Northeast
Utilities System

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October 14, 1994

Docket No. 50-423
B15008

Re: IR 50-423/94-21

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555

Millstone Nuclear Power Station, Unit No. 3
Response to Inspection Report 50-423/94-21
Erosion of Cement from the Millstone Unit No. 3 Containment Mat

In a letter dated August 11, 1994,(1) the NRC Staff requested that Northeast Nuclear Energy Company (NNECO) respond within 45 days of receipt of the inspection report. Specifically, the NRC conducted an inspection to the assess the technical adequacy of NNECO's effort to resolve the issue of erosion of the containment mat porous concrete. At the conclusion of the inspection, the inspector did not have an immediate or short-term safety concern, but was unable to assess the long-term safety implication of the phenomenon. Therefore, the NRC requested that NNECO provide a response to include: (1) our assessment of the issue and (2) plans with milestones for resolution of the concern. A one-week extension to October 14, 1994 was requested in discussions with the Region I Staff.

Attachment 1 provides our response to the requested information. The response includes our plan to continue the mock-up testing to determine the effect of high alumina cement in the porous concrete on the portland cement within the structural concrete. Additionally, we will be conducting a study to determine the effect, if any, of Long Island Sound tidal variations. This study will include evaluating the feasibility of drilling two core-bores adjacent to the containment into the rock passing through the fault plane, to measure the water levels. The data from these two studies will facilitate the evaluation of the dynamic behavior of the containment structure during a seismic event.

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(1) M. C. Modes letter to J. F. Opeka, "NRC Inspection Report No. 50-423/94-21," dated August 11, 1994.

The schedule to complete the testing, assimilate and evaluate all the empirical data, will allow for NRC review during the first quarter of 1996.

Should you have any questions regarding this matter, please contact Mr. W. J. Temple at (203) 437-5904.

Very truly yours,

NORTHEAST NUCLEAR ENERGY COMPANY

J. F. Opeka
Executive Vice President

cc: T. T. Martin, Region I Administrator
V. L. Rooney, NRC Project Manager, Millstone Unit No. 3
P. D. Swetland, Senior Resident Inspector, Millstone Unit Nos. 1, 2, and 3
M. C. Modes, Chief Materials Section, Division of Reactor Safety

Attachment 1

Millstone Nuclear Power Station, Unit No. 3

Erosion of Cement from the Containment Mat

October 1994

Millstone Unit No. 3
Erosion of Cement from the Containment Mat

Introduction:

The Millstone Unit No. 3 Containment Foundation Substructure consists of two layers of porous concrete placed between the bedrock and the containment foundation. During construction, a two-layer rubber membrane was installed between the porous concrete layers to act as a barrier and prevent water from and around the construction area from reaching the foundation structure. This allowed surface water due to rain, etc. above the membrane to flow through 6 (six) inch diameter perforated pipes embedded in the top layer into Engineered Safety Features (ESF) sumps 7A & 7B, while the bottom layer facilitated collection of any ground-water for dewatering purposes. It was expected that after construction and during plant operation, the ESF sumps would be dry and would not collect any ground water from the top layer of the porous concrete. Additionally, it was also expected that the bottom layer would retain water from the surrounding area, and this water would be prevented from entering the top layer of the porous concrete by the continuous waterproof membrane.

To preclude either surface or subsurface water from infiltrating the substructure, all construction joints were sealed with water stops below grade level. In addition all other structures surrounding the containment were designed with drainage systems located under their foundations to collect surface water, primarily due to absorption of local precipitation. These drainage systems discharge into sumps at designated locations. Therefore, the combined effect of waterstops, presence of waterproof membrane and the drainage system surrounding the containment should preclude water from infiltrating into the top porous concrete layer directly below the containment foundation.

Evidence of water-in-leakage into the ESF sumps from the Containment foundation substructure indicates that either the water stops and/or the water-proof membrane of the substructure have been damaged either during or subsequent to construction. The presence of white cement residue emanating from the drains was initially judged to be from the Calcium Aluminate cement concrete and most likely due to washing of cement laitance from the concrete layer. After the mock-up testing, it was determined that the leaching of white residue was a result of the apparent chemical reaction between the two types of cement used in the construction.

Potential Safety Implications

By design, a rupture in the water-proof membrane does not create adverse nuclear safety consequences and accordingly the drainage system is classified as Non-QA. However, the porous concrete has been classified as a QA Category I Component since it acts as support for the containment structure foundation.

Continuous erosion of cement from the porous concrete affects its bearing strength, which in turn reduces its ability to resist design based loading. Maintaining the structural integrity of the containment substructure with the loss of bond strength of the porous concrete is of importance particularly during a seismic event and creates a safety concern which requires a thorough investigation. Therefore, Northeast Nuclear Energy Company (NNECO) has initiated a testing program to identify the cause and to implement corrective actions to address this concern.

Accessibility

Enclosed Fig. 3.8-57 (sheet 1 of 2), "Details of Waterproof Membrane," is extracted from Unit No. 3 FSAR SECTION 3.8 showing the layout of drainage pipes, the porous concrete layers, the rubber membrane and the seal concrete, etc.

