ENCLOSURE

SAFETY EVALUATION

FOR

VALIDATION OF BECHTEL COMPUTER CODE SASSI FOR APPLICATION TO

WATTS BAR NUCLEAR PLANT SOIL-STRUCTURE INTERACTION ANALYSIS

TENNESSEE VALLEY AUTHORITY (TVA)

WATTS BAR NUCLEAR PLANT (WBN) UNITS 1 AND 2

DOCKET NOS. 50-390 AND 50-391

1.0 INTRODUCTION

TVA has proposed using Bechtel computer code SASSI to perform soil-structure interaction (SSI) analysis of Watts Bar Nuclear Plant (WBN) soil-supported Category I structures for the Evaluation (Set B) and New Design or Modification (Set C) Seismic Analysis (Ref. 1). According to Bechtel (TVA consultant), the SASSI code was previously accepted by the staff for the Diablo Canyon Nuclear Plant Long Term Seismic Evaluation Program. However, the staff has not yet established generic acceptability of the code for application to nuclear plant licensing. Therefore, the staff determined that review for WBN on a case-by-case basis is required.

The review was accomplished through two review meetings that were conducted at the Bechtel office in San Francisco on April 26, 1989, and on August 11 and 17, 1989. During the review meetings, the staff and its consultant reviewed the Bechtel computer code generic verification/benchmarking and the plant-specific SSI study for two representative soil-supported WBN structures. At NRC request, Bechtel performed the plant-specific SSI study for the diesel generator building (DGB) and refueling water storage tank (RWST). Both the DGB and RWST are shallowly embedded. The two structures differ in material and configuration, and hence differ in dynamic characteristics.

2.0 PURPOSE AND SCOPE

The purpose of this Safety Evaluation Report is to document the findings of the staff and consultant regarding the technical adequacy of (a) the generic verification of the Bechtel computer code SASSI, and (b) the plant-specific benchmarking of SASSI code through the SSI study for the DGB and RWST at WBN. The findings form the basis for the staff to determine the validity for a case-by-case application of the SASSI code to the Set B and Set C seismic analyses of the soil-supported Category I structures at WBN.

The plant-specific SSI study was performed for the Set B seismic analysis for the Safe Shutdown Earthquake (SSE) condition using the mean soil profile. The three-dimensional (3D) coupling effect on structural response due to the three earthquake components was included in the study as requested by the staff. The technical adequacy of the soil data and structure models of the DGB and RWST as used in the SSI study was not reviewed during the review meetings. Those aspects of the analysis will be reviewed during the implementation phase of the Set B and Set C seismic analyses.

3.0 DISCUSSION OF AUDIT FINDINGS

Staff review findings for both the generic and plant-specific validation of the Bechtel code SASSI are discussed in this section.

3.1 Generic Validation of SASSI Code

For review of the generic verification and benchmarking, the staff and consultant focused on three areas, namely, the computation of impedances, wave scattering and response spectrum. Methods acceptable to the staff and consultant as the bases for the generic validation were those which employed close form solution or other SSI analysis techniques previously accepted by the staff for the licensing of other plants.

Bechtel's SASSI Validation Manual contains twenty validation test problems (Ref. 2). The staff and consultant reviewed fifteen of those problems which explicitly or implicitly benchmark the impedance calculation and, where applicable, wave scattering effect due to embedment and/or non-vertical incident waves. The fifteen problems are summarized in the following table.

Test Prob. No.	Objectives of Benchmarking	Reference Solution
2	Impedances and SSI response of a building with a surface founded circular base on a uniform half space with a vertically incident seismic wave.	Close form
3	Response of a circular base founded on surface of a uniform half space and subjected to a vertically incident pulse.	Close form
4	Impedances and wave scattering for a square surface footing on a uniform half space and subjected to inclined incident waves.	Close form
5	Impedances of a circular surface footing on a layered half space.	Close Form
6	Response of a fully embedded circular footing on a uniform half space subjected to both vertical and horizontal incident waves.	Close form
7	Impedances of a square surface footing (rigid in center and flexible at edge) on a uniform half space.	Close form
8	Impedances of two nearby square surface footings on a uniform half space.	Close form
9	SSI response of a building with a shallowly embedded circular base on a layered half space.	Bechtel CLASSIF

12	Vertical response of a square and flexible footing at surface of a uniform half space and subjected to vertical loading on footing.	Close form
13	Impedances of a rigid cubical footing fully embedded at top of a uniform half space.	Close form
15	Scattering response of a rigid massless cylinder embedded in a surface layer and subjected to vertical incident S-wave.	Close form
16	Scattering response of a rigid massless cylinder fully embedded at top of a uniform half space and subjected to surface Rayleigh wave.	Close form
17	Vertical compliances of a strip footing on top of a viscoelastic layered half space.	Close form
18	Vertical compliances of a ring foundation at top of a uniform half space.	Close form
19	Compliances of a circular footing on top of a uniform half space.	Close form

Except for Validation Test Problem No. 9, all test problems that were reviewed use close form solution as the basis for validation and were found acceptable. In Test Problem No. 9, the solution from the Bechtel CLASSIF code is based on a surface foundation because embedment cannot be included in the CLASSIF code. Therefore, the CLASSIF solution in Test Problem No. 9 is approximate. The reference solution, though approximate by nature due to the omission of embedment, is sufficient for qualitatively benchmarking the SASSI solution because the structure is only shallowly embedded. The CLASSIF code theory has been previously accepted by the staff on a case-by-case basis in the licensing review of some other plants. To assist the staff and consultant in a better understanding of the significance of the shallow embedment, Bechtel provided additional information which compares the foundation impedances computed with the SASSI code for both the embedded and unembedded conditions (Ref. 2). Based on the previous CLASSIF acceptance and the data provided regarding comparative foundation impedances, Validation Test Problem No. 9 was considered acceptable.

The Bechtel SASSI Validation Manual does not specifically address the verification of the algorithm for response spectrum computation. Bechtel presented a comparison of the response spectra computed by SASSI and another Bechtel computer code, CE921, for a given acceleration time history of motion (Ref. 4). The CE921 code was used to generate the new amplified response spectrum (ARS) for Browns Ferry Nuclear Plant and was accepted by the staff (Ref. 8). The staff and consultant reviewed the response spectrum comparison between SASSI and CE921, and concluded that the SASSI response spectrum computation algorithm is acceptable.

3.2 Plant-Specific Benchmarking of SASSI Code

According to the plan accepted by the staff during the first review meeting (April 26, 1989), Bechtel would perform an SSI study for the DGB and RWST based on the Set B seismic analysis criteria for the SSE condition. The control motion in free field would be the SSE motion prescribed at the rock outcrop, and the mean soil profile would be used. The Bechtel CLASSIF code would be applied to the generation of the reference solution against which the SASSI solution would be benchmarked. Both the as-built embedded configuration and a hypothetic surface-founded configuration would be considered for each structure. Because embedment effect cannot be explicitly accounted for by CLASSIF code, the CLASSIF solution for the embedded condition would be computed in an approximate manner by using foundation impedances that are empirically modified from the impedances for the surface-founded condition.

Both structures are essentially shallowly embedded. The DGB is 135' x 110' in plan, 32' in height, and supported on a 10'-thick basemat. The finished grade and the top of basement are at elevations 741' and 742', respectively. With the rock foundation at elevation 695', the total thickness of the soil layers is about 46'. Beneath the basemat, the native soil was removed and replaced by a 9'-thick layer of crushed stone fill. See Fig. 1 for the EW cross section of the DGB and soil foundation (Ref. 5).

The RWST is 43.5' in diameter and about 44' tall. It is supported on a 3.7'-thick basemat that is essentially embedded in the soil, with the finished grade and top of basemat being at elevations about 728' and 729', respectively. With the rock foundation located at elevation 693', the total thickness of the soil layers is about 35'. A 12'-thick layer of crushed stone fill replaced the native soil beneath the basemat. See Fig. 2 for the elevation view of the RWST and soil foundation (Ref. 6).

The SSE free-field control motion for Set B analysis has a peak acceleration of 0.22g and 0.15g in the horizontal and vertical directions, respectively. It is defined as the free-field motion at the rock foundation located at elevation 695' and 693' for the DGB and RWST, respectively. The three components of the free-field control motion used in the study are statistically independent artificial time histories generated by Bechtel, each having a total duration of 30 seconds. The 5% damping acceleration response spectrum of the EW component of the free-field control motion is illustrated in Fig. 3 (Ref. 5). The technical adequacy of the artificial time histories was not covered under the scope of this review.

