UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

SOUTHERN CALIFORNIA EDISION COMPANY

SAN ONOFRE NUCLEAR GENERATING STATION UNIT NO. 1

DOCKET NO. 50-206

INTAKE STRUCTURE

1.0 INTRODUCTION AND BACKGROUND

The San Onofre Unit 1 (SONGS-1) intake structure is a large reinforced concrete structure which provides the structural transition from the pipes used to collect and discharge seawater for condenser cooling and for safety-related salt water cooling. The intake structure is essentially a reinforced concrete tunnel with the top slab open at the screen well. Figures 1 and 2 show the plan view and longitudinal section through the intake structure.

The licensee observed excessive leakage during an attempt to dewater the north pump well and screen well while SONGS-1 was in an extended outage. Upon initial investigation to determine the cause for this leakage, the licensee discovered local spalled concrete at the north pump gate slot and corrosion of the reinforcing steel. Subsequently, the licensee investigated the entire structure for possible deterioration of the structure. The investigation included visual inspection, concrete coring and chipping. Additional tests and examinations included petrographic examinations and chemical testing for chloride content.

The licensee has reported the results of its investigation in Reference 1 and also discussed this with the staff in a meeting on August 23, 1984 (Ref. 2). The following is the brief summary of the conditions found for the concrete, the reinforcement near the inside surfaces of walls and slabs, and the outside reinforcement.

- Concrete: The licensee reported that the problem with the concrete was that delaminations were evident in areas of the pump wells and screen wells. The delamination occurred in the inner wall of the structure. Consequently, the concrete no longer provided significant corrosion protection to the reinforcing steel in these areas.

- Inside Wall Reinforcement: Some of the reinforcing steel on the inside surface of the structure in the pump and screen wells in contact with seawater was found to be corroded, with enough steel gone to remove the structural function of the bar. The rebar corrosion in the pump wells was considerably more severe than in the screen well area. Some of the smaller bars in the ceiling of the pump well area were also found to be corroded. The licensee concluded that the condition of the steel was structurally questionable and it would be considered satisfactory only if it was replaced with new reinforcing steel.

- Outside Wall Reinforcement: The licensee reported that cores taken completely through the walls and floor consistently indicated that the outside layer of steel reinforcement did not show any sign of corrosion. The outside portion of the concrete also did not show any sign of delaminations.

This safety evaluation addresses the extent of corrosion damage, the licensee's assessment of the structural capacity of the intake structure (pre-repair), and the corrective actions taken by the licensee.

2.0 INTAKE STRUCTURE CORROSION AND REPAIR

2.1 Extent of Corrosion Damage

Visual examination of the inside surface (seawater side) of the intake structure reported by the licensee indicated discoloration in some areas, attributable to corrosion byproducts which had collected on the surface. Core samples were taken and they showed concrete delaminations between 3 and 4 inches in a plane parallel to the surface. Almost all of the initial samples contained either one or two delaminations on the seawater side which were generally filled with corrosion byproducts. Some cores passed through reinforcing steel, which showed either surface corrosion or, in some cases, extensive corrosion deterioration. Core samples taken from the outside surface (soil side) of the intake structure showed sound concrete structure with no signs of rust products or delamination. Concrete chipping in selected areas showed that reinforcing steel corrosion and concrete delaminations are primarily limited to the interior areas of the pump wells and screen wells. The area between the screen wells and the tsunami gates indicated sound concrete with reinforcing steel in excellent condition, except for areas at the gate slots and areas with no structural significance. In the screen wells the reinforcing steel corrosion is still noticeable but significantly less degradation has occurred compared to areas in the pump wells.

The licensee stated that visual and microscopic examination of the corroded steel rebar indicate the presence of extensive amounts of iron hydroxides resulting from corrosion of embedded steel. The iron-oxide deposits have been found to be a mixture of black, magnetic oxide (magnetite Fe_3O_4) with traces of green ferrous iron-oxide. Silver nitrate testing revealed the presence of water soluble chloride ions. Chloride concentration profiles were obtained from core samples ranging from 12-inch deep to the full thickness of the wall. The results also show that chloride concentration increases from about 0.4% on the surface of the inside wall (seawater side) to about 1.2% chloride 4 inches into the wall (where the steel rebar is located). Then the chloride level decreases drastically to almost zero beyond 14 inches into the wall. The chloride concentration begins to increase again beyond 22 inches and reaches a level of 300 ppm at the surface of outside wall. Chloride analyses of the seawater and the water in contact with the outside wall gave the results of 1.9% and 300 ppm, respectively.

