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SEISMIC ANALYSIS OF REACTOR EXHAUST AIR FILTER COMPARTMENT(U)

CHUNG GONG, E. L. FUNDERBURK and JEFFREY W. JERRELL

September 1990

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SEISMIC ANALYSIS OF REACTOR EXHAUST AIR FILTER COMPARTMENT(U)

By

CHUNG GONG, E. L. FUNDERBURK and JEFFREY W. JERRELL

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CONTENTS

1. INTRODUCTION AND SUMMARY

The Filter Compartment (FC) in this analysis is a generic reactor airborne activity confinement filter compartment which possesses all the essential physical and mechanical properties of the Savannah River Site (SRS) confinement filters of Reactor Buildings K, L, and P. The filters belong to the Airborne Activity Confinement System (AACS). These filters absorb a significant amount of radioactive effluents from the exhausting air.

This generic FC is located on the roof of the 105 Exhaust Stack building at the elevation of 55 feet. The center of the top nozzle is at 75 feet. The exterior of the FC resembles the appearance of a "trailer" (see Figure 1) with measurement: 21 feet 9 inches in length, 8 feet 10 inches in width and 21 feet 6 inches tall. Inside the FC, at the upper part of the compartment, there is a plenum which guides the exhausting air flow from the top (inlet) nozzle. Underneath the plenum there are three upright filter racks (for the Carbon, HEPA, and Demister filters respectively) (see Figure 3).

The whole FC structure is made of aluminum alloys. The frame and racks are mostly composed of beams and columns with **I**, **T**, **L**, and rectangular sections and the composition of two or more of these sections which are made of 6061-T6 alloys. The skins of all the six faces of the FC are made of *curved* shells. The plenum is constructed with both flat plates and *curved* shells. The nozzles are large cylindrical shells with a radius of 28.625 inches. The shells and plates are made of 3003-H112 (and H16) aluminum alloys.

The base of the FC is in contact with the rail-dolly on the building roof. The two nozzles are loosely connected to the exhaust pipes from the building wall through neoprene gaskets such that sliding motion along the cylindrical interfaces is not restricted.

The seismic excitation is input indirectly from the output of the seismic analysis of the 105 exhaust stack building in the form of floor response spectra. However, the 105 exhaust stack building was analyzed for seismic motions defined by free-field ground response spectra with a ZPA (Zero Period Acceleration) of 0.2G for all three orthogonal components of ground motion and a shape consistent with USNRC Regulatory Guide 1.60.

Based upon equivalent dynamic analysis of the FC, DuPont engineers suggested modifications on the existing FC with heavy I-section beams [1].

The scope of this "phase I" analysis, as requested by Seismic Engineering [2], is to carry out a "scoping analysis" of Frequency Analysis and Response Spectrum Analysis of the FC with DuPont suggested conceptual modifications.

Our suggestion was that the existing FC without conceptual modifications be analyzed first. However, the schedule urgency of the project and with guidance from the previous seismic analysis established the priority to perform the analysis for the FC with modifications in the "phase I" calculation.

1.1 SUMMARY

A general purpose Finite Element Analysis program, ABAQUS, is used to perform the Modal Response Spectrum Analysis of the FC. The heavy stiffeners suggested by the modifications and the vertically fixed base boundary conditions make the FC considerably stiff. Consequently, the fundamental frequency of the FC reaches 14.925 Hertz, which is higher than what was expected. The effective mass for the vertical vibration modes is only 3% of that for the horizontal modes. At this frequency (14.925 Hertz) the effective vertical spectral acceleration is reduced to 1.29 G and the effective horizontal spectral acceleration diminishes to 0.75 G. With these low spectral accelerations, both the displacement and stress responses of the FC are accordingly small.

