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MIDLAND PROJECT
MIDLAND DOCKET NO 50-329, 50-330
LIMIT ANALYSES TO EVALUATE SERVICE WATER
PUMP STRUCTURE EAST AND WEST WALL CAPACITIES
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REPORT FOR THE SERVICE WATER PUMP,
SERIAL 16009, DATED MARCH 2, 1982
ENCLOSURE: APPENDIX B - LIMIT ANALYSIS OF SERVICE
WATER PUMP STRUCTURE

On December 10, 1981 and January 11, 1982, meetings were held with the Staff and its consultants to discuss concrete cracks in the auxiliary building, the service water pump structure, the diesel generator building and the feedwater isolation valve pits. A subsequent report was provided to the NRC Staff by the above-referenced correspondence of March 2, 1982 which presented an evaluation of the significance of cracks observed in the service water pump structure. After their review of the crack evaluation report provided by our referenced correspondence, NRC Staff members requested that a more detailed analysis be made to evaluate the east and west walls of the service water pump structure. Therefore a limit analysis of the service water pump structure was undertaken.

In response to this request, we are providing the enclosed report entitled "Limit Analysis of Service Water Pump Structure." Because this more detailed analysis forms an integral part of the previous report transmitted by our reference correspondence, it has been designated as Appendix B and should be attached to the earlier report transmitted in March 1982. The enclosed Appendix B describes the approach used for the limit analyses made to evaluate the capacity of walls and the results obtained. The analyses were made for various hypothesized loading conditions. Wall capacities were estimated assuming cracked sections.

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The results of the more detailed analyses presented in the enclosed appendix indicate that the walls have sufficient in-plane shear capacity to resist hypothesized forces. For all cases evaluated, it was determined that shear and moment capacity of walls in the service water pump structure would not limit the capability of the structure to resist in-plane forces. These conclusions fully substantiate those conclusions already presented in our earlier correspondence of March 2, 1982.

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APPENDIX B

LIMIT ANALYSIS OF SERVICE WATER PUMP STRUCTURE

by

W. G. Corley and A. E. Fiorato*

INTRODUCTION

In the main body of the report entitled "Evaluation of Cracking in Service Water Pump Structure at Midland Plant" (February 1982), cracks observed in the Service Water Pump Structure were described and their significance was evaluated. Observed cracks were primarily attributed to restrained volume changes that occur in concrete during curing and subsequent drying. No evidence of stuctural distress was observed. Although the possibility of settlement related cracking at the intersection of the north overhang with the south portion of the structure could not be completely eliminated, crack patterns did not support the conclusion that settlement was a primary cause of cracking.

As a measure of significance of observed cracks relative to future integrity of the structure, the tensile stress that uncracked concrete may be assumed to carry was compared to available tensile capacity provided by structural reinforcement crossing the cracks. This calculation was made for sections in the vicinity of cracks that had a measured width of 0.010 in. or greater. In the calculation, concrete is assumed to carry a

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LIMIT ANALYSIS OF SERVICE WATER PUMP STRUCTURE

APPENDIX B

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principal tensile stress of $4\sqrt{f'_c}$ where f'_c is specified concrete compressive strength.

Based on calculations of tensile capacity, it was determined that available horizontal reinforcement in the east and west walls of the Service Water Pump Structure provided a resistance of approximately 97% of the tensile stress that could be assumed to be attributed to concrete. Resistance provided by vertical reinforcement exceeded by a significant margin the tensile stress assumed to be carried by concrete. It was reasoned that if cracks in these walls had an inclination of at least 15° from vertical, both vertical and horizontal reinforcement would be sufficiently mobilized so that the resultant of forces would exceed the stress attributed to concrete tensile strength. It was therefore concluded that resistance provided by the reinforcement was sufficient.

Nuclear Regulatory Commission staff members reviewed the report entitled "Evaluation of Cracking in Service Water Pump Structure at Midland Plant." After review, staff members requested that a more detailed analysis be made to evaluate the east and west walls of the Service Water Pump Structure. Therefore a limit analysis of the Service Water Pump Structure was undertaken. This analysis includes consideration of interior walls as well as east and west exterior walls. The objective of this Appendix is to describe the approach used for the limit analysis and the results obtained. Although it is not feasible to predict every limit case, limit analysis cases described in the following sections serve as examples of the inherent strength of the structure.

