SEISMIC AND DYNAMIC SHIPPING ANALYSIS OF SSC MAGNETS

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INTRODUCTION

SSC magnets have been analyzed for their response to both typical seismic and trucking loads using ANSYS. Two different models have been used since significant differences exist between magnets installed in a tunnel and magnets as they are shipped on a truck. The vacuum shell was not part of the seismic model; thus, only cryostat response is available for this case. No problem is anticipated, however. Thermal shields were not analyzed for either case, and these could be a possible problem. Further work is recommended.

DYNAMIC ANALYSIS USING ANSYS

The finite element code ANSYS can provide solutions to four general types of dynamic problems. They are:

1) modal analysis
2) harmonic analysis
3) transient linear dynamic analysis
4) transient non-linear dynamic analysis

All calculations presented here will be of the first type, modal analysis. Typically one thinks of modal analysis as providing natural frequencies and mode shapes (eigenvalues and eigenvectors) to a specific problem. Only relative displacements are available so that true stress and reaction force evaluation is not possible. However, ANSYS also has

the very powerful spectrum option technique in the modal analysis which can provide true stresses and deflections. It is based on the concept of shock response spectrum, or more simply response spectrum. A response spectrum is a plot of the maximum displacement, velocity, or acceleration response of a group of idealized single degree of freedom oscillators to a specific dynamic load. These idealized oscillators can have damping so that a structure with the same percentage of critical damping can be analyzed for maximum deflections. A system with n degrees of freedom is transformed into n single degree of freedom systems.

The following discussion on the actual use of ANSYS assumes version 4.1. A general discussion of modal analysis is found in sections 2,8, 2.9, and 1.12. Restart capability for combined static and dynamic analysis is located in section 2.23. Required PREP 7 inputs for modal analysis are found in the Load Option Module and Master Degree of Freedom Module. POST 27 is used for combining modes (including closely spaced modes which we do not have in the SSC analysis). Note also that POST 28 is available for the creation of response spectra from displacement vs. time histories.

ANSYS uses a powerful technique called dynamic condensation for solving the dynamic response of structures. See chapter 13 of reference 1. ANSYS also uses the Guyan reduction procedure for reducing the number of unknows prior to analysis. The stiffness matrices are exact, but mass and damping matrices are approximate. Mass is redistributed to master degrees of freedom based on dynamic condensation. Three mode extraction techniques are available, with the full extraction from

reduced matrices (householder extraction) being selected for our problem as recommended. See chapter 9 of reference 2 for master degree of freedom selection.

A big deal is made over the various methods of combining modes. What is being discussed is the way to combine all significant mode displacements to obtain the maximum overall response (deflection, stress...) of the structure. In general, all this fancy stuff is for closely spaced modes (in frequency) and is used by the NRC. A simple square root-sum of the squares technique is used for all the SSC analysis. The assumption made in combining modes is that they are all in phase, which is the worse case.

ANSYS input for this SSC model:

1) Set up model
2) KAN,2: select modal analysis
3) KAY,2,n: Option module; expand first n modes;
   n=16 were selected for this problem since no significant modes are expected beyond this value; only expanded modes can be post processed.
4) KAY,3,n: Option module; print first n reduced mode shapes.
5) KRF,1(or2): Activates nodal and reaction force calculations.
6) FREQ, SV, SVTYPE, SED: All these commands are found in the load option module. FREQ activates the spectrum option. Note that SVTYPE selects the type of response spectrum input.

7) MCOMB: This is a very confusing command and is not required for our analysis. It does not combine modes as implied in the manual. It merely writes POST 27 type commands to a file 24 which can then be used to combine modes.

8) M: Master degree of freedom selection. Only for the shipping analysis where the vacuum shell was used, were M.D.O.F. selected manually. The vacuum shell is so light in comparison to the single phase, no M.D.O.f. would be selected for reasonable numbers of master modes.

9) TOTAL: Automatic M.D.O.F. selection. Typically 50 to 70 total M.D.O.F were selected. Fifty usually seems adequate, but the model is fairly cheap to run, so 70 was sometimes selected to be safe. No significant differences were found if rotational modes were negleted.

10) SRSS: POST 27 square root-sum of the squares command.

SSC MODEL AND GEOMETRY

Global X	Magnet Axis
Global Y	Support Post Axis
Global Z	Lateral Direction
Orgin	Bottom of Center Post
Post Height	8.375"
Height of Magnet Center Line	14.1875"
Height of Vacuum Shell Center Line	10.375"
Post Locations (axial)	-272.5"
	-136.5"
	0"
	136.5"
	272.5"
Overall Cryostat Length	653.6"
Overall Vacuum Shell Length	659"
Cryostat Mass	24.1 lbs/inch=15,750 lbs
Cryostat Young's Modulus[3]	35×10^6 psi
Cryostat Pipe	10.891" O.D.x.1875" wall
Vacuum Shell	24" O.D.x.25" wall

Two different models were constructed for the seismic analysis and the shipping analysis. The shipping model is more complex and includes the vacuum shell. In addition, three static deflection analyses were performed on the shipping model at different support locations.

SEISMIC MODEL:

Figures 1 and 2 show the seismic model. Note that figure 2 is a highly distorted view but enables the reader to understand the model. STIF 9 pipe elements are used for both the single phase assembly and the support posts. All support posts are fully constrained at their bases. Seismic loads are input at these "grounded" locations. STIF 8 3D spar elements are used for the axial anchors and are seen just to the left and right of the center post in figure 2. Figure 3 gives the location of the axial anchors. These two elements are also fully constrained at the bottom end but have no rotational constraints because they are spar elements. The connections between the single phase (y = 8.375") are made with very rigid STIF 9 pipe elements having negligible mass.

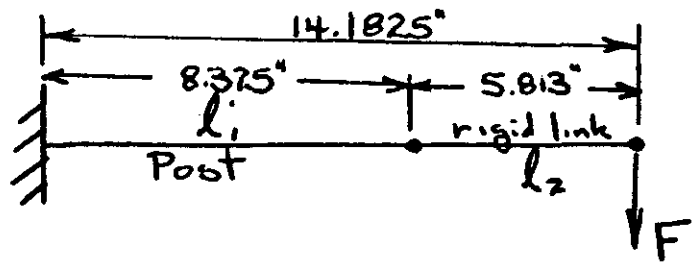
The connection between the rigid links and the top of each post is made with duplicate nodes and coupling equations. Thus, the connection between cryostat and post is free in X (magnet axis direction) and free to rotate about y (post axial direction). This simulates the slide and pivot connection at the top of each post.

The five support posts are modeled with pipe elements having the appropriate dimensions to give the same values of axial and lateral stiffness as found by experiment. Safety factors and stress levels can be found by substituting calculated deflections back into Tom Nicol's support post ANSYS model and test results. We will assume an axial stiffness of 400,000 lbs/inch and a lateral stiffness of 8429 lbs/inch when the lateral load and the deflection are measured at a point 5.81" above the post. The corresponds to the height of the single phase assembly center line above the posts.

Assume $E = 4 \times 10^6$ psi

K axial $= \frac{AE}{L} = 4 \times 10^5 = A \times 4 \times 10^6/8.375$

Area = .8375 in²



Deflection at the load = deflection at $\ell_1 + \ell_2 \times$ rotation at ℓ_1.

Neglecting shear deflection and for small angular changes,

$$\Delta y = \frac{F\ell_1^3}{3EI} + \frac{M_0\ell_1^2}{2EI} + \ell_2\left(\frac{F_1^2}{2EI} + \frac{M_0\ell_1}{EI}\right)$$

$$M_0 = F\ell_2$$

Solving for I,

$$I = \frac{F}{\Delta y}\frac{I}{E}\left(\ell_1^3/3 + \ell_1^2\ell_2 + \ell_1\ell_2^2\right)$$

Using $F/\Delta y = 8429$ lbs/inch,

$I = 1.868$ in⁴ $= \pi/64\ (D_o^4 - D_i^4)$

Area $= \pi/4\ (D_o^2 - D_i^2)$

$I = 1/16 \times \pi/4 \times \text{Area}\ (D_o^2 + D_i^2)$

Solving for D_o^2,

$$D_o^2 = 1/2\left(\frac{16I}{A} + \frac{4A}{\pi}\right)$$

D_o = 4.287" (ANSYS input)

D_i = 4.161"

t = .063" (ANSYS input)

STIF 9 elements used for the posts employ the option which neglects shear deflection. A check was run using ANSYS with a single post. ANSYS and the above equation for deflection agree exactly.

The axial anchors are also modified in ANSYS to give the correct overall stiffness. These anchors are made from G-10 tube, 11.125" long x 2.0" O.D.x.055" wall. End connections make the completed support 16" long, however. Assuming a modulus of 4×10^6 psi and no elasticity in the end connections,

$$K = \frac{AE}{L} = (\pi x 2x.055x4x10^6)/11.125 = 1.24x10^5 \text{ lb/inch}$$

Modify the area to account for the 16" overall length.

$1.24 \times 10^5 = A \times 4 \times 10^6/16$

Area = .469 in ^{2} (ANSYS input)

Axial anchors are assumed to weigh 2 lbs.

$$\text{Density} = \frac{2/386.1(\text{in/sec}^2)}{.496x16} = 6.53 \times 10^{-4} \frac{16\text{-sec}^2}{\text{inch}^4}$$

Posts are assumed to weigh 5 lbs. giving a density of 3.1×10^{-3} (lb-sec^2/ inch^4).

Seismic input is taken from acceleration spectrum response curves provided by the A.E.C.[4]. This report is attached as an appendix. The accleration curves with .5% damping were chosen as input. Vertical and

horizontal response spectra from this report are used appropriately. Initially confusing to use, these tripartite logrithmic plots are explained in chapter 8 of reference 1. In addition, these curves are scaled down to .3g from the normalized 1g values. SDRC recommends .4g scaling, but the actual value will obviously depend on the site which is selected. There is also some evidence that a large attenuation in earthquakes appear around the 50 meter depth level. Note that g values must be converted into inches/sec^2 by using the factor 386.1.

SHIPPING MODEL:

The shipping model is considerably more complex than the seismic model. Figures 4 and 5 show the model with the two possible support (connection to truck) locations. All of the original seismic model is still used here, except that the grounding constraints are removed and the support posts are replaced with 3 1/2" diameter steel shipping pins. The single phase assembly is always assumed to be in vertical contact with the shipping pins due to the initial gravity loading.

The base of all five support posts and the two axial anchors are rigidly coupled to the vacuum shell pipe elements through the use of the CERIG command. There is only a translational coupling between axial anchors and vacuum shell. Three orthogonal STIF 4 spring elements create the attachment to the truck at two locations. Figure 4 shows the supports at the 32 foot span, and figure 5 shows the attachment at the two mid-posts. With 2 sets of three springs any type of truck attachment can be easily modeled. Obviously the ends of these springs are the "grounds" through which the dynamic loads are applied. A

rotational constraint about the axis must also be used at the two vacuum shell support location nodes. Spring elements have no rotational degrees of freedom so that the model will undergo a rigid body rotation without this additional constraint. Physically our attachments are to the O.D. of the vacuum shell over a finite arc length rather than the center line of the magnet as it can only be done in ANSYS when STIF 9 elements are used.

A STIF4 spring element is added to each end of the single phase assembly. These are then coupled (CP command) in the X direction to the two ends of the vacuum shell. Although the heat leak model does not incorporate Belleville washer end springs, furture magnets are expected to use them for long distance shipping. In order for them to effectively reduce stress level in the axial anchors, they must be several times stiffer than the X component of stiffness of the anchors which is 1.1×10^5 lbs/inch per anchor. 5×10^5 lbs/inch would probably be a reasonable value. Presently we are concerned with only the heat leak model, and these end springs have been given negligible stiffness for all of the following discussions.

Shipping inputs are taken from MIL-STD-810D. Figures 6, 7, and 8 are these inputs for vertical, longitudinal, and transverse loads. All curves were extrapolated "straight back" to 5 Hz to cover single bump events as recommended by SDRC. These input loads are a worse case environment for typical cross country shipping conditions. Certainly careful transportion across the Fermilab site will give much lower but as of yet unkown values. Load values are in terms of power spectral desities (g^2/Hz). Inputs into ANSYS must be in terms of $(in/sec^2)^2$/hz), so we must mutiply the given values by $(386.1)^2 = 1.49 \times 10^5$.

See chapter 22 of reference 1 for the definition of power spectral density.

SEISMIC RESULTS

Figures 9, 10, 11 are the dominant modes for the lateral, axial, and vertical excitation directions. Figure 12 is the combined modal response from POST 27 processing. These figures were calculated using 50 M.D.O.F selected automatically and excluding all rotational degrees of freedom. Figure 13 shows the negligible change when 60 M.D.O.F. were selected including rotational degrees. Note that the first mode from the lateral excitation, and the second mode from axial excitation overshadow all other modes.

A single beam model which is exactly the same as a single post was analyzed to check the accuracy of the SSC model. One fifth of the total single phase mass was added as a STIF 21 mass element at the top of the post assembly. The fundamental mode of the SSC magnet is found t be 4.58 Hz. The test beam model has a fundamental frequency of 5.05 Hz or 4.83 Hz depending on whether the rotational inertia option in STIF 21 was neglected or selected. Simple hand calculation gives 5.05 Hz. Since natural frequency = $1/2\pi \sqrt{k/m}$, this is a fairly large difference. Giving the SSC cryostat essentially infinite stiffness made little difference in the fundamental frequency value. Setting the cryostat density to a very small value and adding lumped mass elements above each post, gives a first mode frequency of 5.05 Hz, exactly as in the test beam problem. Total mass values for the SSC model are known to be correct, because they are summed in the printout. Comparing figures 9 and 13 shows no change in frequency when rotational M.D.O.F. are allowed. I attribute the difference between the SSC model and the test beam problem to inaccuracies in the dynamic condensation calculations performed by ANSYS.

Figure 14 is a summary of maximum deflections in the simple test beam problems for a wide range of stifness and damping. Doubling the post stiffness will halve the deflection, but stress levels are nearly identical since the Young's modulus was doubled. Clearly, introducing greater damping is the only method of reducing stress levels. G-10 and graphite composites have small material damping values especially at low temperatures [5, 6, 7].

Reaction Forces and Moments:

For seismic activity we must be very concerned with the structural integrity of the support posts and axial anchors. We are presently a factor of ~2 away from a design which can survive a .3g AEC type earthquake. Tom Nicol's test results show that the current post design can survive only a .37" lateral deflection (as measured at y = 14.1875") due to local buckling.

ANSYS gives a .67" maximum deflection.

Combined Modal Response

Post Location (Axial Position)	Fx (lbs)	Fy (lbs)	Fy (lbs)	Mx (in-lbs)	Mz (in-lbs)
-272.5"	0	989	3934	70128	435
-136.5"	0	2684	3980	71687	793
0	0	976	4695	73225	1790
136.5	0	2693	5250	75298	793
272.5	0	1027	4354	71279	433
Axial Anchor					
node 22	10601	6157	0	0	0
node 23	10601	6152	0	0	0

Note that the total force in the axial anchors is 12,259 lbs.

True stress in axial anchor = $12{,}259/\pi x2.0x.055$

= 35,500 psi

Conclusion:

As presently designed, support posts will fail in a .3g earthquake, and axial anchors are marginal but would probably survive.

SHIPPING RESULTS

As with the seismic results, dominant mode and combined modal response plots are provided here for the 4 different truck support conditions.

Guide to the Plots 15 to 35:

Filename	
VSSC26	Rigid Connection at Mid-Posts
VSSC29	Air Spring Connection at Mid-Posts
VSSC30	Rigid Connection Between Posts, 32 Foot Span
VSSC31	Air Spring Connections at 32 Foot Span

Load Step 1: Vertical Excitation

Load Step 2: Longitudinal Excitation

Load Step 3: Lateral Excitation

Filename	Lowest Frequency Hz	Combined Modal Max. Deflection
VSSC26	5.4	.92"
VSSC29	1.9	3.6
VSSC30	5.9	.459"
VSSC31	2.6	3.13"

Naturally one gets much larger deflections when the magnet is attached to the trucks through air springs. The majority of all the deflection comes from the support spring elongation.

Reaction forces at the support points and at the connections between posts and vacuum shell are the important values. We also need to examine static gravity loads. Figures 15 to 35 are the important

modes for the 4 dynamic modes and include plots of combined modal deflections. Not all "significant" modes as defined by the .001 significance default value used by ANSYS are included in these figures. See specific computer plot outputs for complete details.

Table 1 is a summary of the combined modal reaction forces as found at the truck attachment locations. Only one support is listed since the reaction forces are virtually indentical for the two supports. Note that all values are positive since they are obtained by calculating the square root of the sum of the squares. We can see that adding air springs causes a significant reduction in overall reaction loads. Changing support location from mid-posts to the 32 foot span location makes little difference.

Table 2 gives the forces, moments, and bending stresses at the base of the most highly stressed shipping pins (support posts). For all cases the pins will remain elastic. Again there is little advantage to be found in locating the supports at the mid-poss or the 32 foot span locations. Air springs create a large reduction in pin stresses and axial anchor stresses.

Axial Anchor True Stress:

$18{,}900/(\pi x 2x.055) = 54{,}800$ psi w/o air springs

$10{,}400/(\pi x 2x.055) = 30{,}100$ psi with air springs

Only positive values are found in table 2 for the reason discussed above. Examining the specific mode printout shows, for example, that axial anchors have opposite and nearly equal values for the primary mode in the X direction as expected.

Static deflections and forces in the support pins are provided in table 3. The compressive static load in the support pins is probably not enough to offset dynamic loads especially for the cases without air springs. Some bounce is possible. Further work is required to study this problem.

Conclusions:

1) Shipping pins are O.K.
2) Axial anchors will fail without air spring supports.
3) There is little difference to be found in the choice of support location, although I recommend the 32 foot span to reduce overall deflections.
4) End springs between cryostat and vacumm shell will be required for cross country shipping. This analysis needs to be done.
5) Careful shipping of the heat leak model across the FNAL site should be no problem, but be careful of sudden starts and stops.
6) Further study of possible loss of contact between pins and cryostat is required.

Table 1

Reaction Forces at Support Points
for Combined Modal Shipping Response

Filename	Fx	Fy	Fz	Mx
VSSC26	16400	27560	5060	15210
VSSC29	10895	16420	1530	2990
VSSC30	16295	28330	4030	15940
VSSC31	10430	17050	1560	4840

Table 2

Reaction Forces at the Base
of the Most Highly Stressed Support Post
for the Combined Modal Shipping Response

				Element Coordinate System					
	Support Post with max Stress	Fx	Fy	Fz	Mx	My	Mz		Force in
				Global	Coordinate	System			
Filename	Base Node #	Fy	Fx	Fz	My	Mx	Mz	σBend	Axial Anchors
VSSC26	3	16200	0	2837	0	39598	65822	18250	18930
VSSC29	3	3990	0	423	0	6505	32087	7776	10360
VSSC30	1	10660	0	1715	0	23832	100,080	24440	18800
VSSC31	3	5023	0	464	0	6934	30830	7507	9900

Table 3

Deflections in Vacuum Shell and
Reaction Forces at the Base of the Shipping Columns
for Static Gravity Loading

Filename	Support Location	Δy Center	Δy End	Fy1	Fy2	Fy3	Mz1	Mz2	Mz3
VSSC25	32' span	-.046	-.035	2818	3608	2682	3175	-2359	0
VSSC27	Mid-Posts	+.065	-.346	2617	3719	2603	-297	-184	0
VSSC28	End Posts	-.781	+.253	3378	2960	3288	1276	796	0

Total static vertical load = 19,093 lbs.

Note: 1, 2, and 3 refer to nodes 1, 2, and 3 found at the base of the outer, mid, and center posts. Reaction forces are opposite in sign to what is normally expected; thus, the post are in compression as expected.

References

1) Mario Paz, Stuctural Dynamics Theory and Computation, 2nd ed., Van Nostrand, 1985.

2) Ceeil Rogers, ANSYS Techniques, Swanson Analysis Systems.

3) Wes Craddock, "Measurement of Flexural Rigidity of the SSC Heat Leak Model", FNAL internal memo, 2-3-86.

4) A.E.C., Design Response Spectra for Seismic Design of Nulcear Power Plants, Regulatory Guide 1.60, Dec. 1973.

5) H.M. Ledbette and G. Maerz, "Temperature Dependence of Young's Modulus and Internal Friction in G-10 CR and G-11 CR Epoxy Resins", Cryogenics, Nov. 1980.

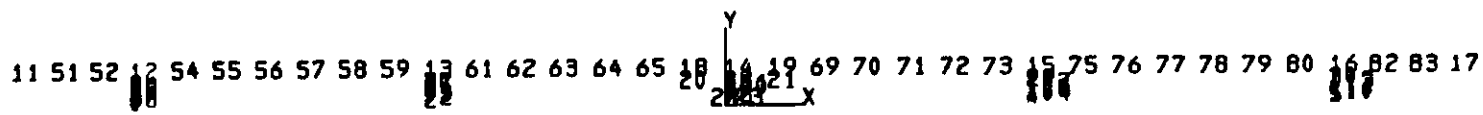
6) H.M. Ledbetter, "Dynamic Elastic Modulus and Internal Friction in G-10 CR and G-11 CR Fiberglass-Cloth-Epoxy Composites, Nov. 1980.

7) T. Hirai and D.E. Kline, "Dynamic Mechanical Properites of Graphite- Epoxy and Carbon-Epoxy Composites, J. Composite Materials, Vol 7, (April 1973) p. 160.