Visual observation of core samples the staff made during a site visit, and the review of licensee's chloride analyses on concrete samples confirmed the presence of extensive amounts of iron hydroxides on corroded carbon steel rebar and that chlorides were not used as an additive in the original concrete mix as evidenced by the low levels of chloride that currently exists within the intake structure. Therefore, the staff agrees with the licensee's conclusion that the structure was not initially contaminated with chloride beyond the low chloride levels naturally occurring in the basic concrete constituents. The high chloride level obtained on concrete core samples resulted from extended exposure to seawater. The ingress of chloride and water into the concrete led to the corrosion of carbon steel rebar due to formation of ferrous chloride. Because subsequent hydrolysis of the ferrous chloride would lower the pH in regions surrounding the rebar, this would lead to the loss of passivity of the rebar. Therefore, the staff agrees with the licensee that chloride intrusion from the seawater caused the rebar corrosion.

2.2 Specified Concrete Requirements

The structure was designed and constructed in accordance with specifications consistent with the ACI-318-63 Building Code. The specification used for SONGS-1 did not permit the use of other admixtures which could contain chlorides and the water used in the mix was required to be of potable quality. Tests for reactive aggregates were performed, in accordance with the specification requirements. The ACI-318-63 Code does not directly specify requirements for structures exposed to seawater. The licensee stated that the specifications for SONGS-1, as well as the original concrete and reinforcement steel details, represented the then-in-effect ACI Code provisions and recommendations for the design environment.

2.3 Visual and Microscopic Examination of the Concrete

The licensee reported that visual and microscopic examination of the concrete indicates that it is in good to excellent condition with the exception of the delaminations on the inside surface. Both core samples and chipped pieces indicated that the concrete has an average compressive strength of 7240 psi and a minimum compressive strength of 5680 psi which is significantly higher than the Code specified minimum design strength of 3000 psi. In addition, both core samples and chipped pieces indicated that the concrete is sound and there is good adhesion of the constituents. The sampled concrete is moderately hard and neither significant bleeding nor segregation of the fresh concrete is indicated.

Based on these test results and observations, the NRC staff agrees with the licensee's conclusion that the concrete was well consolidated.

2.4 Causes of Reinforcing Steel Corrosion

Concrete of high quality, as used in the intake structure, is inherently a sound inhibitor of corrosion in reinforcing steel because of its naturally high alkaline environment (pH of 12.5 or more). The alkalinity renders the reinforcing steel in a passive state which resists corrosion attack. However, the introduction of chlorides, 0.1% or more, into the concrete over a long period of time can lead to breakdown of the passivity of the reinforcing steel and make it susceptible to corrosion attack. Based on the chloride concentration measurements obtained on core samples and the chloride level profile across the wall of the intake structure, the staff agrees with the licensee's conclusion that the delaminations of the intake structure at 4-5 inches of the inside surface (seawater side) were a direct result of corrosion of the reinforcing steel and the formation of chemical products that occupy a larger volume than the reinforcing steel consumed in the reactions.

The staff agrees with the licensee because hydrogen reduction reaction normally occurring at the cathode is kinetically extremely slow. Therefore, depolarization reactions dominate the cathodic reaction.

The staff also agrees with the licensee that the reasons preferential attack occurred in areas of pump wells and screen wells was due to the fact that the circulating water pump well is not electrically isolated with respect to the rebar. This large mass of stainless steel in the pump bays acts as the cathode with respect to the rebar to form a galvanic cell, thus causing accelerated rebar corrosion. In the area of the screen well, exposure to oxygen as a result of operating the stainless steel travelling screens would also increase the rebar corrosion in these areas.