METHODOLOGY

The basic approach used in the limit analysis of the Service Water Pump Structure was to determine if forces that can be induced in the structure are sufficient to exceed capacity of walls assuming the existence of cracks. In-plane shear capacity of cracked walls was of primary concern in the analyses. Capacities were calculated using representative material properties, and section geometries determined from drawings provided by Bechtel.* All walls crossing sections analyzed were considered to contribute to bending and shear resistance. Contributions of exterior and interior walls were calculated assuming the structure to act as a unit. Reinforcement details were checked to insure that available development lengths were adequate.

Figures B-1 and B-2 illustrate hypothesized loading conditions that would induce critical vertical and horizontal forces on wall sections of the Service Water Pump Structure. In Case 1, shown in Fig. B-1, the entire north overhang of the structure was assumed to be unsupported. Thus, the weight of the north overhang would induce shear and moment forces at Section A-A. As shown in Figs. 10 and 11 in the main body of this report, east and west walls of the Service Water Pump Structure contain cracks at locations corresponding to Section A-A in Fig. B-1. The assumption of complete lack of support for the north end of the structure is extremely conservative, but it provides an estimate of maximum shears and moments that could be induced at Section A-A.

*Drawings used for analysis of the Service Water Pump Structure are referenced in Table 2 of the main body of this report.