Since the effective mass of the vertical component is so low, it is justified to carry out the equivalent static analysis for the spectral loading beyond the cut-off frequency, viz., 33.0 Hertz. The ZPA of the vertical spectrum at 33.0 Hertz is 0.81 G. With the reduction factor 0.6667 specified in this calculation, the actual ZPA becomes 0.54 G. The static dead weight responses were computed with 1.0 G vertical gravitation load. Therefore the corresponding dynamic responses to the 0.54 G ZPA can be obtained by multiplying the static responses by the factor 0.54. Adding 54% of the vertical static responses to the dynamic responses, we find that the maximum Von Mises stress in shells is 2,140.5 psi. The maximum beam stresses are 3,356.7 psi for axial and 4,222.7 psi for shear. These stresses are well below the minimum yield strength of the aluminum alloys used in this FC. The maximum horizontal displacement is less than 0.12 inches in the direction along the nozzle axis and the maximum vertical displacement is also a midget 0.13 inches.

Without fastening devices, the dead weight of the FC is insufficient to hold the compartment down to the building roof during a seismic event with 0.2 G ZPA.

The conceptual modifications and the boundary conditions certainly shield the FC well from earthquakes. It is also important to have a better understanding of the real vulnerability and survivability of the FC during a seismic event. Hence a thorough seismic analysis of the "as is" existing FC is recommended.

2. ANALYSIS TECHNIQUES

2.1 Data Available

2.1.1 Geometric Configuration and Mechanical Properties of Structural Members

The geometric configuration and dimensions are obtained from the shop drawings: BPF 211147 drawing numbers FD-405-001 to 026 [3]. The Mechanical Properties of various structural members are computed from the shapes and materials indicated in the drawings.

2.1.2 Materials

Two Aluminum alloys are used in construction of this FC. In general the alloy 3003- H112 (H16 for plenum) is for plate and shell members, while the alloy 6061-T6 is used for beams and columns [3].

2.1.3 Applied Load

Seismic Engineering provided [4] the "Preliminary amplified floor response spectra for AACS filter compartments on K, L, and P, 105 exhaust stack buildings" with 3% damping, as the seismic loading for the response spectrum analysis. These spectra are shown in Figures 4-6.

1. Vertical smoothed floor response spectrum, Figure 4.
2. East-West smoothed floor response spectrum, Figure 5.
3. North-South smoothed floor response spectrum, Figure 6.

2.2 Method

The FC consists of compartment walls, which are built with *curved* shells, two nozzles, a plenum, three filter racks, and the floor and roof, both covered with *curved* shells. The dynamic linear modal seismic response spectrum method was adopted as the practical and expedient scoping analysis method. The actual boundary conditions include gaps and contact surfaces. In using this method, the complicated geometric and structural configurations, as well as the nonlinearities, necessitated linearization of the boundary conditions and certain modeling simplifications. Nevertheless, the objective is to insure that the FC will sustain only elastic deformation, during seismic excitations. After the earthquake the FC elastic deformations must be recovered and thus the FC will be functioning immediately after the shock without any by-pass of effluents. Therefore, linear elastic analysis is the appropriate method to be applied in this case.

2.2.1 Computer Code

ABAQUS is a general purpose Finite Element Analysis program which can perform both Static and Dynamic analyses of linear as well as nonlinear problems. The theoretical manual indicates that this code uses the state-of-the-art approaches in the numerical analysis that is essential for the reliability and accuracy of the calculations. ABAQUS also provides the response spectrum analysis procedure. ABAQUS is installed on the SRS CRAY XMP computer.

2.2.2 Modeling

Both geometric and mechanical properties modeling of the FC are carried out with PATRAN, a pre- and post-processing code.

Phase I of PATRAN modeling sets up the grid of the physical geometric configuration. In this Phase the grid network of lines and patches is constructed according to the geometric configuration of the FC. In this grid network each line and patch passes through the material centroids of the structural members. In phase II of PATRAN modeling the physical beams, plates and shells are mapped onto the grid network as finite elements. In order to include the curvature of the shells in the model, the size of the elements is drastically reduced, since, according to the ABAQUS manual, the surface normals between adjacent curved shell elements must be within 15 degrees apart for smooth connectivity.

Figure 2 shows the overall element mesh of the FC. The *curved* shells are rather composed of flat plates, such that at the edge of the intersection of two adjacent elements there are two distinct normals. However, the angle between these two normals is less than 15 degrees. In ABAQUS a unique normal which is equal to the average of the two normals will be chosen along the edge. The element between edges will be modelled as a *curved* shell element. The unique normal along the intersection edge of adjacent elements provides continuity of curvature. Figure 3, with the side wall shell elements deleted, shows the inside modeling of the FC. This Figure reveals the curved shell elements on all the six faces of the FC. The plenum, and one (the carbon filter rack) of the three filter racks are meshed with plate elements. Except for two rows of plate elements at top and bottom of the Demister filter rack all the filter racks are modelled with beam elements.