ANSYS
86/ 3/12
15.8986
PLOT NO. 1
PREP7 NODES

ORIG SCALING
ZV=1
DIST=359
YF=7.09

Figure 1



MODAL ANALYSIS SSC MAGNET: .3 G EARTHQUAKE: VSSC23

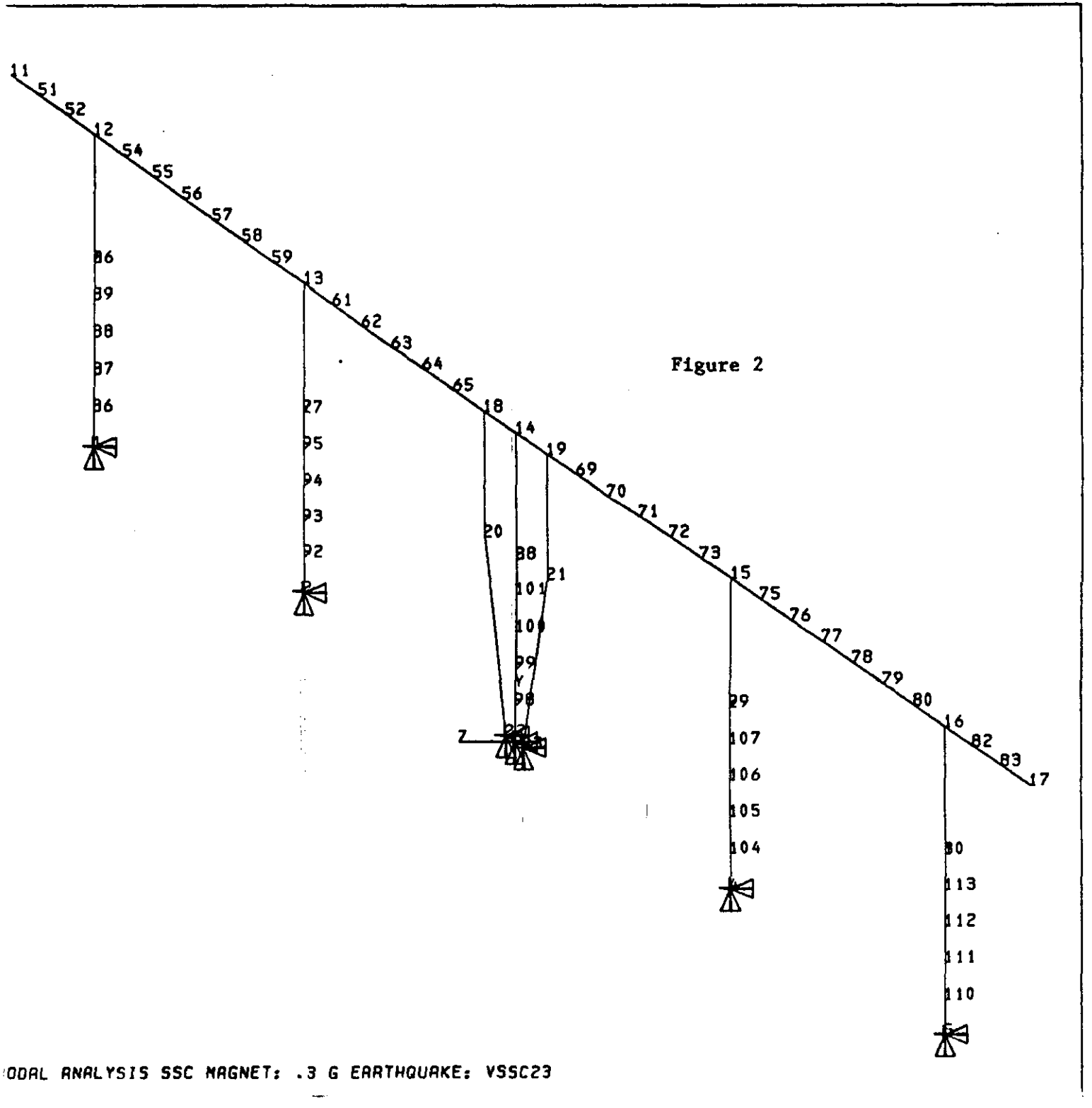


Figure 2

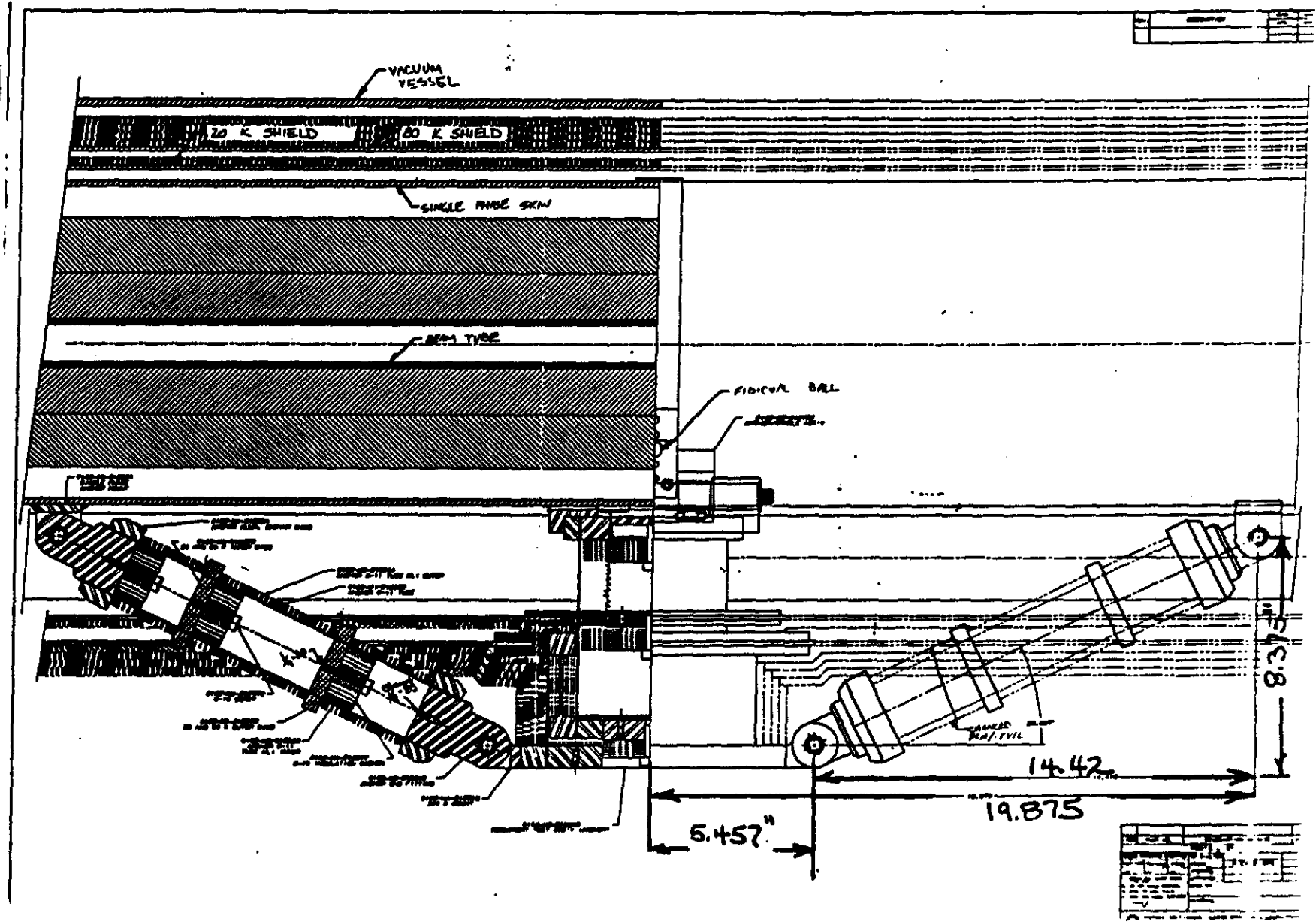
ANSYS
86/ 3/12
15.8986
PLOT NO. 4
PREP7 ELEMENTS
NNUM=1
TOBC=1

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.1
XF=.286
YF=8.44
ZF=.02

ODAL ANALYSIS SSC MAGNET: .3 G EARTHQUAKE: VSSC23

Figure 3

Location of Axial Anchors



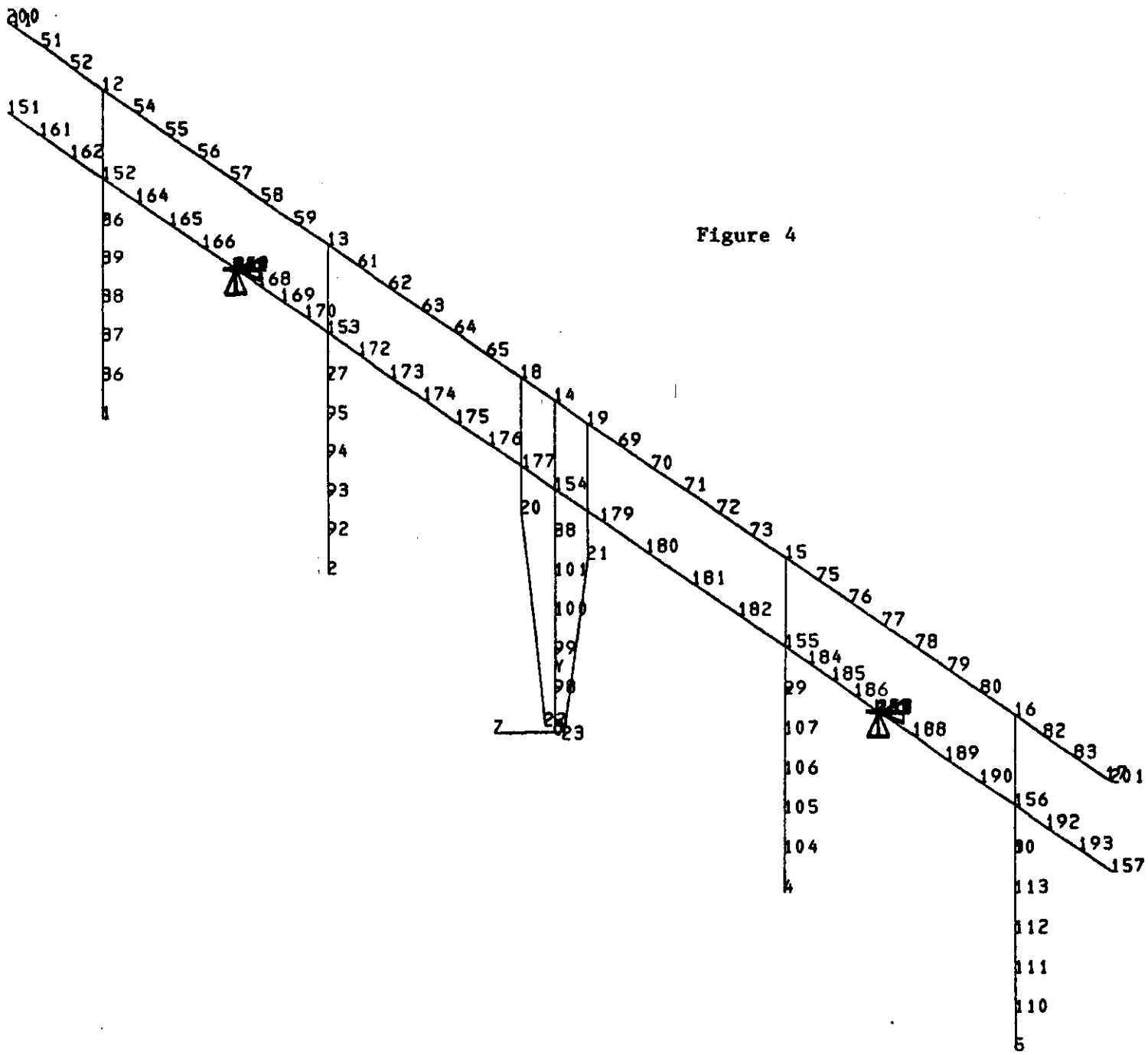


Figure 4

ANSYS
86/ 3/18
16.4267
PLOT NO. 4
PREP7 ELEMENTS
NNUM=1
TDBC=1

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC30

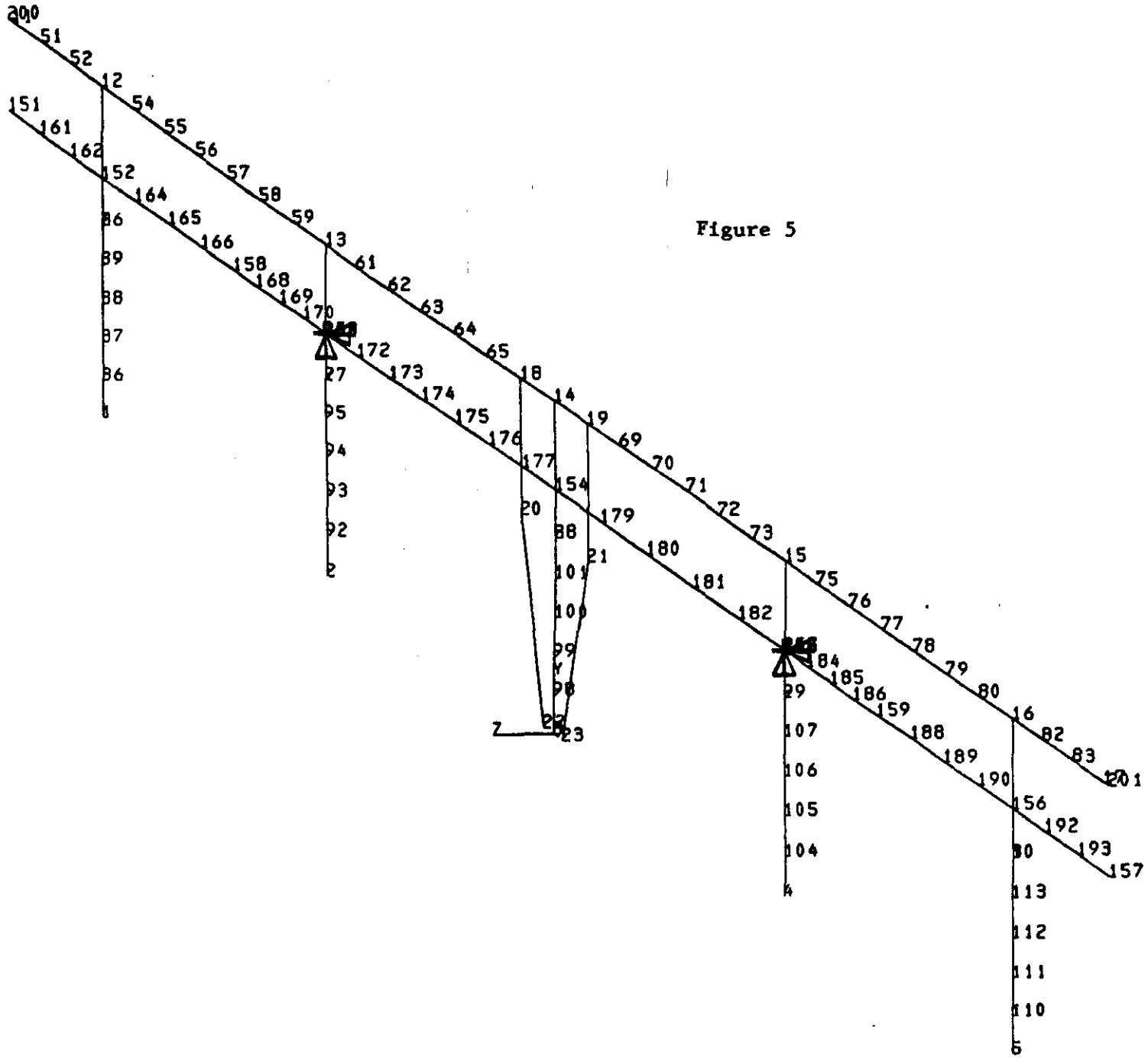
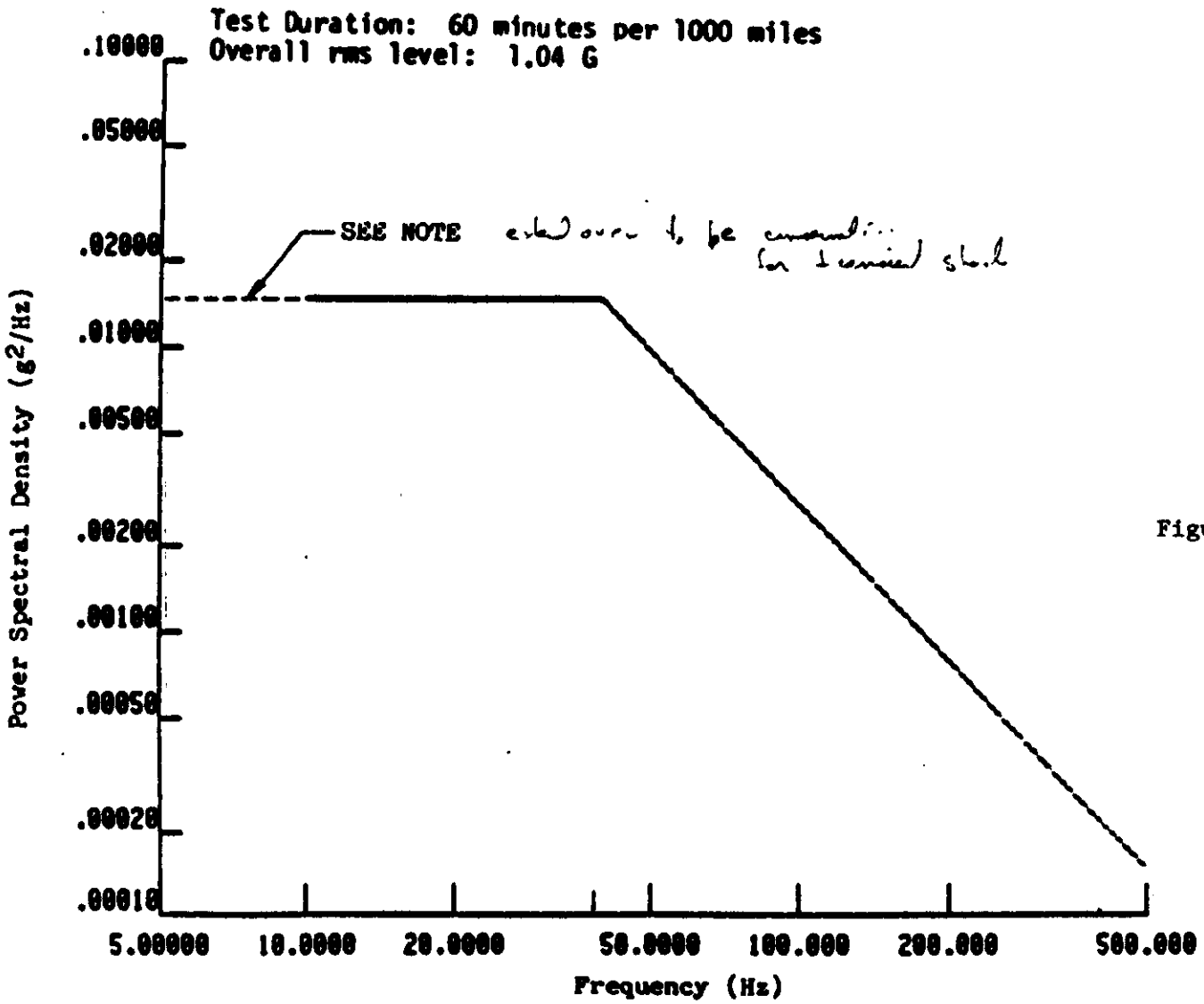


Figure 5

ANSYS
86/ 3/18
16.1147
PLOT NO. 4
PREP7 ELEMENTS
NNUM=1
TDBC=1

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC26



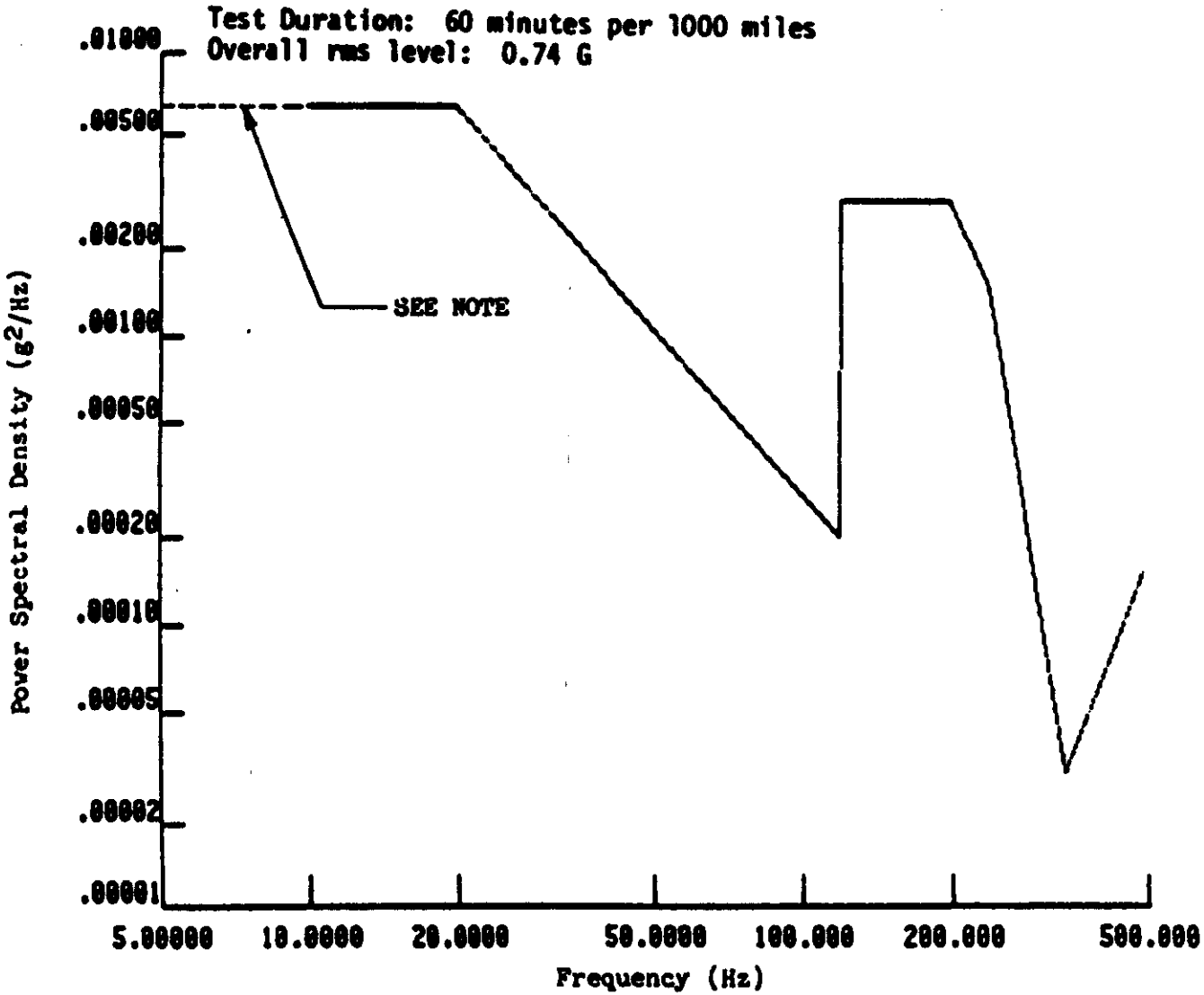
BREAKPOINTS

FREQ	PSD VALUE	
10	.01500	2236
40	.01500	2236
500	.00015	22.36

Figure 6

NOTE: If it is known that excitation is expected below 10 Hz, the curve shall be extended and shaped to comply with the available data.

