LOUISIANA POWER AND LIGHT COMPANY
WATERFORD STEAM ELECTRIC STATION
UNIT NO. 3

SUMMARY EVALUATION
STRUCTURAL SIGNIFICANCE OF BASEMAT NONDESTRUCTIVE TESTING RESULTS

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1.0 PURPOSE

The purpose of this report is to review the results of nondestructive testing (NDT) of Nuclear Plant Island Structure (NPIS) basemat hairline cracks to evaluate their significance with respect to the structural integrity of the NPIS.

2.0 SCOPE

The scope of this report covers the following:

1. Review and interpret data and results of NDT related to basemat as presented in R Muenow's Report of October 1984.

2. Evaluate the significance of the cracks on the structural integrity of the NPIS basemat.

3. Study the crack patterns as defined by NDT, such as inclination, depth, spacing, and width in order to determine the probable causes of basemat and wall cracks.

3.0 BACKGROUND

An NDT program of the basemat hairline cracks was performed by Muenow and Associates Inc. to determine the following:

1. Inclination of the cracks - whether the basemat cracks are vertically and/or diagonally inclined.

3.0 BACKGROUND (Cont'd)

2. Estimate depth, length, and width of the basemat cracks.

As an auxiliary study, the depth of some cracks of the Reactor Containment Building (RCB) wall surfaces above the basemat was evaluated.

This NDT examination was performed at the Waterford 3 Site mainly during the months of July and August 1984.

4.0 NDT RESULTS SUMMARY

4.1 HAIRLINE CRACKS OF BASEMAT (Tables 1, 2 and 3)

The majority of the hairline cracks are oriented in an east-west direction. Based on their appearance and nearness to each other they are grouped into 10 families: 4 on the east side of the RCB and 6 on the west side of the RCB. Seven cracks beneath the RCB were also identified by NDT. These families appear to coincide with each other and probably are interconnected.

Other cracks are oriented in a northeast/southwest or northwest/southeast direction and they are grouped into a total of 7 families. Of these families, 4 of them were evaluated by NDT: 3 in the northeast and 1 in the northwest corner of the RCB. These cracks are also referred to as East or West Diagonal cracks in R Muenow's Report. Two of these cracks appear to coincide with a crack beneath the RCB and probably is a continuous crack.

Ebasco review indicates that within the above families of cracks, the data show cracks originating from the top surface of the basemat (top cracks), some from the bottom surface of the basemat (bottom cracks), and some within the middle portion of the basemat (middle cracks).

4.1 HAIRLINE CRACKS OF BASEMAT (Tables 1, 2 and 3) (Cont'd)

Tables 1 and 2 present a summary of the NDT examination of the basemat hairline cracks on each side of the RCB. This includes length, depth, group spacing and inclination of hairline cracks which originate from the top surface of the basemat. In addition, a summary of other cracks in the middle or near the bottom of the basemat is also included.

Table 3 presents a summary of hairline cracks beneath the RCB.

4.1.1 Depth

East-West Cracks Outside RCB

The depth of cracks varies depending on the locations of the cracks.

The depth of top cracks near the east-west centerline of the RCB is found to be the maximum. The average crack depth in this area is approximately eight (8) feet (Families III, IV, IIIe, IVe). Generally, individual cracks do not extend into the bottom layer of reinforcing steel located approximately ten (10) feet depth from the top surface. The neutral axis for positive bending (tension at top surface of the basemat) is calculated to be approximately 10'-6 from the top surface.

The bottom cracks are found mostly in the vicinity of the east-west centerline of the RCB and their depths range from 2 to 3 feet. Within this area a possible local interconnection between top and bottom cracks is indicated for Cracks J and Ke.

The middle cracks, which appear to be noncontinuous and randomly distributed, are generally less than three (3) ft in depth (e.g., refer to Page 262, R Muenow's Report).

4.1.1 Depth (Cont'd)

The depth of the top cracks away from the east-west centerline of the RCB generally decreases as the distance from the centerline increases. The average crack depth for Families I, II, V, VI, Ie, and IIe is approximately 3'-6. These families have few indications of the bottom cracks. The top and bottom cracks are not interconnected.

East-West Cracks Beneath the RCB

The cracks beneath the RCB as stated in Page 4, R Muenow's Report are "classed noncontinuous and variable depth extending to the region of the lower layer of reinforcement steel."

