WASHINGTON PUBLIC POWER SUPPLY SYSTEM

P.O. Box 968 • 3000 George Washington Way • Richland, Washington 99352

Docket No: 50-508

G03-88-235
August 29, 1988

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U.S. Nuclear Regulatory Commission
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Washington, D. C. 20555

Subject: NUCLEAR PROJECT NO. 3
RESOLUTION OF KEY LICENSING ISSUES
FINAL SUBMITTAL OF SOIL STRUCTURE
INTERACTION INFORMATION

References:
1) Letter, GC Sorensen (Supply System) to GW Knighton (NRC), dated June 27, 1984 (G03-84-410)
2) Letter, GC Sorensen (Supply System) to GW Knighton (NRC), dated July 14, 1986 (G03-86-399)
3) Letter, GC Sorensen (Supply System) to Document Control Desk, dated July 31, 1987 (G03-87-236)

The Supply System has recently had Impell Corporation perform a SASSI analysis of WNP-3. The results of the SASSI analysis and further clarification of the elastic half space analysis that had previously been submitted by Reference 1, 2, & 3 are presented for your review in the attached document. The combined results of the SASSI and elastic half space analysis provide confirmation that the finite element methodology used for the WNP-3 design basis is sufficiently conservative to assure that public health and safety will be protected during and following a safe shutdown earthquake.

With this submittal, sufficient information has been provided for the NRC Staff and their contractor, Brookhaven National Lab, to prepare a safety evaluation or technical evaluation report. We will be pleased to respond to further questions of clarification that you may have.

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If you have any questions, please contact Mr. D. W. Coleman, WNP-3 Project Licensing Manager at (509) 372-5304.

Very truly yours,

G. C. Sorensen, Manager
Regulatory Programs

Attachment

cc: G Vissing/NRC
JR Lewis/BPA
NS Reynolds/BCP&R
EBASCO/New York
M Manrique/Impell
JB Martin/NRC RV
WC Brauer/PP&L
WL Bryan/WWP
C Goodwin/PGE
WJ Finnegan/PSPL

WASHINGTON PUBLIC POWER SUPPLY SYSTEM

WNP-3 SEISMIC DESIGN BASIS MODEL VALIDATION EFFORT

AUGUST 1988

PURPOSE

The purpose of this submittal is to provide additional WNP-3 seismic analysis results such that NRC question 220.13 and Structural Audit Finding Number 1 can be resolved. The principal new results provided by this response are the soil-structure interaction analyses completed by Impell Corporation utilizing the SASSI code (Reference 1). The results of the SASSI analyses are also utilized to justify, or assess, analysis methods implemented in the alternate elastic half space studies completed by the A/E in evaluation of the WNP-3 seismic design basis model results.

CONCLUSIONS

The WNP-3 SASSI analysis results demonstrate that the WNP-3 seismic design basis model results contain significant margin of safety. Specifically, the WNP-3 in-structure design basis spectra envelop the SASSI results by wide margins at the spectral peaks, and are bounding over the SASSI results at all significant building or internal structure vibration modes.

The SASSI results demonstrate that the simplified methods utilized in the A/E's elastic half space seismic studies are satisfactory, since the half space models yield generally conservative results. Local exceedances of the design basis spectra that occur with the half space predictions are limited and are acceptable as indicated by subsystem design margins.

The Supply System concludes that the SASSI analysis results presented with this submittal are sufficient to demonstrate that the WNP-3 seismic design basis model yields conservative and appropriate seismic loadings for the safe design of all plant structures, as well as the associated seismic qualification of plant subsystems. The Supply System further concludes that sufficient alternate analyses have been completed to satisfy the requirements of NuReg-0800 and that concerns relative to the application of deconvolution are resolved.

ORGANIZATION

The balance of this response is organized into a review of the chronology, or genesis, of the basic deconvolution issue and the progression of responses leading to this submittal; a discussion of the open issues associated with the seismic half space study; and finally, closing remarks on the lack of substantiating evidence supporting the basis of Audit Finding Number 1. The chronologic review is provided mainly for orientation and summation purposes, however, brief comments on the basis for the Supply System's position and actions are included in this discussion.

Following the chronologic review is a brief section outlining the application of the SASSI code to the WNP-3 soil-structure interaction problem as performed by Impell Corporation. The major SASSI analysis steps are identified as well as the scope of the WNP-3 modeling effort.

Having established the primary SASSI analysis steps the following section addresses open issues (additional information) relative to the A/E's half space model inputs and results. In addition, this section also presents the important SASSI model analysis results, including comparisons to the design basis model results, for WNP-3. The discussion of open half space model issues relies heavily on the SASSI model results as the basis for conclusive assessments.

The final section discusses the premise of the audit finding and proposes that the NRC concern regarding deconvolution at rock sites should be resolved since the available theoretic and empirical evidence shows that seismic attenuation does occur in stiff soils ("rock") comparable to the WNP-3 founding media.

WNP-3 SEISMIC DECONVOLUTION ISSUE CHRONOLOGY

Because of the lengthy period of time over which the deconvolution issue has been conducted with the NRC, it is worthwhile to review the chronology of the issue for purposes of orientation. Reviewing the major events associated with deconvolution will establish not only the issue's origin, but also the bases for the Supply System's responses, and the subsequent progression of work completed in response to open NRC technical concerns. The WNP-3 deconvolution issue history is summarized by the following highlights.

- The NRC first raised the deconvolution question in a request for additional information, Item 220.13, dated May 3, 1983.

- NRC Audit Finding No. 1 (AF-1), questioning the application of deconvolution techniques to a rock site, resulted from the NRC Structural Audit conducted in the A/E's (Ebasco) New York offices in September 1983. During this audit twenty five findings were established by the NRC review staff. Eight findings were closed prior to issuance of the NRC's November 2, 1983 report, and sixteen remaining finding responses were later submitted to the NRC via Supply System letter dated June 25, 1984. The Supply System response to AF-1 was submitted separately to the NRC via letter dated June 27, 1984.

- NuReg-0800, Standard Review Plan, Section 3.7.2, Revision 1 was issued in July 1981 requiring validation of plant seismic design basis results by application of alternate analysis techniques. In addition, 10 CFR 50.34(g) requires that WNP-3 must include a seismic evaluation in compliance with NuReg-0800 since the project was docketed after May 17, 1982. As a result, and in the spirit of NuReg-0800 Section 3.7.2, the NRC staff concluded that an appropriate resolution to the deconvolution issue of AF-1 would be to conduct a validation analysis utilizing an alternate plant seismic analysis technique.

- The Supply System and Ebasco presented the results of the WNP-3 elastic half space seismic analyses in a meeting with the NRC staff on July 10, 1984. The half space analysis included lumped foundation springs representing both the embedment and half space effects. The seismic criteria motion was applied directly to the plant basemat in the half space study and comparisons with the design basis model frequencies, mode shapes, accelerations, and floor spectra were presented. Where local floor spectra exceedances (amplitude or frequency) occurred, results of subsystem analyses were presented to demonstrate maintenance of design qualification. On the basis of this effort, the Supply System concluded that AF-1 had been resolved by the half space study. The NRC staff concluded that the technical program was fundamentally sound but questioned the boundary conditions applied to the finite element foundation model which was used to generate the embedment (sidewall) spring rates. The NRC staff concluded that they would utilize an independent consultant to evaluate the technical merit of the half space study.

- The Supply System, on July 14, 1986, submitted to the NRC further evaluations of the model utilized by Ebasco to develop the sidewall foundation springs. The supplemental analyses showed that fixing the basemat nodes was a reasonable means to isolate the embedment stiffness when unit loads were applied to the foundation sidewall. The premise of the Supply System analyses was that the sidewall unit load deformation in the unconstrained model must equal (or approximate) the superposition of the elastic half space deformation (at the basemat level) combined with the sidewall embedment deformation when the basemat nodes are fixed. This is simply maintenance of compatibility between the total solution and the incremental solution in which one component is the deformation due to the sidewall stiffness.

- The NRC enlisted the support of Brookhaven National Laboratory (BNL) to review both the WNP-3 elastic half space study and the supplemental study provided by the Supply System which tested the effectiveness of the half space foundation model boundary conditions. BNL commenced their review and on April 7, 1987 the NRC submitted to the Supply System a request for additional information needed by BNL to complete their review. The request was divided into three areas comprising a total of thirteen separate line item requests for additional information or analyses.

- The Supply System submitted its response to the BNL request for additional information on July 31, 1987.

- BNL completed its review of the Supply System's July 31 submittal and documented its findings in an October 15 letter to the NRC (Reference 2). As documented by Reference 2 the Supply System responses were acceptable except for Items 2d, 2e, 2f, 2g, and 3a. Revised responses to each of these open items is provided with this submittal (see section entitled: Brookhaven Additional Information Issues).

- On December 15, 1987 a meeting with the NRC, BNL, Ebasco, and the Supply System was held to discuss the open additional information items requested by BNL. BNL strongly recommended utilization of techniques such as those published by Beredugo et. al. (Reference 3), to formulate the sidewall (embedment) springs for the half space study.

- During January and February of 1988, Ebasco devised an alternate means to develop the sidewall embedment springs from what was termed an "energy approach". The energy approach utilized unit load compliances and deformations established from a finite element half space model and a finite element model of the embedment. No local fixity of basemat nodes were used in these new finite element models. The finite element results were utilized in an energy equation which balanced the total strain energy with the pure half space and embedment strain energies. An outline of the method was informally forwarded to the NRC and was later discussed with BNL via telecon. During the telecon, BNL citing the results of J. E. Luco's paper (Reference 4), concluded that a zero stiffness value would result (i.e., a rigid body displacement) from a static unit horizontal traction load applied to a half space, and thus, the A/E's finite element model half space results could not be applied and were not correct. As a result, BNL could not endorse the approach and again urged the direct application of the methods of Beredugo (Reference 3). Further review of Luco's paper by the Supply System found that the horizontal compliance (inverse of the real part stiffness) has a finite value for all frequencies. And specifically,for the zero frequency (infinite period), the horizontal compliance for the half space is given by Luco as:

$$C_{HH}(0) = [2.0 - v]/[(8)(G)(r)].$$

Where v is Poisson's ratio, G the shear modulus, and r is the footing radius. Figure 4 of Reference 4 also plots the complex horizontal compliance (normalized to $C_{HH}(0)$) as a function of frequency. And as would be physically reasonable, Figure 4 (Reference 4) shows that for the zero frequency the real normalized compliance component is unity (1) while the imaginary component goes to zero. Thus, it is concluded that the zero frequency result of Reference 4 is not a basis for dismissing the energy approach as proposed by Ebasco. Further, it is judged that the static loads applied to the half space finite element models used in the energy approach (with fixed boundaries at "infinity") will yield, or approximate, mean value unit load influence coefficients (i.e., stiffness) as desired.

o The Supply System and Ebasco could not reconcile implementation of the Beredugo methods (and others that were found in the literature) since all such solutions are based on assumed rigid embedded sidewalls. Previous NASTRAN analyses for WNP-3 had demonstrated that the reactor auxiliary building sidewalls are flexible, not rigid as required by available solutions found in the literature. As a result, the Supply System concluded that a limited scope study utilizing a state-of-the-art tool such as SASSI was required. SASSI includes analysis features specifically designed to handle the building embedment effects and flexibility. In addition, SASSI results have been accepted by the NRC for the seismic analysis, and reanalyses, of several nuclear projects.

o On May 11, 1988 the Supply System contracted with Impell Corporation to complete a SASSI analysis for WNP-3 such that the conservatism of the A/E's original design basis seismic model (i.e., the finite element/finite boundaries, deconvolution analysis model) could be demonstrated.

Additional other elements were to be extracted from the model to assess the BNL concerns relative to the half space studies. This Supply System submittal to the NRC summarizes this body of work and responds to each of the open BNL concerns.

WNP-3 SASSI STUDY

SASSI (A System for Analysis of Soil-Structure Interaction) is a prominent soil-structure interaction analysis code which can be used to solve a wide range of SSI problems including WNP-3's deeply embedded, rock founded, nuclear island structure. The SASSI code has passed numerous validation problems and most notably was successfully implemented to predict seismic responses associated with EPRI's Lotung Experiment. Additionally, SASSI code results have been accepted by the NRC at several nuclear projects. In sum, the SASSI code is a state-of-the-art tool which has wide industry acceptance and is well suited to the WNP-3 seismic analysis task.

Impell Corporation was contracted to complete a plant specific seismic analysis utilizing the SASSI code as a result of the Supply System's need to benchmark the WNP-3 seismic design basis model, and assess modeling techniques employed in the A/E's half space model analyses. Impell's experience with the SASSI code is extensive. Recent major efforts include SASSI based requalification analyses for the San Onfre nuclear station and participation in EPRI's Lotung Experiment. Most importantly, Impell's SASSI results, published prior to access to test data, showed favorable agreement with the measured Lotung seismic responses. In sum, Impell Cornoration retains significant experience and credentials in the field of soil-structure interaction, including the application of specialized SSI analysis tools such as SASSI. It is further noted that Impell is a third party contractor having no previous involvement with the WNP-3 seismic design analysis effort.

Impell's effort encompassed a complete SASSI model execution for WNP-3. The basic modeling steps include:

1) Generation of the strain-compatible shear modulus and damping characteristics from the site geophysical properties and input motion using the SHAKE program.

2) Conversion of the WNP-3 NASTRAN building models into SASSI compatible elements and format. Including completion of frequency and mode shape comparisons between the WNP-3 NASTRAN and SASSI building models to ensure equivalence.

3) Development of an integrated foundation and building model. This step includes solution of the layered free-field site response, development of the loading response for each layer, and construction of the excavated soil and building structure finite element mass and stiffness matrices which are needed in the analysis and solution phases of the SASSI procedure. Particular care is taken in these steps to ensure proper layering and nodalization such that all frequencies of interest are passed during execution of the analysis.

4) Perform the two-dimensional SASSI response analysis and generate two percent damping response spectra at the top elevation of each structure and at the center of the basemat. Both horizontal and vertical spectra are generated and plotted with the WNP-3 design basis spectra for ease of comparison.

5) Extraction of the frequency dependent impedance functions from the SASSI program results at selected foundation locations.

The SASSI solution was completed for the WNP-3 East-West horizontal building model and the vertical building model. Only one horizontal direction was examined due to the nuclear island's high degree of symmetry resulting in very similar responses between horizontal directions. (Note: the issue of WNP-3 building symmetry (i.e., ignorable out-of-plane horizontal responses) was addressed by the Supply System's response to Audit Finding 17.) For the SASSI analysis the criteria input motion was applied at grade in the free-field. The analyses are documented and verified in compliance with Impell Corporation's nuclear quality assurance program (Reference 5).

BROOKHAVEN ADDITIONAL INFORMATION ISSUES

Attachment I of Reference 2 outlines BNL's assessment of the additional information responses provided by the Supply System via its July 31, 1987 submittal. In sum, the Supply System responses to Items 2d, 2e, 2f, 2g, and 3a did not resolve BNL's concerns. Each of these items will now be discussed aided by the SASSI results obtained from the study completed by Impell Corporation.

Items 2d and 2g

2d: "Provide analyses to demonstrate that proper sidewall interaction springs can be obtained by fixing nodes along the basemat."

2g: "Provide comparisons of sidewall interactions coefficients with available analytical approaches."

Items 2d and 2g are closely related issues basically involving the validity of the sidewall springs used in the half space model. As will be discussed in the responses to Items 2e and 2f, comparisons with the SASSI generated damping and spring rates differ significantly from the values used in the half space analyses. Yet, as will be presented in the response to Item 3a (i.e., the salient spectral comparisons), it will be shown that the half space results are conservative in nearly all cases as compared to the SASSI results.

In light of the SASSI results being bounded by the WNP-3 design basis spectral results, the Supply System elects to designate Items 2d and 2g as moot issues. SASSI is a verified code (including recent benchmarks with EPRI's Lotung Experiment) with suitable analysis features to accurately assess the WNP-3 embedment and soil (rock) damping effects. The SASSI analysis was executed utilizing standard and accepted methods, and therefore, represents an excellent independent test, or measure, of the conservatism contained within the original WNP-3 seismic design basis model results.

The Supply System also concludes that the SASSI results corroborate the A/E's seismic half space model results. In spite of significant differences in damping and foundation impedances the half space results exhibit (in general) boundedness over the SASSI results with comparable frequency content in most cases. Thus, based on the favorable comparison with the SASSI generated responses, the A/E's methods and parameter input choices for the half space model were, in retrospect, founded on adequate engineering judgments. In other terms, the validity of judgments such as the means for developing static sidewall interaction coefficients are resolved, or at least put into perspective, by comparison to the spectral results obtained from the independent SASSI solution.

The response to Item 3a provides the comparisons between SASSI, the half space, and the WNP-3 design basis spectra. Item 2f includes remarks relative to the apparent lack of model sensitivity to foundation spring rate and frequency dependence.

Item 2e:

"Provide justification for the sidewall damping magnitudes which was used."

The reviewers further stated (via Attachment I of Reference 2) that the use of "shear" material damping was inappropriate for the simulation of sidewall "compressive" damping.

In the original seismic half space study submitted by the Supply System (June 1984), damping on the sidewalls was conservatively assumed to consist of the material damping only (i.e., no radiation damping was considered or included). Since the WNP-3 sidewalls are flexible (as determined by NASTRAN results) both compressive strains and shear strains will result in the rock foundation. Sidewall shearing will also be significant in the vertical mode and shearing contributions will result in the rocking mode as well. Therefore, the assumption of material damping from flexure, or shear responses, is acceptable since significant shear loads are present at the sidewall. In addition, the magnitude of the material damping is significantly less than the radiation damping component which was ignored at the sidewalls in the half space studies. The lower damping values used in the half space analyses could result in some minor shifting of the building frequency response, but the primary effect will be conservative over predictions of maximum spectral amplitudes.

