SEAWALL INSPECTION

SAN ONOFRE NUCLEAR GENERATING STATION, UNIT 1

Prepared for:

SOUTHERN CALIFORNIA EDISON

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Impell Report No. 01-0310-1473
Revision 1

March 1986

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EXECUTIVE SUMMARY

For long term operation of SONGS Unit 1, it was required that a field inspection of the Unit 1 seawall be performed to verify the structural integrity of the sheet pile seawall. This inspection was performed during the Cycle IX outage in December 1985.

The seawall extends approximately 650 feet on the west side of SONGS Unit 1 and protects Unit 1 from flooding during a tsunami event. The seawall was constructed in 1966 and consists of steel sheet piling. Steel sheet pile shapes are rolled steel members with interlocking joints along their edges. Interlocked and driven, the steel sheet piles form a rigid, continuous structure.

The seawall was inspected by excavating at five locations (representing a five percent sample) on the plant side of the seawall. A statistical evaluation of the data indicates very good correlation and the five percent sample size was shown to be more than sufficient to make judgements regarding the entire seawall. In general, the steel sheet pile seawall was found to be in good condition. Practically all of the effects of corrosion were primarily confined in the area from grade to five or six feet below grade. Ultrasonic thickness measurements and pit depth measurements were performed on the sheet pile surfaces to evaluate its structural integrity. Accounting for the effects of corrosion, the maximum calculated stresses for the governing load cases are well below the allowable stresses.

Overall, the seawall can be expected to deteriorate at about the same rate as in the past. An evaluation of the corrosivity of the earth was conducted and it was determined that the soil adjacent to the seawall can be classified as mildly corrosive to non-corrosive.

In conclusion, it was determined that the seawall currently has the structural capacity to withstand the design loading required for its safety related function. Furthermore, the remaining design life of the seawall is expected to be at least 15 years.

PART I

STRUCTURAL EVALUATION OF OF THE SEAWALL SAN ONOFRE NUCLEAR GENERATING STATION, UNIT 1

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REPORT APPROVAL COVERSHEET

Report Title: Structural Evaluation of SONGS-1 Seawall

Report Number: 01-0310-1473 **Revision:** 1

Client: Southern California Edison **Job Number:** 0310-106-1353

Project: SONGS Unit 1 Seawall Inspection Program

RECORD OF REVISION

REVISION	DATE	PREPARED	REVEWED	APPROVED
A	1/10/86	[signature]	[signature]	
0	2/27/86	[signature]	[signature]	Hai Tung Yung
1	3/24/86	[signature]	[signature]	R. Phillips

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1.0 INTRODUCTION

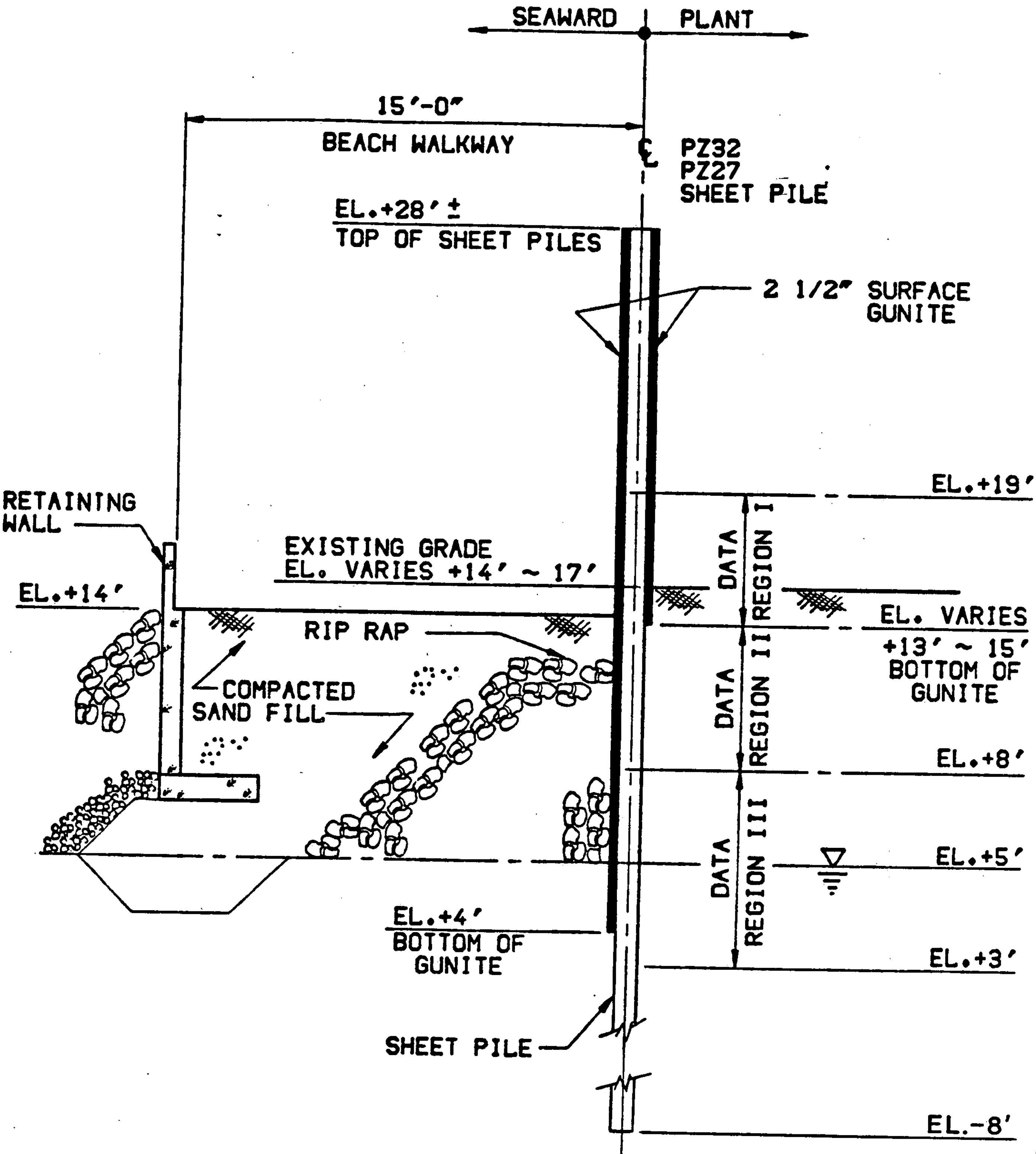
This document presents the procedures, observations and results of the inspection of the seawall protecting San Onofre Nuclear Generating Station, Unit 1. The inspection was performed during the Cycle IX outage in December, 1985 to verify the structural integrity of the Unit 1 seawall.

2.0 DESCRIPTION OF SEAWALL

The seawall extends approximately 650 feet on the west side of SONGS Unit 1 and protects Unit 1 from flooding during a Tsunami event. The seawall was constructed in 1966 and consists of steel sheet piling approximately 36 feet long with an average embedment of 22 feet. Steel sheet pile shapes are rolled steel members with interlocking joints along their edges. Interlocked and driven, the steel sheet piles form a rigid, continuous structure.

The sheet piling was installed in two phases. Phase 1 consisted of driving the sheet piles in the area of the intake structure between stations S11+85 and S12+29, and the rest of the piles along the remaining length of the wall were installed in Phase 2 (see Figure 2). The sheet piles installed in Phase 1 may have an embedment depth of 40-45 feet; however, drawings are not available to verify these dimensions. For the seawall inspection, it has been conservatively assumed that all the sheet piles have an average embedment depth of 22 feet and that the adjacent underground conditions are similar. Therefore, the stress on all of the sheet piles will be similar due to the loading conditions identified in Section 4.0.

Corrosion protection of the sheet piling consists of a coal tar epoxy coating and concrete gunite (with wire mesh) encasement. The gunite extends from the top of the seawall to ten feet below grade on the seaward side (elev + 4) and approximately one foot below grade on the plant side (elev + 13) (see Figure 1).



SECTION

TYPICAL SEAWALL

FIGURE 1

3.0 INSPECTION PROCEDURE

3.1 Objectives

- Determine the in situ steel thickness of the seawall in order to evaluate its structural capacity to withstand the design loading required for its Safety Related Function.
- Identify representative corrosion damaged areas in order to permit an overall evaluation of the sheet piles.
- Evaluate the need for repair of the seawall.

3.2 Sampling Strategy

Achievement of the above listed objectives required a significant amount of inspection. The number of inspection locations as well as the extent of testing was selected to ensure adequate inspection. The inspection locations and the surface areas of the sheet piles that were tested are listed as follows.

3.2.1 Inspection Locations

Inspection was performed at five locations along the seawall with four sheet piles being tested at each location. The five locations are shown on Figure 2. These locations were selected to provide a representative cross sampling of the seawall.

Since an evaluation of the corrosion effects on the sheet piles can be determined by performing tests from one side of the seawall, the above and below grade inspection was performed on the plant side of the seawall.

