safe shutdown capability of the plant during an SSE can be assured. The analysis is essential because the new responses of the safety-related piping, equipments, and structures supported on the cracked mat would behave differently from that on an uncracked mat.

It appears that the seed BNL planted last August is now sprouting, which is relying on the backfill soil and water pressures to prevent the cracks from opening up during earthquakes. Is it a prudent and realistic approach? The Applicant should note that the apparent mistake of BNL cited by the Applicant first appeared in a BNL report in April 1984 and it took eight months for BNL to recognize its mistake, after Dr. Chen and I had repeatedly pointed out the mistake to BNL since last April. The Applicant certainly does not want to learn that the new approach would not work after spending several months additional effort and costly computer runs. In light of the urgent need for a full power license, it seems to be a better alternative for the Applicant to direct its effort to fill and bond the cracks today so it would not have to live with them tomorrow.

John S. Ma
Structural Engineering Section A
Structural and Geotechnical
Engineering Branch
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Enclosure

cc: See next page

cc: w/enclosure:
H. Denton
D. Eisenhut
J. P. Knight
D. Crutchfield
J. Scinto
J. Wilson
G. Lear
D. Jeng
J. Chen

Enclosure 1

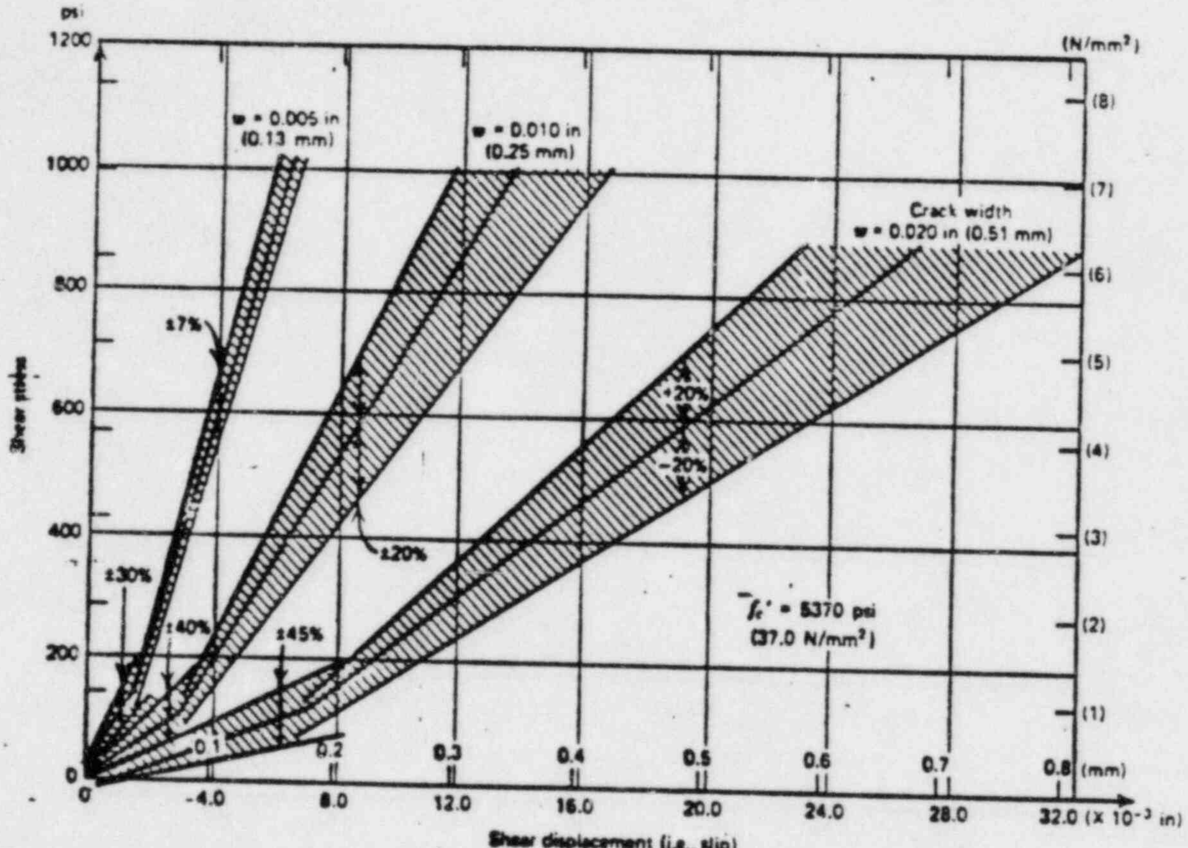

Fig. 7.28. Typical mean shear stress–shear displacement relationships for aggregate interlock mechanism.[7.11]