2.5 Corrective Actions

The licensee has repaired the intake structure so that the walls and slab of the pump well and lower screen well area are strap plated with carbon steel plate strips coated with a coal tar epoxy coating to protect them from corrosion. Sacrificial anodes are added to provide additional protection. Monel anchor bolts are used to attach the plates to the wall. The anchor bolts are fabricated from corrosion resistant material such as ASTM B-164 and grouted in place. The delaminated 3 to 4 inches of concrete was left in place and will be kept in place by pretensioning the bolts to generate compression at the delaminated interface. The delaminated 3 to 4 inches thick concrete will readily resist the compressive stresses induced since the concrete strength is unaffected by the corrosion of reinforcing steel.

The strap plates were used on the walls and ceilings wherever credit for the existing reinforcement could not be taken for the design loads. Additional chipping was done in some areas where heavy reinforcement exists to verify its adequacy. In areas where reinforcement is not required for structural integrity or was determined to be adequate and no lamination of concrete exists, a strap plate was not provided.

Based on experience, the staff finds that the cathodic protection system with sacrificial anodes combined with the coal tar epoxy coating is adequate in protecting the carbon steel strip plates from chloride-induced corrosion attack. However, no remedies are taken to protect the corroded reinforcing steel from continued chloride attack; therefore, it is anticipated that rebar corrosion will continue and further delamination and cracking of concrete adjacent to the carbon steel strip plate may cause them to lose their pretension and, thus, their effectiveness in replacing the corroded reinforcing steel.

The licensee's October 18, 1984 letter stated that a surveillance program to monitor any further corrosion is being developed and that this program will be provided to the staff 90 days prior to the next refueling outage. The NRC staff considers that the inspection of the pump well and the screen well areas during each refueling outage is required to provide reasonable assurance that the intake structure maintains its integrity and meets its design requirements. The staff will review the licensee's surveillance program to evaluate its adequacy and effectiveness.

3.0 STRUCTURAL CAPACITY AND REPAIR

After determining the condition of the intake structure, the licensee undertook an analysis to assess the capacity of the existing structure under various loading conditions. The licensee also devised a repair program to restore the original margins in the structure. The licensee's analysis and repair programs as well as the staff's evaluation are discussed in the following sections.

3.1 Assessment of Existing (Pre-Repair) Structural Capacity

The licensee analyzed the existing (pre-repair) intake structure to determine moments in the various structural elements for applied static and dynamic loads. These loads included dead load, live load (including surcharge and hydrostatic) and loads due to the Systematic Evaluation Program re-evaluation earthquake of 0.67g horizontal and 0.44g vertical peak ground accelerations.

The licensee analyzed intake and discharge culverts as rigid boxes by the moment distribution method. The other elements are analyzed as a one-way or two-way slab between supports. The licensee has justified the rigid box assumption by noting that the exterior layer of wall reinforcement is in excellent condition and provides necessary continuity at slab and wall junctions as negative moments exist at these junctions under all loading conditions. The licensee has further stated that, under the assumption of both pump wells being full, the interior or inside wall experiences minimal moment and the assumption of rigid behavior is appropriate.

In order to determine the moment capacity of a given section the licensee made the following assumptions:

- For those elements that are in direct contact with the seawater no credit was taken for the 3 inches of concrete cover on the inside face.

- The reinforcement as shown for the original design was used in determining the moment capacity.

- Concrete compressive strength was taken to be 4500 psi which takes credit for the in-place wet-cured conditions which is verified by the compressive tests.

Based on the analysis results and the moment capacity calculations, the licensee compared the required reinforcement to resist loads with the existing reinforcement to define the regions of the intake structure for remedial actions. The licensee identified the following three regions and required actions:

- Pump well areas: The interior reinforcing steel was heavily deteriorated on the walls and therefore required remedial action. The ceiling reinforcing steel (underneath the pump deck) was sound with local corrosion only. The outside wall reinforcement was in excellent condition as demonstrated by the core drilling results. Therefore, no remedial action was necessary for the outside wall reinforcement.

