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Iowa Electric Light and Power Company

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ASSISTANT VICE PRESIDENT
NUCLEAR GENERATION

July 11, 1979
LDR-79-101

Mr. James G. Keppler, Director
Office of Inspection and Enforcement
Region III
U.S. Nuclear Regulatory Commission
799 Roosevelt Road
Glen Ellyn, Illinois 60137

Dear Mr. Keppler:

This letter is in response to IE Bulletin No. 79-02. This response is supplemented by our response LDR-79-98 dated July 10, 1979 to your Immediate Action letter of July 6, 1979.

If you have any questions concerning this or our previous response, please contact us.

Very truly yours,

Larry D. Root

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Assistant Vice President
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A Report On

PIPE SUPPORT BASE PLATE DESIGNS

USING CONCRETE EXPANSION ANCHOR BOLTS

(In Response to: NRC IE Bulletin No. 79-02, Rev. 1, dated June 21, 1979)

I. Introduction

This report is in response to NRC IE Bulletin 79-02, Rev. 1, dated June 21, 1979, requiring all licensees and permit holders for nuclear power plants to review the design and installation procedures for concrete expansion anchor bolts used in pipe support base plates in systems defined as Seismic Category I by the NRC Regulatory Guide 1.29, "Seismic Design Classification" Revision 1, dated August, 1973 or by the applicable SAR.

In accordance with the intent of the Bulletin 79-02, the following types of supports have been considered in the present review.

a. Pipe Anchors (Seismic Category I)

b. Pipe Supports (Seismic Category I)

The design and installation of the expansion anchor bolts on the Duane Arnold Energy Center were governed by the following documents:

a. Technical Specification 7884-M-119 for Pipe Hangers, Supports and Restraints

b. Manufacturers Standardization Society MSS-SP-58, Pipe Hangers and Valves

c. American Society for Testing Materials Standards

II. Response to Action Items

1. Verify that pipe support base plate flexibility was accounted for in the calculation of anchor bolt loads. In lieu of supporting analysis justifying the assumption of rigidity, the base plates should be considered flexible if the unstiffened distance between the member welded to the plate and the edge of the base plate is greater than twice the thickness of the plate. It is recognized that this criterion is conservative. Less conservative acceptance criteria must be justified and the justification submitted as part of the response to the Bulletin. If the base plate is determined to be flexible, then recalculate the bolt loads using an appropriate analysis. If possible, this is to be done prior to testing of anchor bolts. These caluclated bolt loads are referred to hereafter as the bolt design loads. A description of the analytical model used to verify that pipe support base plate flexibility is accounted for in the calculation of anchor bolt loads is to be submitted with your response to the Bulletin.

   It has been noted that the schedule for analytical work on base plate flexibility for some facilities extends beyond the Bulletin reporting time frame of July 6, 1979. For those facilities for which an anchor bolt testing program is required (i.e., sufficient QC documentation does not exist), the anchor bolt testing program should not be delayed.

RESPONSE: All pipe anchor and support base plates using expansion anchor/bolts were (re) analyzed to account for plate flexibility, bolt stiffness, shear-tension interaction, minimum edge distance and proper bolt spacing. Depending on the complexity of the individual base plate configuration one of the following methods of analysis was used to determine the bolt forces:

(i) A quasi analytical method, developed by Bechtel was used for base plates with eight bolts or less. A review of the typical base plates used in supporting the subject piping systems indicate that the majority of them were anchored either by 4, 6 or 8 bolts. The plate thickness usually varied from 3/8" to 2" and are not generally stiffened. For these types of base plates an analytical formulation has been developed which treats the plates as a beam on multiple spring supports subjected to moments and forces in three orthogonal directions. Based on analytical considerations as well as on the results of a number of representative finite element analyses of base plates (using the "ANSYS" Code), certain empirical factors were introduced in the simplified beam model to account for (a) the effect of concrete foundation and (b) the two way action of load transfer in a plate. These factors essentially provided a way for introducing the interaction effect of such parametric variables as plate dimensions, attachment sizes, bolt spacings and stiffnesses on the distribution of external loads to the bolts.

The results from a number of case studies indicate excellent correlation between the results of the present formulation and those by the finite element method (using the "ANSYS" Code). The quasi analytical method generally gives the bolt loads greater than the finite element method (FEM).