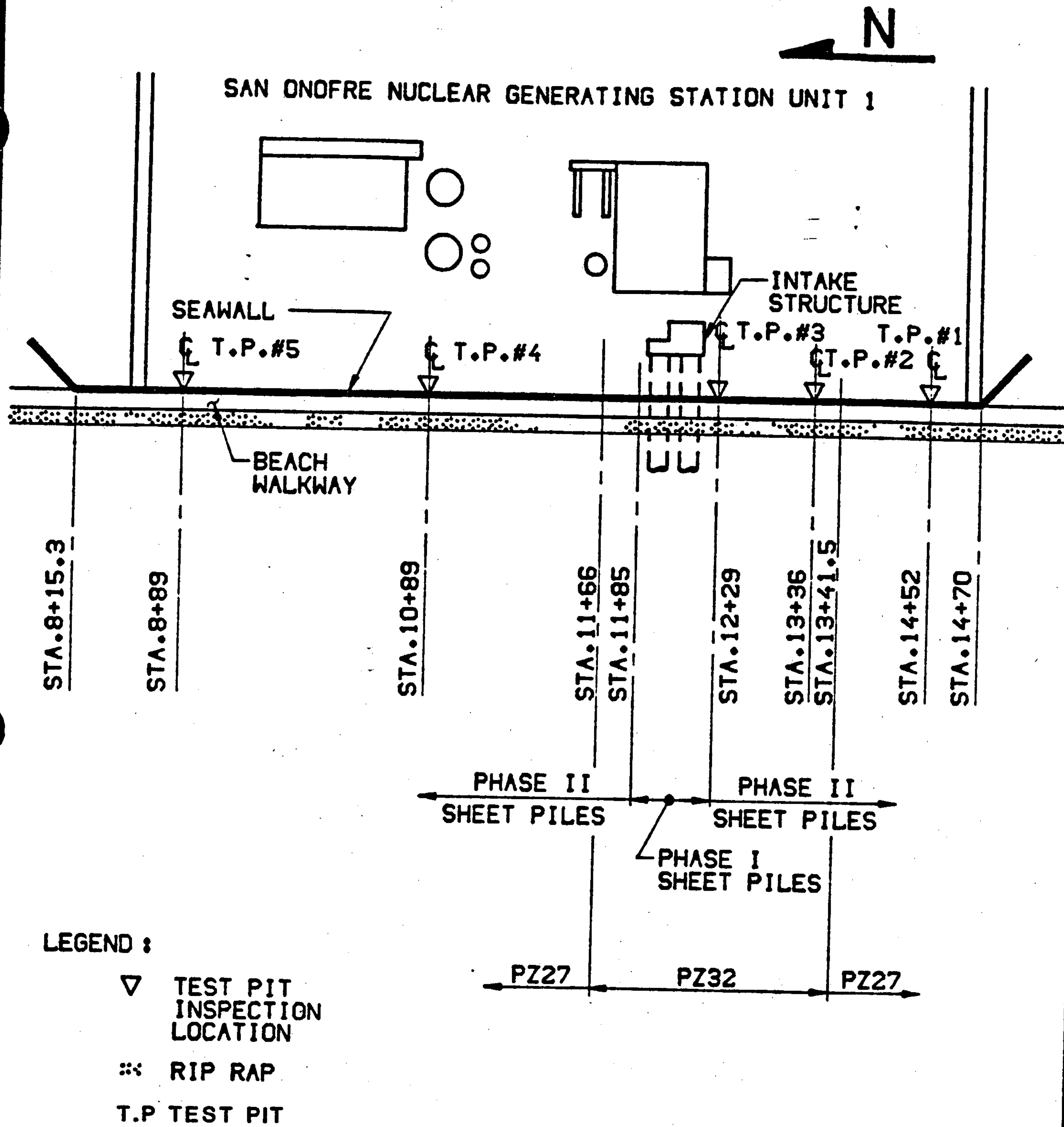
3.2.2 Depth/Height of Sheet Pile Testing and Inspection

All testing necessary to evaluate the critical areas of the sheet pile wall was performed during the cycle IX outage. Critical areas included the portion of the piles with relatively high loads and regions potentially susceptible to corrosion. To cover inspection of these critical areas, testing of the sheet piles was conducted between elevations +3 and +19. Areas considered not to be critical included those portions above or below the area of load application, low load regions or regions in low corrosion areas.

The lowest elevation for testing (+3) was selected based on the following:

1. Testing to elevation +3 covers inspection of all below grade critical areas. These critical areas include:

    a) Areas of Relatively High loads: The seawall is designed to perform during two non-concurrent load cases; tsunami and seismic loads. The moment in the sheet piles in both load cases is very low at elevation +3 and decreases with depth below that elevation.



PLAN

SEAWALL INSPECTION LOCATIONS

FIGURE 2

b) Corrosion Susceptible Areas: Research has indicated that partially encasing steel piling may induce accelerated corrosion at the interface region between the encased and unencased steel [3]. Therefore, it was essential to inspect the interface area at elevation +4 (See Figure 1).

c) Sufficient circulation of oxygen is essential for corrosion to occur. Tests have shown that because of a deficiency of oxygen, steel piling is not appreciably affected by corrosion at a level a few feet below grade or below the water table [4]. Since the availability of oxygen decreases with depth so does the effect of corrosion and, thus, the condition of the sheet piles below elevation +3 will be less critical than the condition at elevation +3 and above.

This condition was verified during the inspection. See Section 3.5.

The maximum height of testing (elevation +19) was selected based on the following:

a) Inspection to elevation +19 will provide adequate information about the surface condition of the above grade portion of the seawall. This was verified during the inspection. See Section 3.5.

b) The applied moments on the seawall above elevation +19 are very small and, therefore, it is not necessary to inspect above elevation +19.

3.3 Test Methods

To determine the condition of the seawall, the following tests were used as applicable:

3.3.1 Ultrasonic Thickness Test

This in-situ test was used to determine the remaining steel thickness of the sheet piles.

3.3.2 Pit Measurements

The degree of pitting was examined by visual inspection and pit depth was measured with pit depth gauges and/or ultrasonic thickness testing equipment.

3.3.5 Sheet Pile Sampling

A total of ten coupons (8 inch diameter) were removed from the below grade portion of the steel sheet piles for laboratory testing. Results of laboratory testing are discussed in Section 3.0 of Part II of this report.

3.4 Data Collection

Inspection of the seawall consisted of an extensive amount of data collection. Testing grid lines were laid out on the surface area of the four sheet piles at each inspection location. The horizontal grid lines were placed at one foot intervals between elevations +3 and +19 and the vertical grid lines were defined as the flange-web junctions and the interlocks of the sheet piles. See Figure 3 for example of grid lay - out. Visual inspection of each grid was performed by a SCE corrosion engineer and the pile surfaces were carefully photographed. Within each grid, an average of five ultrasonic thickness measurements were recorded. All pits with diameters greater than 3/8 inch were "mapped" and the maximum depth of the pits was measured by ultrasonic thickness equipment or pit depth gauges. See figure 4 for sample data sheet. All ultrasonic thickness and pit depth measurements were conducted by American Society of Non-Destructive Testing-TC-1A or American National Standards Institute-45-2-6 qualified SCE technicians. See Reference [12] for Inspection data and photographs.

3.5 Field Observations

The following observations were made during the inspection:

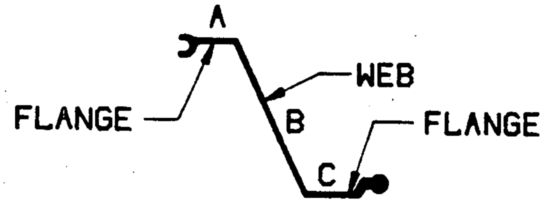
- The sheet pile surfaces protected by gunite were in extremely good condition and relatively little pitting had occurred.

- As expected, the portions of the sheet piling in the area a few feet below the gunite cover (on the plant side) displayed the most corrosion. This corrosion was primarily caused by localized areas of corrosion "pits". These pits were generally of small size (perimeter) but in some cases penetrated through the steel sheet piles.

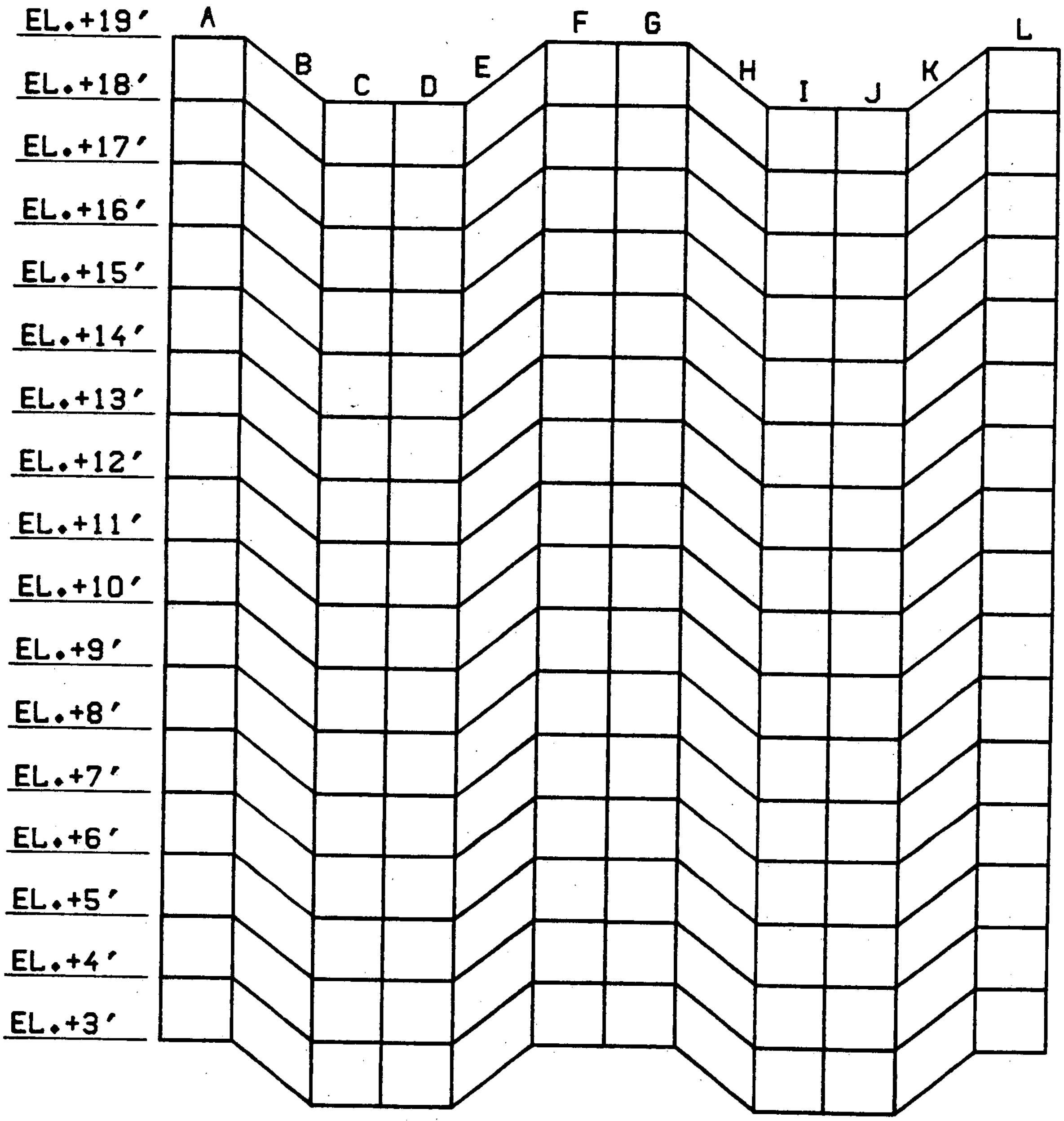
- The effects of pitting and uniform corrosion decreased with depth below the bottom of the gunite cover. Relatively little pitting occurred below elevation +8.

