UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
PORTLAND GENERAL ELECTRIC COMPANY ET AL.	)	Docket No. 50-344
	)	(Control Building)
(Trojan Nuclear Plant)	)	

TESTIMONY OF KENNETH S. HERRING,
OFFICE OF NUCLEAR REACTOR REGULATION,
REGARDING THE SUPPLEMENTAL STARDYNE ANALYSIS
AND ITS EFFECT ON THE STRUCTURAL CAPACITY
OF THE TROJAN CONTROL BUILDING

INTRODUCTION

On August 22, 1978, the NRC was first notified by the Portland General Electric Company (PGE) of the preliminary results of a confirmatory analysis that had just been completed. These results indicated that the total seismic base shear forces for the Control Building were greater than those used in the previous reevaluation. It also indicated a different distribution of the seismic forces to the shear walls than had been assumed previously. This confirmatory analysis consisted of performing a response spectrum modal analysis of a STARDYNE 3-D finite element representation of the Control/Auxiliary/Fuel Building complex.

A meeting was held on August 28, 1978 to discuss the preliminary results of this analysis. PGE, Oregon, Bechtel and the NRC were represented at this meeting. The preliminary results presented by PGE at this meeting were later documented in a submittal from PGE dated September 1, 1978. Final results and an evaluation of the results of the STARDYNE analysis

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were documented in a submittal from PGE dated September 20, 1978, along with responses to a set of NRC questions which were generated as a result of the August 28, 1978 meeting. Documentation regarding further questions raised by the NRC Staff after a review of the September 20, 1978 submittal are given in additional PGE submittals dated October 4, 6, 10, 13 and 16, 1978.

LICENSEE EVALUATION OF THE STARDYNE ANALYSIS

A description of the STARDYNE 3-D finite element model of the Control/Auxiliary/Fuel Building complex is contained in the document attached to the PGE September 20, 1978 submittal entitled "Trojan Control Building Supplemental Structural Evaluation, September 19, 1978." Also contained in this document is a comparison of the results of the forces derived from the original seismic analysis, the reevaluation of the original seismic analysis, and an additional confirmatory TABS analysis. The STARDYNE 3-D finite element analysis results, considering the structure as fixed-base, were used for this evaluation as it was determined that the flexible base STARDYNE analysis predicted loads which not considerably higher than the fixed base results, and these higher loads would tend to be reduced if radiation damping was considered for the foundation. The STARDYNE results were somewhat higher than those predicted by the reevaluation of the original and the TABS analyses, but were less than those used in the original design. Additionally, this STARDYNE model simulated the major walls and floor slabs with plate finite elements having elastic properties representative of the actual walls and floor slabs. Therefore, this model indicated a more realistic distribution of forces to the various walls and floor slabs than did the previous analyses.

Given the better defined, yet higher Control/Auxiliary Building wall loadings, a reassessment of the actual behavior and capacities of these walls was performed using the Schneider and Berkeley test results for reinforced grouted masonry shear piers and the Portland Cement Association test results on reinforced concrete shear panels. This reassessment resulted in a set of criteria which was applied to determine wall capacities and structural behavior. These criteria and the results of their application are described in the previously referenced submittals. Additionally, the walls of the Fuel Building were reassessed, given the forces indicated by the STARDYNE analysis, and were found to meet the appropriate FSAR approved acceptance criteria, namely ACI 318-63. Also, the shear transfer capability at the wall-slab and sidewall-endwall interfaces was investigated and found to be adequate. The shear capacity of the slabs was evaluated in accordance with the shear friction provisions of ACI 318-71. The wall-slab interfaces with the wall were found to have adequate dowel capacities except in the lower elevations of the west wall for which a conservative contribution from shear friction due to dead load would provide the necessary resistance in addition to the dowels. Shear transfer at the side wall-end wall interfaces was found to be adequate considering the dowel capacity of the rebar and the beam-to-column connection capability while neglecting any shear transfer by the concrete.

Due to the distribution of forces throughout the structure predicted by the STARDYNE analysis, an evaluation of the capability of the foundation structures against sliding was performed. The results of this evaluation indicated that the Control/Auxiliary/Fuel Building complex meets the minimum factors of safety for sliding and overturning as specified in the U.S.N.R.C. Standard Review Plan, Section 3.8.5.