Figure 3
Acceleration Power Spectral Density for
Trailer Transportation from MIL STD 810-D



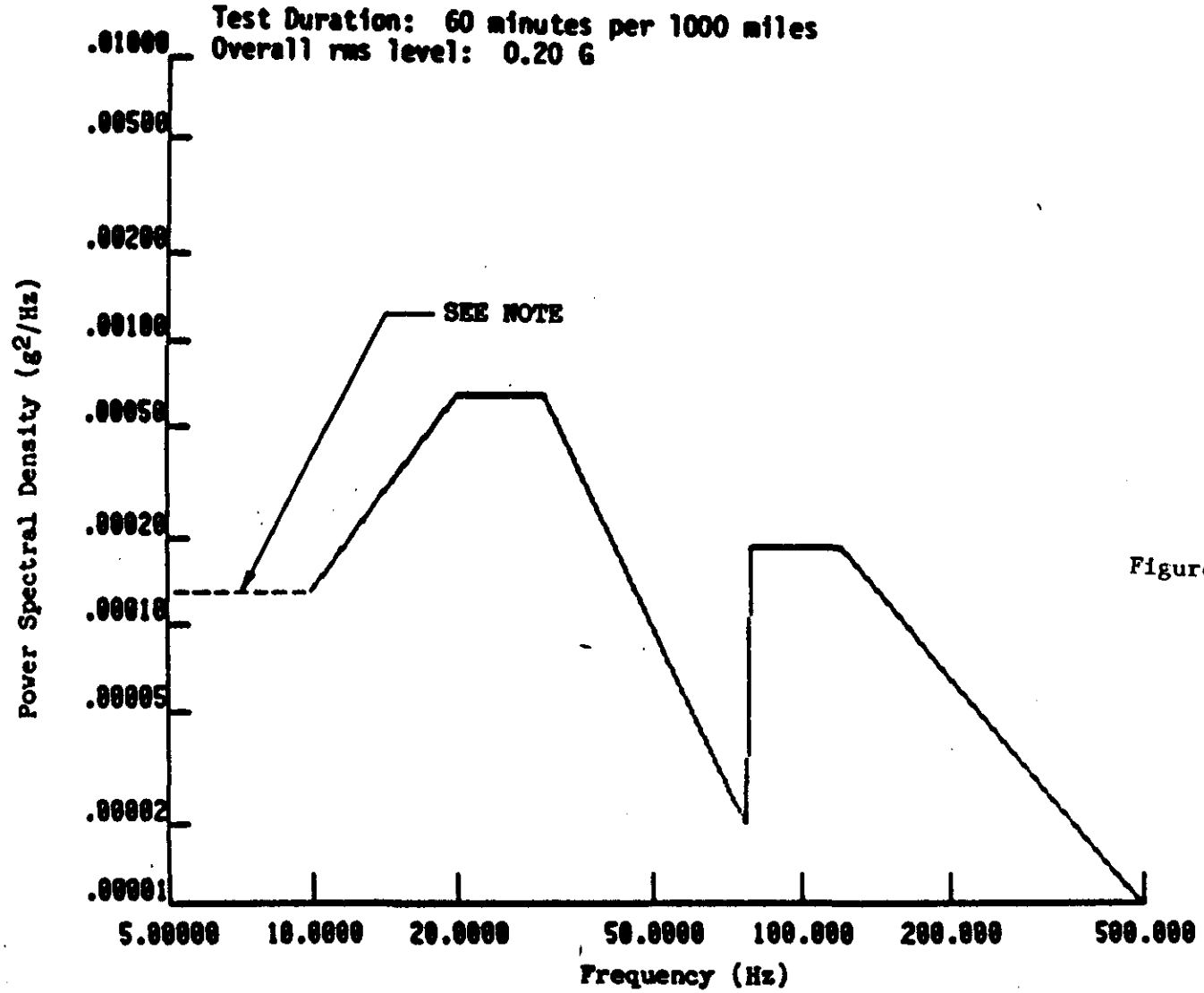
BREAKPOINTS

FREQ	PSD VALUE	
10	.00650	9690
20	.00650	9690
120	.00020	298
121	.00300	447
200	.00300	447
240	.00150	223.6
340	.00003	4.5
500	.00015	22.36

Figure 7

NOTE: If it is known that excitation is expected below 10 Hz, the curve shall be extended and shaped to comply with the available data.

FIGURE 514.3-3. Basic transportation, common carrier environment, longitudinal axis.



BREAKPOINTS

FREQ	PSD VALUE	
10	.00013	19.4
20	.00065	96.9
30	.00065	96.9
78	.00002	3.0
79	.00019	28.3
120	.00019	28.3
500	.00001	1.5

Figure 8

NOTE: If it is known that excitation is expected below 10 Hz, the curve shall be extended and shaped to comply with the available data.

FIGURE 514.3-2. Basic transportation, common carrier environment, transverse axis.

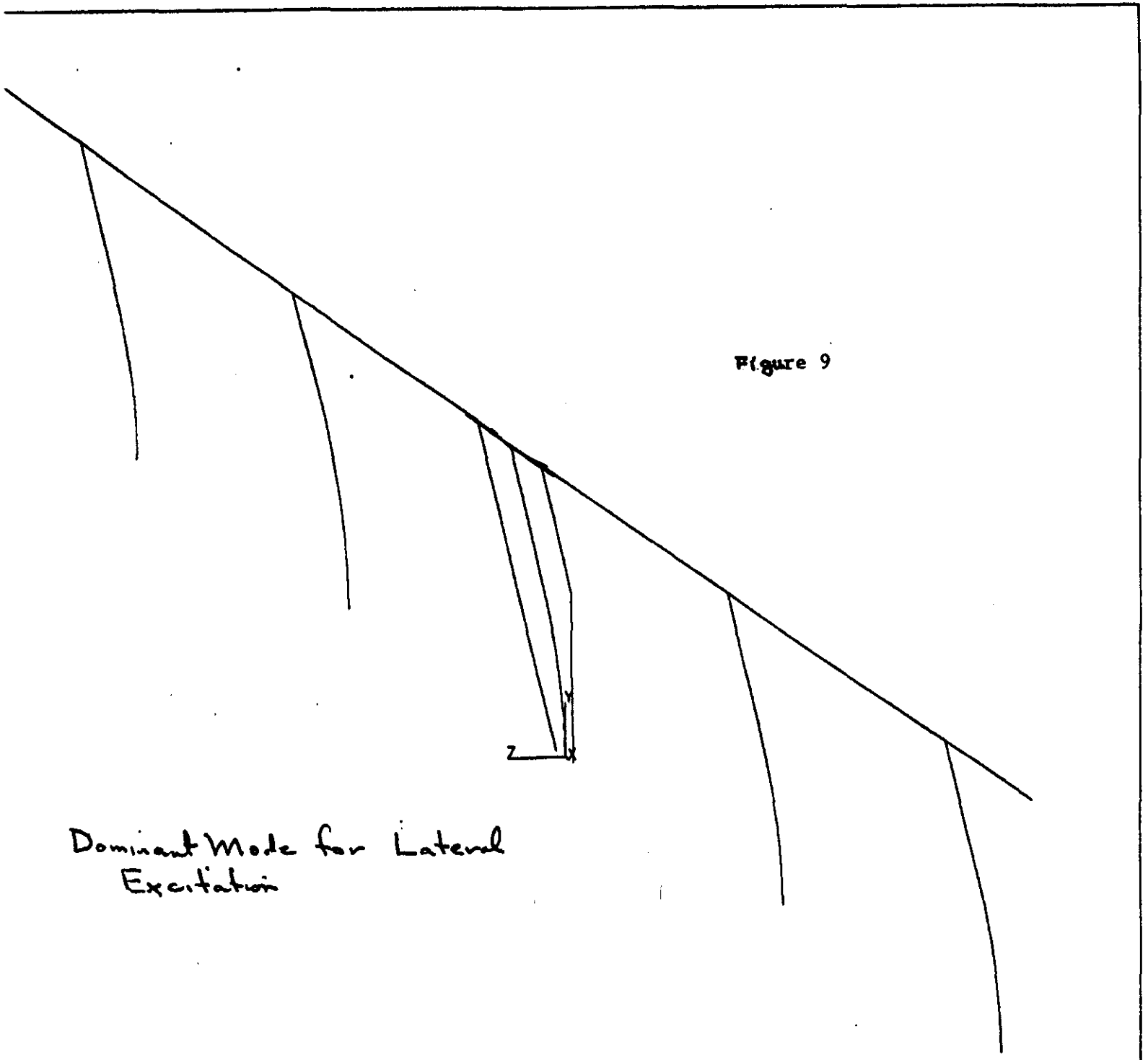


Figure 9

Dominant Mode for Lateral Excitation

ANSYS
86/ 2/25
15.4642
PLOT NO. 7
POST1
STEP=1
ITER=1
FREQ=4.58
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.1
XF=.285
YF=8.46
ZF=.02
DMAX=.645
DSCA=3.89

MODAL ANALYSIS SSC MAGNET; .3 G EARTHQUAKE; VSSC23

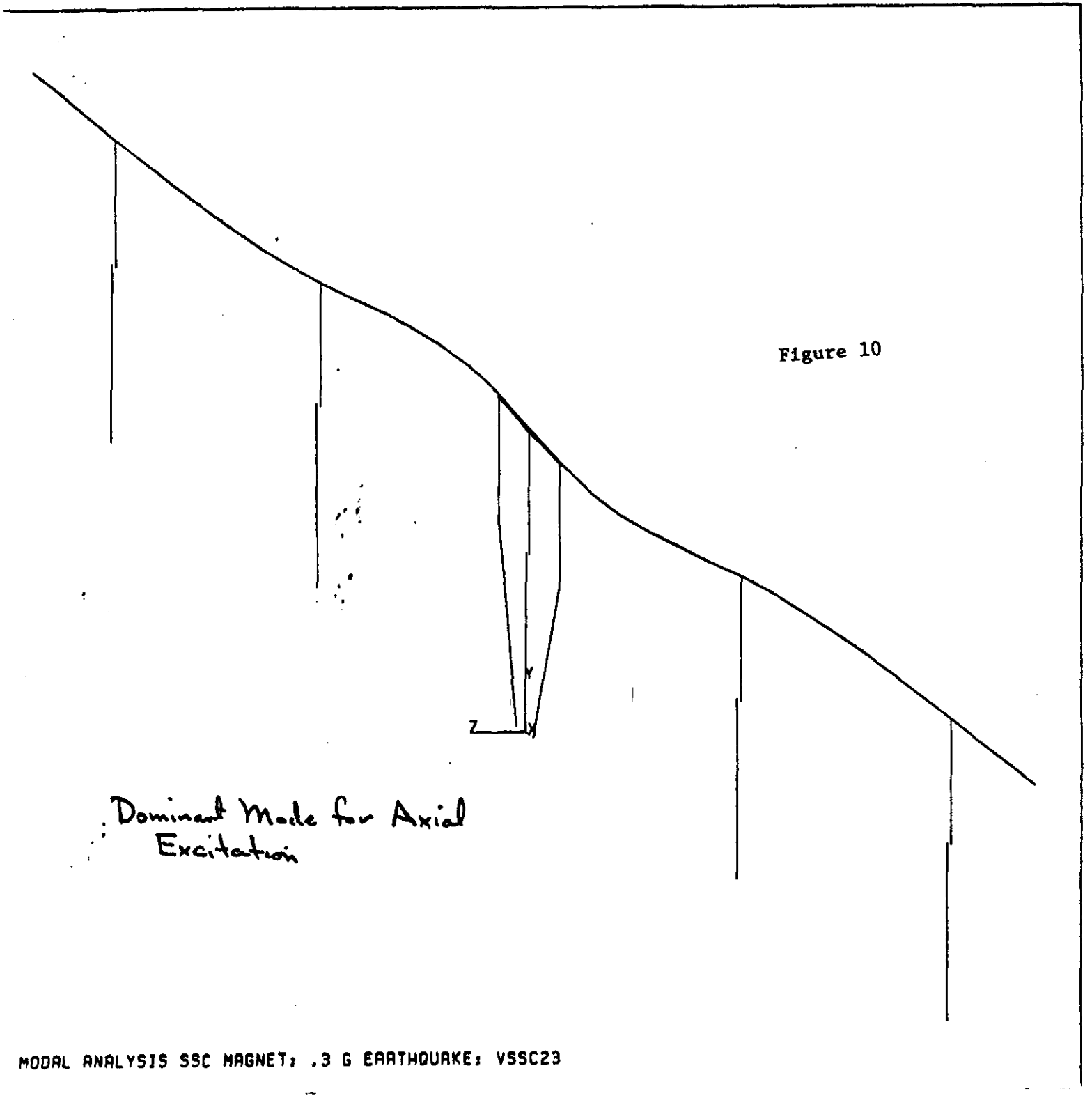


Figure 10

ANSYS
86/ 2/25
15.4758
PLOT NO. 9
POST1
STEP=2
ITER=2
FREQ=9.25
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.1
XF=.285
YF=8.46
ZF=.02
DMAX=.169
DSCA=14.8

MODAL ANALYSIS SSC MAGNET: .3 G EARTHQUAKE: VSSC23

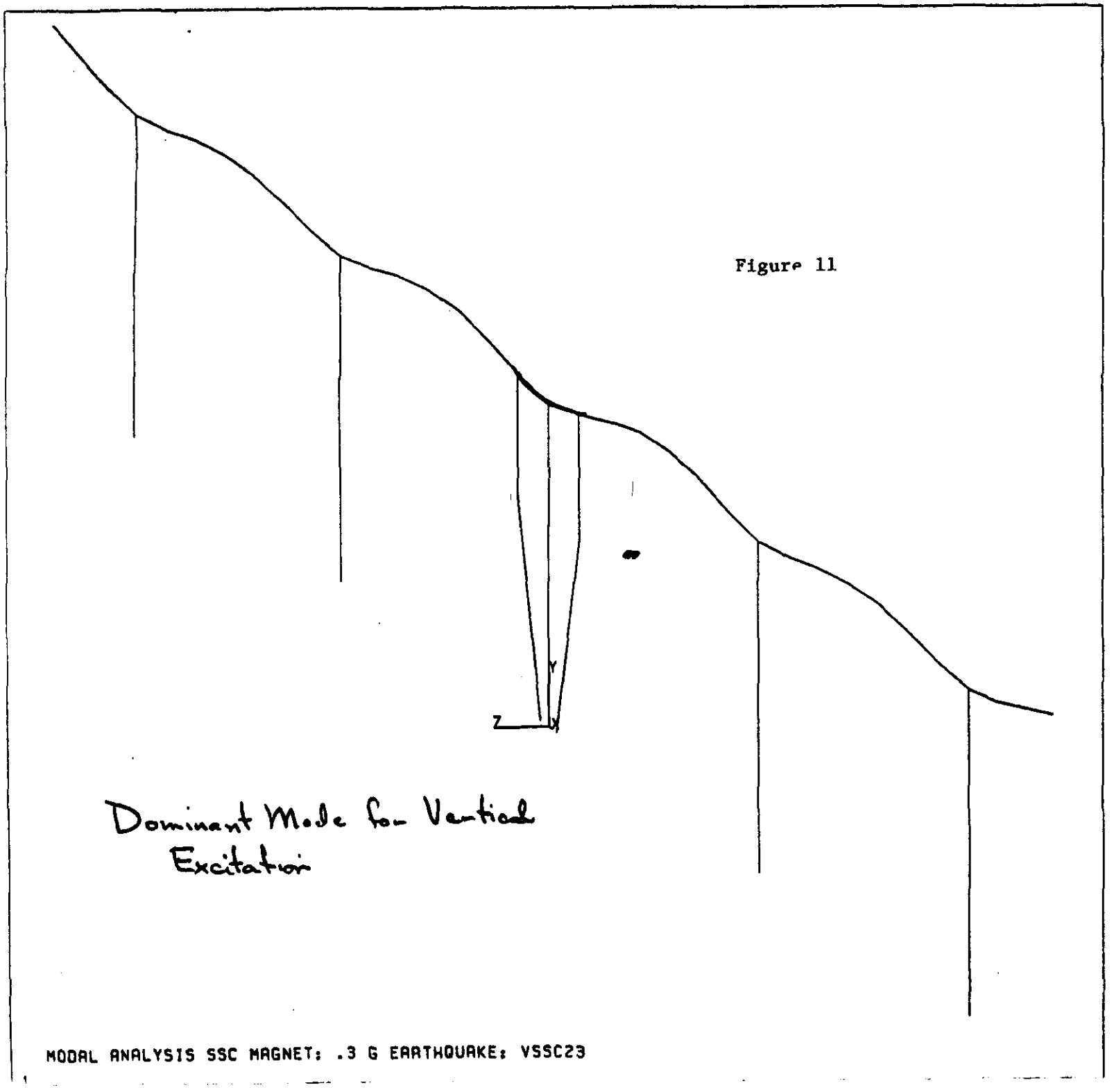


Figure 11

ANSYS
86/ 2/25
15.5106
PLOT NO. 19
POST1
STEP=3
ITER=13
FREQ=28.2
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.1
XF=.285
YF=8.46
ZF=.02
DMAX=.00622
DSCA=403