For each structure, Bechtel first performed a free-field soil response analysis with the soil column analysis code, SHAKE, to determine the free-field motion at the ground surface (finished grade), e.g., Location A as shown in Fig. 4 in the case of the DGB. Fig. 3 provides a spectrum comparison in the EW direction between the free-field control motion and surface motion in the case of the DGB. The free-field surface motion was the input motion for SASSI and CLASSIF codes in the SSI study for both the hypothetic surface-founded condition and the as-built embedded condition. With simultaneous application of the three components of the ground motion to the analysis, the 3D coupling effect on the structural response was accounted for.

During the second review meeting (August 11 and 17, 1989), Bechtel presented the results of the SSI study as discussed in Refs. 5 and 6. For the SASSI analysis, two cases were run for each structure:

- o Case 1 - Hypothetic surface-founded condition, in which the basemat rests on a hypothetic surface that is formed by omitting the soil above the elevation at the bottom of the basemat. For example, Fig. 4 shows the location of the hypothetic ground surface, i.e., Location C, in the case of the DGB.
- o Case 2 - As-built embedded configuration.

For the CLASSIF analysis, four cases were run:

- o Case 1 - The same surface-founded condition as the Case 1 for SASSI.
- o Case 2 - As-built embedded configuration. Embedment effect was approximately accounted for by empirically modifying the surface-foundation impedances generated in Case 1, and wave scattering effect was ignored.
- o Case 3 - Same as Case 2 except that the effect of wave scattering was also included by using the wave scattering functions generated from the SASSI Case 2 analysis.
- o Case 4 - Same as Case 3 except that the approximate CLASSIF impedances were also replaced by the impedances generated from the SASSI Case 2 analysis.

As an example, Figs. 5 provides comparison for SASSI Cases 1 and 2 for the EW component of the amplified response spectrum (ARS) at the center of the DGB roof, elevation 773.5'. Fig. 6 provides corresponding comparison for the CLASSIF Cases 1 through 4.

Review findings by the staff and consultant from the results of the SSI study are discussed in the following:

(1) Bechtel adequately considered the 3D coupling effect on the structure response resulting from the rocking and torsion of the building and from the simultaneous application of the three components of the input ground motion.

(2) For the hypothetic surface-founded condition, the SASSI and CLASSIF solutions are comparable to each other. For example, Fig. 7 shows the ARS comparison at the center of the DGB roof. In the absence of structural embedment, such close comparison was anticipated according to the theories of the two codes. Thus the CLASSIF solution provided a plant-specific validation for the SASSI code in the case of surface-founded structures. The staff and consultant noted the incompatibility between the ground surface (e.g., Location A in Fig. 4), on which generation of the free-field input motion was based, and the hypothetic surface (e.g., Location C in Fig. 4) for the SSI model. However, because the incompatibility is common to both the SASSI and CLASSIF solutions the review finding regarding the SASSI code in the case of surface-founded structures remains valid.

(3) For the as-built embedded condition, the solution for SASSI analysis Case 2 compares well to that for CLASSIF analysis Case 4. This was anticipated because CLASSIF Case 4 was run using both the impedances and wave scattering functions that were generated from SASSI Case 2. For example, Fig. 8 shows the ARS comparison between the two solutions at the center of the DGB roof.

Thus the solution from CLASSIF Case 4 provided the SASSI code with a qualitative benchmarking in the case of embedded structures. In addition, the staff and consultant noted: (a) comparison between CLASSIF Cases 2 and 3 suggested that the empirically modified CLASSIF impedances are not a good approximation to the SASSI impedances at WBN, and (b) comparison between CLASSIF Cases 3 and 4 suggested the wave scattering due to structural embedment is important at WBN.

(4) Comparing the solutions for SASSI Cases 1 and 2 or CLASSIF Cases 1 and 4 initially suggested that structural embedment has the effect of substantially reducing the structural response at WBN. This was especially the case with the DGB, as illustrated in Fig. 5. The staff and consultant, however, did not expect such a substantial reduction in view of the fact both structures are only shallowly embedded. Bechtel Validation Test Problem No. 9, which qualitatively benchmarks the SASSI solution for a shallowly embedded building against a CLASSIF solution for the same building founded on the ground surface, also indicates that the shallow embedment need not substantially reduce the structural response. In view of the incompatibility between the input motion and the hypothetic ground surface assumed in the Case 1 SSI model, as pointed out previously in finding (2), the staff envisioned that re-running the Case 1 analysis with the same SSI model and a compatible input motion will provide a better understanding of the significance of the structural embedment. The compatible input motion in this event would be the free-field motion computed at the hypothetic surface. In lieu of such reanalysis with either the SASSI or CLASSIF code, however, the staff believed the same purpose would be essentially fulfilled by simply comparing the free-field motions at Locations A, B, and C as shown in Fig. 4 in the case of the DGB, where the motion at Location C would be the compatible input motion mentioned previously. Bechtel therefore performed additional soil column analyses with the SHAKE code to compute the EW component of the motions at Locations B and C for the DGB. In addition, Bechtel extracted the EW translational component of the free-field scattered motion at the foundation, i.e., Location D as shown in Fig. 4, from the SASSI Case 2 analysis. Fig. 9 provides a spectrum comparison for the motions at the Locations A, B, C and D (Ref. 5, Appendix A). Around the system frequency of the SSI model for the DGB, which was estimated to be about 4.5 Hz, the spectrum acceleration of motion C is much lower than that of motion A. It suggests that should Case 1 be re-analyzed with motion C as the input the response of the DGB would not be as high as that with motion A as the input. That is, the reduction in structtural response due to the shallow embedment of the basemat would indeed be less substantial than as initially suggested. The initial concern of the staff and consultant was therefore resolved.

(5) As discussed previously in finding (3), the staff and consultant noted the significance of wave scattering on the response of the DGB and RWST due to the structural embedment. The spectrum comparison for motions A, B and D as shown in Fig. 9 led to the same observation. As an additional evidence, Bechtel provided a summary of the results from some published studies on the responses recorded in and around a 1/4-scale containment model during several strong-motion earthquakes (Ref. 7). The scaled model is located in Lotung, Taiwan, and is moderately embedded in a soft soil foundation. Fig. 10 illustrates the vertical cross section of the scaled containment model. Fig. 11 shows the variation of the recorded free-field motions from the surface to -47m in the ground during one of the earthquakes. The earthquake,

denoted by Event LSST07, took place on May 20, 1986. Relative to the surface motion, a reduction in response spectrum is noticeable at -6m, which is about the same elevation as that of the bottom of the basemat. Reduction in the NS direction is more pronounced. Fig. 12 provides a spectrum comparison for the recorded and computed motions at the top of the basemat for Event LSST07. The computed motion was obtained using the CLASSIF code both with and without considering the effect of foundation scattering (or kinematic interaction). For the case including the effect of wave scattering, the scattering functions were generated from a SASSI analaysis. Fig. 12 suggests that wave scattering due to the structural embedment is important to the interpretation and correlation of the SSI response recorded in the containment model. The effect of wave scattering is more pronounced in the NS direction, which is consistent with the larger reduction in free-field motion taking place at -6m in the NS direction.

(6) To further assess the SASSI embedded condition solutions, the staff and consultant compared them to the acceleration responses recorded during earthquake Event LSST07 at the scaled containment model in Lotung (Refs. 7 and 9). The amplification in structural response for both the Lotung model and the SASSI analysis models were reviewed. For each structure, zero period acceleration (ZPA) values at the top of the basemat and the top of the structure were compared to the ground surface ZPA value to assess structural amplification. The Lotung model ZPA values were taken from Ref. 9. The following table provides the relevant ZPA values.

Structure	Direction	Ground Surface	Top of Structure	Top of Basemat
DGB/SASSI Case 2	NS EW	0.5g 0.5g	0.5g 0.5g	0.5g 0.4g
RWST/SASSI Case 2	NS EW	0.5g 0.5g	not available 1.2g	not available 0.5g
Scaled Containment, LSST07	NS EW	0.21g 0.15g	0.22g 0.20g	0.13g 0.15g

For each structure the tabulated ZPA values are typically similar at the top of the basemat and the ground surface. The reduced ZPA values in the EW direction for the DGB and in the NS direction for the containment model could, in the opinion of the staff and consultant, be the result of out-of-phase rocking and translation at the structure bases. Note that the DGB and the containment model are dynamically similar as both are relatively stiff reinforced concrete structures. The RWST is a much more flexible steel structure. As would be expected based on this fundamental structural characteristic, only little to nominal amplification in ZPA at the top of the structure is observed from the analysis of the DGB or the recorded response for the containment model whereas substantial amplification resulted from the analysis of the RWST. Based on these observations, the resultant ZPA amplifications for the SASSI solutions and containment model recorded response are qualitatively consistent thereby providing additional basis for the staff and consultant to conclude that the SASSI code appears reasonable for SSI analysis of embedded structures.

