REPORT ON THE REVIEW OF THE

DIESEL GENERATOR BUILDING AT MIDLAND

OCTOBER, 1983

BY

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TABLE OF CONTENTS

1. INTRODUCTION

The Diesel Generator Building (DGB) at the Midland Nuclear Power Plant (NPP) is a reinforced concrete structure which has undergone excessive unequal settlement since its construction. The concrete walls of the DGB have been more extensively cracked than usually expected of such a concrete structure. On the basis of review and evaluation of the Applicant's (Consumer Power Co.) various analytical studies, remedial measures taken, and the commitments made and of the staff's own assessments, the original structural engineering staff reviewer came to the conclusion that the DGB was acceptable. However, an NRC regional inspector disagrees with the conclusion as to the acceptability of the DGB and has expressed his concerns in a hearing before a Congressional Government Oversight Committee.

In the wake of this controversy, the Division of Engineering (DE) formed an independent Task Group to re-review the structural adequacy of the DGB. The Task Group consists of three members from the structural engineering staff and a consultant team from Brookhaven National Laboratory. The consultant team provides expertise in both structural and geotechnical engineering. The charter of the group and its composition, the names of the Staff, and its consultants involved are included in Appendix I to this report. The Charter of this Task Group has three elements that are interwoven and do not lend themselves to neat separation. The Task Group was charged:

(1) to re-evaluate the structural design and construction adequacy of the DGB as accepted by the structural engineering staff reviewer

(2) to assess the concerns as indicated by comments from other NRC personnel, and

(3) to make recommendations to resolve any lingering concerns.

It is acknowledged that the Task Group has had outstanding cooperation from the Applicant, the structural engineering staff reviewer and its consultants, the geotechnical engineering staff reviewer and its consultant, and NRC Region III Inspector, in either group's on-site inspection, interviews, or design audit in Applicant's A/E office. It is this cooperation that enables the Task Group to assemble all the necessary information and facts in a short period of time. The chronology of the group's various activities and persons contacted are presented in Appendix II to this report.

An independent report written by Brookhaven National Laboratory is included in Appendix III of this report.

2. DESCRIPTION OF THE DGB AND ITS PROBLEMS

The DGB is a two-story, box-type reinforced-concrete (RC) structure with three cross walls that divide the structure into four cells, each of which contains a diesel generator unit. The building is supported on continuous RC footings 10' - 0" wide and 2' - 6" thick founded at plant elevation 628' and resting on a fill that extends down to approximately elevation 603'. The building has exterior wall thickness of 30", roof slab and interior wall thickness of 18". Plan dimensions of DGB are 155' x 70 with a total internal height of approximately 44'. Each diesel generator rests on a 6'-6" thick, RC pedestal that is not structurally connected to the building foundation. Figure 1 shows the general layout of the DGB.

The DGB as implied by its name is a building which houses the diesel generators and is classified as a seismic Category I structure. As such it is designed against the effects of extreme environmental conditions such as seismic load and tornado wind load. The latter includes a wind pressure, a differential pressure and tornado missile impact. The use of thick exterior walls and roof slab is basically a result of the consideration of the effects of the tornado missile impact load.

When the building was approximately 60% complete, unusual settlement and cracking of concrete walls were observed. The building was settling due to the consolidation of the underlying fill while it was partially supported along the north portion by four electrical duct banks acting as vertical piers resting on natural soil below the fill. A soil boring program to determine the quality of the backfill under the foundation discovered that the fill was uncontrolled and improperly compacted. The fill consisted of both cohesive soil, granular soil and lean concrete. The fill ranged from very soft to very stiff for cohesive soil and from very loose to dense for granular soil. At the time of the soil exploration, the groundwater level was observed to be ranging from elev. 616' to 622' and the cooling pond, located about 275 feet south of the building, had a water level at approximately elev. 622'.

In view of the condition of the DGB as described above, it was apparent that corrective measures must be taken to relieve the DGB from its distress. The remedial actions taken by the Applicant can be summarized as follows:

(A) Separate the DGB from the duct banks - The duct banks entering the DGB were isolated from the building, thus relieving the building from the effects of the rigid supports.

(B) Surcharge the DGB and the surrounding area - The purpose of the surcharge was to accelerate the settlement and consolidate the fill material so that future settlement under the operating loads would be within tolerable limits.

(C) Install a permanent dewatering system - The purpose of the permanent dewatering system is to maintain water level below elev. 610' in the area of DGB, thus minimizing the potential of liquefaction of the loose sands contained in the fill.

The effects of the remedial measures taken can be observed from the amount of settlement which the DGB has gone through as indicated in Figure 2 and also from the crack sizes and crack patterns of the walls as shown in Figure 3. Details of both settlement and cracking issues are discussed in the following sections.

3. SETTLEMENT AND CRACKING ISSUES

As a result of the remedial actions taken by the Applicant, it appears that the settlement of the DGB has mostly stabilized. However the fact still remains that the building has undergone unusual settlement and its walls have experienced extensive cracking. It has given rise to the concern of the DGB's structural capability to fulfill the function of protecting the safety-related equipment located therein as originally designed. In order to alleviate this concern and to assure that the structural integrity is preserved, the Applicant undertook a number of structural re-analyses using the FSAR criteria and the ACI 349 criteria and taking the settlement and cracking into consideration. On the basis of the results of the re-analyses, the Applicant concluded as follows:

(a) The settlements during early stages of construction and during the surcharge did not cause any unusual distress or significant loss of structural strength. As a result of surcharging, future settlement can be conservatively predicted and will not be excessive. The installation of the permanent dewatering system has eliminated any potential for liquefaction of the sand backfill below the DGB during a seismic event.

(b) Cracking of the walls during construction and surcharging has not impaired the ultimate strength of the structure.

(c) The building will be re-evaluated for its structural adequacy when the allowable limit for the cracking width is exceeded under the established monitoring program, thus insuring its safety function.

The structural engineering staff reviewer and its consultants with findings of their own independent assessments in essence concurred with the Applicant's conclusions. However, the geotechnical engineering staff reviewer and its consultant together with the Region III inspector disagreed.

A major point of contention was that the Applicant's analyses linearized the unequal settlements and thus the effect of unequal settlements has not properly been considered. The Region III inspector also contended that, because actual cracking of the concrete walls was not considered in the Applicant's analyses, the rebar stresses as calculated by the Applicant were not representative of the stress for the loading combinations considered.

In what follows the Task Group shall present its major observations of the analyses performed by the Applicant and by the consultants to the structural engineering staff, the issues raised, and its assessment of the Applicant's conclusion on the DGB structural integrity.

4. STRUCTURAL RE-ANALYSES

In the preceding section, it is indicated that the Applicant has made a number of structural re-analyses and used the results of the re-analyses to justify the DGB structural adequacy, and that there have been concerns expressed as to the appropriateness of the re-analyses. The essential elements of the applicant's re-analyses are succinctly summarized.

Settlement Analyses

Settlement of the DGB is time-dependent and load-dependent, but a complete and accurate settlement history does not exist. On the basis of the availability of the measured or estimated settlement values at various stages of construction, four cases of settlement analyses were performed by the Applicant as listed in Table 1, with the corresponding settlement values shown in Figure 2. With the exception of Case 1A which was analyzed by long hand computation and by idealizing the partially completed DGB as a series of individual beams, the other three cases were analyzed by computer through the discretion of the DGB into a number of finite elements as exemplified in Figure 4. Case 1A was accomplished by passing deflection curve through any three measured neighboring settlement points and selecting the one with the largest curvature for moment computation, and eventually, stress determination. This calculation indicated that the measured displacements would result in a maximum rebar stress of 11 ksi. For the other three settlement cases, individual finite-element models were used. For settlement Case 1B, the finite-element model represents the structure as built to el. 662 f 0 in.

For settlement Cases 2A and 2B, the finite-element model represents a fully completed structure. For Cases 1B, 2A, and 2B, springs were typically calculated at each nodal point along the foundation by dividing the structural load represented at the selected point by the measured or predicted settlement at that point. The finite-element analysis of each case then involved several iterations in which the soil springs were varied until the deflected shape of the DGB, as calculated by the model, approximated the "best fit" settlements. The resulting deflections of the DGB from these analyses as shown in Figures 5 and 6 are not in conformance with the measured values and are almost linearly related. The magnitude of stresses would depend on the final cycle of iteration selected and would bear no relationship to the actual stresses resulting from settlement. Other analyses performed by the Applicant consisted of (1) using zero and near zero soil springs to simulate the soft soil condition, and (2) considering the DGB to be simply supported. The purpose of these analyses was to study if the DGB has the capability of bridging voids and soft spots in the soil.

In an attempt to provide more insight into the problem the consultant to the structural engineering staff was requested to make an independent analysis by using the measured settlement values at 12 locations as input. It was found that the DGB should have cracked extensively and yielded to failure. However, the cracking condition as exhibited by the DGB does not bear out the conclusion of the analysis. It was, therefore, concluded by the staff's consultant that the DGB did not experience the settlement as measured and that the analysis did not reflect the actual settlement history of the DGB.

Cracking Analysis

Cracks in reinforced concrete (RC) members may be caused by the conditions of hardening or curing of the concrete (its shrinkage) or by excessive stresses in the materials (induced by too heavy loads, settlement of the footings and/or changes in temperature). Cracks due to excessive stresses appear most frequent in the tension zones and are seldom encountered in the compression zone of concrete members. Cracks in the RC walls of the DGB are caused by a combination of shrinkage, unequal settlement and temperature changes.

Drying shrinkage and thermal contraction cause shallow cracks at surface.As soon as the cracks are formed the tensile strain is relieved. In the case of cracks due to unequal settlement the tensile strain is to be resisted by the reinforcing steel. The purpose of the cracking analysis is to determine the rebar stresses from the measured crack width. First, the Applicant made an analysis of a single through crack in a subsection of the east wall of the DGB by using the Automatic Dynamic Incremental Non-linear Analysis (ADINA) computer program. The purpose of this analysis was to evaluate the ultimate capacity of a concrete section containing a single crack. As such, the results of the analysis are of only limited value in assessing the effects of the cracks. As a further attempt to resolve the concerns on cracking, the Applicant sought the opinion of Professor M. A. Sozen of the University of Illinois. On the basis of the crack patterns and crack-size, Prof. Sozen estimated the stresses in the rebar across the cracks to be in the range of 20 to 30 ksi.

The structural engineering staff reviewer also made his own assessment by combining the rebar stresses estimated from crack widths with stresses resulting from the Applicant's analyses for other operating loads. It showed that the resultant stress was within the acceptance criteria (Tr. 11086).

In order to assure the structural integrity of the DGB, the Applicant has proposed a crack monitoring and evaluation program to be used during the life of the DGB, in addition to an initial repair program. Specific acceptance criteria (i.e. alert limits and action limits) for crack width and crack width increases have been specified by the structural engineering staff reviewer and agreed to by the Applicant.

5. VIEWS ON THE ISSUES RAISED

The four concerns as raised by Region III inspector, Dr. R. B. Landsman, are directly quoted from his memorandum to R. F. Warnick, Director, Chief of Special Cases of NRC Region III, dated July 19, 1983, as follows.

I. Concern:

"My first concern deals with the finite element analysis that Consumers Power Company (CPCo) used to show that the building is structurally sound. Their model of the building assumed a very rigid structure without any cracks. The building has numerous cracks, reducing the rigidity of the structure. The effects of these cracks have not been taken into account in the analysis. CPCo's interpretation of the settlement data as a straight line approximation always stems from their position that the building is too rigid to deform as indicated by actual settlement readings. The settlement of the building occurred over a period of time during different phases of construction. It is this time dependent effect that was also not used in their model. Even CPCo expert Dr. Corely testified at the ASLB hearings that the analysis should have "taken into account cracking and time dependent effects" in order to give correct results. Finally, the staff's official position, as stated by Dr. Schauer, on CPCo's analysis was, "The staff takes no position with regard to that analysis."