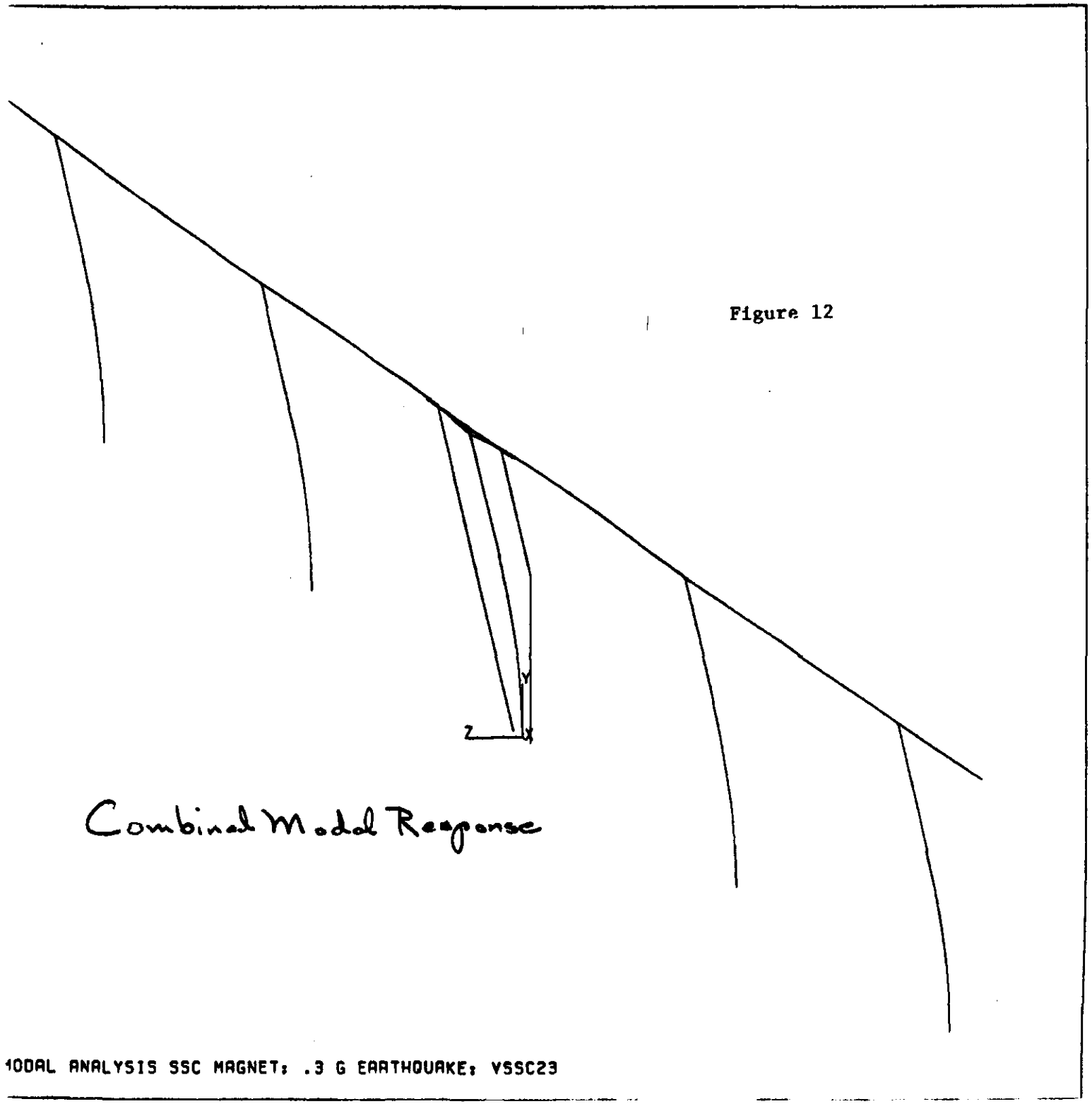


Figure 12

ANSYS
86/ 2/25
16.2703
PLOT NO. 1
POST1
STEP=1
ITER=1
FREQ=-1
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.1
XF=.285
YF=8.46
ZF=.02
DMAX=.667
DSCA=3.76

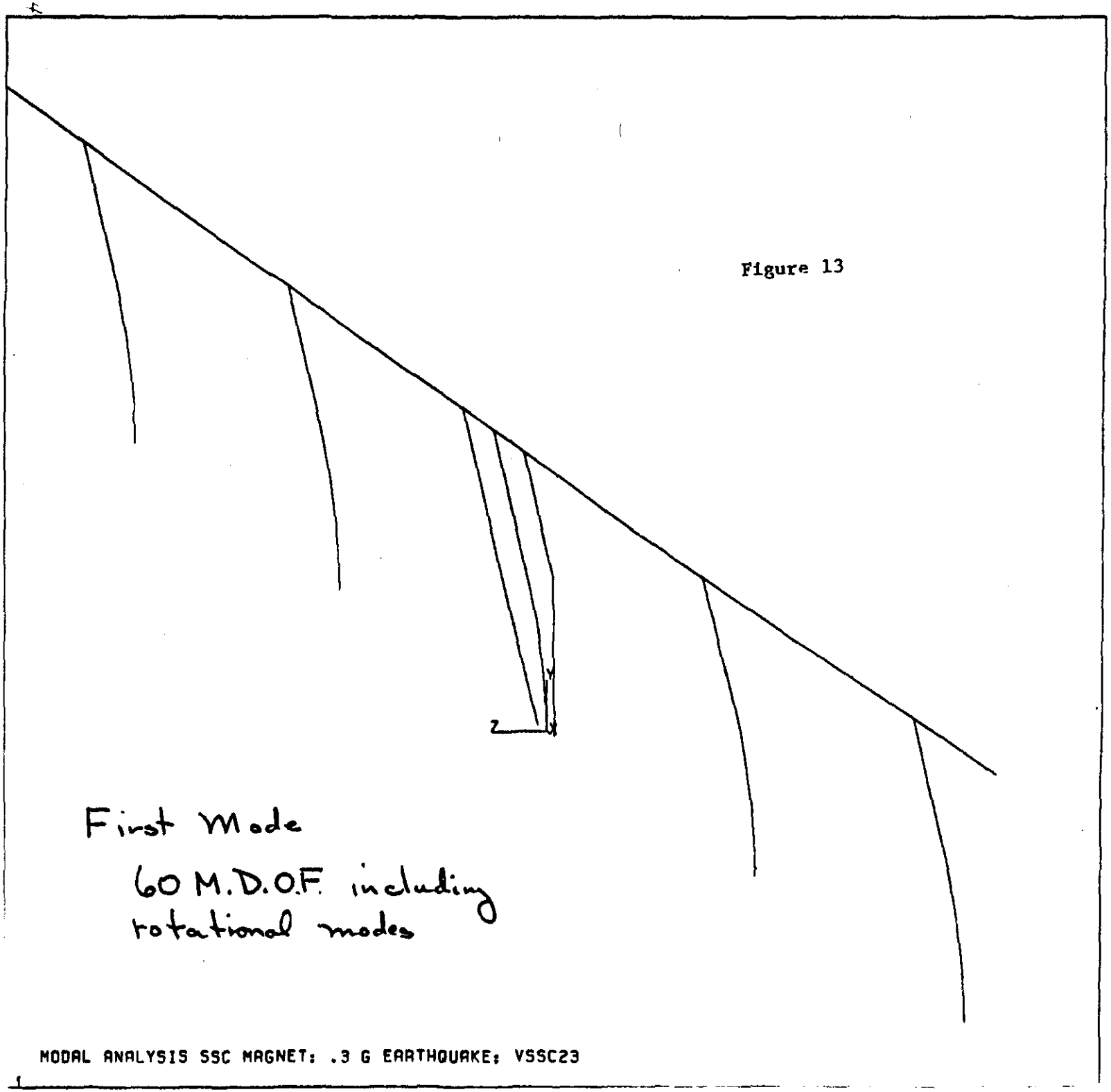


Figure 13

ANSYS
86/ 3/12
15.9289
PLOT NO. 7
POST1
STEP=1
ITER=1
FREQ=4.58
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.1
XF=.285
YF=8.46
ZF=.02
DMAX=.615
DSCA=4.08

MODAL ANALYSIS SSC MAGNET: .3 G EARTHQUAKE: VSSC23

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Wes Craddock
1-28-86

Maximum Deflection of a Single Post With a Concentrated Mass Simulating the Current SSC Post Design

Deflection for Various Stiffness vs. Damping

Input: Based on a .3g A.E.C. (1.60) horizontal seismic input.

E 10^6 psi	Stiffness Ratio at .05% $E\Delta y/E\Delta y_{(4.0\times10^6)}$
2	1.05
4	1.0
6	.97
8	.95
12	.93

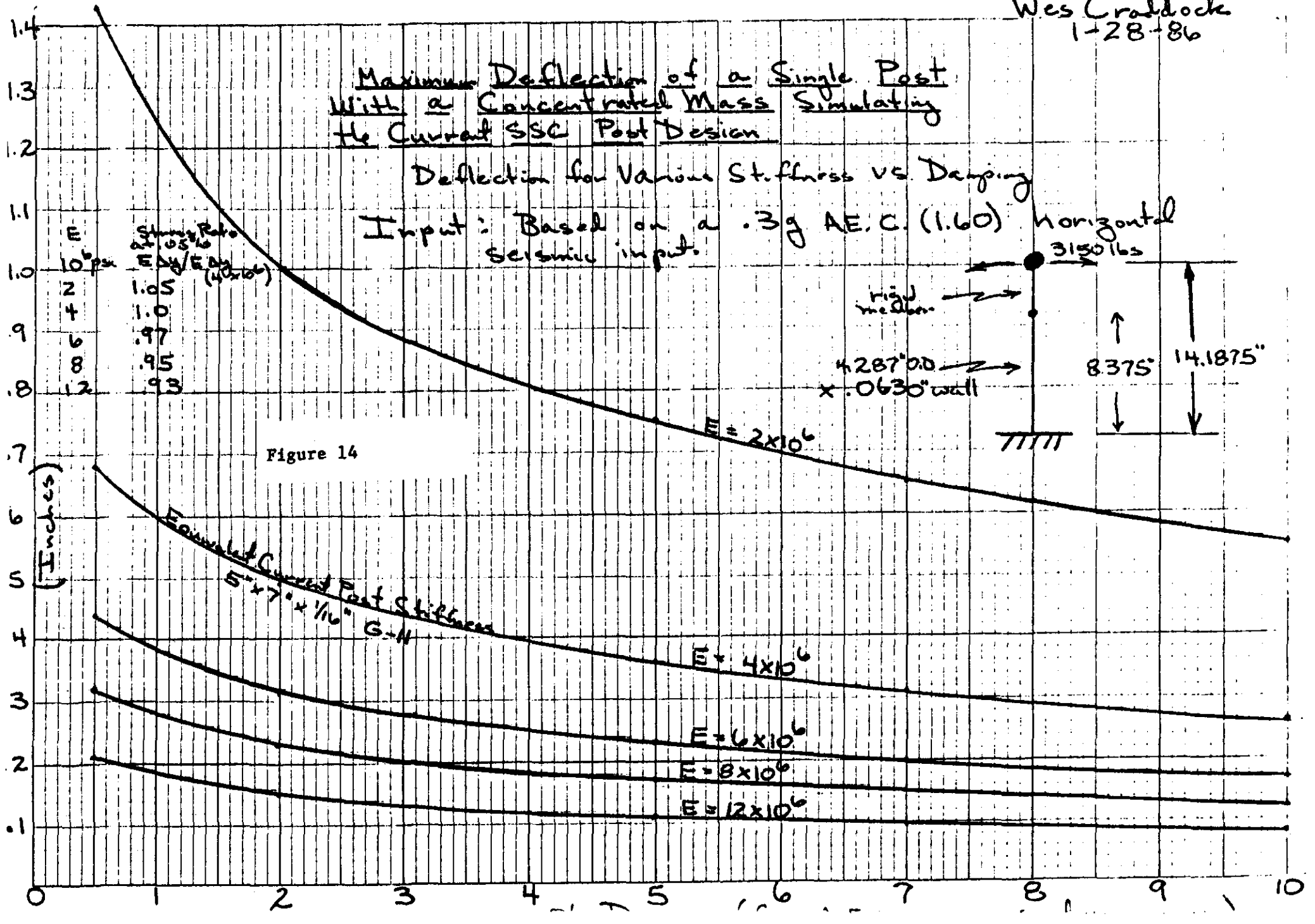

Figure 14

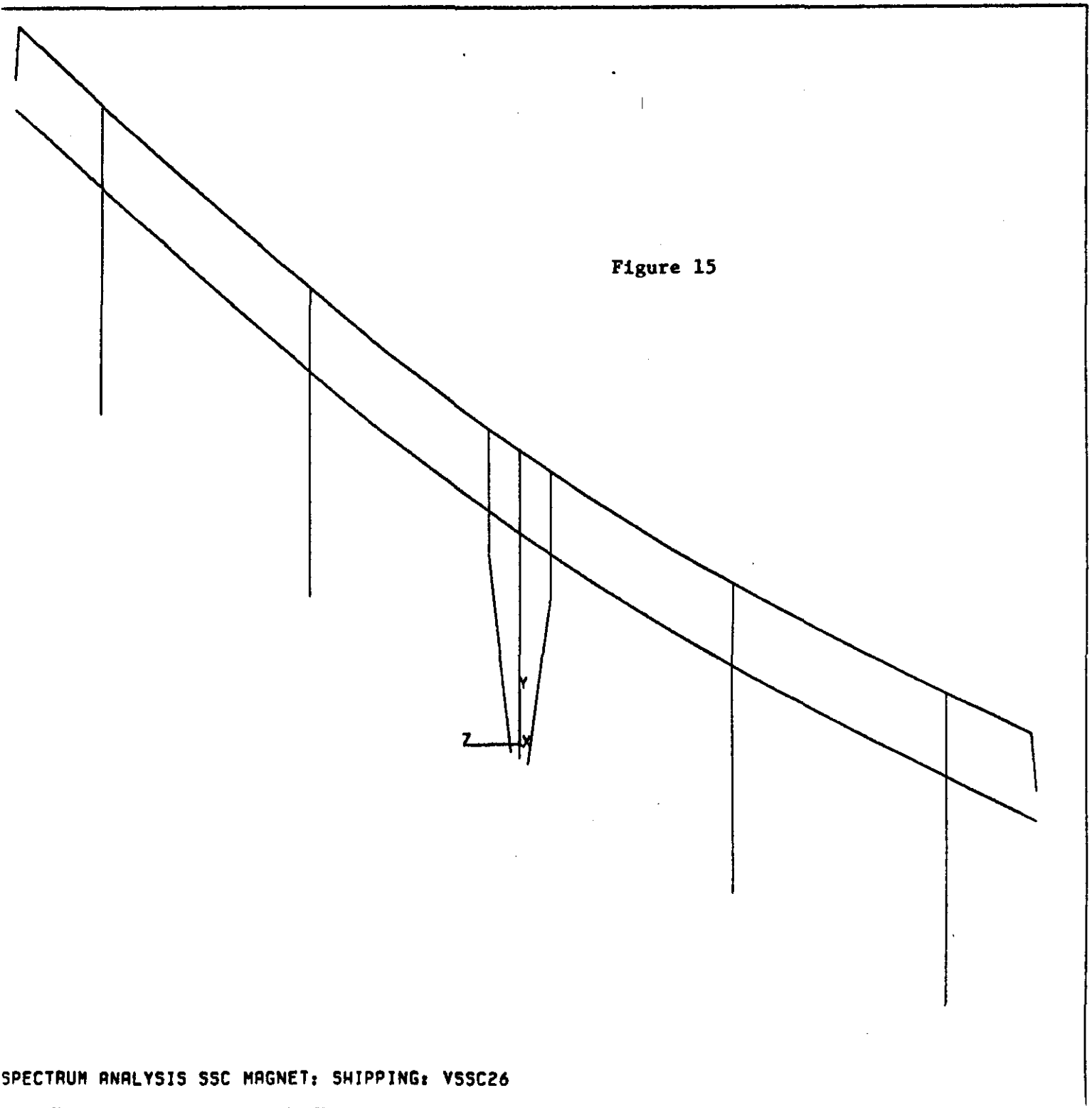

Figure 15

ANSYS
86/ 3/18
16.1672
PLOT NO. 7
POST1
STEP=1
ITER=2
FREQ=5.43
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.872
DSCA=2.9

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC26

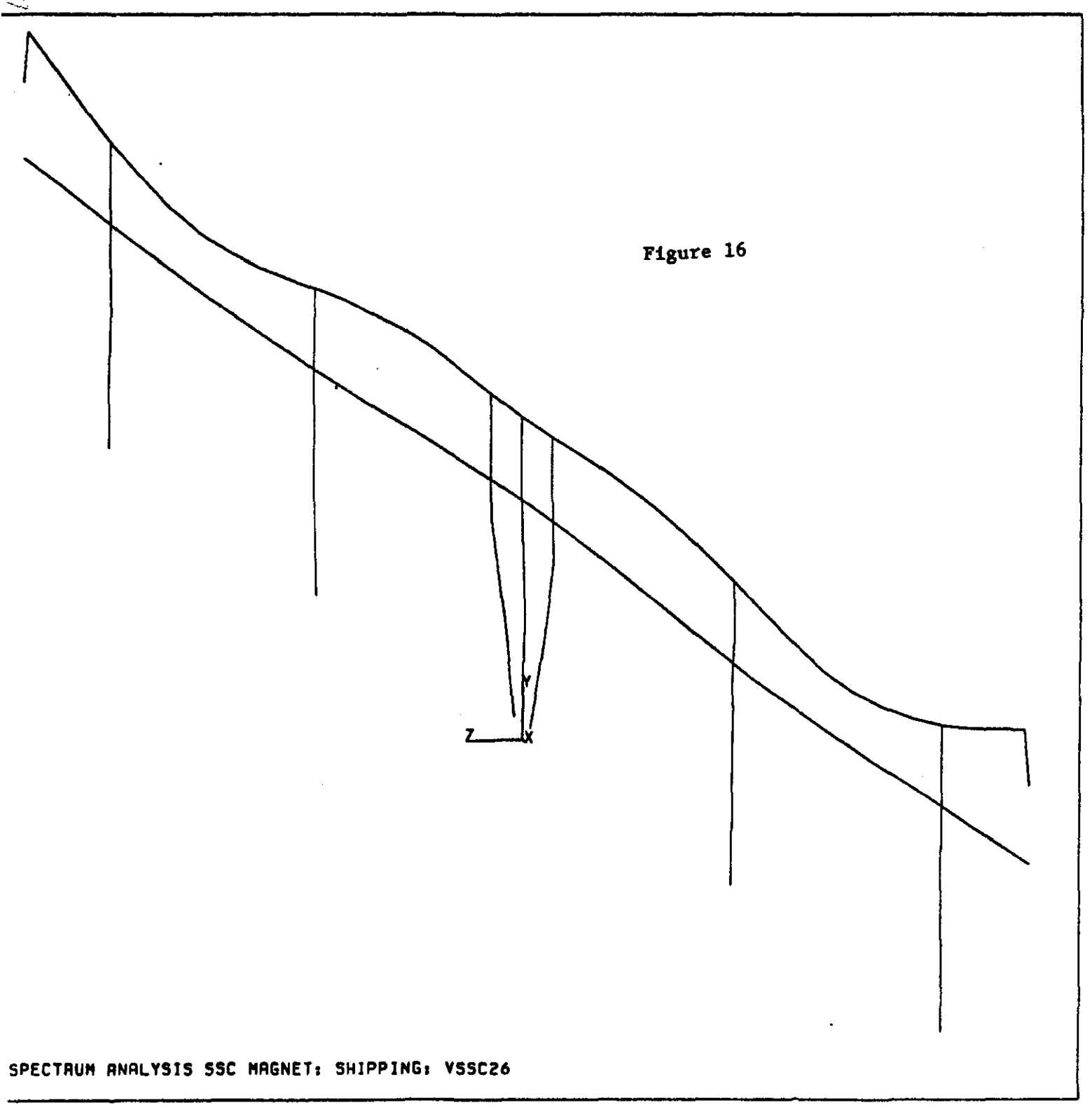

Figure 16

ANSYS
86/ 3/18
16.1725
PLOT NO. 8
POST1
STEP=1
ITER=8
FREQ=17.9
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.0845
DSCA=29.9

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC26

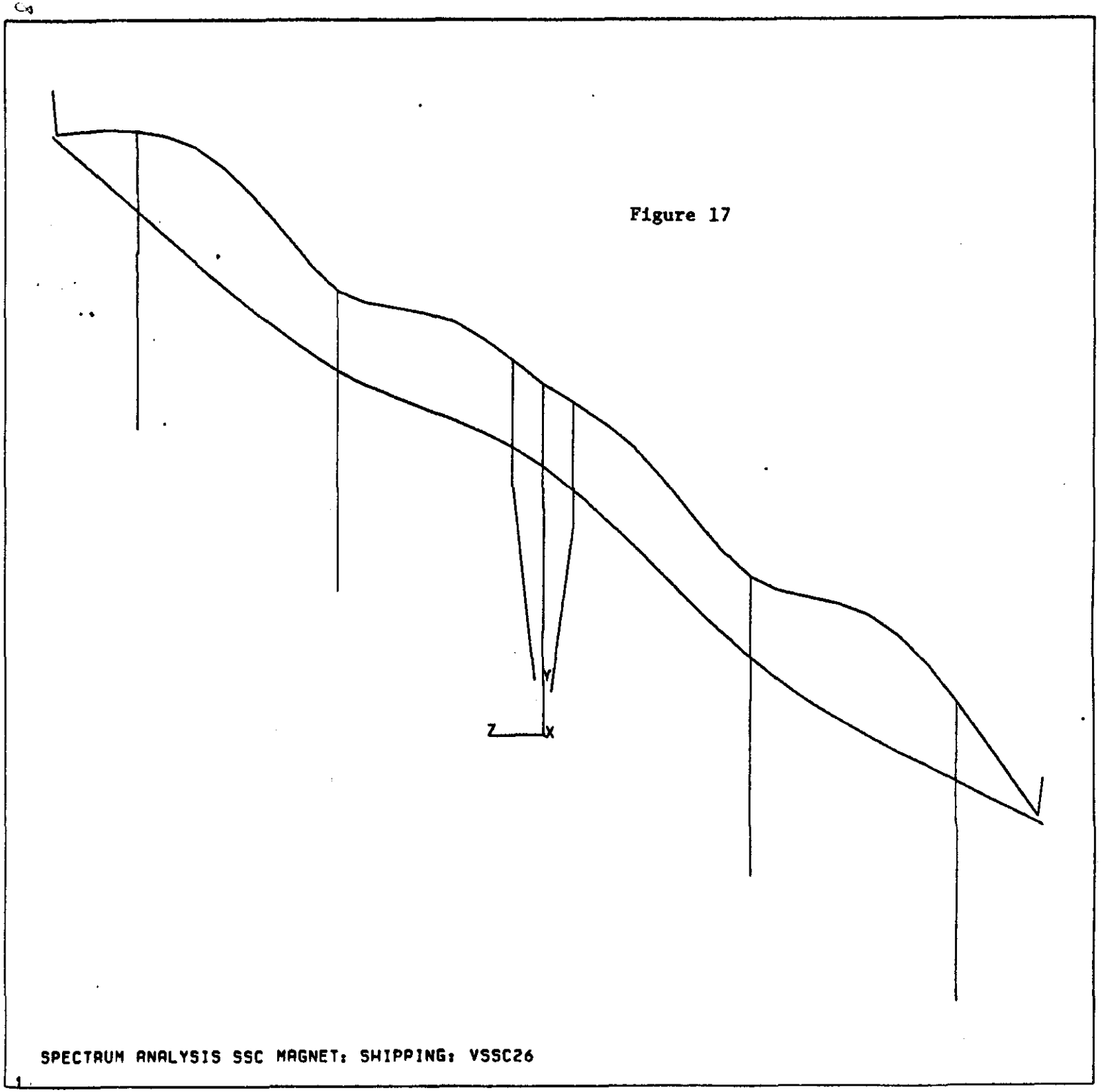

Figure 17

ANSYS
86/ 3/18
16.1783
PLOT NO. 9
POST1
STEP=1
ITER=12
FREQ=24.4
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.105
DSCA=24

