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EFFECTS OF CRACKS ON SERVICEABILITY OF STRUCTURES AT MIDLAND PLANT

by

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INTRODUCTION

A series of previous reports have presented an evaluation of the structural significance of cracks observed in the Feedwater Isolation Valve Pits, Auxiliary Building Control Tower and Electrical Penetration Areas, Diesel Generator Building, and Service Water Pump Structure at Midland Nuclear Power Plant Units 1 and 2.[(1-4)**] Observed cracks in these structures were described and the significance of the cracks with regard to future load carrying capacity was discussed. A site plan for the Midland Plant, which indicates buildings evaluated, is shown in Fig. 1.

This report contains a discussion of effects of observed cracks on serviceability of the structures evaluated. Primary emphasis is given to durability of the concrete structures over their service life. Recommendations for repair of selected areas are also made.

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**Numbers in parentheses refer to references listed at the end of this report.

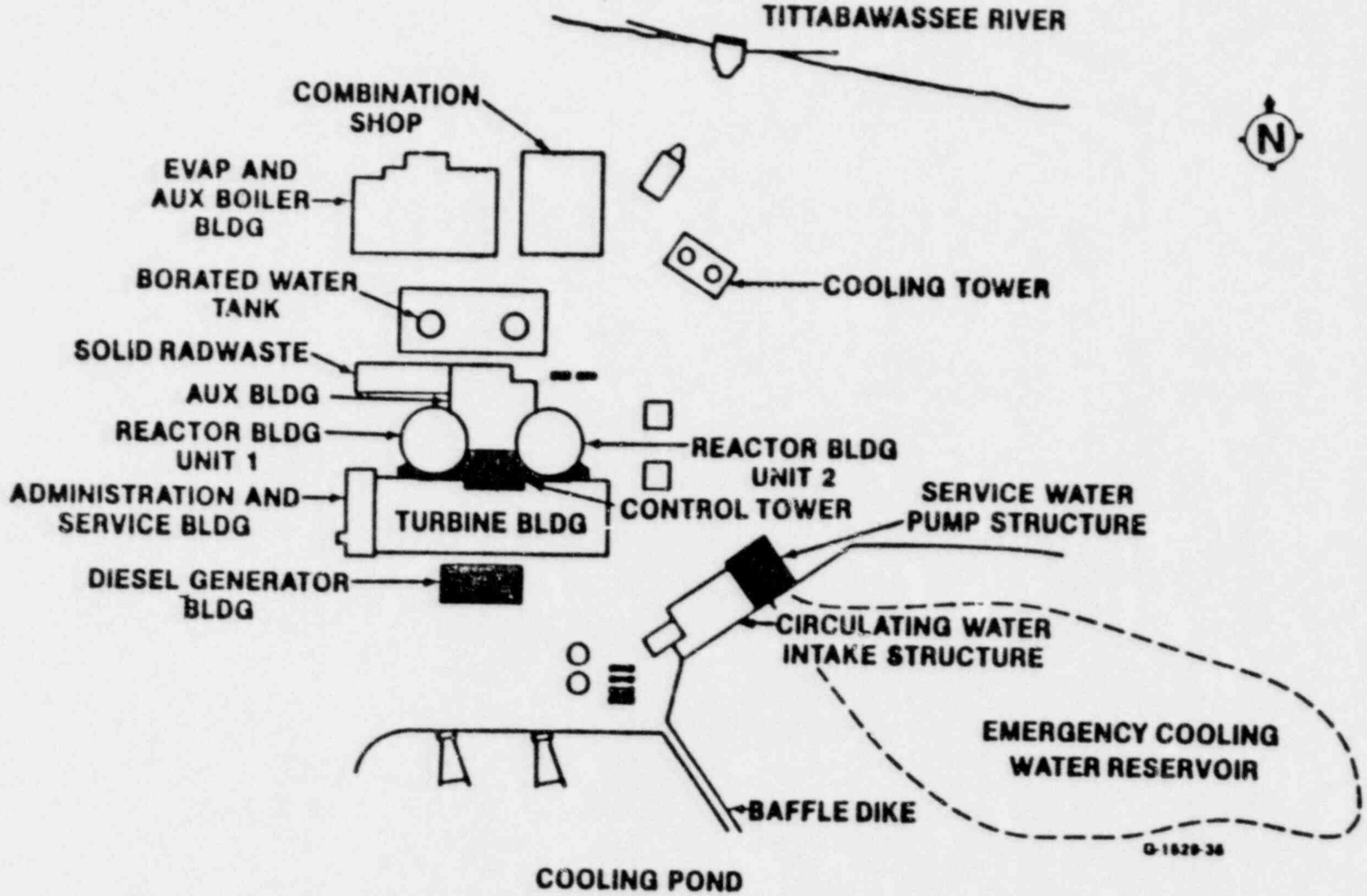

FIG. 1 SITE PLAN

OBSERVED CRACKS IN MIDLAND PLANT STRUCTURES

Cracks observed in the Feedwater Isolation Valve Pits and the Auxiliary Building Control Tower and Electrical Penetration Areas of Midland Plant Units 1 and 2 were primarily attributed to restrained volume changes that occurred during curing and drying of concrete. Cracks observed in the Diesel Generator Building were attributed to restrained volume changes, and reported differential settlement between duct banks under the building and the north and south portions of the building. Cracks observed in the Service Water Pump Structure were attributed primarily to restrained volume changes although the occurrence of settlement related cracking could not be entirely dismissed.

In terms of future serviceability of these structures, and potential problems with durability, cracks located in exterior exposed surfaces would be expected to have the most significant influence. This is because exposure conditions for exterior surfaces are more severe than those for interior surfaces. Maximum reported crack width in exterior surfaces of structures investigated at Midland was approximately 0.025 in. However, most observed cracks were significantly smaller than this maximum value. The fact that observed crack widths were spread over a wide range is consistent with most observations of cracking in concrete members. Crack widths are inherently subject to wide scatter.(5,6)

American Concrete Institute Committee 224 lists "tolerable crack widths" for reinforced concrete members as a function of

different exposure conditions.[6] For interior members, a "tolerable crack width" of 0.016 in. is listed. For exterior members subject to humidity, moist air, or in contact with soil, the "tolerable crack width" is listed as 0.012 in. ACI Committee 224 emphasizes that "it should be expected that a portion of the cracks in the structure will exceed these values by a significant amount."[6] Committee 224 also notes that their tabulation of width limits "is a general guide for tolerable crack widths at the tensile face of reinforced concrete structures for typical conditions and is presented as an aid to be used during the design process."[6] The crack widths are related to service conditions.