Comment:

The first part of this concern is that the cracks have not been considered in the Applicant's analyses. As indicated in previous discussion, cracks in the walls of the DGB are due to a combination of shrinkage, unequal settlement and temperature changes. Ordinary drying shrinkage and temperature change cracks are generally surface cracks. As soon as the cracks are formed, the tensile strain is relieved. Cracks due to differential settlement are generally through cracks across the wall thickness and, therefore,reduce the stiffness of the structural members. Structural engineers involved in reinforced concrete design are well aware of this fact. In order to take cracking of structural members into consideration, structural engineers first assume these members are uncracked and perform the structural analyses to obtain the moments, shears and axial forces required for the design of member sections. In designing the members concrete is then assumed to be cracked and does not take tension. Such a procedure of analysis and design is a standard practice and is, in fact, recommended by the ACI 318-77 code.

The second part of this concern is that the actually measured settlements have not been used in the Applicant's analyses.
From the settlement data available it is obvious that settlement was continuing with the progress of construction with the maximum attained after the removal of the duct bank restraints and at the end of surcharging. In the early stages of construction the components such as the continuous strip footings, and wall portions forming the lower part of the DGB were most likely very flexible, and deflected in conformance with the settlement without creating any excessive stresses in the as-built portion of the DGB. There might be cracks in some of the components of this portion of the DGB due to shrinkage and/or displacement of the green concrete as a result of settlement. In order to adequately consider effects of settlement over the period of time during different phases of construction, the analytical models would have to be different for different phases of construction and to be meaningful there should be settlement measurements corresponding to each

phase. However, there are no such detailed settlement measurements available, especially for the early stages of construction. The settlement measurements which are available correspond to those in the later stages of DGB construction, that is, when the as-built portions of the DGB are relatively rigid. The Applicant performed three separate finite element analyses for which measured and/or predicted settlement values are available. The measured and/or predicted settlement values are used as data points in linearizing the settlement. The differences between the measured/predicted settlement values and the resulting linearized values have been discounted as survey inaccuracies. This is basically equivalent to assuming that the north and south walls underwent rigid body motions. The computed stresses from this model are due to racking only. The stresses obtained in the process of linearizing the settlements, therefore, do not represent the actual settlement stresses.

The use of survey inaccuracies to discount the differences between the measured/predicted settlements and the linearized values is not convincing in view of the fact that all the settlements have not occurred after the completion of the DGB construction.

The third part of this concern is that the time dependent effect has not been considered in the Applicant's analyses. The Applicant has considered the four stages of construction, therefore the time factor has been taken into consideration but in a very gross manner. As indicated in the preceding comment in order to assess accurately the stresses in the walls of the DGB, detailed information on wall cracks (time-dependent) and on settlement values (also time-dependent) would be required for each step in the construction. There is no detailed information on either the cracks or the settlement values to cover the whole time span of construction. Basically this portion of the concern is inherent in the above two portions of the concern.

The fourth portion of the concern is that the structural engineering staff reviewer has taken no position with respect to the Applicant's analysis. From the preceding comments it is obvious that the adequacy of the Applicant's settlement analysis is questionable and it cannot be relied on to reach any conclusion. The structural engineering staff reviewer took a practical approach by ignoring the analysis, and resorted to the solution through crack analysis.

II. Concern:

"My second concern deals with the acceptance of the diesel generator building in the SSER #2 which was subject to the results of an analysis to be performed by the NRC consultants using the actual settlement values. The consultants testified at the ASLB hearing that this analysis gave unacceptable results and this portion of the SSER should be stricken. They are basing their unacceptable results and comments on their finding of very high stresses obtained in areas where no cracks exist. Therefore, the actual settlement values are not accurate enough (are in error) to be used in an analysis. The consultants, as well as CPCo, ran a linear analysis (structure always in the elastic range) instead of a plastic analysis which would allow a redistribution of loads in the structure. Therefore, supposed areas of high stress, where cracks are not located, may not exist due to redistribution of loads. Finally, the staff's official position, as stated by Mr. Rinaldi, on this analysis as performed by the consultants, was that the actual settlement values could not be relied upon to determine if the diesel generator building meets regulatory requirements."

Comment:

The first portion of concern is that the structural engineering staff reviewer disregarded the results of an analysis done by its consultants on the basis of the actual settlement values. This portion of the concern is in essence the same as the first concern. It is indicated in the comment on the first concern that the settlement was continuing with the progress of construction. When the strip footing concrete was placed, settlement started. Since the footing is a comparatively thin slab, it would likely deform with the settlement without creating excessive stresses. With the build-up of the walls, settlement increases and rigidity also increases. When the intermediate floor slab and the roof slab were completed, the complete structure became a very rigid structure and any settlement should be nearly linear unless there were weak sections across the building. To analyze the completed DGB on the basis of the settlement values which were accumulated during the construction and after its completion would result in exceedingly high stresses which are not representative of the actual values.

The second portion of this concern is that the staff has not used plastic analysis. It is suggested, that in order to conform to the measured settlement values a plastic analysis should be made to allow redistribution of loads in the structure. This observation is valid providing that rebar in the walls and slabs of the DGB have undergone yielding and plastic hinges have formed. It is the judgment of this Task

Group that, without the knowledge of accurate geometry of the DGB at the various phases of settlement, a non-linear model accounting for plastic effects would not be meaningful.

The third portion of this concern is the staff's official position that the results of the analysis by the staff's consultants on the basis of actual settlement measurements cannot be relied upon to determine if the DGB meets regulatory requirements. From the preceding comments, one cannot accurately calculate the stresses in the completed DGB without settlement data from the initial phase of construction. Given the unavailability of the data necessary to complete the input to the analysis by the staff's consultant, the previously stated staff position is reasonable.

III. Concern:

"My third concern deals with the fact that we are not following normal engineering practice in accepting the building by using a crack analysis approach because there is no practical method available today to analyze a complex structure with cracks in it. The basis of this concern is that there are no formulas available that can estimate stresses in a complex stress field like those which exist in this building. Thus, the evaluation of the structure based on the staff's crack analysis using empirical unproven formulas to determine the rebar stresses is unacceptable."

Comment:

This concern is related to the use of crack analysis to accept the DGB. Contrary to the concern expressed there are computational tools available to relate crack width to rebar stresses, but in effecting the analyses one still has to make some major simplifying assumptions which requires the judgment of the analyst. The results of such analyses in most likelihood will not be exactly the same as what actually exists. In the case of DGB the estimation of rebar stresses from the sizes of cracks is admittedly an approximation. However, it is the judgment of the Task Group that this is the only practical approach available to evaluate the DGB rebar stresses.

In evaluating the rebar stresses estimated from crack widths the following, as a minimum, needs to be considered and documented by the Applicant: whether or not the cracks are through the wall thickness; the sizes and locations of the cracks; whether or not the cracks are growing in width and/or length; whether or not the number of cracks are increasing; and whether the estimated rebar stresses due to settlement are less than the allowable values after accounting for load combinations is made.

IV. Concern:

"My fourth concern deals with the staff accepting the building by relying on a crack monitoring program to evaluate the stresses during the service life of the building. If cracks exceed certain levels, recommendations will be made for maintaining the structural integrity of the building. The basis for my concern deals with the lack of crack size criteria and the lack of formulated corrective action to be taken when the allowed crack sizes are exceeded."

Comment:

This concern questions the staff's acceptance of the DGB on the basis of a crack monitoring program which is not well defined in crack size criteria and in corrective action. The DGB is designed for combinations of dead, live, tornado and earthquake loads, and therefore it is expected to be able to resist these loads and their loading combinations with adequate margins of safety as designed. However, as a result of settlement which was not considered in the original design, the margins of safety have been reduced to some extent and there is some uncertainty as to its capability to resist the design loads. The purpose of monitoring the cracks is to insure that if there is any change in the condition of the structure it will be observed and appropriate actions can be taken, if necessary. The structural engineering staff reviewer has specified and the Applicant has agreed to the crack size criteria and the corrective action to be taken when the allowed sizes are exceeded. The Task Group is of the opinion that, while the approach is reasonable, details of the program should be further examined and improved. It should also be noted that the crack monitoring program should be in complement with a settlement monitoring program, since any assessment based on either of the two monitoring programs alone may be misleading.

6. AN ASSESSMENT OF THE DGB

Before assessing the structural adequacy of the DGB, let us examine general characteristics of structures in their capability to adapt to the settlement of the foundation soil. Structures may be classified as highly flexible, practically flexible, highly rigid and practically rigid on the basis of their deformability with respect to the settlement of the foundation soil.

Highly flexible structures follow the displacement of the foundation soil surface at all points. An example of such a structure is an earth embankment. Non-uniform (differential) settlements do not give rise to any complications in the deformation of such a structure.

Highly rigid structures either have a uniform settlement when subjected to a symmetrical load with symmetrical distribution of the soil compliance, or else tilt without bending. As an example of this are grain elevators, factory chimneys (smoke stacks), blast furnaces, etc. These structures level out the settlements, i.e., they perform in conjunction with the soil bearing material. It is because of re-distribution of the pressure by the structure that differential settlement effect of the supporting material diminishes.

Practically rigid structures, which include most buildings and many engineering structures (multispan trestles and bridges with continuous structural members, reservoirs, storage tanks, etc.), cannot closely follow the foundation soil deformations at all points and, because of differential settlement, are subject to bending. Such structures level out only in part the non-uniform settlements of the foundation soil surface. This results in the development of additional forces in the supporting members of the structures, which are usually disregarded in the course of their designing. Hence the possible development of cracks in such members.

Practically flexible structures largely follow the displacements of the soil surface, i.e., they bend (such as low single-story buildings), but over short sections they are capable of levelling out to a certain extent the differential settlement. This results in the emergence of usually insignificant additional forces in the supporting members. In the event of highly non-uniform settlements these forces can cause the development of cracks and fractures.

On the basis of above classification and because of the box-type construction with heavy reinforced concrete walls and slabs, the completed DGB can be considered as a highly rigid structure. However, in the process of construction, the as-built portions of the DGB at different stages of construction can be considered to vary from highly flexible, practically flexible, practically rigid to highly rigid. It is believed that most of the settlement and settlement cracks appeared at the various stages of construction. However, the cracks have not been carefully studied and mapped at each stage of construction so that a reasonable correlation of the cracks with all the causes can be established. Only the cracks which were mapped in January 1980 have been identified as shrinkage and/or settlement cracks. Most of the cracks which have been identified to be due to unequal settlement are the cracks in the cross-walls, the movement of which was restrained by the duct banks.

The DGB design, as indicated by Applicant's analyses, is controlled by the tornado wind. Under such a load, especially the postulated internal pressure, the full strength of the walls will be mobilized, and there will be a redistribution of the load, if there exist localized high stress areas. This will also be true if the seismic loads are considered. One can make such judgments on the basis of the observation that the DGB is a highly redundant structure. The structural elements are not columns and beams. They are heavy reinforced concrete walls and slabs. With necessary repair work to be done and with adequate monitoring programs, there is reasonable assurance that the structural integrity of the DGB will be maintained and its functional requirement will be fulfilled.