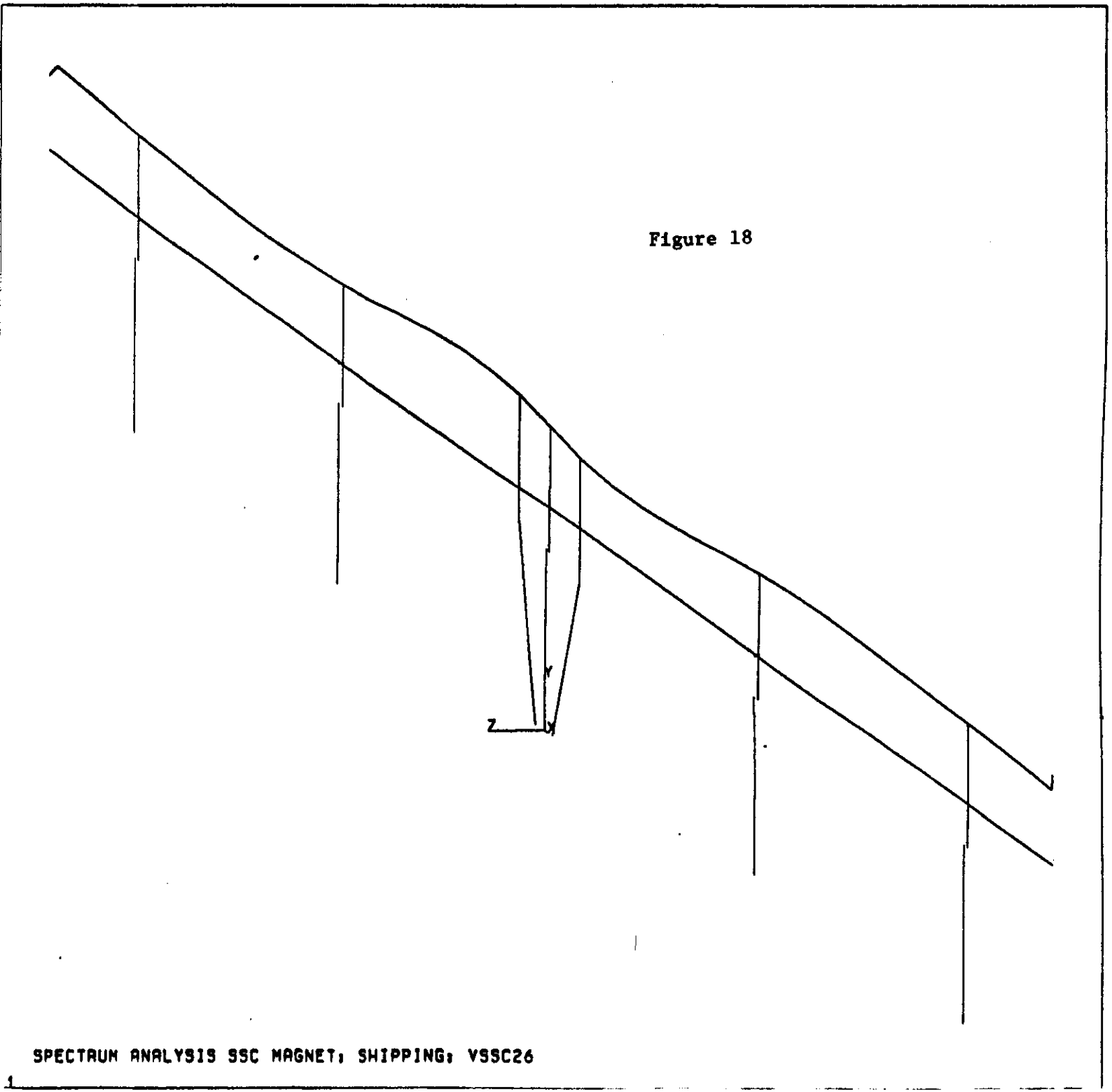

Figure 18

ANSYS
86/ 3/18
16.1964
PLOT NO. 11
POST1
STEP=2
ITER=5
FREQ=9.32
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.251
DSCA=10.1

SPECTRUM ANALYSIS SSC MAGNET; SHIPPING; VSSC26

1

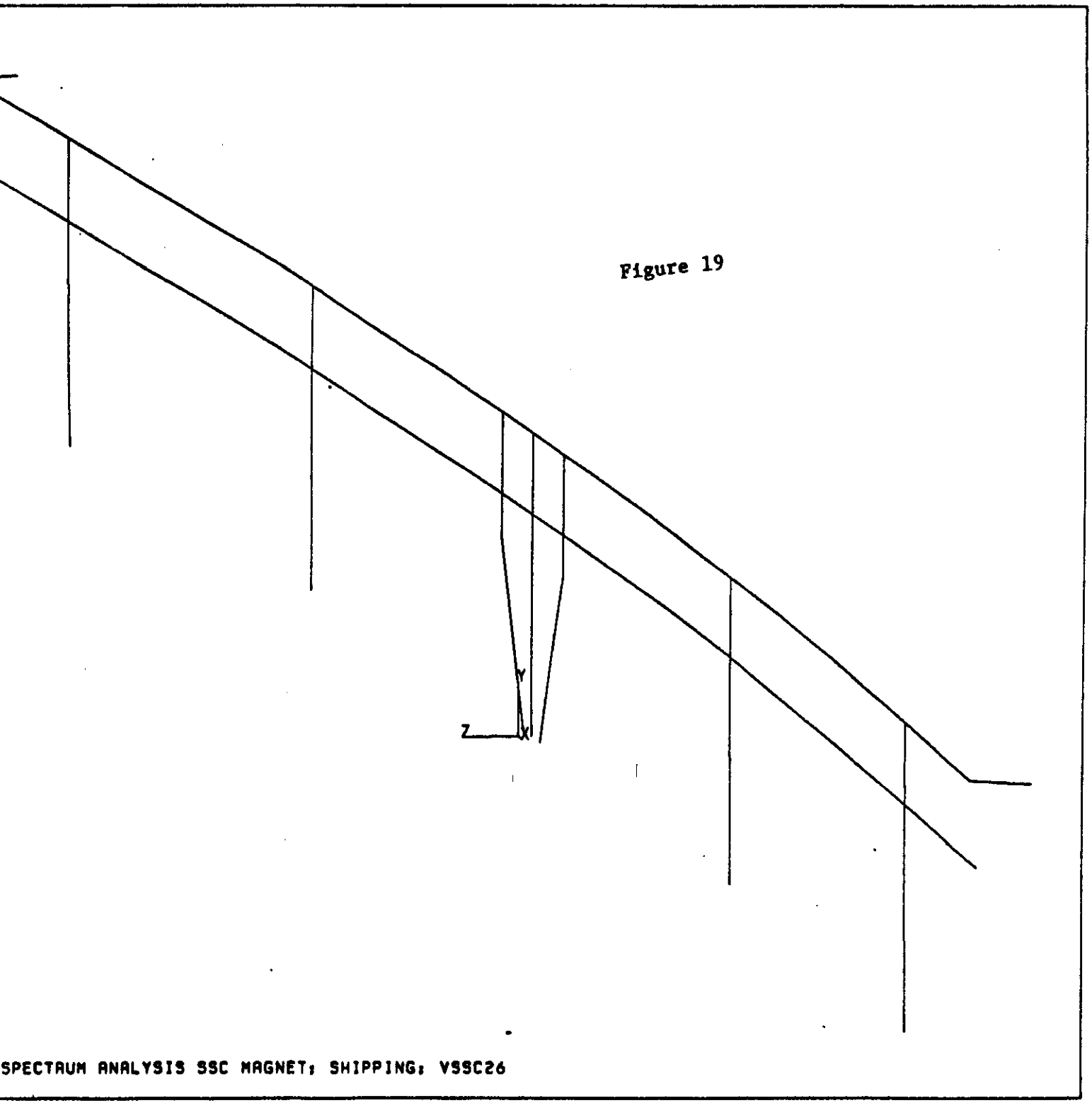

Figure 19

ANSYS
86/ 3/18
16.2353
PLOT NO. 14
POST1
STEP=3
ITER=1
FREQ=5.38
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.0841
DSCA=30.1

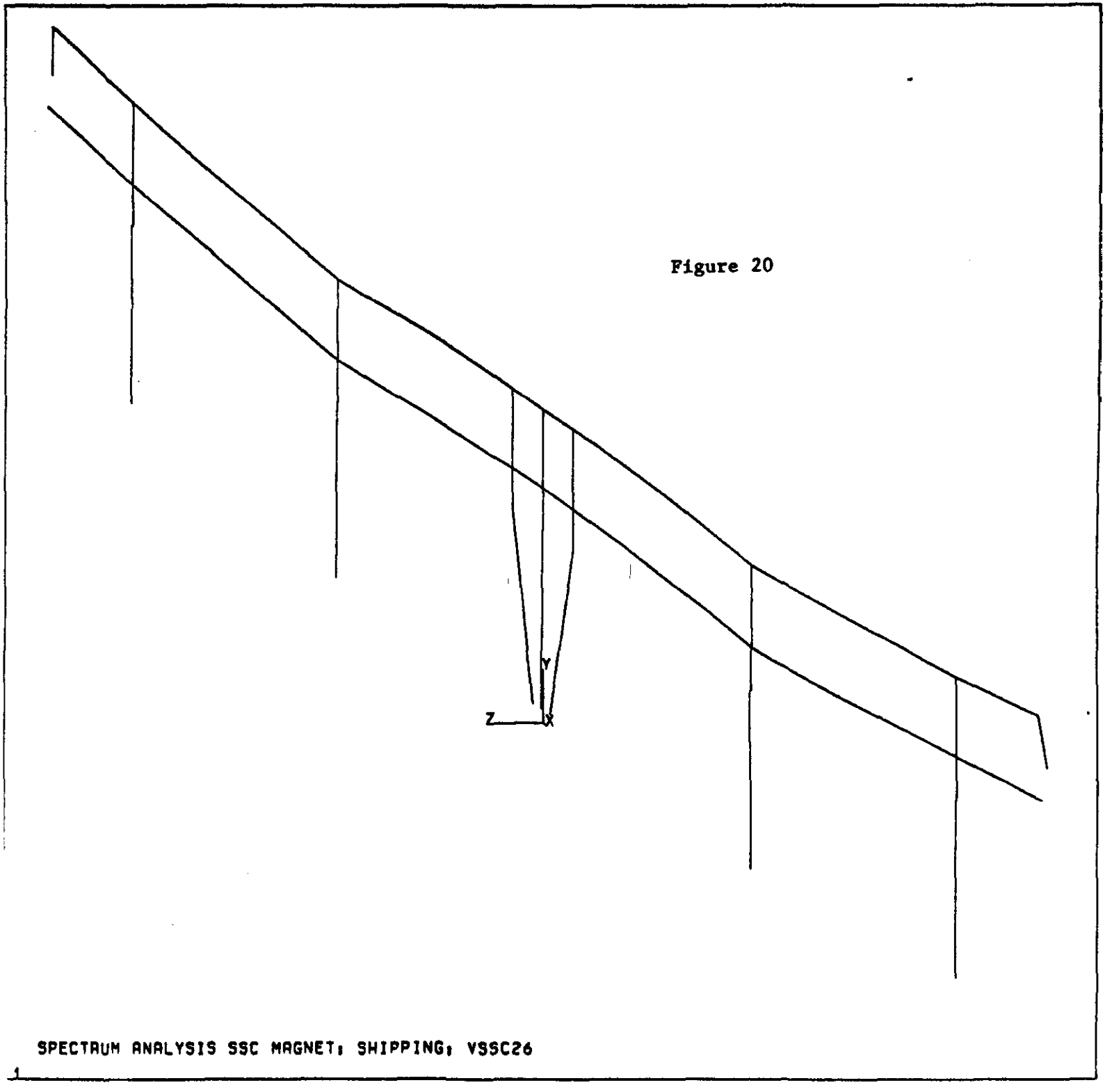

Figure 20

ANSYS
86/ 3/18
14.5589
PLOT NO. 1
POST1
STEP=1
ITER=1
FREQ=-1
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.92
DSCA=2.75

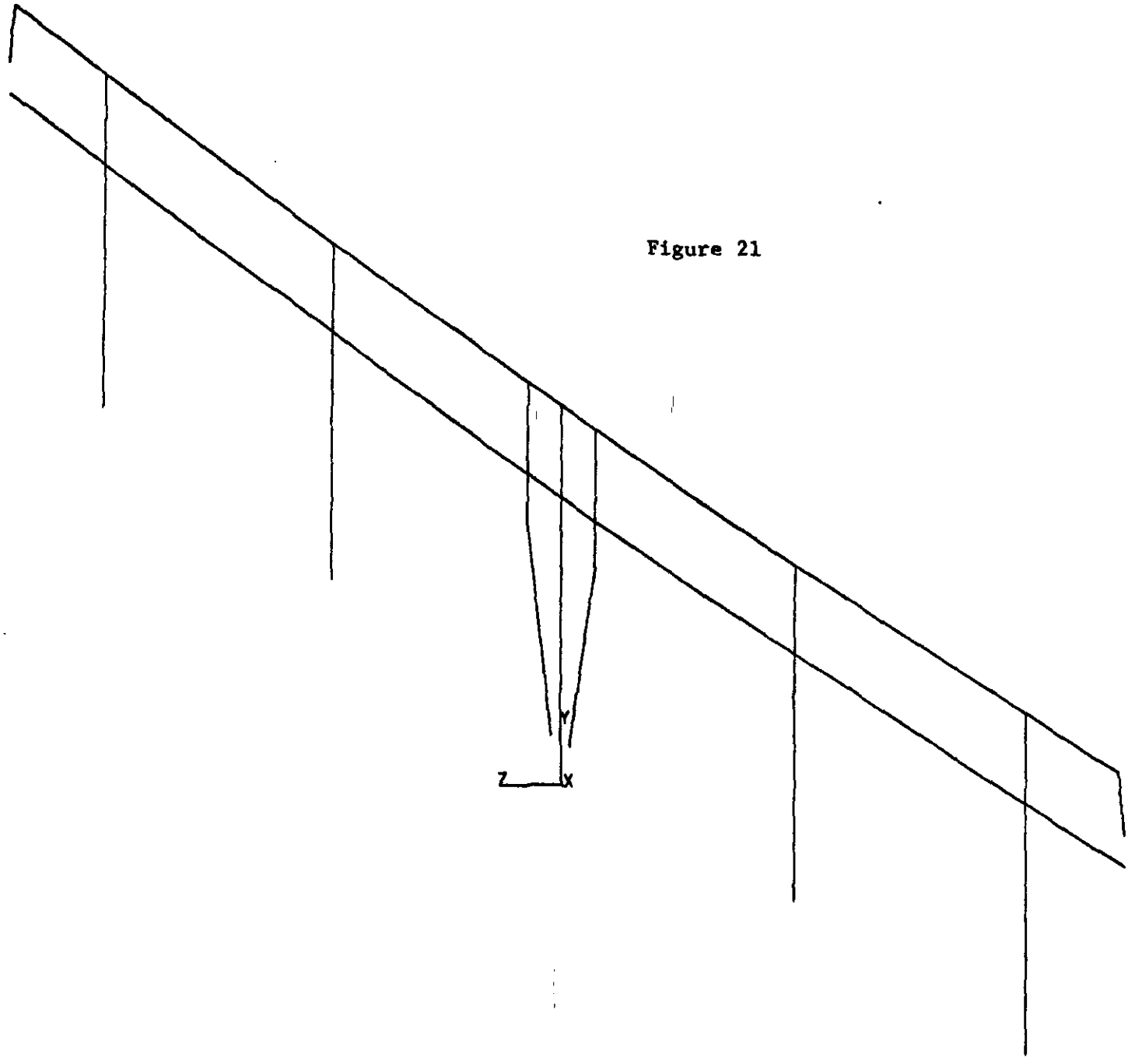

Figure 21

ANSYS
86/ 3/18
16.2044
PLOT NO. 7
POST1
STEP=1
ITER=4
FREQ=2.56
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=3.14
DSCA=.807

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC29

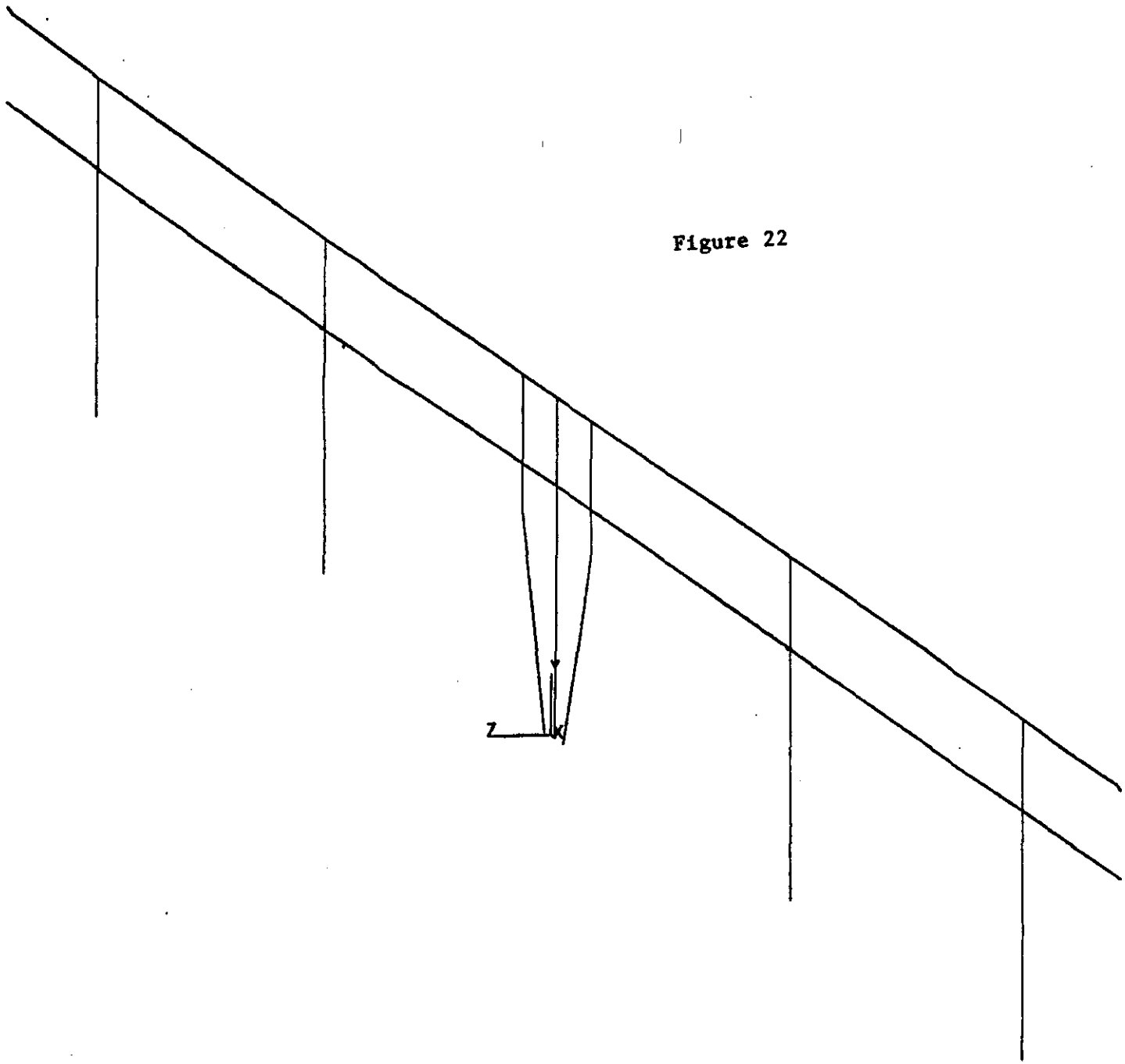

Figure 22

ANSYS
86/ 3/18
16.2272
PLOT NO. 12
POST1
STEP=2
ITER=5
FREQ=2.56
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=1.73
DSCA=1.46