The maximum reinforcing steel strains were estimated to be approximately 6 times the yield strain. This is slightly less than the previous re-evaluation estimates of maximum reinforcing steel strain.

The maximum amounts of interstory displacements within the Control Building and interstructure displacements between the Control Building and Containment, and the Control Building and Turbine Building were conservatively estimated considering increased nonlinear behavior of the Control Building. The Turbine Building displacements were refined from those in the original analysis considering the as-built configuration of the Turbine Building. The Control Building displacements were conservatively estimated using the stress results from the STARDYNE elastic analysis for the west wall (the major and most highly loaded wall relative to its capacity) of the Control Building and a shear stress vs. shear strain curve derived from the Berkeley and PCA tests by averaging since the walls consist of about equal portions of concrete and masonry. These displacement evaluations indicated a maximum interstory displacement of 0.53 inches in the N-S direction within the Control Building (between Elevations 45' and 61'). The maximum displacement at the top of the building was determined to be about 0.09 inches in the E-W direction and 0.9 inches in the N-S direction. A survey of the Control, Auxiliary and Fuel Buildings concluded that larger interstory displacements than anticipated (i.e. greater than 1 inch between floors) could be tolerated. The maximum interstructure displacements determined from their analyses, about 2.4 and 2.49 inches between the Control and Turbine Buildings in the N-S and E-W directions, respectively, at the top of the Control Building and about 0.76 inches of separation between the Control Building and Containment at Elevation 77', were found to be tolerable.

The implications of the STARDYNE analysis results on the floor response spectra, including the effect of the maximum estimated nonlinear structural behavior were also addressed. The Control Building elastic floor response spectra corresponding to the STARDYNE analysis were derived from the original response as described in the prevously referenced submittals. The STARDYNE predicted loads on the west wall of the Control Building and the shear stress vs. shear strain derived from the PCA and Berkeley test data were again used in this evaluation. The impact of the response spectra as modified to correspond to the STARDYNE analysis, including estimates of the effects of nonlinear behavior, on the safety related equipment, components and systems (especially that required for ECCS and safe shutdown) in the Control, Auxiliary and Fuel Buildings was assessed. The Control Building cable trays and their supports were reanalyzed and found to meet the appropriate original FSAR criteria. A reanalysis of the only safety related piping in the Control Building resulted in the addition of only two seismic restraints. This portion of the reevaluation concluded that there is reasonable assurance that the safety related components, equipment and systems in the Control, Auxiliary and Fuel Buildings would not be affected by the response spectra derived from the STARDYNE reevaluation.

An evaluation was also made of the earthquake acceleration level at which significant nonlinear behavior would begin, corresponding to 2 percent damping for the structure. Their calculations were performed using the wall capacities which did not consider the effects of vertical earthquake (which is required to be combined by absolute sum with the horizontal component according to the licensed criteria) or the refined dead load distributions, and took wall loadings from the STARDYNE analysis which did not approximately limit wall loadings to their capacities (especially capacities controlled by bending moment). This evaluation indicated an earthquake acceleration level of about 0.10 "g" to 0.12 "g" as the point where the more significant walls (those controlled by shear rather than bending moment capacity) reach the assumed cracking nominal shear stress level.

NRC EVALUATION

The NRC has reviewed the referenced information submitted by the licensee, and highlighted in the previous discussions. The Staff's evaluation and conclusions are presented in the following discussions.

The STARDYNE 3-D finite element analysis was reviewed. The fixed-base modal analyses of this structure using the FSAR defined response spectra considered modes up to a frequence of 18.7 Hz with corresponding modal effective weights in the N-S and E-W directions of 94 percent and 91 percent, respectively, of the total weight. Therefore, modes higher than 18.7 Hz should not contribute significantly to the response. Modal responses were combined using the SRSS technique, considering closely spaced modes to be combined by the "10% grouping method," which is acceptable under current criteria. Use of the fixed-base STARDYNE model, rather than the flexible base STARDYNE model, is acceptable since the differences in response between these two models was not significant when radiation damping from the foundation for the flexible base model was conservatively neglected. Also, U.S.N.R.C. Standard Review Plan, Section 3.7.2 indicates that fixed-based analyses are acceptable if the shear wave velocity for the foundation medium is greater than or equal to 3500 fps, which is lower than the Trojan in-situ shear wave velocities.