The presence of crack widths in excess of selected tolerable values occurs because crack limits can only be related to equations that predict "probable" maximum widths.[6] Although this probable value usually means that approximately 90 percent of crack widths in the member are below the calculated value, isolated cracks in excess of twice the width of the computed maximum can occur.[6] Research data also indicate that the range in randomness of crack widths increases with size of member.[6]

It should also be noted that equations for evaluating crack widths of flexural members are related to instantaneous or short term loading. Volume changes related to shrinkage, creep, or temperature and humidity variations, are not taken into account. For beams under nominally constant loading, research data have shown that crack widths can increase significantly with time.[7]

Thus, the maximum width would not be expected to remain constant after a crack initially forms. Therefore, in evaluating cracks in an existing structure, tolerances developed for design can not be arbitrarily applied.

For structures evaluated at the Midland Plant, most of the cracking, and crack growth, related to restrained volume changes should have taken place since construction was completed. Future movement of cracks related to normal volume and temperature changes should not affect conclusions developed in this report. However, cracks that may develop as a result of unanticipated settlement or from underpinning operations should be evaluated to determine their effects. The need for repair of such cracks can only be determined after their significance has been evaluated. Evaluation of such cracks has been included as part of the "Recommended Program for Monitoring Structural Integrity" of Midland Plant structures.[1-4]

Based on the above discussion, crack widths observed in structures investigated at the Midland Plant are judged to be within the range implied by published tolerable crack width limits.

DURABILITY OF CONCRETE STRUCTURES AT MIDLAND

This discussion covers durability of concrete as related to structures investigated at the Midland Plant. Emphasis is given to durability questions relevant to observed cracks in the Feedwater Isolation Valve Pits, Auxiliary Building Control Tower and Electrical Penetration Areas, Diesel Generator Building, and Service Water Pump Structure. Prior to discussing specific

measures for each structure, a basic discussion of durability of concrete structures is presented.

Durability of concrete is defined as "its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration."(8,9) With regard to questions of potential durability problems in Midland Plant structures, three types of concrete deterioration were considered: freezing and thawing, chemical attack, and corrosion of reinforcement.

Freezing and Thawing

Although the actual mechanism is quite complicated, freeze-thaw damage is basically caused by expansion and diffusion of freezing water in the pore system of cement paste and aggregates.(8,9,10) Freeze-thaw cycles cause progressive deterioration as a result of continued expansive pressures from excess water that freezes in concrete. Since freeze-thaw deterioration requires the presence of absorbed water that can be frozen, the occurrence of freeze-thaw deterioration on vertical surfaces is rare.