Based on findings (1) through (6) above, the staff and consultant conclude that the plant-specific benchmarking for the SASSI code is reasonable. The adequacy of the artificial time histories of SSE control motion, soil data and structure models as used in the SSI study was not reviewed during the review meetings. Those analysis attributes will be reviewed later when TVA completes the Set B and Set C seismic analyses.

4.0 CONCLUSIONS

Based on the findings from two review meetings, the staff concludes that:

(1) Both the generic and plant-specific validation of the Bechtel SASSI code appear reasonable.

(2) The Bechtel SASSI code is acceptable on a case-by-case basis for application to the Set B and Set C seismic analyses of the soil-supported Category I structures at WBN.

5.0 REFERENCES

(1) Letter from TVA to NRC, "Watts Bar Nuclear Plant - Revision to Corrective Action Program Plan," June 29, 1989.

(2) "SASSI Validation Manual," Bechtel Power Corp., July, 1988.

(3) "Impedance Functions for SASSI Validation Test Problem No. 9," handout prepared by Bechtel, August 14, 1989.

(4) Bechtel Calculation No. 89-1, "Validation of Response Spectrum Calculation in Computer Program SASSI," April 24, 1989.

(5) "Task Report on Watts Bar Nuclear Plant Seismic Analysis for Diesel Generator Building, Comparisons of SASSI and CLASSI Analyses," prepared by Bechtel North American Power Corporation, September 8, 1989 (Rev. 1).

(6) "Task Report on Watts Bar Nuclear Plant Seismic Analysis for Refueling Water Storage Tank, Comparisons of SASSI and CLASSI Analyses," prepared by Bechtel North American Power Corporation, September 8, 1989 (Rev. 1).

(7) "Task Report, Summary of Lotung Experiment Relating to the Effect of Foundation Scattering on Seismic Response of Structures with Embedded Foundations," prepared by Bechtel North American Power Corporation, September 8, 1989.

(8) NRC Inspection Report No. 50-260/88-39, June 14, 1989.

(9) W. S. Tseng and K. Lilhanand, "Soil-Structure Interaction Analysis of Quarter - Scale Containment Model Experiment in Lotung, Taiwan," published in Proceedings: EPRI/NRC/TPC Workshop on Seismic Soil-Structure Interaction Analysis Using Data from Lotung, Taiwan, EPRI NP-6154, Vol. 2, March, 1989.

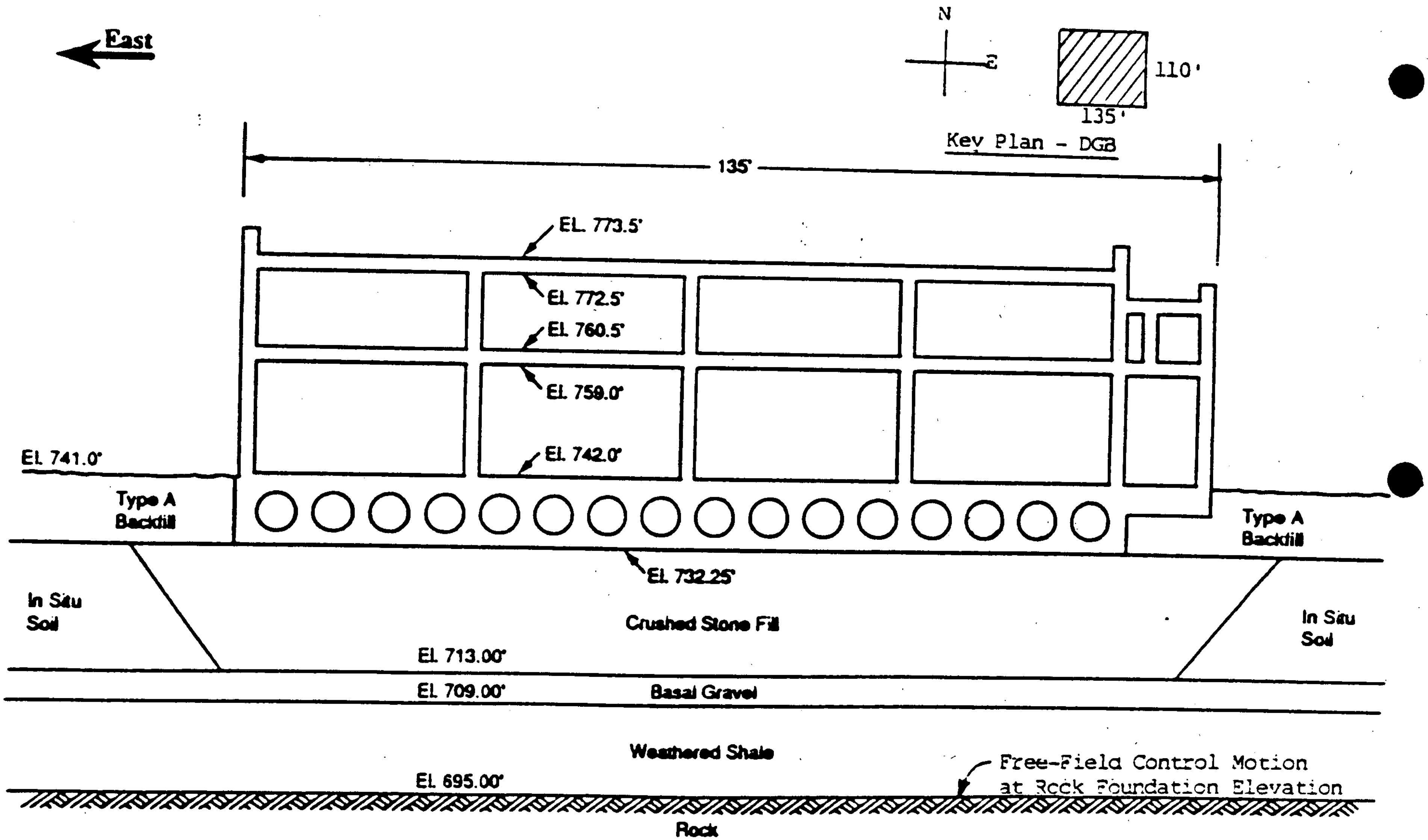

Fig. 1 E-W Cross Section of Diesel Generator Building and Foundation Soil (Ref. 5)