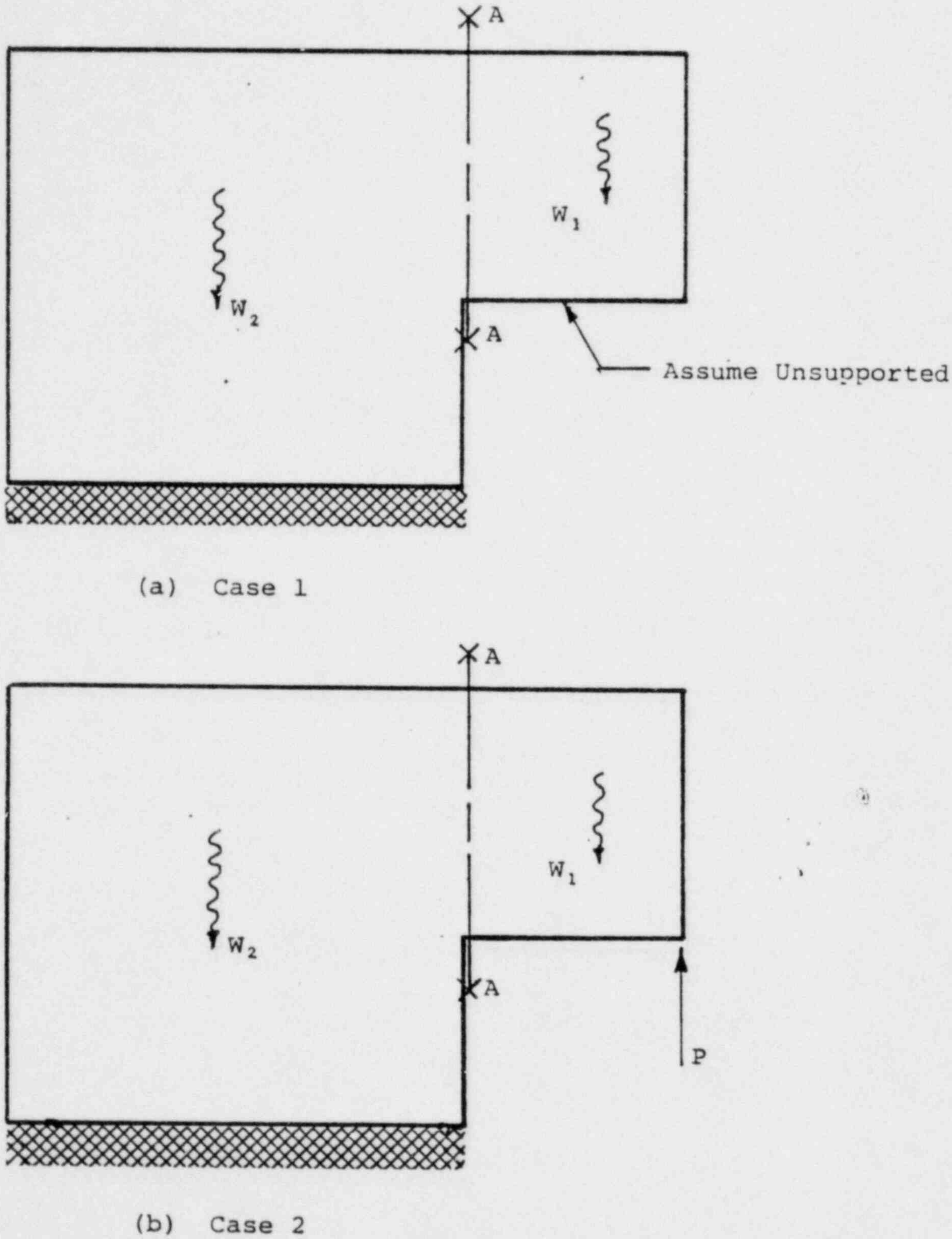
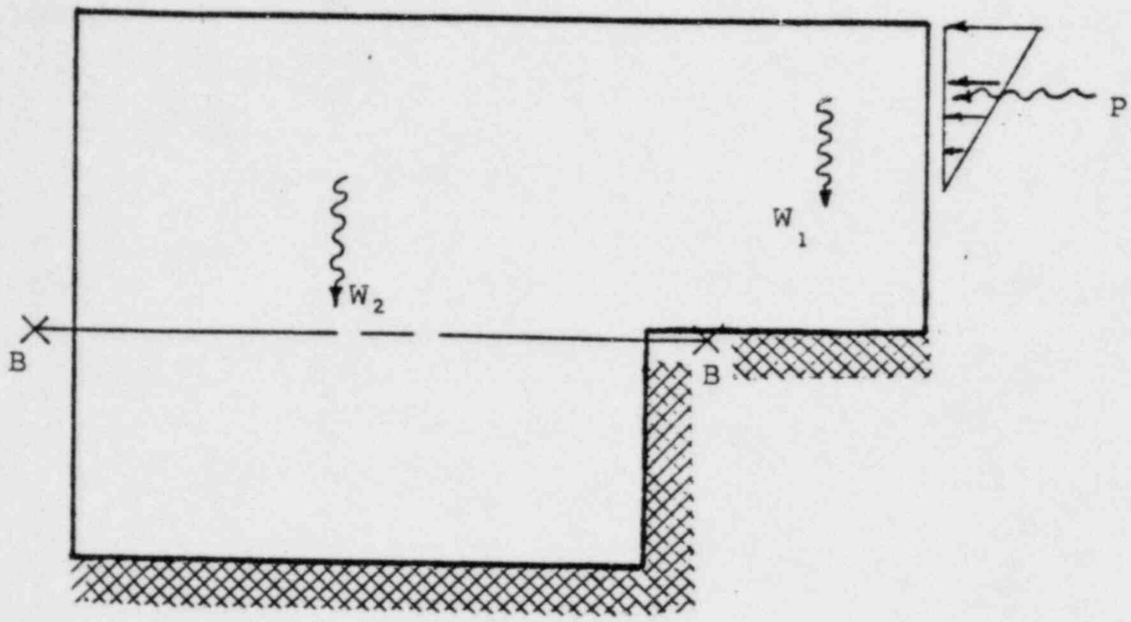


Fig. B-1 Hypothesized Loading Conditions for Critical Vertical Forces on Service Water Pump Structure