- The below grade gunite cover on the seaward side of the seawall was still adhering to the wall and the steel surface was in excellent condition.

- It was observed that the seawall between stations S11+66 and S13+41.5 was constructed with PZ32 sheet piling instead of the PZ27 section shown on the design drawings (see Figure 2). This sheet pile section has higher section properties (about 27% stronger) than the specified sheet pile section (PZ27). See Appendix A for comparison of section properties.



TYPICAL CROSS SECTION OF SHEET PILE
(PZ27 OR PZ32)



SAMPLE OF SHEET PILE GRID LAYOUT
FIGURE 3

SCE Southern California Edison

NDEP REPORT # 1UT-021-85

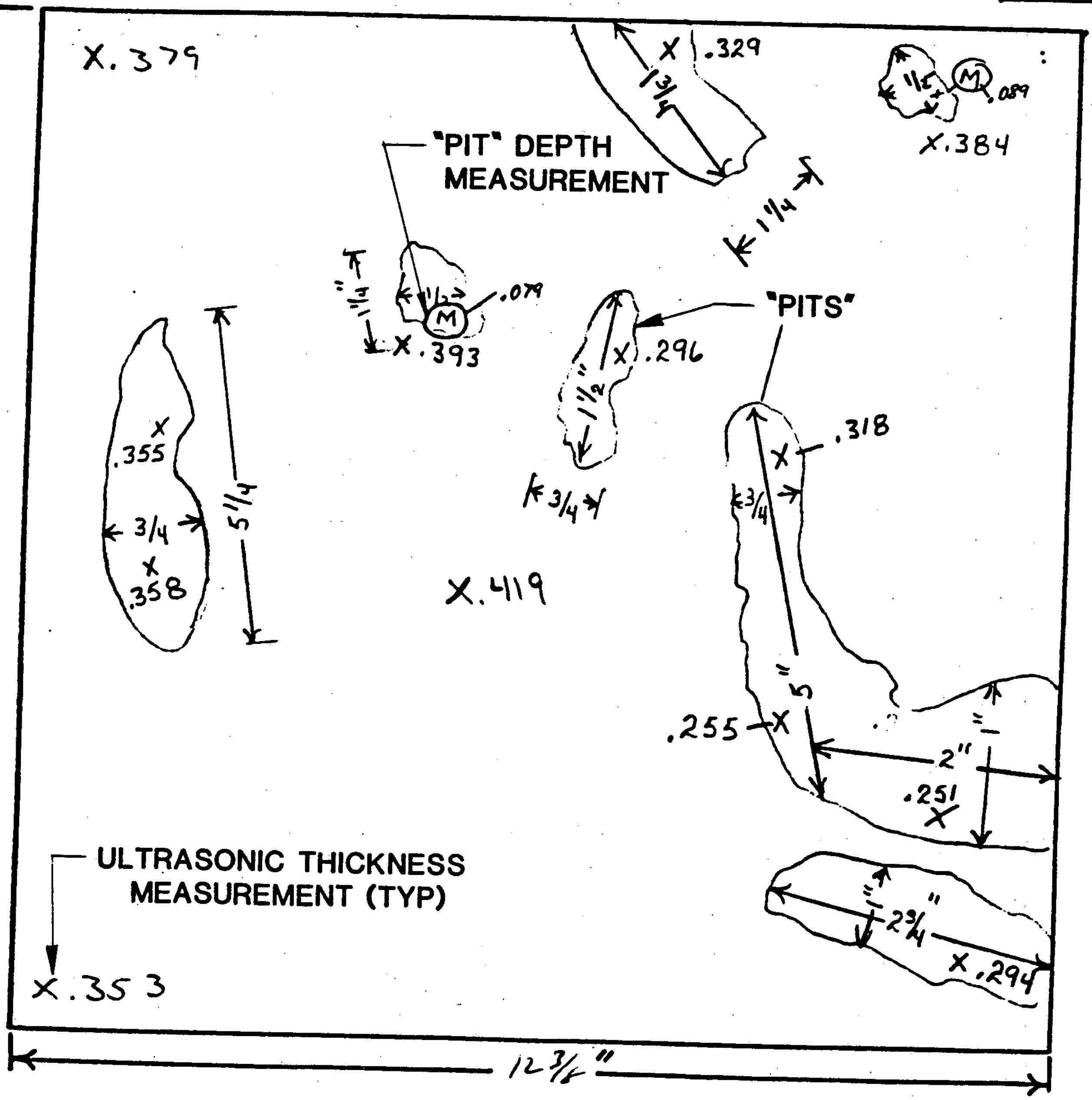
PG 112 OF 200

HOLE # 4

PANEL #

4 - 11 - H

ELV. 11



ELV. 10

UNIT 1 SEAWALL INSPECTION

INSPECTOR: MIS II

DATE: 12-5-85

FIGURE 4 - SAMPLE DATA SHEET

4.0 GENERAL DESIGN CRITERIA

4.1 Nature of Loading

4.1.1 Tsunami Loads

The main purpose of the seawall is to protect Unit 1 from flooding during a tsunami event. The tsunami loads include the hydrostatic and hydrodynamic effects of the tsunami [2].

4.1.2 Seismic Loads

The seawall is designed to withstand a Design Basis Earthquake (DBE) with a horizontal ground acceleration of 0.67g.

4.2 Load Combinations

The seismic and tsunami loads are considered to be sequential, non-simultaneous events with respect to their stress inducing effects on the seawall.

4.3 Method of Structural Analysis

Both the seismic and tsunami forces have been treated as equivalent static loads for the purpose of structural analysis. This is consistent with the original design methods.

4.4 Allowable Stresses

The allowable stresses for the ASTM A328 Sheet Piling (PZ27 and PZ32) are as follows:

- DBE and Tsunami Allowable Bending Stress, F_b = 1.6x25 ksi = 40 ksi[9]
- Yield Stress, Fy = 42 ksi[10]

5.0 STRUCTURAL ANALYSIS OF SEAWALL

5.1 Objectives

The main objective of the structural analysis was to determine the actual stresses in the seawall at the inspection locations defined in Section 3.2.1, accounting for the reduced strength of the wall due to corrosion effects.

5.2 Analysis Assumptions and Procedures

5.2.1 General

The section properties of the sheet pile seawall were calculated with the design assumptions and procedures appropriate for each of the three

"Regions". The definitions of the Regions are addressed in Section 6.3 and shown on Figure 1. The following comments apply to all of the structural analyses in the three regions.

- The structural loads used to determine the maximum stresses correspond to the load cases defined in Section 4.0.
- The sheet pile sections were assumed to have the dimensions (excluding steel thickness) as specified in the manufacturers catalog.
- The maximum sheet pile stress was calculated at each elevation for each sheet pile shape (PZ27 and PZ32).

5.2.2 Regions I and III

The corrosion effects in Regions I and III are relatively free of any pitting damage and, therefore, the reduction of sheet pile section modulus due to pitting is negligible. For the purpose of calculating section modulus, it was conservatively assumed that the average steel thicknesses of the inspection "grids" were the ultrasonic thickness measurements of nominal steel thickness.

5.2.3 Region II

The corrosion effects in Region II are different than in Regions I and III because of the occurrence of pitting and, as a result, the actual section modulus was calculated in a manner to account for the effects of pitting.

5.3 Results

The maximum calculated stresses at the inspection locations of the seawall are shown in Table 1. As indicated, all of the maximum stresses are well below the 40 ksi allowable stress.