Diagonal Cracks (Northeast/Southwest and Northwest/Southeast)

The average depth of these cracks, which in plan view run diagonally to the plant grid, is less than four (4) feet. A few bottom and middle cracks are present, however, there are no indication of interconnection between the top and bottom cracks.

4.1.2 Inclination

All hairline cracks in the basemat evaluated by NDT are essentially vertical. In Page 2, R Muenow's Report stated that "there is no evidence of diagonal (shear) cracks; either occurring singularly or as a connection between two individual cracks within the areas investigated."

4.1.3 Length

The cracks are variable in their length. The east-west cracks outside the RCB extend between the exterior walls of the RCB and the NPIS. The diagonal cracks extend from the exterior wall of the RCB but end well before they reach the exterior wall of the NPIS. When the cracks

4.1.3 Length (Cont'd)

interse with a construction joint they go through the construction joint. It appears that there are 4 to 5 families of cracks that extend from the east to the west side of the NPIS basemat since many of the individual families located in three areas (east, west and beneath the RCB) coincide and are probably joined.

4.1.4 Spacing

The east-west crack families have an average spacing of approximately 11'-0. The diagonal (north-east/southwest or northwest/southeast) crack families have an average spacing of approximately 15'-0 at the exterior wall of the RCB.

4.1.5 Width

The NDT evaluation has estimated the crack width to be less than .007 in. and all the cracks are tight. Our recent field surface measurement of crack L found the maximum crack width to be .003 in. Our field surface measurements in 1977 found the crack width to be between .002 and .005 in.

4.2 HAIRLINE CRACKS OF RCB WALL

Four hairline cracks on the exterior surface of the RCB wall near the basemat (Elev -35.0 ft) were evaluated using NDT. All of them were found to penetrate less than one (1) ft of the 10 ft wall thickness (Table 4).

5.0 PROBABLE CAUSES OF CRACKS

The causes of the top hairline cracks were evaluated in 1977 and 1983 (References 1 & 2) and the conclusion was that they were mainly due to flexure of the basemat from initial loading (prior to the completion of superstructure). The NDT evaluation has determined that all the top cracks are vertically inclined, extremely narrow and do not generally extend below the neutral axis.

The cause of bottom hairline crack is also considered to be due to flexure of the basemat resulting from the final loadings as the superstructure was completed. This conclusion is consistent with the cracks having been formed due to readjustment of basemat convex shape as the superstructure loads were applied to a mat cambered and slightly prestressed (see Figure 2 of Reference 2 attached).

From the summary of NDT results, it is clear that the top cracks are greater in number than the bottom cracks. This reflects that the crack pattern generally followed the mat flexure, which was found to be predominantly convex shape throughout the construction stages. The top cracks are located primarily in an east-west band centered on the RCB centerline. This matched closely the area of maximum convex flexure of the basemat in the early stages of construction as shown on Figure 2.

The crack width produced is well within the allowable crack width of the ACI Codes. Section 1508.6, ACI 318-63 Code for control of cracking states that "....the average crack width at service load at the concrete surface of extreme tension edge, does not exceed 0.010 in. for exterior members..." Section 10.6.4, ACI 318-83 Code Commentary for control of flexure cracking states that "...for interior and exterior exposure respectively, ... limiting crack widths of 0.016 and 0.013 in.

5.0 PROBABLE CAUSES OF CRACKS (Cont'd)

The NDT examination performed at service load conditions has established the estimated crack width to be less than .007 in. and the actual field measurements of crack "L" less than .003 inch. When the basemat hairline cracks were first observed under the RCB in mid-1977, the crack widths were observed to be between .002 and .005 in. The tensile stress in the reinforcing steel associated with these observed crack width (±.005 in.) is small and within the allowable design limits (less than 10%).

In Reference 1, it was stated that "...The mat, as are all other reinforced concrete structures, is designed to carry loads and in so doing depends only on the compressive and shear strengths of concrete and the tensile strength of reinforcing steel. No credit is taken in the design for the tensile strength of concrete, ... Thus, as loading on the foundation mat causes flexure and resultant tension of the concrete, cracks are expected to form. This cracking enables transfer of the tensile load from the concrete to the embedded reinforcing steel as contemplated in the design of all steel reinforced concrete structures."

Although the predominant cause of hairline cracks has been concluded to be flexure, it is recognized that other factors such as thermal and/or shrinkage may have contributed to the development of some of these cracks.