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC29

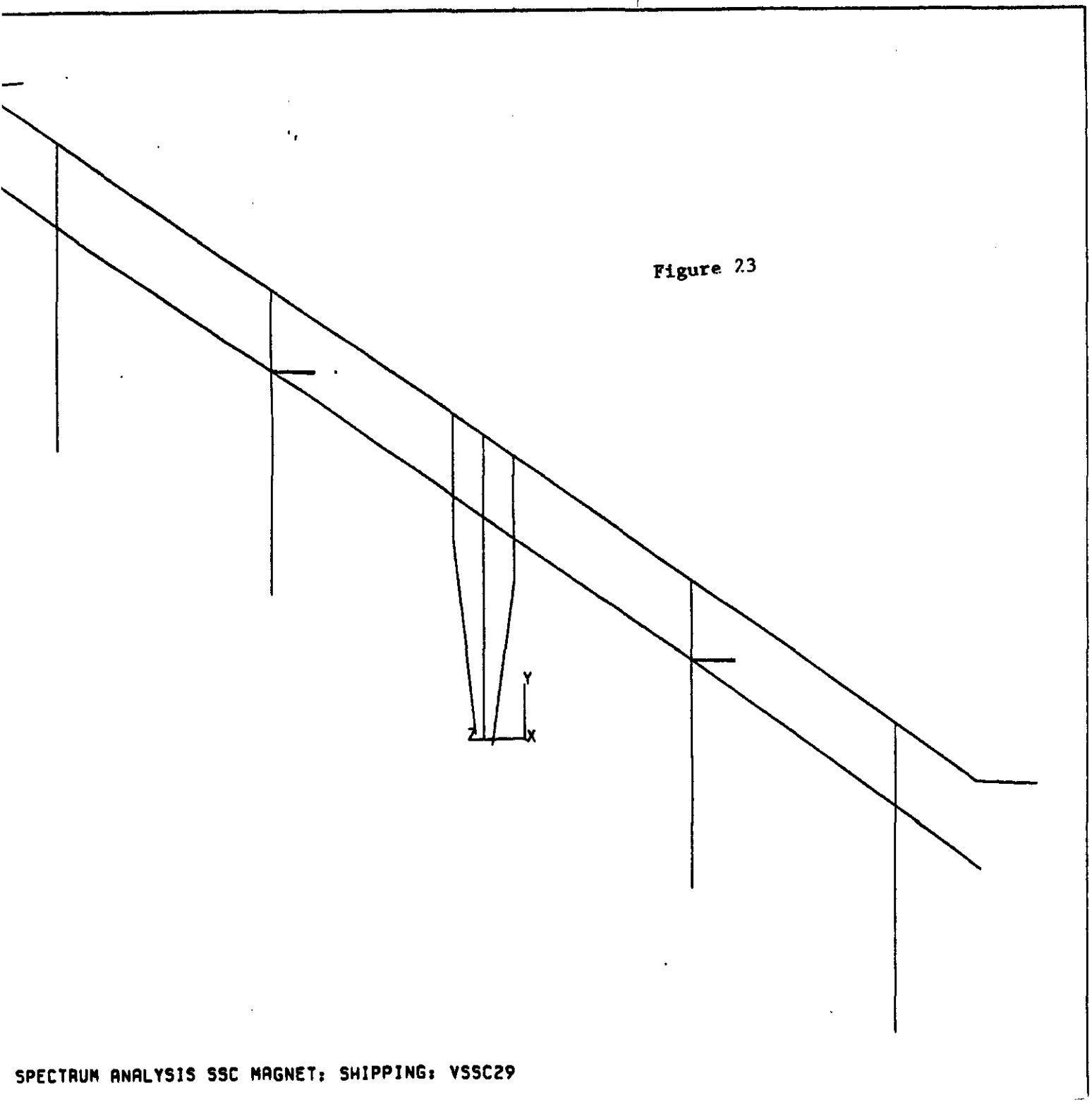

Figure 23

ANSYS
86/ 3/18
16.2592
PLOT NO. 14
POST1
STEP=3
ITER=3
FREQ=2.55
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.294
DSCA=8.62

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC29

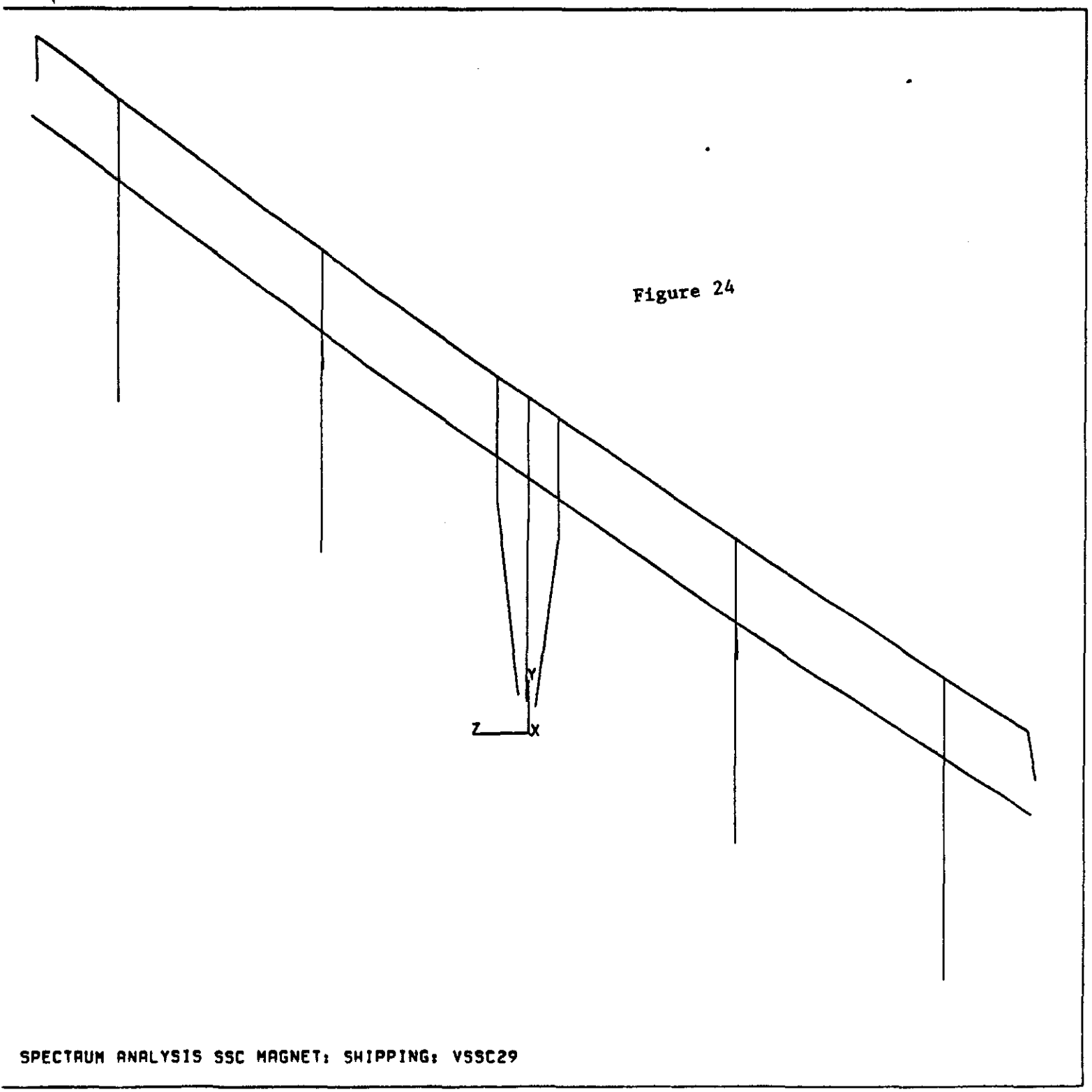

Figure 24

ANSYS
86/ 3/18
17.0064
PLOT NO. 1
POST1
STEP=1
ITER=1
FREQ=-1
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=3.6
DSCA=.703

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC29

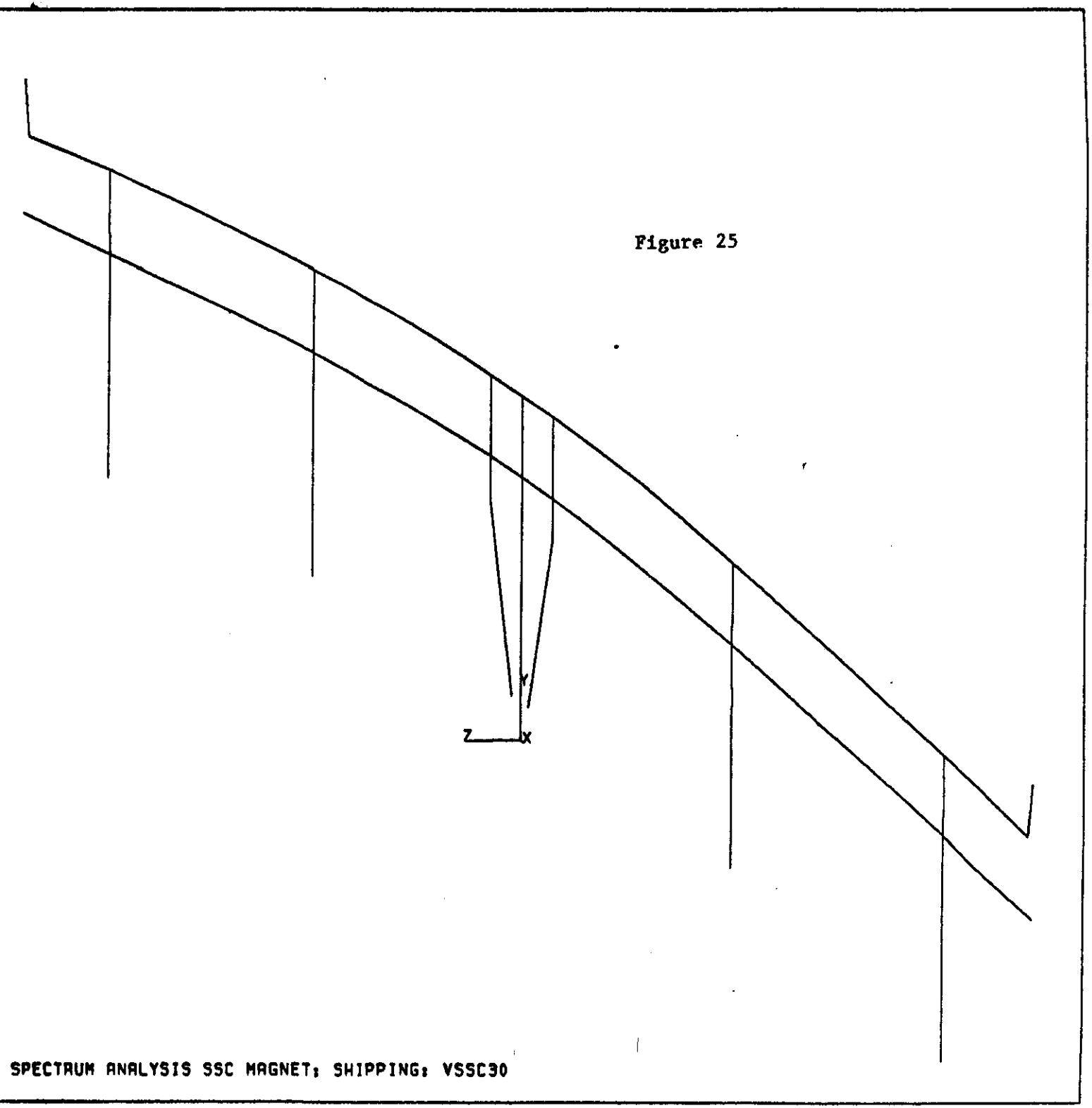

Figure 25

ANSYS
86/ 3/18
16.4853
PLOT NO. 7
POST1
STEP=1
ITER=2
FREQ=5.98
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.226
DSCA=11.2

SPECTRUM ANALYSIS SSC MAGNET; SHIPPING; VSSC30

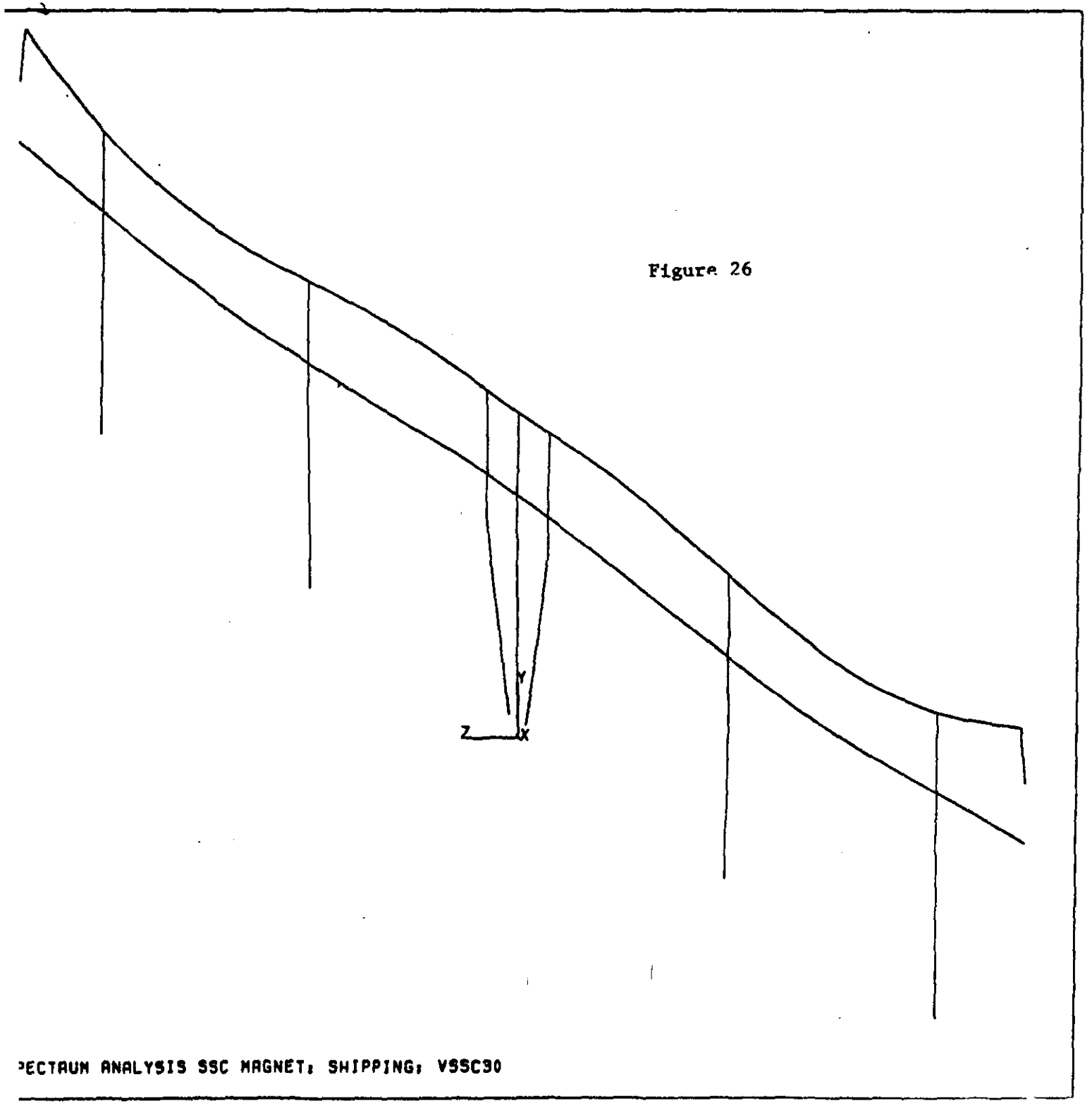

Figure 26

ANSYS
86/ 3/18
16.4892
PLOT NO. 8
POST1
STEP=1
ITER=8
FREQ=16.6
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.298
DSCA=8.49

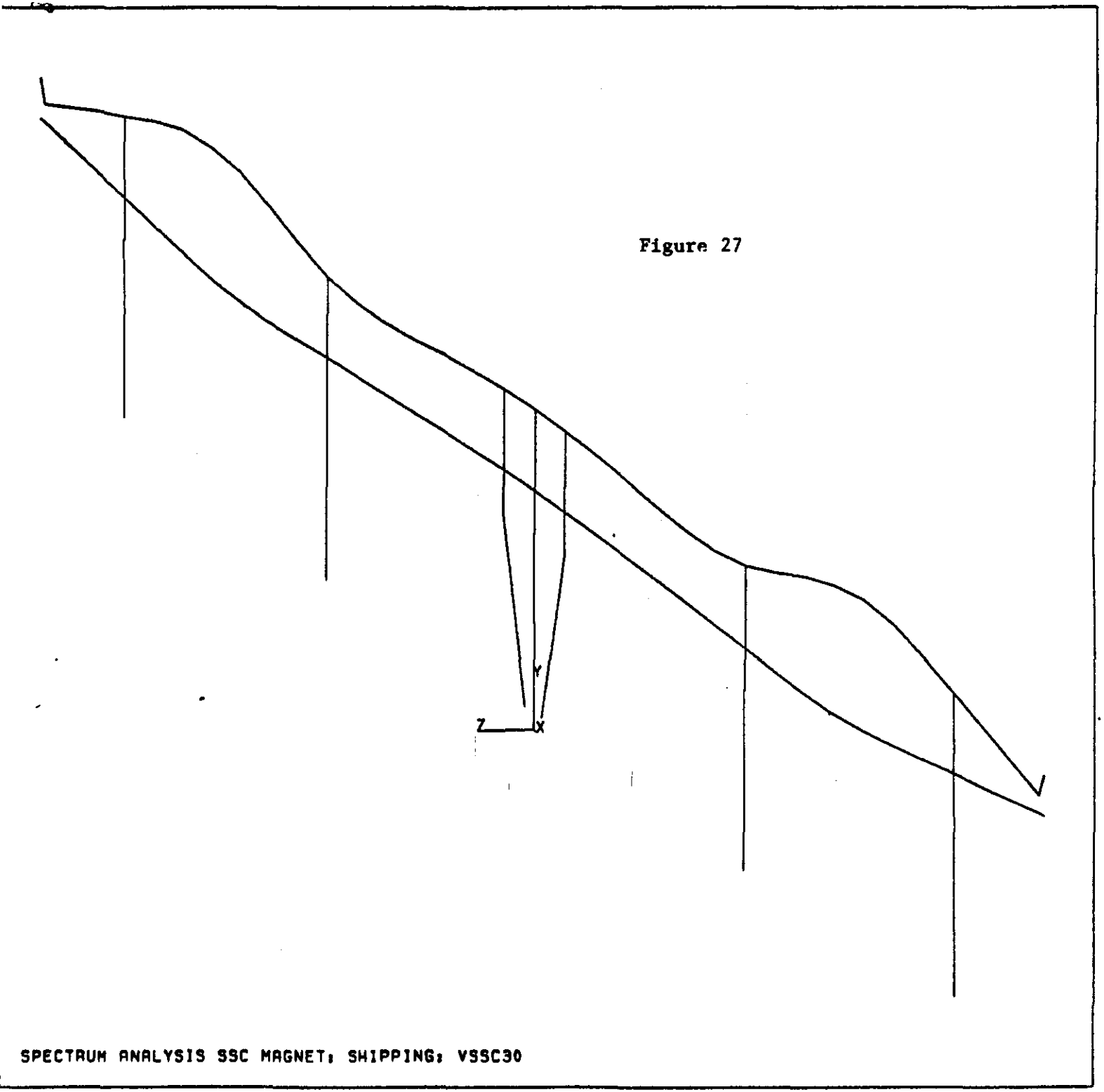

Figure 27

ANSYS
86/ 3/18
16.4925
PLOT NO. 9
POST1
STEP=1
ITER=12
FREQ=21.6
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.156
DSCA=16.2

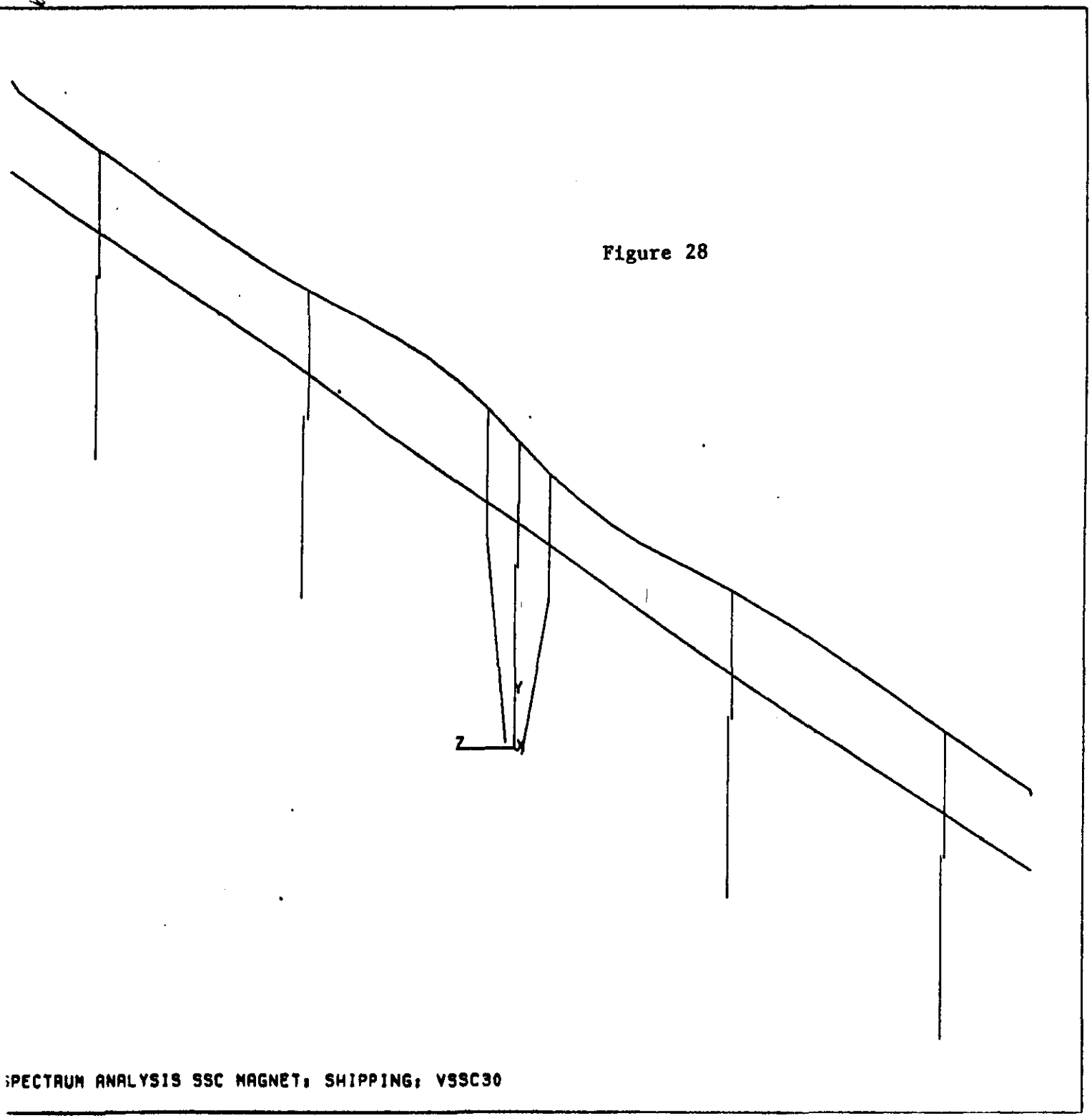

Figure 28

ANSYS
86/ 3/18
16.5000
PLOT NO. 10
POST1
STEP=2
ITER=3
FREQ=9.26
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.252
DSCA=10