Table 1

Maximum Calculated Stresses

Region	Elev. (ft)	Max Stress (ksi) PZ27 (Location)	Max Stress (ksi) PZ32 (Location)
	19-18	2.6(4-19-JKL)	2.6(3-19-JKL)
I	18-17	2.6(1-19-GHI)	2.6(3-18-JKL)
	17-16	3.3(4-17-JKL)	2.9(3-17-GHI)
	16-15	4.2(4-16-JKL)	4.0(3-16-ABC)
	15-14	5.2(4-15-JKL)	5.0(2-15-ABC)
	14-13	7.2(1-14-JKL)	4.4(2-14-GHI)
	13-12	8.1(1-13-GHI)	11.4(2-13-JKL)
II	12-11	11.3(1-12-JKL)	9.7(3-12-DEF)
	11-10	12.9(4-11-GHI)	9.8(3-11-DEF)
	10-9	12.4(4-10-JKL)	*10.6(3-10-JKL)
	9-8	13.0(4-9-DEF)	12.2(2-9-ABC)
	8-7	9.9(4-8-JKL)	8.2(2-8-ABC)
	7-6	8.8(5-7-DEF)	7.6(3-7-ABC)
III	6-5	7.2(1-6-DEF)	7.6(3-6-ABC)
	5-4	5.5(4-5-ABC)	4.1(2-5-JKL)
	4-3	3.4(5-4-DEF)	2.7(2-4-ABC)

*A stress of 20.0 ksi was calculated at this elevation at location 3-10-DEF. However, this higher stress was caused by a corroded hole adjacent to a sheet pile weld splice and is considered not to be representative of the corrosion effects on a typical sheet pile surface.

6.0 STATISTICAL ANALYSIS OF SEAWALL

6.1 Extreme Value Statistical Method

The present state of technology offers no practical way of determining the effects of corrosion on the embedded portions of the seawall other than direct physical examination of the steel surface. Because a complete inspection would require an impractical amount of excavation, statistical techniques can be used to predict the effects of corrosion for the entire seawall with the excavation and examination of a representative sample of the seawall. Extreme value statistics is the statistical method that was used for the prediction of the magnitude of corrosion areas that will be encountered on the seawall with the inspection of only a very small portion of the seawall structure [5, 6, 7, 8].

For the seawall inspection, a sampling size of five percent was used to evaluate the entire seawall. This sample size is much larger than the minimum size requirement for the extreme value method (one percent sampling) [5, 6].

6.2 Objective of Statistical Analysis

The objective of using the extreme value statistical method is to verify that the data correlates as defined by the extreme value statistical method and, as a result, the entire seawall can be accurately evaluated by the inspection of a five percent sampling of the seawall.

6.3 Evaluation Regions

In order to effectively apply the extreme value method it is necessary to evaluate the seawall in the regions where there is a statistical relation between data over the entire length of the seawall. Selection of these regions was based upon separating the different adjacent sheet pile surface conditions (i.e., gunite vs. non-gunite covered steel) and identifying the areas with relatively large amounts of corrosion. Based on these factors, the seawall can be statistically evaluated by dividing the sheet piles into three regions. These regions are identified as follows: (see Figure 1)

- Region I: This region covers the portion of the sheet piling that has a gunite cover on both sides of the steel. This extends between the top elevation of testing (elevation +19) to the bottom of the gunite cover (approximately elevation +13). Generally speaking, most of this region is above grade.

- Region II: This region extends between the bottom level of gunite on the plant side (elevation varies) to elevation +8 and has been identified as the area having relatively large amounts of corrosion.

- Region III: This region covers the lowest portion of the inspection area of the sheet piles and extends between elevation +8 and +3.

6.4 Results of Statistical Analysis

6.4.1 General

A number of statistical analyses were performed for all three regions. The data was analyzed and plotted in ascending order on extreme value graph paper and the "Best Fit" line or "line of expected extremes" was plotted for each statistical run. An example of the extreme value graphs are shown on Figures 5, 6, and 7. These graphs represent the statistical analyses performed for the PZ27 sheet piles. The analyses for the PZ32 sheet piles are included in the calculations [11] but are not shown in this report.

The closeness of fit of the line to the data points is an indication of the degree to which the values agree with the theoretical extreme value distribution. This agreement has been evaluated by the construction of "Confidence Bands". These curves are those on each side of the line of expected extremes as shown on Figure 5. The separation of the curves depends on the scatter and number of pieces of data. The plotted data acceptably agrees with the extreme probability theory if 2/3 of the plotted points fall within the "Confidence Bands" [5].

The following comments apply to all of the statistical analyses in the three regions.

- As mentioned previously, inspection of the seawall indicated the use of different sizes of sheet piling; PZ27 and PZ32. Since the size and steel thicknesses of the two different sheet piling shapes are not the same, the different sheet pile shapes were evaluated separately.