7. CONCLUSIONS AND RECOMMENDATION

Most of our conclusions have been expressed in our comments to the concerns they may be summarized as follows:

1. Analyses of the DGB either by linearizing the settlements or by applying the settlements as measured render unrealistic results. The stresses due to settlement are either underestimated or overestimated. A realistic analysis would be one which simulates the stage-by-stage construction of the DGB, and uses the actual and more detailed settlement measurements at each stage. However, such settlement history for the DGB does not exist. For this reason, the Task Group believes that a rigorous analysis to compute rebar stresses is unattainable.

2. The estimation of rebar stresses from the crack width is admittedly an approximation. The estimated stresses of 20 to 30 ksi appear to be reasonable. However to be convincing a detailed procedure of crack analysis should be documented and provided.

3. Inconsistences in the documentation of the settlement history needs to be resolved. For example, the Midland Units 1 and 2 Executive Summary dated August, 1983 states that for the July 1978 period, the maximum settlements recorded were 3.5 inches while Figure ES-14 of the same document indicates a maximum of 1.99 inches for the same period.

4. The current monitoring program is inadequate to deduce future distress. Thus, an adequate monitoring program for both settlement and cracks should be developed and implemented to assure that the structural integrity of the DGB should be maintained during the life of the plant.

5. On the basis of the overall evaluation, it is nevertheless felt that the DGB in its current state can fulfill its functional requirement .

6. It is recommended that a repair program be developed and implemented.

TABLE 1

DIESEL GENERATOR BUILDING

SETTLEMENT CASES

CASE	TIME PERIOD	PERIOD	PORTION OF BLDG COMPLETE
1A	3/78 - 8/78	PRE-SURCHARGE	WALLS TO ELEV 654'
1B	8/78 - 1/79	PRE-SURCHARGE	WALLS TO ELEV 662' (BELOW MEZZANINE SLAB)
2A	1/79 - 8/79	SURCHARGE	COMPLETE BUILDING
2B	9/79 - 12/2025	40 YEAR	COMPLETE BUILDING

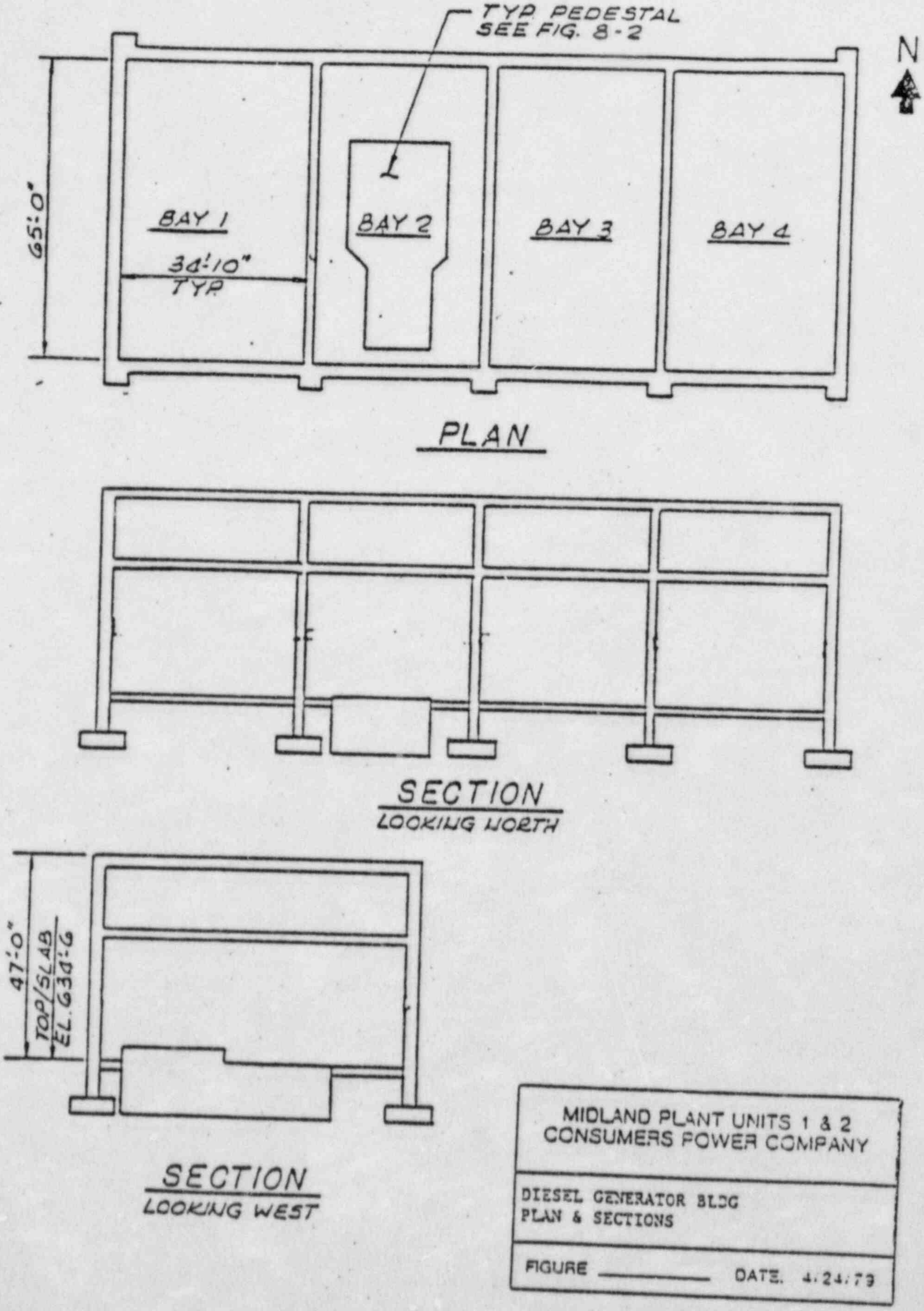
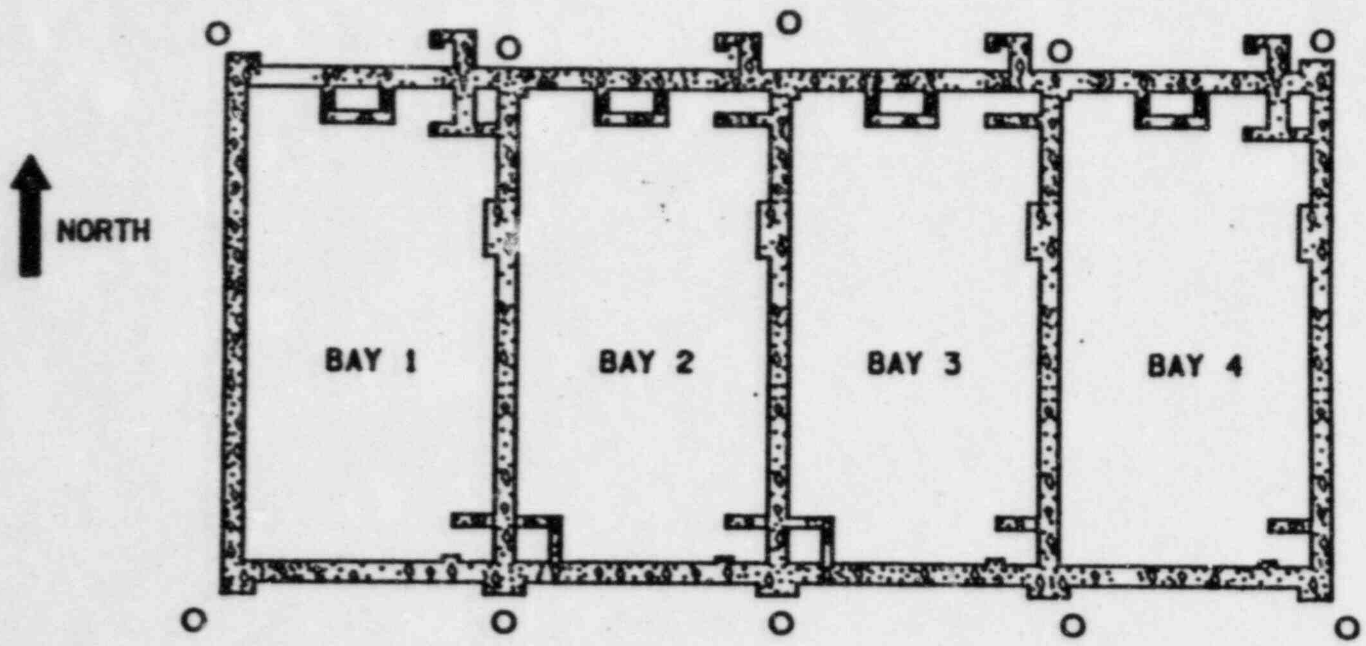

TYP. PEDESTAL
SEE FIG. 8-2
N
65'-0"
BAY 1
BAY 2
BAY 3
BAY 4
34'-10"
TYP.
PLAN
SECTION
LOOKING NORTH
47'-0"
TOP/SLAB
EL. 634'-6
SECTION
LOOKING WEST
MIDLAND PLANT UNITS 1 & 2
CONSUMERS POWER COMPANY
DIESEL GENERATOR BLDG
PLAN & SECTIONS
FIGURE
DATE. 4/24/79

FIGURE 1

LINE A	1.19	1.02	0.90	0.85	0.76
LINE B	0.77	1.09	1.54	1.98	2.41
LINE C	1.50	1.51	1.78	1.86	1.91
LINE D	1.33	1.15	1.19	1.18	1.29
TOTAL	4.79	4.77	5.41	5.87	6.37



LINE A	1.67	1.42	1.28	1.44	1.99
LINE B	1.14	1.12	1.46	1.92	2.21
LINE C	3.00	2.92	3.16	3.37	3.24
LINE D	1.62	1.67	1.69	1.98	1.89
TOTAL	7.43	7.13	7.59	8.71	9.33