The hairline cracks in RCB walls are found to be superficial by NDT and, therefore appear to be caused by shrinkage. These cracks are apparently not related to adjacent basemat cracks, which were caused by mat flexure.

The basic cause of the basemat flexing and cracking bears no importance to the present structural integrity of the basemat. The cracks are present and such presence can be evaluated as to their significance on the structural integrity.

6.0 SIGNIFICANCE OF CRACKS AND EFFECTS ON STRUCTURAL INTEGRITY

The following conclusions are of importance in the determination of the significance of the cracks in the Waterford 3 basemat and their effect upon the structural integrity of the basemat:

1. The cracks are flexural cracks possibly combined in some cases with thermal shrinkage cracks.

2. There are no diagonally oriented cracks within the basemat which indicates that no excessive diagonal tension, hence no excessive shear, exists or has existed within the mat and confirms the design calculations which predicted this.

3. There are no through cracks from top to bottom of the basemat with the possible exception of a very few localized areas where top and bottom flexural cracks have apparently coincided and joined.

4. Presently there is virtually no water seepage or wetness present at any of the observed cracks and the amount of water seepage in the past has been minimal causing only a wetness of the basemat in the immediate vicinity of the cracks. The cracks are believed to have filled with laitance. The stress condition at the top of the basemat has become compression since the occurrence of the original cracking. These conditions assure the continued no water seepage condition during the operation of the plant. Hence, the amount of water seepage meets the original design intent for minimal water leakage.

5. The width of the cracks and the spacing between them indicates a low steel stress as a result of the flexure which caused the concrete to crack.

6.0 SIGNIFICANCE OF CRACKS AND EFFECTS ON STRUCTURAL INTEGRITY (Cont'd)

6. The crack pattern is in an east-west direction generally which signifies that it resulted from early settlements of the basemat occurring as it was placed or shortly thereafter. The cracks lying in a northeasterly or northwesterly direction were influenced by the rigidity of the early placements of the RCB wall. The cracks are rather localized in a band running east-west and centered on the RCB centerline.

7. The cracks in the RCB wall are shallow, shrinkage induced and are not related to the cracks in the basemat. The existence of cracks in the basemat and the wall at the same, or nearly the same, location appears to be coincidence.

8. The concrete quality is uniform and there are no significant voids and/or honeycombs within the mat. This indicates that the concrete consolidation was more than adequate during construction. The concrete strength is indicated to be 5,000 to 7,000 psi by NDT, which is higher than the required design strength of 4,000 psi.

The cracks in the Waterford 3 foundation basemat create no negative effect on the structural integrity of the basemat and on the ability of the basemat to resist adequately any design load combinations. They do not reduce the structural strength of the basemat. The cracks, being quite tight, will not increase any flexure of the basemat and hence will not cause any transfer of load to building members.

Reinforced concrete members subjected to flexural loads are designed to accept cracking of the concrete in the tension zone. The ACI code for design of reinforced concrete structures states that tensile strength of concrete is not to be relied upon and that all tensile stresses are to be directed to the steel reinforcing. For this to occur, the concrete must crack since it has lower rigidity than the steel. The steel, then, is the structural component in the cracked tension zone.

6.0 SIGNIFICANCE OF CRACKS AND EFFECTS ON STRUCTURAL INTEGRITY (Cont'd)

When reversal of stresses occur and a previously cracked tension zone becomes subjected to compressive forces, the cracks close and the adjacent sides of the cracks bear against each other, provided that the reinforcing steel did not previously exceed the yield stength. In the Waterford 3 basemat the cracks are closed or very narrow indicating that the steel has never exceeded the yield strength. The concrete crack surfaces are well able to bear against each other. Therefore, the flexural strength is not impaired.

The ability of the basemat to resist shear is not impaired by the presence of vertical cracks. The width of the cracks is very small and the face of the cracks is rough. Concrete cracks are by their nature rough and, provided that the crack width is small, the shear capacity across the crack is equal to that of uncracked concrete due to the interlocking nature of the rough surfaces. The crack widths as measured are small assuring an excellent interlocking mechanism. It is further believed that the cracks have been filled with a laitance which will tend to re-cement the surfaces together and provide further assurance of shear capability.