- Screen well areas: The inside wall reinforcement at lower levels was found to be about 20% corroded. One could postulate that based on observation of rust deposits on the surface, the potential for eventual delamination existed. Thus, the effectiveness of the bond was questionable and repair of the lower portion of this area was considered prudent.

- Intake area: The structure from the pump wells to the tsunami gates was in good condition in areas required for structural integrity and adequate reinforcement exists to resist the design loads. Therefore, no remedial action was necessary in this area.

3.2 Remedial Actions

As described in the previous section, the license determined that the reinforcing steel in the inside surface of the walls of the pump well and lower screen well area was corroded and no credit can be taken for this steel. Therefore, the licensee undertook the following remedial actions:

The walls and slab of the pump well and lower screen well area were strap plated with carbon steel plate strips coated with a coal tar epoxy coating to protect them from corrosion (See Figs. 3 and 4). Sacrificial anodes were added to provide additional protection. Monel anchor bolts were fabricated from corrosion resistant material such as ASTM B-164 and were grouted in-place. The delaminated 3 to 4 inches of concrete was left in place and is kept in place by pretensioning the strap anchor bolts to generate compression on the delaminated interface.

The above described strap plates were designed to resist maximum tensile stress which would develop at the inside face under the design loads. A composite action was assumed between existing concrete and strap. The composite actions between the concrete and strap was assured by designing monel anchor bolts to be shear connectors and by grouting and preloading them. The design of anchor bolts was checked by both American Concrete Institute shear friction methodology and AISC shear connectors design. The straps were not preloaded by the forced displacement of walls prior to plate installation.

3.3 Evaluation

The staff, in addition to its review of the information contained in References 1 and 2, visited the site on September 6, 1984 to observe the intake structure repair installation. Installation procedures were as prescribed and were apparently proceeding without problems. The staff and licensee representatives also met on September 6, 1984 and February 13, 1985 to discuss the analysis, the corrective measures being taken, and the surveillance procedures. With regard to the licensee's analysis procedure and repair methods, the staff finds the following:

- The licensee's assumption of rigid box behavior is reasonable because the negative moment at the junctions of exterior walls and slabs will be resisted by outside reinforcement which has been shown to be in good condition. Considering the loading conditions on the exterior of the intake structure, i.e., soil pressure together with hydrostatic pressure, it is reasonable that the negative moment will occur at junctions under all loading conditions.

- The licensee in a meeting on February 13, 1985 stated that the situation of only one pump well being full occurs only during maintenance conditions and as such it is not necessary to evaluate the intake structure for the resulting loading condition. The licensee is currently discussing this position with the staff. If the loading conditions resulting from the maintenance operations are to be evaluated, further staff review will be required to assure that under the assumptions of dewatering and only one pump well being full, the intake structure will retain the functional and structural integrity as originally designed.

- The use of the concrete compressive strength of 4500 psi is adequate as the cores taken from the structure indicate that the lowest total compressive strength was 5680 psi.

- The licensee's determination of the regions to be repaired is reasonable and based on detailed investigation of the existing structural conditions. Further, the licensee has committed to include in station procedures appropriate surveillance requirements to monitor new installation and existing reinforcement which have been relied upon to resist postulated load conditions. As stated in Section 2.5 of this safety evaluation, the staff will review the surveillance program to assure that the structural integrity is maintained.

- The licensee's use of the steel straps to restore the function of the inside reinforcement is adequate. The composite action between the strap and concrete is designed on a sound basis using two separate codes.

4.0 CONCLUSION

Based on the above reviews, the NRC staff finds that the licensee has identified the cause of rebar corrosion which has led to delamination of concrete inside surface of the intake structure. The staff also finds that coal tar epoxy coating and the cathodic protection system with sacrificial anodes are adequate to protect the carbon steel strip plates which were bolted to the concrete wall. Because the corroding reinforcing steel is not cathodically protected, its continued corrosion could lead to loss of pretension of the steel plates. Although an adequate surveillance program can provide advance warning of concrete delamination because of continued rebar corrosion, no information was provided on a surveillance program. The licensee did commit to provide a surveillance program 90 days prior to the next refueling outage. The staff recommends that the licensee's surveillance program include provisions for inspecting the pump well and the screen well areas during each refueling outage, so that there is a reasonable assurance that the intake structure maintains its integrity and meets its design requirements. The staff will review the proposed surveillance program. Subject to the resolution of issues relative to the investigation of the effects of dewatering and only one pump well being full and the surveillance program, the staff finds that the licensee's evaluation and repair of the intake structure is adequate and the structure can withstand both normal operating loadings and postulated earthquake loads based on 0.67g maximum ground acceleration.