The porous concrete layers are located underneath the containment mat below EL. (-) 37'-6". Below this elevation, the porous concrete substructure laterally abuts 4 inch thick, hollow concrete blocks from EL. (-) 38'-0" to EL. (-) 27'0", about 11'-0" high. Seal concrete has been placed between the hollow concrete blocks and the vertical rock ledge, completely sealing the 11' height from top of the bedrock to the top of the containment mat. Above the containment mat, a 4 to 5 foot thick concrete ring wall was placed against the vertical rock ledge up to the grade level EL. (+) 24'-0". The perforated drain pipe in the porous concrete is located at (-) 37'-6", about 60' below the grade level. This construction sequence precludes access to the porous concrete layer to determine the extent of erosion, and the degree of erosion of cement. Because of the above situation, NNECO has concluded that mock-up testing is the most desirable approach for assessing the status of the porous concrete.

Engineering Study

Prior to resorting to mock-up testing at the Alden Research Laboratory (ARL), NNECO Engineering had undertaken an effort to determine the root cause of this problem. In addition to water intrusion to ESF sumps from the containment foundation, the plant also is experiencing, at the same time, water-in-leakage in the

east wall of the ESF Building at EL (+) 12'-6" (adjacent to a duct-bank) and at the interface of the Auxiliary Building/Containment walls EL (+) 4'-6". The water intrusion in these areas can be observed during a rain storm with substantial surface runoff. Minor leakage is also found during the dry season of the year.

A review of the design documents indicates that the groundwater observations made at the site prior to and during construction during a rain storm indicated that the water table in the structural fill around the structures could reach as high as EL (+), 22'-0". This is very close to the finished grade (EL +24).

A review of the porous concrete mix design (ref. 3) indicates that its strength is 1000 psi. Also, the cement to aggregate ratio is 1 to 6 and the ratio of water to cement is 0.38. This is insufficient to produce a concrete mix with homogeneous consistency. Rather, the amount of cement and water used is enough to obtain a thin cement coating of the aggregate surfaces and produce a stiff mixture closely approximating placing raw aggregate without cement. After in-place consolidation, the nesting of aggregates would be in a stable position at point contact with each other leaving a substantial amount of aggregate surface area not in contact.

Using the above process, NNECO had postulated a scenario within the cement erosion from base of the containment mat may be attributed to the hydro dynamic water pressure which may have been capable of dislodging the cement from the aggregate surface and washing the laitance to the drain pipe into the sumps. Elimination of water-in-leakage into the containment foundation could possibly eliminate the cement wash out. Therefore, an aggressive action plan was initiated to monitor yard sumps (#1 to #3) and to draw water from and around the foundations of the structures surrounding the containment, while maintaining the pumps operable at all times. It addition mock-up testing (Ref. 1, 2, 4 & 5) was initiated to determine the extent and the degree of cement erosion from the porous concrete.

Mock-up Test

Phase I: The primary objective of the proposed mock-up testing was to intentionally maximize the voids in the porous concrete creating the worst case scenario of water porosity environment to maximize the potential for cement to wash out. This was accomplished during the placement of the porous concrete layers by loosely placing the concrete in 4 to 5 inch layers using minimum consolidation.

The result of the mock-up testing showed that, in the absence of the two layers of rubber membrane and of the 2 inch thick seal mortar between the porous concrete, the two different cements used to construct each layer appear to chemically react with each other and adversely affect the design strength of the porous concrete. This apparent chemical reaction, not erosion, facilitated by the flow of water may be responsible for the leaching out of the white residue from the porous concrete.

Another important observation made during the mock-up test was that the aggregates in the porous concrete were able to maintain their nesting structure intact when confined laterally. Even under a loosely compacted condition (i.e., walking on aggregates), the load bearing media had adequate strength to carry static loads. Since the results of the mock-up test were different than the objectives (i.e. the membrane was eliminated to facilitate mold construction, but provided an adverse chemical reaction), the test results were classified as inconclusive and a phase II mock-up test was initiated immediately thereafter.

Phase II: The scope of work in Phase II is the same as Phase I except for the sequence of construction of the mock-up test molds. The "as-built" conditions of the containment substructure, including the rubber membrane, seal mortars between the two porous concrete layers and the method of concrete placement and consolidation were included in the construction of the test molds. The resulting test data appears to be meaningful and reasonable and allows for technical conclusions to be drawn in predicting the actual strength loss in the porous concrete.

Summary of NRC Inspection Findings

As a result of the inspection performed during August 1-5, 1994, the NRC identified the following concerns:

Item #1 The test and evaluation of the interface between the high Alumina Cement in the porous concrete and the Portland Cement in the Containment Basemat has not yet been completed;

Item #2 Dynamic behavior of the containment structure during seismic events should be evaluated. This evaluation should address the high pore pressure because of the clogged drainage system, the changes in normal

(vertical) loads, and the seismic vibration and its effect on the bearing capacity of remaining coarse aggregate.

Item #3 The effect of high/low tides in the Long Island Sound on the drainage/seepage under the containment should be evaluated.

NNECO acknowledges that the NRC findings are valid and reasonable. The above cited aspects were not factored into the construction of either phase I or phase II mock-up test samples. This will require additional mock-up testing to address the above issues effectively.

Proposed Plan of Action:

Audit Item #1 Enclosed Figure III-1 represents the proposed Phase III mock-up test mold. It measures 11'0" by 11'0" divided into two chambers. The first (11'0" by 6'0") will be used to model the porous concrete to simulate the "as-built" construction of the containment foundation substructure. The second (11'0" by 5'0") will be constructed within the intermediate membrane and 1" thick seal mortar.

The objectives of the proposed mock-up tests are:

1. Evaluate the potential chemical reaction between the high alumina cement and the Portland Cement structural concrete. Not only the bond strength at the interface plane of the two cements will be observed, but also the compressive strength will be assessed to determine if any loss of strength has occurred when compared to the strength of the samples cored out from the sister mold, fig. III-2.