The structural integrity may have been slightly enhanced by the chain of events which led to the occurrence of the cracks. The width of the cracks indicates that at some time there was sufficient tensile strain at the top of the basemat to crack it and the tension was transferred to the top reinforcing steel. The strain, as represented by the width of the cracks, was only sufficient to put a small tensile stress in the steel, however, the evidence shows that it occurred early in the life of the basemat and prior to the application of most of the dead load from the structures above. Subsequent loading on the basemat to the service level of loading now present requires that the top of the basemat be in compression. The amount of compressive stress actually present is reduced by the amount of initial tensile stress due to the early flexure. While this is small it does add to the conservatism of the design.

6.0 SIGNIFICANCE OF CRACKS AND EFFECTS ON STRUCTURAL INTEGRITY (Cont'd)

Several other factors not accounted for in the design of the Waterford 3 basemat add to the conservatism of the basemat and to the available strength.

The Waterford basemat was designed without taking advantage of the axial compression forces present due to the high soil forces acting on the side walls of the Nuclear Plant Island Structure. These forces are directly transmitted into the basemat as compression. The presence of axial compression on a member in flexure and shear increases the shear capability of the concrete.

The shear resistance of a reinforced concrete member, such as a beam or slab, has other components which also have not been utilized in the Waterford basemat design and analysis. The concept of shear friction, wherein slight shearing movements within the member result in high increased compressional forces across the crack and increased resistance to shear can add considerably to the ultimate shear capability of a member. The Waterford basemat would engage such shear friction forces if stressed beyond the capability of the concrete and reinforcing steel alone. Dowel action of the flexural reinforcing steel has also been shown to add significantly to the ultimate shear capability of a reinforced concrete member. The flexural reinforcing steel at the top and bottom surfaces of the Waterford basemat would engage such action.

Considering each of the above items individually and in concert, EBASCO concludes that the cracks in the Waterford 3 basemat, as defined by the nondestructive testing, have no adverse influence on the structural integrity of the basemat. It is fully capable of functioning as required by the design.

<u>REFERENCES</u>

1. Affidavit of Joseph L Ehasz, Ebasco Services Incorporated, submitted before the Atomic Safety and Licensing Appeal Board, USNRC, September 1983.

2. "NPIS Wall Hairline Crack Evaluation," by Ebasco Services Incorporated, April 1984.

TABLE 1 - SUMMARY OF CRACKS WEST SIDE OF RCB

Family	Crack I.D.	Top Crack: Test Lines	Top Crack: Length (exposed)	Top Crack: Depth (ft.) Min	Top Crack: Depth (ft.) Max	Top Crack: Depth (ft.) Average	Family Spacing	Presence of Subsurface Cracks (See Notes): Bottom Crack: Below Bottom Re-bar	Presence of Subsurface Cracks (See Notes): Bottom Crack: Through Bottom Re-bar	Presence of Subsurface Cracks (See Notes): Middle Crack	Inclination
I	A	7	7'- 6	1	2	2		*	*	*	vertical
	B	7	9'- 0	2	3	3		*	*	*	vertical
	C	12	16'- 6	1	3	2		*	*	*	vertical
				Average		2	±10'	*	*	*	vertical
II	D	5	6'- 0	2	5	4		*	***	*	vertical
	E	1	2'- 0	3	3	3		*	*	**	vertical
	F	6	9'- 0	4	10	5		**	**	*	vertical
	G	4	6'- 0	1	5	4		*	*	*	vertical
				Average		4	±16'				
III	1	4	5'- 0	7	10	8		**	**	*	vertical
	H	6	9'- 0	5	10	8		**	**	*	vertical
	J	20	28'- 0	3	12	9		***	****	**	vertical
	K	10	13'- 0	3	11	8		**	***	*	vertical
				Average		8	±10'				
IV	L	10	28'- 0	6	10	8	±8'	**	**	*	vertical

Notes: *None
**Presence of crack is not probable since only at one or two test line location(s).
***Presence of crack is probable since indication at several test locations but not interconnected with top crack.
****Similar to *** except probably interconnected with top crack.