R. Park and T. Paulay, "Reinforced Concrete Structures," John Wiley & Sons, 1975, page 323.

Enclosure 2

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MIDDLE SOUTH UTILITIES SYSTEM

October 31, 1983

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3-A1.01.04
Q-3-A14.19.01

Director of Nuclear Reactor Regulation
Attention: Mr. G. W. Knighton, Chief
Licensing Branch No. 3
Division of Licensing
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

SUBJECT: Waterford 3 SES
Docket No. 50-382
Response to NRC Basemat Questions

REFERENCE: 1.) Letter dated October 17, 1983 from G. W. Knighton to R. S. Leddick

Dear Sir:

Reference 1 transmitted to LP&L a set of questions relating to the structural integrity of the Waterford 3 basemat. Please find attached our response to those questions. On October 26, 1983, a draft of this response was given to those members of the staff conducting an independent evaluation of the Waterford 3 basemat; however, the attached response provides some additional information resulting from discussions held at that time. Responses to additional clarifying questions posed by your staff at that time are being investigated and will be provided to you shortly.

I would also like to take this opportunity to emphasize not only LP&L's commitment to support a timely resolution of your concerns, but also LP&L's complete confidence that the application of engineering practices and regulatory guidelines to the design of the Waterford 3 basemat have fully accounted for any and all conditions and functional requirements which the Waterford 3 basemat will realistically see. More detailed discussions of the bases of our confidence can be found in the attached response and in the reports and evaluations previously forwarded to you. As you are probably aware, LP&L retained a renowned engineering specialist, Harstead Engineering Associates, to investigate this matter independently of the evaluations performed by the NRC staff and Ebasco Services, Inc. I would like to conclude by noting to you the closing sentences of the Harstead Engineering Associates final report, which summarizes the results of their engineering and technical evaluation:

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> "While the seepage of water from the cracks precipitated the investigation, all aspects of the [basemat] design were considered, not just those associated with the cracks and seepage. It is our conclusion that the design of the mat is extremely conservative...Therefore, we see no need for any remedial measures or the necessity of additional analyses", (HEA Report No. 8304-2 dated October 12,1983).

Since timely resolution of this issue is of considerable import to LP&L, we are willing to support the staff review in any way possible. Please let me know if you have any additional questions or identify the need for additional information.

K. W. Cook
Nuclear Support and Licensing Manager

KWC/RMF/pjl

cc: E. L. Blake, B. W. Churchill, W. M. Stevenson, J. Wilson,
G. L. Constable

Introductory Question I

In a condensed form, this is a request to provide discussions of the following:

a. Postulated path of ground water though the mat addressing:

   1. vertical construction joints
   2. vertical through cracks
   3. localized porous zones

b. The adequacy of the analysis and design of the mat.

c. The effect of possible porous zones on the structural integrity of the mat.

Response

We have concluded that the most probable path of the seeping water which is showing as moisture at some hairline cracks in the surface of the mat originated at flexural cracks at the bottom of the mat and follows embedded items which intersect these cracks, such as structural steel rebar support structures and conduit, horizontally through the mat to an intersection with hairline cracks at the top of the mat. These hairline cracks were mapped during the period of August 30-September 2, 1983 (Reference 1, Appendix A and Subsections 4.5 and 4.6). The path of the water seeping through the hairline cracks need not be determined with a high degree of certainty in order to ascertain that the cracks are not indicative of a safety concern. When the NRC's independent reviewer postulates mechanisms such as vertical through cracks or localized porous zones, they should be evaluated based on project records and I&E inspections currently in NRC hands to determine whether such mechanisms are credible. This later approach is the one independently adopted by both Harstead Engineering Associates and Ebasco in evaluating this concern and these independent evaluations arrived at the same conclusion that no safety concerns exist. Recognizing that a portion of the information available to Ebasco and Harstead Engineering Associates is not currently available to your independent reviewers, it is of course necessary to identify and supply this information so that informed decisions can be made. We will be glad to support your review by supplying any such information as you identify a need. There is no direct evidence, nor is it reasonable to assume, that vertical through-cracks have occurred and/or localized porous zone exist. We base this statement on the following points:

a. The cracks were found to reflect a pattern of flexure resulting in the development of tension stresses in the concrete, which type of cracking only extends through to the neutral axis. This type of cracking is expected in concrete construction. The formation of vertical or near vertical through-cracks would imply an occurrence of shear failure in the mat concrete. Under such an assumption one would expect to find hairline cracks in the high shear stress zones and along the edges of walls and columns. However, no such crack patterns have been identified.