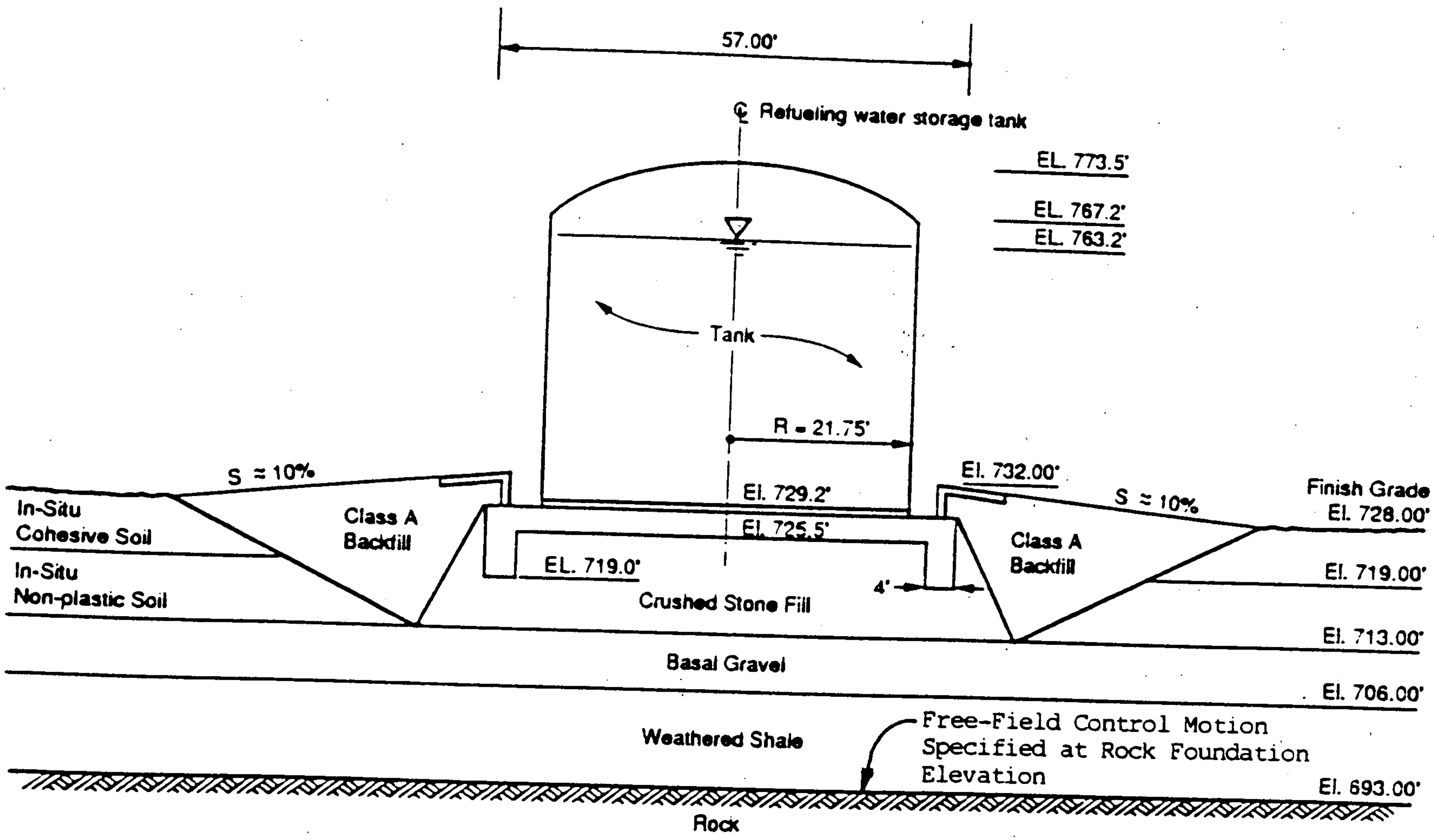

Fig. 2 Cross Section of Refueling Water Storage Tank and Soil Foundation (Ref. 6)

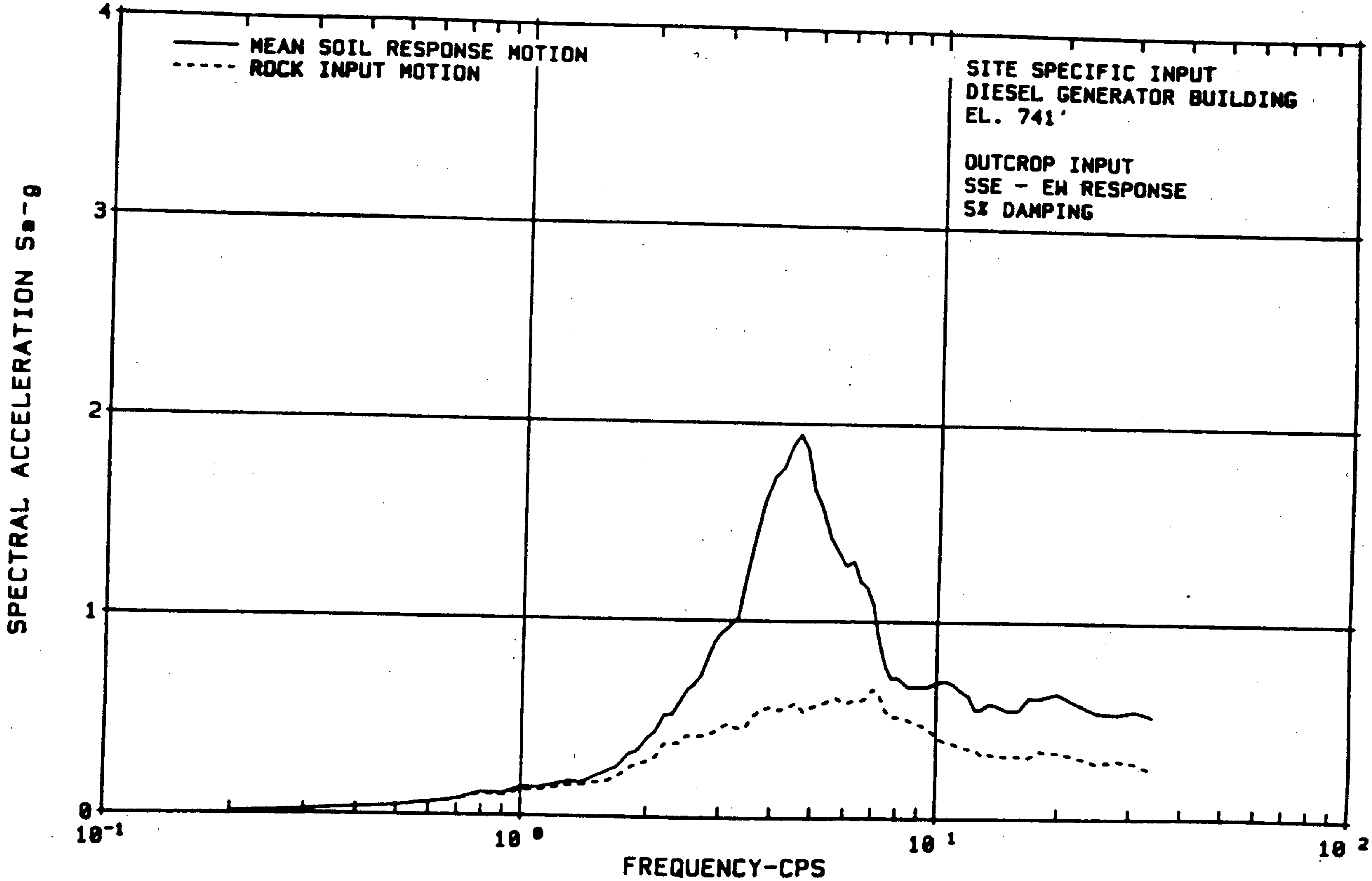

Fig. 3 5% Damping ARS of Free-Field Control Motion at Rock Outcrop and Free-Field Surface Motion at Grade (Motion A) Illustrated in Fig. 4 for Diesel Generator Building, EW Direction (Ref. 5)