The STARDYNE model simulated the major shear walls and floor slabs with plate finite elements having elastic properties representative of the actual walls and floor slabs. This provided a better representation of the structure than did the original seismic structural model. A comparison of the total N-S base shears obtained from the STARDYNE analysis and the reevaluation of the original analysis for the entire Control/Auxiliary/Fuel Building complex (19590 KIPS and 18480 KIPS, respectively) indicates that the results of the models do not differ substantially. (It should be pointed out that the large capacity available in the E-W direction in excess of the applied loads indicates that the N-S direction is more critical due to the higher loading relative to the capacity. Behavior in the N-S direction was, therefore, focused on in depth.) Also, for the dominant first N-S mode, the frequencies predicted by the STARDYNE and the original analysis, 6.8 Hz and 6.2 Hz, respectively, are in good agreement. (The E-W modes in these two models did not agree as well (8.5 Hz vs. 6.9 Hz, respectively); however, the N-S direction is most critical. Therefore, this discrepancy would not be expected to effect the conclusions drawn from an in-depth study of the N-S direction). These factors give confidence to the accuracy of the STARDYNE model.

The basic significant difference between these two analyses is that the more refined STARDYNE analysis predicted greater torsional contributions to the loading of the Control Building than did the original model. The increase in the total base shear for the Control Building predicted by the STARDYNE analysis over the reevaluation of the original analysis in the N-S direction was about 20%, while the predicted Fuel Building base shear decreased. Although the TABS analysis predicted linear forces and different torsional behavior of the structure than the above two analyses, in view of the inability of the beam-like behavior TABS model to adequately represent the flange effect of cross walls and the behavior of box-type wall systems such as those found in the building complex and the relatively good agreement of the two models discussed above, the accuracy of the TABS analysis results is questionable and should not reflect on the credibility of the STARDYNE results. Because of the differences in the mathematical formulations (structural representation) between the original model and the STARDYNE model, differences in response between these models would be expected.

As delineated in the licensee's submittals, a new set of criteria to determine wall capacity was determined from the original Schneider criteria by accounting for the increased shear capacity of the test specimens due to compressive stresses developed in them from the testing apparatus, along with other considerations. Comparison of the capacities predicted by this "modified Schneider criteria" with the Schneider and Berkeley test results indicates good, somewhat conservative agreement. The initial comparison with the Berkeley data was made from specimens with H/L of about 1. Additional preliminary Berkeley test results for walls with H/L = 0.5 indicate that the basic modified Schneider criteria are conservative when applied to these additional specimens even when applied to a test specimen with no horizontal reinforcement. This test specimen had a capacity which was much greater than the 150 psi Trojan limit. It should be noted that the composite Trojan walls have been indicated to be stronger than the blocks in the test specimens. Bending moment was considered to limit a wall's capacity if this indicated a lower shear capability of the wall than the modified Schneider criteria.

Wall capacities were computed and compared to the loads derived from the STARDYNE linear elastic analysis which allowed members to reach their total elastic stiffness-derived loading, irrespective of capacity. Given the large ratios of capacity to load for the members parallel to the E-W direction due to an E-W earthquake (except for a few minor members with capacities controlled by moment), this direction was not evaluated in detail. The positive margins and the fact that the stiffness of the

Fuel Building (which is loaded well below its capacity) would be expected to have a greater stiffening effect on the complex in the E-W direction than in the N-S direction should preclude any significant inelastic behavior from developing which would significantly effect the response in that direction. The lower ratios of capacity to load for the members parallel to the N-S direction due to an earthquake in the N-S direction would indicate potentially greater nonlinear behavior than for the E-W direction. Thus, this direction was considered in detail.