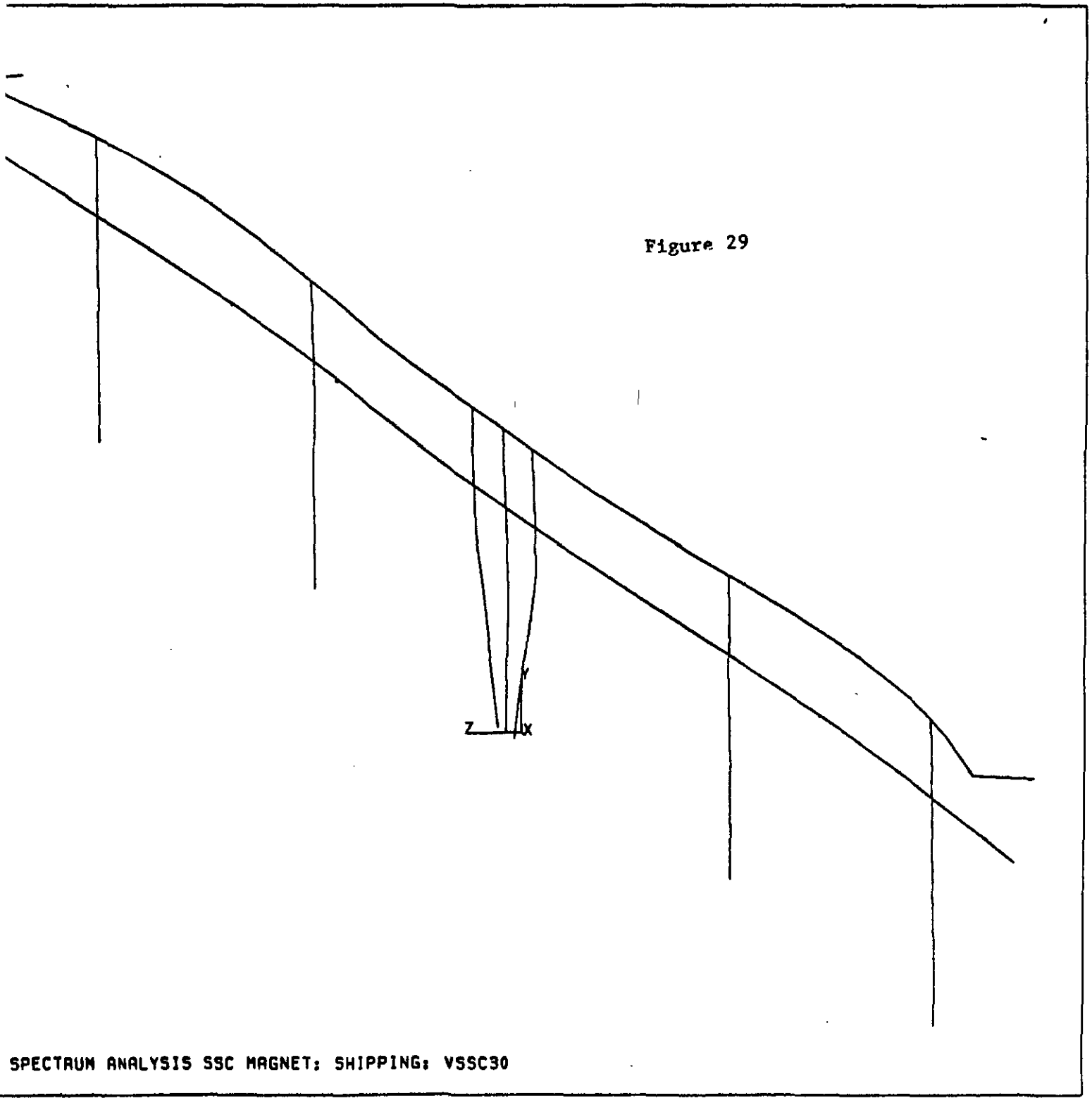

Figure 29

ANSYS
86/ 3/18
16.5289
PLOT NO. 16
POST1
STEP=3
ITER=6
FREQ=14.8
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.0569
DSCA=44.5

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC30

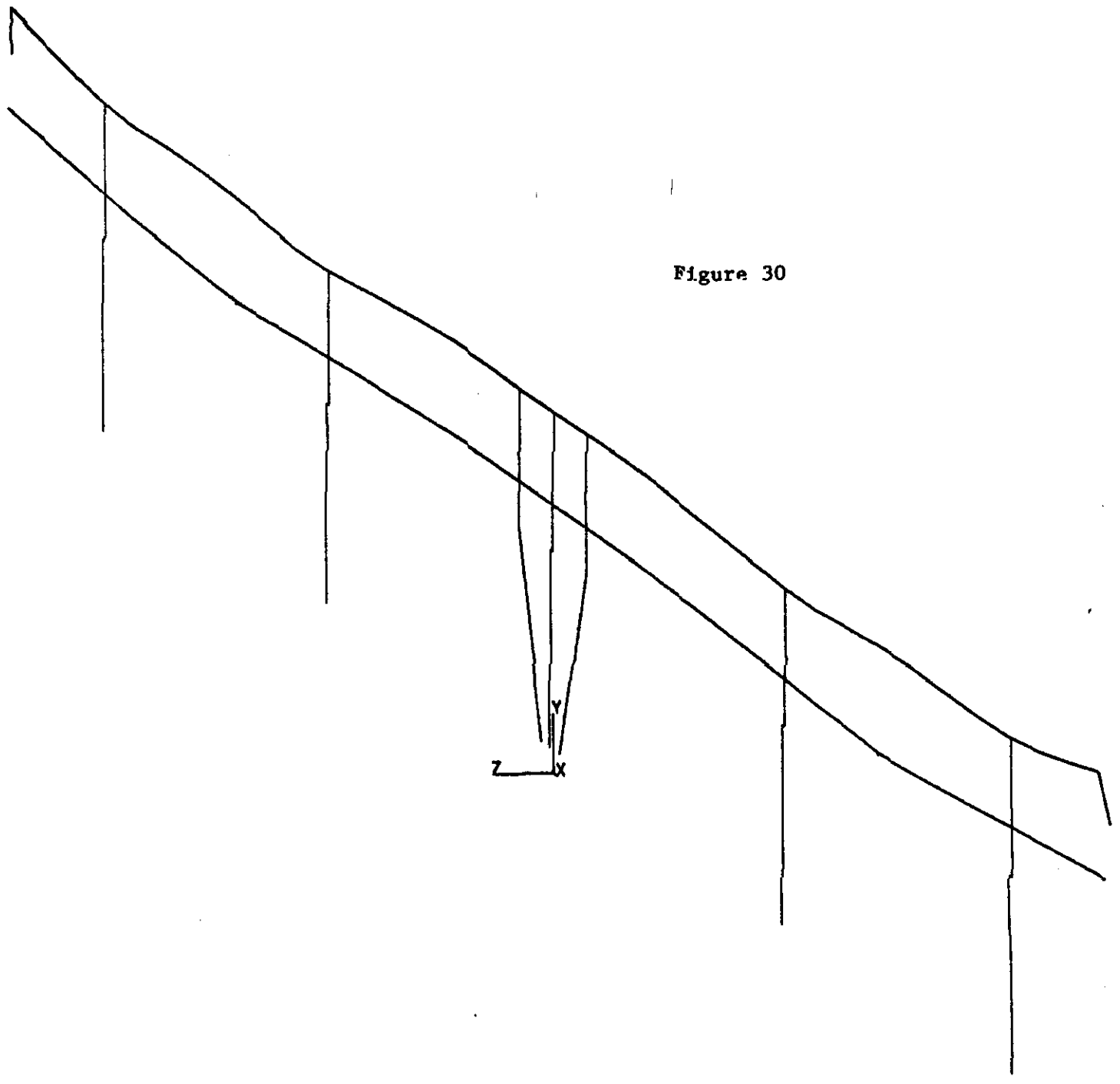

Figure 30

ANSYS
86/ 3/19
10.5097
PLOT NO. 1
POST1
STEP=1
ITER=1
FREQ=-1
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.459
DSCA=5.52

SPECTRUM ANALYSIS SSC MAGNET; SHIPPING; VSSC30

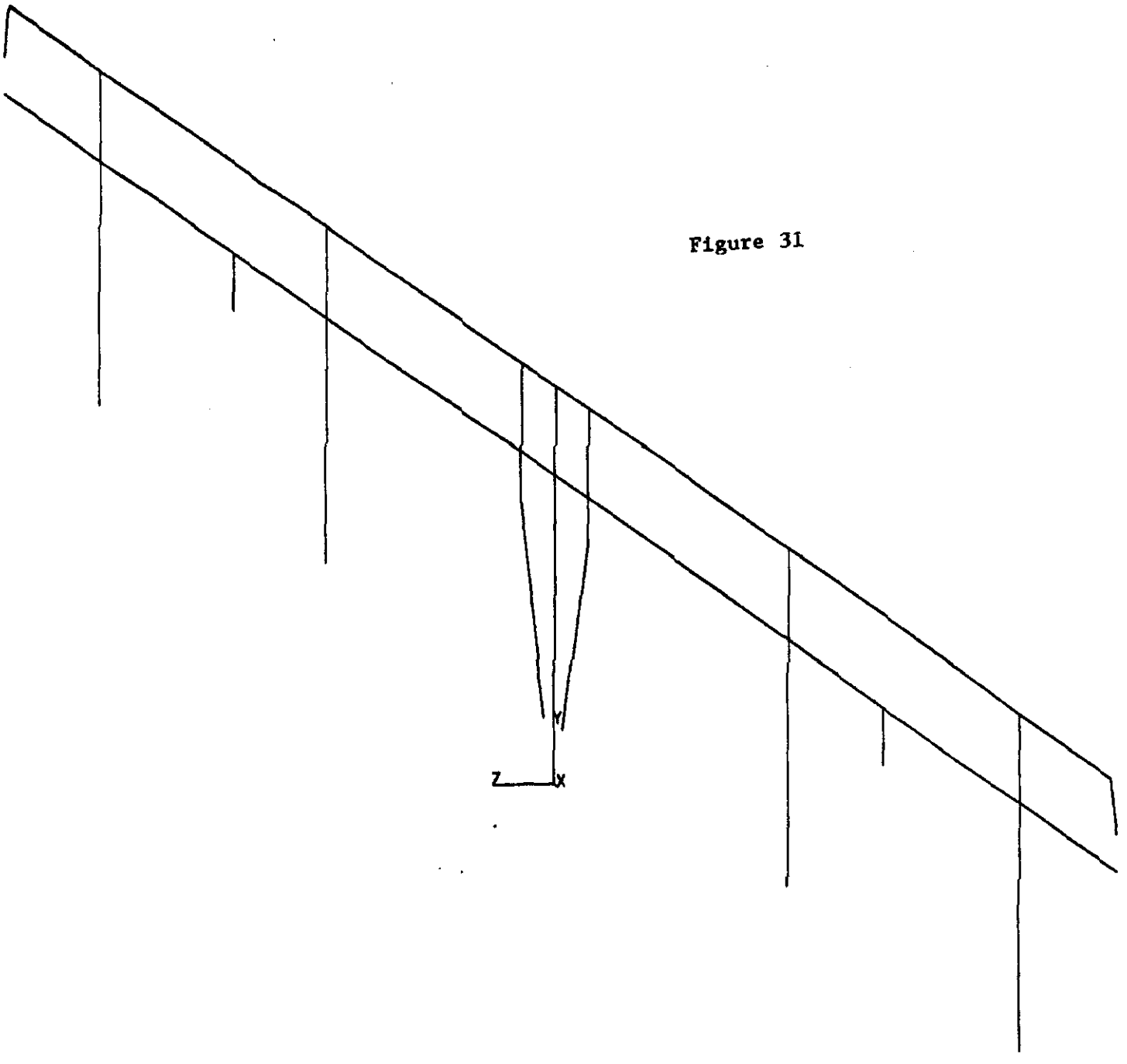

Figure 31

ANSYS
86/ 3/18
16.9028
PLOT NO. 7
POST1
STEP=1
ITER=3
FREQ=2.61
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=2.64
DSCA=.96

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC31

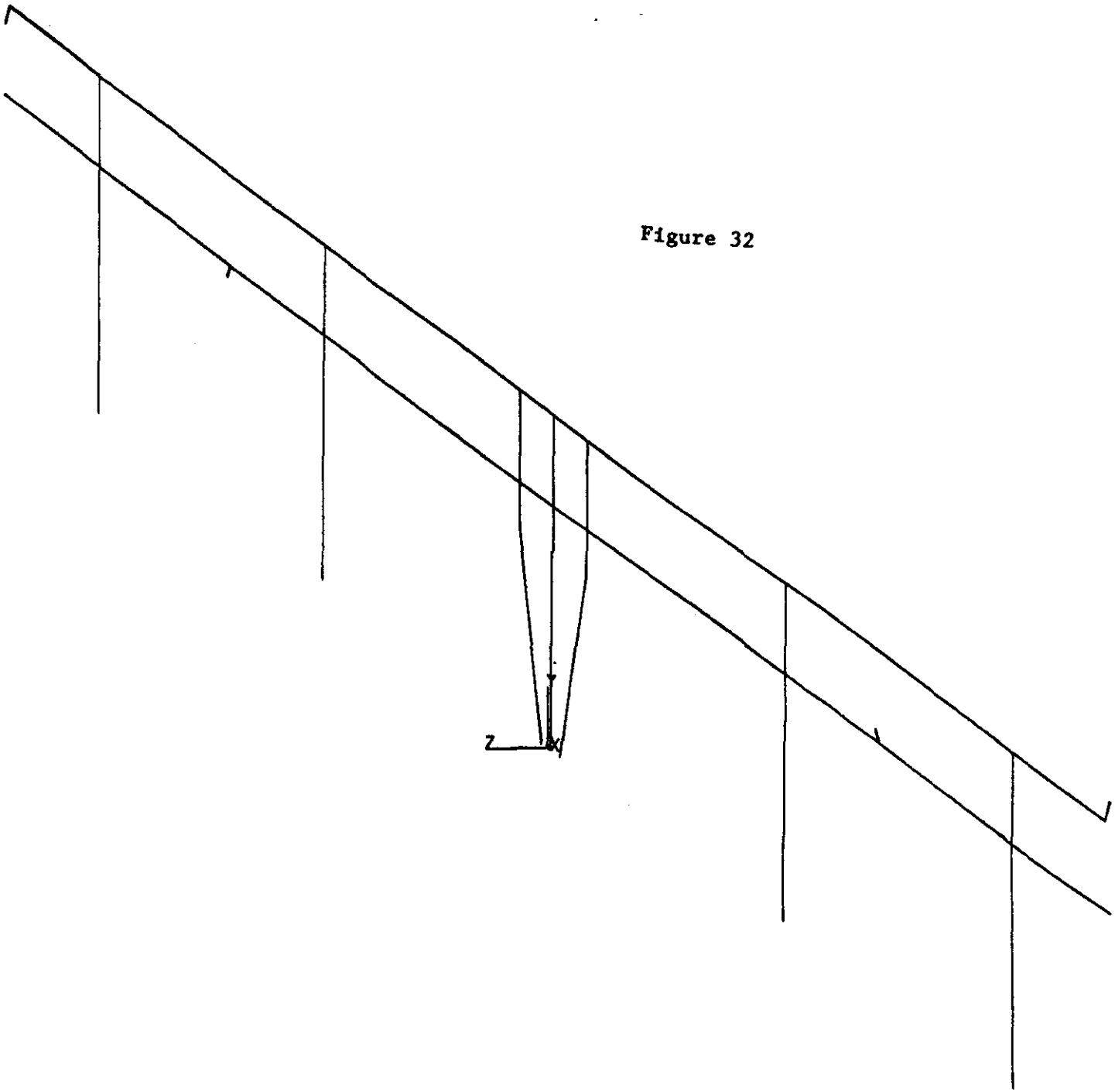

Figure 32

ANSYS
86/ 3/18
16.9122
PLOT NO. 9
POST1
STEP=2
ITER=1
FREQ=2.55
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=1.78
DSCA=1.42

SPECTRUM ANALYSIS SSC MAGNET; SHIPPING; VSSC31

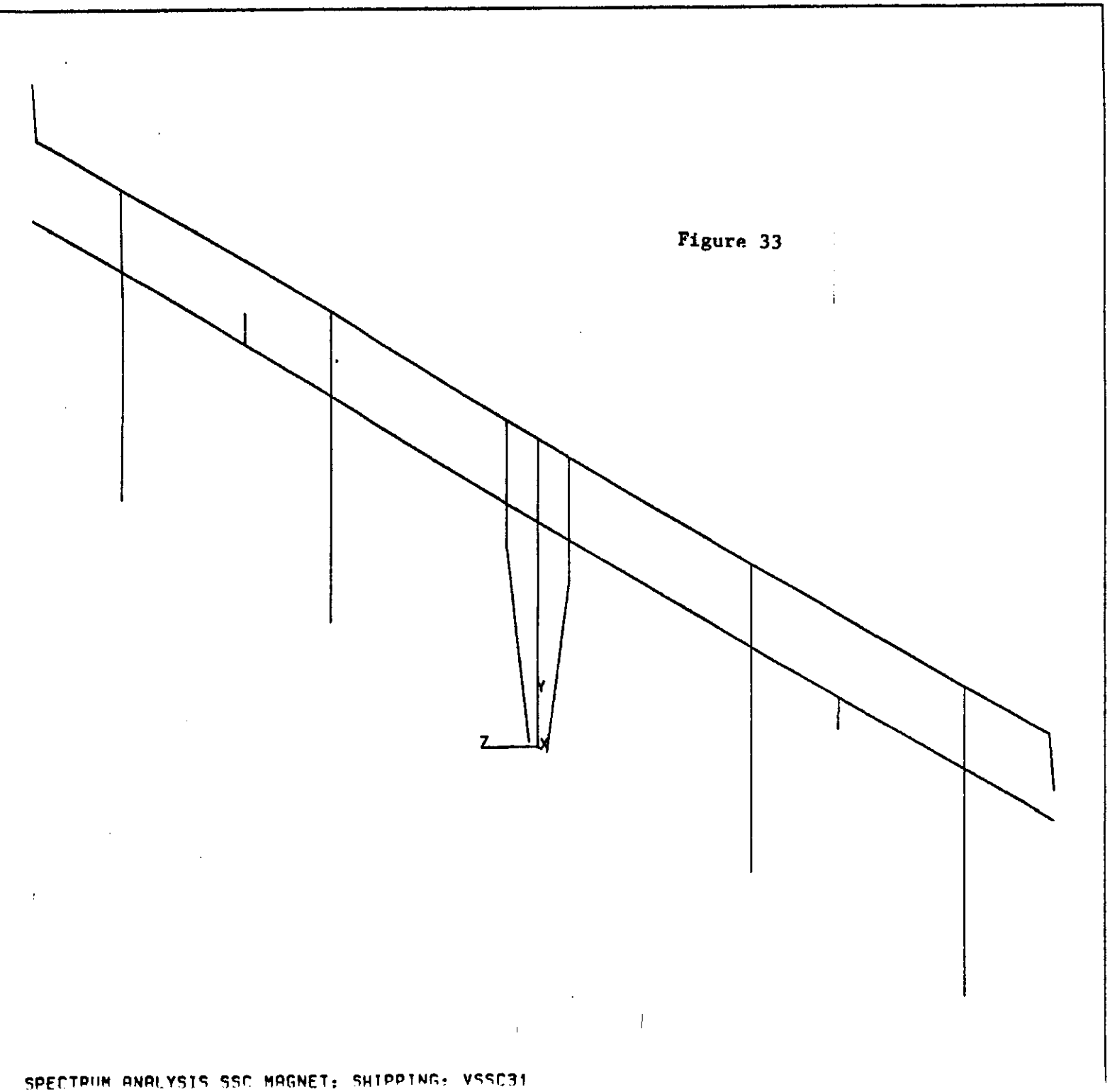

Figure 33

ANSYS
86/ 3/18
16.9178
PLOT NO. 10
POST1
STEP=2
ITER=5
FREQ=2.65
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.598
DSCA=4.23