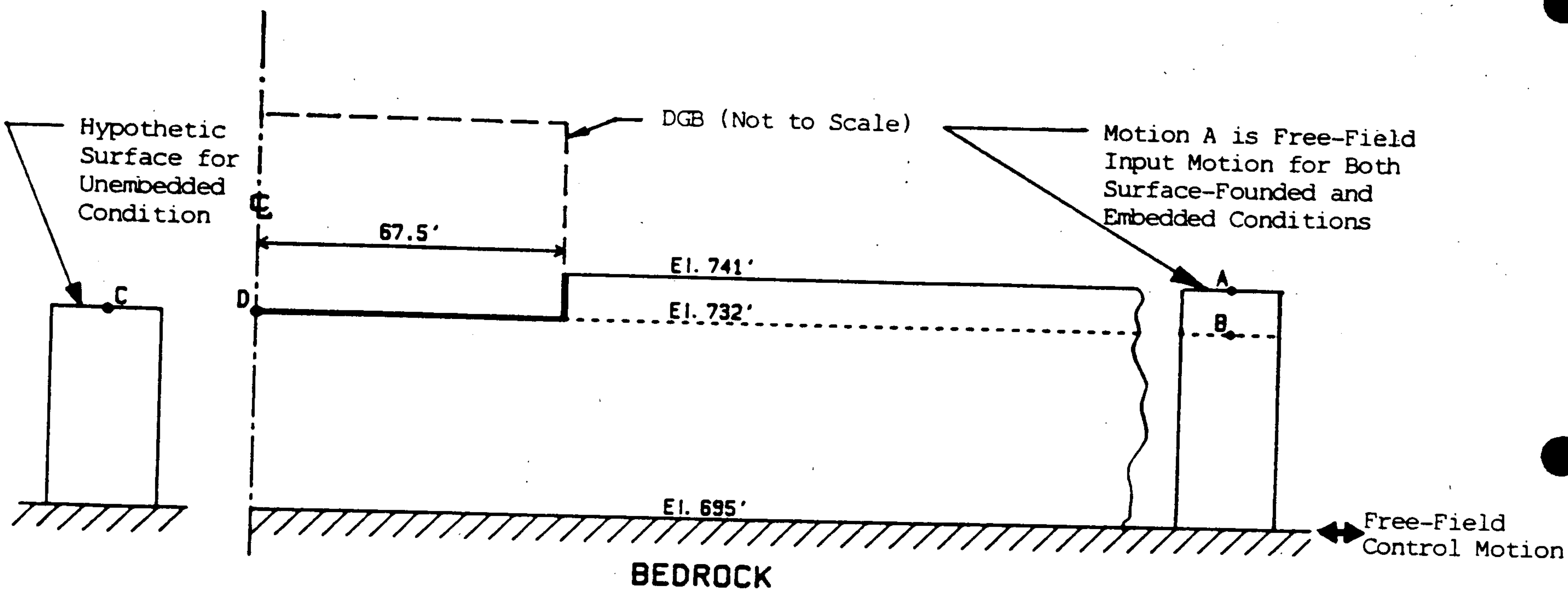

Fig. 4 Locations for Control Motion at Rock Foundation, Free-Field Soil Motions A, B, C, and Free-Field Scattered Motion D for the Diesel Generator Building SSI Study

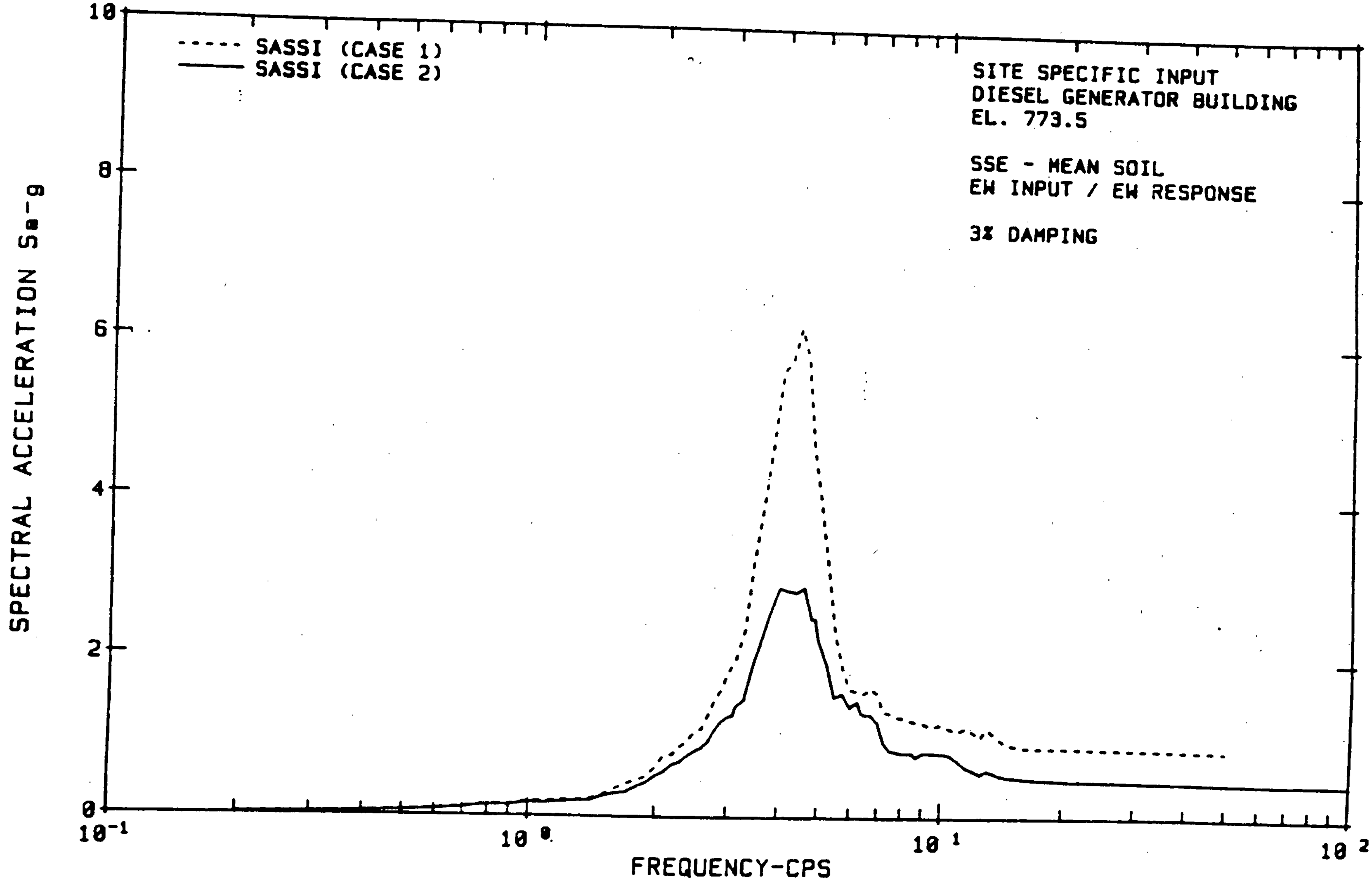

Fig. 5 Comparison of SASSI Solutions for Surface and Embedded Foundation Conditions - Diesel Generator Building, EW Direction, 3% Damping ARS at Top of Building (Ref. 5)

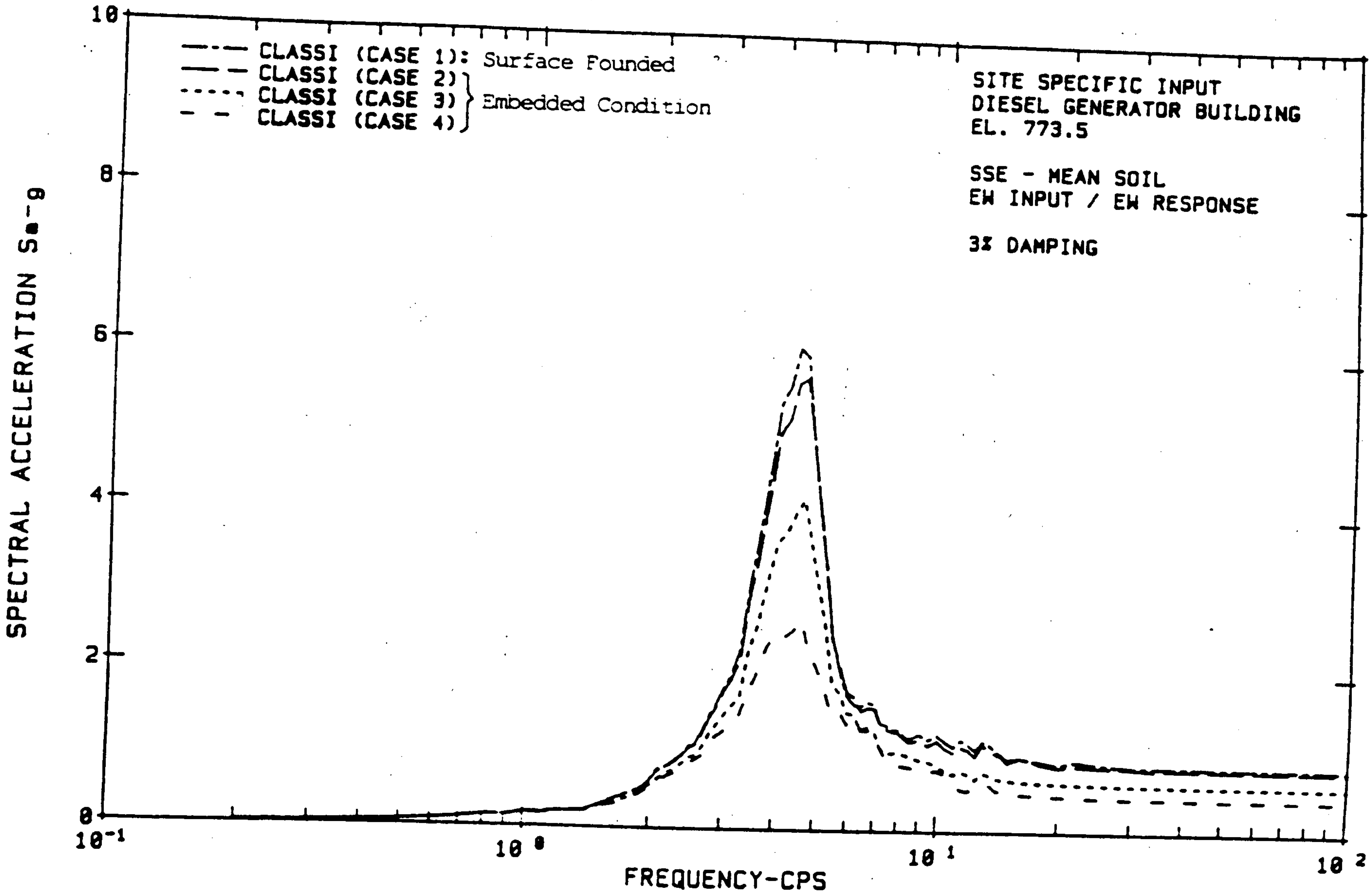

Fig. 6 Comparison of CLASSI Solutions for Surface and Embedded Foundation Conditions - Diesel Generator Building, EW Direction, 3% Damping ARS at Top of Building (Ref. 5)