5.0 ACKNOWLEDGEMENT

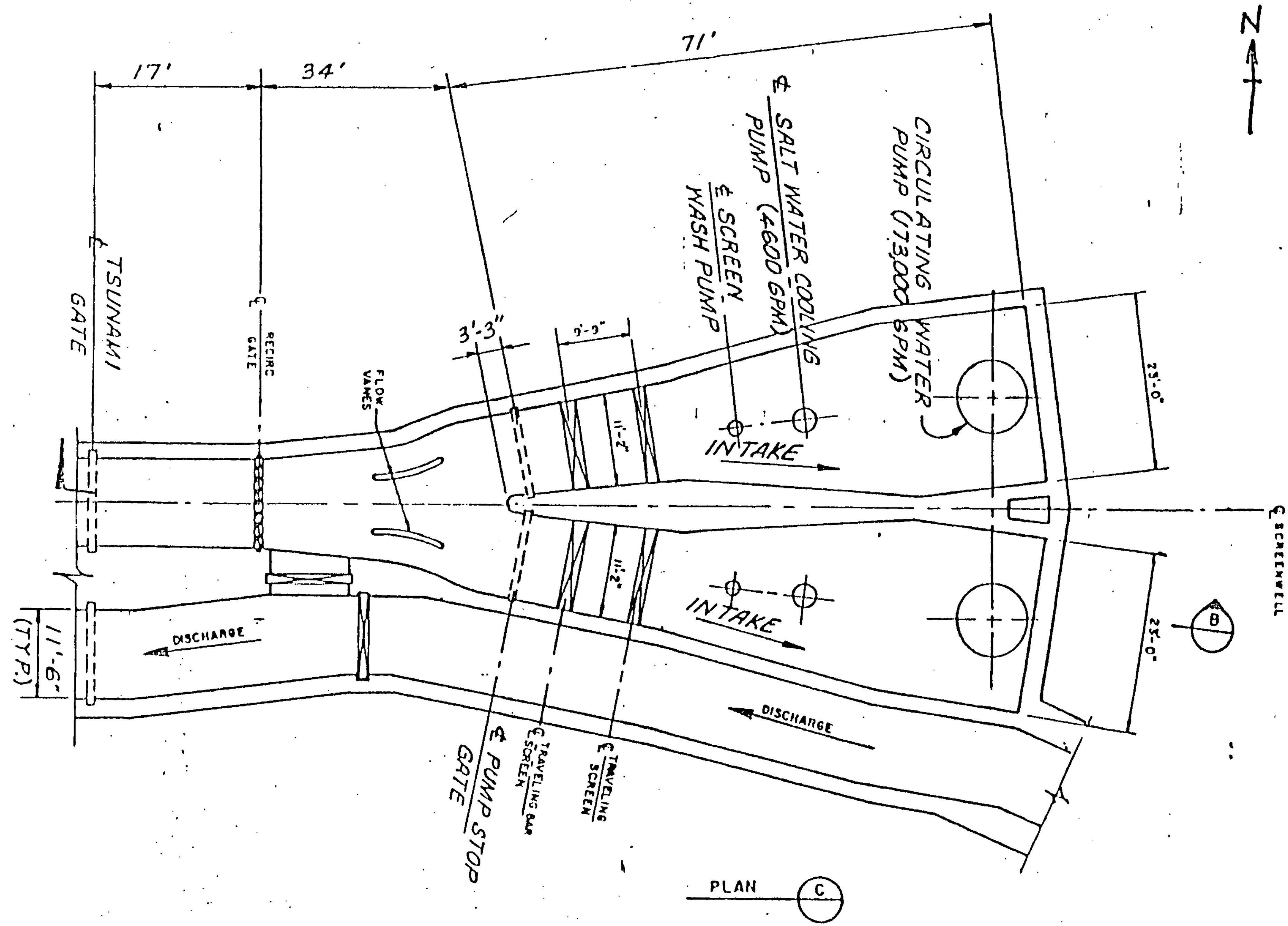
P. Wu, N. Chokshi, and W. Paulson contributed to this evaluation.