2. Address the long term effects of the water flow on the concrete by conducting a series of compressive tests of the core samples for a duration of 6-12 months. During this period the flow of water will be regulated to simulate water porosity through two 6" diameter inlet nozzles to a rated flow provided by least a foot head of water. Intermittent flow of water will also be introduced to represent the no-flow in-leakage condition. In addition to the above, reverse flow of water will also be performed

during the mock-up testing because of uncertainty as to the direction of flow underneath the containment mat.

The mock-up test procedure, the water flow method and the schedule for testing the samples has been enclosed. Table III-1 includes the proposed core samples along with the procedure for mock-up testing. Also proposed is a time dependent compressive strength test to study the trend of the compressive strength characteristics of the test samples. There are two possible trend patterns which are identified in Fig III-3. If the test results indicate that the sample's compressive strength follows with trend I, then testing will be truncated at 6 (six) months. On the other hand, if the test results indicate a decrease in strength with time, as shown in trend II, then the sample tests would continue to a max. duration of 12 months. Therefore, to address the long term effect of water flow through the porous concrete, the response will depend on the characteristics of fig III-3 curves. Thus, the Phase III mock-up test would not only provide the effect of the chemical reaction between the structural concrete cement and the Calcium Aluminate cement, but also provide results that would allow a deterministic evaluation of the long-term effect on the structural integrity of the porous concrete layers as a foundation substructure.

Audit Item #2 The forces on the containment foundation will be evaluated for the loads as defined in the Unit 3 FSAR SECTION 3.8.5; "Foundations" and NUREG-800 Standard Review Plan Section 3.8.1-II (3), (4), "Design and Analysis Procedure," and Section 3.8.5-II (3), (4), "Design and Analysis Procedure," and Section 3.8.5-II (3), (4) and (5), "Structural Acceptance Criteria."

The factor of safety against flotation will be evaluated for the following loading combinations:

1. $1.0D + 1.0L + 1.0F + 1.0E^1 \leq 1.1$

2. $0.9D + 1.4F \leq 1.1$

Where D = Dead weight of the structure

L = Live load or the permanently installed equipment weight

F = Buoyant force due to floods. In this case, the upward pressure on the containment foundation will be used based on the subsurface water level as measured in item # 3.

E^1 = The seismic force of the containment assumed to act vertically upward.

The net normal force on the aggregate of the porous concrete due to the above loads will be determined to assess the effect on the bearing capacity of the remaining coarse aggregate.

Audit Item #3 Enclosed Fig. 3.8-24 (1 of 3), detail of ring girder at ESF Building -is extracted from MP3 FSAR Section 3.8. The ring girder, encompassing from South to Column Line 48.5 passing West, represents the portion of the ring beam which acts as an arch in preventing the rock from sliding at the seismic fault plane impacting onto the containment wall. The pore water pressure impinging on the containment mat due to Long Island Sound tidal variations may infiltrate through the fault plan to the underside of the containment mat.

In order to address this issue, NNECO will evaluate the feasibility of drilling two 4" diameter holes, one close to the containment wall and another in the general area of the containment. These bore holes act as piezometers and would help to determine the water levels, which would then be reviewed periodically.

The bore hole close to the containment, will be drilled to EL (-) 40'-0" passing through the fault plane and stop just below the porous concrete media. This facilitates the study of the possible influence of pore-water pressure due to Long Island Sound tidal variations.

The second bore will be limited to the top of the bedrock. The purpose of this hole would be to measure the water table in the structural fill due to rainstorm surface run-off. In addition to quantifying inflow of

water, a program will be instituted to monitor ESF pump (7A & 7B) operation time.

Schedule:

The Phase III workscope is intended to address the long term strength aspect of the porous concrete The time forecast for testing and assimilating all test data will take approximately 15 months after construction of the test mold. Therefore the completion of test evaluation and submittal of report to the NRC for review will be first quarter of 1996.

References:

1. NUSCO specification #SP-CE-354, Rev. 1; Porous Concrete Mock-up Testing (Phase I) for Engineering Evaluation of Cement Erosion from the MP3 containment Meeting dated 3/9/92.

2. NUSCO specification #SP-CE-363; Porous Concrete Mock-Up Testing (Phase II) for Engineering Evaluation of Cement Erosion from MP3 Containment Mat, dated 2/12/93.

3. Stone & Webster Engineering Corp. Specification #2199.150-281 (C-281), for mixing and delivering concrete dated May 2, 1973, and addendum #1 to Rev. 1 dated 2/10/84; issued to SONECO Service Inc.

4. Stone & Webster Engineering Corp. Specification #2199.150-282 (C-282) Rev. 2 for Concrete Testing Services, dated June 26, 1973 and addendum #1 to Rev. 2 dated June 3, 1982 issued to Pittsburgh Testing Laboratory.

5. Porous Concrete Mock-up Testing Report #178-92/M295F by Alden Research Laboratory dated Nov. 1991.

6. Porous Concrete Mock-up Testing Report #161-93/M295F by Alden Research Laboratory dated Nov. 1993.

Fig III-1 continued

PROCEDURE FOR MOCK-UP TESTS (work this with Fig III-1)

The following delineates the sequence of tests and the procedure to collect test data after seven days of curing the concrete, the mock-up mold shall be hydrotested with the following sequence:

Cycle I

1. Close the 6" diameter inlet #2, 6" diameter outlet #1, and 2-1" diameter drain orifices.

2. 6" diameter outlet #2 shall be kept open.