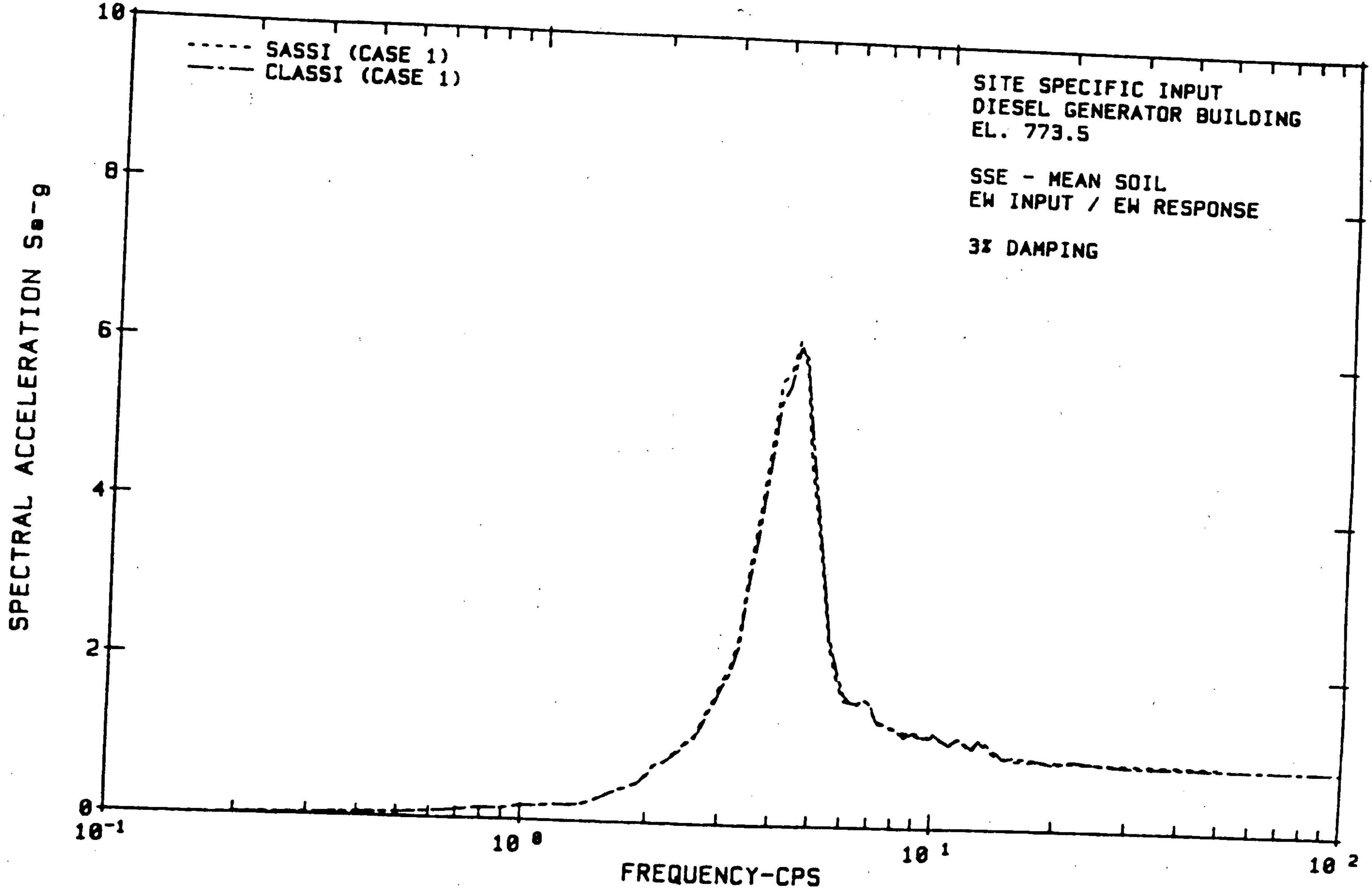

Fig. 7 Comparison of SASSI and CLASSI Solutions for DGB ARS for the Hypothetic Surface-Founded Condition, EW-Direction at the Top of Building (Ref. 5)

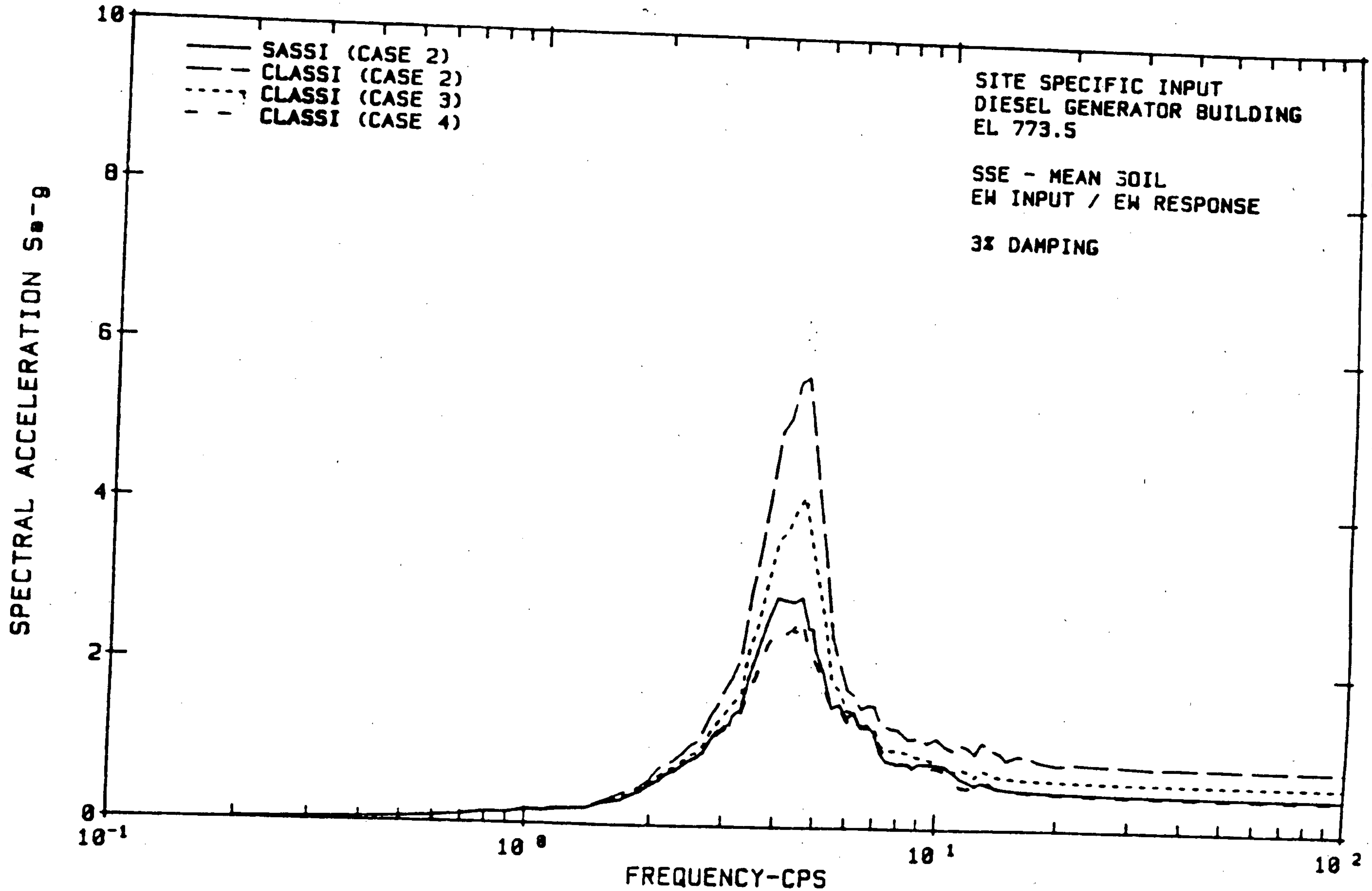

Fig. 8 Comparison of SASSI and CLASSI Solutions for DGB ARS for the Embedded Condition, EW-Direction at the Top of Building (Ref. 5)