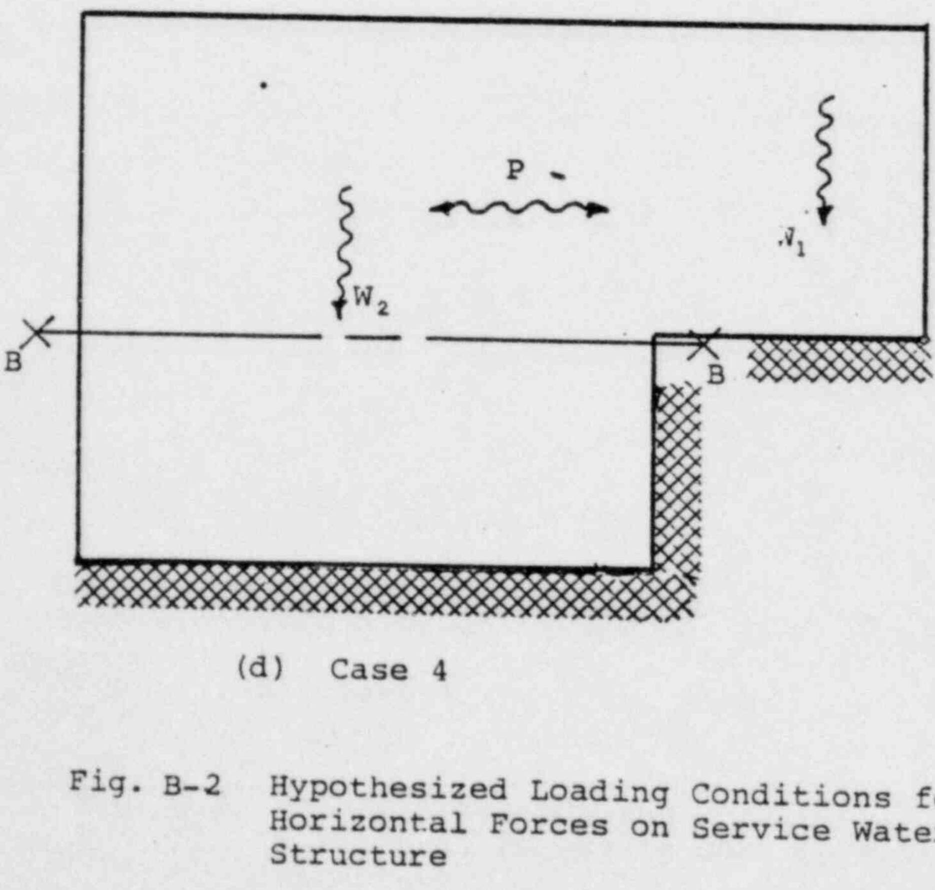
The second case considered for determination of maximum vertical forces that could be induced in the Service Water Pump Structure walls is shown in Fig. B-1, Case 2. This case assumes that a vertical force P is applied at the extreme north end of the structure in the upward direction. Such a force could be assumed to occur if control of jacking operations during underpinning is lost. Case 2 was evaluated by calculating the force P that would be required to induce yielding at Section A-A or that would overturn the structure.

In addition to evaluating critical sections for vertical shear forces, two cases were considered for transfer of horizontal shear forces in walls of the Service Water Pump Structure. These are illustrated in Fig. B-2. Case 3 assumes a horizontal load applied to the north wall of the Service Water Pump Structure. This force induces moments and shears at Section B-B. The limit on magnitude of this horizontal force was determined by evaluating shear and moment capacities at Section B-B, and also by considering rigid body movement of the structure.

The final hypothesized loading condition that was analyzed is shown in Fig. B-2, Case 4. This condition considers horizontal forces induced in walls of the Service Water Pump Structure as a result of seismic motion. If such a force is developed, it would be necessary to transfer horizontal shear through Section B-B. This section was analyzed by considering shear capacity at Section B-B, and also by evaluating the magnitude of forces that can reasonably be expected as a result of ground accelerations.