SPECTRUM ANALYSIS SSC MAGNET: SHIPPING: VSSC31

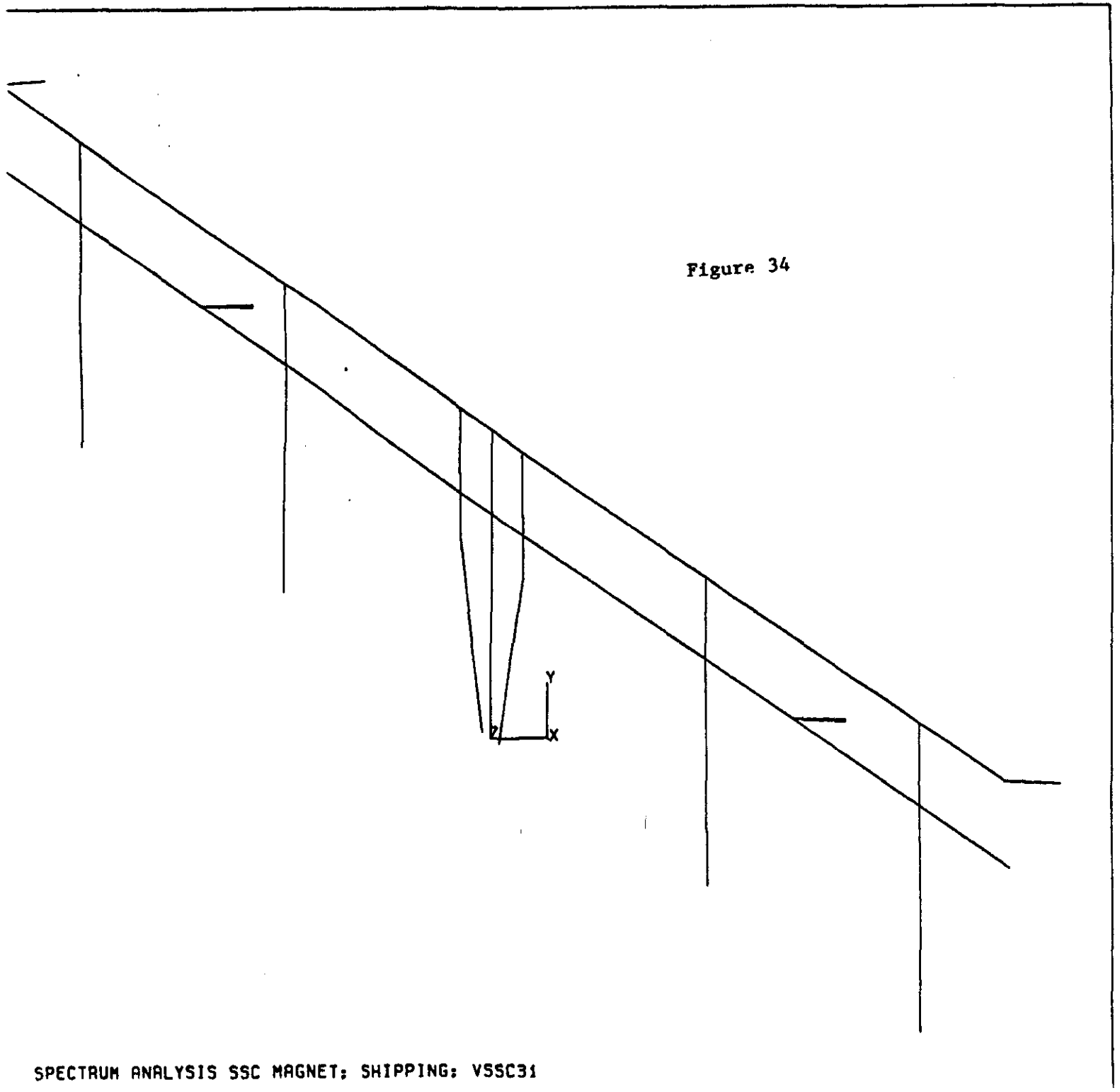

Figure 34

ANSYS
86/ 3/18
16.9386
PLOT NO. 12
POST1
STEP=3
ITER=2
FREQ=2.6
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=.247
DSCA=10.2

SPECTRUM ANALYSIS SSC MAGNET; SHIPPING; VSSC31

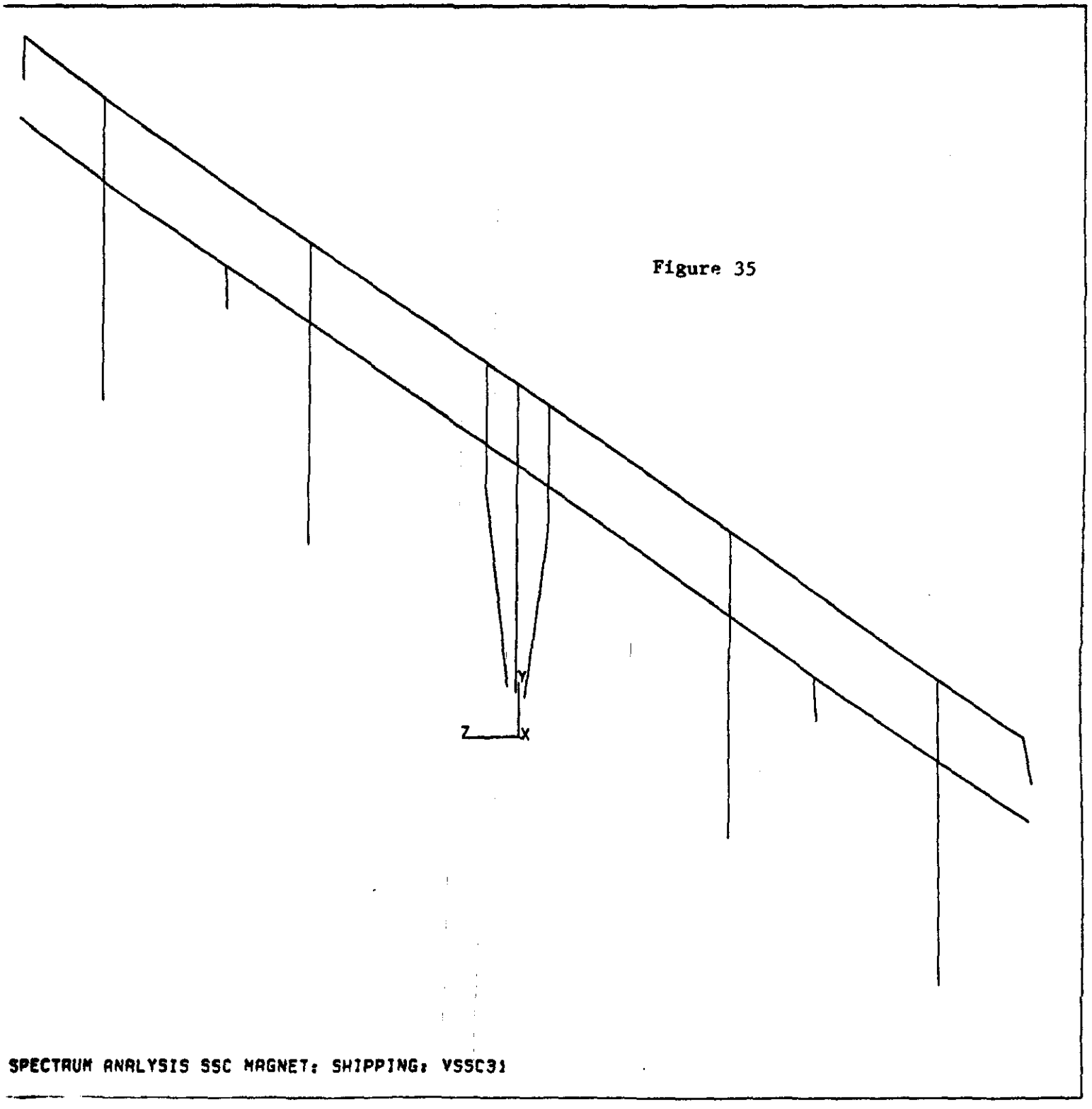

Figure 35

ANSYS
86/ 3/18
17.0703
PLOT NO. 1
POST1
STEP=1
ITER=1
FREQ=-1
DISPLACEMENT

ORIG SCALING
XV=10
YV=.5
ZV=.7
DIST=25.3
XF=.187
YF=8.52
ZF=.0131
DMAX=3.13
DSCA=.81

Revision 1
December 1973

U.S. ATOMIC ENERGY COMMISSION

REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

REGULATORY GUIDE 1.60

DESIGN RESPONSE SPECTRA FOR SEISMIC DESIGN OF NUCLEAR POWER PLANTS

A. INTRODUCTION

Criterion 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires, in part, that nuclear power plant structures, systems, and components important to safety be designed to withstand the effects of earthquakes. Proposed Appendix A, "Seismic and Geologic Siting Criteria," to 10 CFR Part 100, "Reactor Site Criteria," would require, in part, that the Safe Shutdown Earthquake (SSE) be defined by response spectra corresponding to the expected maximum ground accelerations. This guide describes a procedure acceptable to the AEC Regulatory staff for defining response spectra for the seismic design of nuclear power plants. The Adviory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

In order to approximate the intensity and thereby estimate the maximum ground acceleration[1] of the expected strongest ground motion (SSE) for a given site, proposed Appendix A to 10 CFR Part 100 specifies a number of required investigations. It does not, however, give a method for defining the response spectra[1] corresponding to the expected maximum ground acceleration.

The recorded ground accelerations and response spectra of past earthquakes provide a basis for the rational design of structures to resist earthquakes. The Design Response Spectra,[1] specified for design purposes, can be developed statistically from response spectra of past strong-motion earthquakes (see reference 1). An extensive study has been described by Newmark and Blume in references 1, 2, and 3. After reviewing these referenced documents, the AEC Regulatory staff has determined as acceptable the following procedure for defining the Design Response Spectra representing the effects of the vibratory motion of the SSE, 1/2 the SSE, and the Operating Basis Earthquake (OBE) on sites underlain by either rock or soil deposits and covering all frequencies of interest. However, for unusually soft sites, modification to this procedure will be required.

In this procedure, the configurations of the horizontal component Design Response Spectra for each of the two mutually perpendicular horizontal axes are shown in Figure 1 of this guide. These shapes agree with those developed by Newmark, Blume, and Kapur in reference 1. In Figure 1 the base diagram consists of three parts: the bottom line on the left part represents the maximum ground displacement, the bottom line on the right part represents the maximum acceleration, and the middle part depends on the maximum velocity. The horizontal component Design Response Spectra in Figure 1 of this guide correspond to a maximum *horizontal ground acceleration* of 1.0 g. The maximum ground displacement is taken proportional to the maximum ground acceleration, and is set at 36 inches for a ground acceleration of 1.0 g. The numerical values of design displacements, velocities, and accelerations for the horizontal component Design Response Spectra are obtained by multiplying the corresponding values of the maximum ground displacement and acceleration by the factors given in Table I of this guide. The displacement region lines of the Design Response Spectra are parallel to the maximum ground displacement line and are shown on the left of Figure 1. The velocity region lines slope downward from a frequency of 0.25 cps (control point D) to a frequency of 2.5 cps (control point C) and are shown at the top. The remaining two sets of lines between the frequencies of 2.5 cps and 33 cps (control point A), with a break at a frequency of 9 cps (control

[1] See definitions at the end of the guide.

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7. Transportation
8. Occupational Health
9. Antitrust Review
10. General

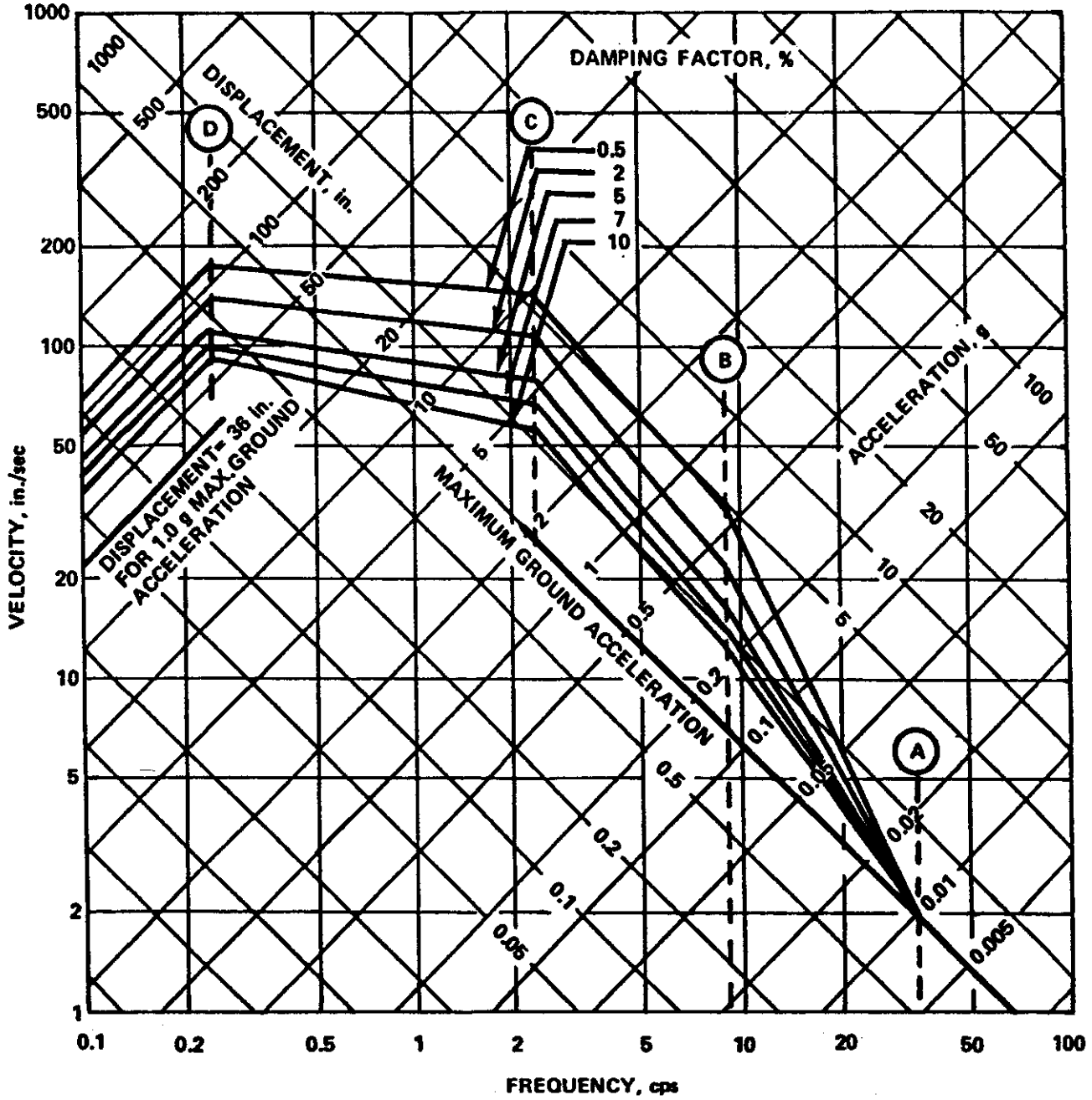

FIGURE 1. HORIZONTAL DESIGN RESPONSE SPECTRA – SCALED TO 1g HORIZONTAL GROUND ACCELERATION

DEFINITIONS

Response Spectrum means a plot of the maximum response (acceleration, velocity, or displacement) of a family of idealized single-degree-of-freedom damped oscillators as a function of natural frequencies (or periods) of the oscillators to a specified vibratory motion input at their supports. When obtained from a recorded earthquake record, the response spectrum tends to be irregular, with a number of peaks and valleys.

Design Response Spectrum is a relatively smooth relationship obtained by analyzing, evaluating, and statistically combining a number of individual response spectra derived from the records of significant past earthquakes.

Maximum (peak) Ground Acceleration specified for a given site means that value of the acceleration which corresponds to zero period in the design response spectra for that site. At zero period the design response spectra acceleration is identical for all damping values and is equal to the maximum (peak) ground acceleration specified for that site.

TABLE I

HORIZONTAL DESIGN RESPONSE SPECTRA RELATIVE VALUES OF SPECTRUM AMPLIFICATION FACTORS FOR CONTROL POINTS

Percent of Critical Damping	Amplification Factors for Control Points			
	Acceleration[1] [2]			Displacement[1] [2]
	A(33 cps)	B(9 cps)	C(2.5 cps)	D(0.25 cps)
0.5	1.0	4.96	5.95	3.20
2.0	1.0	3.54	4.25	2.50
5.0	1.0	2.61	3.13	2.05
7.0	1.0	2.27	2.72	1.88
10.0	1.0	1.90	2.28	1.70

[1] Maximum ground displacement is taken proportional to maximum ground acceleration, and is 36 in. for ground acceleration of 1.0 gravity.

[2] Acceleration and displacement amplification factors are taken from recommendations given in reference 1.

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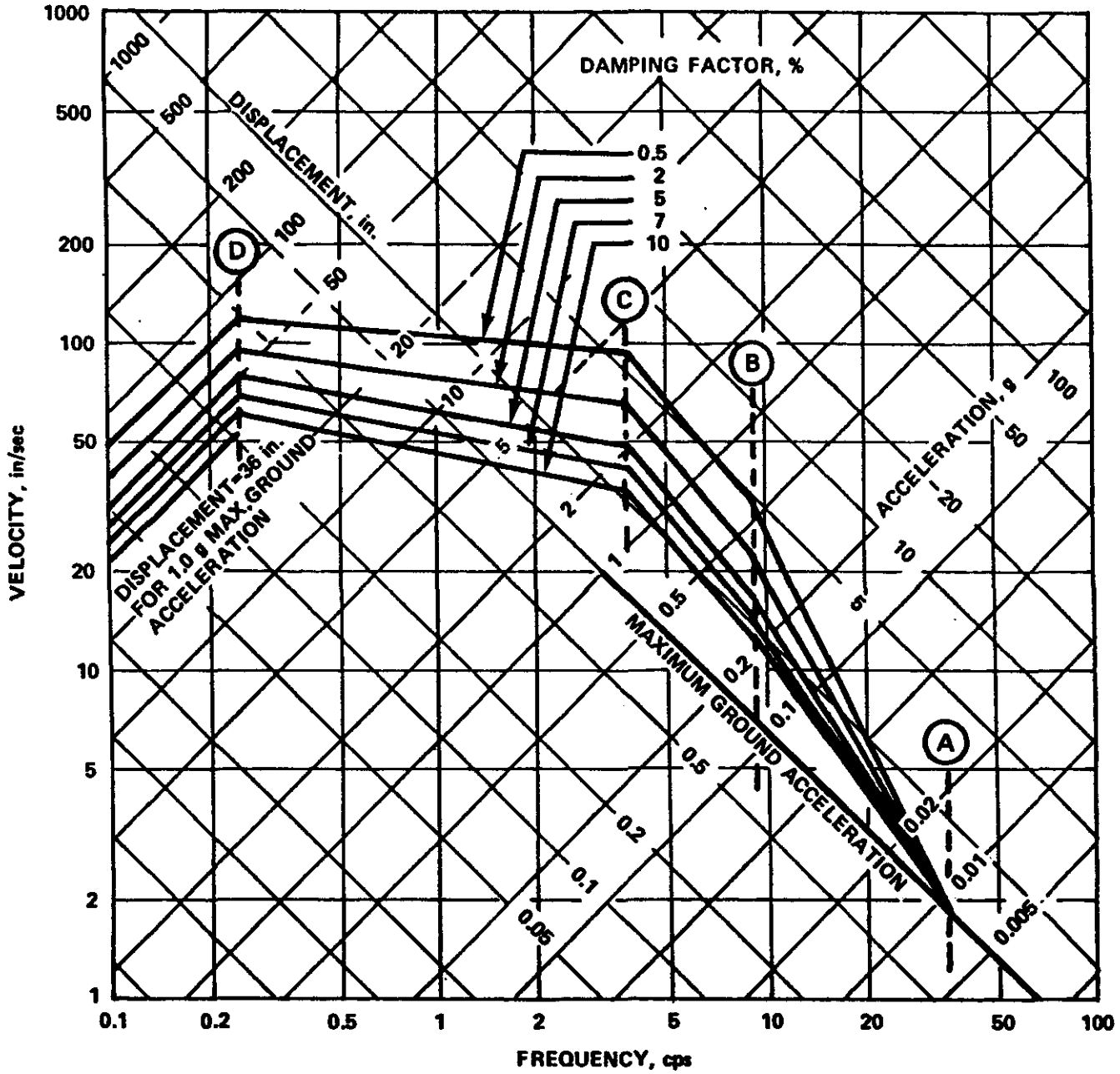

FIGURE 2. VERTICAL DESIGN RESPONSE SPECTRA – SCALED TO 1g HORIZONTAL GROUND ACCELERATION