TABLE 1 - SUMMARY OF CRACKS WEST SIDE OF RCB (Cont'd)

Family	Crack I.D.	Test Lines	Length (exposed)	Top Crack Depth (ft.) Min	Top Crack Depth (ft.) Max	Top Crack Depth (ft.) Average	Family Spacing	Presence of Subsurface Cracks (See Notes): Bottom Crack Below Bottom Re-bar	Bottom Crack Through Bottom Re-bar	Middle Crack	Inclination
V	M	4	6'- 0	4	5	4		*	*	*	vertical
	N	3	5'- 0	2	6	3		*	*	*	vertical
	2	3	5'- 0	1	3	2		*	*	*	vertical
	3	9	12'- 0	1	5	2		*	*	*	vertical
	P	9	14'- 0	8	10	9		*	**	*	vertical
	R	1	2'- 0	2	2	2		*	*	*	vertical
	Q	3	8'- 0	3	5	4		*	*	*	vertical
	S	3	4'- 0	4	4	4		*	*	*	vertical
	T	14	20'- 0	3	10	6		*	***	*	vertical
	Y	3	6'- 0	1	1	1		*	*	*	vertical
				Average		4					
VI	U	9	14'- 0	2	10	5		*	**	*	vertical
	V	5	13'- 0	2	5	3		*	*	*	vertical
	X	22	25'- 0(+)	1	5	3		*	*	*	vertical
				Average		4					
VII	West Diagonal	19	27'- 0	1	4	3		**	***	*	vertical

Notes: *None
**Presence of crack is not probable since only at one or two test line location(s).
***Presence of crack is probable since indication at several test locations but not interconnected with top crack.
****Similar to *** except probably interconnected with top crack.

TABLE 2 - SUMMARY OF CRACKS EAST SIDE OF RCB

Family	Crack I.D.	Top Crack: Test Lines	Top Crack: Length (exposed)	Depth (ft.) Min	Depth (ft.) Max	Depth (ft.) Average	Family Spacing	Presence of Subsurface Cracks (See Notes): Bottom Crack, Below Bottom Re-bar	Bottom Crack, Through Bottom Re-bar	Middle Crack	Inclination
	Ae	4	6'- 0	1	1	1		*	*	*	vertical
Ie	Be-Ce	5	6'- 0	1	4	3		*	*	*	vertical
	De	2	4'- 9	1	1	1		*	*	*	vertical
	le	2	3'- 0	3	3	3		*	*	*	vertical
				Average		2	+10'				
IIe	Ee	4	4'- 6	1	1	1		*	*	*	vertical
	Fe	8	12'- 0	2	10	6		*	***	*	vertical
				Average		4	+13'				
IIIe	He	5	6'- 0	2	3	2		**	*	**	vertical
	Je	5	7'- 0	2	4	3		***	*	**	vertical
	Le	8	13'- 0	3	12	7		***	**	*	vertical
				Average		6	+11'				
IVe	Ke	15	26'- 0	4	12	8	+16'	**	****	*	vertical
	Del	3	4'- 0	1	1	1		*	*	*	vertical
Ve	De3	15	23'- 0	1	6	3		*	*	*	vertical
	De4	5	10- 0	1	1	1		*	*	**	vertical
				Average		2	+15'				

Notes: *None
**Presence of crack is not probable since only at one or two test line location(s).
***Presence of crack is probable since indication at several test locations but not interconnected with top crack.
****Similar to *** except probably interconnected with top crack.

TABLE 2 - SUMMARY OF CRACKS EAST SIDE OF RCB (Cont'd)

		Top Crack						Presence of Subsurface Cracks (See Notes)			
								Bottom Crack		Middle Crack	
		Test	Length	Depth (ft.)			Family	Below	Through		
Family	Crack I.D.	Lines	(exposed)	Min	Max	Average	Spacing	Bottom Re-bar	Bottom Re-bar		Inclination
VIe	De5	17	24'-0	1	10	3		***	*	***	vertical
	De6	5	7'-3	2	6	4		**	*	*	vertical
					Average	4					
	De7	9	12'- 0	1	6	3		*	**	***	vertical
VIIe	De8	8	10'- 0	1	3	2		*	***	***	vertical
	De9	11	15'- 0	1	5	2		**	*	***	vertical
					Average	2					

Notes: *None
**Presence of crack is not probable since only at one or two test line location(s).
***Presence of crack is probable since indication at several test locations but not interconnected with top crack.
****Similar to *** except probably interconnected with top crack.