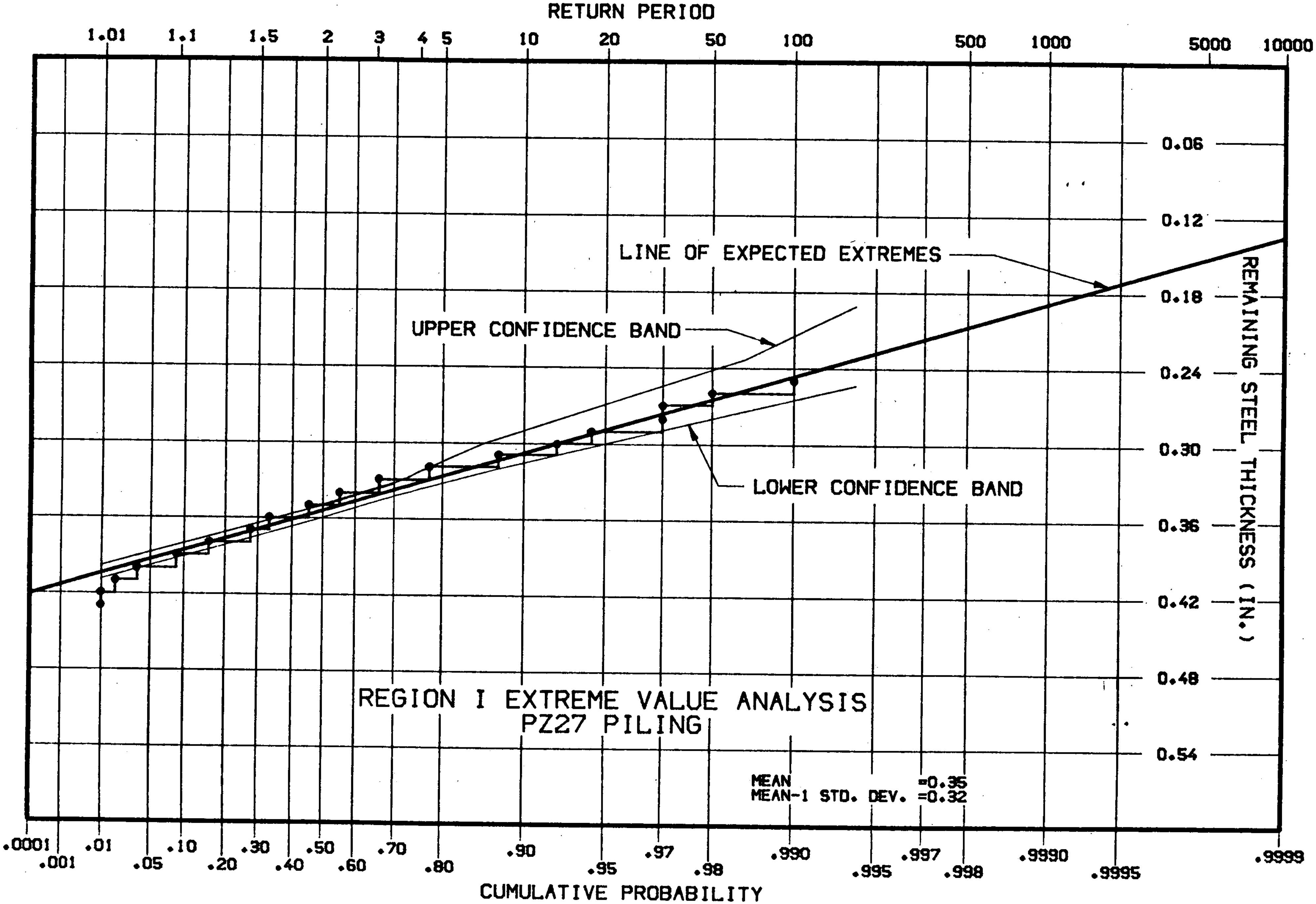


FIGURE 5 - EXTREME VALUE GRAPH

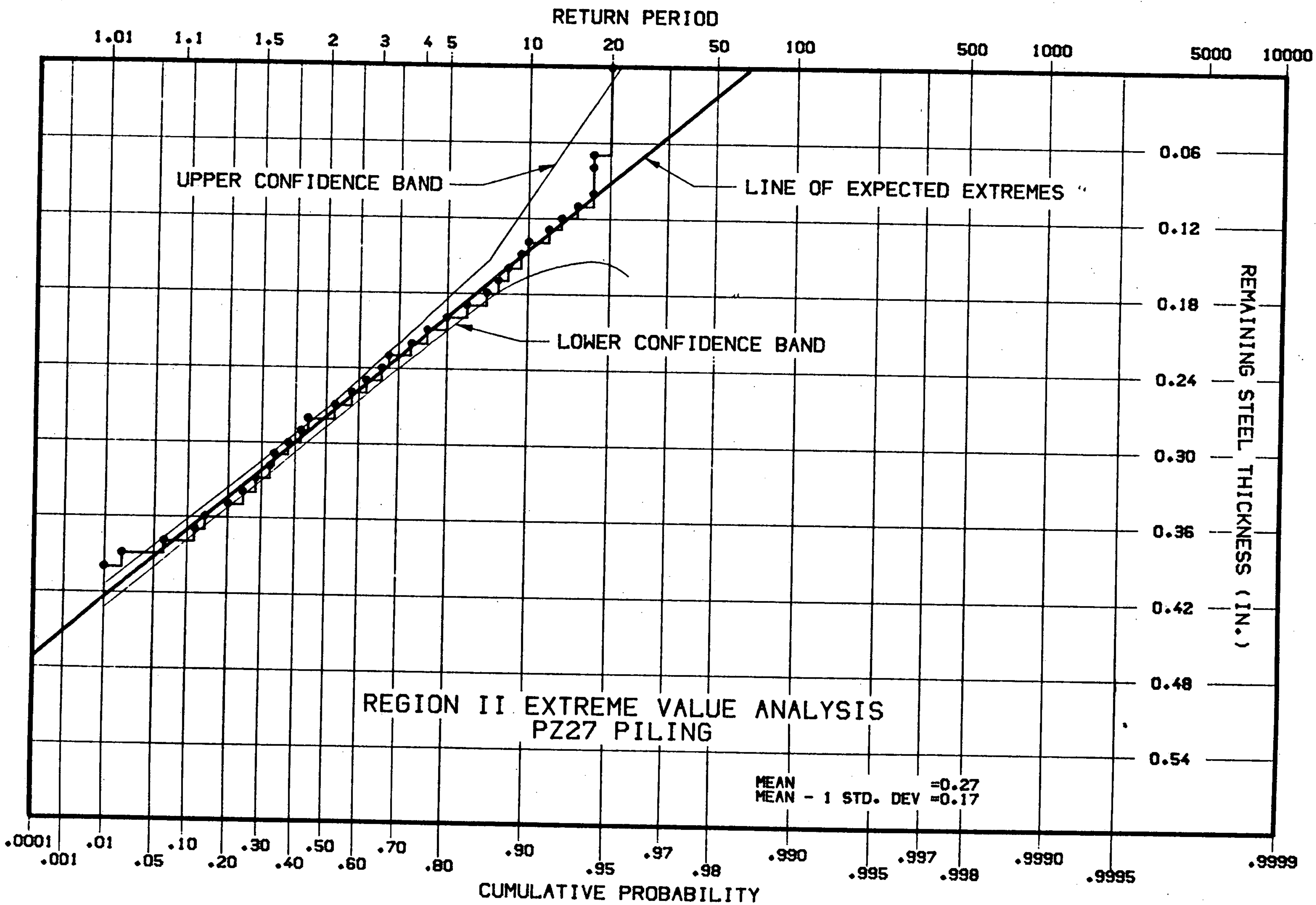


FIGURE 6 - EXTREME VALUE GRAPH

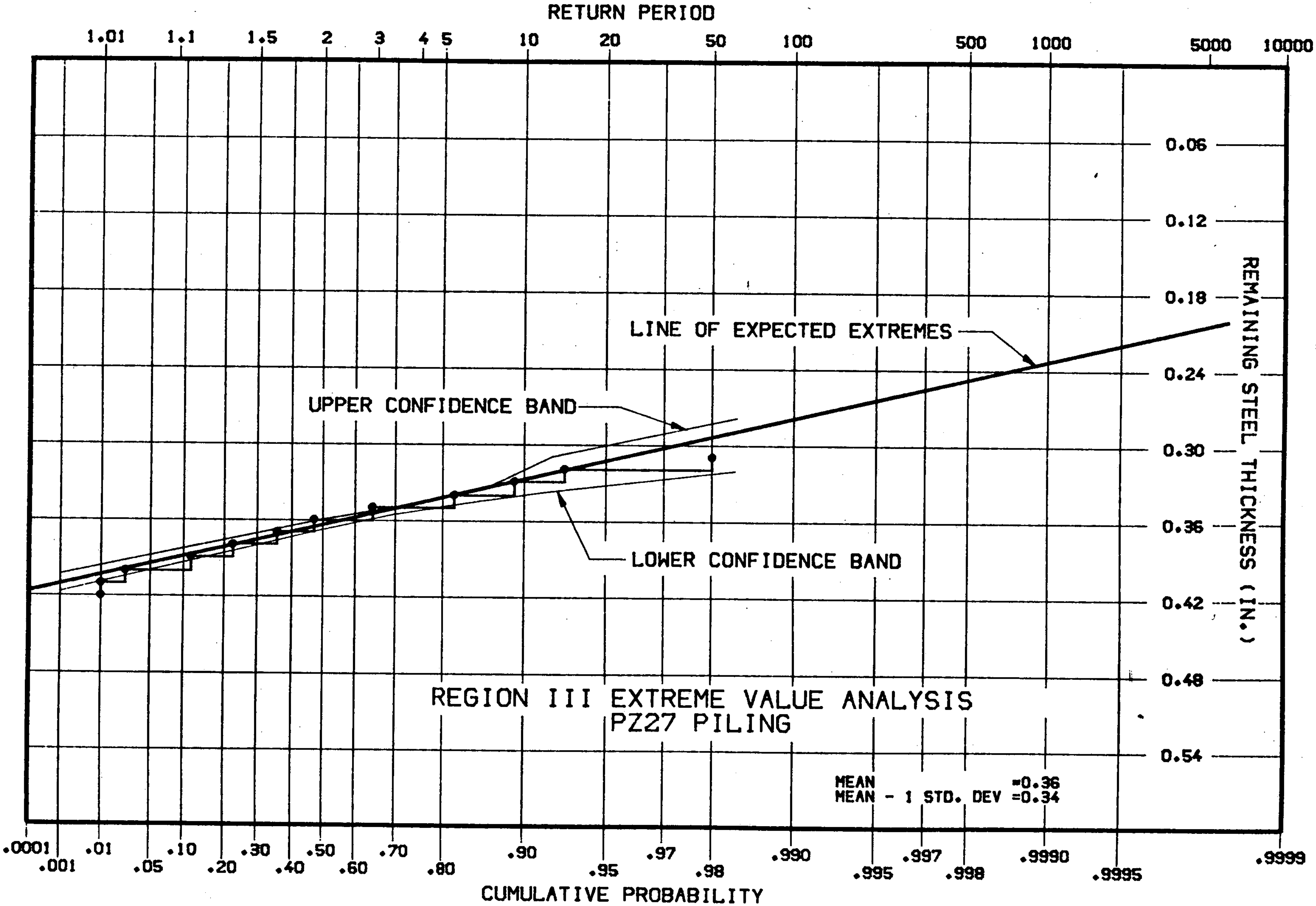


FIGURE 7 - EXTREME VALUE GRAPH

- The statistical units used for all of the analyses were the grids as identified in Section 3.4.
- The structural loads used to determine the maximum stresses correspond to the load cases defined in Section 4.0.

6.4.2 Region I Results

The corrosion effects in Region I were relatively free of any pitting damage. Therefore, the extreme values evaluated in each of the inspection grids were the ultrasonic thickness measurements of the steel thickness. These extreme values were statistically analyzed as discussed above and the results for the PZ27 piles are shown on Figure 5. The mean value for this Region is 0.35 inches. The mean minus one standard deviation is 0.32 inches.

6.4.3 Region II Results

The corrosion effects in Region II is different than in Regions I and III because of the large occurrence of pitting. It is important to evaluate the effects of pitting since pitting can reduce the strength of the sheet piles. Thus, the extreme values evaluated in each of the inspection grids were the lesser of either the nominal steel thickness measurements or the minimum steel thickness measured in any pit. The results of the statistical analysis for Region II are shown on Figure 6. The mean value for this Region is 0.27 inches. The mean minus one standard deviation is 0.17 inches.

6.4.4 Region III Results

The data in Region III was analyzed in the same manner as in Region I. See Section 6.4.2. See Figure 7 for sample of extreme value graph for Region III. The mean value for this Region is 0.36 inches. The mean minus one standard deviation is 0.34 inches.

6.5 Conclusion

In each of the statistical analyses of the seawall, most of the plotted points fell within the control curves and, therefore, the data agrees with extreme probability theory. This shows that if the remainder of the seawall were examined, the corrosion characteristics can be expected to be highly similar to those identified in the sample pits. This indicates that the seawall can be adequately analyzed with the amount of inspection data obtained.

7.0 ESTIMATION OF REMAINING DESIGN LIFE

Analysis has shown that the Unit 1 seawall will be able to perform as designed, without any repair, for a period of at least 15 years. This analysis was based on the following assumptions.

- The design life estimation was conservatively calculated by using the maximum moment applied at the average of the critical section moduli in Region II (critical region).
- Conservatively, the corrosion rate of the seawall was assumed to continue at the rate it has in the past. (See Part II, Seawall Corrosion Survey, conclusion No. 7). This rate was calculated by assuming a straight line corrosion rate over a period of 20 years.
- The original steel thickness of the sheet piles was originally ten percent thicker than the nominal thickness specified for the PZ27 and PZ32 sheet pile shapes.
- The critical section can develop a stress of 40 ksi.

8.0 SUMMARY AND RECOMMENDATIONS

8.1 Summary of Conclusions

The following conclusions can be made from the results of the inspection.

- The effects of corrosion decrease with depth; therefore, inspection of the seawall to elevation +3 was adequate.
- The structural integrity of the entire seawall can be determined by the inspection of a 5 percent sample.
- The seawall currently has the structural capacity to withstand the design loading required for its safety related function and has a remaining design life of at least 15 years.

8.2 Recommendations

It is recommended that another inspection of the Unit 1 seawall be performed in 15 years to re-evaluate its structural integrity.

9.0 REFERENCES

[1] Letter from D. G. Eisenhut (NRC) to K. P. Baskin (SCE) Regarding "Contingent Rescission of Suspension," and Supporting Safety Evaluation Report, dated November 21, 1984.