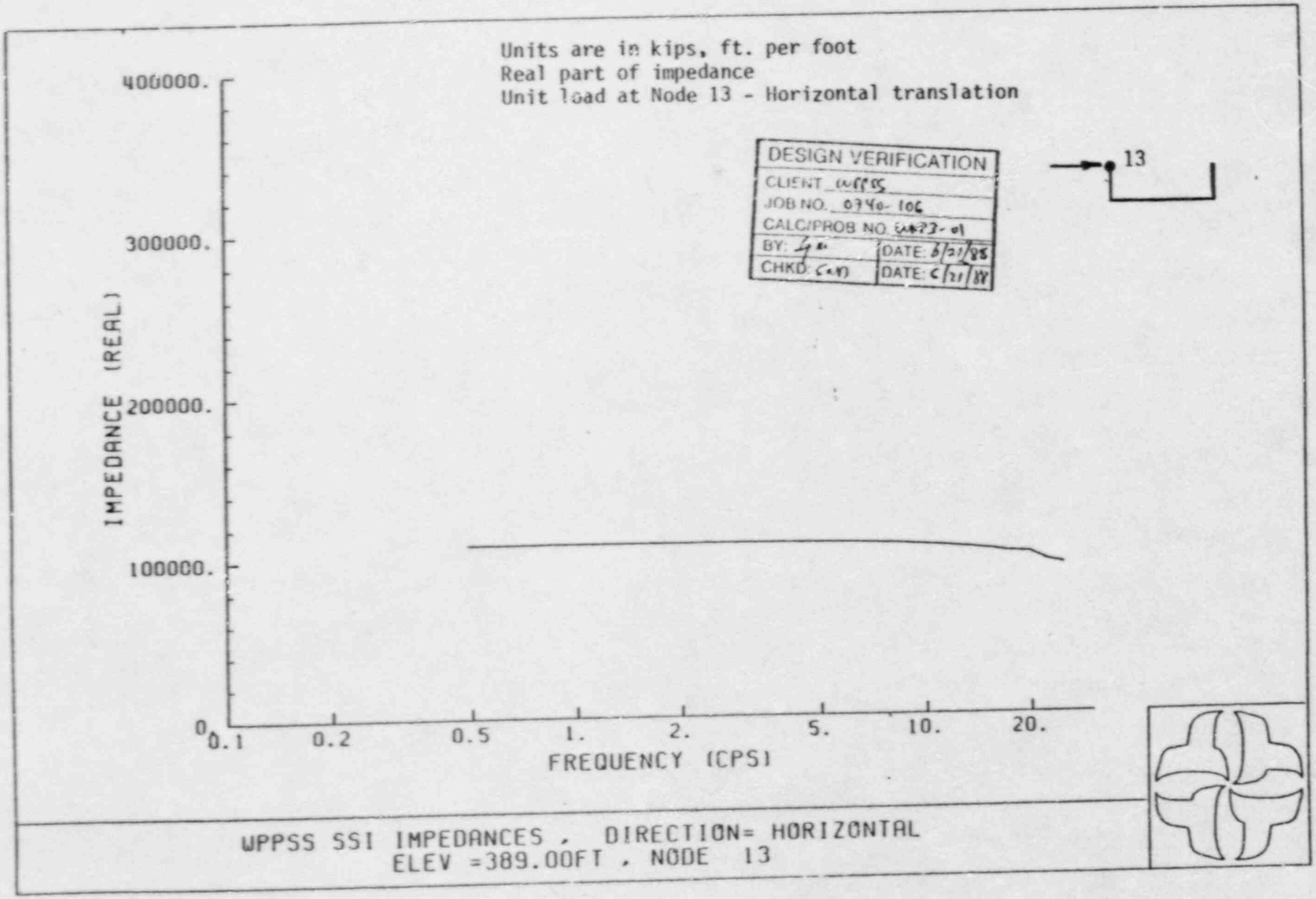
Again, review of the spectral comparisons provided in response to Item 3a do show the character of the half space results to over predict the SASSI responses, and at some local frequencies exceed the design basis spectral amplitudes. Albeit approximate, a quick means for assessing the conservatism in ignoring the sidewall radiation damping component is found by simply comparing the half space model input with Beredugo's damping prediction. Application of the methodology of Reference 3 would yield a 25 percent of critical damping value for the embedment sidewall, as compared to a 2.4 percent material damping value that was used in the half space model.

Item 2f

"Provide justification for the use of static analyses in place of frequency dependent sidewall interaction coefficients."

Figures 2f-1 through 2f-14 provide the SASSI results for both the real and imaginary parts of the complex frequency dependent impedances. Cases are included for lateral, vertical, and rocking modes. Basemat results are also included with these figures. As can be seen from these SASSI results, the real part lateral impedances are basically invariant with respect to frequency, and thus static sidewall interaction coefficients are quite appropriate.

Review of the real part impedances for the vertical and rocking basemat cases (Figures 2f-6 and 2f-7) show a strong dependence with frequency. Taken as an isolated result it would appear from the results of Figures 2f-6 and 2f-7 that utilization of static foundation impedances are not appropriate for the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DESIGN VERIFICATION
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JOB NO.
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ELEV =389.00FT , NODE 13

Figure 2f-1

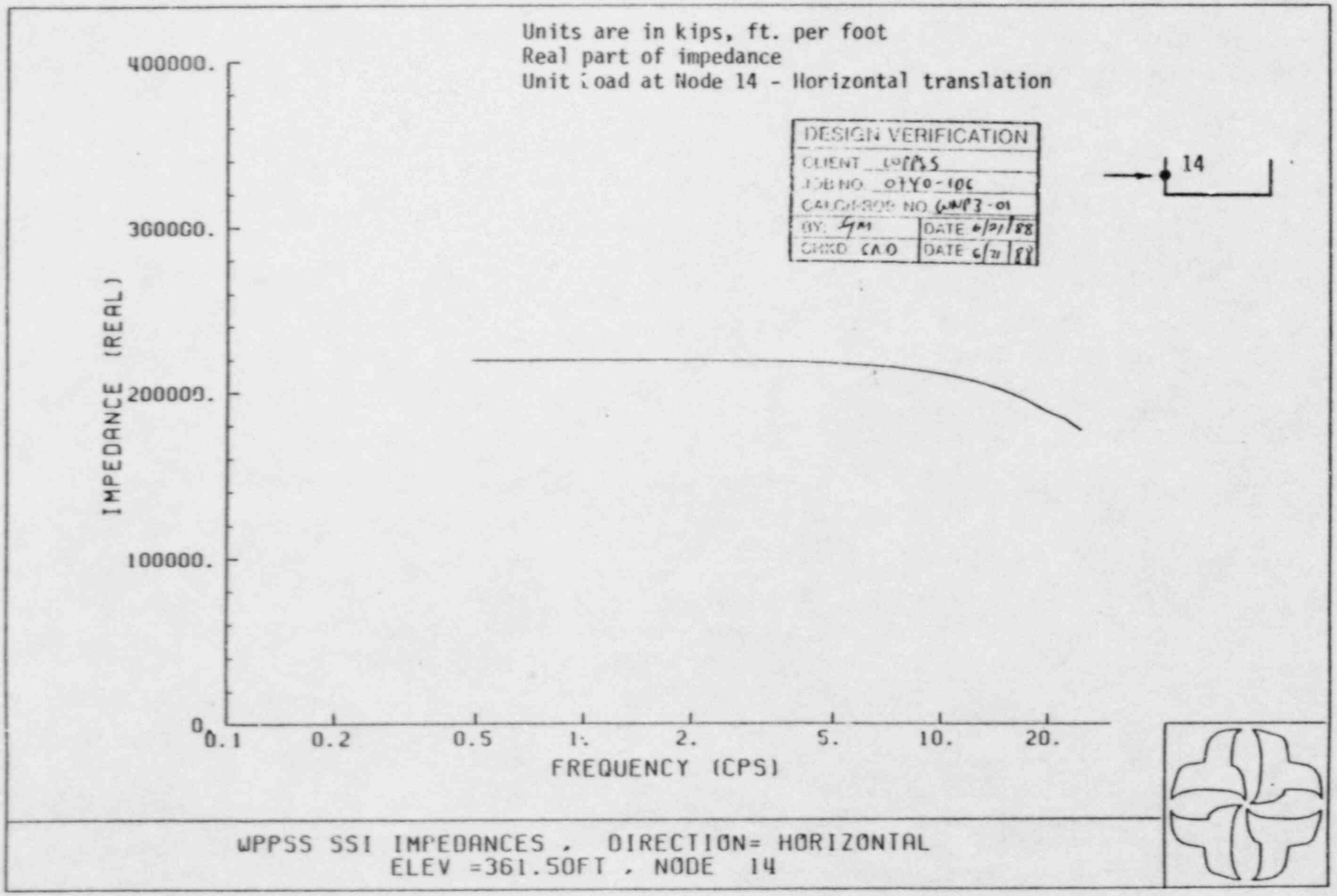
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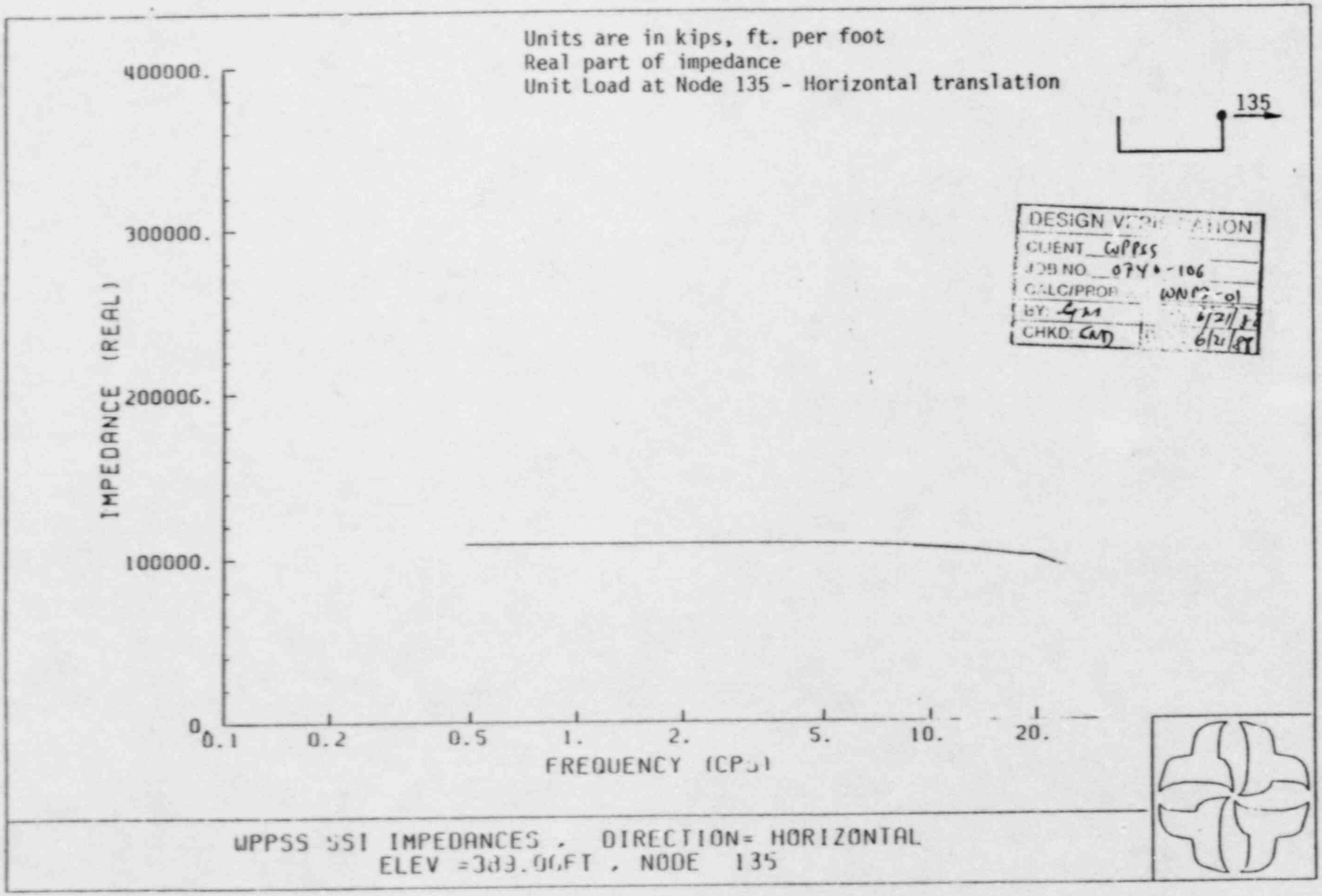
Figure 2f-2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Real part of impedance
Unit Load at Node 135 - Horizontal translation
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CALC/PROB WNP2-01
BY: GM 6/21/87
CHKD: CAD 6/21/87
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Figure 2f-3

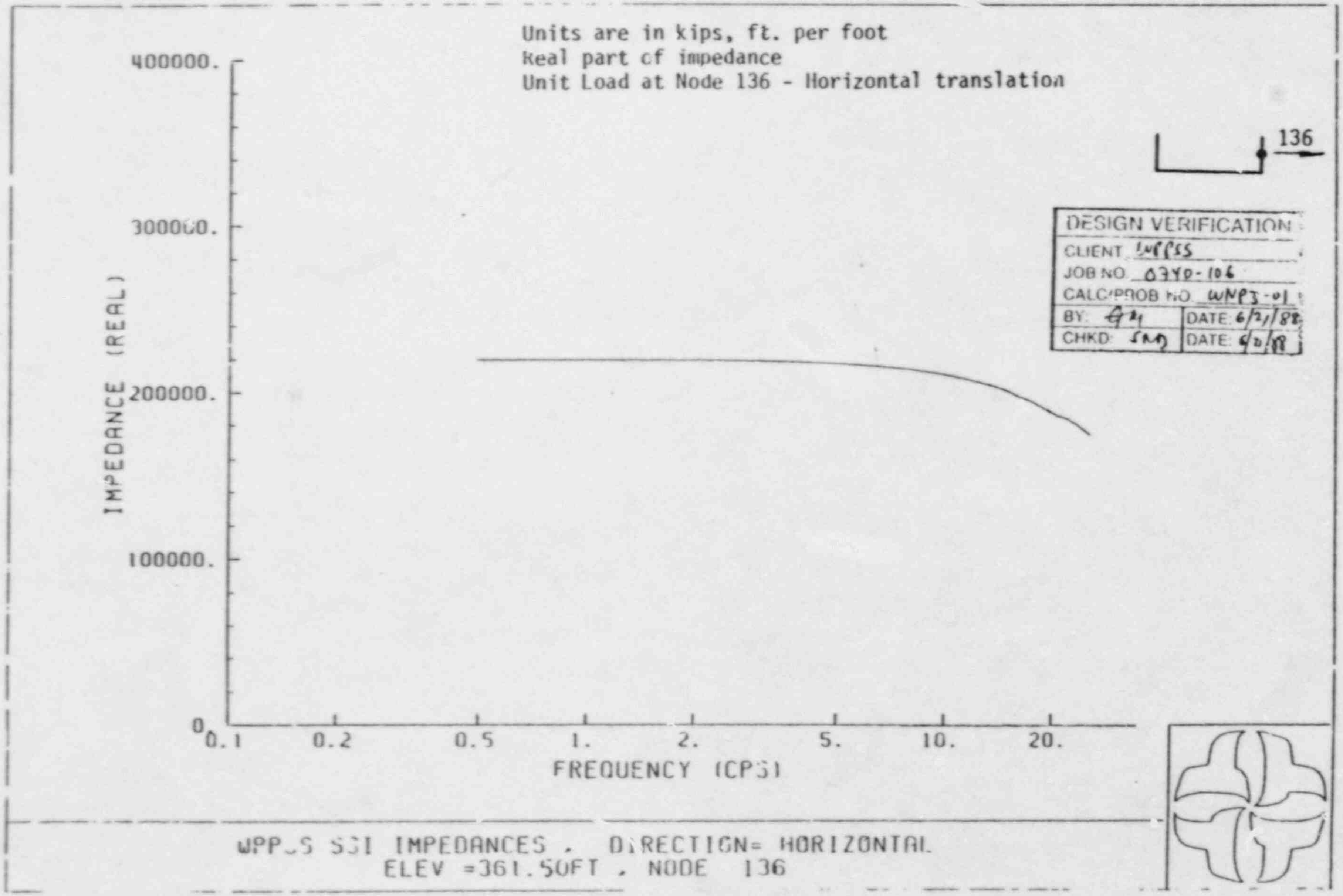
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Figure 2f-4