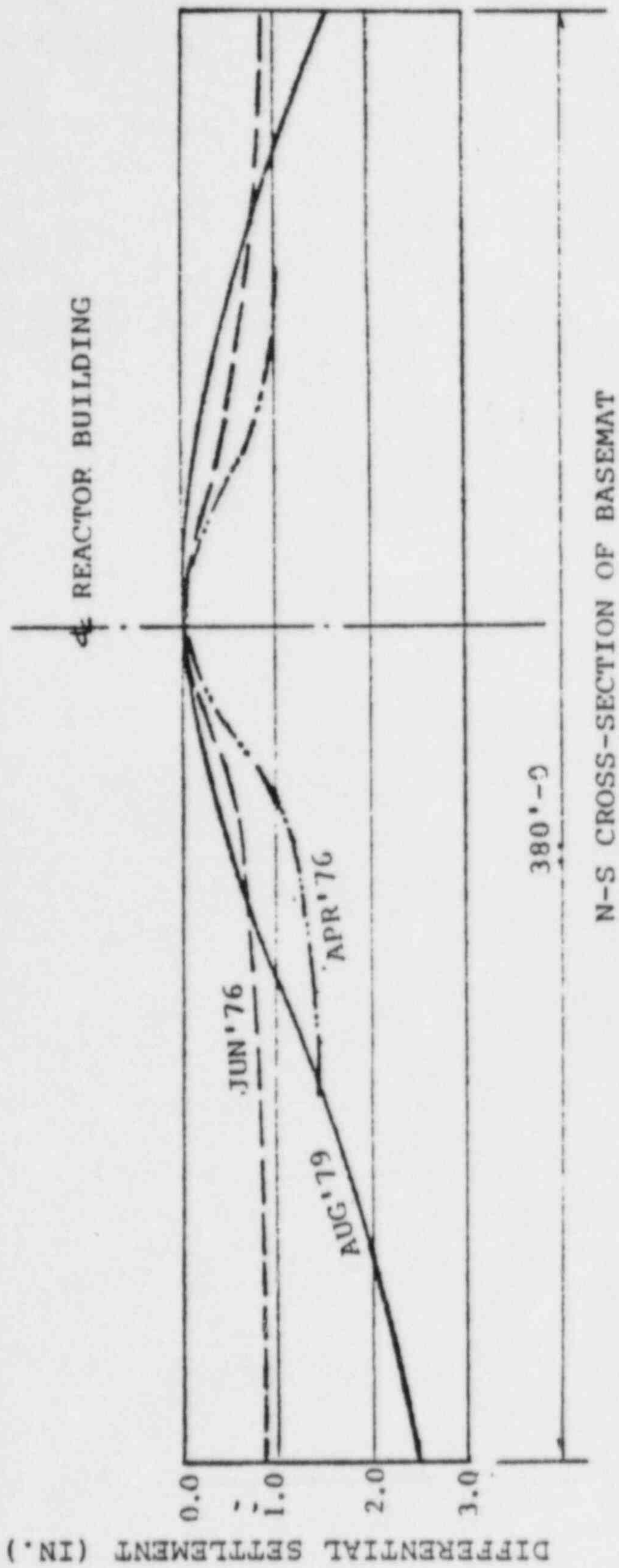
TABLE 3 - SUMMARY OF CRACKS BENEATH RCB

Crack I.D.	Correlation with 1977 Mapping	Depth	Inclination	Spacing @ C.L. RCB	Remarks
6	None (Note 1)	Variable	vertical		All cracks are intermittent, based on NDT evaluation and 1977 Mapping Data.
				18'	
2	None (Note 1)	"	"		
				12'	
1	Yes	"	"		
				9'	
7	Partial	"	"		
				6'	
3	Yes	"	"		
				9'	
5	Partial	"	"		
				13'	
4	Yes	"	"		
			Average Spacing =	11'	

Note 1 - This crack was not identified during 1977 mapping of cracks beneath RCB.

TABLE 4 - SUMMARY OF CRACKS IN RCB WALLS

Crack I.D.	Test Lines	Maximum Dept of Penetration (ft.)	Inclination	Remarks
RCB 1	3	1	Perpendicular to wall surface	Wall thickness = 10'- 0
RCB 2	3	1	"	"
RCB 3	3	1	"	"
RCB 4	3	1	"	"



NOTE: VERTICAL EXAGGERATION = 300

DATE –/11/84	WATERFORD SES UNIT NO. 3 BASEMAT CURVATURE	Figure 2
	EBASCO SERVICES INCORPORATED	

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NONDESTRUCTIVE TEST EVALUATION
OF BASE MAT CONCRETE
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