REVIEW OF SOIL-STRUCTURE INTERACTION AND SEISMIC ANALYSIS OF CATEGORY I STRUCTURES SOUTH TEXAS PROJECT

Prepared for
HOUSTON LIGHTING AND POWER COMPANY
Houston, Texas

by

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Brown & Root, Incorporated
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Gentlemen:

At your request, we have reviewed soil-structure interaction and seismic analysis of Category I structures for the South Texas Project. Our report is attached. We are pleased to have been of service to you.

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1.0 INTRODUCTION

This review of soil-structure interaction and dynamic analysis of Category I structures at the South Texas Project (Units 1 and 2) has been carried out by a panel of independent consultants composed of Dr. Anil K. Chopra, Professor of Civil Engineering at the University of California - Berkeley, Dr. Jose M. Roesset, Professor of Civil Engineering at the University of Texas - Austin, and Dr. Robert V. Whitman, Professor of Civil Engineering at the Massachusetts Institute of Technology. Dr. Whitman acted as chairman for the panel, who refer to themselves hereafter as the Consultants.

The study of soil-structure interaction had been performed by Woodward-Clyde Consultants (WCC), using a series of 2-dimensional finite element analyses for several cross-sections through the proposed plant. In each such analysis, the several structures were idealized as solid (but flexible) 2-dimensional bodies and were modelled by finite elements. The soil was likewise modelled by finite elements, with modulus and damping adjusted for computed dynamic strain. The results of these analyses were computed time histories of motion at the bases of the several structures.

These motions were then used by Brown and Root to define input to 3-dimensional, lumped mass, stick models for the structures. The response of these rigid models, with foundation stiffness and damping to include torsional effects, to the input base motions was analyzed using the STRUDL computer program.

2.0 TERMS OF REFERENCE

The panel was convened by WCC and Brown & Root, Inc. and requested to review finite element soil-structure interaction and seismic response analyses specifically used for the STP site and prepare a report summarizing comments and conclusions based on this review, including the following matters:

- Applicability of the finite element method for soil-structure interaction analyses to the STP site
- Applicability of procedures used for the seismic analysis of Category I structures
- Sources of conservatism including the input motion
- Conservatism of results

3.0 PROCEDURES FOLLOWED IN THE REVIEW

A preliminary meeting at WCC-San Francisco on 23 January, 1981 was attended by Drs. Chopra and Roesset. At and subsequent to that meeting, the following documents were provided to the Consultants by WCC:

1. Woodward-Clyde Consultants, "Soil-Structure Interaction Studies, South Texas Project, Units 1 and 2," WCC Foreign Document No. WCR-9028-2-1

2. Woodward-Clyde Consultants, letter dated 20 April 1981 by Charles S. Hedges to Robert V. Whitman, transmitting a copy of the STP FSAR section on the seismicity and earthquake information.

3. Brown & Root, Inc. "GSDC-Subsection 3.1, Seismic Analysis" TRD Document No. 5A369SD001-D/DCN/11-26-79, Letter ST-BR-WC-1217, SFN:D-0540, dated April 13, 1981.

4. Brown & Root, Inc. "Final Seismic Analysis of Reactor Containment Building" TRD Document No. 3N160SR165-A, Letter ST-BR-WC-1228 dated April 27, 1981.

5. Brown & Root, Inc. "Mathematical Model for the Reactor Building; Frequencies, Periods and Mode Shapes of the Reactor Building Model" Letter ST-BR-WC-1208, SFN: D-0540, P-0087, dated April 6, 1981.

6. Brown & Root, Inc. "Final Design Floor Response Spectra for Category I Structures", South Texas Project, TRD Document No. 3N160SR044-D, Letter ST-BR-WC-1217, SFN: D-0540, dated April 13, 1981.

7. Brown & Root, Inc. "Miscellaneous Seismic Analysis" Document No. 3Y600SC301-A, Letter ST-BR-WC-1230, dated April 29, 1981.