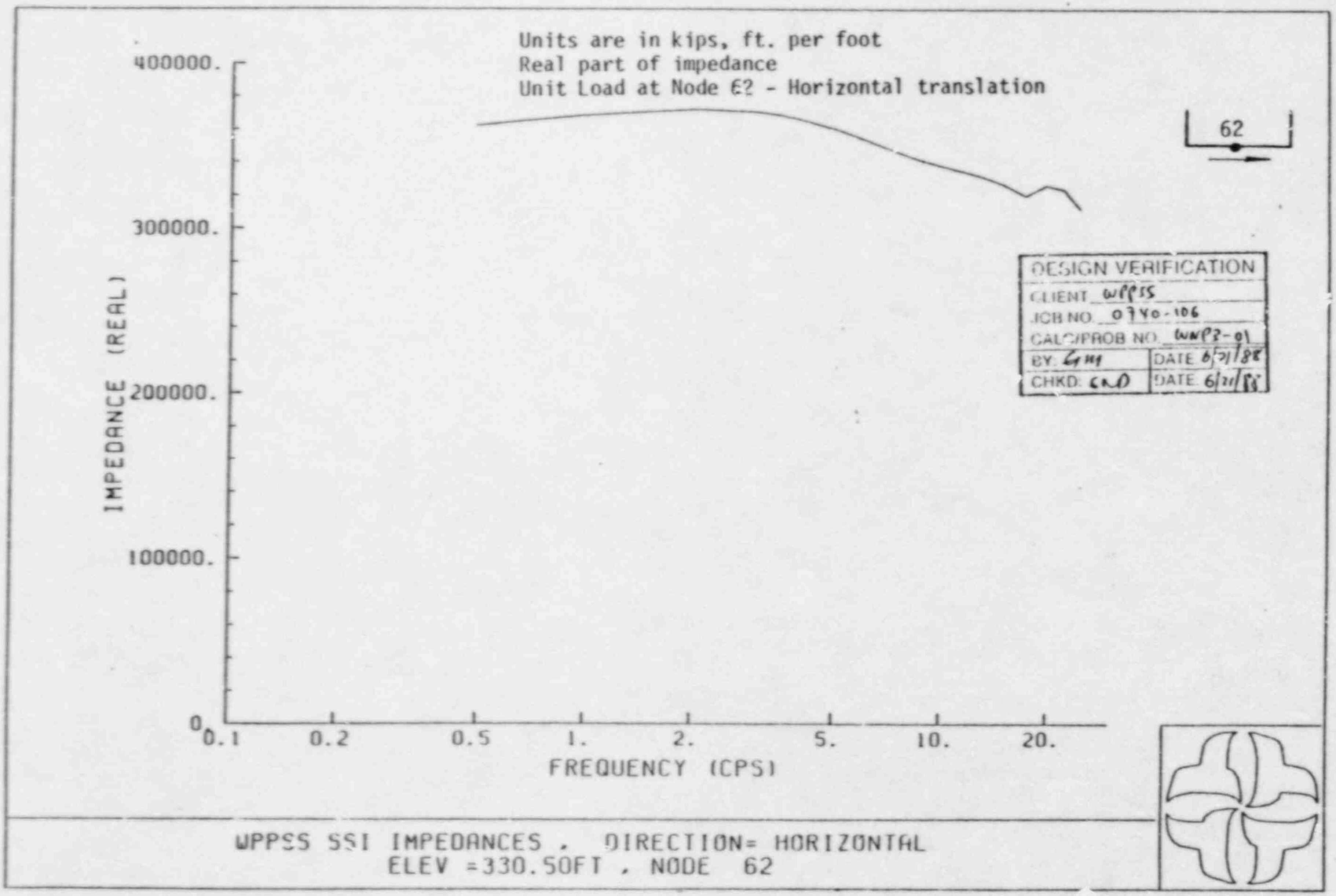
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Figure 2f-5

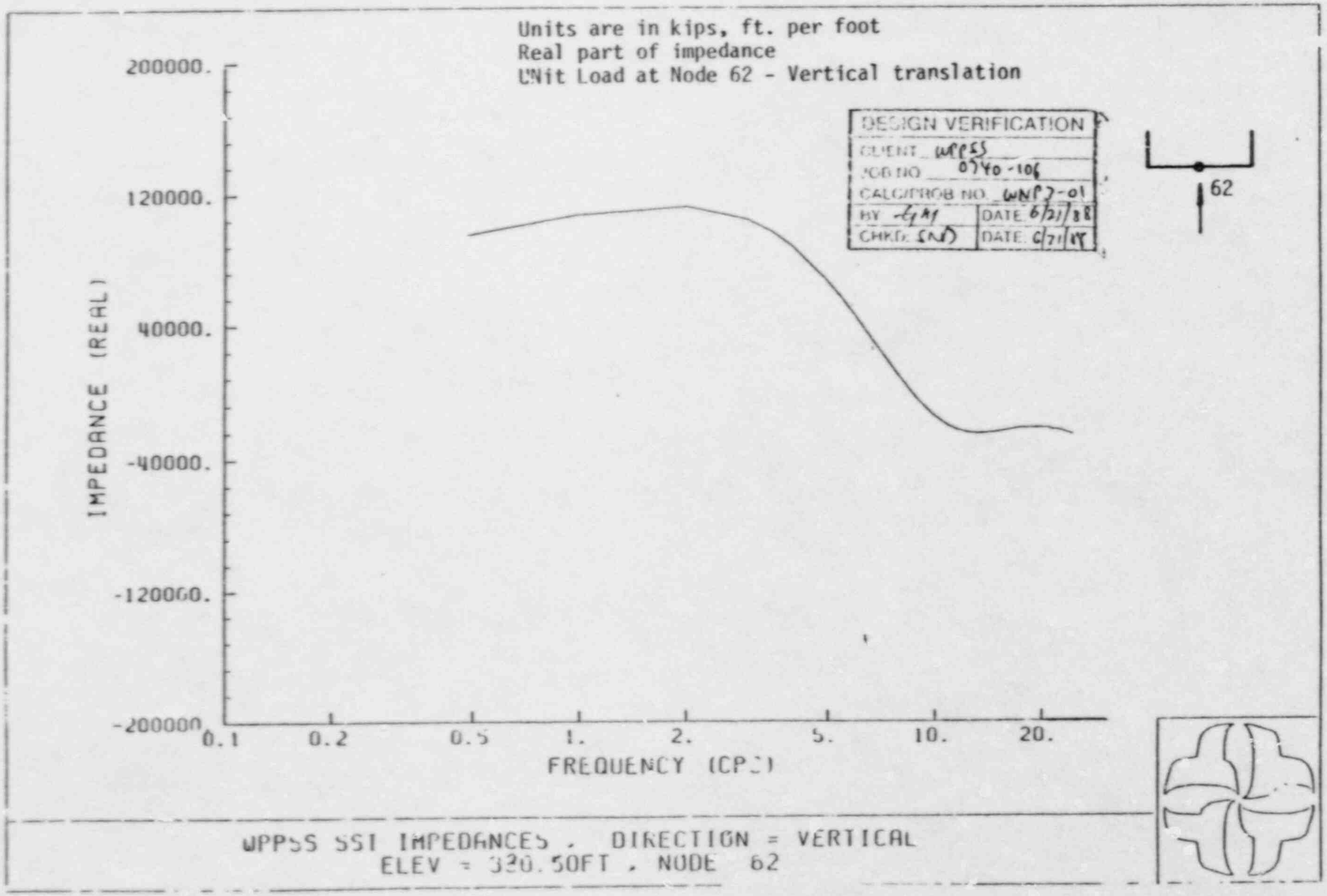

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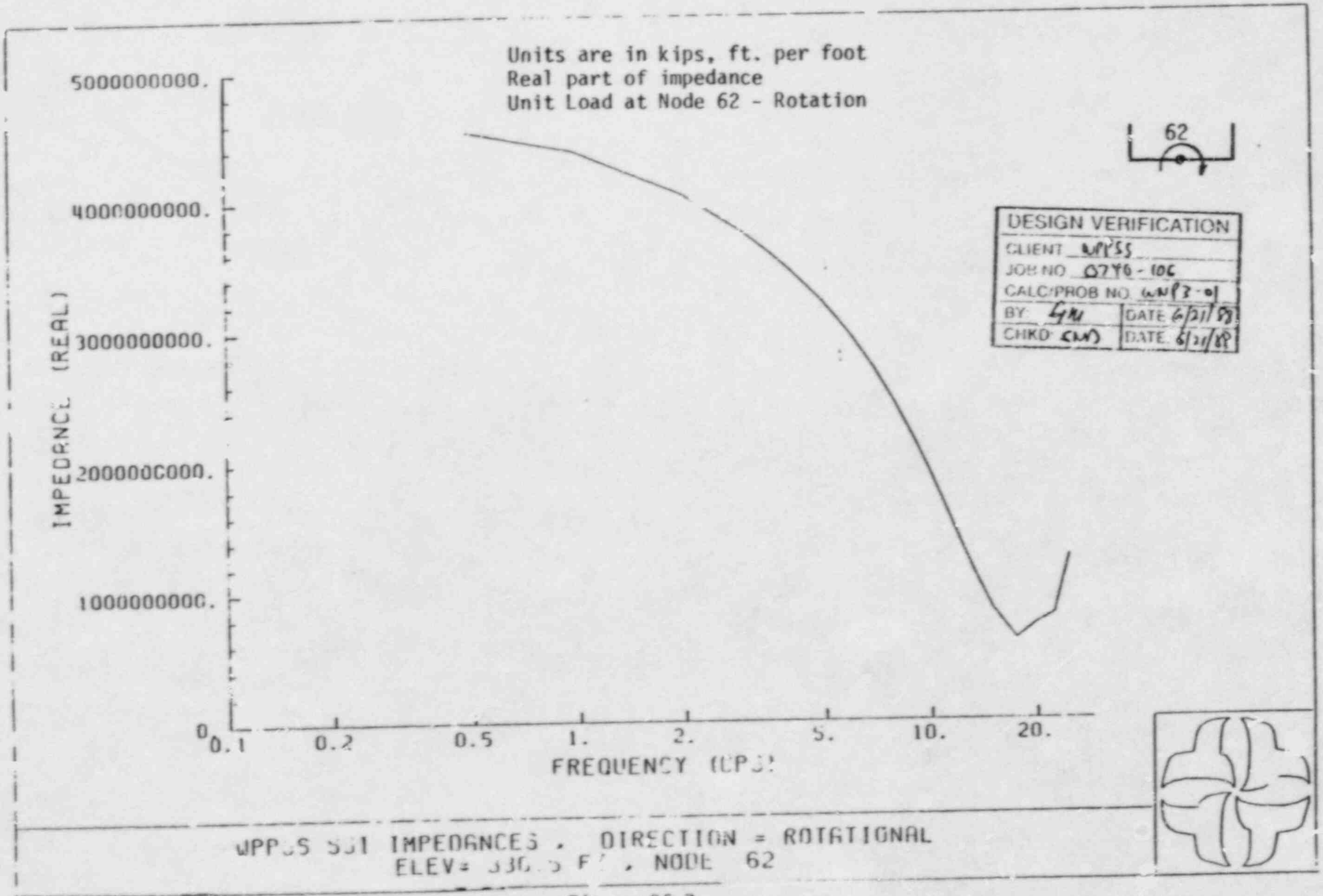
Figure F-6

-15-



Units are in kips, ft. per foot
Real part of impedance
Unit Load at Node 62 - Rotation
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DESIGN VERIFICATION
CLIENT WPPSS
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ELEV= 330.5 FT . NODE 62

Figure 2f-7

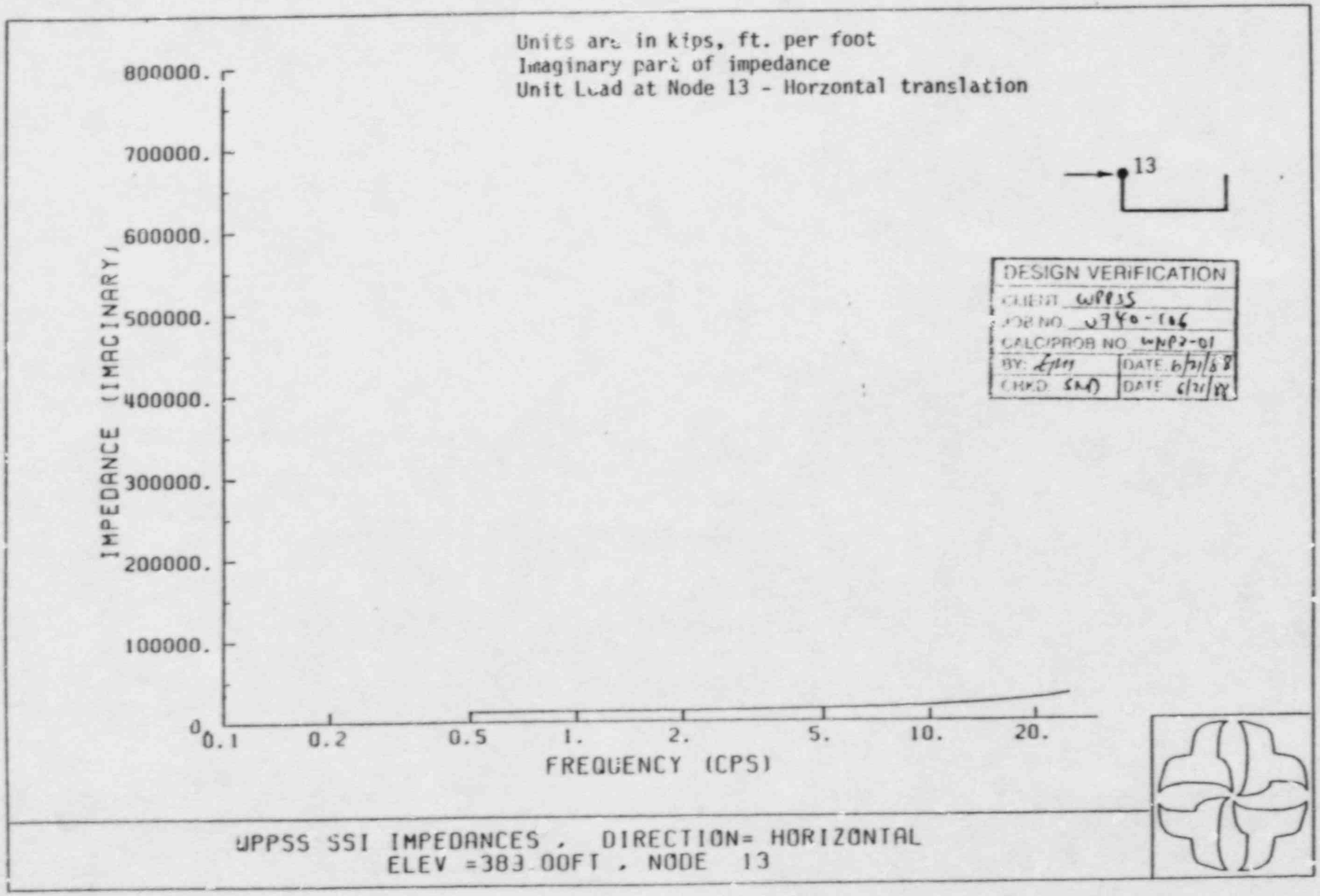
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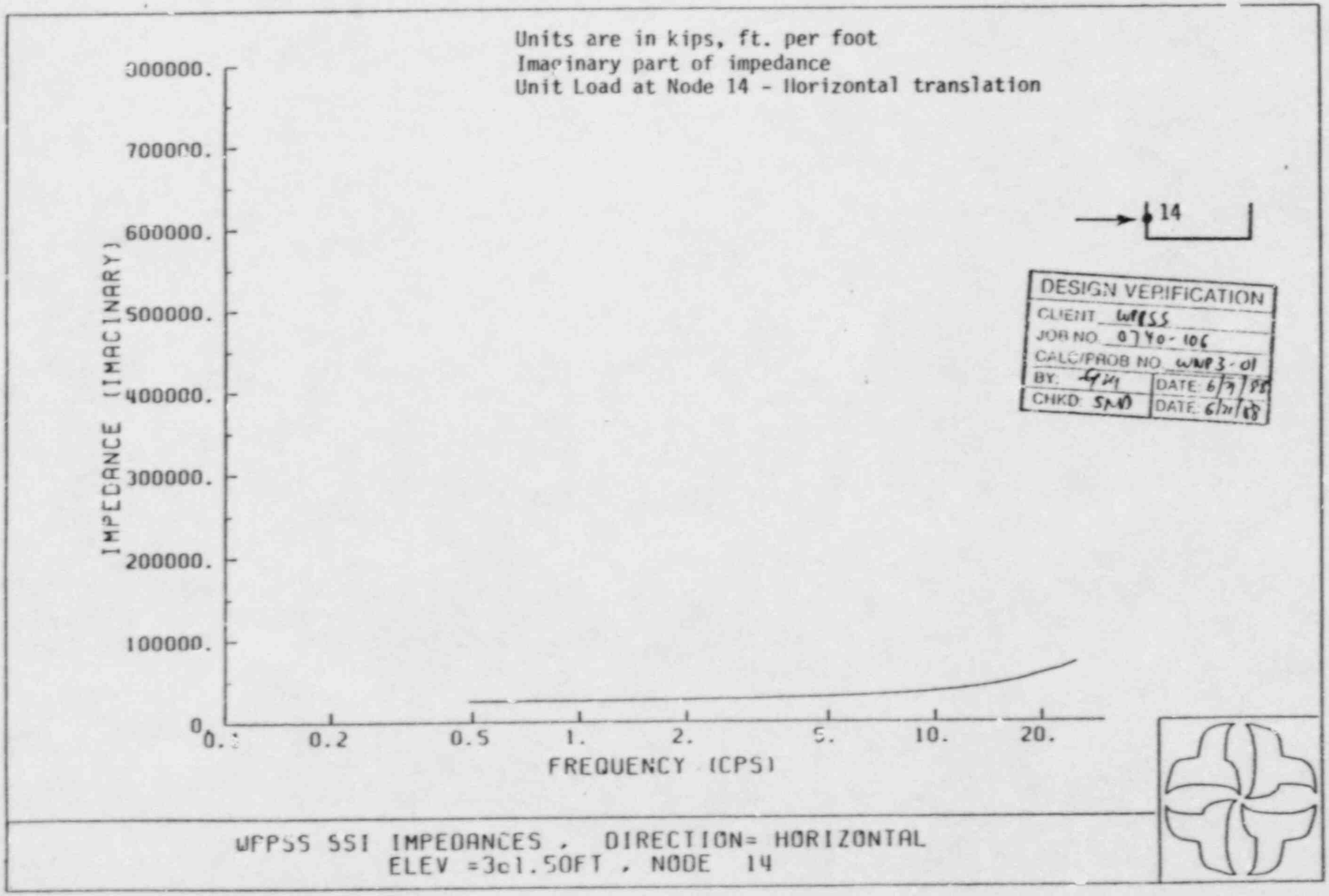
Figure 2f-8