6.0 REFERENCES

1. "Structural Evaluation and Repair of SONGS-1 Intake Structure" - Bechtel Power Corporation, October 2, 1984.

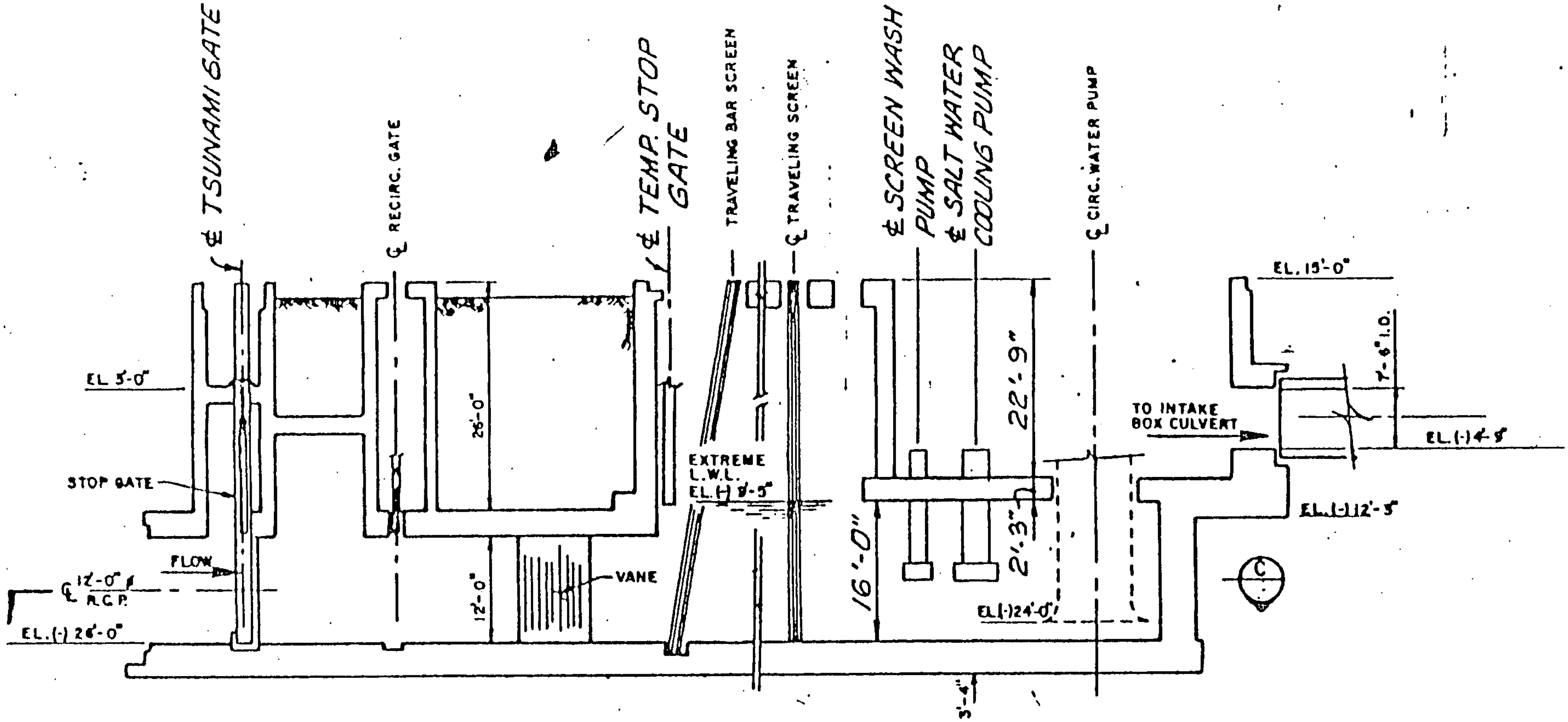
2. "Summary of August 23, 1984 Meeting"; issued by NRC Project Manager, August 27, 1984.