The N-S direction was evaluated to study the effects of redistribution of forces among the walls for cases of limiting the capacities of large walls, limiting vertical shear transfer and limiting the capacities of all walls in the system. This last case is considered to be the most realistic since the members governed by shear behavior were not loaded beyond their capacity in the analysis. Those members which exceeded their capacity in the initial STARDYNE analysis were governed by more ductile bending moment behavior. Limiting the loading of the bending-moment behavior-controlled members in this analysis more correctly simulated actual behavior. These analyses indicated a good capability for redistribution of forces to the various walls. For the most realistic case mentioned above, the lowest ratio of capacity to load for the most critical N-S wall between Elevations 45 and 77 was determined to be $\frac{4980}{4320} = 1.153$ and was associated with the west wall of the Control Building between Elevations 45 and 61. The capacity here considered vertical earthquake components and the revised dead load. Vertical shear transfer, and shear transfer at the floor slabs and wall interfaces was shown to be adequate. The difference in the uncracked shear modulus used in the analysis and the shear modulus derived from cyclic test data would not have a significant impact on magnitudes of response since the spectral accelerations associated with the dominant first mode reduced frequency in each direction will still be obtained from the relatively flat portion of the response spectra. Because the response is dominated by the fundamental modes in the respective directions, some increase in the higher model accelerations will not offer a significantly greater contribution to response.

In view of the fact that the steel framing is designed to carry the vertical loads and that the results of the above analyses as presented by the licensee considered forces resulting from a linear elastic seismic analyses and neglected the increased energy dissipation (and, therefore, lower seismic loading) which would result from any nonlinear behavior of the structure, there is reasonable assurance that the structure will withstand the required SSE with sufficient margin to insure the safety of the public.

However, in the previous NRC testimony it was indicated that since the 0.15 g OBE loads are essentially the same as the 0.25 g SSE loads and the more significant members were predicted to begin reaching their capacities, as defined in the initial reevaluation, at approximately 70 percent of the total predicted SSE loading, there was reasonable assurance that the more significant walls would remain essentially elastic for up to a 0.11 g earthquake. Under the assumption that nonlinear behavior (first cracking) begins when a member's load reaches approximately 1/2 of its total capacity, the STARDYNE analysis indicates that the west wall of the Control Building will begin nonlinear behavior at approximately $\frac{4980}{2(4320)}$ = .58 of the total SSE elastically calculated load. Therefore, these results indicate that nonlinear behavior will begin at an earthquake level (considering 2 percent structural damping) of about .58 x .15g = 0.087g. (Also, if it is considered that the STARDYNE analysis predicted an approximate 20 percent greater base shear for the Control Building than did the reevaluation of the original analysis, the previous reasoning for the acceptability of a 0.11g earthquake would imply an appropriate lowering of the 0.11g). Therefore, rounding down rather than up for conservatism in the analyses, the STARDYNE analyses would necessitate that the facility now be shut down and inspected in the event that an earthquake occurs before the modifications are completed which exceeds the facility criteria for a 0.08g effective peak ground acceleration earthquake.

Additionally, the reinforced concrete Fuel Building Structure was reevaluated considering the loads from a factored 0.15 g OBE (essentially 1.4 times the SSE loads) and was found to meet the FSAR acceptance criteria of ACI 318-63. In most cases the capacity of these walls greatly exceeded their OBE loading. It is concluded that the Fuel Building (for both the OBE and SSE) remains within FSAR criteria.

The reevaluation of the foundation indicated minimum factors of safety against sliding and overturning for the Control/Auxiliary/Fuel Building complex in accordance with those specified in the U.S.N.R.C. Standard Review Plan Section 3.8.5. Given the information on the foundation supplied by the licensee, the method of analysis which determined the resistance of the complex using loads derived from the linear elastic seismic response spectrum analysis, and the fact that the building base shears determined from the STARDYNE analyses are less than those used for the original design, there is reasonable assurance that the structure is stable.

Maximum reinforcement steel strains were estimated from the results of the STARDYNE analyses. The estimate of approximately 6 times the yield strain is less than that evaluated in the testimony regarding the initial reevaluation and is therefore acceptable.