3. Regulate the inflow water through 6" diameter inlet #1 to a rated flow of at least a foot head of water.

4. Stop the water for 7 days of inflow and drain the impounded water from the mold by opening the 2-1" diameter orifices.

5. Test samples shall be cored out of the mod per sequence identified in Table III-1.

6. Fill the cored sample's holes with crushed stone and no consolidation is necessary.

7. Start the flow of water in the reverse order. i.e.
   a) Close inlet #1,
   b) Close outlet #2 and 2-1" diameter drain orifices,
   c) Open outlet #1,
   d) Regulate and flow the water using inlet #2 for 21 days,
   e) Before core boring samples, drain the water from the mold by opening 2-1" diameter drain orifices.

8. Continue Cycle 2 to 12 by repeating the above sequence of Cycle 1.

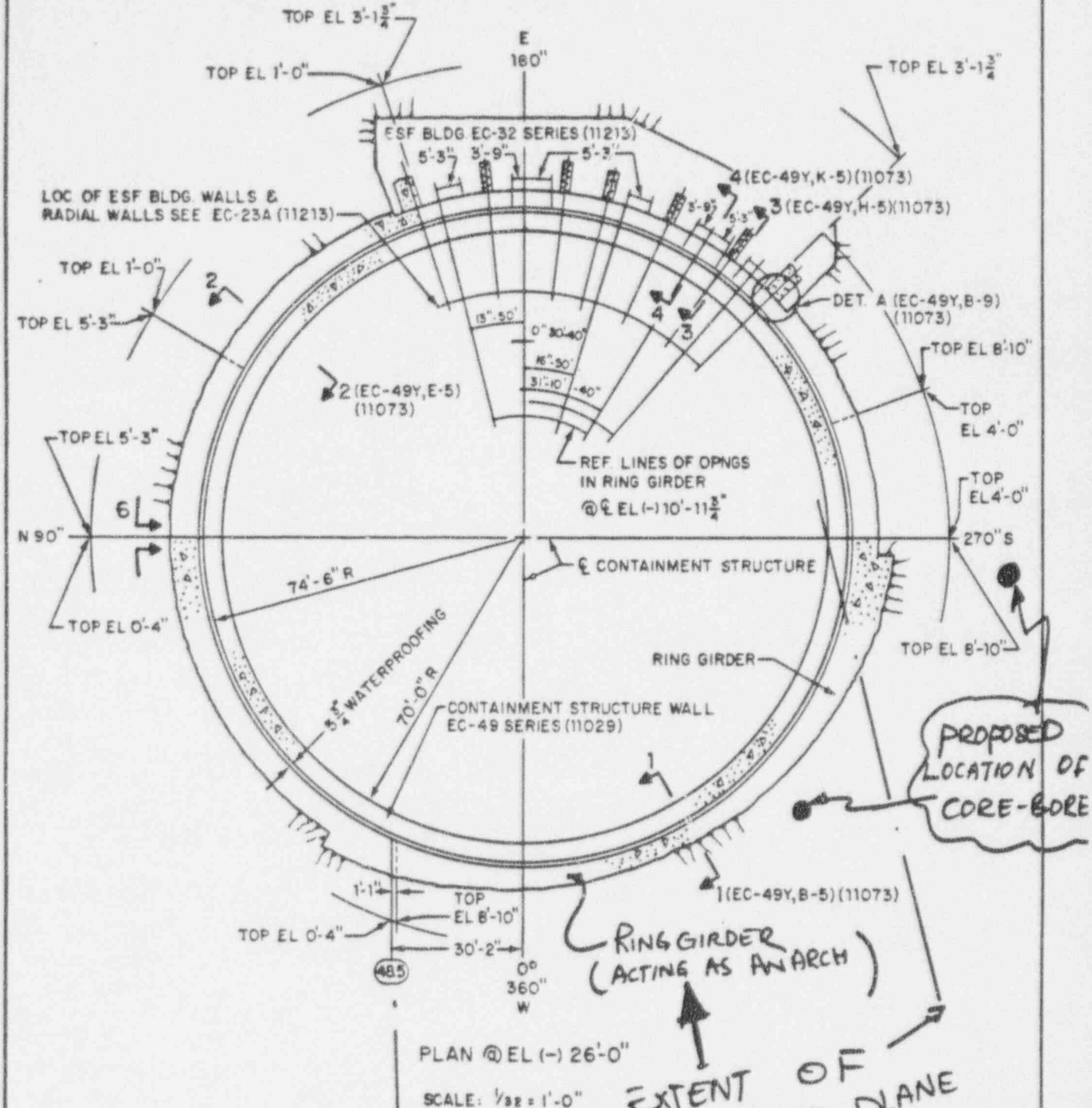
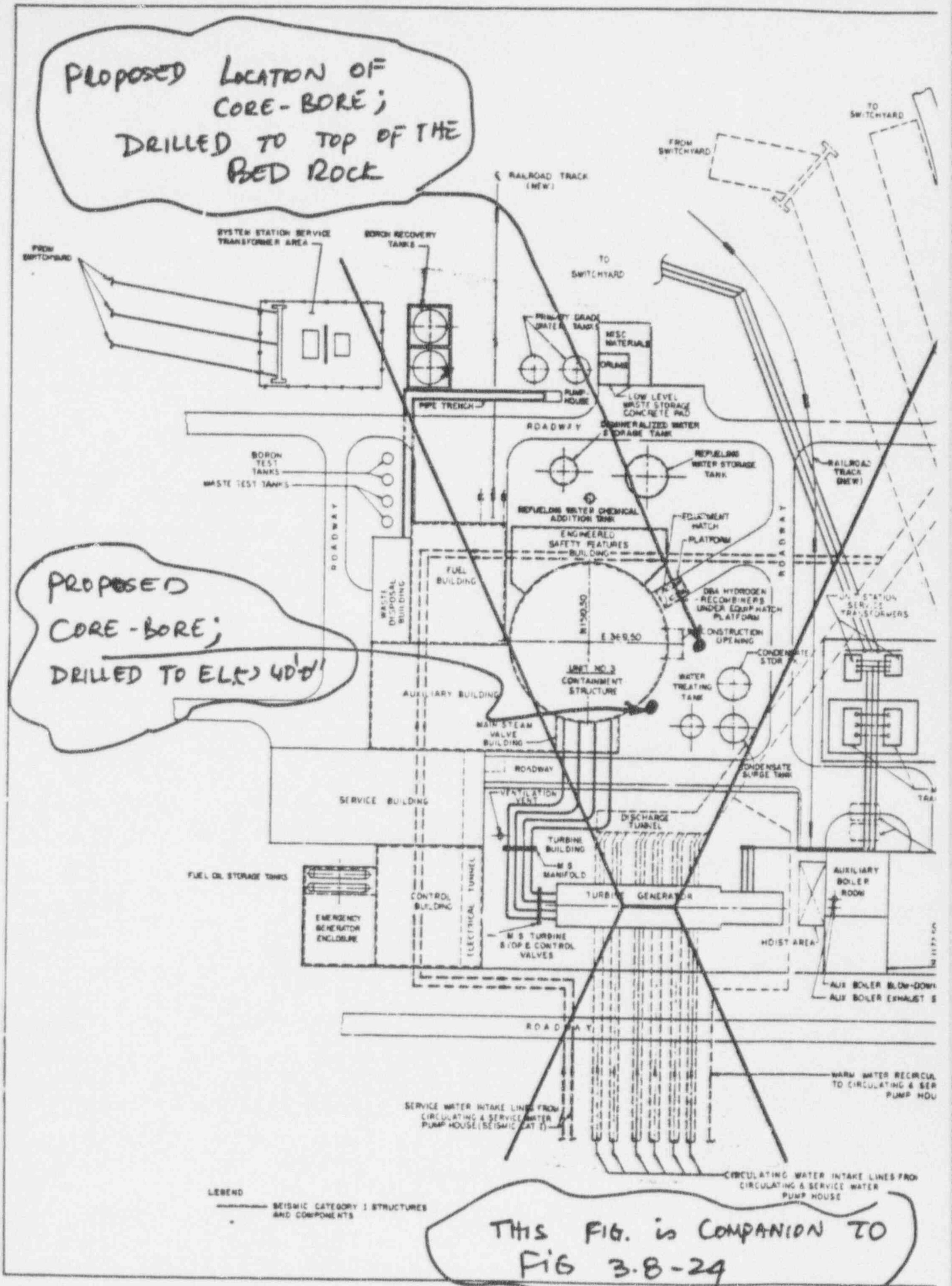