Although the effect of plate flexibility has been explicitly considered in the quasi analytical formulation described above, the impact of prying action on the anchor bolts was determined not to be critical for the following reasons:

a. Where the anchorage system capacity is governed by the concrete shear cone, the prying action would result in an application of an external compressive load in the cone and would not therefore affect the anchorage capacity.

b. Where the bolt pull out determines the anchorage capacity, the additional load carried by the bolt due to the prying action will be self-limiting since the bolt stiffness decreases with increasing load. At higher loads the bolt expansion will be such that the corners of the base plate will lift off and the prying action will be relieved. This phenomena has been found to occur when the bolt stiffness in the finite element analysis was varied from a high to a low value, to correspond typically to the initial stiffness and that beyond the allowable design load.

A computer program for the analytical technique described above has been implemented for determining the bolt loads for routine applications. The program requires plate dimensions, number of bolts, bolt size, bolt spacing, bolt stiffness, the applied forces and the allowable bolt shear and tension loads as inputs. The allowable loads for a given bolt are determined based on the concrete edge distance, bolt spacing, embedment length, shear cone overlapping, manufacturer's ultimate capacity, and a design safety factor. The program computes the bolt forces and calculates a shear-tension interaction value based on the allowable loads.

The shear-tension interaction in the anchor bolts has been accounted for in the following manner:

1. Where the applied shear force is less than the frictional force developed in the shear plane between the steel and the concrete surface for balancing the imposed loads, no additional provisions are required for shear.

2. Otherwise, the total applied shear is required to be carried by the bolts in accordance with the following interaction formula.

$$\left(\frac{T}{T_A}\right)^2 + \left(\frac{S}{S_A}\right)^2 \leq 1.0$$

Where T and S are the calculated tensile and shear forces and T_A and S_A are the respective allowable values.

(ii) For special cases where the design of the support did not lend itself to the foregoing method, the finite element method using the "ANSYS" code and/or other standard engineering analytical techniques with conservative assumptions were employed in the analysis.

(iii) Other cases were solved using an approach based ~~on~~ the strength design method given in the ACI 318-77 code.

Of 558 large piping supports utilizing concrete expansion bolts, 524 have been analyzed for plate flexibility. Thirty-one (31) plates require modification because the safety factor is less than five. Eight plates have a safety factor of less than two which is acceptable during the interim period while modifications are being made. Analysis of the remaining 34 is continuing.

2. Verify that the concrete expansion anchor bolts have the following minimum factor of safety between the bolt design load and the bolt ultimate capacity determined from static load tests (e.g., anchor bolt manufacturer's) which simulate the actual conditions of installation (i.e., type of concrete and its strength properties):

   a. Four - For wedge and sleeve type anchor bolts.

   b. Five - For shell type anchor bolts.

   The bolt ultimate capacity should account for the effects of shear-tension interaction, minimum edge distance and proper bolt spacing.

   If the minimum factor of safety of four for wedge type anchor bolts and five for shell type anchors can not be shown then justification must be provided.

RESPONSE: In the current design review, factors of safety (i.e., ratio of bolt ultimate capacity to design load) four for wedge type and five for shell type anchor bolts were used for service load cases. When extreme environmental loads are included, a factor of safety of three is acceptable in accordance with Section B.7.2 of the Proposed Addition to Code Requirements for Nuclear Safety Related Concrete Structures (ACI 347-76) August, 1978.

It is noted that the particular manufacturers anchor bolts requirements are considered with the required factor of safety in order to provide a conservative support loading.

3. Describe the design requirements if applicable for anchor bolts to withstand cyclic loads (e.g., seismic loads and high cycle operating loads).

RESPONSE: In the original design of the piping systems Bechtel considered deadweight, thermal stresses, seismic loads, and dynamic loads in the generation of the pipe support design loads. To the extent that these loads include cyclic considerations, these effects would be included in the design of the hangers, base plates and anchorages.

The safety factors used for concrete expansion anchors, installed on supports for safety related piping systems, were not increased for loads which are cyclic in nature. The use of the same safety factor for cyclic and static loads is based on the FFTF Tests. The test results indicate:

1. The expansion anchors successfully withstood two million cycles of long term fatigue loading at a maximum intensity of 0.20 of the static ultimate capacity. When the maximum load intensity was steadily increased beyond the aforementioned value and cycled for 2,000 times at each load step, the observed failure load was about the same as the static ultimate capacity.

2. The dynamic load capacity of the expansion anchors, under simulated seismic loading, was about the same as their corresponding static ultimate capacities.

4. Verify from existing QC documentation that design requirements have been met for each anchor bolt in the following areas:

   a. Cyclic loads have been considered (e.g. anchor bolt preload is equal to or greater than bolt design load). In the case of the shell type, assure that it is not in contact with the back of the support plate prior to preload testing.

   b. Specified design size and type is correctly installed (e.g. proper embedment depth).