Only a limited number of beam cross-sections with simple geometric configurations are available in the ABAQUS code. Therefore all the sectional properties of beams with simple as well as composite cross sections are manually computed [6] (see Table 1). The complicated beam cross section configurations make it difficult to precisely calculate beam stresses. A list of section points for all the beams in this model is conservatively estimated based upon best engineering judgements. This list of section points is part of the ABAQUS input data.

2.2.2.1 **Material (mechanical) Properties**

Two aluminum alloys are used in this FC construction, viz., 3003-H112 (H16), and 6061-T6. According to the " ALCOA Structural Handbook " by Aluminum Company of America, 1960, Tables 3a, 4a, and 4b:

Alloys	**6061-T6**	**3003-H112**	**3003-H16**
Weight(lb/in^3)	0.098	0.099	0.099
Young's Modulus(ksi)	10,000	10,000	10,000
Shear Modulus(ksi)	3,750	3,750	3,750
Poisson's Ratio	0.3333	0.3333	0.3333
Yield Strength(ksi)(T)	35	10	21
Yield Strength(ksi)(C)	35	9	19
Yield Strength(ksi)(S)	20	6	12
Yield Strength(ksi)(B)	56	17	33

where (T), (C), (S), and (B) denote Tension, Compression, Shear, and Bearing respectively.

Weight of Filter Compartment Components [4]

Component	Source of Information	Weight(lbs)
Carbon cell	Vendors QA Report	140
Particulate filter	Shipping Weight	50
Demister cell	Call to vendor	11
32 Carbon cells		4480
32 Particulate filters		1600
24 Demister cells		264
Weight of FC (including filters)	Analysis	21155

Equivalent Carbon Cell Plates (on both faces of the Rack):

Thickness	= 0.3 inches
Weight	= 0.405 lbs / in^3
Young's Modulus	= 7,250 ksi
Shear Modulus	= 2,788.46 ksi
Poisson's Ratio	= 0.30

Material Damping for all components and members is conservatively estimated as 3% of critical damping.

2.2.2.2 **Finite Element Discretization**

There are two important criteria for the discretization of this finite element model, viz.,

1. There must be a sufficient number of elements to describe the geometric configuration and the connectivity of the FC structure.

2. At the highest mode of this analysis (i.e. at frequency = 33 Hertz), there must be about ten elements in each of the wave lengths, such that the error in the analysis will be kept below 5% from the analytic solution. (Ref. " Dispersion and Anisotropy Induced in Finite Element Analysis ", by Chung Gong , 1974). Note that the wave lengths in beam and shell members are calculated in accordance with the respective theories (e.g., Timoshenko beam theory, Mindlin plate and beam theories).

According to these two criteria, the FC structure was discretized into approximately 10,000 nodal points and about same number of beam and shell elements. Mathematically, in this model, a beam is described by a line and a shell element is a sheet without volume.

All the lines representing beams and columns and the 2-D manifolds as shells are geometrically located at the centroids of the real physical structural members which in actuality are three dimensional solid elements. The voids left by the mathematical modeling are filled either by rigid members or through **M**ulti-**P**oint **C**onstraints (MPC). Particularly, the *curved* shell skins of the six faces of the FC are welded to the beams and columns. The *curved* shells and the beam or column elements are connected with MPC's. For smoothness of the connectivity between adjacent curved shell elements, the arc angular length of each element is maintained less than 15 degrees.

The beam elements used in ABAQUS are type B31 which is a 2-node beam with linear interpolation. Two doubly curved shell elements used in this model from the ABAQUS element library are Quadrilateral shell element S4R5 and Triangular shell element STRI35.

