WILLIAM J. HALL
3105 VALLEY BROOK DR.
CHAMPAIGN, ILLINOIS 61820
217 356-0663

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Mr. Bert L. Barnes
EG&G Idaho/TSB
P. O. Box 1625
Idaho Falls, ID 83415

Dr. Tom Cheng
Systematic Evaluation Program Branch
Division of Licensing
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Re: San Onofre Nuclear Generating Station Unit No. 1 (Docket No. 50-206)
EG&G Consultant Agreement No. C84-100396 - WIS-50-84
Adequacy of Structural Beam Supports for Safety Related Piping

Gentlemen:

In accordance with the scope of work of the noted consultant agreement this letter report is concerned specifically with two of the three designated topics, namely (a) review of submittals regarding interpretation and application of concepts relating to "ductility factors" and (b) observations and suggestions resulting from attendance and participation in a meeting at IMPELL, Inc. headquarters in Bannockburn, Illinois on 15 May 1984 with representatives in attendance from Southern California Edison, IMPELL, USNRC, Bechtel, and associated consultants.

INTRODUCTION

The material reviewed prior to and following this meeting includes (a) a USNRC letter dated December 30, 1983 entitled "Subject: Summary of December 14, 1983 Meetings," (b) a USNRC letter dated February 6, 1984, entitled "Subject: Summary of January 31, 1984 Meeting," (c) a USNRC letter dated February 8, 1984, entitled "Subject: Proposed Restart Plan for San Onofre Nuclear Generating Station, Unit No. 1," and (d) a USNRC letter dated March 7, 1984 entitled "Subject: Seismic Evaluation of Structural Elements." Other even more highly pertinent documentation reviewed consisted of 58 pages of agenda presentation at the 15 May 1984 meeting, and the report NUREG/CR-0098 by N. M. Newmark and W. J. Hall.

The technical problem under consideration involves the behavior of beams which in turn provide the basis of support for the safety related piping and associated pipe supports. In the San Onofre Plant there are approximately 200 beam supports of this type supporting piping greater than 2-in. diameter and of these approximately 60 to 80 were identified by the licensee as potentially experiencing some degree of modest inelastic behavior (a ductility factor of 3 or less) under excitation corresponding to the current evaluation criteria and when analyzed by the current approximate analysis methods employed by contractors of Southern California Edison (SCE, the licensee). Of these 60 to 80 beams, four were identified as having significant inelastic behavior (a ductility factor greater than 10) and we were advised that these four beams are being fixed so as to remain either elastic or with limited inelasticity commensurate with the other noted beams.

The safety issue under consideration here centers around the fact that these piping systems are required for safe shutdown during and following a seismic event. More specifically, the concern here is primarily that connected with the permit for restart of the San Onofre Unit No. 1 facility insofar as assessing whether or not the method of calculation employed for evaluating the inelastic behavior is in fact physically tolerable and reasonable to expect or permit under the circumstances in the short term in permitting the plant to start operation. Additionally some degree of consideration as to what might be reasonably prudent to undertake for upgrade in the long term, if any, also is addressed briefly.

The objectives of the 15 May 1984 meeting as stated by the licensee were (1) "Demonstrate the applicability of estimating inelastic dynamic response of structures utilizing linear elastic analyses" and (2) "Demonstrate that limited ductility of the supporting structure does not have an adverse effect on the functionality of the piping system nor on the load distribution to the supporting structure." These topics are addressed in some detail in line with the previously stated purposes of the meeting in the material that follows.

APPLICANT'S STUDIES

In beginning the presentation the licensee cited three approximate approaches employed for determination of the ductility demand from elastic response analyses based on (1) the reserve energy technique as developed by J. A. Blume, (2) the ductility factor method as given generally by Newmark and Hall, and Clough and Penzien, and (3) the SONGS 1 Return to Service Criteria which is a modified form of the reserve energy technique whereby the force levels are replaced by an interaction expression. These techniques for estimating the expected amount of nonlinear (or inelastic) behavior are approximate in nature. And, particularly so, when it is appreciated that in an earthquake the excitation leads to reversals of motion (up and down or back and forth) with the associated hysteretic and damped deformation behavior.