The estimates of the maximum N-S interstory displacements within the complex and displacements between the Control Building and Containment and the Control and Turbine Buildings should be an upper limit. Firstly, the Control Building displacements were conservatively estimated by considering elastically calculated stresses in the west wall of the Control Building (the shear controlled wall most highly loaded relative to its capacity) in conjunction with an average stress-strain curve for the Control Building structure. (It should be noted that the concrete compressive strengths for the PCA tests were about 3000 psi and the as-built strength of the Trojan core concrete is about 6000 psi. Therefore, the Trojan cores should be somewhat stiffer than indicated by the PCA tests.) Energy dissipation in nonlinear behavior, any stiffening effects of the Control Building walls which were loaded less with respect to their ultimate capacities, and stiffening effects from the interconnected Fuel Building (which remains essentially elastic based on the comparison of factored OBE loads to member capacity in this structure) were conservatively neglected. Secondly, the relative displacements were added absolutely. The minimum Control Building displacements in the less critical E-W direction from an E-W earthquake were also estimated using the stresses for the North wall of the Control Building which is representatively stressed relative to its capacity. As mentioned before, this direction is loaded substantially lower, relative to the capacity, than the N-S direction and the estimated displacements in this direction were about a factor of 10 lower than those in the N-S direction. The shear stress vs. shear strain curve derived from the Berkeley and PCA cyclic shear wall tests was used in both evaluations. Therefore, the effects of small cracking on the initial elastic shear modulus were considered. Also, this stress-strain curve included the effects of shear modulus reduction at the onset of nonlinear behavior (assumed to be at a shear stress of 100 psi for the composite walls). The predicted maximum displacements were found to be tolerable. This evaluation demonstrates that there is adequate assurance that increased displacements resulting from nonlinear behavior of the Control Building will not have any adverse effects on public safety.

The implications of the STARDYNE analysis results on the floor response spectra, including the effects of the maximum estimated nonlinear structural behavior, were assessed. Spectra corresponding to the STARDYNE analysis were derived from the response spectra derived in the original analysis as described in the September 20, 1978 and October 6, 10, and 13, 1978, responses to NRC questions. Further investigation has indicated that anomalies between the original and STARDYNE dynamic structural models indicate that differences between the original and STARDYNE floor response spectral shapes may exist (i.e., STARDYNE implies potential spectral peaks which were not indicated by the original analysis). However, the magnitudes of the differences between the spectra cannot be quantified with acceptable tolerances at this time. As indicated by letter dated October 16, 1978, from the licensee to the NRC, these anomalies and the effects of these anomalies upon the safety-related components, equipment, piping and systems required to prevent an accident or mitigate the consequences of an accident are under additional continued investigation. In cases where the response spectra anomalies indicate noncompliance with the seismic design criteria of the operating license, suitable modifications or requalification will be performed to reestablish the original license requirements prior to resumption of plant operation. This will be performed for all such identified equipment located above elevation 45' in the Control, Fuel, and Auxiliary Building complex. This information will be reviewed by the NRC Staff. We will advise the Board of our findings.

CONCLUSION

Based upon the NRC review and evaluation of the information resulting from the supplemental STARDYNE analyses and submitted by the licensee, the previous NRC conclusion that there is adequate assurance that the structure, in its existing configuration, can withstand the effects of an SSE, including the less severe OBE, at the Trojan site remains unchanged. However, the previously stated earthquake level at which the plant should be shut down and inspected (0.11 g EPGA, which prior testimony indicated was approximately the level at which nonlinear behavior of the significant shear walls might begin) has been altered by the supplemental information. This refined earthquake level should be established according to the facility OBE seismic criteria at 0.08 g EPGA. The Staff continues to conclude that the originally intended margins of safety have been reduced and that the previously stated applicable codes are not satisfied. Contingent upon the satisfactory completion of our review of the information to be submitted by the licensee regarding their investigation of the floor response spectra, as outlined above, we have thus concluded that interim operation for the approximately one-year period necessary to effect structural repairs and improvements is appropriate; however, the original structural safety margins should be restored to the extent practicable in order to ensure adequate protection of the health and safety of the public during the long-term operation of the facility.

This evaluation, which has concluded that interim operation should be permitted, has not considered the effects on interim operation of on-going modifications to the Control Building since the proposed modifications are not known in detail at this time. Prior to the time modifications are authorized, the Staff will assess whether modifications or portions thereof will require the facility to be shutdown prior to and during their performance or other appropriate actions taken.