LEGEND

O —— DIESEL GENERATOR BUILDING SETTLEMENT MARKER

SETTLEMENT IN INCHES FOR

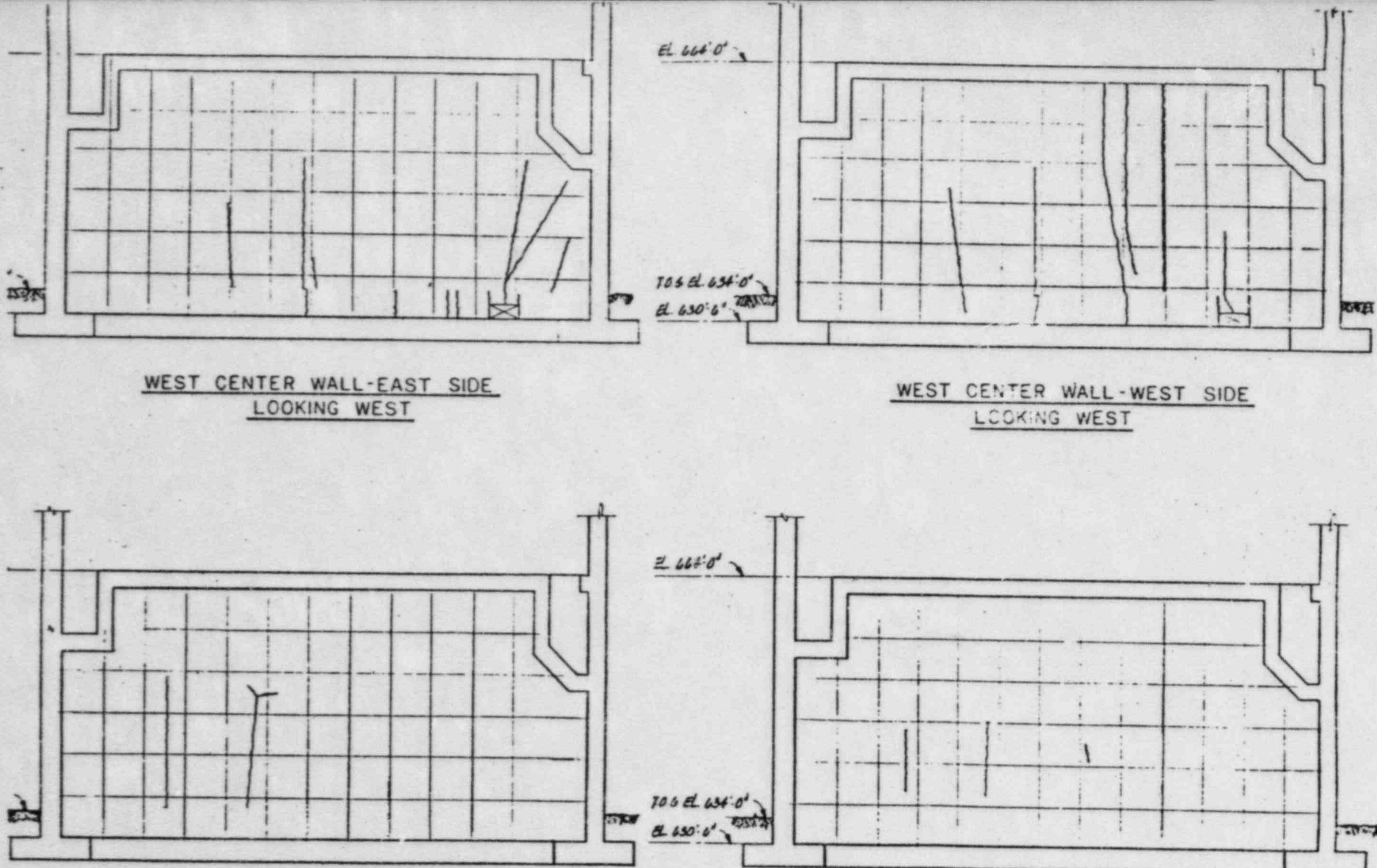
PRE-SURCHARGE PERIOD (3/78-8/78)............LINE A
PRE-SURCHARGE PERIOD (8/78-1/79)............LINE B
SURCHARGE PERIOD (1/79-8/79) ....LINE C
POST SURCHARGE PERIOD (9/79-12/2025)........LINE D
ASSUMING SURCHARGE REMAINS IN PLACE

FIGURE 2

DIESEL GENERATOR BUILDING
EXECUTIVE SUMMARY

SUMMARY OF ACTUAL AND ESTIMATED SETTLEMENTS

FIGURE ES-14



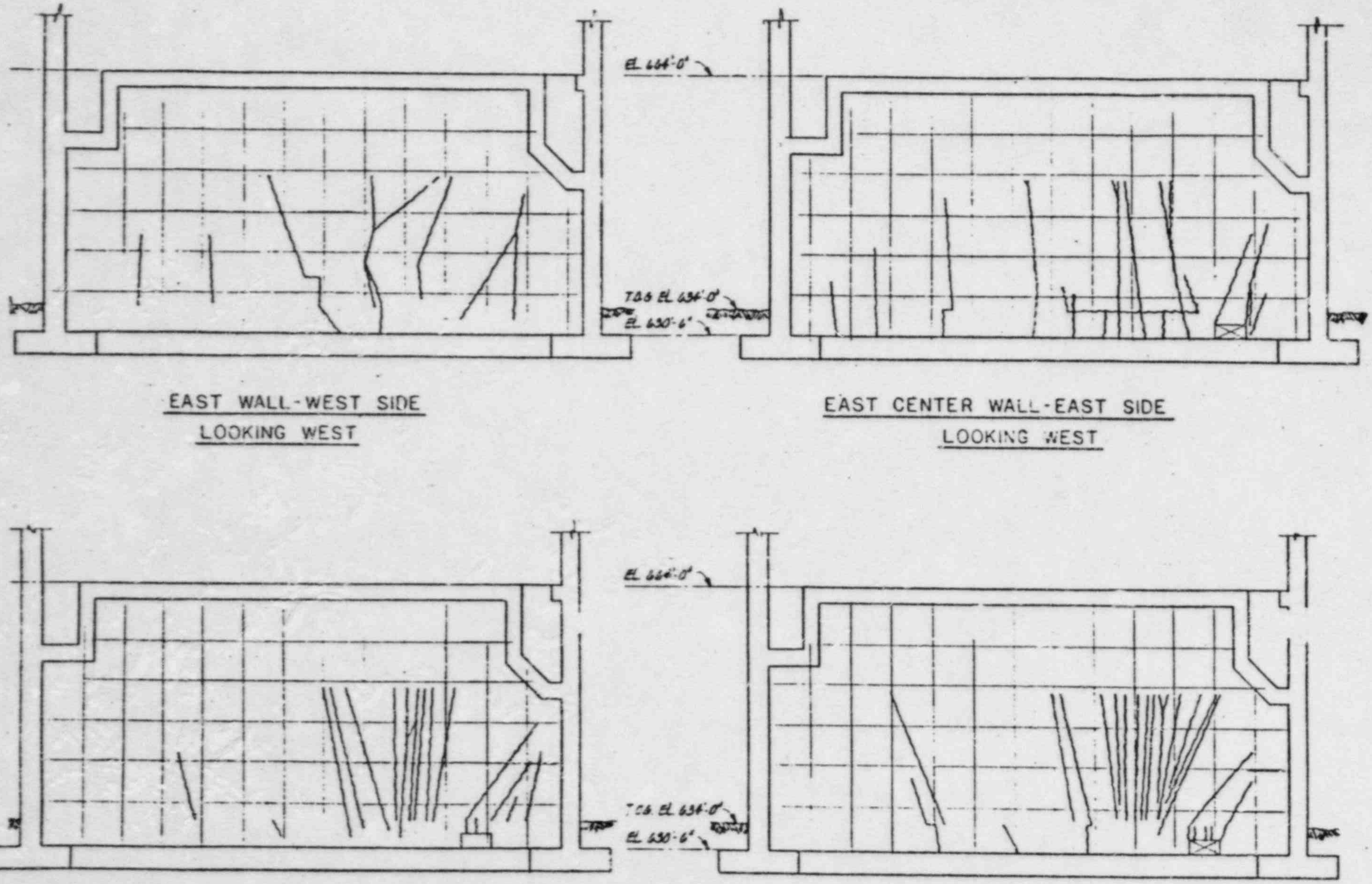
WEST CENTER WALL-EAST SIDE
LOOKING WEST

WEST CENTER WALL-WEST SIDE
LOOKING WEST

WEST WALL-EAST SIDE
LOOKING WEST

WEST WALL-WEST SIDE
LOOKING WEST

FIGURE 3 - A - 1



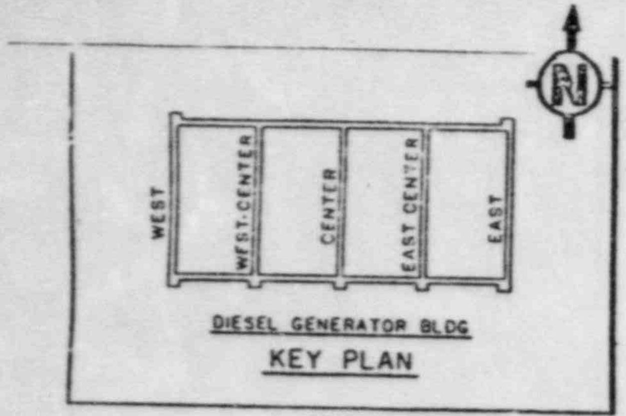
EAST WALL-WEST SIDE
LOOKING WEST

EAST CENTER WALL-EAST SIDE
LOOKING WEST

CENTER WALL-EAST SIDE
LOOKING WEST

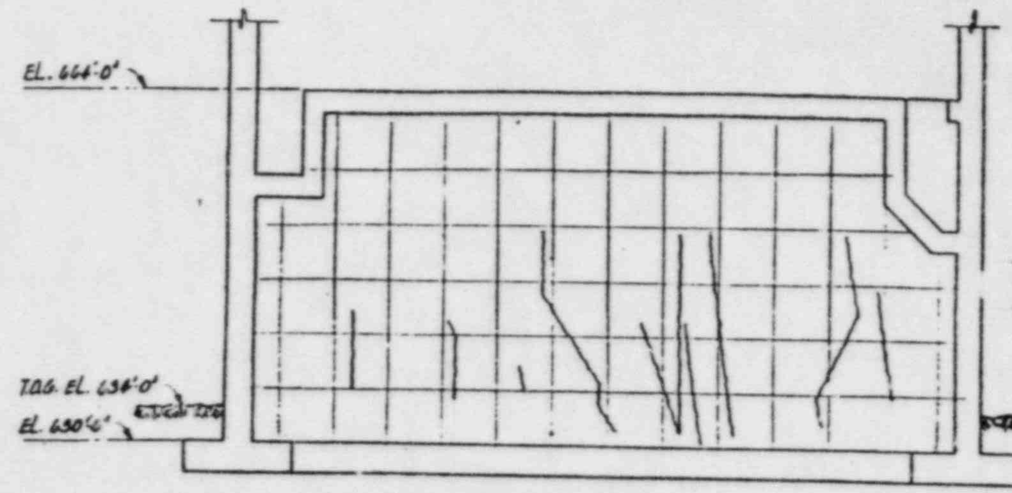
CENTER WALL-WEST SIDE
LOOKING WEST

FIGURE 3 A - 2

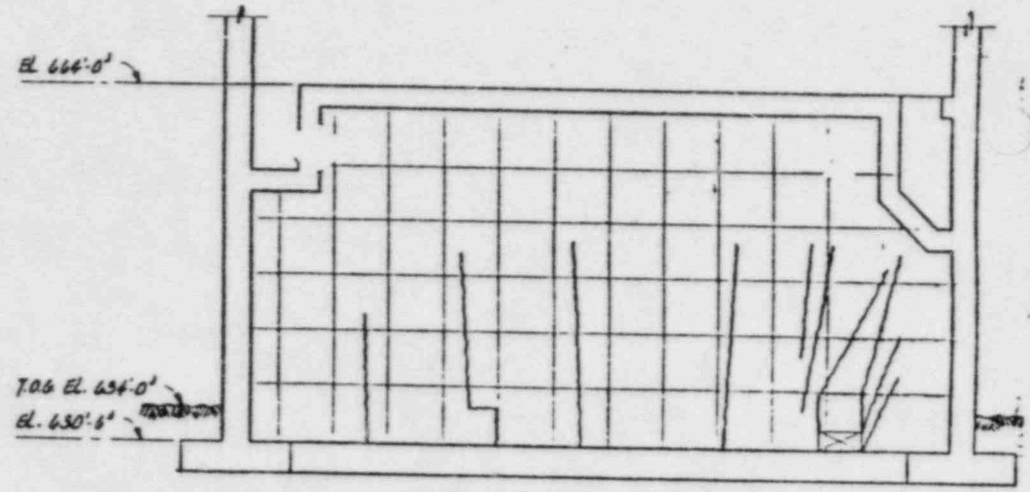


NOTES

1. CRACK SHOWN WERE MAPPED PRIOR TO PLACING THE PRELOAD (12-13-78 TO 12-18-78).
2. NORTH & SOUTH WERE NOT MAPPED SINCE NO SIGNIFICANT CRACKS WERE OBSERVED.
3. IN GENERAL, ALL CRACKS WERE HAIRLINE WITH SOME CRACKS WITH A THICKNESS OF 28 MILS AS OF 2-2-79.