In order to provide some basis for evaluation of these approximate expressions the licensee's contractors carried out one rather detailed series of sample calculations with a beam of approximate properties and dimensions typical of those in the system of 200 beams considered, and particularly the 60 to 80 beams cited earlier. The beam was subjected to some eight specific loading cases involving different time histories with different frequency contents, some of which were filtered to emphasize certain time domain effects, changes in beam frequency, changes in the beam strength levels, etc. The time-varying load was applied at the center of the beam which under the circumstances should lead to essentially the same results as if the supports were excited; in reality the beam and piping systems are connected resulting in a complex interactive system. The estimates of deformation (ductility ratio) were obtained in one case through use of a standard calculational technique (ANSYS) of some recognized analytical rigor, the ductility factor method involving comparison of maximum linear response to yield level response, and a third case involving the modified reserve energy technique. The limited study tended to indicate that the ductility factor method led to results reasonably in line with those for the ANSYS solution. On the other hand the modified reserve energy technique gave estimates of the ductility factor which were as much as three to five times the values given by the ANSYS solution, or in one case even less than that given by the ANSYS solution. The licensee stated that this showed that the reserve energy technique was conservative, which in fact might be considered to be the case, but in my opinion showed in this particular case that the reserve energy technique was really not a very accurate technique for estimating the inelastic behavior. Or, put another way, the modified reserve energy technique, which appeared to lead in most cases to an overestimate of deformation, was not particularly representative of the inelastic behavior that might be expected, and thereby makes one a little suspicious of the generality of application. This demonstration reinforces my belief that at least two different approximate techniques for estimating ductilities should be employed in such studies.

On the other hand the ductility value employed by the licensee as a criterion for the beams ($\mu \leq 3$) appears reasonable. However it is not the sole criterion relating to adequacy of the system as a whole, as the presentation by the licensee clearly indicated. For example, if the pipe stress increases unacceptably as a result of support beam deformation, even if $\mu = 1.2$ for example, then the deflection of the beam is too large; in such case the ductility ratio upper limit is meaningless. In reality the situation is quite complex and involves consideration of the interconnected piping and other supported loads, pipe supports, beam supports, in a system sense of adjacent supports. Clearly the excitation and response (as it affects behavior) of the system, or portions of the system need to be examined carefully and rationally to be sure that functionality is maintained. Thus for such a complex system some degree of parameter variation is needed as a part of the study to bound possible modes of response (behavior). The studies by the licensee to date suggest that such an approach is being followed, at least in part.

The licensee reported that it had held two meetings with Dr. V. Bertero, UC Berkeley, in connection with the behavioral response of the beams and that Dr. Bertero had expressed concern about ensuring that the beams would meet their strength requirements and not be subject to difficulties arising from local buckling, torsion, shear, or lateral torsional buckling. In the discussion at the 15 May meeting I gathered that the requirements for the flange width versus thickness ratios, and web depth versus thickness ratios were essentially in accordance with Part 2 of the AISC Code which is intended to ensure plastic beam action; that torsion was not believed to be a factor but needs to be examined in more detail; that the lengths of the beams and the dimensions of the beams were such that shear was not believed to be a factor in the response of these beams, although there was some considerable discussion about the connections (as discussed later herein); and that the lateral torsional buckling problem was being examined carefully and bracing installed in many cases for both the top and bottom flanges in view of the fact that the beams can vibrate in a manner that would lead any given flange to be in both compression and tension under limited local excitation.

As far as connections are concerned, it was emphasized in the discussions that great care must be taken to ensure that the connections remain effective as load carriers especially under the situation where the beams are deformed some limited amount. The connector elements (for example bolts, welds and clip angles) and the beam webs must be able to withstand the distortions associated with the flexure of the beams as well as the forces that might arise from shear, flexural, or axial distortion. The discussion by the licensee's contractors indicated these details would be monitored carefully as a part of the upgrade program. There was an indication that a number of the connections were being modified to ensure their adequacy.

A portion of the presentation at the 15 May meeting centered around the piping and the pipe support evaluation studies. The analyses carried out (for 25 large bore systems) were described in some detail with regard to consideration of gravity loads, thermal growth, the use of elastic seismic response spectra, seismic anchor motions, the functional stress limits, and the evaluation of the pipe supports in line with ASME Level D limits. These analyses showed that approximately one quarter of the pipe supports had to be upgraded in some manner -- 35 modifications and 70 new installations were required to meet the current evaluation criteria. The pipe stress criteria were reported to have been met in all cases studied thus far.

There was some discussion of the methods of combining the piping loads with dead loads and other system loads (including associated seismic inertial response) to arrive at an estimate of the loads to be applied to the beams to estimate inelastic behavior, if any. The procedure described appeared generally sound although some additional recommended calculations described later herein should serve to provide insight as to the conservatism of the load combination schemes, particularly for the seismic loadings.

As the concluding portion of the licensee's presentation the results of two specific typical beam analyses were described in some detail. The beams were subjected to the just noted loadings and the strength properties (moments and axial loads) calculated for use in the modified reserve energy approach to estimate the ductility ratio. It is to be noted that these are <u>decoupled</u> linear element type calculations in which the pipes and pipe supports are not coupled into the system. The dynamic loadings are handled as pseudo-static loadings. The estimated ductility ratios for the two cases ranged from about 2-1/4 to 1-3/4. These calculations were carried out for one specific piping system.