2.2.2.3 **Boundary Conditions**
For each of the two nozzles at the nozzle-pipe interface, the translational displacement along the nozzle axis and the rotation about the nozzle axis are discontinuous. The rest of the degrees of freedom at this interface are to be modeled as if the nozzle-pipe interface is continuous. The restraint due to the latch between the two nozzles, the upper guide and the dog legs or lower guides is conservatively not included. At the interface between the FC base and the rail-dolly, the horizontal displacement along and perpendicular to the rail at each of the two guide cones is set to zero. All other contact points at the base of the FC were set to have no vertical movements [2,4]. This decision was guided by the previous information and judgement that the weak and flexible rail-dolly, if included in the model, will further amplify the FC response, and in turn will reduce the possibility of showing adequacy of the FC.

2.2.2.4 **Modal Combination**
The subspace iteration technique is applied to extract the natural frequencies and the corresponding characteristic mode shapes of the FC structure. For the purpose of efficiency and obtaining answers with reasonable engineering accuracy the number of eigenpairs requested is set to 30, the highest frequency of interest is 33.0 Hertz, the maximum number of iterations allowed is 20, the number of vectors used to define the subspace is 60, and the default tolerance is used (i.e., 1.0E-05).

The modal responses for all modes below 33 Hertz shall be combined according to the Square Root of Sum of Squares (SRSS) method [5].

The effect of higher modes with frequencies greater than or equal to 33 Hertz shall be computed and accounted for using the Zero-Period-Acceleration (ZPA) method which uses the ZPA to perform static analysis in each direction of seismic shock. The ZPA is the spectral acceleration at 33 Hertz unless a different frequency is justified.

The resultant response of all the lower modes below 33 Hertz shall be combined with the resultant response of all the higher modes using the SRSS procedure.

The three components of earthquake shock (two horizontal and the vertical) shall be considered to act simultaneously. The seismic response for each individual unidirectional shock shall be combined by the SRSS procedure to obtain the response due to three components acting simultaneously [2,5].

2.2.2.5 **Floor Response Spectra**
The floor response spectra for East-West Horizontal, North-South Horizontal, and Vertical accelerations (in terms of gravitation G) are given in graphic form [4] (see Figures 4-6). These spectra are carefully digitized (Table 2) and reproduced in graphic form for comparison (see Figures 7-10). The input acceleration in the building analysis, which generated the floor response spectra, was a 0.2G ZPA (Zero-Period-Acceleration) USNRC Regulatory Guide 1.60 Ground Spectra with an amplification factor of 2.0. This amplification factor of 2.0 was used to provide a margin for an increase of ground response spectra to a 0.3G ZPA, and to provide a seismic motion input at higher elevation (El. 66') on the inlet and outlet nozzles as well as to allow for the differences in the three reactors' analyses. Because of the different orientation in the L and P Reactors, the two Horizontal spectra are numerically enveloped, i.e., in the response spectra analysis the two horizontal spectral components will use the same enveloped spectrum. To obtain the floor response spectra corresponding to the 0.2G ZPA ground response spectra (in the building analysis), a reduction factor of 0.6667 (2/3) is applied to all the three components of the floor response spectra for this analysis.

2.3 Computer Dynamic Modal Response Spectrum Analysis

2.3.1 Test Runs

Several test runs were performed to check the capacity of the computer as well as the program ABAQUS. Detailed testing experiences are discussed in the Appendix A.

2.3.2 Dynamic Analysis of Full Model with MPC's

2.3.2.1 With the necessary MPC's implemented in the full model, the frequency analysis of this model indicated an increase in frequency as expected. The cut-off frequency is 33.0 Hertz. The Response Spectrum Analysis is performed up to 20 eigenmodes which includes the 33.0 Hertz mode. Again the results indicate that the maximum Von Mises stress in shell elements is still within 5.0 ksi. If ABAQUS could provide data combination (for stresses in elements and displacements and reaction forces at nodal points) from various output files, then the result would be combined (absolutely adding) with the Static Analysis. The Static analysis would use the same numerical model with static gravitational loads. The gravitational loads would be computed from the Spectral data at the cut-off frequency (i.e., 33.0 Hertz).

However, for the time being ABAQUS does not have the capability to do the combination and the tight schedule does not permit an in-house development of a post processing program. An alternative strategy is applied to solve this problem.