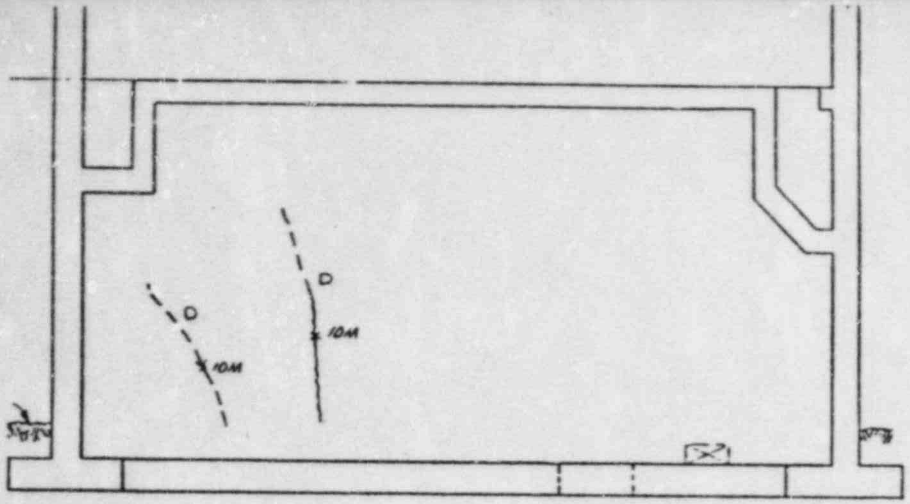


EAST WALL-EAST SIDE
LOOKING WEST

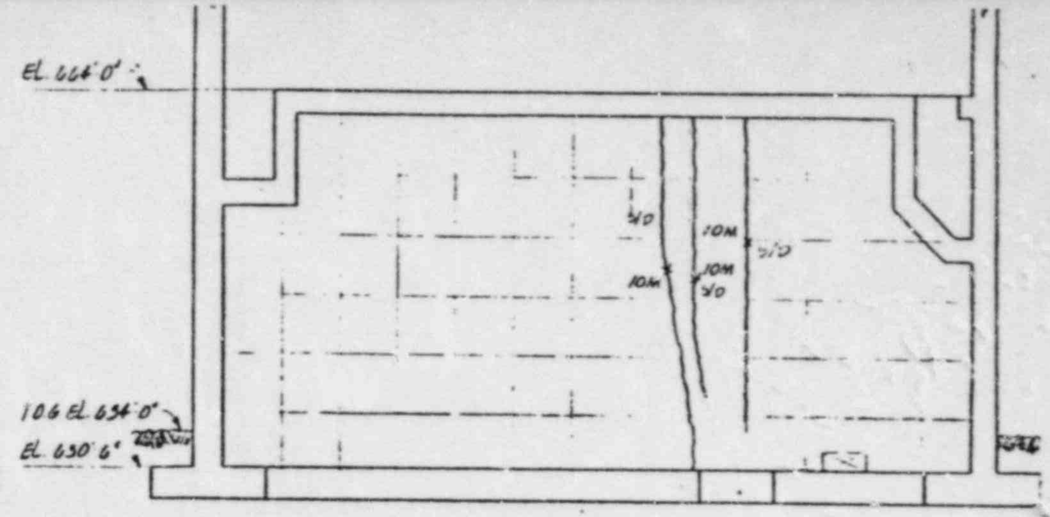


EAST CENTER WALL-WEST SIDE
LOOKING WEST

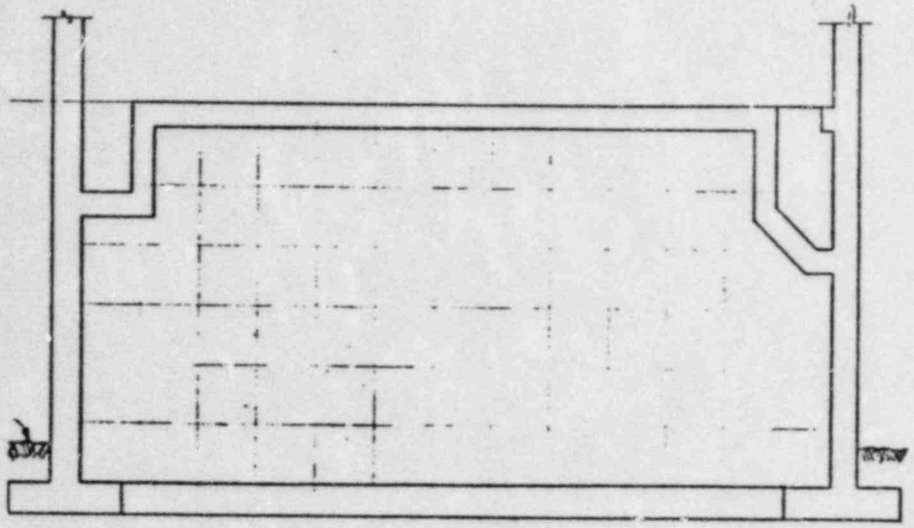
FIGURE 3 A - 3



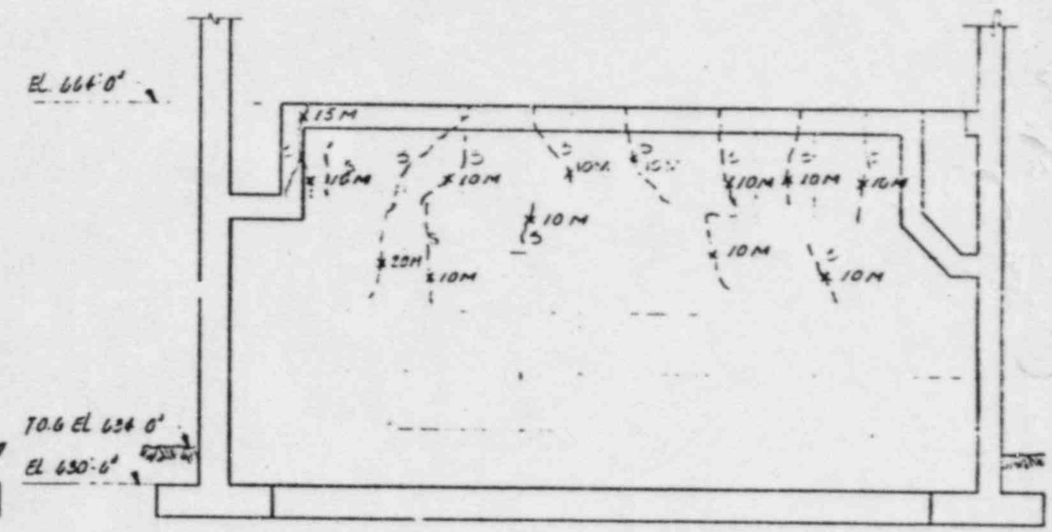
WEST CENTER WALL-EAST SIDE
LOOKING WEST



WEST CENTER WALL-WEST SIDE
LOOKING WEST

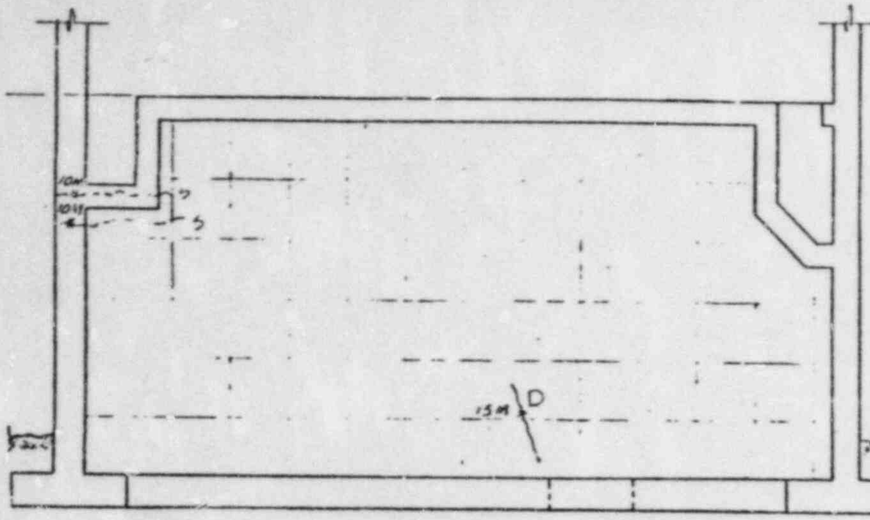


WEST WALL-EAST SIDE
LOOKING WEST



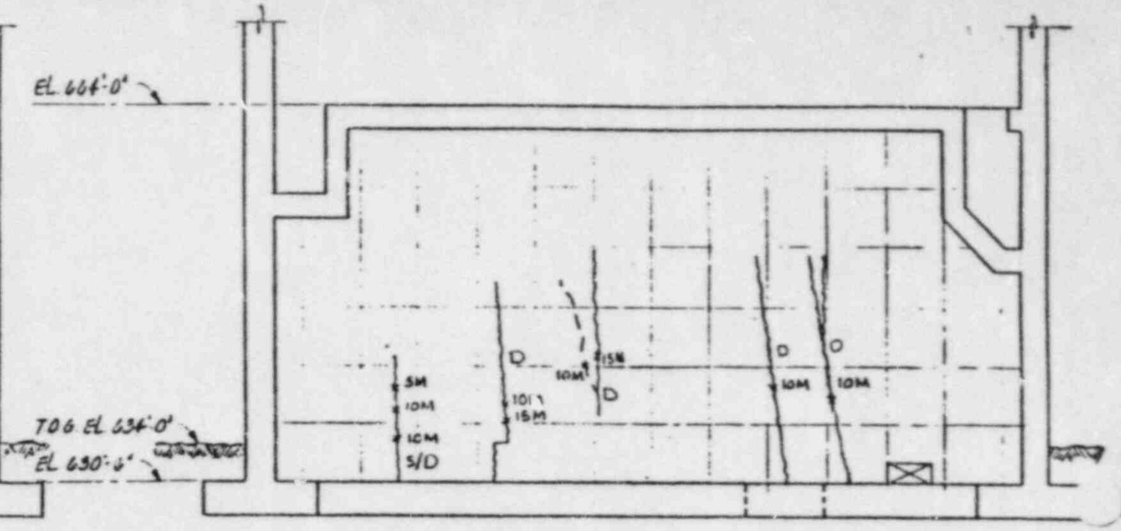
WEST WALL-WEST SIDE
LOOKING WEST

FIGURE 3 B - 1



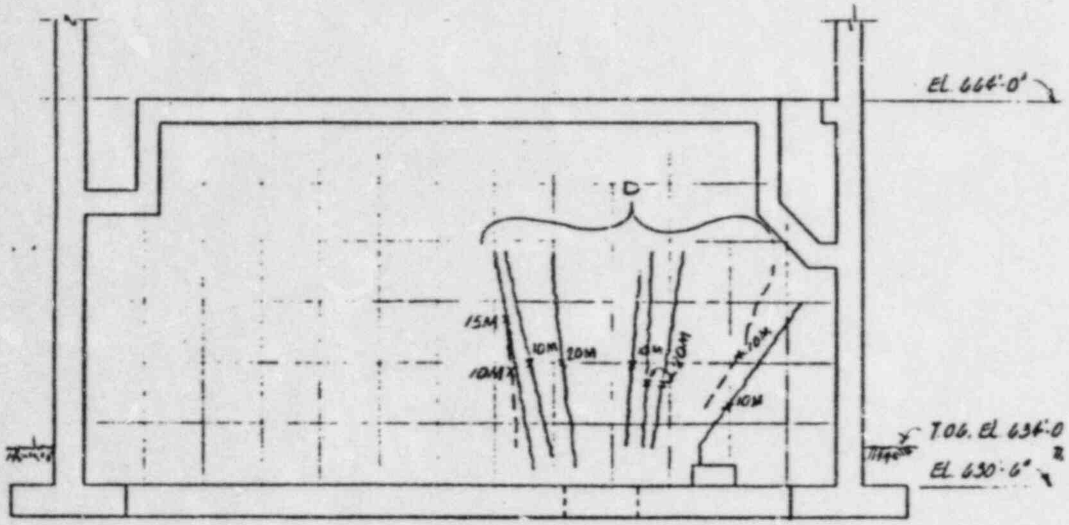
EAST WALL - EAST SIDE

LOOKING WEST



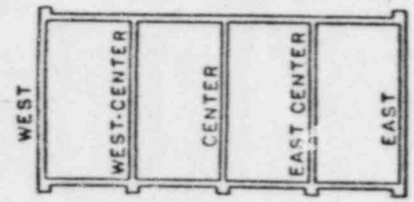
EAST CENTER WALL - EAST SIDE

LOOKING WEST



CENTER WALL - EAST SIDE

LOOKING WEST



DIESEL GENERATOR BLDG

KEY PLAN

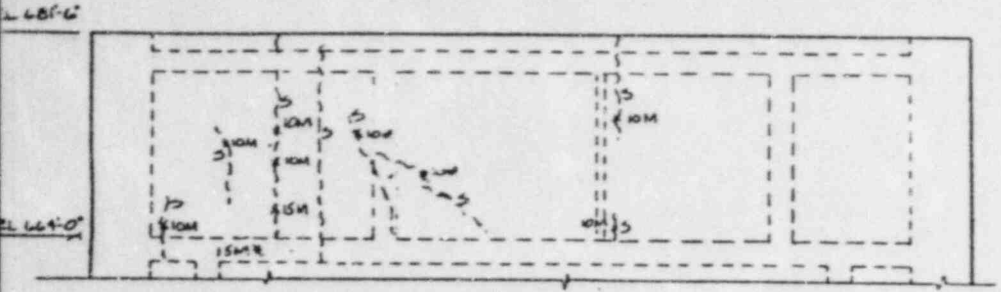
NOTES

1. IN GENERAL ALL CRACKS MAPPED IN DEC 1978 WERE HAIRLINE. SOME CRACKS HAD A THICKNESS OF 28 MILS AS OF 7-7-79.

