TRIP REPORT FOR AUDIT CONDUCTED AS PART OF BNL

EXPERT PANEL REVIEW OF DIABLO CANYON

LONG TERM SEISMIC PROGRAM

C.J. COSTANTINO

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1.0 INTRODUCTION

This report presents a summary of the actions taken during the audit conducted as part of the review of the Diablo Canyon Long Term Seismic Program (LTSP). The audit was conducted by Drs. C.J. Costantino and A.J. Philippacopoulos of Brookhaven National Laboratory (BNL) and Dr. R. Pichumani of the U.S. Nuclear Regulatory Commission (NRC), during the period of June 9-11, 1987 at the offices of the Bechtel Corporation. This audit is associated with the effort described under Task 3 of the independent review program being conducted by BNL.

The objective of the audit was to critically assess the calculational program being conducted by the LTSP Project Team to evaluate potential soil-structure interaction (SSI) effects by performing detailed calculations using the CLASSI and SASSI computer programs. These calculations fall into three categories, namely,

(a) calculations for given structure/halfspace configurations for which analytic solutions are available for comparison purposes;
(b) calculations for specific configurations using both computer codes for mutual comparison; and
(c) calculations using either computer code for configurations applicable to the Diablo Canyon site.

The objective of the first set of calculations is to debug the codes and ensure that they are generating results which are compatible with analytic solutions. The second category of calculations is to show that both codes yield the same response results for the same configuration, while the third set is to generate SSI response results applicable to the DC site.

The specific objectives of the audit team were the following:

(a) ascertain and evaluate the applicability of the analytic bases and formulation of both the CLASSI and SASSI codes;

(b) perform a detailed audit of the modifications made to the programs and the calculations made by the LTSP Project Team;

(c) quantify the specific ranges of applicability of the codes by determining ranges of numerical stabilities and computational sensitivities;

(d) audit the numerical output generated for both the generic structure/halfspace configurations and the specific configurations of interest at the DC site.

2.0 TECHNICAL DISCUSSION

The first activity conducted by the audit team was to review in detail the analytic bases and formulation of both the CLASSI and SASSI computer programs. To this end, a presentation was made by the LTSP Project Team, followed by detailed discussions and evaluations, including review of output for the various computer runs. The following summarizes these discussions.

2.1 CLASSI Review

BNL personnel had previously invested a significant effort in learning, debugging and making operational the CLASSI Code originally distributed in the early 1980's. This code treats arbitrarily shaped rigid foundations placed on the surface of an elastic layered halfspace. The code generates frequency dependent impedance functions and scattering matrices for the case of nonvertically propagating body waves. The current version of CLASSI being implemented by the LTSP Project Team has been modified to include (a) new algorithms for computing and inverting Green's functions (Ref. 1), (b) capability to determine forced vibration response for comparison purposes, and (c) capability to treat multiple foundations to allow for study of structure/structure interaction. Other relatively minor modifications were made to enhance the input/output capability of the code. It should be mentioned that the code is now operational on both the CDC/Cray and IBM mainframe machines.

Benchmarking of the updated CLASSI Code was conducted by the LTSP Project Team by comparing results generated by CLASSI with available solutions for 16 cases. These solutions were obtained from analytic, numerical and experimental data available in the open literature. The audit team selected 6 of these calculational packages for detailed review. These problems were:

1. Test Problem 2 - Rigid Circular Footing on Two-Layer Elastic Soil; File No. 999 - Calculation No. 3-02
2. Test Problem 10 - Strip Foundation on Layered Soil; File No. 999 - Calculation No. 3-10

3. Test Problem 3 - Impedance of Square Foundation; File No. 999 - Calculation No. 3-03
4. Test Problem 7 - Multiple Foundation on Layered Halfspace; File No. 999 - Calculation No. 3-07
5. Test Problem No. 15 - Circular Rigid Disk Subjected to Vertical Trapezoidal Time History; File No. 999, Calculation No. 3-15
6. Test Problem No. 16 - Measured Response from a Japanese Experiment; File No. 999 - Calculation No. 3-16.

The above problems were selected specifically to check the impedance, scattering and forced vibration aspects of the CLASSI computation.

2.2 SASSI Review

The formulation of the CLASSI program used by the LTSP cannot treat the following aspects of the SSI problem: (a) flexible foundation and (b) embedment effects. To overcome these restrictions, the SASSI Code, formulated by Lysmer, et al.,(Ref. 2), is being used by the Program Team. The SASSI Code is again restricted to treat the elastic, horizontally layered, soil site, but uses a finite element formulation of the foundation model to allow for inclusion of both the embedment and foundation flexibility effects. Again, a detailed debugging effort was undertaken by the LTSP Project Team to check the validity of the code. Modifications were made to expand the capability of the code as well as to enhance input/output options. Again, the SASSI Code has been made operational on an IBM mainframe.