Units are in kips, ft. per foot
Imaginary part of impedance
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FREQUENCY (CPS)
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CALC/PROB NO. WNP3-01
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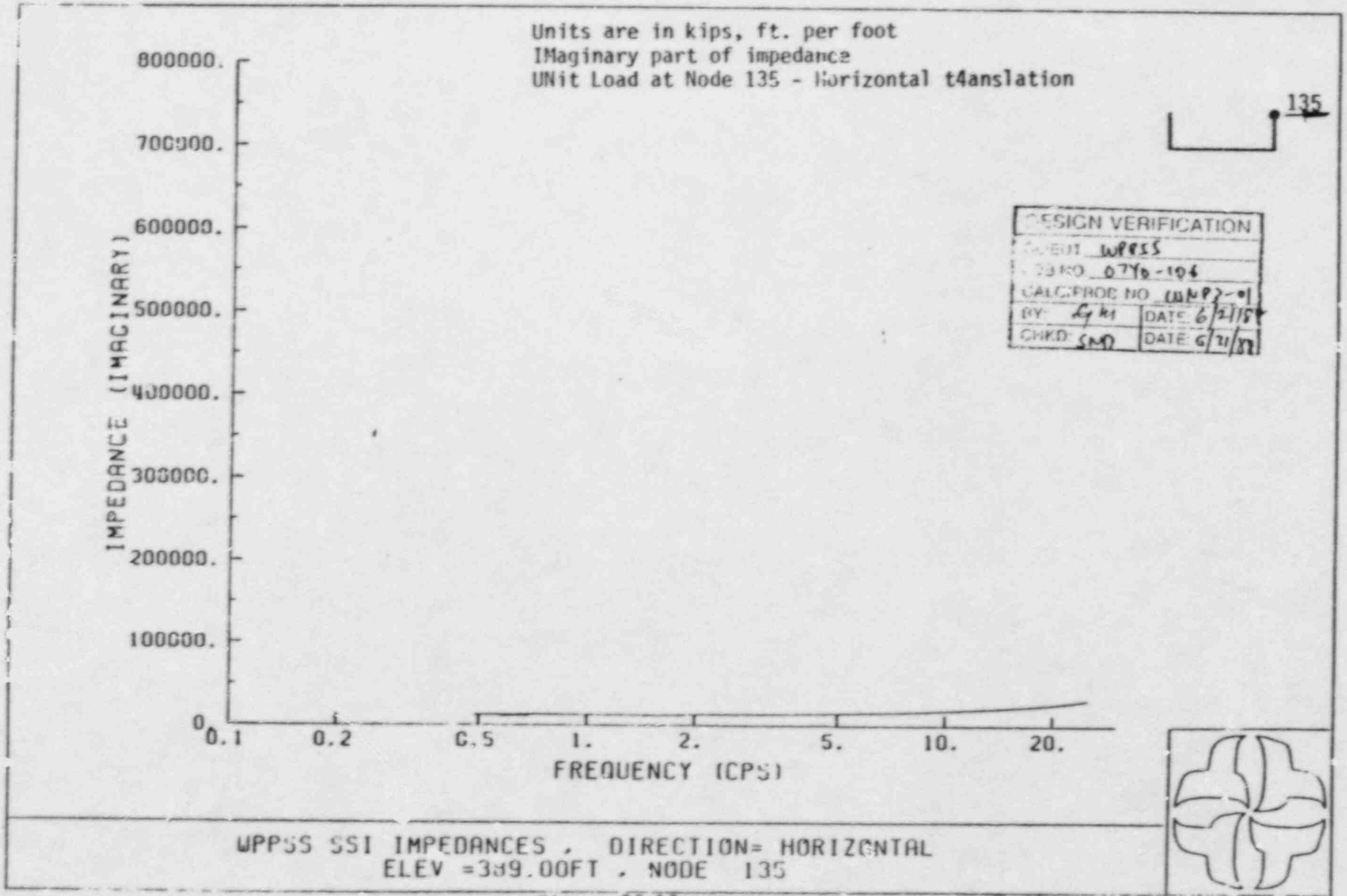
ELEV =361.50FT , NODE 14

Figure 2f-9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FREQUENCY (CPS)
WPPSS SSI IMPEDANCES , DIRECTION= HORIZONTAL
ELEV =389.00FT . NODE 135

Figure 2f-10

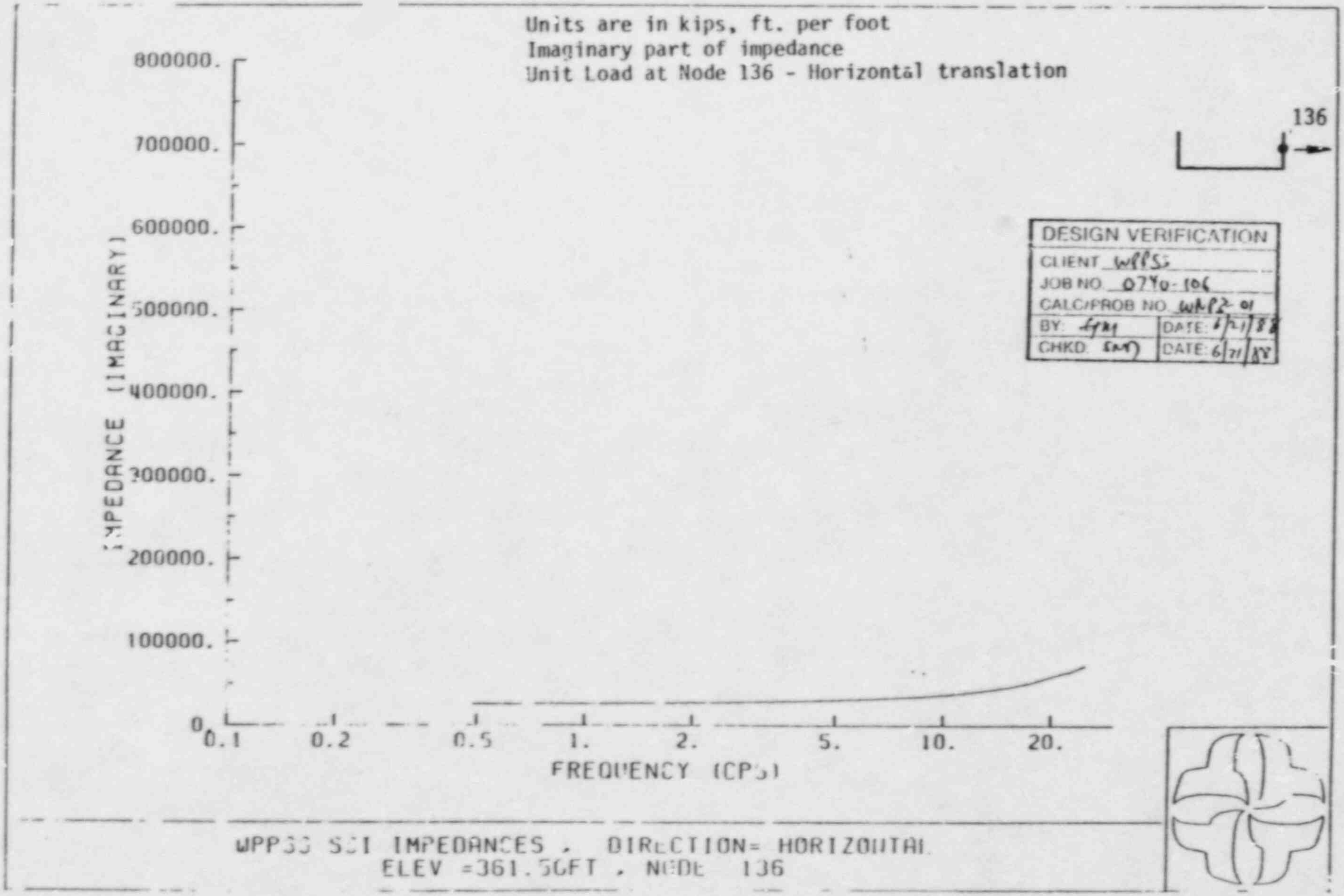

Units are in kips, ft. per foot
Imaginary part of impedance
Unit Load at Node 136 - Horizontal translation
136
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO. 0740-106
CALC/PROB NO. WNP2-01
BY: GJM DATE: 6/21/88
CHKD: SMJ DATE: 6/21/88
IMPEDANCE (IMAGINARY)
800000.
700000.
600000.
500000.
400000.
300000.
200000.
100000.
0.
0.1
0.2
0.5
1.
2.
5.
10.
20.
FREQUENCY (CPS)
WPPSS SSI IMPEDANCES , DIRECTION= HORIZONTAL
ELEV =361.5GFT , NODE 136

Figure 2f-11

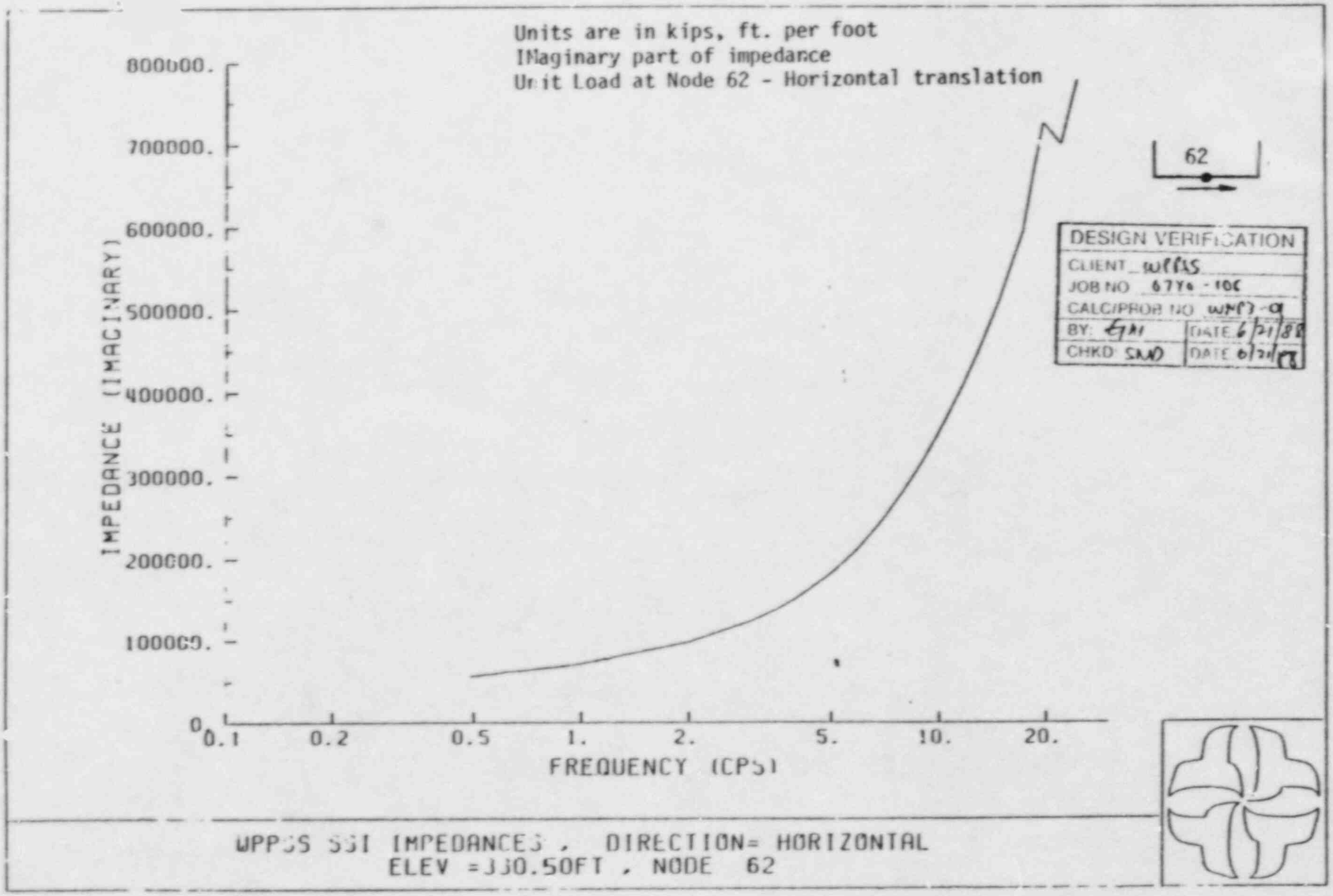

Units are in kips, ft. per foot
IMaginary part of impedance
Unit Load at Node 62 - Horizontal translation
800000.
700000.
600000.
500000.
400000.
300000.
200000.
100000.
0
IMPEDANCE (IMAGINARY)
0.1
0.2
0.5
1.
2.
5.
10.
20.
FREQUENCY (CPS)
62
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO 6794-106
CALC/PROB NO WNP3-01
BY: GAI
DATE 6/21/88
CHKD SND
DATE 6/21/88
WPPSS SSI IMPEDANCES , DIRECTION= HORIZONTAL
ELEV =330.50FT , NODE 62