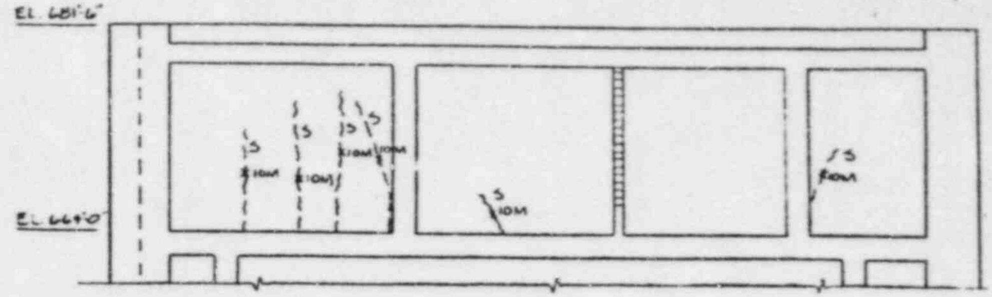
2. FOR CRACK MAPPING OF WALLS FROM EL. 664'-0" TO EL 681'-6" SEE FIG. 28-3

3. CRACKS LESS THAN 10 MILLS IN SIZE ARE NOT SHOWN.

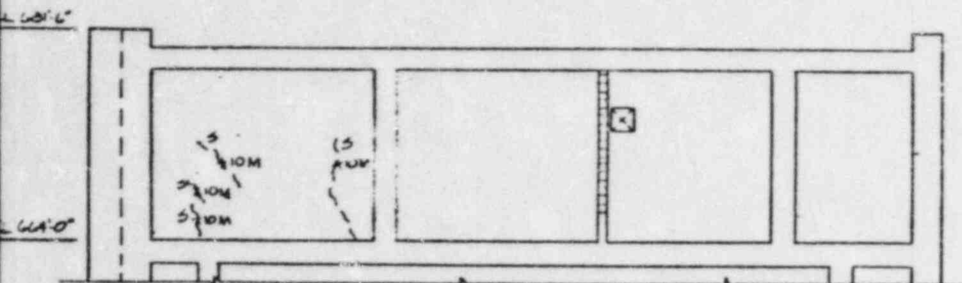
FIGURE 3 B - 2



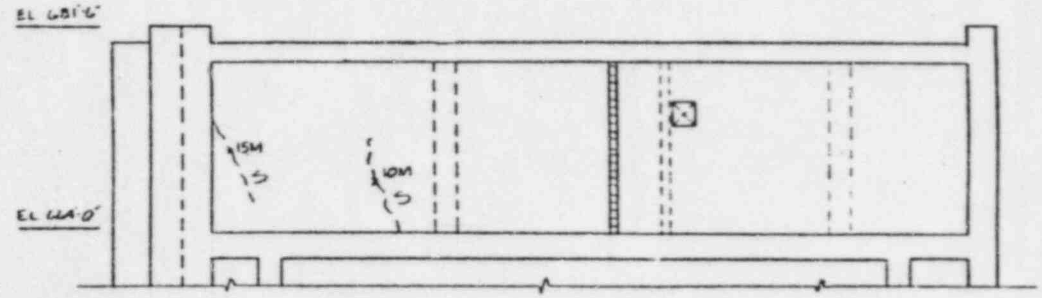
EAST WALL - EAST SIDE
LOOKING WEST



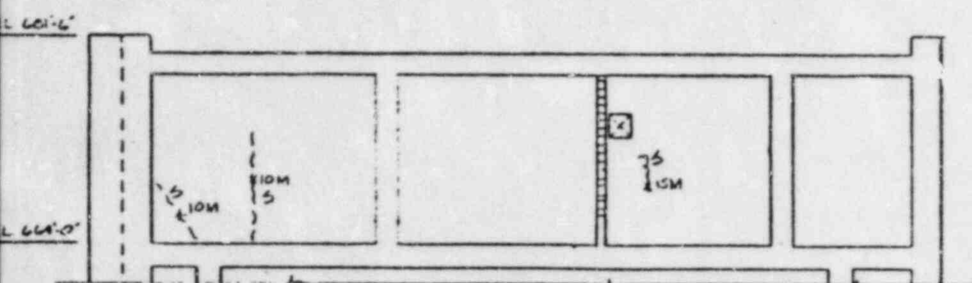
EAST WALL-WEST SIDE
LOOKING WEST



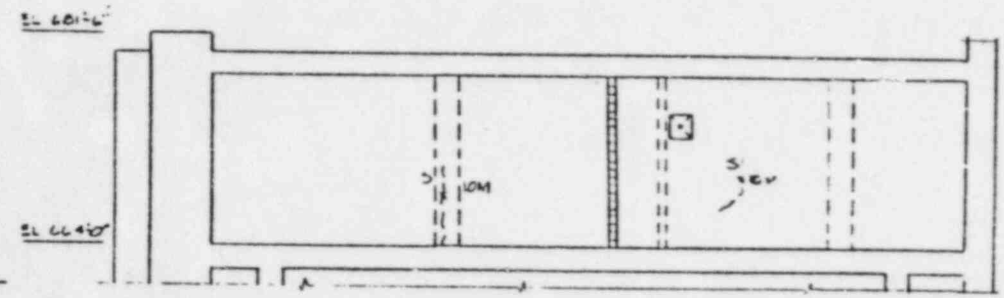
EAST CENTER WALL-WEST SIDE
LOOKING WEST



EAST CENTER WALL-EAST SIDE
LOOKING WEST

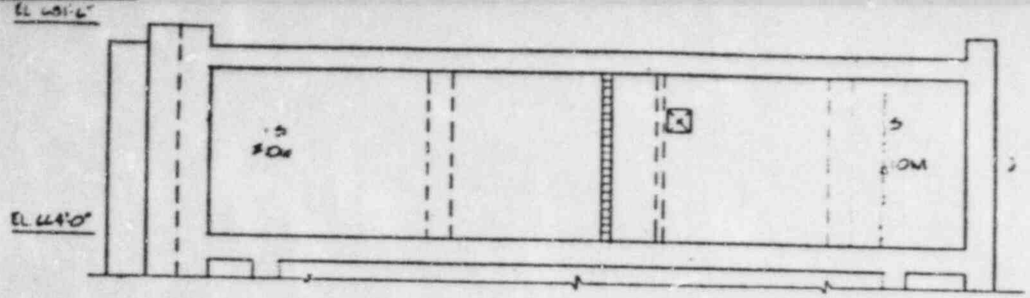


CENTER WALL-WEST SIDE
LOOKING WEST

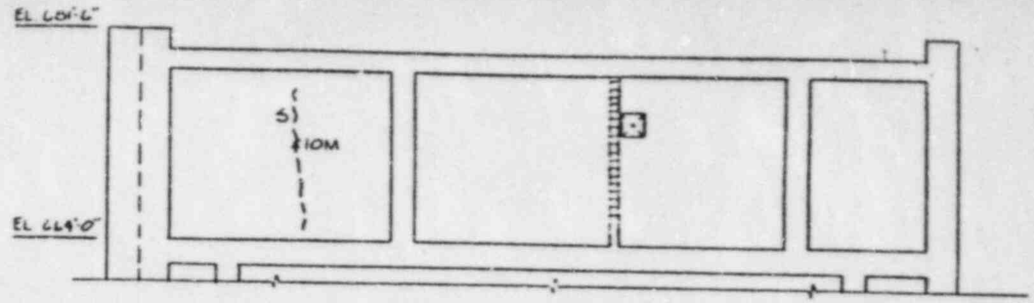


CENTER WALL-EAST SIDE
LOOKING WEST

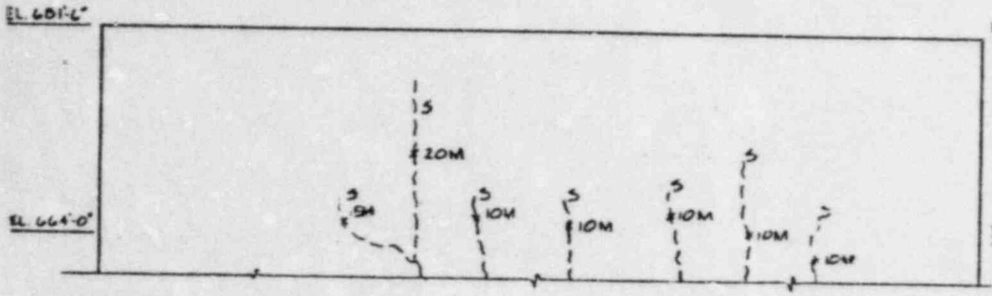
FIGURE 3 B - 3



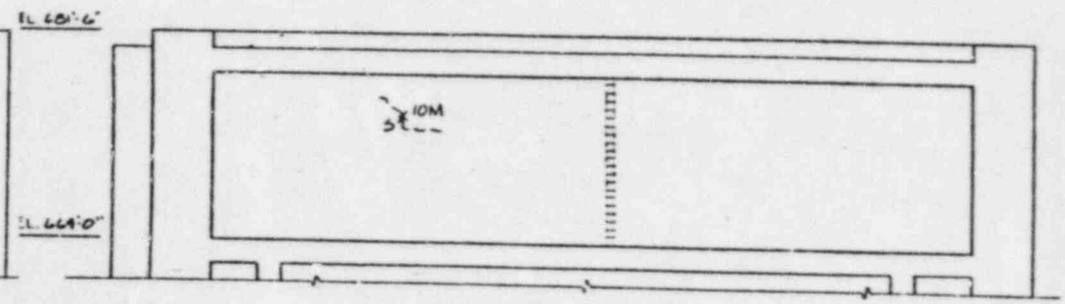
WEST CENTER WALL - EAST SIDE
LOOKING WEST



