11/17/81

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
UNION ELECTRIC COMPANY	)	Docket Nos. STN 50-483
	)	STN 50-486
(Callaway Plant, Units 1 and 2)	)	

TESTIMONY OF JOHN S. MA, Ph.D, P.E.

Q. Please state your name, present position, and professional qualifications?

A. My name is John S. Ma. I am currently employed as a senior structural engineer in the Structural Engineering Branch of the Office of Nuclear Reactor Regulation of the U.S. Nuclear Regulatory Commission. I received a B.S. degree in Civil Engineering from Chung-Yuang University, Taiwan, Republic of China, a M.S. degree in Civil Engineering from the University of Missouri, Rolla, Missouri, and a Ph.D degree in Civil Engineering with a specialization in concrete structures from the University of Texas, Austin, Texas. I am a registered civil engineer in the State of California. My experience in construction includes airport and residential projects. My design experience includes low- and high-rise commercial and residential buildings, school buildings, industrial buildings, and nuclear power plant structures. My research experience includes concrete structures testing and computer programs development.

Q. What is the purpose of this testimony?

A. The purpose of this testimony is to address Joint Intervenors' Contention I.C.2 concerning concrete imperfections in the Callaway Reactor Containment Building Dome.

Q. Are you the technical reviewer of the Callaway Plant for the Structural Engineering Branch of the Office of Nuclear Reactor Regulation?

A. Yes.

Q. As part of the technical review for Callaway, did you review the adequacy of the reactor containment dome?

A. Yes.

Q. What is your conclusion as to the adequacy of the reactor containment dome?

A. The as-built concrete containment dome is adequate.

Q. Please describe the basis for your conclusion?

A. My conclusion is based on the following facts:

1. that the NRC inspector's finding has concluded that the field general quality assurance and quality control program represents an appropriate commitment to quality;

2. that examinations with both nondestructive and destructive techniques have indicated that the concrete imperfection is of a localized nature and limited in size in an otherwise excellent-to-average quality of concrete;

3. that the cause of the concrete imperfection can be logically attributed to the difficulties encountered in the field, placing concrete on a sloping surface without exterior forms; and

4. that in an engineering evaluation performed by me considering the concrete imperfection with data submitted at NRC's request by and for the Applicant, I concluded that actual concrete strength in compression is higher than its original design strength and the area of reinforcing steel being provided is more than required and the reinforcing bar lapping length and embedment length being provided is longer than needed, and this has resulted in more than enough to compensate for any deficiency created by the aforementioned concrete imperfection, thus making the as-built dome adequate in meeting its design requirements.

My engineering evaluation will include structural problem identification, description of the problems, and resolution of the problems, as a result of the concrete imperfection.

STRUCTURAL PROBLEM IDENTIFICATION

From the structural point of view the phenomenon of concrete imperfection in the Callaway dome relates to the question of overall concrete compressive strength. The amount of strength lost would be proportional to the degree and size of the imperfection.

The nondestructive testing and excavation have revealed that the imperfection consists mainly of the voids on the under and down-hill side of the outer layer hoop reinforcing steel, with a maximum length of the voids along the bar being approximately three feet. The consequence of the voids is a loss of bond between the steel and concrete. The loss of bond also occurs to the radial tie bars because their 90-degree bend extension is tied in parallel with the outer layer hoop steel.

Therefore, these two types of reinforcing steel should be analyzed for their adequacy considering the loss of bond due to the voids.

DESCRIPTION OF THE PROBLEM

The containment structure is designed to hold a volume of gaseous fluid at the Design Bas Accident (DBA) pressure combined with the elevated temperature associated with the DBA for a period of time during which the pressure and temperature rise to a peak level and then recede with time to some lower level. The internal pressure will produce hoop tension in the containment shell and this hoop tension must be resisted by the combination of the prestressing tendon and hoop reinforcing steel. Perhaps a wooden barrel containing liquid can be used to better explain the function and importance of the prestressing tendon and hoop reinforcing steel in a concrete containment shell, including the dome. The wooden staves that form barrels have the identical function and importance as concrete to a concrete containment structure; the ropes or metal bands (straps) that are tightly wound around the wooden staves have the identical function and importance as the prestressing tendon to a concrete containment structure; the untightened metal bands resembles the hoop reinforcing steel to a concrete containment. When the ropes or bands are tightened, they are under tensile prestress and they also put the wooden staves under compressive prestress, and both these prestresses resist the hoop tension produced by the internal liquid pressure. It is, therefore, understood that the wooden staves must be strong enough to take the compressive prestress and the ropes or bands to provide tensile prestress and tensile stress. The ropes or bands must be continuous so that hoop force or stress can be provided continuously around the hoop, because forces cannot be put into a broken band.