FIGURE 3.8-24 (1 OF 3)
DETAIL OF RING GIRDER AT ESF BUILDING
MILLSTONE NUCLEAR POWER STATION UNIT 3
FINAL SAFETY ANALYSIS REPORT


PROPOSED LOCATION OF CORE-BORE; DRILLED TO TOP OF THE BED ROCK
PROPOSED CORE-BORE; DRILLED TO EL(-) 40'0"
THIS FIG. is COMPANION TO FIG 3.8-24
RAILROAD TRACK (NEW)
TO SWITCHYARD
FROM SWITCHYARD
SYSTEM STATION SERVICE TRANSFORMER AREA
BORON RECOVERY TANKS
PRIMARY GRADE WATER TANKS
MISC MATERIALS
STORAGE
PUMP HOUSE
LOW LEVEL WASTE STORAGE CONCRETE PAD
PIPE TRENCH
ROADWAY
DEMINERALIZED WATER STORAGE TANK
REFUELING WATER STORAGE TANK
BORON TEST TANKS
WASTE TEST TANKS
REFUELING WATER CHEMICAL ADDITION TANK
ENGINEERED SAFETY FEATURES BUILDING
EQUIPMENT HATCH
PLATFORM
FUEL BUILDING
WASTE DISPOSAL BUILDING
DBA HYDROGEN RECOMBINERS UNDER EQUIP HATCH PLATFORM
UNIT STATION SERVICE TRANSFORMERS
N 1510.50
E 369.50
CONSTRUCTION OPENING
CONDENSATE STOR TK
WATER TREATING TANK
UNIT NO 3 CONTAINMENT STRUCTURE
AUXILIARY BUILDING
MAIN STEAM VALVE BUILDING
CONDENSATE SURGE TANK
SERVICE BUILDING
VENTILATION VENT
DISCHARGE TUNNEL
TURBINE BUILDING
M S MANIFOLD
FUEL OIL STORAGE TANKS
EMERGENCY GENERATOR ENCLOSURE
CONTROL BUILDING
ELECTRICAL TUNNEL
TURBINE GENERATOR
M S TURBINE STOP & CONTROL VALVES
AUXILIARY BOILER ROOM
HOIST AREA
AUX BOILER BLOW-DOWN
AUX BOILER EXHAUST
WARM WATER RECIRCUL TO CIRCULATING & SER PUMP HOU
SERVICE WATER INTAKE LINES FROM CIRCULATING & SERVICE WATER PUMP HOUSE (SEISMIC CAT I)
CIRCULATING WATER INTAKE LINES FROM CIRCULATING & SERVICE WATER PUMP HOUSE
LEGEND
SEISMIC CATEGORY I STRUCTURES AND COMPONENTS