[2] "Work Package Design Criteria, Seawall Inspection, SONGS Unit 1," Southern California Edison document Number M-86141, Revision 0 dated November 1, 1985.

[3] "Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments," A.I.S.I., 1981.

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[5] Steinert, W. W., "Use of Extreme Value Statistical Theory in the Evaluation of Corrosion Problems," prepared for presentation at the N.A.C.E. Northeast Regional Meeting, Hartford, Connecticut, 1975.

[6] Wagner, J., "Statistical Analysis of Pipeline Corrosion, "Appalachian Underground Corrosion Short Course, 1977.

[7] Gumbel, E. J., "Statistics of Extremes," Columbia University Press, N.Y., 1958.

[8] Gumbel, E. J., "Statistical Theory of Extreme Values and Some Practical Applications," U. S. Department of Commerce, National Bureau of Standards Applied Mathematics Series 33 Issued February 12, 1954.

[9] "SONGS 1 Seawall Seismic Study Calculations," Southern California Edison Calculation Number DC-1650.

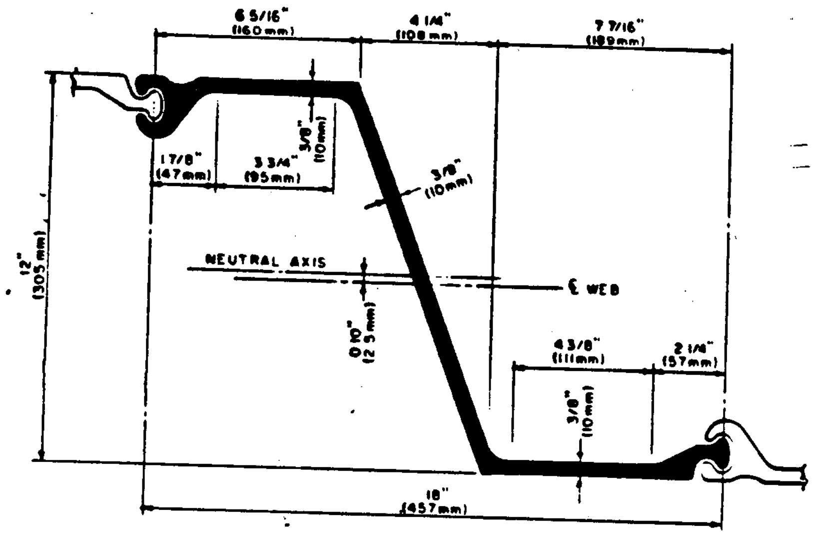
[10] "Steel Sheet Piling Handbook," United States Steel, 1983.

[11] "Seawall Evaluation Calculations," Southern California Edison Calculation Number DC-2288.

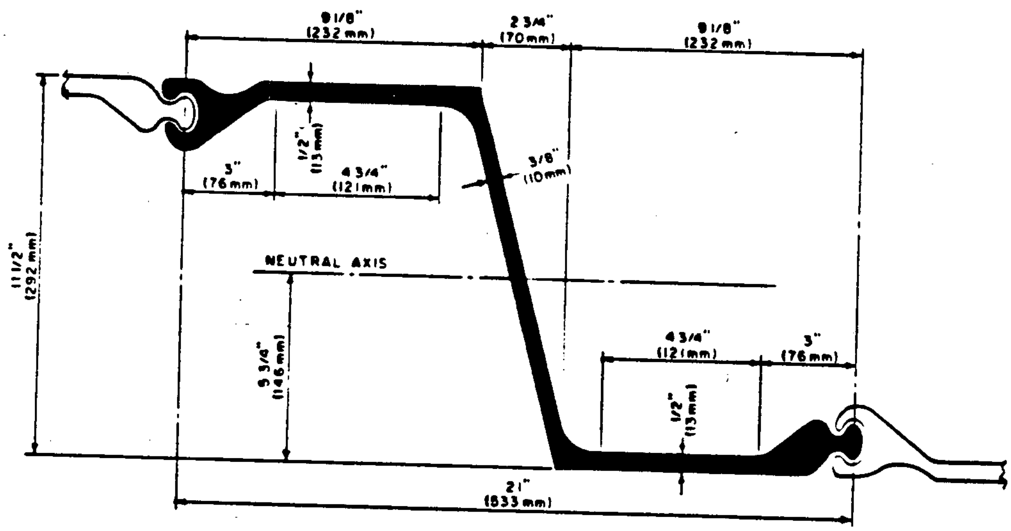
[12] "3366-OPC Seawall Examination Data," Southern California Edison.

APPENDIX A

Details and Properties/Z Piling



PZ32



SHAPE	NOMINAL DRIVING DISTANCE PER PILE	THICKNESS		WEIGHT		SECTION MODULUS		AREA	MOMENT OF INERTIA PER PILE
		WEB	FLANGE	Per Lineal Foot of Pile	Per Square Foot of Wall	Per Pile	Per Foot of Wall		
	INCHES	INCHES	INCHES	POUNDS	POUNDS	$INCHES^3$	$INCHES^3$	$INCHES^2$	$INCHES^4$
PZ27	18	3/8	3/8	40.5	27.0	45.3	30.2	11.9	276
PZ32	21	3/8	1/2	56.0	32.0	67.0	38.3	16.5	386

PART II

SONGS UNIT 1 SEAWALL

CORROSION SURVEY

SOUTHERN CALIFORNIA EDISON

PART II
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SONGS UNIT 1 SEA WALL

CORROSION SURVEY

1.0 SCOPE

In December 1985 SCE performed an evaluation of the San Onofre Nuclear Generating Station Unit 1 sea wall. This involved an inspection of the sea wall piling, as exposed in five test pits, an evaluation of corrosivity of the earth in the area of the wall, and a metallurgical evaluation of the carbon steel sea wall piling. This part of the report discusses the above and provides the conclusions resulting from the evaluations of the San Onofre Nuclear Generating Station Unit 1 sea wall.

2.0 SOIL ANALYSES

Soil samples were collected from each test pit as delineated in Table 1. The resistivity and pH of all soil samples were measured in a laboratory. Chemical analyses of the soil were performed on selected samples to determine carbonates, bicarbonates, chlorides, sulfates, iron, copper, calcium, magnesium and sodium concentrations in accordance with applicable ASTM Standards.

The electrical resistivities were measured in an agra soil resistivity box using a Nilsson Model 400 soil resistivity meter. The chemical analyses were made on a 5-to-1 water soil extract. Test results are summarized on the attached Table 2 converted to milligrams per kilogram of dry soil. The saturated electrical resistivities are considered high, indicating clean sand.

Sample C Elevation 5 ft. Pit No. 3, and Sample C Elevation 4 ft. Pit No. 1 taken near the wall on the plant side can be considered corrosive or moderately corrosive. These samples were taken at an elevation that is normally below the water table which would greatly restrict the availability of oxygen and thereby limit the progress of any corrosion reaction. Sample C, Elevation 11 ft. 6 in. Pit No. 4, which is corrosive, was removed from the sea side of the wall in an area where the wall is protected by a heavy cover of gunite.

In the area of the wall displaying the greatest corrosion (Grade to + 8 ft.) only one sample is considered to be moderately corrosive (test pit 3 sample D). All others are classed as mildly corrosive.

In general, the soil samples extracted from the area of the SONGS Unit 1 sea wall are basically clean sands low in chemical content rated for the most part as mildly corrosive to non-corrosive to steel.

3.0 METALLURGICAL EVALUATION

The sea wall at San Onofre Unit 1 is constructed from sheet piling conforming to ASTM Standard A328, Steel Sheet Piling.

ASTM Standard A328 covers carbon steel sheet piling of structural quality for use in the construction of dock walls, sea walls, coffer-dams, excavations and like applications.

A total of ten coupon samples were extracted from the steel wall. These samples were numbered based on their test pit and field location. Five coupons displaying the most severe corrosion were submitted to a laboratory for test. These coupon samples designated as TP1-E13, TP2-H13, TP3-E12, TP4-E10.5, and TP5-E12.5 were extracted as shown in Table 3.

In the laboratory the coupons were cleaned of corrosion deposits, sectioned into one inch wide strips and transverse thickness measurements carried out. The maximum depth of any localized corrosion was measured.

Table 4 documents the nominal thickness of each coupon, the nominal corrosion rate, and the average localized corrosion rate.

The nominal corrosion rates of coupons TPI-E13, TP4-E10.5, and TP5-E12.5 were not calculated since the average measured thickness of the coupon was about 0.38" (after cleaning and stripping off the corrosion products), which is equal to or larger than the reported original nominal thickness of 0.375".

The steel used for the sheet pile is a low carbon structural steel with the mechanical properties as tabulated in Table 5.

The tensile tests were performed on the flat tensile specimens machined from each coupon. The mechanical properties demonstrate acceptable strength and ductility.

4.0 CATHODIC PROTECTION SYSTEM PERFORMANCE

In order to determine the level of cathodic protection provided to the wall by the existing station cathodic protection system, potentials were recorded in each test pit first with the system energized, then with the system cycling at one minute intervals. The rectifier systems were turned on for 39 seconds and then off for 21 seconds. The output of all rectifiers was also recorded and the individual outputs are tabulated in Table 6. The total system output at the time of the test was 1022 amperes.

Potentials measured in the test pits are tabulated in Table 7. The "off potentials" (polarized potentials) of Table 8 are in most cases less than 850 MV relative to a copper-copper sulphate reference cell. The measurements generally indicate that the wall in most areas is receiving some degree of protection. An anomaly exists in test pit No. 2 and is discussed in Section 6.0, Assessment for Future Deterioration.