b. The formation of vertical through cracks would imply overstress in shear, however, the design of the mat is conservative so that such an overstress would not occur. (Reference 2)

c. The interconnection of the tension hairline cracks with those near the top and the bottom of mat was possible because of the presence of the embedded structural steel beam and column system utilized to support the top layer reinforcing bars, and other embedded items - steel plates, electric conduits and equipment anchor bolts, etc. The surfaces of these embedded structural items have provided additional vertical and horizontal seepage paths within the mat concrete interconnecting the fine concrete tensile cracks.

d. The placement of mat concrete was accomplished under an approved quality assurance program to implement a satisfactory production, placement and curing of the concrete to meet the design requirements and to prevent the occurrence of voids or other deficiencies in the concrete. The compression tests continuously performed during all construction periods had provided the assurance that the concrete had properly obtained the required 28-day compression strength, 4000 psi.

e. Any localized porous zones which were formed because of construction difficulties have been identified during and immediately following placement and properly treated and repaired. These areas involved only the placement of Blocks 10B and 19, and the results of the treatment have been documented.

With regard to the adequacy of the analysis and design of the mat, evaluations performed as part of our normal Quality Assurance program, and the additional independent evaluation performed by Harstead Engineering Associates, have provided adequate assurance of the Waterford 3 basement capability to perform as required.: HEA notes that "The basement is very structurally redundant and is very capable of carrying loads well in excess of the applied loading combinations", (Reference 2, Section 6.0; emphasis added). The presence of the flexural cracks discovered does not alter in any way our confidence in the basemat performance capability. "Cracking of the type evidenced at the top of the Waterford 3 basement is expected in concrete construction, and is assumed in establishing the structural capacity requirements in the ACI 318 Code", (Reference 2, Section 6.0; emphasis added).

We believe that the adequacy of the analysis and design of the mat has been well demonstrated. While a reanalysis of the mat to take into account the effect of possible localized porous zones has not been done, we believe that because we have been unable to discover any factual basis for such zones, and furthermore believe that our Quality Assurance program effectively ensured that no such zones exist (See response parts d & e above), such reanalysis is neither necessary nor warranted. We further believe the staff will concur with this position when they have had an opportunity to evaluate our documentation and the results of inspections by the I&E staff.

Question 1 Was the mat treated as a one dimensional beam or two dimensional plate in structural analysis?

Response: In the structural analysis, the mat was treated as a two dimensional plate. For the design and analysis procedures used for the mat, please refer to FSAR Section 3.8.5.4.

Question 2 How were the shear and bending moment (flexure) diagrams of the mat obtained for proportioning the depth of the mat and the area of reinforcing bars?

Response: The shear and bending moment of the mat were obtained from the finite element analysis to include all cases of related load combinations as discussed in FSAR Section 3.8.4.3.2. The reinforcement steel areas were calculated based on the maximum shear and moment in E-W and N-S directions obtained for each of the mat elements from the results of finite element stress analyses.

Furthermore, Harstead Engineering Associates (HEA) has concluded on the basis of an independent review and analysis that the bending reinforcement is well over that required (Reference 2, Section 6.3).

Question 3 State the causes of the convex shape of the mat prior to placement of the containment vessel fill concrete.

Response: The convex shape of the mat resulted from a complex series of events involving the placement of the concrete mat and the scheduling of concrete placement for the superstructure. The construction of the mat was divided into 28 blocks. The blocks located beneath the containment were placed first and then the blocks away from the containment were placed. Three E-W strips (Strips 1, 2 and 3) of the mat beneath the containment were placed and completed prior to the placement of the mat strips north and south of the cont inment (Strips 4, 5 and 6). The block placement dates for each of the mat blocks are given in FSAR Figure 2.5-118. The top elevation of the concrete for each block was essentially level with that of the previous block at the time of placement, which previous block had already undergone some settlement. Therefore each block would settle so its surface would reflect the differential settlement only from the time of placement.