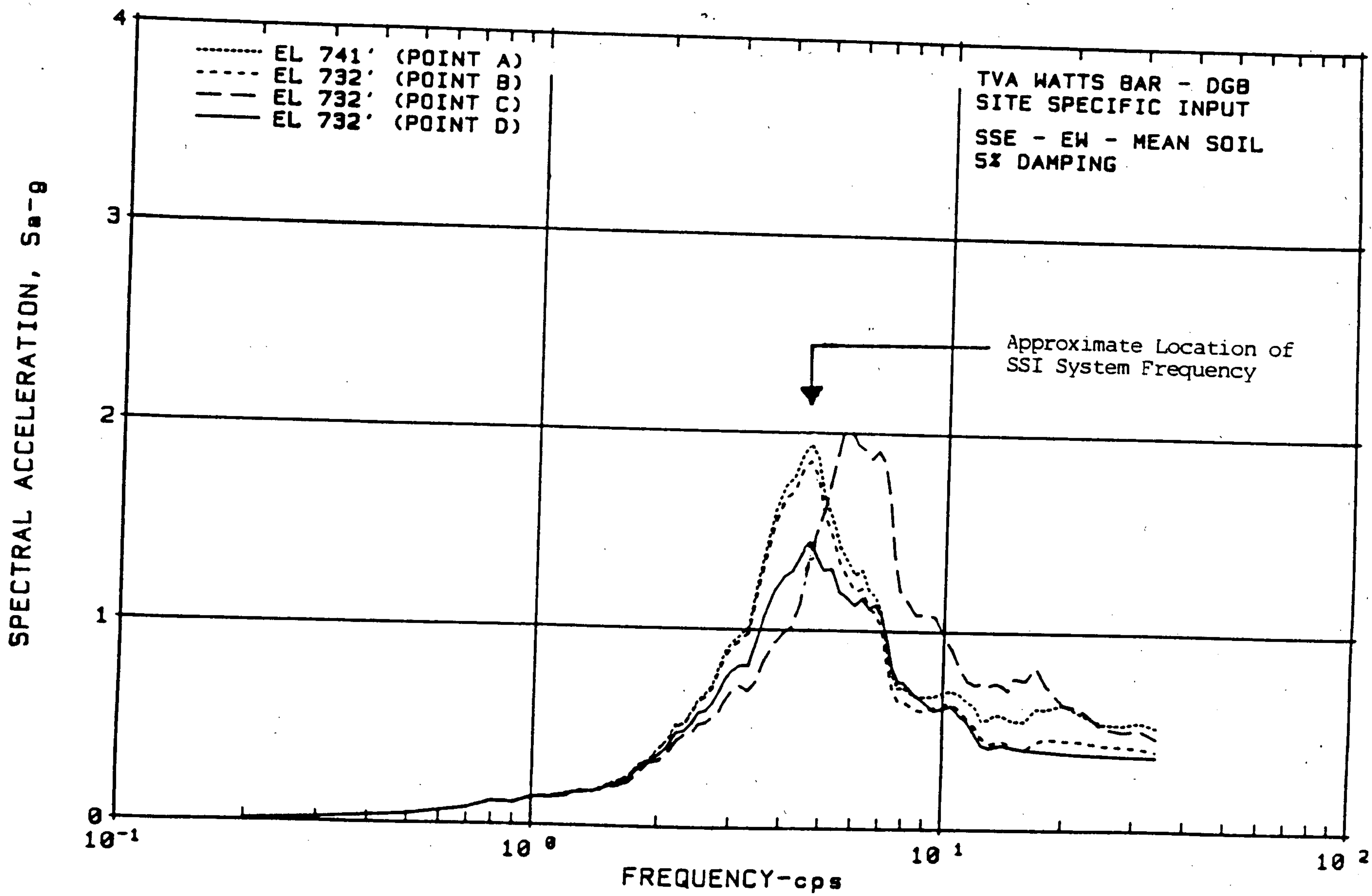

Fig. 9 Comparison of 5% Damping Spectra in EW Direction for Free-Field Motion at Locations A, B, C and D Shown in Fig. 4 for DGB (Ref. 5)

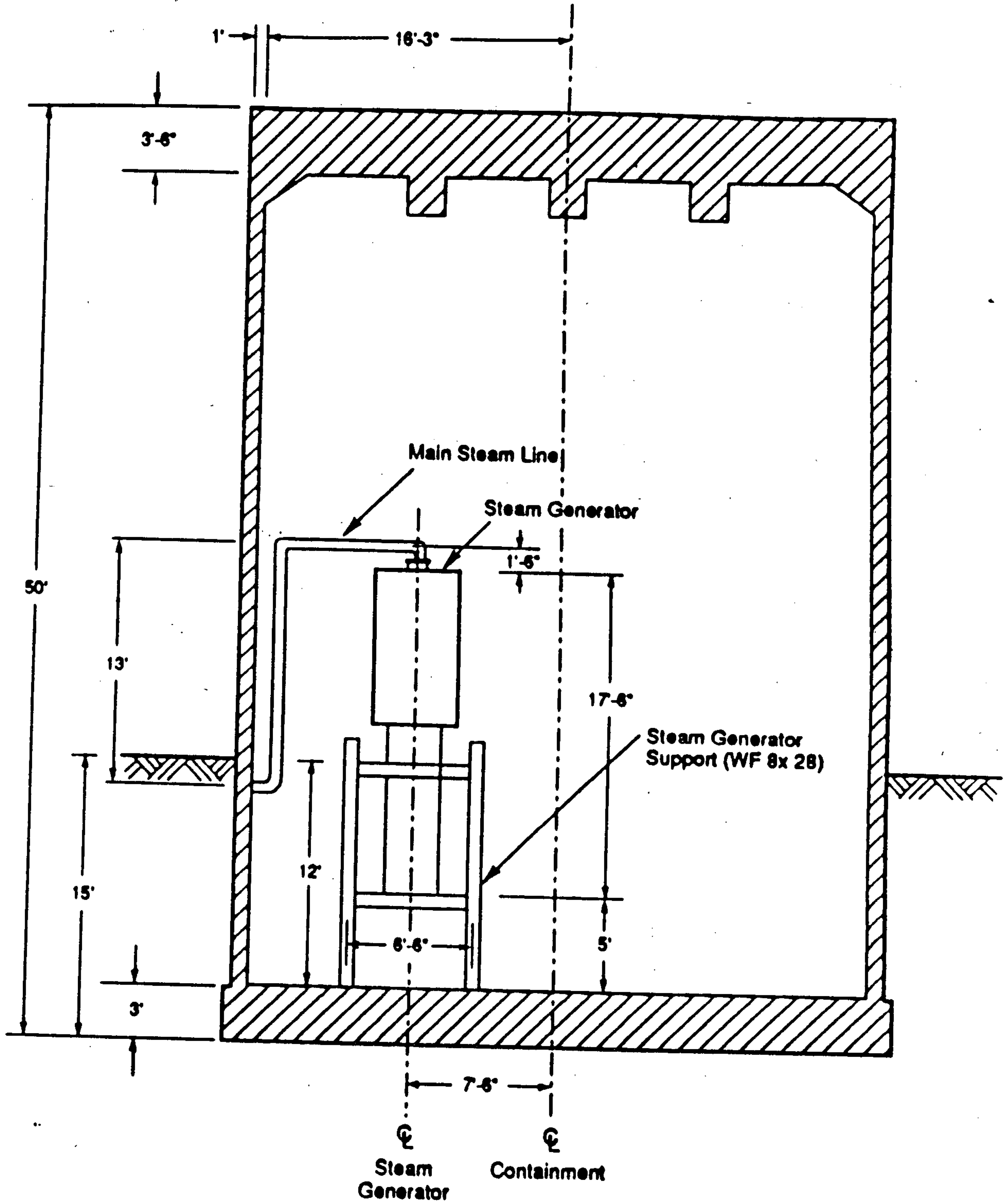

Fig. 10 Vertical Cross Section of the 1/4-Scale Containment Model Located in Lotung, Taiwan (Ref. 7)