5.0 CORROSION

A visual inspection of the steel piling surface exposed in the five test pits indicates that the most corrosion occurs from about elevation + 13 ft. or + 15 ft. to elevation + 8 ft. (Region II). From elevation + 8 ft.to elevation + 3 ft., only minor corrosion is observed.

Most corrosion occurred in Test Pit Nos. 1, 2, and 3. The atmospheric portion of the wall and the sea side buried portion are in good condition with only minor indication of corrosion. The plant side piling exposed in Test Pit No. 5 is in extremely good condition, while the surfaces of the piling exposed in Test Pit 4 display minor corrosion.

Among the factors that govern the corrosion rate of the sheet piling that make up the sea wall are the 1) corrosivity of the environment, and 2) presence of coupled dissimilar metals.

Generally, the portion of the sea wall coated with gunite is provided with an environment that does not support corrosion. However, the plant side of the wall that is underground, which is coated with coal tar, is exposed to a soil environment at defects in the coating.

Since the soil can be classed as sand (Reference 3), it is considered porous. Asphalt paving and soil compaction in the area tends to limit the availability of oxygen on the plant side of the wall to some extent. The products of corrosion formed in this soil are somewhat porous and tend to diffuse into the soil.

The corrosion of the sea wall is the result of two corrosion cells. The two cells are described as follows:

A. Within five feet of the wall buried about a foot in the earth is a bare copper cable which is a portion of the station ground grid. The sea wall is electrically connected to the station ground grid for safety reasons. This action creates a bi-metallic couple and steel being the more active material corrodes with the copper ground grid serving as the cathode.

B. The top portion of the steel wall is coated with gunite causing the top portion to be cathodic with respect to the portion of wall buried in the earth. The electrolytic environment of concrete, being entirely different from that of the earth surrounding the wall, results in differences in the steel-to-environment potential. This results in the steel in earth being anodic to the steel in the concrete and the couple then causes the below grade portion of the wall to corrode.

The above corrosion cells combine to cause the steel wall to corrode primarily in the area exposed to a soil environment just below grade on the plant side. These mechanisms have operated for over twenty years and have resulted in an acceptable level of corrosion as discussed and structurally evaluated in Part 1.

6.0 ASSESSMENT FOR FUTURE DETERIORATION

The rate pits grow on a steel structure in the soil under a given set of conditions tend to follow a exponential equation, $P = kt^N$, where P = depth of deepest pit in time, t, and K as well as N are constants. The National Bureau of Standards in Circular No. 579 indicates that values of "N" for steel in well aerated soils approach 0.1 and may be 0.9 for poorly aerated soils. Values of "N" on the order of .1 results in a rapid decrease in penetration rate versus time. Under these conditions, pitting attack decreases with the passage of time. On the other hand, if "N" is near 1.0 in value, the penetration rate is a constant and maintains this value over long periods.. The worst case condition for pitting attack of steel in soil then is the latter case. Consequently, we can conservatively assume that pit growth on the San Onofre sea wall will continue at the rate they have penetrated in the past, provided that the conditions that have existed in the past are not altered.

The off potentials (polarized potentials) in all test pits fail to meet the 850 MV criteria for adequate cathodic protection. The values obatained indicated that the wall is receiving some degree of protection. However, the degree of protection afforded the wall is not sufficient to arrest all corrosion. An anomaly exists in test pit No. 2 in that with the energization of the cathodic protection system, the potential of the wall shifted in the positive direction. However, retesting in test pit No. 2 three days later proved that potential shifts were in the negative direction at that time.

7.0 CONCLUSIONS

Based upon our observations and tests of the exposed sea wall piles in the five test pits, we conclude the following:

1. In general, the soil in the area of the sea wall associated with SONGS Unit 1 can be classified as mildly corrosive to non-corrosive.
2. The carbon steel piling of the SONGS Unit 1 sea wall conforms to ASTM Standard A328.
3. The observed corrosion of the sea wall is of a form of localized attack (pitting attack) and is typical for carbon steel in soil.

4. Corrosion seems to decrease in severity as one progresses from the south to the north along the wall.

5. Corrosion is primarily confined to an area from grade to elevation + 8 ft. (Region II) and is limited to the plant side of the wall. The above grade portion of the wall on the seaward side displays little evidence of corrosion except at a few localized areas where the gunite coating was damaged. The core samples (total of ten) indicate practically no attack to the below grade portion of the seaward side of the wall.

6. The corrosion on the SONGS Unit 1 sea wall can be attributed to:

   a. The corrosion cell created by the bi-metallic couple of the steel sea wall and the station ground grid.

   b. The corrosion cell caused by the passivated section of wall covered by gunite and the buried section exposed to soil.

7. The sea wall will continue to deteriorate at about the same rate as in the past.

8.0 FUTURE SURVEILLANCE OF STRUCTURE

A surveillance program will be initiated as follows:

1. A monitoring program will be established to examine the sea wall at periodic intervals to ascertain its structural integrity.

2. An annual potential survey of the wall, including assessment of corrosion rate, grounding, interference, and level of cathodic protection is to be established.

9.0 REFERENCES

1. National Association of Corrosion Engineers Standard RP-01-69, Recommended Practice Control of External Corrosion on Underground or Submerged Metallic Piping Systems

2. National Bureau of Standards Circular 579, Underground Corrosion

3. Western States Corrosion Seminar 19 Paper No. 33, What is Corrosive Soil, M. J. Schiff

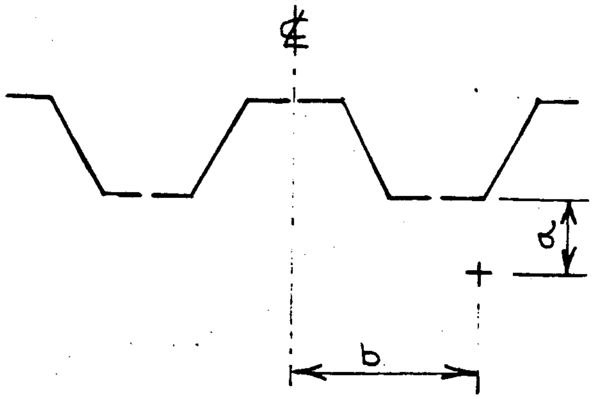
4. Corrosion and Corrosion Control (text) H. H. Uhlig, John Wiley and Sons, Inc., Second Edition

5. McKnight & Associates Report No. SCE151230 dated January 15, 1985, Determination of Sea Wall Integrity

6. M. J. Schiff & Associates, Report No. 85183, dated December 22, 1985

TABLE 1

LOCATION OF SOIL SAMPLES



Test Pit	Sample	Dimension a	Dimension b	Elevation	Remarks
#1	A	-0'- 6"	-1'-10"	13 ft.	Sea side of wall
	B	+0'- 6"	-4'- 0"	4 ft.	
	C	+0'- 6"	+4'- 0"	4 ft.	
	D	+0'- 6"	-4'- 0"	15 ft.	
	E	+0'- 6"	+4'- 0"	15 ft.	
#2	A	+0'- 6"	+5'- 0"	5 ft.	
	B	+0'- 6"	-5'- 0"	5 ft.	
	C	+1'- 0"	-5'- 0"	11 ft.	
	D	+1'- 0"	+5'- 0"	11 ft.	
#3	A	+0'- 3"	-4'- 9"	6 ft.	
	B	+1'- 0"	-4'- 9"	11 ft.	
	C	+5'- 0"	+0'- 6"	5 ft.	
	D	+1'- 4"	+2'- 8"	12 ft.	
#4	A	+0'- 6"	+4'- 4"	5'- 5"	
	B	+0'- 8"	+4'- 8"	11'- 0"	
	C	-0'- 8"	-1'-10"	11'- 6"	Sea side of wall
	D	+1'- 0"	-5'- 0"	6'- 0"	
	E	+2'- 4"	-5'- 0"	12'- 0"	
#5	A	+1'- 4"	-4'- 2"	4'- 0"	
	B	+1'- 4"	+4'- 0"	4'- 0"	
	C	+1'- 8"	-4'- 3"	14'- 0"	
	D	+1'- 8"	+4'- 0"	14'- 0"	