In addition, the subsoils beneath the mat in the area which was placed first had started their consolidation process earlier as compared to the areas which were placed later. The lag in the starting of the consolidation introduced part of the differential settlement creating the convex shape. Furthermore, the area of the containment was left unloaded by superstructure concrete for a considerable period of time while the area outside the shield building was loaded by superstructure concrete during the period of steel containment erection. This resulted in further differential settlements causing the convex mat shape. As noted in FSAR Figure 2.5-118, the convex shape is only a matter of approximately two inches in height differential over the 380 foot length of the basemat.

Question 4 — Figure 2.5-117, Composite Foundation Mat Settlement, indicating the mat settlement in the N-S direction from 1975 to 1980, does not indicate a convex shape for the mat. Was the convex shape observed only in the E-W direction?

Response: The convex shape was observed in E-W and N-S directions. FSAR Figure 2.5-117 plotted the average of the absolute block settlements within each E-W mat strip, and not relative settlements. Relative settlements are shown in Figure 2.5-118.

Question 5 — Figure 2.5-117 indicates a concave shape for the mat, but Figure 2.5-118 indicates a convex shape for the mat. Clarify the apparent inconsistency between these two figures.

Response: FSAR Figure 2.5-118 shows the mat differential settlement contours which had used Block No. 6, the first block placed, located at the center of the containment area, as a reference point. The figure indicates that the amount of differential settlement increases in the area of the mat away from the containment area.

Question 6 — Furnish the settlement data for the mat from 1981 to present.

Response: The settlement of the mat has practically stabilized since the second quarter of 1979 as reflected in FSAR Figure 2.5-117, Sheet 1 of 2 (Amendment 33). Beginning in 1981, the bench mark points for settlement measurement were transferred from the mat to the exterior walls; the readings are shown in FSAR Figure 2.5-117, Sheet 2 of 2 (Amendment 33).

Question 7 Describe the procedures used to determine the subgrade modulus for mat design; how were the effects of the heave (which was larger than estimated) accounted for in determining the subgrade modulus?

Response: As noted by HEA in Reference 1 (Section 6.0), the selection of the subgrade modulus applicable to the foundation soils and mat geometry is judgemental. The actual value used in the design analysis was a mean value of:

1. A typical textbook value
2. A value derived using Waterford 3 soils data and soil recompression characteristics.

The heave phenomenon was taken into consideration in the recompression program of the subsoil system. The recompression process had been completed earlier in the stages of construction, as discussed in FSAR Subsection 2.5.4.1.3.2b) (Page 2.5-96), "the average heave readings at the site were recompressed to their initial readings by July, 1977."

Furthermore, for the finite element analysis, additional conservation was established by assuming a variable spring, ie, the soil springs under the Reactor Building were reduced to 70pci while the area adjacent to the Reactor Building was set at 110pci. The other parts of the mat remained at 150pci. HEA agreement with this approach is indicated in Reference 2 (Section 6.0).

Question 8 Was a waterproofing membrane placed around all the exterior faces of the mat?

Response: A waterproofing membrane was placed around the exterior face of the mat from the top of the mat down to 2'-0 below the top of the mat (FSAR Figure 3.4-1).

Question 9 Are the seepage zones in close proximity to vertical construction joints?

Response: Only a small part of the hairline cracks exhibiting moisture are located in close proximity to vertical construction joints. In a few cases, a construction joint appears to have seepage. The fact that construction joints have little seepage is to be expected in that construction joints have continuous waterstops. Obviously random forming cracks will not have mechanical water stops. Considering the substantial hydrostatic ground water head, the amount of seepage is insignificant, indicating considerable resistance to water pressure.

Question 10 Were waterstops placed in the vertical construction joints, and if so, where?

Response: Two nine inch PVC waterstops were provided at all vertical construction joints of the mat. The bottom waterstop is located 2'-6 above the bottom of the mat, and the top is 2'-0 below the top of the mat.

References

1. HEA Report No. 8304-1 dated September 19, 1983

2. HEA Report No. 8304-2 dated October 12, 1983