Dated: April 24, 1985.



SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

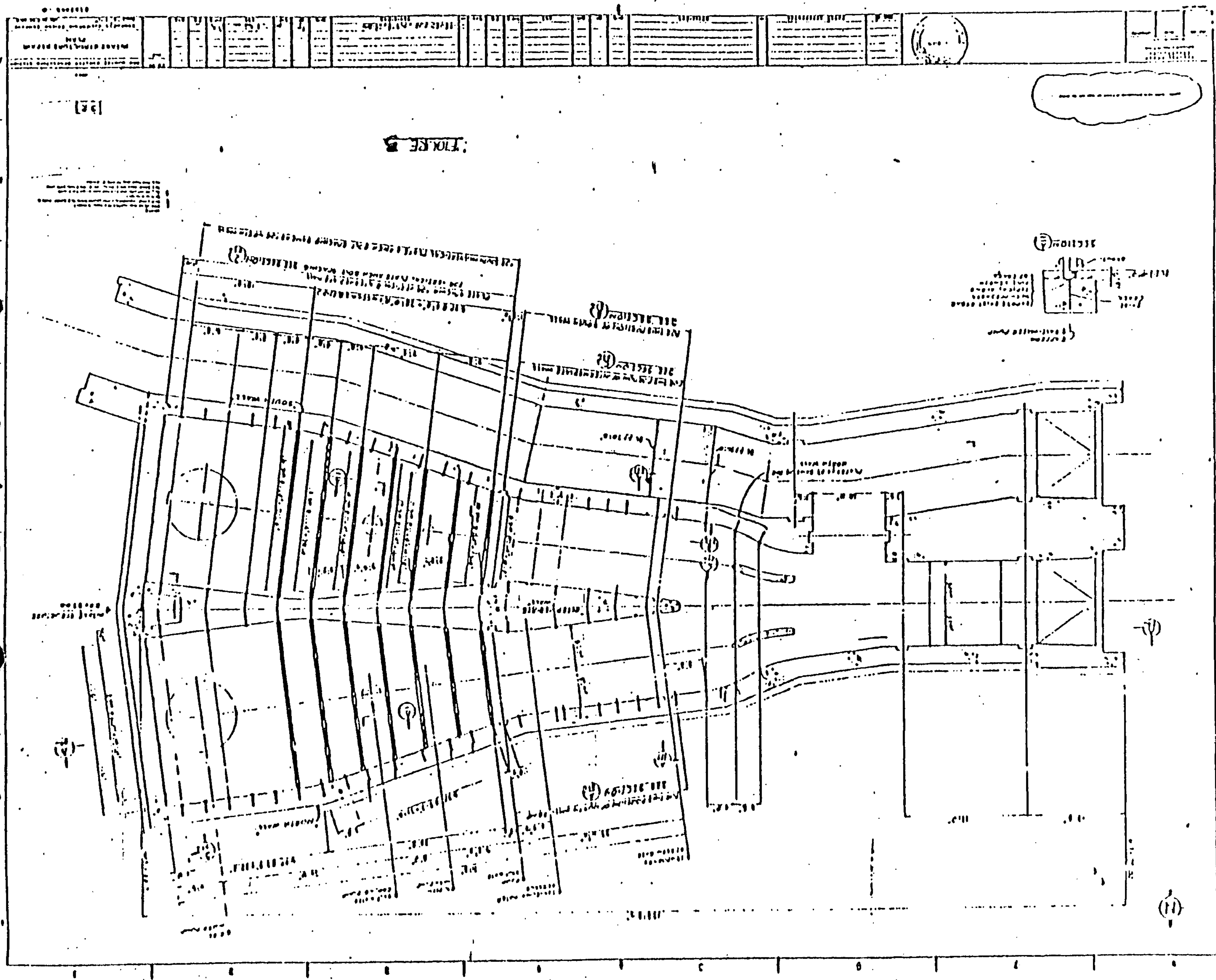
FIG. 1 INTAKE STRUCTURE (PLAN VIEW)