The prestressing tendons are continuous over the entire dome. However, the hoop reinforcing steel bars are not. This is because that reinforcing steel bars are usually cut to practical lengths for both shipping and field handling convenience purposes. Therefore, a closed loop of hoop reinforcing steel may contain several splices. Most of the splices in the Callaway dome are of the mechanical type which is similar to welding one end of the reinforcing steel to another end of the bar to be joined. In this kind of splice, forces can be transferred from one bar through the splice to the other directly without the help of concrete, as if there were no splices made. However, there are some hoop reinforcing steel bars which did use lap splice, simply lapping the two bars together for a certain length. In lap splices, forces can only be transferred from one bar to the other through concrete bond. The voids on the under side of the hoop reinforcing splices have somewhat weakened concrete bond. Therefore, the ability of the lap splices to transfer tensile force was examined.

The issue in the radial reinforcing tie bars due to the voids is not a splicing one as just described. Rather, it is an anchorage length or embedment length question. Experiments show that if a bar has enough embedment in concrete, it cannot be pulled out. Such a bar reaches its yield strength and fails in tension and is considered as fully anchored in concrete. On the other extreme, no force or stress can be put into a bar with zero embedment in concrete. Force or stress can only be put into a bar in a length embedded in concrete that is necessary to take it out through concrete bond.

Had the prestressing tendons been applied at the outer surface of a containment dome as the ropes or bands do onto the wooden staves of barrels, the radial ties would not have been required because the entire concrete dome would be in compression. Since the prestressing tendons are located at the middle surface of the dome, the tightening of the tendons could theoretically create a tendency to pull the lower portion of the dome away from the upper portion because concrete possesses very little tensile strength. The radial ties are intended to carry any tensile stress or force that may be developed in the upper portion of the concrete dome beyond and above the tendon surface due to prestressing effect. Since the extension of the 90-degree bend of the radial ties is anchored in a zone where voids have been found, the needed anchorage length through which to develop tensile force was also examined.

RESOLUTION OF THE PROBLEMS

A. Concrete Compressive Strength

Since the concrete imperfection in the Callaway dome is localized and limited in size and since the actual 90-day concrete strength in compression has attained 7,290 pound per square inches, (psi), far exceeding the 6,000 psi design strength, it is concluded that the concrete strength in compression of the dome is still more than adequate considering the existence of voids. And the fact that no failure or distress occurred during the stage of applying prestressing force is an indication of being good concrete.

B. Splice Length of Hoop Reinforcing Steel

The length of lap splices required through which to develop or transfer stresses were established by tests. Based on this test data, mathematical equations were derived for calculating splice lengths for all sizes of reinforcing bars under different situations. The higher tensile stress or force needs to be developed or transferred through a lap splice requires a longer lapping length. Among all the design loding conditions, one of them considering 1.5 times the DBA pressure in combination with the thermal effect associated with the DBA would produce the highest tensile stress of 44,500 psi in the outer layer hoop reinforcing steel. In order to develop and transfer this 44,500 psi tensile stress in the #9 hoop steel, spaced at 12 inches on center, in concrete with compressive strength being assumed at 7,290 psi, the required lapping length is calculated at about thirty-one (31) inches in accordance with Section 12.2 of the most current Building Code Requirements For Reinforced Concrete (ACI-318-77). Some research reports on bond and splicing of tensile reinforcing bars that came later than the publication of the ACI-318-77 Code have also been reviewed, and they confirmed that the calculated 31 inches of lapping length is conservative in this case. The maximum length of the voids on the under side of the hoop steel being reported is about thirty-six (36) inches and this is equivalent to 18 inches in length assuming, totally, no bond around the perimeter of the hoop bar. Subtracting this 18 inches away from the 76 inches lapping length being actually provided, it still leaves

58 inches to compare with the 31 inches required. Therefore, there is ample margin of safety reserved for the lap splice length.

C. Anchorage Length of Radial Steel Ties

For the prestressing force effect, the anchorage length of the radial ties required is about eleven (11) inches and the long leg of the ties is embedded in concrete about 16 inches, which is more than the 11 inches required. Therefore, even assuming no bond at all for the shorter leg which is anchored in concrete where voids were found, there is enough embedment length for the tie to be effective to develop force required for the prestressing force effect.

D. Conclusion

In conclusion, requirements of concrete codes in the designing and detailing of reinforcing steel and in concrete strength have provided the major margin of safety to the containment dome over its design strength, and the designer has also added some extra margin of safety over the code requirements. In view of the nature of the concrete imperfection noted, the as-built concrete dome still has an ample and acceptable margin of safety.