Benchmarking of the SASSI Code was made using a set of twenty test problems. The results of these computations are contained in a three-volume set labeled Calculation No. DCPP-LTSP-SSI Job 17928, Calculations 2-01 through 2-20, entitled "SASSI Test Problems, Calculation Sheets". The audit team reviewed in detail six of these twenty test problems, which again relate to the three primary aspects of the SSI problem. These are:

1. Test Problem 3 - Circular Rigid Disk Subjected to Vertical Trapezoidal Time History
2. Test Problem 5 - Impedance Functions for Rigid Circular Foundation on Surface of Two Layer Soil

3. Test Problem 14 - Multiple Foundation on Layered Halfspace
4. Test Problem 15 - Rigid Cylinder Embedded in Layered Soil on Rigid Base (Comparison with Kausel Solution)
5. Test Problem 17 - Strip Foundation on a Layered Soil
6. Test Problem 18 - Embedded Massless Foundation

2.3 Problems for DC Site

In addition to the comparison problems listed above, specific calculations for foundation configurations appropriate to the Diablo Canyon Site were reviewed. These calculations were made using both the CLASSI and SASSI Codes. The foundation was discretized into a three layer rock system overlying an elastic halfspace, with the foundation mat placed at elevation 91'. The shear wave velocity of the rock varies from 2600 fps to 4800 fps, with the specific properties taken from Ref. 3. The input to these calculations was a time history fitted to the original Hosgri spectra.

Calculations were made for both the RCB as well as the Auxiliary Building, using the new stick models developed by the LTSP Project Team for these facilities and which were reported on previously. Plots of stiffness and damping parameters as a function of frequency were presented. For those structural configurations run with both CLASSI and SASSI, the only differences in results observed occurred at the peaks of floor response spectra. These differences are most likely due to differences in the structural damping formulations used in the two codes (i.e., element vs. modal damping) rather than anything intrinsic to the SSI aspects of the calculation. The specific calculations reviewed were contained in calculation book DCPP-LTSP-SSI Job No. 17928 and referred to as:

Calculation No. 5-01 - Containment Bldg. Analysis with CLASSI
Calculation No. 6-01 - Containment Bldg. Analysis with SASSI
Calculation No. 5-02 - Auxiliary Bldg. Analysis with CLASSI
Calculation No. 6-02 - Auxiliary Bldg. Analysis with SASSI
Calculation No. 5-03 - Containment Bldg. & Auxiliary Bldg. with CLASSI
Calculation No. 6-03 - Containment Bldg. & Auxiliary Bldg. with SASSI

The last two calculations were performed to estimate structure-to-structure effects at the DC Site.

3.0 CONCLUSIONS AND RECOMMENDATIONS OF AUDIT

The results of the audit confirmed that the LTSP Project Team is, in fact, conducting an excellent evaluation of SSI effects as part of the site evaluation. They have modified and debugged the two computer programs so that these two codes, based on fundamentally separate concepts, yield essentially the same results in the regions of their applicability. They should be commended for their efforts.

Some specific recommendations were made to the Team to ensure that the numerical results which will be generated for the site are complete and reliable. These are described in the following.

(a) The LTSP Project Team should include in the final report a description of all the numerical stability criteria that must be considered in generating adequate results with either code. Specifically for the CLASSI Code, these are associated with (a) numerical integration scheme for computing Green's functions for the layered medium, (b) spatial interpolation of Green's funcion to generate impedances and (c) discretization of foundation area. For the SASSI code, these criteria are associated with (a) the bottom boundary halfspace transmitting model, (b) the generation of the compliance matrix and (c) the finite element discretization of the foundation model. These criteria should be clearly set forth in the final report together with references to all major previous studies from which these criteria were developed.

(b) In the verification studies completed to date for both CLASSI and SASSI, the comparison plots generated should show the specific ranges of applicability, using the criteria assembled in the document described in (a) above.

(c) In the calculations to be done for the Diablo Canyon site, these ranges of applicability should again be clearly indicated on any plots generated. In addition, any differences in computed results from comparable CLASSI/SASSI runs should be noted and reasons for the differences appropriately described and documented.

(d) The final report should describe all modifications made to CLASSI and SASSI to arrive at the production versions being used for the LTSP.

In conclusion, it is our opinion that the LTSP Project Team has shown that the results using both the CLASSI and SASSI Codes to predict the Diablo Canyon site response are acceptable and the analysis techniques used are at the forefront of the current state-of-the-art of SSI calculations.

REFERENCES

1. R.J. Apsel, "Dynamic Greens's Functions for Layered Media and Applications to Boundary Value Problems", Ph.D. Dissertation, UCSD, 1979.

2. J. Lysmer, et al., "A System for Analysis of Soil-Structure Interaction", User's Manual, CE Dept., UC Berkeley, April 1987.

3. "Review of Rock Site Properties, Priority Task I for DC-LTSP", by Bechtel Corp. for PG&E, February 1986.