Figure 2f-12

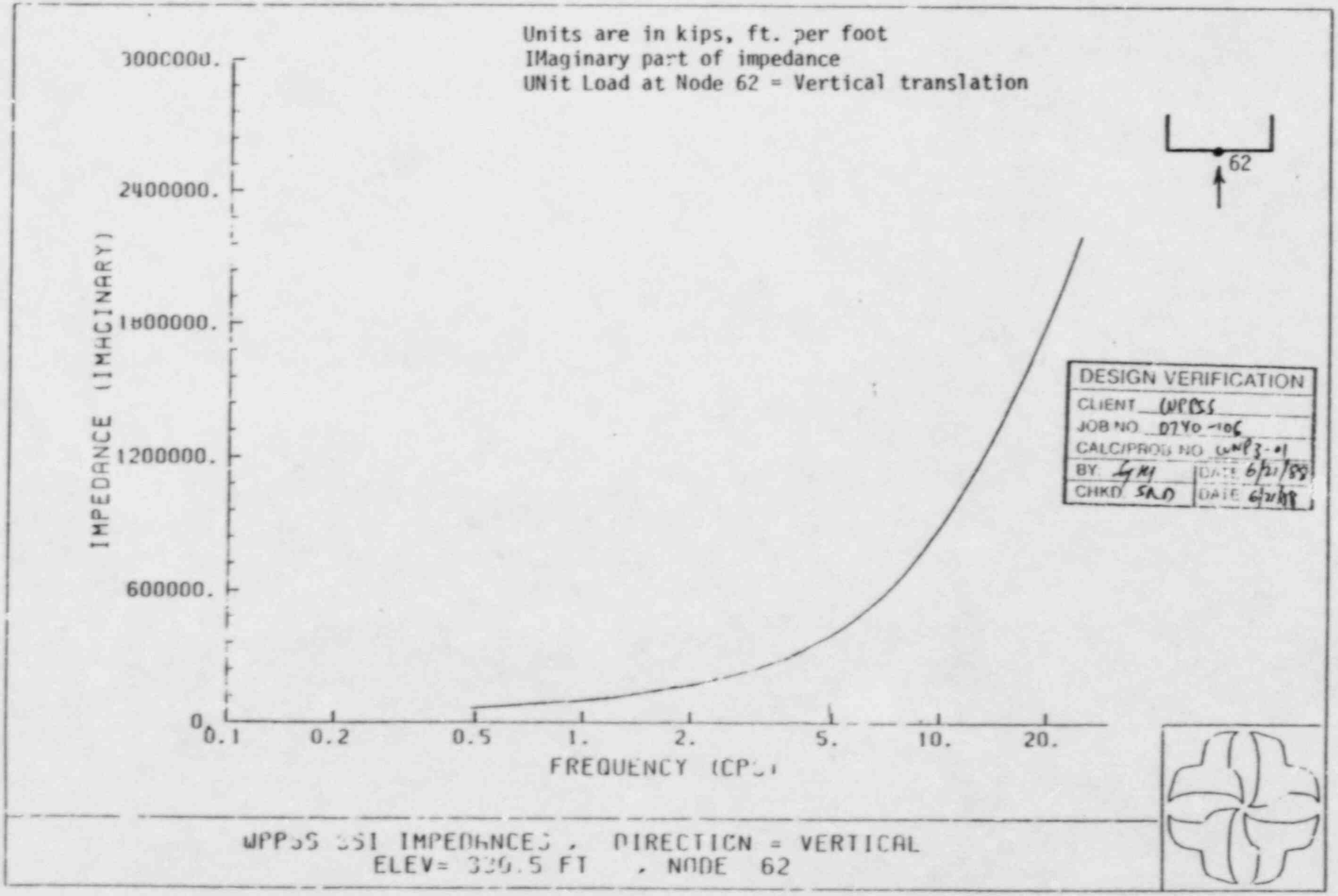
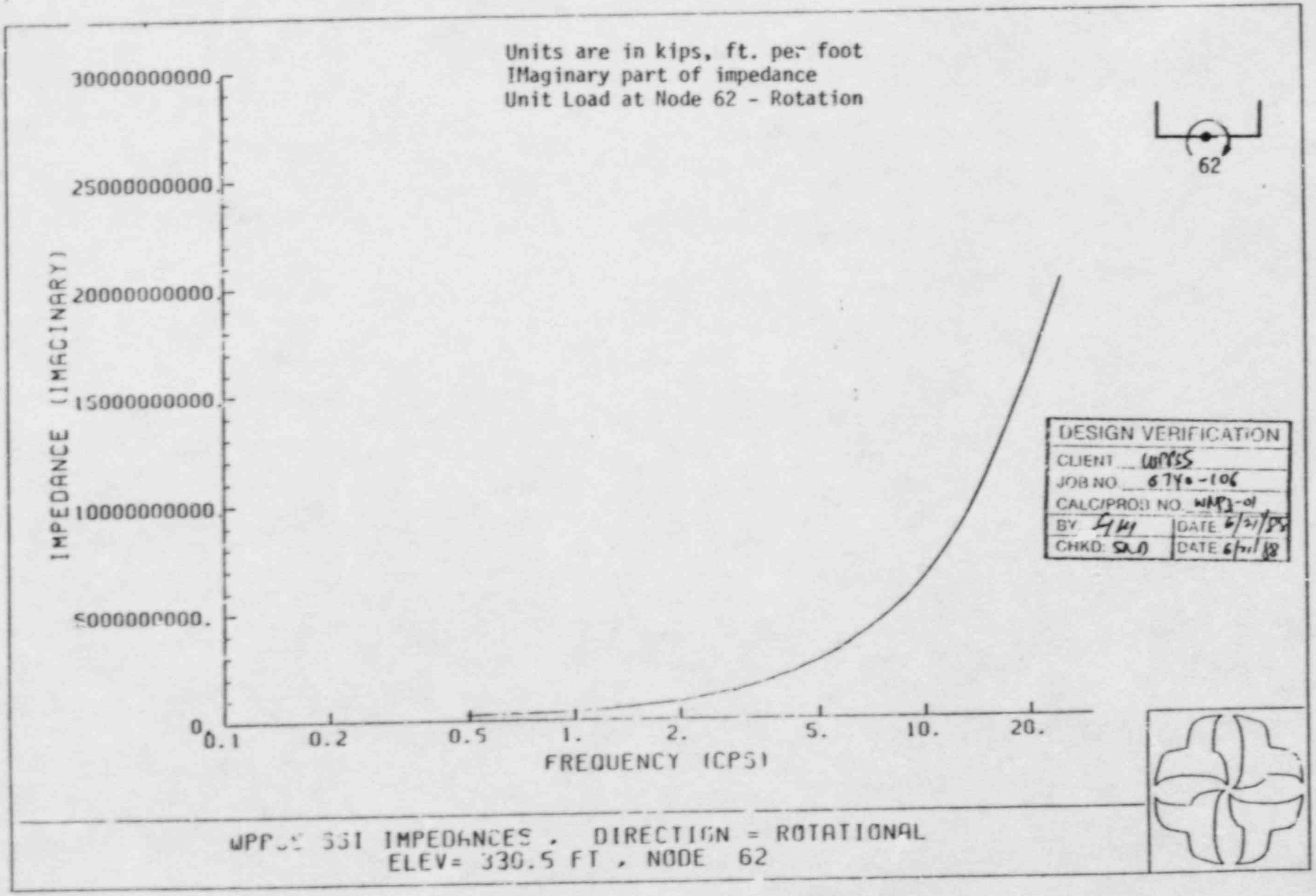

Units are in kips, ft. per foot
IMaginary part of impedance
UNit Load at Node 62 = Vertical translation
3000000.
2400000.
1800000.
1200000.
600000.
0
IMPEDANCE (IMAGINARY)
0.1
0.2
0.5
1.
2.
5.
10.
20.
FREQUENCY (CPS)
62
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO. 07Y0-106
CALC/PROG NO. WNP3-01
BY: GMY DATE 6/21/88
CHKD: SAD DATE 6/21/88
WPPSS SSI IMPEDANCES , DIRECTION = VERTICAL
ELEV= FT , NODE 62

Figure 2f-13



Units are in kips, ft. per foot
IMaginary part of impedance
Unit Load at Node 62 - Rotation
62
IMPEDANCE (IMAGINARY)
30000000000.
25000000000.
20000000000.
15000000000.
10000000000.
5000000000.
0
0.1
0.2
0.5
1.
2.
5.
10.
20.
FREQUENCY (CPS)
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO 6740-106
CALC/PROB NO. WNP3-01
BY
DATE
CHKD
DATE
WPPSS SSI IMPEDANCES , DIRECTION = ROTATIONAL
ELEV= 330.5 FT , NODE 62

Figure 2f-14

vertical and rocking modes. However, if the model responses (Item 3a) are examined between the frequency domain solution (SASSI) and the static half space solution, then it can be inferred that the use of static vertical and rocking foundation impedances provides satisfactory results since the character of the responses are similar.

The apparent lack of model sensitivity to the frequency variation in vertical and rocking foundation impedances is judged to result from two primary analysis factors. First, in the SASSI solution the complex frequency dependent stiffness matrix, included in the equation of motion for the complete solution, is of the form:

$$\underline{C} = \underline{K} - w^2\underline{M}$$

where $\underline{K}$ is the complex stiffness matrix, w the frequency of vibration and $\underline{M}$ the mass matrix. Even though the complex stiffness matrix $\underline{K}$ may have a strong functional dependence on frequency, the total frequency dependent stiffness matrix $\underline{C}$ is probably dominated over most of the frequency range by the frequency-squared times mass term. This is especially true as frequency increases and, in our case, $\underline{K}_{real}$ diminishes. Thus, for the specific case of WNP-3, the use of static, or mean value, foundation stiffnesses could be applied (for a simplified study) since the mass stiffness is apparently controlling. Also, it is recognized that a significant mass damping term exists in the SASSI stiffness formulation.

Although the SASSI rocking impedance is functionally dependent on frequency it is seen that all of the lateral foundation impedances are basically invariant with frequency. Since the rocking mode is coupled with the lateral sidewall impedances the rocking response is therefore not simply governed by the rotational rocking impedance. For the Auxiliary Building (at least) it is reasonable to assume that fairly strong couples would be formed by the frequency independent sidewall impedances. Thus, these static (frequency independent) impedance couples will act to temper the rocking response with respect to vibration frequency. It is also noted from a review of the SASSI impedance verses frequency figures that the rocking impedance is diminishing with increasing frequency, with a corresponding substantial increase in imaginary impedance (i.e. component damping). These results also tend to infer that the rocking component, as compared to the sidewall lateral impedances, becomes less dominant and more highly damped over much of the frequency range. Finally, it is worthwhile to observe that the same general impedance trends can be observed in Beredugo's formulations for the rigid sidewall case as presented by Reference 3.

In the half space modeling approach it was the intent, following the recommendations of Reference 6, that limiting the available model damping would permit a compromise in the foundation impedance accuracy (i.e., the use of static value foundation springs). The low damping input raises model responses and tends to broaden the frequency range where response amplitudes are of interest. Indeed the results provided in response to Item 3a show this trend of the half space model results enveloping the SASSI results.

To quantify, or isolate, the effect of individual parameters (e.g., mass affects, impedance values, etc.) on model sensitivity is not the Supply System's objective. Rather, the issue for WNP-3 is: are the design basis spectra conservative when compared to results from an acceptable alternate solution? And secondly, given the half space model assumptions and analysis methodology are the response results reasonable and consistent? The benchmark results provided by the SASSI study resolves each of these issues. Specifically, the WNP-3 seismic design basis spectra contain a significant level of conservatism, and the seismic half space study retains a good deal of merit as a comparative solution.

Finally, as measured by the SASSI response results (Item 3a) the Supply System concludes that for the specific case of WNP-3's soil conditions it is justified (for a comparative study) to assume static sidewall interaction coefficients as derived from a consistent finite element foundation model and unit influence load application methodology.

Item 3a

"Provide a comparison of the fini e element finite boundary calculations with the half space approach."

The intent of this BNL concern was to seek an explanation, or justification, of the differences between the design basis model and the half space study floor spectra results. Since a mutually agreed approach for generating the half space model foundation springs was not established, a SASSI study incorporating all aspects of the foundation media and building model was completed as an alternative to the half space approach. Floor spectra results from the WNP-3 SASSI study (Reference 5) are plotted in Figures 3a-1 through 3a-10. For comparison purposes, the corresponding design basis floor spectra is plotted with each of these figures. Both the SASSI and design basis floor spectra which are presented by these figures are SSE responses at two percent damping.

Figures 3a-1 through 3a-10 present the maximum horizontal and vertical building/internals responses found at the highest respective structure elevation. In addition, the responses at the center of the basemat are also plotted for the horizontal and vertical directions. Because of the high degree of symmetry between the North-South and East-West horizontal building models it is only necessary to examine one horizontal direction for comparison to the design basis floor spectra results. With each figure the corresponding fundamental building frequency (f_1) is given for reference purposes. For example, Figure 3a-7 cites the fundamental vertical Reactor Auxiliary Building frequency as 17.1 Hertz. Because of its rigidity the basemat "frequency" is taken as characteristic of the ZPA, or say greater than 33 Hertz. And thereby the response of the basemat is governed by the dynamic interaction of the soil and building model elements.

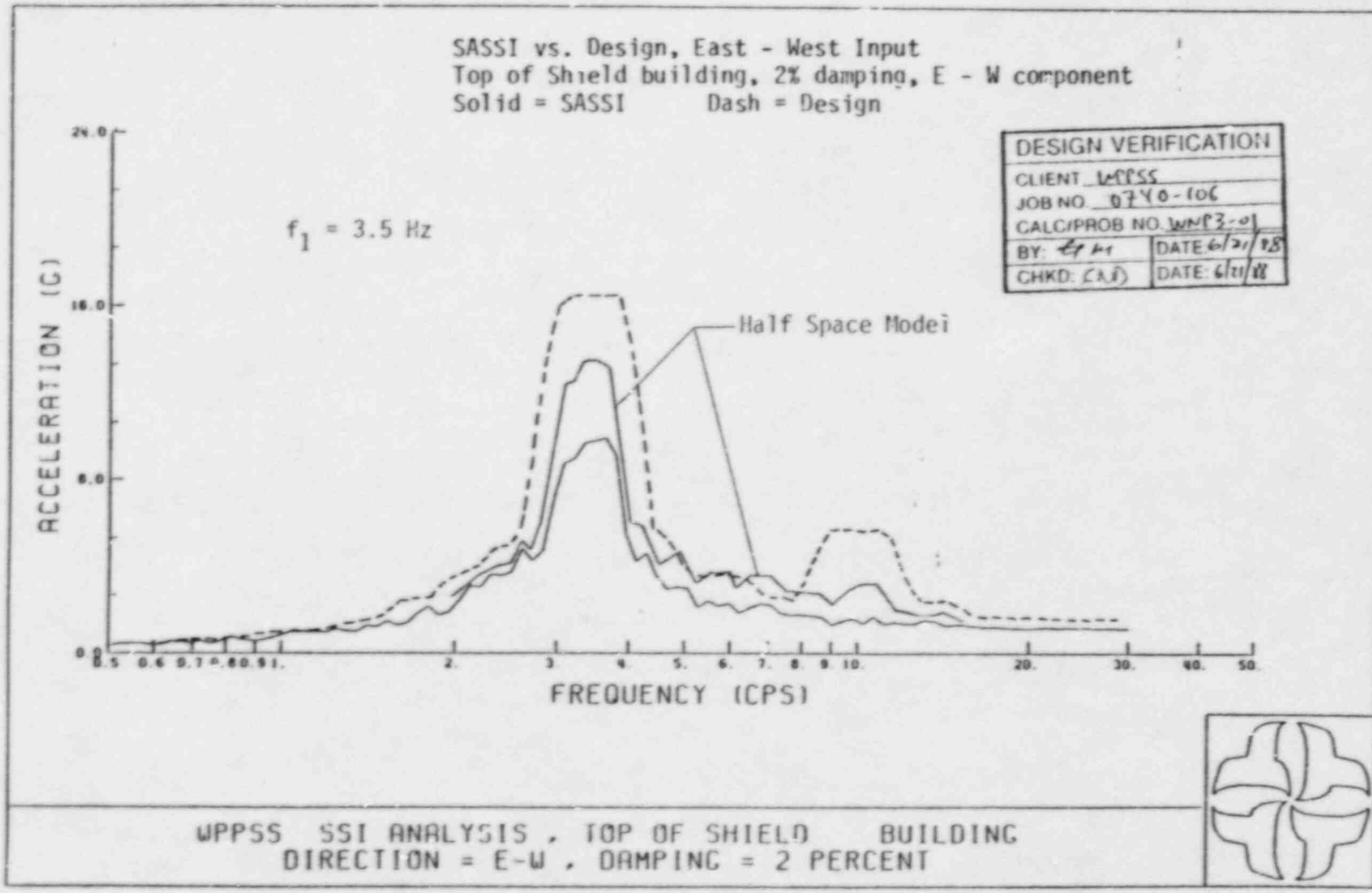

SASSI vs. Design, East - West Input
Top of Shield building, 2% damping, E - W component
Solid = SASSI Dash = Design
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO. 0740-106
CALC/PROB NO. WNP3-01
BY:
DATE 6/21/88
CHKD:
DATE: 6/21/88
f_1 = 3.5 Hz
Half Space Model
ACCELERATION (G)
FREQUENCY (CPS)
WPPSS SSI ANALYSIS , TOP OF SHIELD BUILDING
DIRECTION = E-W , DAMPING = 2 PERCENT