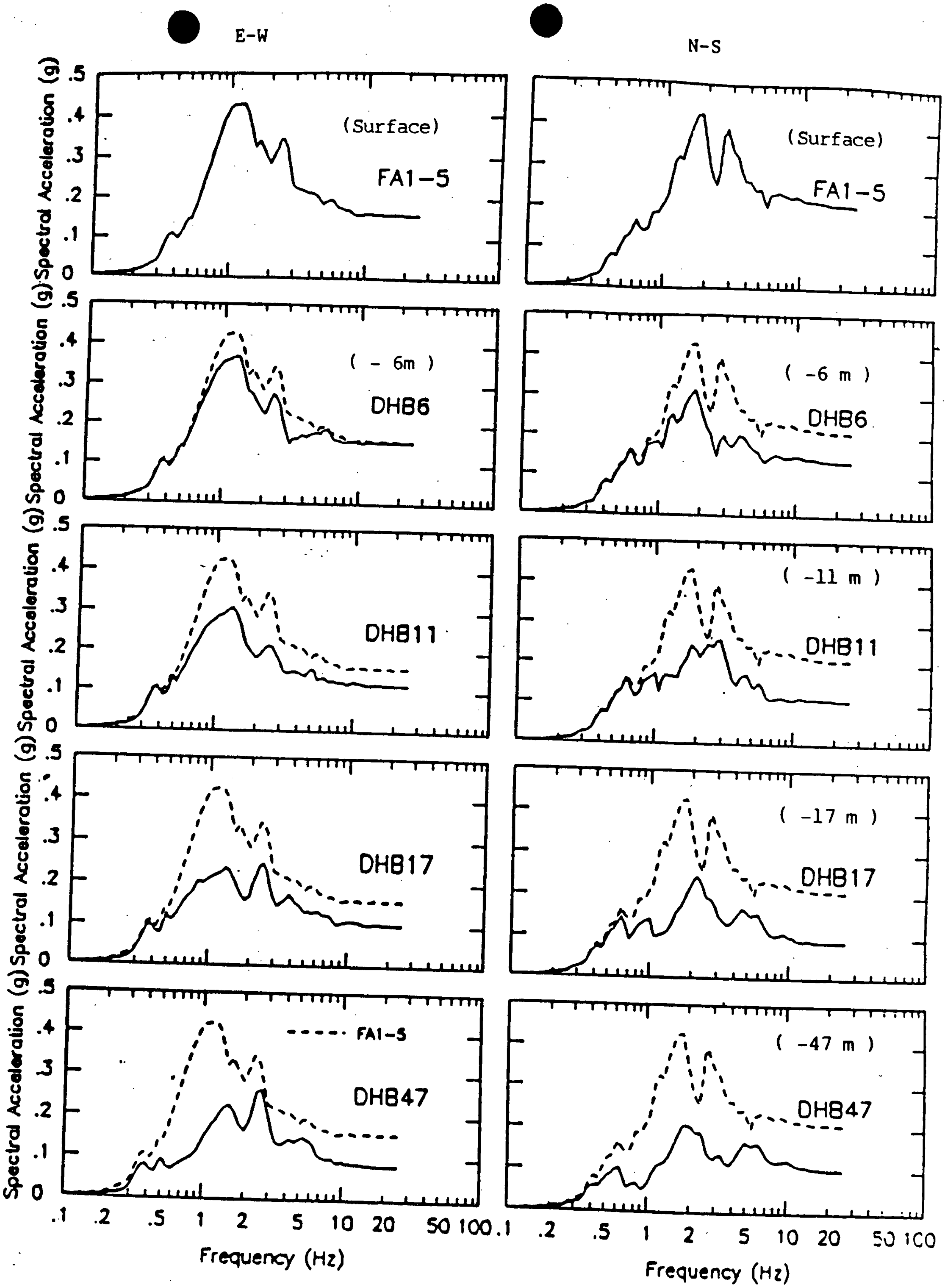

Fig. 11 5% Damping Response Spectra of Recorded Ground Motions at Different Depths at Station DHB, Event LSST07 (Ref.7)

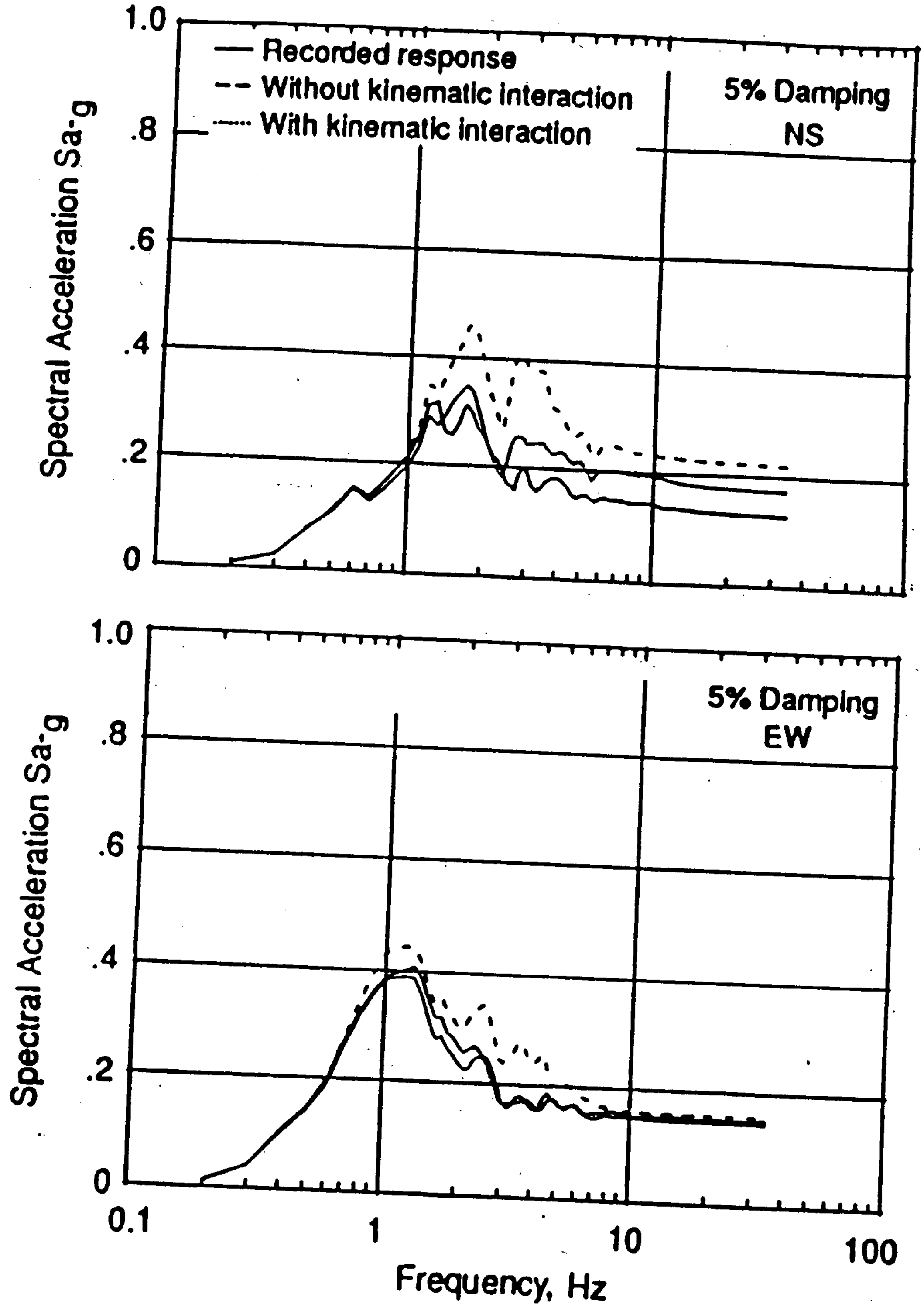

Fig. 12 Comparison of Response Spectra of Computed and Recorded Motions at Top of Basemat, Event LSST07 (Ref. 7)