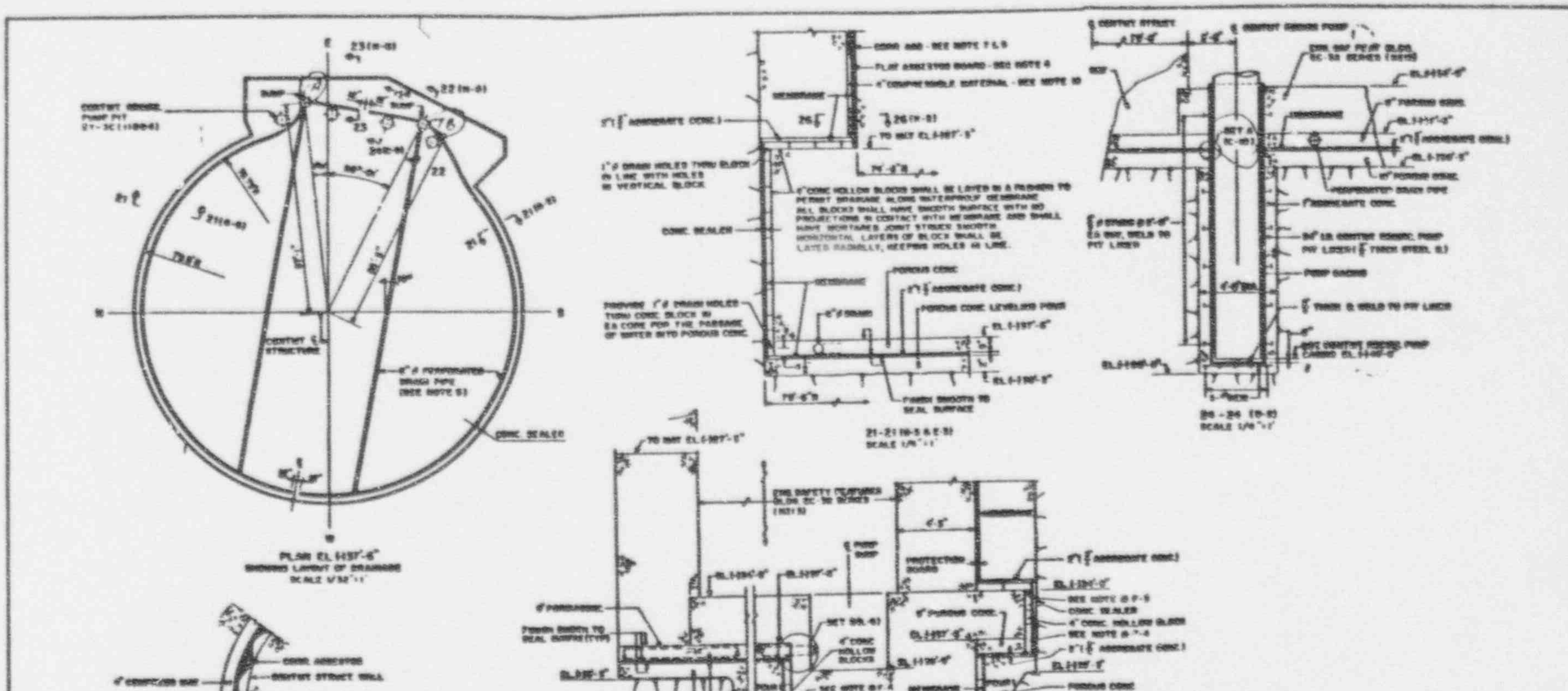
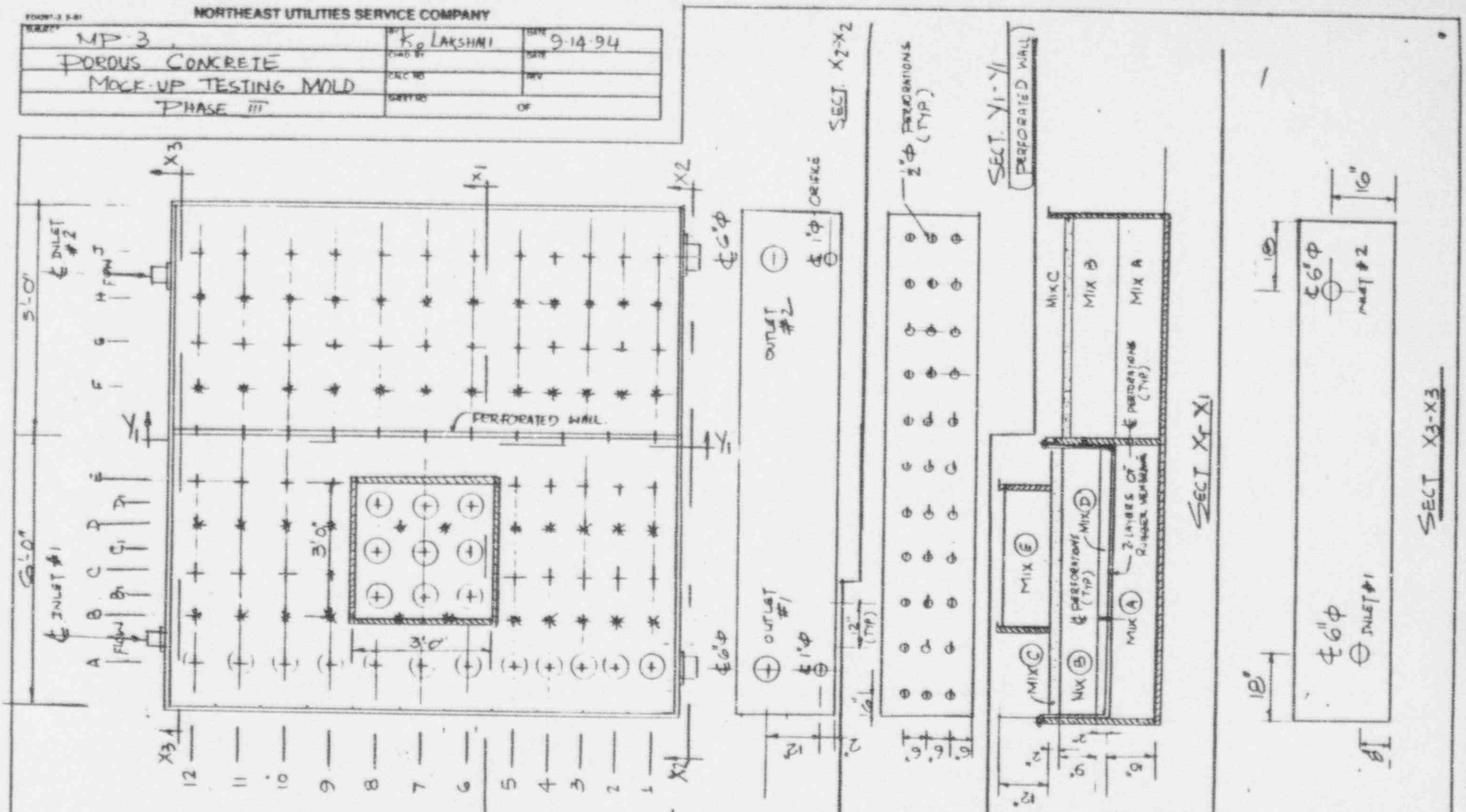