WEST CENTER WALL - WEST SIDE
LOOKING WEST



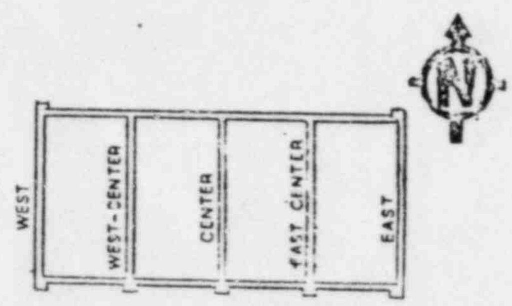
WEST WALL - WEST SIDE
LOOKING WEST



WEST WALL - EAST SIDE
LOOKING WEST

NOTES

1. CRACKS SHOWN WERE MAPPED ON JAN. 1980.
2. SEE FIG 28-2 FOR TYPICAL CONSTRUCTION SEQUENCE
3. SEE FIG 28-2 FOR CRACK MAPPING OF WALLS FROM ELEVATION 630'-6" TO 664'-0".
4. SEE FIG 28-2 FOR [illegible] NOTES AND LEGEND



DIESEL GENERATOR BLDG
KEY PLAN

FIGURE 3 E - 4

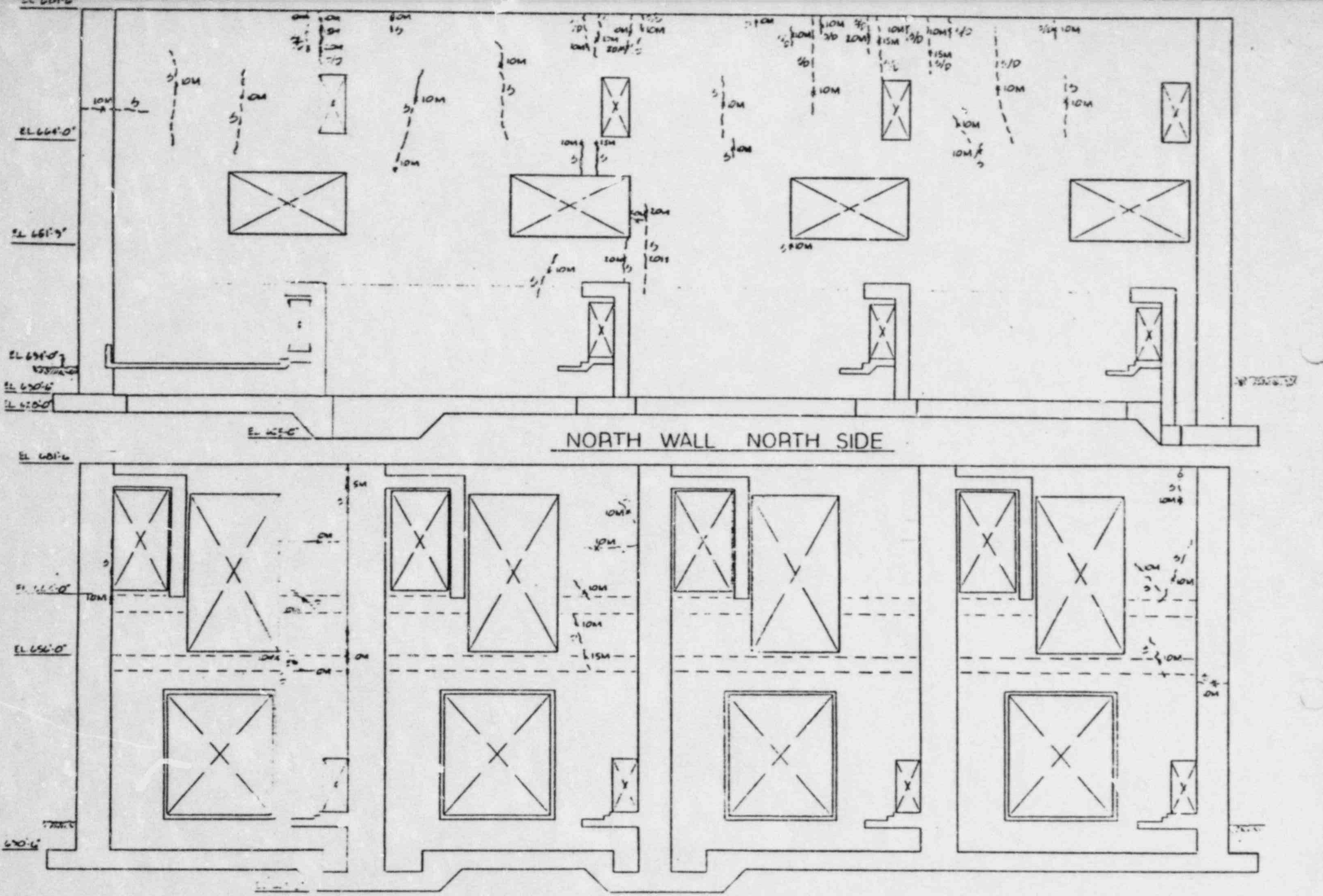
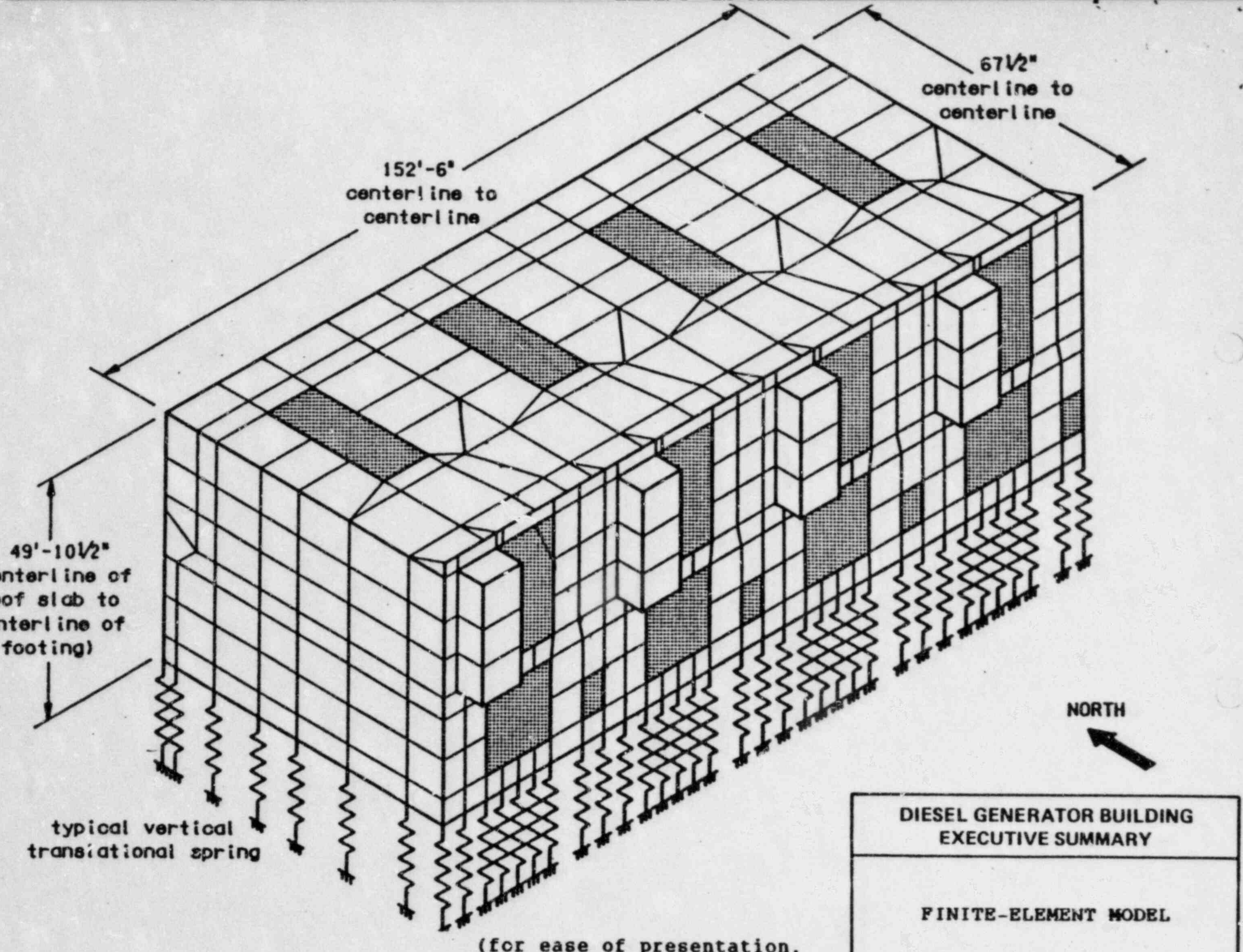


FIGURE 3 B - 5

SOUTH WALL SOUTH SIDE

LOOKING NORTH



(for ease of presentation,
only vertical translational
springs have been depicted)