The Consultants have also been provided with the report:

> Woodward-Clyde Consultants, Brown & Root, Inc. and Consultants "Review of Soil-Structure Interaction and Seismic Analysis of Category I Structures; South Texas Project, Units 1 and 2." Report prepared for Houston Lighting and Power Company, WCC Foreign Document No. WCR-9028-1-3, May 1981.

Based upon a study of these documents, the Consultants generated a number of questions and requests for clarification which were discussed during a meeting at WCC in San Francisco on 15 April 1981. We have also drawn upon our general familiarity with recent and current practice with regard to soil-structure interaction and seismic analysis.

The general approach followed by the Consultants involved:

- Developing a thorough understanding of the assumptions made and the procedures used at various stages of the analyses
- Studying selected results for consistency and reasonableness, employing a few crude hand calculations to check some aspects of the computed responses
- Reviewing selected results in the light of the experience of the consultants.

Our conclusions reflect combined judgement based on the results of such considerations.

4.0 APPLICABILITY OF THE FINITE ELEMENT METHOD FOR SOIL-STRUCTURE INTERACTION ANALYSIS

The two-dimensional finite element method used by WCC was a generally accepted procedure in 1975. From our examination, it is clear that great care was taken in the development of the model for the soil profile and of the finite element representation, and in the selection of the parameters for the model. All of the regulatory requirements concerning uncertainty in soil properties and concerning the variations of ground motions with depth were satisfied. The Consultants have examined carefully a number of aspects of the results, particularly the computed response spectra at the base of the Reactor Containment Building. These results appeared to be quite reasonable for the depth of embedment and the soil properties and to be consistent with the natural frequencies of the building.

The two-dimensional finite element analysis of course can only approximate the various three-dimensional aspects of the problem: three-dimensional interaction that occurs for an isolated structure, the three-dimensional aspects of interaction among adjacent structures, and the effect of generalized surface waves impinging upon the complex of structures. For each of these effects, arguments can be made that the effect might lead to either an increase or a decrease in response and the arguments would change with system properties and for different frequencies. At present, there is no method of analysis for embedded structures which is fully developed and implemented in a computer program and which is reliable and properly takes into account all of these effects plus the heterogenous and non-linear nature of soil. Thus, the results of the WCC analysis procedures, used with proper engineering judgement and conservatism, are satisfactory for soil-structure interaction analyses of the STP site.

In short, if this project were starting up fresh today, the Consultants would accept essentially the same types of analysis as that completed by WCC.

5.0 APPLICABILITY OF PROCEDURES USED FOR THE SEISMIC ANALYSIS OF CATEGORY I STRUCTURES

The Consultants have reviewed in a general way the methods used by Brown & Root to compute the dynamic response of a building subjected to a specified time-history of horizontal, vertical or rocking motion at its base. Attention was directed at the formulation of the analysis, and at the computed mode shapes and modal frequencies for the Reactor Containment Building. The Consultants did not review the appropriateness of the lumping of masses and springs nor the numerical values assigned to these elements, except for the torsional spring constant for the soil, which was reviewed. The inquiry also did not include the numerical techniques used to complete the analysis, nor did it extend to the accuracy of the computer program.

The program used for the analysis required input motions (horizontal, vertical and rocking) at a single point of the base. On the other hand, the finite element analysis by WCC had provided motions at three points of the base. The required vertical, horizontal and rocking motions were computed from the three available motions under the assumption that the base is rigid. This is a reasonable and rational procedure. A comparison of the response spectra for the resulting single motions with those obtained from the SSI analysis indicates that there were practically no differences.

The computed mode shapes and frequencies of the Reactor Containment Building appeared, in general, to be quite reasonable.

The Consultants judged it appropriate to use frequency independent stiffness and damping to represent the torsional resistance of the soil. The influence of the torsional elements upon the overall response is quite small.