In summary, then, insofar as the May 15 presentation is concerned, the matter was one of reviewing the details of an approach that would permit one to make a judgment as to whether or not the approach being followed was a practical and efficient one for arriving at a basis for plant operation at least for a short time. It is my opinion that the method of approach will lead to an acceptable basis for evaluating capability for the short term if supplemented with additional effort as described next.

INTERPRETIVE OBSERVATIONS AND SUGGESTIONS

Clearly one can expect some limited inelastic behavior in these beams and connections under the current evaluation criteria-related excitation. The calculations reported at the meeting in terms of the limited inelastic behavior of the beams and the resulting pipe stress results as reported suggest that the system would not be impaired in the event of evaluation criteria-type earthquake excitation. Clearly the licensee and its contractors had carried out an extensive amount of work to arrive at this particular position and it appeared to be well documented generally.

A related concern would be whether or not difficulties (loss of system function) could be expected if the earthquake excitation were slightly larger than criteria specified. Or put another way, is there a reasonable margin? A first overview suggests to me that some margin clearly exists but it should be identified as a part of the analyses carried out in conjunction with the evaluation process.

At the meeting I noted that I do have concerns, based on my experience, with the use of linear analyses to predict inelastic behavior. Clearly the use of an energy balance approach (involving conservation of energy) is rationally correct, especially if momentum concepts are correctly handled. However, the nature of the response of a beam under earthquake excitation, where it undergoes piece-wise cyclic yielding behavior, leads these linear techniques to give approximate estimates at best. For this reason I was pleased to see that the ANSYS solution, which would be expected to be reasonably characteristic of the behavior that might be expected, gave results suggesting limited nonlinear behavior. To repeat, I believe at least two independent approximate procedures should be employed to estimate the support beam ductility ratio.

I pointed out that from a rational point of view one should look at the behavior from several different viewpoints. First of all the studies for the most part were carried out as uncoupled studies; the pipe stress and the beam deformations were studied in the absence of system connectivity. Such studies would be extremely complicated and expensive if they could be done at all. In other words, up to now the various effects have been studied in isolation (as uncoupled elements). Indeed the study of the various elements in this manner is a necessary and proper part of the process. Another aspect however that I believe should be examined more fully is that of looking at each system as a whole in the light of the expected behavior of the local elements. For example, if it could be concluded, and such may well be the case, that one would expect no more than one or two adjacent beam supports to yield slightly (a "local" system effect) and if it could be shown that this did not cause any difficulties with the piping system functionality, then this might be a completely acceptable situation. On the other hand if it were judged that two, three or even four adjacent pipe supports yielded to the extent that potential system functionality difficulties could occur then one might conclude that this was too much of a local system type deformation situation to be tolerated, and some fix must be carried out in that region of the system to ensure that system integrity and a satisfactory margin of safety were maintained. It is envisioned that it should be possible to arrive at some grouping of supporting beam elements and in turn that representative analyses can be made that are applicable to each grouping. It is appropriate to point out that there is some basis for believing that some inelastic behavior in the response of the system may well be desirable in the sense of absorbing energy imparted to the system, providing damping, and maintaining a functional system especially if this energy absorption is predictable and controlled from the standpoint of total system response.

It is my recommendation that the licensee carry out one or two simple coupled analyses involving as many as perhaps three or four adjacent supporting systems, for which yielding is potentially possible, to study both the local behavior as examined by the licensee to this point in time and a sector of total system response. It may well be that it will be found that when the coupled analysis is carried out that the deformations are equal to or significantly less than those in the uncoupled situation. One or two analyses of this type would go a long way to provide additional confirmation of the basis of judgment for assessing the adequacy of the system to function properly and maintain an adequate margin of safety under the expected excitation.

At this point it would seem logical that a team of engineers knowledgeable of the results of such studies could, by careful inspection of each of the critical safety systems in the plant, draw reasonably valid judgments as to the adequacy of the support beams and connections on a system basis, and identify zones of local "soft spots," if any, that may need additional study. It would seem logical, and completely acceptable to me on the basis of this approach, to believe that a rationally based judgmental assessment could be carried out that would be adequate for permitting restart of this facility under conditions noted and that would be acceptable from the standpoint of maintenance of functionality in terms of safe shutdown during and after the earthquake postulated for this site.

For the long term and preparatory to the time of first subsequent shutdown for refueling it would seem that it would be appropriate to carry out a more rationally based system-wide study of each of the safety systems on the basis of a mutually agreed upon and acceptable analysis approach. On the basis of these studies, the nature of which is yet to be determined, the licensee should undertake such fixes as might be required to ensure that the system's functionality is clearly that which would be expected under the criteria. Such a study may or may not entail upgrade of the systems over and above that situation which is found to be the case under the studies currently being carried out.

This concludes my comments.

Sincerely yours,

W. J. Hall

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