Figure 3a-1

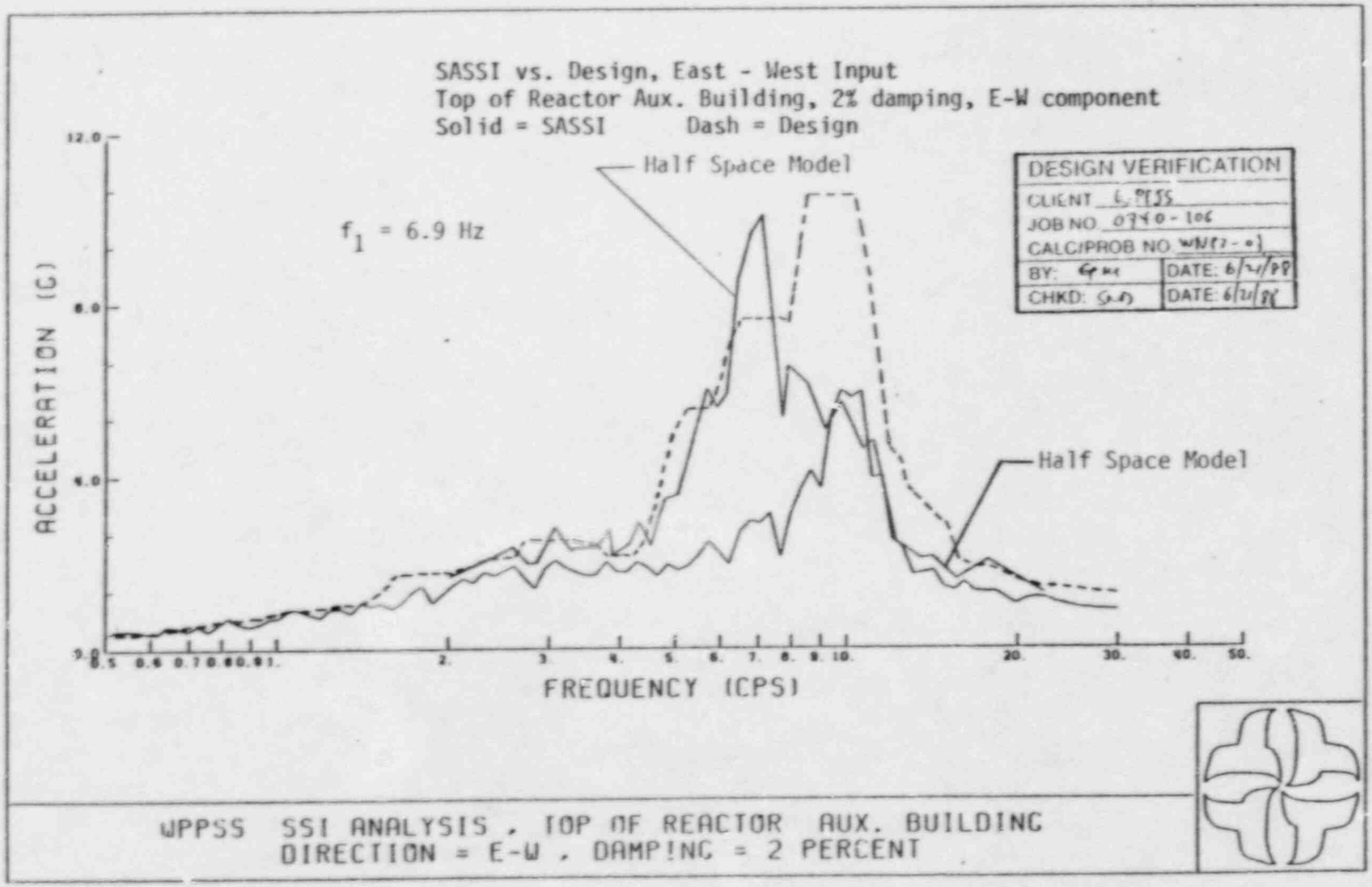
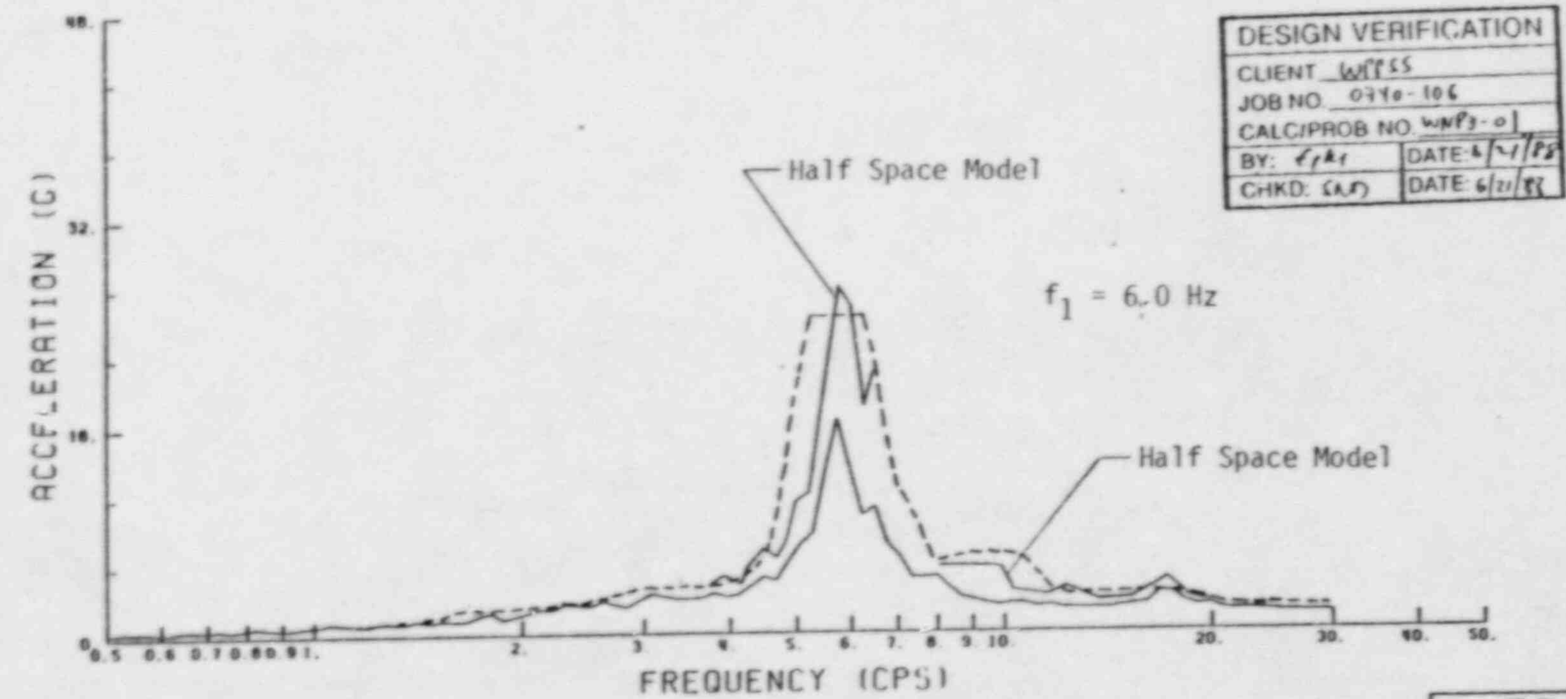

SASSI vs. Design, East - West Input
Top of Reactor Aux. Building, 2% damping, E-W component
Solid = SASSI Dash = Design
Half Space Model
Half Space Model
f1 = 6.9 Hz
ACCELERATION (G)
FREQUENCY (CPS)
DESIGN VERIFICATION
CLIENT
JOB NO. 0740-106
CALC/PROB NO.
BY:
DATE:
CHKD:
DATE:
WPPSS SSI ANALYSIS , TOP OF REACTOR AUX. BUILDING
DIRECTION = E-W , DAMPING = 2 PERCENT

Figure 3a-2

SASSI vs. Design, East - West Input
Top of Containment Vessel, 2% damping, E-W component
Solid = SASSI Dash = Design



WPPSS SSI ANALYSIS . TOP OF CONTAINMENT BUILDING
DIRECTION = E-W . DAMPING = 2 PERCENT

Figure 3a-3

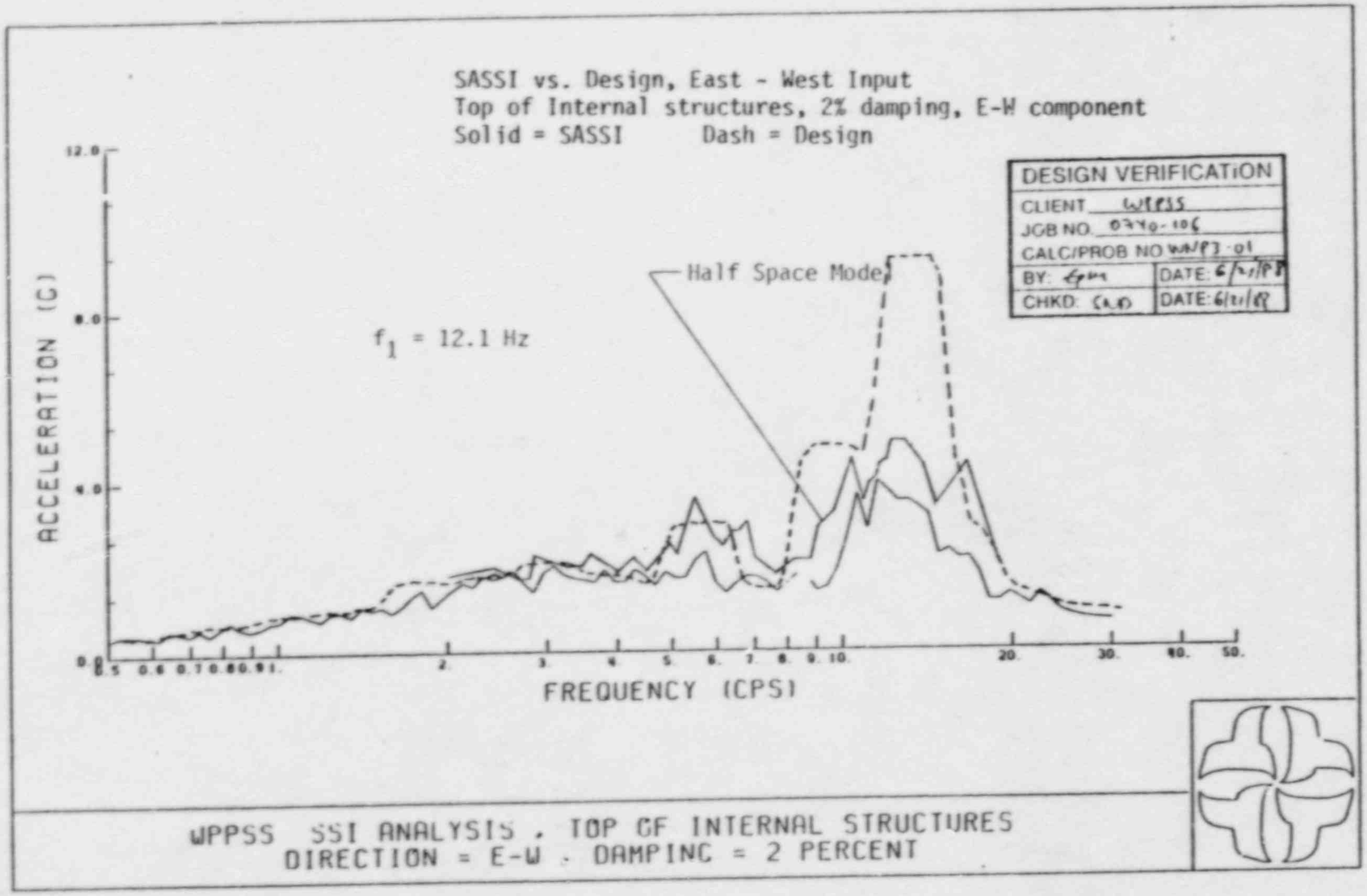

SASSI vs. Design, East - West Input
Top of Internal structures, 2% damping, E-W component
Solid = SASSI Dash = Design
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO. 0740-106
BY:
DATE:
CHKD:
DATE:
Half Space Mode
f1 = 12.1 Hz
ACCELERATION (G)
12.0
8.0
4.0
0.0
0.5 0.6 0.7 0.8 0.9 1.
2. 3. 4. 5. 6. 7. 8. 9. 10.
20. 30. 40. 50.
FREQUENCY (CPS)
WPPSS SSI ANALYSIS . TOP OF INTERNAL STRUCTURES
DIRECTION = E-W . DAMPING = 2 PERCENT

Figure 3a-4

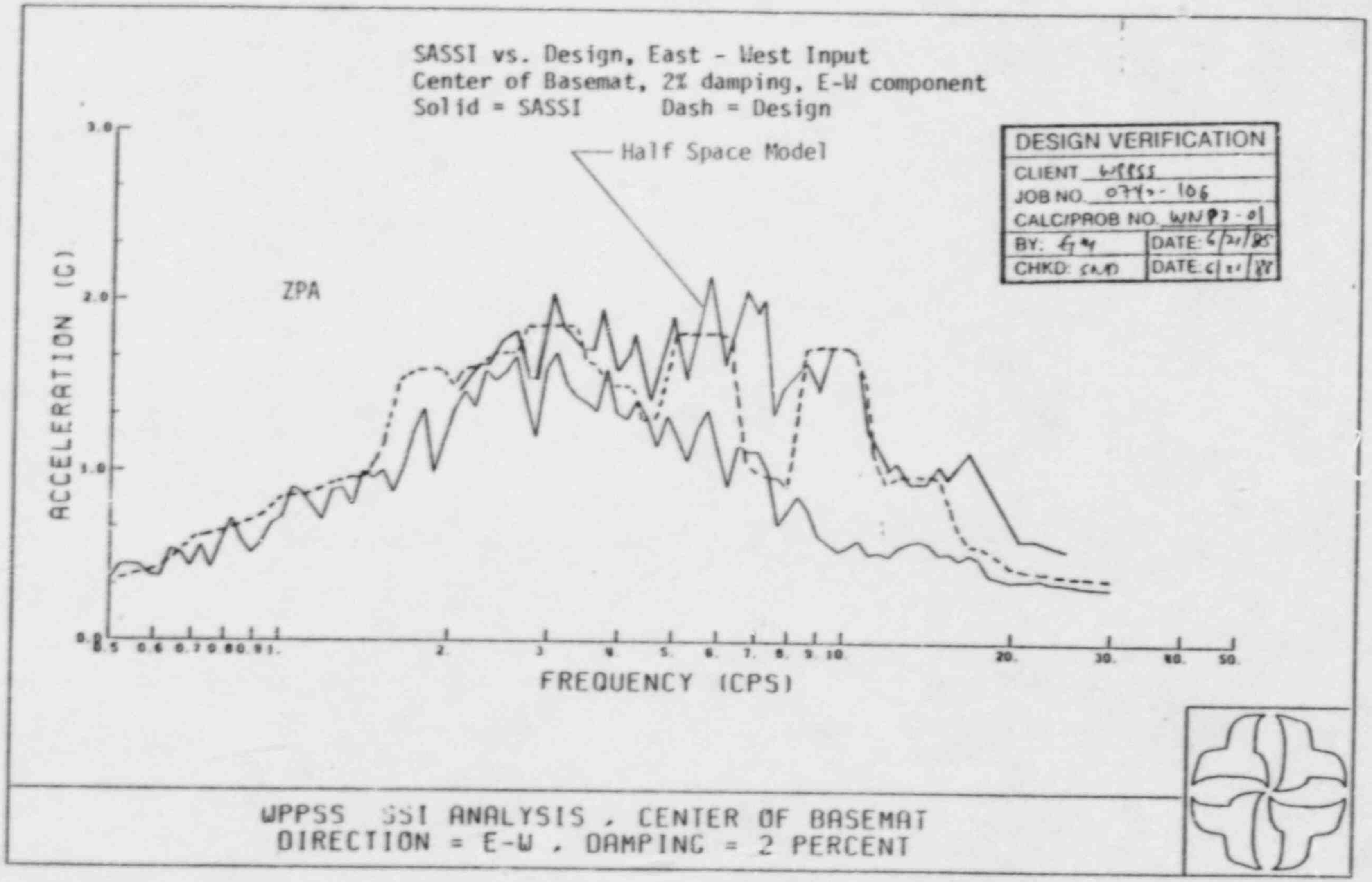

SASSI vs. Design, East - West Input
Center of Basemat, 2% damping, E-W component
Solid = SASSI Dash = Design
Half Space Model
ZPA
ACCELERATION (G)
FREQUENCY (CPS)
DESIGN VERIFICATION
CLIENT
JOB NO.
CALC/PROB NO.
BY:
DATE:
CHKD:
DATE:
WPPSS SSI ANALYSIS , CENTER OF BASEMAT
DIRECTION = E-W , DAMPING = 2 PERCENT

Figure 3a-5

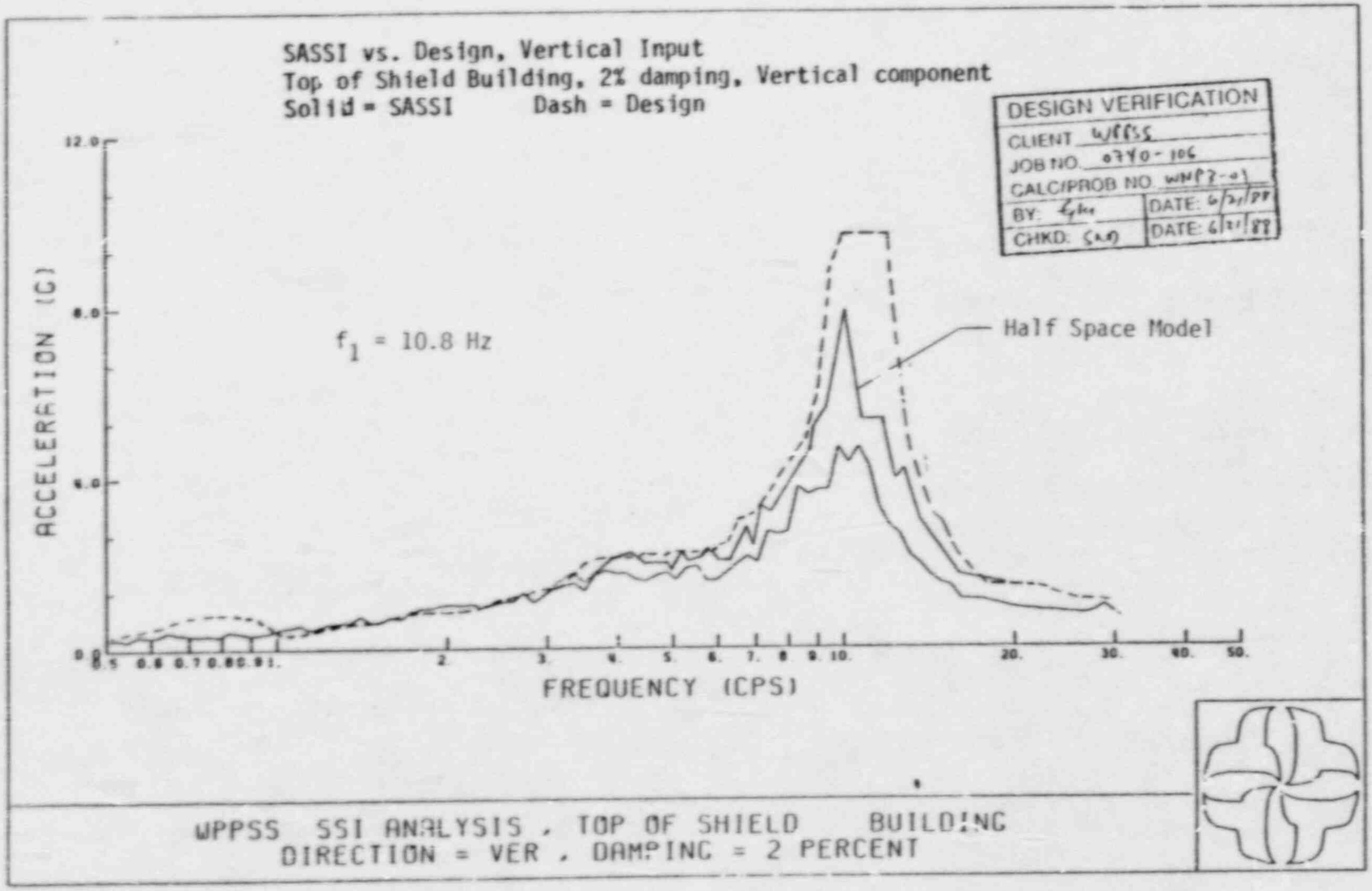

SASSI vs. Design, Vertical Input
Top of Shield Building, 2% damping, Vertical component
Solid = SASSI Dash = Design
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO. 0740-106
CALC/PROB NO. WNP3-01
BY:
DATE: 6/21/88
CHKD:
DATE: 6/21/88
f_1 = 10.8 Hz
Half Space Model
ACCELERATION (G)
12.0
8.0
4.0
0.0
FREQUENCY (CPS)
0.5
0.6
0.7
0.8
0.9
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
20.
30.
40.
50.
WPPSS SSI ANALYSIS , TOP OF SHIELD BUILDING
DIRECTION = VER , DAMPING = 2 PERCENT