FIGURE 3.8-57 (SHEET 1 OF 2)
DETAILS OF WATERPROOF MEMBRANE
MILLSTONE NUCLEAR POWER STATION
UNIT 3
FINAL SAFETY ANALYSIS REPORT

NORTHEAST UTILITIES SERVICE COMPANY

MP-3	BY K. LAKSHMI	DATE 9-14-94
POROUS CONCRETE	CHKD BY	DATE
MOCK-UP TESTING MOLD	CHEC'D	REV
PHASE III	SHEET NO	OF



LEGEND: + or (+) — LOCATION OF 6"Φ CORE BORINGS. (TOTAL # OF CORES = 69)

* — LOCATION OF PERFORATED METAL CAGES (TOTAL # = 48.)

FIG. III-1

PROCEDURE FOR MOCK-UP TESTS (work this with Fig III-1)

The following delineates the sequence of tests and the procedure to collect test data after seven days of curing the concrete, the mock-up mold shall be hydrotested with the following sequence:

Cycle I

1. Close the 6" diameter inlet #2, 6" diameter outlet #1, and 2-1" diameter drain orifices.

2. 6" diameter outlet #2 shall be kept open.

3. Regulate the inflow water through 6" diameter inlet #1 to a rated flow of at least a foot head of water.

4. Stop the water for 7 days of inflow and drain the impounded water from the mold by opening the 2-1" diameter orifices.

5. Test samples shall be cored out of the mod per sequence identified in Table III-1.

6. Fill the cored sample's holes with crushed stone and no consolidation is necessary.

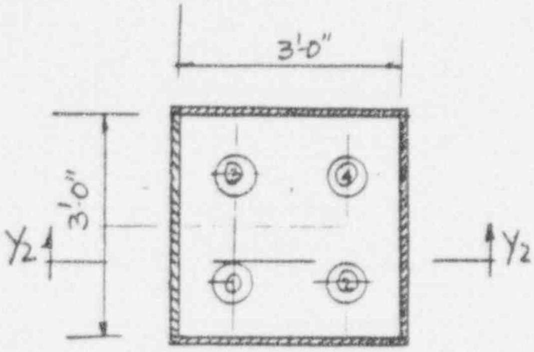
7. Start the flow of water in the reverse order. i.e.
   a) Close inlet #1,
   b) Close outlet #2 and 2-1" diameter drain orifices,
   c) Open outlet #1,
   d) Regulate and flow the water using inlet #2 for 21 days,
   e) Before core boring samples, drain the water from the mold by opening 2-1" diameter drain orifices.

8. Continue Cycle 2 to 12 by repeating the above sequence of Cycle 1.

EDA297-3 9-91

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT MP3	BY Klakshmi	DATE 9.14.94	
Porous Conc. Mock-Up Testing	CHKD BY	DATE	
Sister Mold - Phase III	CALC NO	REV	
	SHEET NO	OF	



PLAN

NOTE:

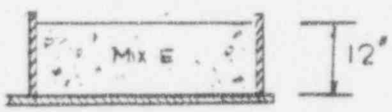
(+) Location of Core Samples.