Resistance to freeze-thaw damage is obtained by designing structural members to minimize exposure to moisture, by using concrete having low in-place permeability, by using a low water-cement ratio, by using air-entrainment, and by using sound aggregates.(8,9,10) Concrete with low permeability does not absorb as much water which can later freeze.

According to information provided by Bechtel, concrete mixes used in walls of the buildings investigated at the Midland Plant had water-to-cementitious material ratios ranging from 0.41 to

0.47. These ratios are withi the limit of 0.50 recommended by American Concrete Institute Committee 201 for concrete resistance to freeze-thaw damage.[8] In addition, since exterior exposed surfaces in walls of the structures are unlikely to collect or transmit water, occurrence of freeze-thaw damage is judged to be unlikely. It is not expected that cracks of the type observed in the inspected structures would have potential to collect and retain water.

Chemical Attack

Dry concrete does not react with dry chemicals.[8,9] For deterioration to take place, chemicals must be in solution and in sufficient concentration to provide an aggressive environment.[8,9] Although buildings are exposed to a number of potentially corrosive chemicals under normal environmental and atmospheric conditions, concretes generally resist chemical attack from normal conditions of exposure.

American Concrete Institute Committee 515 has prepared detailed tables on effects of chemicals on concrete.[11] General types of chemical attack include acid or alkali attack, or sulfate attack. Concrete's resistance to chemical attack is dependent upon the type and concentration of the chemical solution in contact with the concrete, the temperature and pressure of the solution, and the quality of the concrete.[9]

Deterioration of concrete by acids is primarily the result of the reaction of acids with calcium hydroxide in the hydrated portland cement paste.[8,11] This results in the formation

of water-soluble reaction products and subsequent disintegration of the concrete. Strong alkaline solutions (over 20%) attack other constituents in the hardened paste to cause disintegration.(8,11) Sulfate attack results from complex chemical reactions between sulfate solutions and constituents of hydrated portland cement paste that result in expansive compounds which cause progressive disintegration of concrete.(8,11) In all cases the rate of chemical attack is more rapid in warmer climates.(8-11)

Conditions at the Midland Plant suggest the following hypothetical situations as being conducive to chemical attack:

1. Highly concentrated acid solutions in the cooling pond that could attack concrete in walls of the Service Water Pump Structure.
2. High sulfate contents in the soil, in the cooling pond, or in groundwater adjacent to the concrete structures.
3. Atmospheric pollution that could, in combination with moisture, form "acid rain."

According to Michigan MPDES Permit Application, Amendment 3, dated September 30, 1981, the pH* level of the cooling pond water can range from 7.0 to 9.0. This pH level can be compared to that of potable groundwater which has a pH of approximately 7.0. Seawater has a pH range from 8.0 to 9.0 Thus, pH levels of the cooling pond water are not unusual.

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*The pH value of a solution is a measure of its acidity on basicity. A neutral solution, or pure water, has a pH of 7. Stronger acids have lower pH values.(9)

With regard to sulfate attack, no unusual levels of sulfates in soils or groundwater at the Midland Plant have been reported to Construction Technology Laboratories staff. Sulfate levels in the cooling pond are listed in the Michigan MPDES Permit Application, Amendment 3, dated September 30, 1981. According to the permit, sulfate levels can reach maximum values of 908 mg/l (908 ppm of SO_4). This compares to values of 2500 to 3000 mg/l of sulfate present in seawater. Potable ground water has a sulfate level of approximately 30 mg/l.

American Concrete Institute Committee 201 considers sulfate levels in water of 150 to 1500 mg/l as a "moderate exposure" condition, and recommends a maximum water-cement ratio of 0.50 for this exposure condition. As mentioned previously, structures at the Midland Plant have water-to-cementitious material ratios of 0.41 to 0.47. These ratios are below the limit recommended by ACI Committee 201. Committee 201 also recommends that Type II cement be used for "moderate exposure" conditions. According to Bechtel, Type II cements were used in concretes for the structures evaluated. Therefore, the structures should have adequate resistance to sulfate attack.

Generally, air pollution severe enough to cause damage to concrete structures would not be tolerated on the basis of environmental concerns. Therefore, it is not anticipated that external walls which are exposed to the atmosphere at the Midland Plant would be susceptible to any more damage than would occur in any concrete structure located in a similar environment.