Figure 3a-6

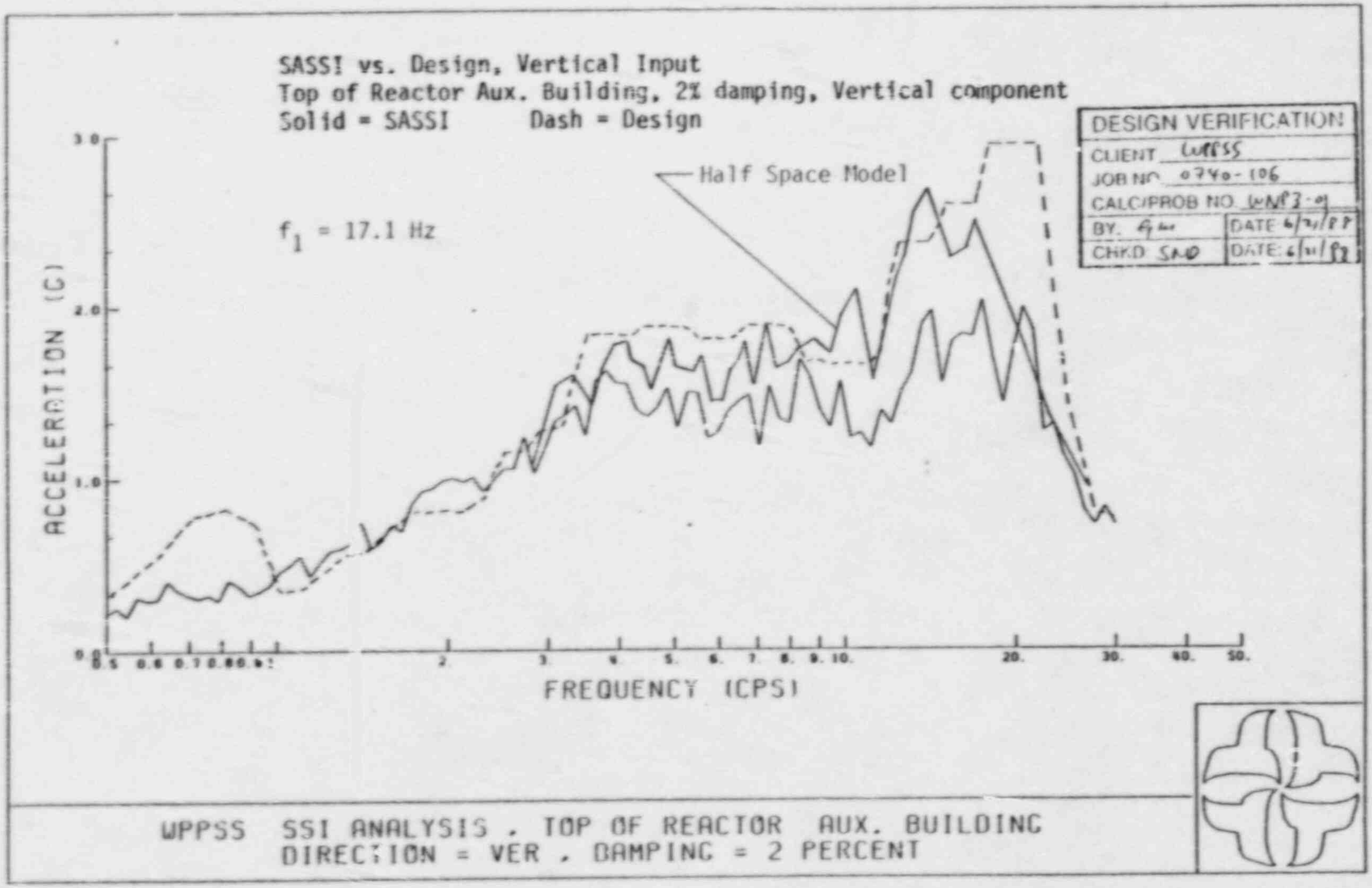
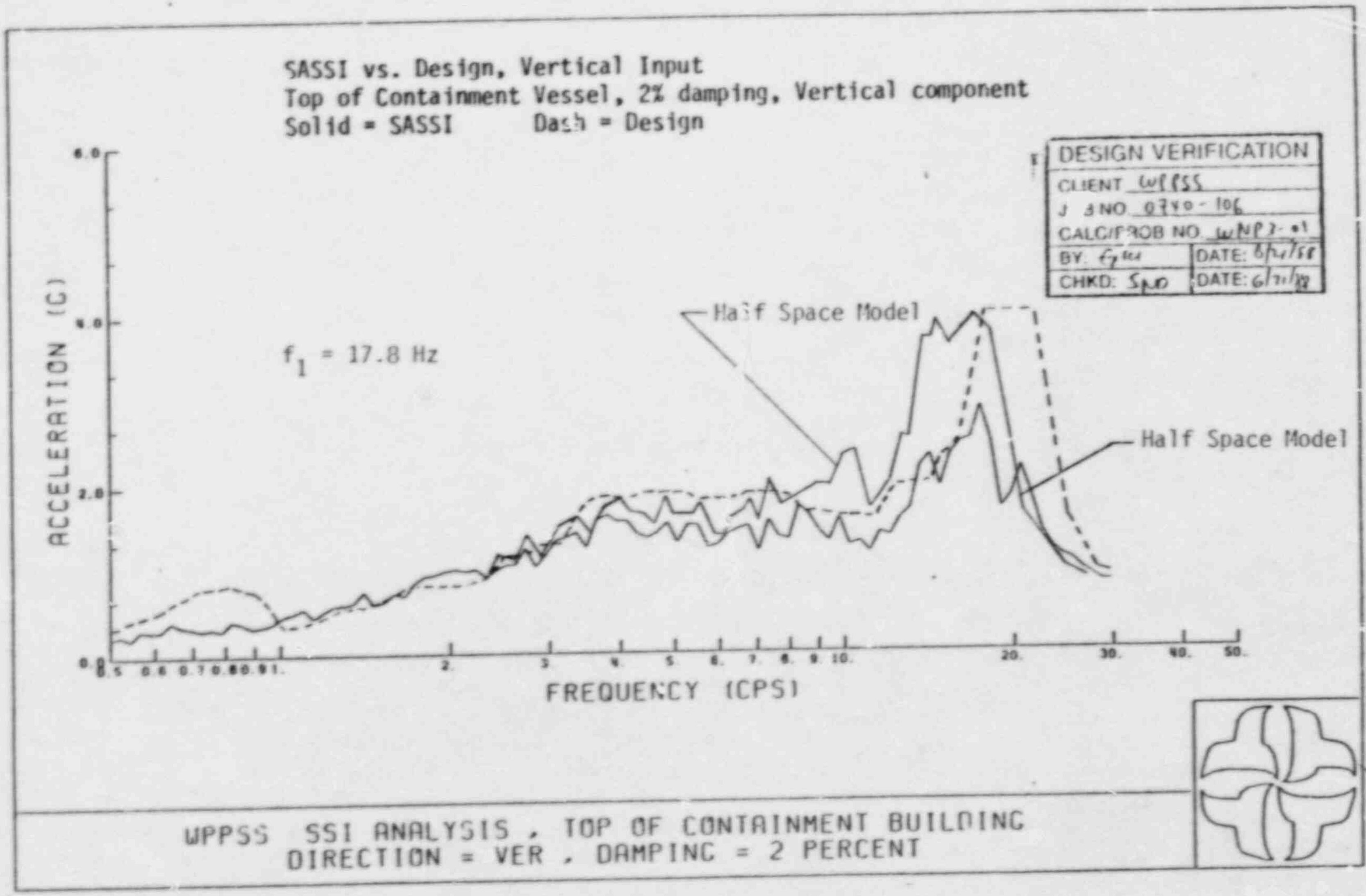

SASSI vs. Design, Vertical Input
Top of Reactor Aux. Building, 2% damping, Vertical component
Solid = SASSI Dash = Design
Half Space Model
f1 = 17.1 Hz
ACCELERATION (G)
FREQUENCY (CPS)
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO 0740-106
CALC/PROB NO. WNP3-01
WPPSS SSI ANALYSIS . TOP OF REACTOR AUX. BUILDING
DIRECTION = VER . DAMPING = 2 PERCENT

Figure 3a-7



SASSI vs. Design, Vertical Input
Top of Containment Vessel, 2% damping, Vertical component
Solid = SASSI Dash = Design
DESIGN VERIFICATION
CLIENT WPPSS
J B NO. 0740-106
CALC/PROB NO. WNP3-01
BY:
DATE:
CHKD:
DATE:
Half Space Model
Half Space Model
f1 = 17.8 Hz
ACCELERATION (G)
FREQUENCY (CPS)
WPPSS SSI ANALYSIS , TOP OF CONTAINMENT BUILDING
DIRECTION = VER , DAMPING = 2 PERCENT

Figure 3a-8

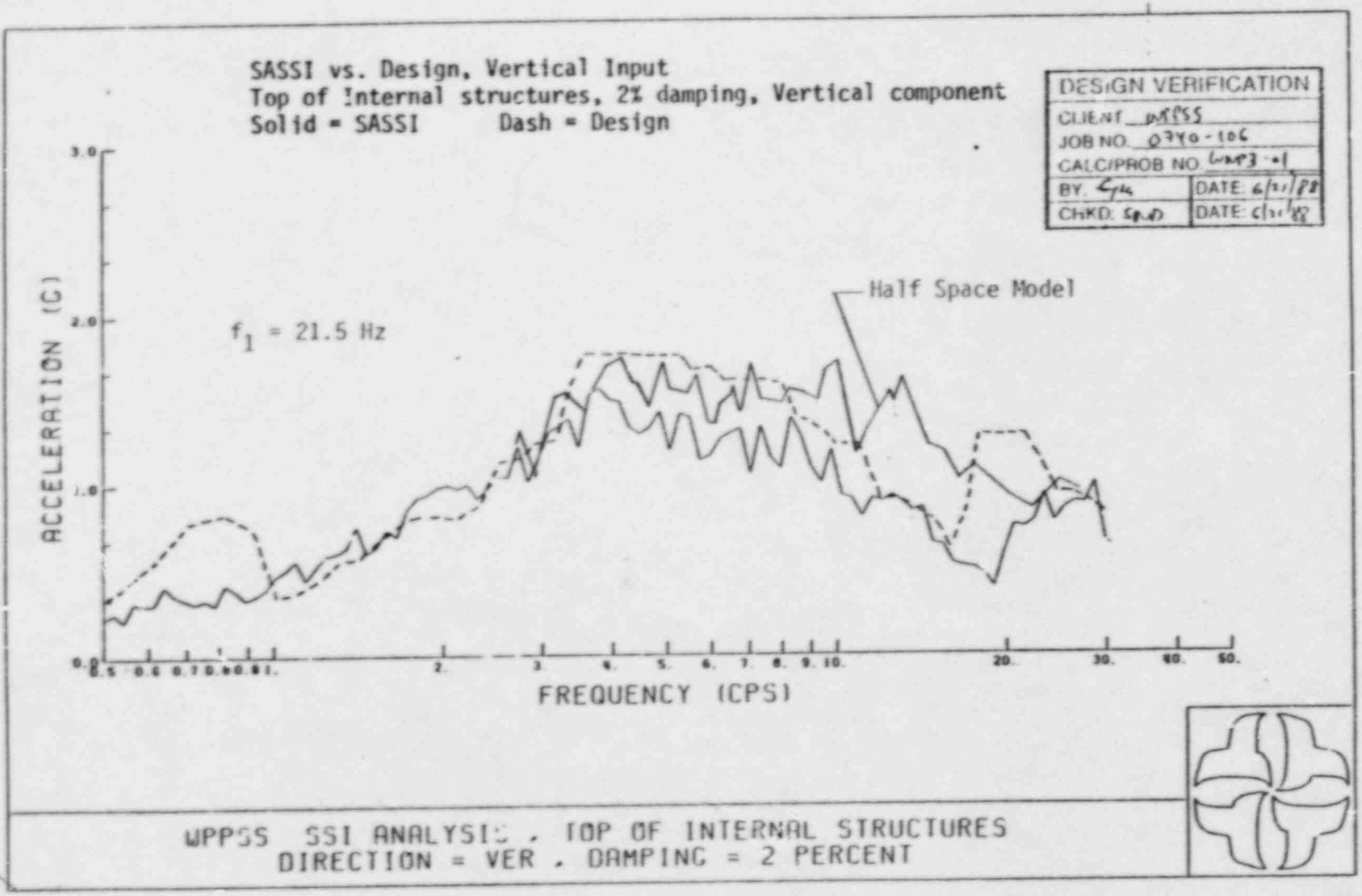

SASSI vs. Design, Vertical Input
Top of Internal structures, 2% damping, Vertical component
Solid = SASSI Dash = Design
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO. 0740-106
CALC/PROB NO. WNP3-01
BY:
DATE: 6/21/88
CHKD:
DATE: 6/21/88
Half Space Model
f_1 = 21.5 Hz
ACCELERATION (G)
3.0
2.0
1.0
0.0
0.5 0.6 0.7 0.8 0.9 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 20. 30. 40. 50.
FREQUENCY (CPS)
WPPSS SSI ANALYSIS , TOP OF INTERNAL STRUCTURES
DIRECTION = VER . DAMPING = 2 PERCENT

Figure 3a-9

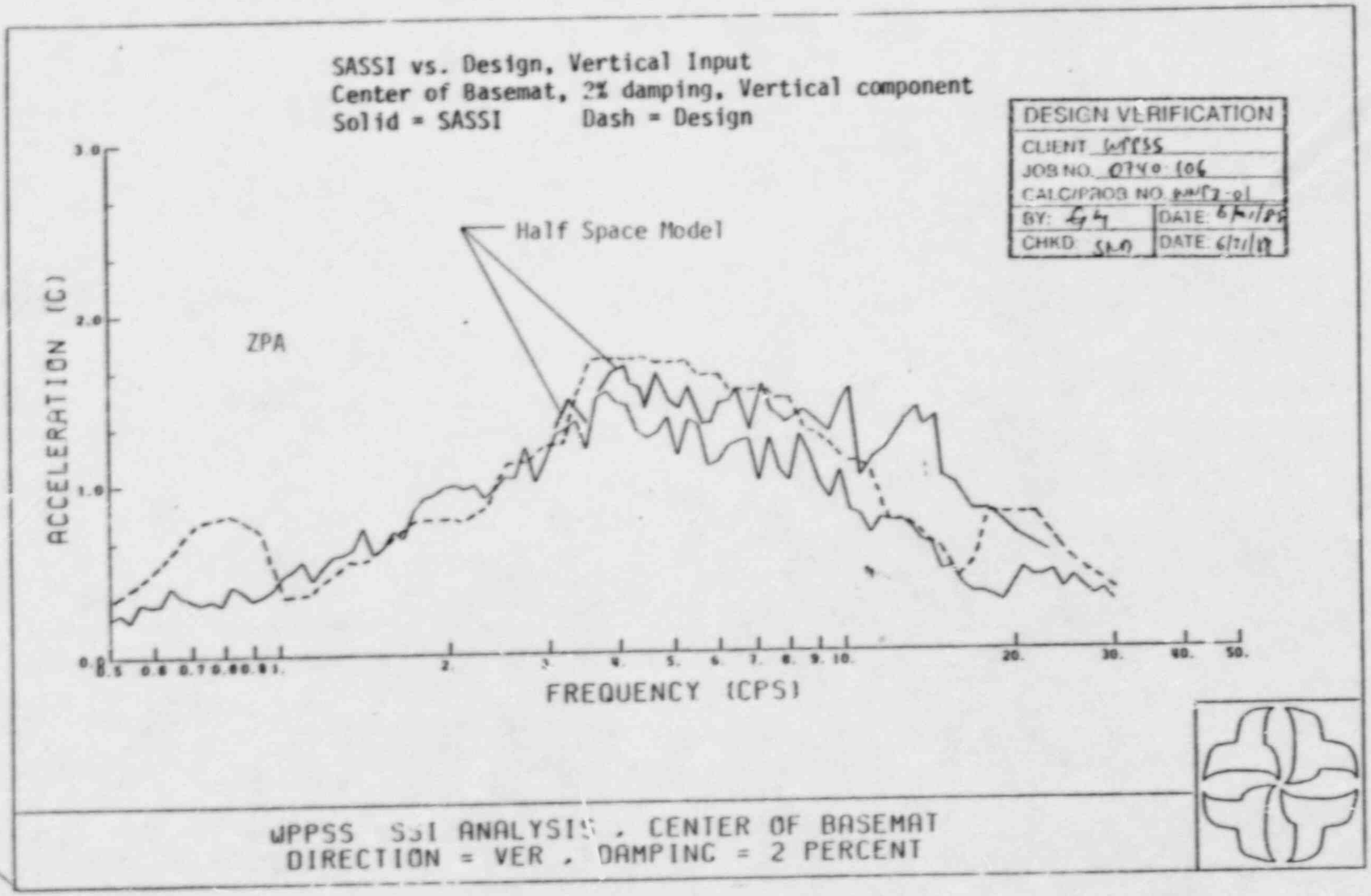

SASSI vs. Design, Vertical Input
Center of Basemat, 2% damping, Vertical component
Solid = SASSI Dash = Design
DESIGN VERIFICATION
CLIENT WPPSS
JOB NO. 0740-106
Half Space Model
ZPA
ACCELERATION (G)
3.0
2.0
1.0
0.0
FREQUENCY (CPS)
2.
3.
4.
5.
6.
7.
8.
9.
10.
20.
30.
40.
50.
WPPSS SSI ANALYSIS . CENTER OF BASEMAT
DIRECTION = VER . DAMPING = 2 PERCENT

Figure 3a-10

A comparative review of the SASSI versus design basis spectral results shows that the SASSI results are bounded at virtually all frequencies of interest. In general, at the fundamental building frequency of interest, the design basis spectral accelerations are more than 100 percent higher than the SASSI predicted results. Trivial exceedances of the design basis spectra do occur with the vertical responses at low (i.e., less than 2.5 Hertz) frequencies; but the acceleration magnitude differences are small in this regime, and most importantly, no active building or subsystem frequency response is found at these long periods (i.e., the WNP-3 design is stiff, as evidenced by the referenced fundamental building frequencies).