2.3.2.2 The calculation in 2.3.2.1 was repeated with additional input data. Various composite sections (besides simple sections) of beams (and columns) are used in this model, as it is almost impossible to compute the beam stresses precisely. The beam geometrical properties have been manually calculated [6]. In this run we also (based upon our best conservative engineering judgement) insert a list of the section points (see Table 3) for each beam section, at which beam stresses are recorded. The maximum beam axial stress in this calculation is 2,726 psi. and is in the floor of the FC.

2.3.2.3 By inspection of the frequency spectrum of the previous calculation we decided to include the first 26 [7] modes in the Response Spectrum Analysis. A few improvements are incorporated in this new model.

First, the interface between the exhaust pipe beam and the nozzle shell is connected through a couple of equations. In each of the equations, the motion of a node on the beam was made equal to the average motion (in the Y-Z plane) of eight nodal points on the nozzle shell in the same plane (includes the beam node). These equations provide continuity between the nozzle shell and the exhaust pipe beam. In the meantime, the beam can freely move (relative to the nozzle shell longitudinally and rotationally) in the axial direction.

Second, as we observed in the previous runs, the partially supported plenum flat plate absorbs most of the energy in the symmetric modes. The partially supported plate shows excessively large deflection (1.305 inches) and high stress concentration (4778.0 psi Von Mises stress) which are not necessarily realistic. In this model, we removed the partially supported flat plate in the plenum. Due to the removal of the flat plate, the fundamental frequency of the FC system moved up from 5.0929 Hertz to 14.925 Hertz. The frequency outputs from these two calculations are shown in Tables 6 and 7 respectively.

By including the first 26 modes in the Response Spectrum Analysis, this model contains a spectral frequency up to 41.579 Hertz which, according to the effective mass calculation, indicates that the system has at least 99% of the total effective mass participated in the response. The maximum Von Mises stress in shells reduced to 1453.0 psi (element number 351 which is at the top nozzle wall). The maximum axial stress in the floor beam increases a little to 2,739 psi.

In spite of the slight increase in maximum beam stress, the Von Mises stresses in shells in both runs (the models with and without the partially supported plenum flat plate) are very close to each other, except, of course, for the partially supported flat plate. Further examination of the Von Mises stress contours indicates that in the previous model all the high stresses in the shell elements are concentrated in the partially supported flat plate (plenum). It confirms that the new model calculation is at least as reliable as the previous one.

Figure 11 is a contour plot of Von Mises stress in shell elements in the whole structure. It indicates stress concentration in the nozzle shell elements. Figure 12, with the side wall shell elements removed, shows the stress concentration on the bottom of the FC at the location of the guide cones. Figure 13 shows a blowup in the stress concentration area of the upper nozzle wall.

For the beam elements, ABAQUS provides both sectional forces, moments, and sectional stresses. However, the stress calculation in ABAQUS is incorrect for the Response Spectrum Analysis. The sectional stresses for the beam elements are recalculated as follows:

1. For each type of beam, find the maximum sectional force component with respect to all the beams in this type. That is, the collection of all the six components of maximum sectional forces may not occur in any particular beam element, but certainly the collection will envelope all the maximum forces in this type of beam.

2. Divide axial force and the shear forces by the sectional area to obtain the axial stress and shear stresses, respectively, in the beam section.

3. Based on engineering judgement, the location of maximum stress in the beam section is determined by giving the local coordinates **x**, **y** with respect to the centroid of the section.

4. Defining $\mathbf{r=SQRT(x^2 + y^2)}$, torsional stress is then computed by taking torque times **r** and dividing by the torsional stiffness of the beam.

5. Add the torsional stress to the square root of the sum of squares of the shear stresses (in step 2) to obtain the combined shear stress.

6. Use conventional theory to compute the bending stresses in each direction (**x**, **y** are used properly)

7. Add the axial stress to the two bending stresses to obtain the combined axial stress.

8. Assuming minimum axial stress to be zero, the combined axial and shear stresses provide principal stress and maximum shear stress in the beam.

9. The calculation procedure as well as the final results for all types of beams used in this model are shown in Table 4.

The maximum principal stress in the beams is 2.74 ksi, and maximum shear is 2 ksi, both well below the yield strength.