SECTION (B)
FIG. 1

SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

FIG. 2 INTAKE STRUCTURE



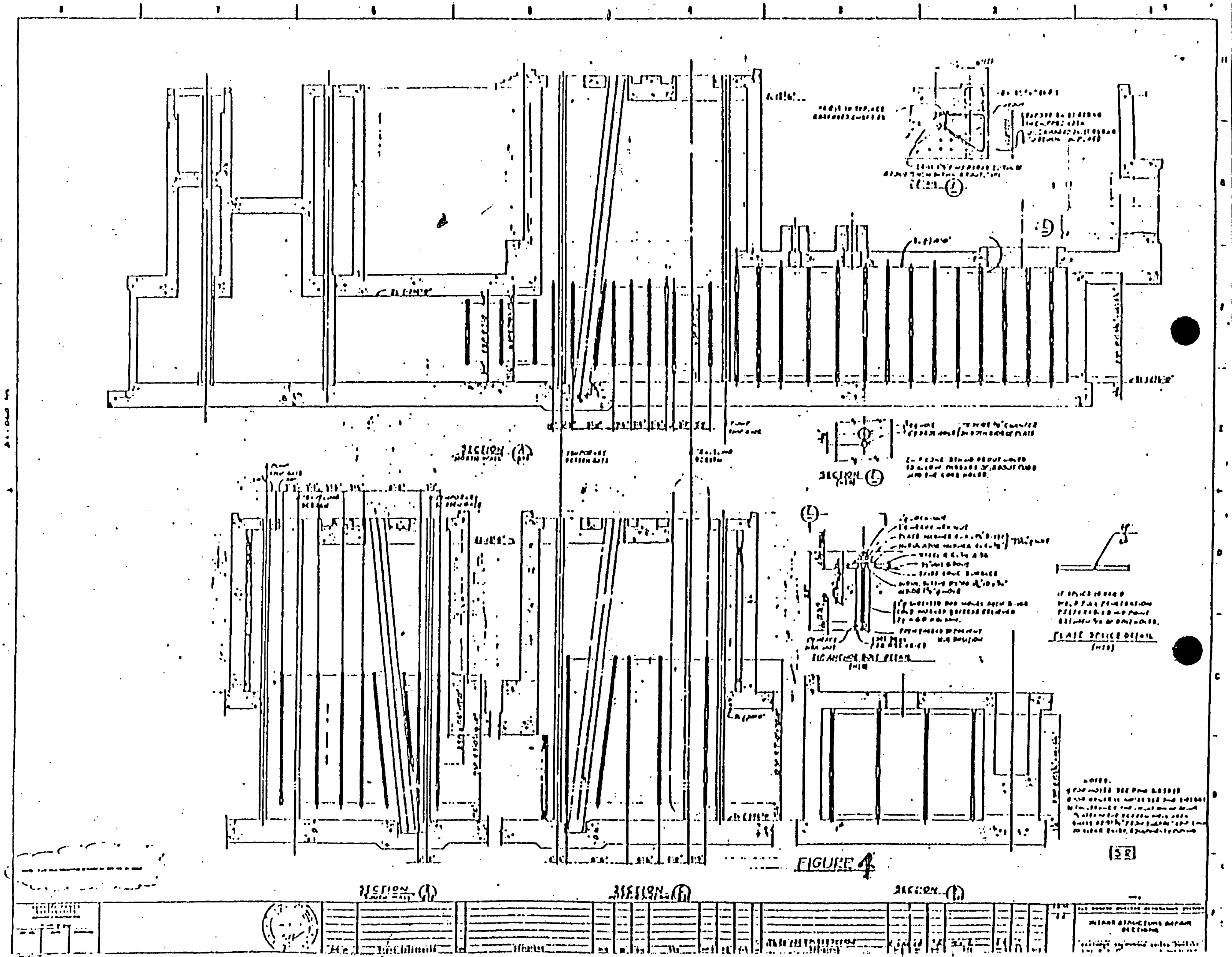


FIGURE 4