With regard to concrete's resistance to chemical attack, the presence of cracks would expose more surface area to chemical solution. However, considering the exposure conditions and concrete quality for structures at the Midland Plant, it is concluded that chemical effects would not be any more severe than for other concrete structures in the area.

Corrosion of Reinforcement

Concrete normally provides a high degree of corrosion protection for embedded reinforcement.[8,9] This protection occurs because high alkalinity of the concrete provides a passive environment for the steel. In addition, air dry concrete provides a relatively high electrical resistivity which helps to resist corrosion.[8]

Corrosion of reinforcing steel is considered to be an electrochemical process.[8,9] Electrochemical corrosion results from flow of electric current and accompanying chemical reactions within the concrete. Flow of electric current can be induced by stray electrical currents, by contact between different metals in concrete, or by differential concentration cells that may develop within the concrete. The principal type of electrochemical corrosion in concrete structures occurs as a result of corrosion cells that develop within the concrete and steel.[8]

Normally corrosion is prevented because a passive iron oxide film forms on the surface of the steel. This film occurs in the presence of moisture, oxygen, and water-soluble alkaline products formed during hydration of cement. However, the

passive film can be destroyed if the alkaline environment of the concrete is lost. Reduction in alkalinity can occur by carbonation of the hydrated portland cement or by ingress of chloride ions in the presence of oxygen.(8,9) Penetration of oxygen and chloride ions through concrete can result in corrosion cells being formed. The cells form when anodic and cathodic areas develop along steel reinforcement because of differences in moisture content, oxygen concentration, and chloride ion concentration.(8) Corrosion is initiated at anodic areas on reinforcement.

Since products of corrosion ("rust") take up a larger volume than the original steel, expansive forces are eventually generated as corrosion becomes severe. These forces can cause cracking and spalling. Primary elements essential for electrochemical corrosion in reinforced concrete are:

1. Presence of an electrolyte
2. Presence of oxygen

An electrolyte is a solution capable of conducting electric current by ionic flow.(8) For example, moisture and chloride ions will form an electrolyte capable of conducting a "corrosion current."

Generally, steps taken to prevent corrosion are related to providing a low permeability concrete with adequate cover over reinforcing steel. While it would appear that presence of cracks in concrete structures would increase risk of corrosion, no conclusive evidence has been found to indicate that any relationship exists between crack widths and corrosion.(12) It

has been found that cracks with widths less than 0.06 in., which run approximately transverse to the direction of reinforcing steel, have little influence on corrosion.[8,12] A greater risk of corrosion occurs from cracks that run along the line of the reinforcing bar.[8,12]

For structures investigated at the Midland Plant, it is not anticipated that corrosion would be a problem with regard to future durability. The presence of cracks in exterior wall surfaces above grade will have little effect on corrosion because these areas are not subject to moisture conditions conducive to corrosion damage. The same is true for walls that are below grade level but above the water table.

For walls below the water table and for the south wall of the Service Water Pump Structure adjacent to the cooling pond, the potential does exist for build up of chloride ions as a result of alternate wetting and drying of concrete.

It should be noted that the chloride level in the cooling pond adjacent to the Service Water Pump Structure is relatively low. According to the Michigan MPDES Permit Application, Amendment 3, dated September 30, 1981, chloride (Cl) concentration in the cooling pond can reach a maximum of 425 mg/l. This concentration can be compared to the level of chloride in seawater which can be 19,000 mg/l. Potable ground water would have chloride levels of approximately 20 mg/l. Thus, the cooling pond environment is not severe. However, as a precaution against possible build up of chloride ions in the splash zone

of the cooling pond, it is recommended that this area of the wall be coated to prevent possible ingress of chloride.

The Michigan MPDES Permit Application also indicates that the pH level of the cooling pond water can range from 7.0 to 9.0. This pH level can be compared to that of seawater which ranges from 8.0 to 9.0 and that of potable groundwater, which is approximately 7.0. The pH level in the cooling pond water is not considered to be low enough to severely reduce the alkaline environment that the concrete provides for reinforcement.

RECOMMENDATIONS FOR REPAIR

Epoxy injection of existing cracks above the water table in the Feedwater Isolation Valve Pits, the Auxiliary Building Control Tower and Electrical Penetration Areas, the Diesel Generator Building, or the Service Water Pump Structure is not required to ensure future structural integrity. Epoxy injection would have no influence on capacity of these structures since the existing cracks are not detrimental to capacity.

Although epoxy injection would increase overall stiffness of the cracked structures, it is unlikely that original stiffness would be recovered,[13] nor is it necessary to recover the original stiffness.