2.3.3 Static Analysis (Gravitation)

For the purpose of evaluating the reasonableness of the boundary conditions between the base of the FC and the rail-dolly, i.e., zero vertical deflection, and for computing static response of the FC, the stress distribution due to dead weight is computed in this Static Analysis. The maximum Von Mises stress in the plenum shell element 6107 is 446.4 psi. The maximum shear stress in the upper side wall - horizontal I-beam (element 3484) with nodes 4676 and 4727 beams is 1468.0 psi. The maximum axial stress in a plenum beam (element 2198) with nodes 875 and 876 is 401.4 psi.

3. CONCLUSION AND SUGGESTIONS

3.1 Conclusion

The Finite Element Model of the Filter Compartment provides detailed simulation of the essential parts of the structure. Sophisticated modeling techniques are demonstrated in the modeling of curved shells, nozzle ribs, the connections between beams and columns and shells through MPC's and the partial continuity between the nozzle shells and the exhaust pipes which were modelled with beam elements. All these meticulous efforts are necessary for the integrity and preciseness of the numerical model. The first frequency, 14.925 Hertz, of the FC without the partially supported plenum plate is the consequence of the Boundary Conditions. The complete constraining of the FC base in the vertical direction and the connectivity between the nozzle walls and the exhaust pipes from the building wall make the vertical symmetrical modes as rigid body motions.

1. Overall the stresses in both the shells and beams are low.

   * Maximum Von Mises stress in shells:

Dynamic with 26 modes:	1,453.0 psi
Static with dead weight:	446.4 psi
Total	1,899.4 psi

* Maximum Shear stress in beams:

Dynamic with 26 modes:	1,962.0 psi
Static with dead weight:	1,468.0 psi
Total	3,430.0 psi

* Maximum principal stress in beams

Dynamic with 26 modes:	2,738.5 psi
Static with dead weight:	401.4 psi
Total	3,139.9 psi

These stresses are well below the limiting stress i.e., 90% of the yield stress. The lowest shear strength is 90% of 6,000 psi, or 5,400 psi. Note that the Von Mises stress in the partially supported plenum flat plate is also less than 5,000 psi.

The fundamental frequency of this model is 14.925 Hertz which is beyond the frequencies where peak accelerations occur in the floor response spectra. The peak of the vertical spectrum is maintained at 5.35 G within the frequency range from 8.4 to 12.4 Hertz. The peak of the enveloped horizontal floor response spectrum has a value of 6.4 G within the frequency range from 3.8 to 6.0 Hertz. The vertical component with a wide peak range could cause a tremendous impact upon the FC. However, the vertical motion of the FC is severely restricted by the boundary conditions. The effective mass of the vertical component in the frequency analysis is only about 3% of that of the horizontal components. Therefore the influence of the vertical floor response spectrum to the FC is considerably diminished.

The horizontal modes certainly dominate the seismic activity of the FC, yet for frequencies beyond 12.8 Hertz the enveloped horizontal floor response spectrum shows the acceleration of 1.13 G which is only 17.7% of the peak value, 6.4 G.

The low stress level in this calculation as compared with the previous analysis (even though these are completely two different approaches, this one is dynamic while the previous calculation was static) is mainly due to different loading and boundary conditions.

2. Based upon the mass density used in this analysis, the total weight of the FC is 21,155 pounds. At the base of the FC there are 215 nodal points which are vertically constrained to the rail-dolly. Eight nodes,

as the guide cones, are also constrained in horizontal directions to the rail-dolly.

The pressure distribution over the base cannot be uniform. Listed here is the vertical pressure distribution over the 215 nodes on the FC base (see Table 5). Table 5 lists, for every base node, the maximum reaction force during a seismic event, the reaction force from the dead weight, and the difference between the two reactions. For clarity, the difference of the reactions is also separated into two columns, the positive force implies uplifting, whereas the negative force implies down-holding. The total dead weight is 22,565 pounds which is slightly heavier than the weight calculated from mass, probably due to numerical inaccuracy (about 6.7%).