Insofar as the Consultants could judge, regulatory requirements concerning broadening of floor response spectra peaks and the combining of different motions were satisfied.

6.0 CONSERVATISM IN THE ANALYSIS

The Consultants identified several aspects of the analysis which introduce conservatism with regard to the forces and floor response spectra developed for design.

- The choice of 0.10g for the SSE and 0.05g for the OBE appears to be quite conservative for the location of the STP, although the Consultants did not attempt to review in detail the seismology and tectonics of the region. For the magnitudes and distances considered, however, an acceleration of 0.07g at the site already is a conservative estimate for the SSE. Increasing it to 0.10g in order to satisfy minimum requirements represents a substantial factor of safety.

- The time series of acceleration used for the SSI analyses have response spectra which are at or above the target spectra in the complete range of frequencies of interest, for all values of damping.

- In order to comply with certain requirements on the free-field peak acceleration at the foundation of the deepest building and upon the response spectra at this elevation, the control motions were increased still further (up to 40%) above the just-mentioned values. For most response frequencies this requirement introduces additional conservatism in the input motions.

- The approximate procedure for assigning base motions to the Diesel Generator Building and Fuel Handling Building is definitely conservative.

- The heights of many of the peaks in the floor response spectra are conservatively high. This conservatism results in part from mismatches between the natural frequencies of the approximate two-dimensional model for the structure as used in the finite

element analysis and those for the more detailed three-dimensional model employed for the dynamic analysis of the building. Conservatism is also introduced in the approximations used in the process of accomplishing the analysis; e.g. use of conservative multipliers in the combination of floor response spectra obtained from analyses performed separately for each of the three directions.

- The spectral peaks for vertical motion caused by the vertical OBE appear to be somewhat too high. This conservatism resulted from using a thickness of soil in the finite element model which, while appropriate for the case of horizontal excitation, implies diminished radiation damping under vertical vibrations at frequencies less than about 4 Hz.

The afore-mentioned effects are all the result of either deliberate conservatism or of using a conservative approximate method of analysis in lieu of a more exact analysis.

There were a number of other steps taken to cover the possible effects of uncertainty in various parameters. Among these steps were the broadening of the peaks of computed spectra and variation of the shear modulus of the soil by -40% and +50% from the expected value. These are prudent steps, which, for a given control motion, are intended to ensure that actual response will not exceed the response used for design.

The responses computed for frequencies in the range from about 1 Hz to about 3 Hz are not as conservative as those computed at other frequencies. The requirement of enveloping 60% of the control motion's response spectral ordinates is just met in this range and the regulatory requirement is itself less conservative in this same range.

There is one matter about which the Consultants are neutral with regard to conservatism.

- Response of the actual 3-dimensional case as compared to the 2-dimensional representation assumed in the analysis of soil-structure interaction. This matter has already been discussed in Section 4. On the one hand, the Consultants cannot prove that the responses to the specified earthquake might not be larger at some frequency than those computed in the 2-dimensional finite element analysis. On the other hand, we know of no arguments, observations or computed results which present compelling proof that the actual responses will be larger.

In this matter, the Consultants feel that there is not convincing evidence of conservatism. This does not mean we feel the computed responses are unconservative. Given the current state-of-knowledge we simply cannot be certain and further, we believe that the questions cannot be resolved at this time by further analysis. We are quite satisfied with the results adopted for purposes of design.

The Consultants have not identified any aspect of the analysis which is clearly unconservative to a significant degree

7.0 CONCLUSIONS

Taking all considerations into account, the Consultants believe that the procedures used for analysis of soil-structure interaction and dynamic analysis are appropriate for the STP, and - if implemented properly or conservatively - should lead to forces and floor response spectra which are conservative for use in design. Where computed results were examined in detail, they appeared to be either correct or conservative, suggesting appropriate implementation for at least those parts of the analysis.