   If sufficient documentation does not exist, then initiate a testing program that will assure that minimum design requirements have been met with respect to sub-items (a) and (b) above. A sampling technique is acceptable. One acceptable technique is to randomly select and test one anchor bolt in each base plate (i.e. some supports may have more than one base plate). The test should provide verification of sub-items (a) and (b) above. If the test fails, all other bolts on that base plate should be similarly tested. In any event, the test program should assure that each Seismic Category 1 system will perform its intended function.

   The preferred test method to demonstrate that bolt preload has been accomplished is using a direct pull (tensile test) equal to or greater than design load. Recognizing this method may be difficult due to accessibility in some areas an alternative test method such as torque testing may be used. If torque testing is used it must be shown and substantiated that a correlation between torque and tension exists. If manufacturer's data for the specific bolt used is not available, or is not used, then site specific data must be developed by qualification tests.

   Bolt test values of one-fourth (wedge type) or one-fifth (shell type) of bolt ultimate capacity may be used in lieu of individually calculated bolt design loads where the test value can be shown to be conservative.

<u>RESPONSE</u>: It is not necessary that the bolt preload be equal to or greater than the bolt design load. Pipe supports and anchors are subjected to static and dynamic loads. The dynamic loads are seismic loads which are short duration cyclic loads. This type of cyclic load is not a fatigue load, so the amount of preload on the bolts will not greatly affect the performance of the anchorage. (In addition, preload is lost over the life of the plant due to creep and other similar phenomena). Therefore, if the initial installation torque on the bolt accomplished the purpose of setting the wedge, then the ultimate capacity of the bolt is not affected by the amount of preload present in the bolt at the time of cyclic loading. For vibratory loads during plant operation, the expansion anchors have successfully withstood long term fatigue environment as discussed in the previous section.

4. Response (Continued)

Existing Q.C. documentation did not verify that design requirements regarding specified design size and type of installation were met. Iowa Electric requested Bechtel to develop a test program consistant with Bulletin 79-02.

A sampling program developed to provide a 95% confidence level of less than a 5% failure rate indicated that zero failures in a sample of single bolts on 58 randomly selected anchors would result in the desired objective.

The acceptance criteria for anchor bolts included bolt size and length, plug-to-shoulder dimensions, thread engagement, drawing conformance, bolt bottoming out, shell in contact with base plate, test torque, concrete failure or excessive slippage and gap between concrete and plate.

On July 3, 1979 we informed your office that the preliminary results from testing all bolts at 21 anchors indicated a rejection rate of about 40%. On July 6, 1979 we met with members of the NRC staff and presented our findings at that time. Based upon the results of that meeting you issued an Immediate Action letter. The response to that letter is provided by our letter LDR-79-98 dated July 10, 1979.

The following summarizes the information related during the July 6, 1979 meeting.

146 bolts have been tested with a total rejection rate of about 40%. A further evaluation of the rejected installations indicates that slightly over half of these rejections are rejections for deficiencies which do not result in a failure of the anchor. Further evaluation of the 34 supports shows that 25 supports will accept the applied loads, 4 supports require further evaluation, and five supports were assumed to fail due to more than one bolt in the support failing.

In addition to the information provided in response to the Immediate Action letter, Iowa Electric has completed a visual inspection of accessible seismic loaded large pipe supports in the RHR, RCIC, Core Spray and HPCI systems. The results of this inspection indicate an approximate 13% rejection rate (loose nuts or bolts or bottomed bolts) which is consistant with (although less than) the results presented July 6, 1979. All loose nuts and bolts have been tightened. Bottomed bolts are being shimmed and tensioned as a temporary corrective action.

Iowa Electric plans to repair all deficient seismic loaded supports identified above in the HPCI system by July 20, 1979 and the supports in the RCIC system by July 27, 1979.

4. Response (Continued)

The torque values used in the field verification program were developed from the empirical equation:

$$M+ = KPD$$

where

$M+$ = torque value (in lbs)

K = frictional coefficient

P = bolt tension (lb)

D = bolt diameter (in)

The frictional coefficient is attached by many factors - any typically varies between 0.2 to 0.3. Minimum values were used to yield tension values in the test program of not less than 25% of the ultimate tensile capacity of the expansion anchor.

Small piping design for seismic loads for the DAEC utilized the rigid range method of analysis. This is a chart analysis method that yields results which can be shown to be highly conservative.

A random sample test program is being developed by Iowa Electric which will be conducted in parallel with the program for correction of deficiencies in the large pipe supports to determine the basis for the as-installed condition of small piping at the DAEC.

Our testing program is continuing, and any results will be factored into our continuing evaluations. It is our intent to change out all shell type anchor bolts with wedge type anchor bolts. We will keep you advised on our schedule and plans.