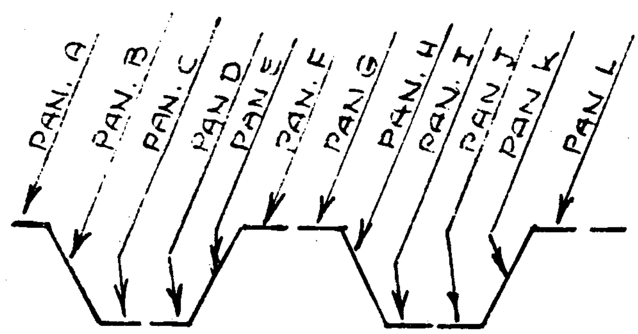
TABLE 2

SOIL ANALYSES SUMMARY

TEST PIT	SAMPLE	EC (MICRO-MHOS)	CALCIUM (mg/kg)	MAGNESIUM (mg/kg)	SODIUM (mg/kg)	CARBONATE (mg/kg)	BICARBONATE (mg/kg)	IRON (mg/kg)	COPPER (mg/kg)	CHLORIDE (mg/kg)	SULPHATE (mg/kg)	pH	RESISTIVITY (AS REC.) OHM-CM	RESISTIVITY (SAT.) OHM-CM
1	A	.07	40	TR.	46	0	122	3.3	.05	71	35	9.5	10,000+	5,700
	B											7.2	10,000+	10,000+
	C	.09	40	TR.	69	0	122	6.9	>.05	142	30	7.2	4,800	1,200
	D											8.3	10,000+	9,300
	E	.05	TR.	TR.	58	0	122	0.9	0.3	71	15	9.2	10,000+	10,000+
2	A	.03	TR.	TR.	46	0	TR.	1.3	>0.5	71	25	8.9	10,000+	10,000+
	B	.04	TR.	TR.	58	0	TR.	-	-	71	40	8.8	10,000+	10,000+
	C											8.5	10,000+	10,000+
	D											8.4	10,000+	10,000+
3	A											7.4	4,000	1,900
	B	.05	TR.	TR.	58	0	TR.	15	>.05	71	45	9.4	10,000+	5,300
	C	.48	120	TR.	402	0	244	0.8	>.05	708	120	8.1	1,100	610
	D											9.1	2,600	900
4	A	.03	TR.	TR.	46	0	TR.	0.3	>.05	71	35	8.5	10,000+	10,000+
	B	.05	TR.	TR.	46	0	122	2.8	>.05	71	25	8.4	10,000+	5,000
	C	.80	80	24	805	0	610	1.5	.06	1062	110	8.4	930	510
	D											8.6	10,000+	10,000+
	E											8.0	10,000+	10,000+
5	A	.04	TR.	TR.	58	0	TR.	.7	>.05	71	45	8.0	10,000+	9,800
	B											8.2	10,000+	10,000+
	C	.09	40	TR.	58	0	122	9.9	>.05	142	20	10.1	10,000+	9,800
	D											8.0	10,000+	9,100

TABLE 3

LOCATION OF SPECIMENS
CORED FROM SEA WALL



PLAN VIEW OF SEA WALL

TEST PIT	SPECIMEN	PANEL	ELEVATION	REMARKS
1	TP1-E13	E	13 FT	TESTED IN LAB
1	TP1-H5	H	5 FT	
2	TP2-H13	H	13 FT	TESTED IN LAB
2	TP2-E9	E	9 FT	
3	TP3-E12	E	12 FT	TESTED IN LAB
3	TP3-H5	H	5 FT	
4	TP4-E10.5	E	10.5 FT	TESTED IN LAB
4	TP4-H4.5	E	4.5 FT	
5	TP5-E12.5	E	12.5 FT	TESTED IN LAB
5	TP5-H3.5	H	3.5 FT	

TABLE NO. 4

CORROSION RATE OF CORED SAMPLES
REMOVED FROM SEA WALL

SAMPLE NO.	NOMINAL THICKNESS	LOCALIZED MINIMUM THICKNESS AT CORROSION PITS	AVERAGE GENERAL CORROSION RATE BASED ON NOMINAL THICKNESS	LOCALIZED CORROSION RATE BASED ON MAX. PIT DEPTH
1	0.4000"	0.2670"	-	0.0054"/year
2	0.3007"	0.0800"	0.0037"/year	0.0148"/year
3	0.3058"	0.0890"	0.00346"/year	0.0143"/year
4	0.3862"	0.2570"	-	0.0003"/year
5	0.3804"	0.3250"	-	0.0025"/year

Original nominal thickness: 0.375"

Nominal thickness was averaged over 45 measurements.

TABLE NO. 5

RESULTS OF TENSILE TESTS ON FLAT TENSILE SPECIMENS

SAMPLE NO.	YIELD STRENGTH PSI	TENSILE STRENGTH PSI	ELONGATION PERCENT	REDUCTION OF AREA PERCENT
1	51,000	78,600	23.0	42.2
2	56,300	75,100	24.0	51.7
3	62,300	80,600	22.0	45.7
4	47,900	74,900	23.0	47.3
5	50,700	74,500	27.0	45.3

TABLE 6

RECTIFIER DATA SHEET

DATE 12/05/85 TIME 8:00 a.m.-4:30 p.m. RECORDED BY, R. BUTNER

RECTIFIER	LOCAL MTR. VOLTS	LOCAL MTR. AMPS	SHUNT OHMS	MEA SHUNT mV	CALC. AMPS	MEA. VOLTS
#1 A1	24.2	15.0	.001	14.7	14.7	24.0
#1 A2	8.5	19.5	.000833	15.9	19.08	8.31
#1 A3	26.25	18.0	.001	17.2	17.2	25.7
#1 A4	8.5	29.5	.000833	23.0	27.61	8.66
#1 A5	20.7	14.6	.001	14.7	14.7	20.5
#1 A6	26.5	14.0	.001	14.0	14.0	25.8
#1 A7	21.0	13.5	.001	12.6	12.6	20.7
#1 A8	24.5	13.0	.001	12.5	12.5	24.1
#1 A9	8.75	21.9	.000833	17.6	21.13	8.26
#1 A10	8.9	21.2	.000833	17.0	20.40	8.29
#1 A11	6.75	23.0	.000833	18.3	21.97	6.40
#1 A12	7.0	23.2	.000833	18.5	22.21	6.49
#1 A13	8.4	25.8	.000833	20.8	24.97	8.15
#1 A14	8.5	19.3	.000833	15.6	18.73	8.32
SPA #1	18.0	3.2	.001	3.5	3.5	18.92
SPA #2	19.0	7.0	.001	7.0	7.0	17.90
SPH. Encl	86.0	18.0	.001	17.7	17.7	83.1
SPH. 200V	75.0	40.0	.000667	27.9	41.85	77.1
SPH. 36V	36.5	4.0	.000667	2.8	4.20	36.2
#2-3 A1	18.7	33.5	.000833	27.0	32.41	18.27
#2-3 A2	20.7	28.0	.000833	22.4	26.89	20.9
#2-3 A3	12.0	26.2	.000833	21.0	25.21	11.54
#2-3 A4	17.7	30.0	.000833	24.1	28.93	17.35
#2-3 A5	17.8	33.2	.000833	27.4	32.89	17.41
#2-3 A6	9.2	27.5	.000833	22.6	27.13	9.13
#2-3 A7	11.0	36.0	.000833	29.4	35.29	10.53
#2-3 A8	9.5	29.5	.000833	23.0	27.61	9.2
#2-3 A9	10.25	29.8	.000833	23.9	28.69	9.86
#2-3 A10	9.75	31.0	.000833	25.0	30.01	10.86
#2-3 A11	9.7	30.0	.000833	24.3	29.17	9.29
#2-3 A12	10.6	37.0	.000833	0.9	37.09	10.35
#2-3 A13	9.5	29.5	.000833	23.3	27.97	8.88
#2-3 A14	9.0	32.8	.000833	26.9	32.29	8.75
#2-3 A15	10.4	34.8	.000833	28.3	33.97	10.17
#2-3 A16	10.0	28.4	.000833	24.3	29.17	10.15
#2-3 A17	10.75	30.0	.000833	24.6	29.53	9.68
#2-3 A18	9.5	28.5	.000833	22.7	27.25	9.28
#2-3 A19	9.2	32.9	.000833	26.9	32.29	8.90
#2-3 A20	8.6	34.0	.000833	28.0	33.61	8.44
#2-3 A21	7.7	25.5	.000833	19.7	23.65	7.48
#2-3 A22	8.9	25.8	.000833	20.6	24.73	8.43
#2-3 A23	11.0	32.0	.000833	25.6	30.73	11.61

TOTAL 1022.47A

TABLE 7

ENERGIZED AND POLARIZED POTENTIAL SURVEY DATA

TEST PIT NO.	ELEVATION	PILE	ENERG. POT.*	RECTIFIER ON*	RECTIFIER OFF*	REMARKS
1	2-1/2 ft.	SOUTH	708	724	675	
		CEN SO	709	723	674	
		CEN NO	709	723	675	
		NORTH	709	724	674	
2	2-1/2 ft.	SOUTH	923	778	880	Potential shift is positive instead of negative
		CEN SO	922	784	885	
		CEN NO	921	769	872	
		NORTH	921	778	880	
3	2-1/2 ft.	SOUTH	753	712	705	
		CEN SO	752	712	705	
		CEN NO	753	713	705	
		NORTH	753	713	705	
4	2-1/2 ft.	SOUTH	781	826	695	
		CEN SO	780	826	695	
		CEN NO	780	826	695	
		NORTH	780	826	695	
5	2-1/2 ft.	SOUTH	923	974	778	
		CEN SO	923	974	778	
		CEN NO	922	973	778	
		NORTH	922	973	778	

*Potentials are in millivolts relative to a copper-copper sulphate reference electrode

TABLE 8

POTENTIAL SURVEY TEST PIT NO. 2
SUPPLEMENTAL TEST

LOCATION	ELEVATION	PILE	ENERG. POT.	RECTIFIER ON	RECTIFIER OFF	REMARKS
NORTH	11 Ft.	SOUTH	530	515	395	
		CEN SO	530	515	395	
		CEN NO	530	515	395	
		NORTH	530	515	395	
SOUTH	11 Ft.	SOUTH	555	569	425	
		CEN SO	554	569	425	
		CEN NO	554	569	425	
		NORTH	554	569	425	
NORTH	5 Ft.	SOUTH	884	877	707	
		CEN 2	884	877	707	
		CEN 3	884	877	707	
		NORTH	884	877	707	
SOUTH	5 Ft.	SOUTH	750	592	452	
		CEN 2 SO	750	592	452	
		CEN 3 SO	750	592	452	
		NORTH	750	592	452	
CENTER	2 1/2 Ft.	SOUTH	830	825	751	
		CEN 2 SO	830	825	751	
		CEN 3 NO	830	825	751	
		NORTH	830	825	751	

*Potentials are in millivolts relative to a copper-copper sulphate reference electrode.