DIESEL GENERATOR BUILDING
EXECUTIVE SUMMARY

FINITE-ELEMENT MODEL

FIGURE ES-13

FIGURE 4

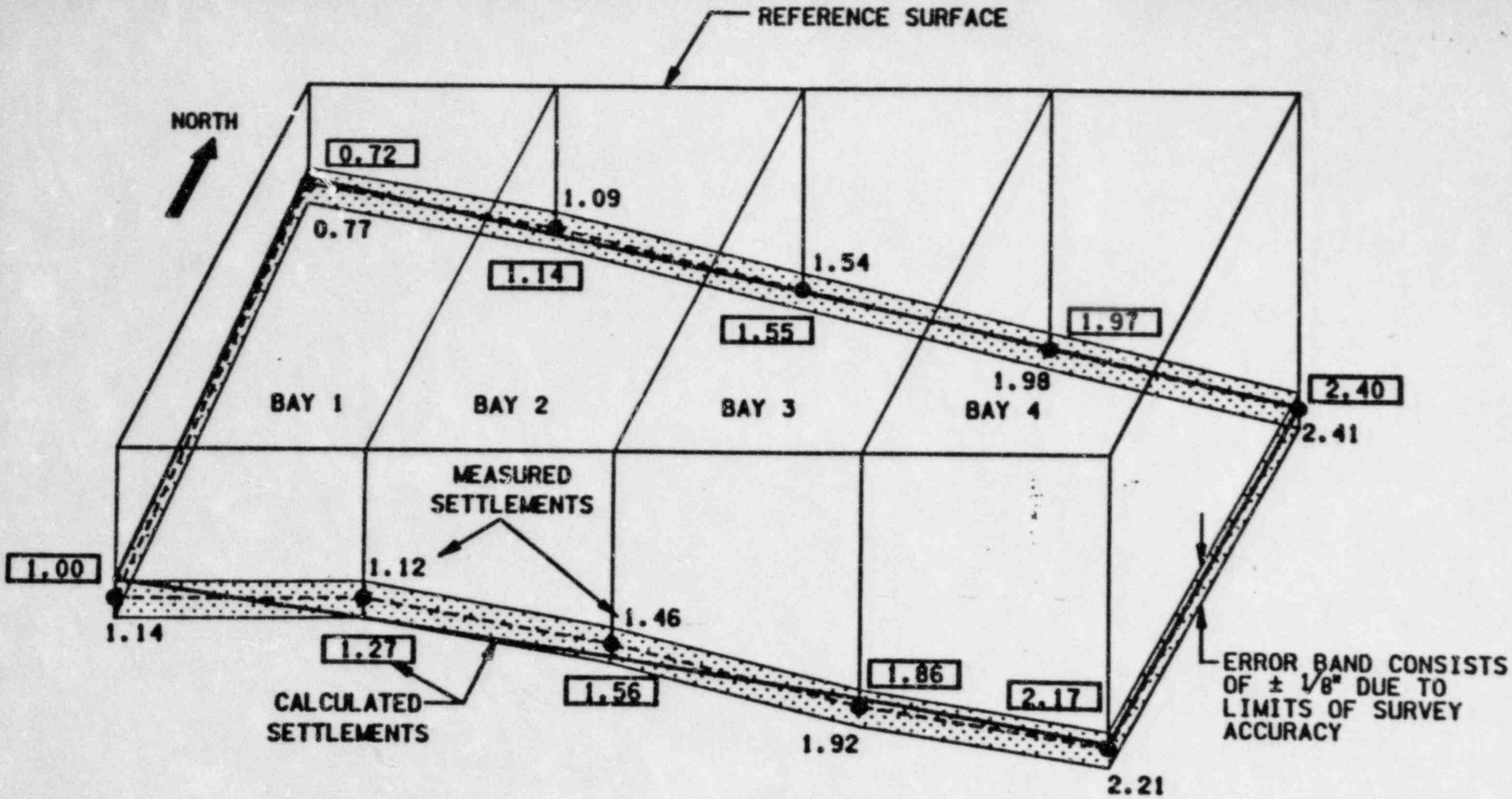


FIGURE 5

DIESEL GENERATOR BUILDING EXECUTIVE SUMMARY
COMPARISON OF SETTLEMENT VALUES PRE-SURCHARGE PERIOD AUGUST 1978 - JANUARY 1979
FIGURE ES-15

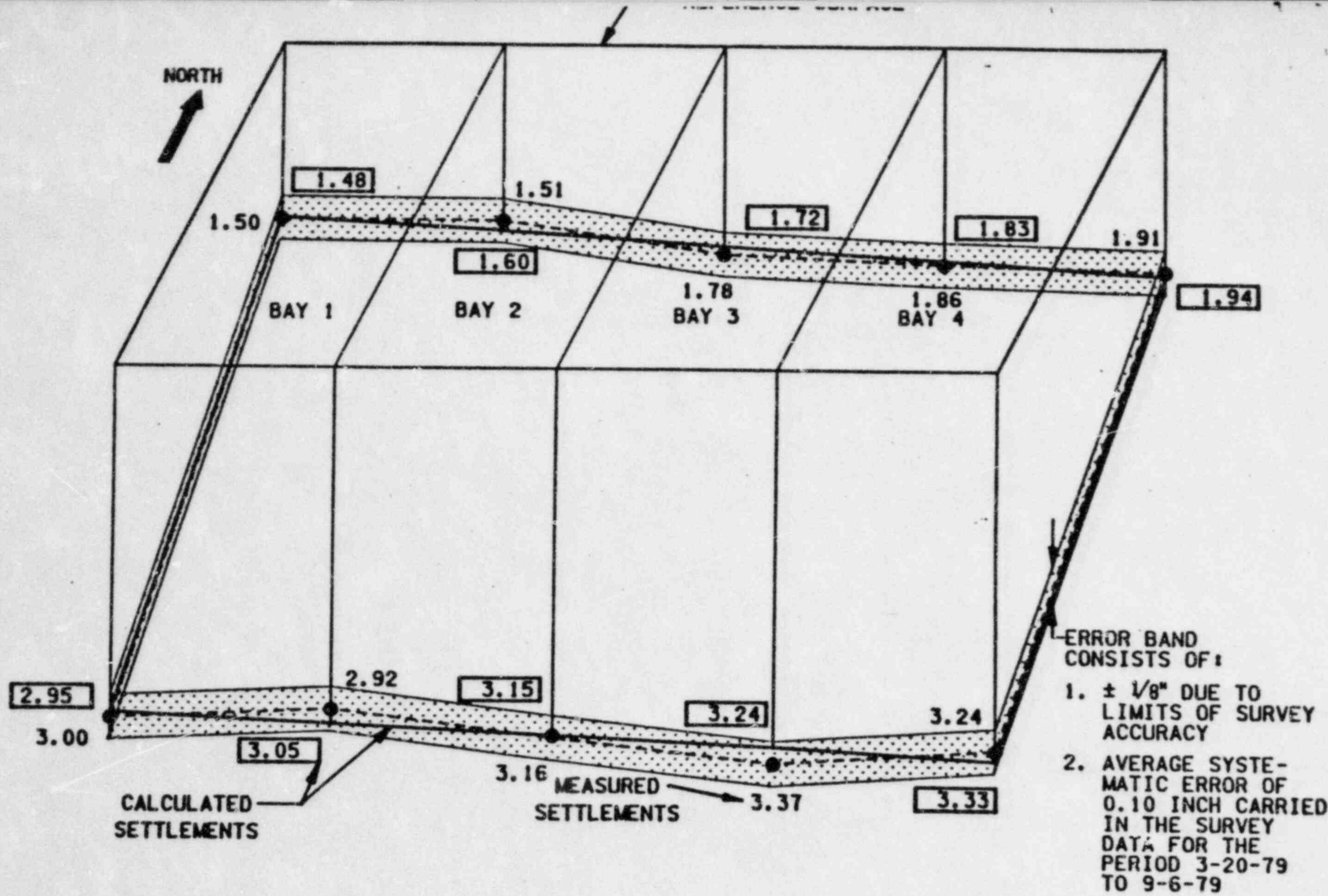
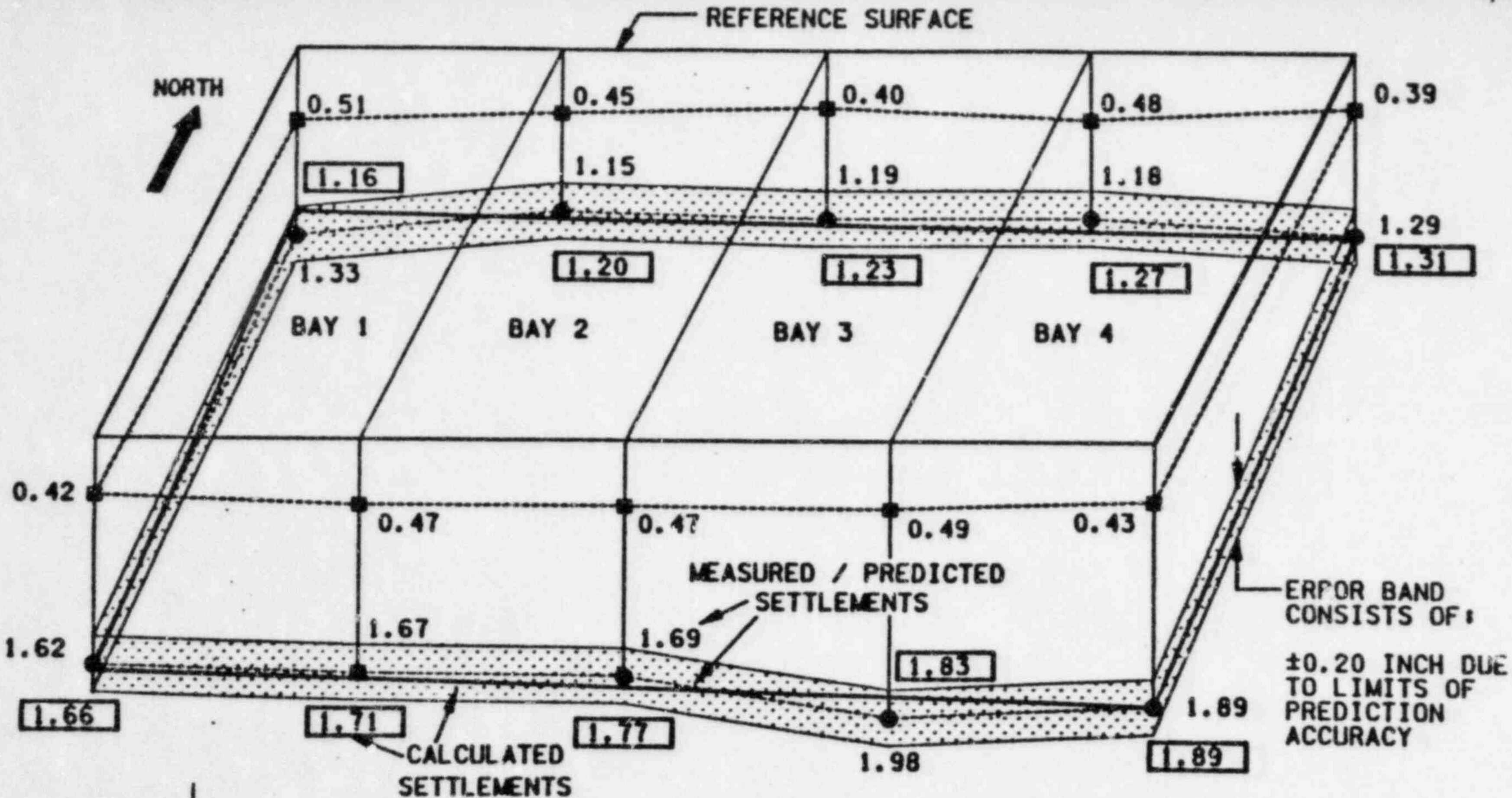


FIGURE 6

DIESEL GENERATOR BUILDING EXECUTIVE SUMMARY

COMPARISON OF SETTLEMENT VALUES
SURCHARGE PERIOD
JANUARY 1979 - AUGUST 1979

FIGURE ES-16



ACTUAL MEASURED SETTLEMENT FROM SEPT.14, 1979 TO DEC.31, 1981. THESE INCLUDE EFFECT OF DEWATERING TO APPROXIMATELY EL. 595', AND REPRESENT MOVEMENT OF THE STRUCTURE DUE TO SETTLEMENT OF THE FILL AND NATURAL SOIL BELOW.

ACTUAL MEASURED SETTLEMENTS FROM SEPT.14, 1979 TO DEC.31, 1981 PLUS ESTIMATED SECONDARY COMPRESSION SETTLEMENT FROM DEC.31, 1981 TO DEC.31, 2025 ASSUMING SURCHARGE REMAINS IN PLACE.

FIGURE 7

DIESEL GENERATOR BUILDING
EXECUTIVE SUMMARY

COMPARISON OF SETTLEMENT VALUES
POST-SURCHARGE PERIOD
SEPTEMBER 1979 - DECEMBER 2025

FIGURE ES-17

APPENDIX I

COMPOSITION OF TASK GROUP

NRC Staff: Task Group Leader	Dr. Pao-Tsin Kuo, Section Leader Structural Engineering Section B Structural and Geotechnical Engineering Branch
	Dr. Chen P.Tan, Structural Engineer Structural Engineering Section B Structural and Geotechnical Engineering Branch
	Mr. Norman D. Romney, Structural Engineer Structural Engineering Section B Structural and Geotechnical Engineering Branch
NRC Consultants:	Dr. A. J. Philippacopoulos, Associate Scientist Structural Analysis Division Brookhaven National Laboratory (BNL)
	Dr. Charles A. Miller, Senior Consultant Structural Analysis Division Brookhaven National Laboratory
	Dr. Carl J. Costantino, Senior Consultant Structural Analysis Division Brookhaven National Laboratory