Core # 1 & #2 - Comp. Test @ 28 days

Core # 3 & #4 - Comp. Test @ 60 days.

Concrete Mix Design E.
Min Designed Comp Strength.

$f_c' = 3000$ psi @ 60 days



SECTION Y_2-Y_2

FIG. III - 2

MP3 PHASE III MOCK-UP TESTING

TABLE III-1

SCHEDULE OF CORE SAMPLE TESTS

POROUS CONCRETE

Duration in Months	Compressive Strength in psi	
	Core Samples Unconfined Compressive Strength	Core Samples ** Confined Compressive Strength
Month #1	1A, 1E, 1G	1C, 1J, 1B, 1F
Month #2	2A, 2E, 2G	2C, 2J, 2B, 2F
Month #3	3C, 3E, 3J	3A, 3G
Month #4	4C, 4E, 4J	4A, 4F
Month #5	5A, $5C_1$, 5G	5B, 5E, 5H, 5J
Month #6	6A, 6C, 6G	6J, 6F
Month #7	7A, 7B, 7J	7C, 7G
Month #8	$8B_1$, $8D_1$, 8J	8A, 8G
Month #9	9C, 9E, 9G	9A, 9D, 9F, 9J
Month #10	10A, 10E, 10G	10C, 10J, 10F
Month #11	11A, 11E, 11G	11B, 11C, 11G, 11H
Month #12	12A, 12C, 12G	12D, 12E, 12H, 12J

**NOTE: Incremental stress strain curves shall be plotted.

MILLSTONE UNIT THREE
PHASE III
POROUS CONCRETE MOCK-UP TESTING

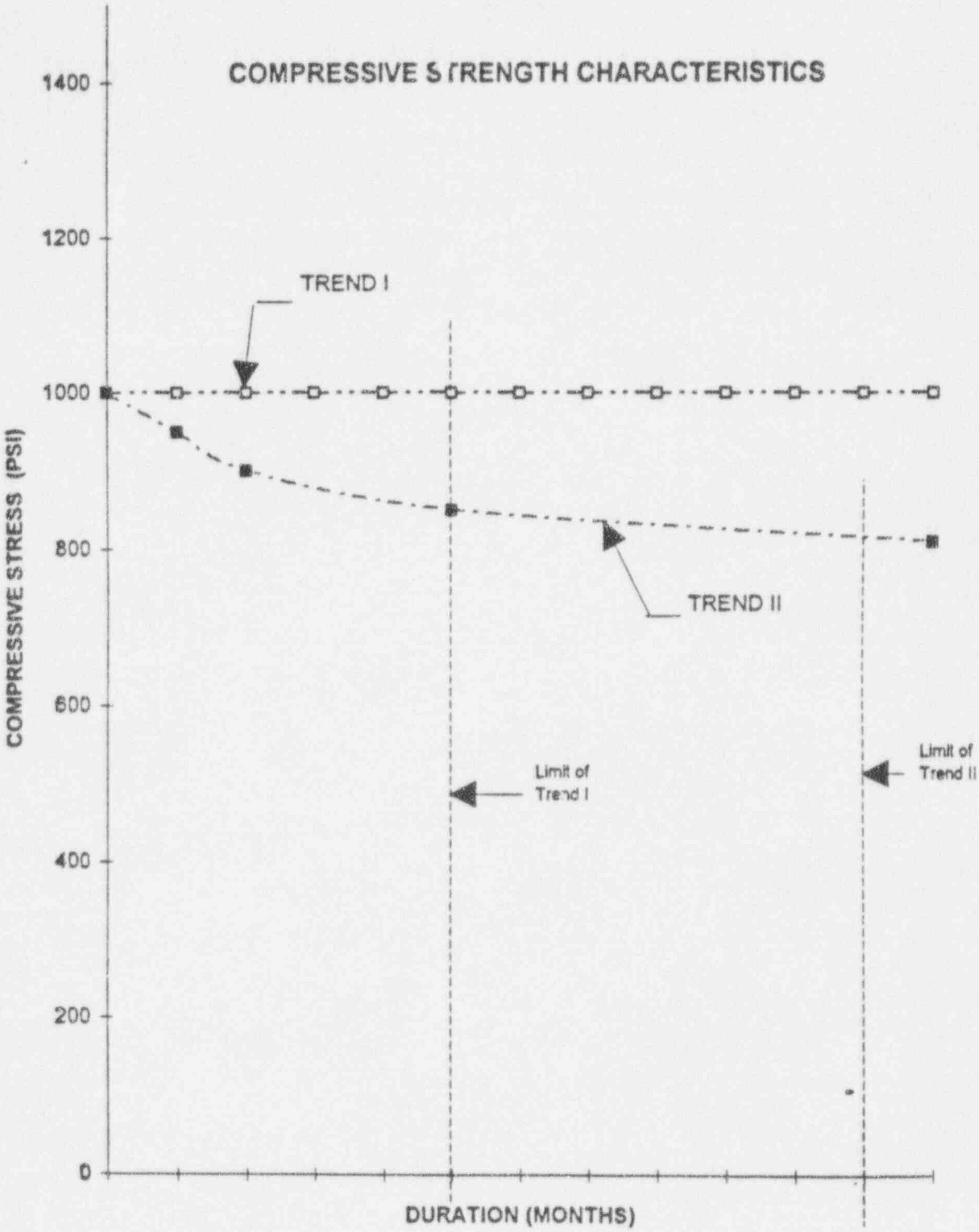


FIG. III - 3