Examination of Figure 3a-8 shows a small exceedance of the design basis spectra at approximately 13 to 15 Hz, but the associated containment fundamental vertical frequency, although close, is higher (17.8 Hz). Thus, direct building frequency matching at the exceedance does not result, however, containment mounted subsystems active in this frequency regime could experience an approximate 10 percent vertical component seismic load increase. But again, it is noted that the exceedance is small, and further, that the relative acceleration magnitude compared to the horizontal response is small. Furthermore, WNP-3's total seismic loads are derived as the SRSS combination of the two horizontal and the vertical direction as required by Regulatory Guide 1.92. Thus, a minor exceedance of the vertical component is greatly suppressed by the combination of the larger horizontal responses. Of course, other design conservatisms in terms of design allowables, damping, as well as the basic conservatism of assuming concurrent maximum responses for all three directions of seismic motion (as cited by Newmark, R.G. 1.92), all compound to form a very large margin of safety.

In sum, the Supply System concludes that the WNP-3 SASSI analysis results demonstrate that the WNP-3 seismic design basis model results contain significant margins of safety. Specifically, the WNP-3 in-structure design basis spectra envelop the SASSI results by wide margins at the spectral peaks, and are bounding over the SASSI results at all significant building or internal structure vibration modes.

Figures 3a-1 through 3a-10 also plot the two percent damping curves generated from the A/E's elastic half space study. These curves are plotted in the range from 2.0 to approximately 20.0 Hz. Where the half space curves overlay the SASSI or design basis curves the half space plotting is suspended for purposes of clarity. The half space curves are labeled on each figure.

In general terms, the half space results show frequency characteristics similar to the design basis or SASSI results. And as a further generalization, the half space results are bounded in magnitude between the SASSI and design basis spectral results. Furthermore, the half space results are bounded by the design basis results at each of the respective building fundamental frequencies, except for the Reactor Auxiliary Building (RAB).

Figure 3a-2 shows that the peak of the half space response for the RAB is near the fundamental response of this structure (6.9 Hz). Whereas both the SASSI and design basis models shift the spectral response of this foundation-interfaced structure up to near 10 Hz. A stiffening affect with the surrounding foundation media is judged to cause this shift. The discrete soil support interfaces (i.e., lumped foundation springs) applied in the half space model would in effect yield less constraint on the RAB than the continuous finite element boundaries applied in the SASSI and design basis model techniques. In any case, the SASSI results at 6.9 Hz are (by a factor of three) far below either the design basis or half space results (see Figure 3a-2).

Other exceedances (outside of the building frequencies of interest) do occur with the half space model. Specifically, Figures 3a-8 and 3a-9 show frequency shifts and magnitude increases which are significant. These exceedance are mitigated largely in that they are relatively low magnitude vertical responses (i.e., SRSS combination effects), and secondly, subsystem evaluations (June 1984 submittal) show substantial design margins of safety.

In sum, the Supply System concludes that the half space model results are a basic and sound first approximation to the design basis model spectral results, however, the isolated spectral exceedances which result must be rationalized against other inherent and applied design conservatisms which exist in the WNP-3 seismic design basis.

PREMISE OF AUDIT FINDING NUMBER 1

The premise of AF-1 is summarized by the reviewer's contention that a reduction in seismic motion with depth is not expected because the rock foundation is an elastic media. Specifically, the reviewer states: "..Since the rock is essentially elastic in the range of interest, a reduction in motion at the basemat from that postulated at the surface would not be expected". The Supply System does not agree with this premise either from a theoretic or empirical point of view.

THe WNP-3 nuclear island is a deeply embedded structure essentially socketed into rock down to a depth of over 60 feet. For this depth, even the simplistic assumption of wave propagation in an elastic medium would predict wave attenuation, particularly at higher frequencies (see for example Reference 7). In other words, it is theoretically as well as physically impossible for a motion to have identical characteristics between the surface and at any depth below the surface. This is particularly true for surface motions which are broad banded, rich in all frequencies in the range of interest, such as in the case for the WNP-3 seismic design.

Figures (AF-1)-1 and (AF-1)-2 show a comparison of the SASSI spectral results obtained at the basemat foundation elevation with the free-field or control motion input to the SSI analysis. These figures depict the effects due to SSI. As expected, it is seen that some reduction does occur as compared with the free-field motion. Also as expected, the interaction effects are shown to be more significant in the range of the structural frequencies (e.g., approximately 3 to 20 Hz, depending on motion direction, with reductions as large as 45 percent). At very high frequencies, the free-field motion and the interaction motion are basically identical. This particular effect demonstrates the conservatism of the SASSI calculations. In addition, the SASSI methodology has been shown to conservatively predict reductions of motion over the embedment depth as compared to actual recorded responses. This was demonstrated, for example, by the Lotung experiment where SASSI predicted reductions of a lessor magnitude than those actually recorded.

Empirical results from downhole arrays also substantiate that rapid seismic attenuation with depth occurs in rock (see References 8, 9, and 10). Seismic data from Tateyama and Choshi test sites (Reference 8), as well as Iwaki (Reference 10) are judged to be representative of the WNP-3 sandstone site. And each of these test sites show rapid measured seismic motion attenuations

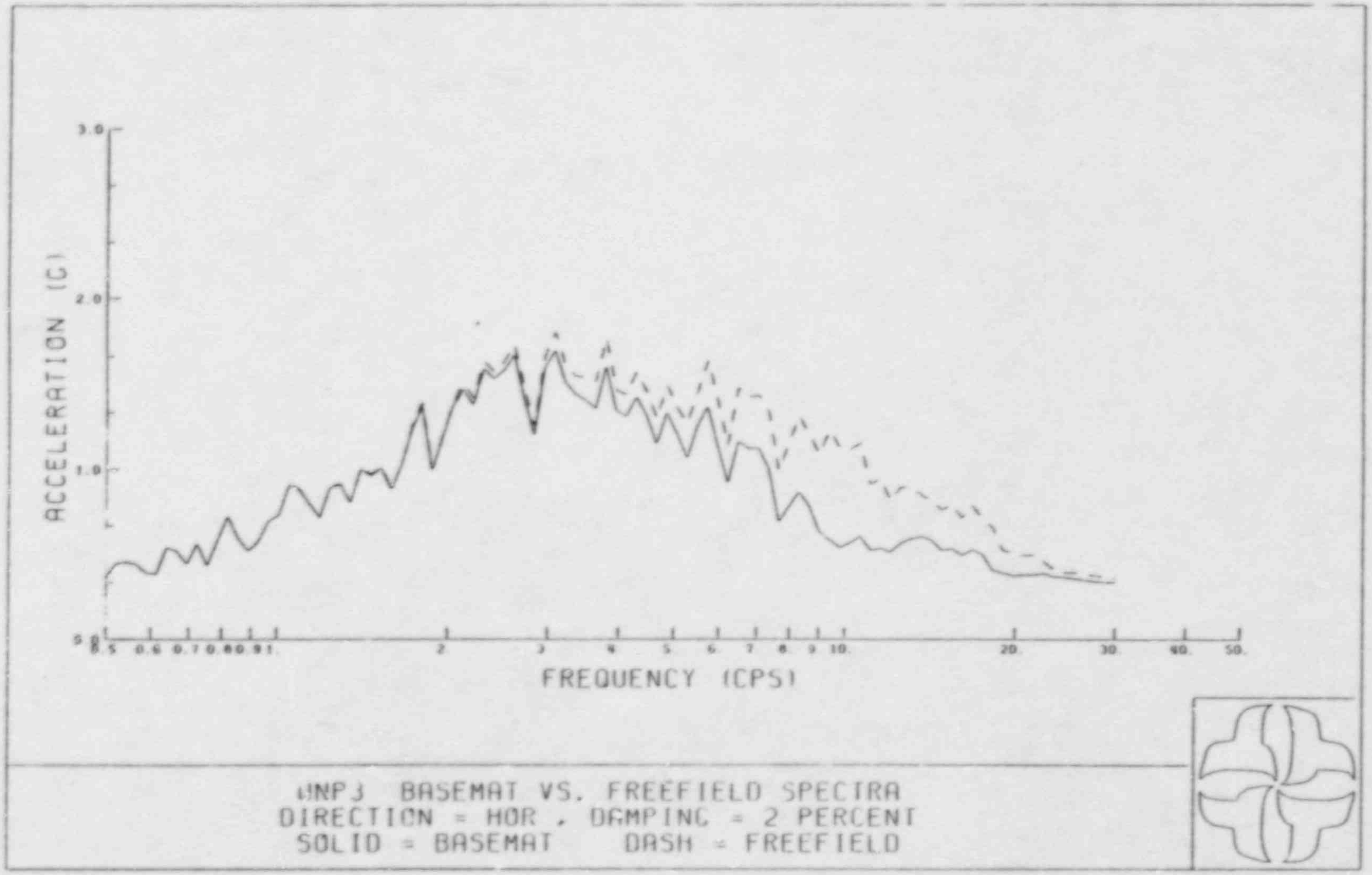

ACCELERATION (G)
FREQUENCY (CPS)
WNP3 BASEMAT VS. FREEFIELD SPECTRA
DIRECTION = HOR , DAMPING = 2 PERCENT
SOLID = BASEMAT DASH = FREEFIELD

Figure (AF-1)-1

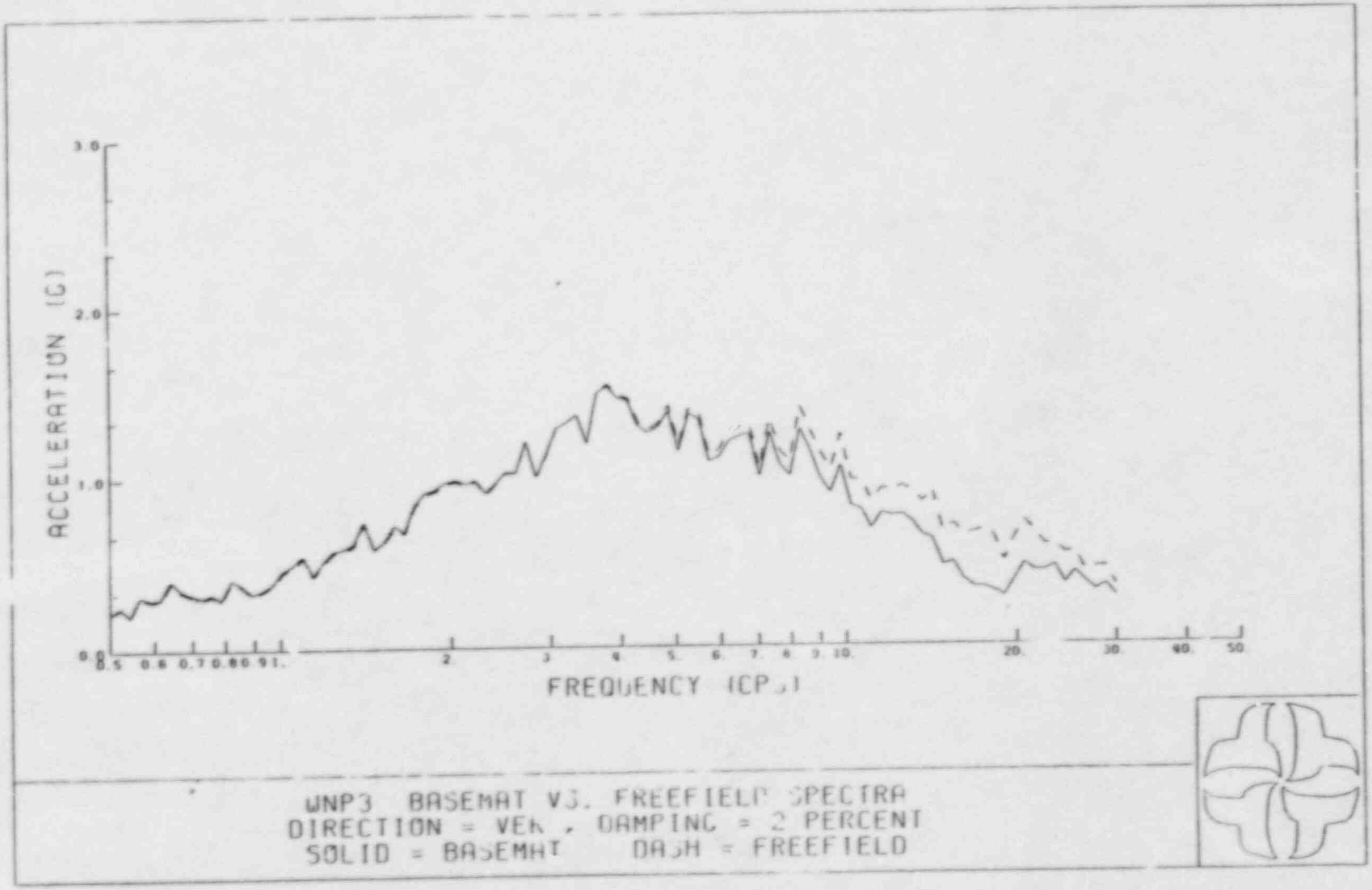

3.0
2.0
1.0
0.0
ACCELERATION (G)
0.5
0.6
0.7
0.8
0.9
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
20.
30.
40.
50.
FREQUENCY (CPS)
WNP3 BASEMAT VS. FREEFIELD SPECTRA
DIRECTION = VER , DAMPING = 2 PERCENT
SOLID = BASEMAT DASH = FREEFIELD

Figure (AF-2)-2

with depth. Moreover, the measured results are consistent with the WNP-3 analysis results which show a 35 percent reduction of the surface motion at the basemat elevation. Reference 11 also presents SHAKE analysis comparisons with empirical data from sites which are comparable with WNP-3. The SHAKE results are consistent with the empirical data and show significant attenuation with depth.

In conclusion, the Supply System finds that deconvolution in a rock media is substantiated by theory and published seismic data for comparable rock sites. Thus, the Supply System recommends that the NRC's concern as identified in AF-1 be closed.

Finally, in the spirit of the requirements of NuReg-0800 (SRP 3.7.2), the Supply System is obliged to validate the conservatism of the WNP-3 seismic design basis model by application of alternate and independent analysis techniques. In fulfillment of this SRP requirement, the comparative SASSI analysis spectral results, as completed by Impell Corporation (Reference 5), are submitted with this response.

REFERENCES

1) Impell Standard Program SASSI - "A Computer Program for Dynamic Soil-Structure Interaction Analysis", Version 2.0, March 1985. Users Manual Revision 0.

2) Letter No. 2115, Brookhaven National Laboratory, A. Philippacopoulos to R. Pichumani (NRC), "Status of WNP-3 Review", dated October 15, 1987.

3) Y. O. Beredugo, et. al., "Coupled Horizontal and Rocking Vibration of Embedded Footings", Canadian Geotechnical Journal, Volume 2, 1972.

4) J. E. Luco, et. al., "Dynamic Response of Circular Footings", Journal of Engineering Mechanics, ASCE, October 1971.

5) Letter No. 0740-106-001, Impell Corporation, M. A. Manrique to D. M. Bosi (Supply System), "WNP3 2-D SASSI Analyses", dated June 21, 1988, with enclosure: Impell Calculation No. WNP3-01, "WNP3 - 2D SASSI SSI Analysis", Rev. 0, dated June 21, 1988.

6) R. C. Murray, et. al., "Seismic Review of the Oyster Creek Nuclear Power Plant as Part of the Systematic Evaluation Program", U.S. NRC, NuReg/CR-1981 UCRL-53018.

7) W. Flugge, "Handbook of Engineering Mechanics", Chapter 64, "Propagation of Elastic Waves", First Edition, 1962.

8) O. Syun'itiro, et. al., "Recently Developed Strong Motion Earthquake Instruments Array in Japan", Research Committee of Strong-Motion Earthquake Instrumented Arrays on Rock Sites", Circa. 1983.

9) C. Y. Chang, et. al., "Engineering Characterization of Ground Motion", NuReg/CR-3805, Volume 3, February 1986.

10) R. J. Hanson, "Seismic Design for Nuclear Power Plants", The M.I.T. Press, Library of [illegible]ess No. 79-110237.

11) C. Y. Chang, Draft Paper: "Use of Observational Data in Evaluating Theoretical Models of Ground Response", Geomatrix Consultants, Inc., San Francisco, California.