(c) Case 3



(d) Case 4

Fig. B-2 Hypothesized Loading Conditions for Critical Horizontal Forces on Service Water Pump Structure

RESULTS OF ANALYSES

This section presents results of limit analyses made for hypothesized loading conditions shown in Figs. B-1 and B-2.*

Case 1 - North End of Structure Unsupported

If it is assumed that the entire north overhang of the structure is unsupported, the deadweight W_1 shown in Fig. B-1 will induce moment and shear at Section A-A. Calculated dead weight of the north end of the structure, excluding equipment weight, would induce a nominal vertical shear stress of approximately 130 psi on walls of the structure at Section A-A. Shear resistance at Section A-A was calculated by shear friction theory in accordance with Section 11.7 of American Concrete Institute Building Code Requirements for Reinforced Concrete (ACI 318-77). Based on shear friction analysis, the nominal shear stress that can be resisted at Section A-A is approximately 275 psi. Shear friction analysis assumes the presence of a crack at the section being evaluated.

The moment at Section A-A induced by dead weight W_1 was calculated to be approximately 50% of the yield moment at that section. Thus, if the north overhang of the Service Water Pump Structure were completely unsupported, reinforcement would not yield in flexure nor would nominal shear capacity be exceeded.

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*Analyses described in this report did not include evaluation of potential foundation failures. However, if foundation failures were to limit capacity at lower forces than calculated for cases considered, nominal stresses in the walls would be even lower.

Case 2 - Upward Force on North End of Structure

For Case 2 it was hypothesized that a concentrated force (line load) was induced along the north wall of the Service Water Pump Structure. Calculations were made to determine potential limits on the magnitude of this force.

The upward force shown in Fig. B-1 for Case 2 can increase until either shear or moment capacity at Section A-A is exceeded or until the structure uplifts. Calculations indicate that uplift of the structure would be the limiting criterion. The load P that would lift the structure would result in a nominal shear stress of approximately 150 psi in walls at Section A-A. Immediately adjacent to the north wall of the structure, the nominal shear stress would be approximately 275 psi. Calculated shear friction capacity of a vertical section through the walls in the north end of the Service Water Pump Structure corresponds to a nominal shear stress of approximately 275 psi. Therefore, shear capacity is adequate. The moment at Section A-A corresponding to uplift of the structure was calculated to be approximately 50% of the yield moment.

Case 3 - Horizontal Load on North Wall

Case 3, illustrated in Fig. B-2, assumes the presence of a horizontal force on the north wall of the Service Water Pump Structure. Limits on the magnitude of this force were estimated by considering moment and shear resistance at Section B-B as well as potential rigid body movement of the structure. The horizontal force assumed for Case 3 was applied at 2/3 the height of the north wall above top of grade. This corresponds to a triangular force distribution.

For the assumed loading condition, the force that would overturn the structure would induce a nominal shear stress of approximately 225 psi at Section B-B. Analysis of shear resistance at Section B-B using shear friction theory indicates a shear capacity of approximately 310 psi. Thus the structure would tend to overturn before shear friction resistance was exceeded.

Assumptions made for Case 3 are unrealistically conservative. It is not possible to develop a force of the magnitude required to either overturn the structure or exceed shear friction capacity. The force required to overturn the structure corresponds to a uniform pressure of approximately 60 psi on the north wall. Design tornado wind load for the structure corresponds to approximately 2.3 psi.

If the horizontal force is assumed to act on the south wall, an even larger pressure is required to reach shear friction capacity of the vertical walls.

Case 4 - Horizontal Inertial Forces

The final hypothesis that was considered is Case 4 illustrated in Fig. B-2. Case 4 considers development of inertial forces that could potentially induce critical shear stresses in walls of the Service Water Pump Structure. Calculations for this condition indicate that horizontal forces large enough to exceed the shear friction resistance along Section B-B are equivalent to the deadweight of the structure excluding equipment. To generate such forces, a seismic event well in excess of what can reasonably be expected would be required.

SUMMARY AND CONCLUSIONS

This report presents a summary of limit analyses made to evaluate capacity of walls of the Service Water Pump Structure at Midland Nuclear Power Plant Units 1 and 2. Analyses were made for various hypothesized loading conditions to demonstrate inherent strength of the structure. Wall capacities were estimated assuming cracked sections. Results indicate that the walls have sufficient in-plane shear capacity to resist hypothesized limiting forces. For all cases evaluated, it was determined that shear capacity of walls in the Service Water Pump Structure would not limit capability of the structure to resist in-plane forces.