Epoxy injection of existing cracks in exterior and interior walls above the water table is not considered essential to ensure durability of the structure. Freeze-thaw damage is not considered likely in the walls because the vertical surfaces provide adequate drainage to prevent water from being trapped.

Freeze-thaw deterioration does not occur in unsaturated concrete. In addition, atmospheric exposure conditions at the Plant are not reported to be unusually severe. Therefore deterioration from chemical attack is not anticipated. Finally, in the absence of chloride ions, the alkaline atmosphere at the level of the reinforcing bars will prevent damage from corrosion in walls above the water table.

For cracks in walls below the water table, epoxy injection or other means of stopping leakage is recommended. This recommendation represents a precautionary measure against possible durability problems that could result from a gradual build up of chlorides or sulfates as concrete is subjected to repeated wetting and drying. Epoxy injection can be applied from the interior surface. Only cracks with visible signs of leakage need to be injected. A water insensitive epoxy system should be used. General guidelines on epoxy injection have been reported by American Concrete Institute Committee 546.(14)

It is recommended that a surface coating be applied to the exterior of the south wall of the Service Water Pump Structure. This coating should cover the splash zone area of the wall adjacent to the cooling pond.* This recommendation is a precautionary measure against possible corrosion problems that

*It is reported that the water level in the south cells of the Service Water Pump Structure is maintained at the same elevation as the cooling pond. Since conditions in these cells are not conducive to repeated wetting and drying, as in the exterior splash zone, coating of interior walls is not considered necessary.

could result if a gradual build up of sufficient chloride ion occurs as the concrete adjacent to the cooling pond is subjected to repeated wetting and drying. The coating will restrict ingress of chloride ions carried by the cooling pond water.

The splash zone can be generally defined as the portion of wall subject to repeated wetting and drying. According to the Midland Plant Final Safety Analysis Report, Revision 33, dated April 1981, the maximum operating water level in the cooling pond is at elevation 627 ft. The minimum level is at elevation 618 ft. The minimum level is based on a 100-day drought with no stream withdrawals made from the Tittabawassee River. Thus, the minimum level would not be reached under normal conditions. The normal operating level of the cooling pond ranges from elevation 626 ft to elevation 627 ft.

It is recommended that the exterior surface of the entire width of the south wall be coated between elevation 626 ft and elevation 637.5 ft. This will provide protection from chloride build up caused by repeated wetting and drying under normal operating conditions.

Peformance criteria for the coating material include:

1. The coating material should cover cracks
2. The coating material should have a low enough modulus to permit natural movement of cracks
3. The coating should be able to withstand the range of environmental conditions that can be encountered at the site
4. The coating should be water resistant

5. The coating should bond to damp concrete

6. The coating material should resist debonding from moisture movement or vapor pressure within the wall

7. The coating should exhibit long-term stability

8. The coating should not react with chemicals in cooling pond water

According to manufacturers' data, the following coatings are considered suitable for the intended application:

1. Rubberstone Hi-Fill Fibrated.

   United Coatings, Inc.
   1130 E. Sprague Avenue
   Spokane, Wash. 99202

2. Aquaflex

   Dural International Corp.
   95 Brook Avenue
   Deer Park, N.Y. 11729

3. Sika-Top 144

   Sika Chemical Corp.
   Box 297
   Lyndhurst, N.J. 07071

Other suitable coatings may be available. American Concrete Institute Committee 515 provides recommendations for use of waterproofing barrier systems on concrete.[11]

It is recommended that repairs be made after completion of underpinning operations.

SUMMARY AND CONCLUSIONS

This report presents a discussion of observed cracks in the Feedwater Isolation Valve Pits, Auxiliary Building Control Tower and Electrical Penetration Areas, Diesel Generator Building, and Service Water Pump Structure located at Midland Nuclear Power

Plant Units 1 and 2. Effects of observed cracks on future durability of the structures are discussed.

Observed cracks in walls above the water table are not expected to have a significant influence on future durability of the structures. Therefore, epoxy injection of these cracks is not considered necessary.

For cracks in walls below the water table, it is recommended that epoxy injection or other means be used to stop leakage. This precautionary measure is intended to prevent possible corrosion problems that could result from gradual build up of chloride ions.

It is also recommended that the south wall of the Service Water Pump Structure be coated within the splash zone area adjacent to the cooling pond. The coating represents a precautionary measure against possible corrosion problems that could result from gradual build up of chloride ions.

It is recommended that repairs be made after completion of underpinning operations.

Epoxy injection of existing cracks is not required to ensure future structural integrity.

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