Without special devices to fasten the base of the FC to the rail-dolly and the rail-dolly to the roof of the building, as assumed in this analysis, the FC will certainly have uplift during the seismic events. In Table 5, it shows that among the 215 base nodes, 81 nodes have down-holding dead weight reaction forces larger than the the dynamic uplifting forces, specially at those nodes in the vicinity of the carbon filter rack, where the dead weight reaction forces are much stronger than the dynamic forces. Nevertheless, the 113 base nodes with uplifting reaction forces will be detached from the rail-dolly if fastening devices are not provided at those nodes. At the moment a node is detached from the rail-dolly, the reaction force at that node is reduced to zero and the dynamic force at that node will be redistributed to other nodes which still have down-holding reaction forces over the dynamic forces. This reaction force redistribution process will continue over all the 215 base nodes. If the total dead weight were heavier than the total dynamic forces, there would be no uplifting or overturning for the FC. However, the total dead weight of the FC is only 22,565 lbs, whereas the total dynamic force is about 35,642 lbs. Because of the uneven distribution of the reaction forces, the total uplifting forces (17,482 lbs) is almost four times that of the down-holding forces (4,405 lbs). This explains why the FC will be tossed by the seismic events.

3. Maximum Dynamic Displacements

Dx = 0.1137 inches	Node 2233	the plenum
Dy = 0.0773 inches	Node 2051	middle of roof
Dz = 0.0374 inches	Node 5174	mid of sidewall

4. Maximum Dead Weight Displacements

Dx = 0.0451 inches	Node 2051	middle of roof
Dy = 0.0971 inches	Node 2051	middle of roof
Dz = 0.0017 inches	Node 662	top of side wall

It is interesting to observe that the maximum vertical displacement (Dy) from the dynamic analysis (0.0773 in.) is smaller than that from the static analysis (0.0971 in.). Apparently, the high vertical spectral acceleration (5.35 G) has little effect upon the FC. In the frequency analysis, it indicates that the vertical component of the motion has only 2% of the total vertical effective mass (1.5 mass unit which is approximately 3% of the horizontal component) in the first mode (14.925 Hertz). At this frequency the vertical spectral acceleration is 1.94 G. The next significant contribution is from the sixth mode with frequency 25.114 Hertz, at which the vertical spectral acceleration is only 0.93 G. Assuming the contribution from the sixth mode and the rest of the higher modes is 98%, then the total vertical spectral acceleration will be: 0.02 * 1.94 + 0.98 * 0.93 = 0.9502 G. In this analysis a reduction factor (0.6667) was applied. Consequently, the total effective vertical spectral acceleration is about 0.6335 G which is only 63% of the gravitation (while the calculation shows that the vertical dynamic displacement is about 80% of the static. Apparently the rest 17% of the vertical dynamic displacement is contributed by the horizontal modal components) . Therefore in this analysis, the vertical dynamic response is less than the static response.

Since the effective mass of the vertical component is so low (only 3% of that of the horizontal component), it is justified to carry out the equivalent static analysis for the spectral loading beyond the cut-off frequency, viz., 33.0 Hertz. The ZPA of the vertical spectrum at 33.0 Hertz is 0.81 G. With the reduction factor 0.6667 specified in this calculation, the actual ZPA becomes 0.54 G. The static dead weight responses were computed with 1.0 G vertical gravitation load. Therefore the corresponding dynamic responses to the 0.54 G ZPA can be obtained by multiplying the static responses by the factor 0.54. Adding 54% of the vertical static responses to the dynamic results, the final dynamic responses are as follows:

* Maximum Von Mises stress in shells:

Dynamic with 26 modes:	1,694.1 psi
Static with dead weight:	446.4 psi
Total	**2,140.5** psi

* Maximum Shear stress in beams:

Dynamic with 26 modes:	2,754.7 psi
Static with dead weight:	1,468.0 psi
Total	**4,222.7** psi

* Maximum principal stress in beams

Dynamic with 26 modes:	2,955.3 psi
Static with dead weight:	401.4 psi
Total	**3,356.7** psi

Maximum Dynamic Displacements

Dx = 0.1163 inches	Node 2233	the plenum
Dy = 0.1297 inches	Node 2051	middle of roof
Dz = 0.0374 inches	Node 5174	mid of sidewall

As suggested by Reference [7], the dynamic responses were obtained through the response spectrum analysis with the first 26 eigenmodes included. According to the frequency analysis (see Table 7) only the first 13 eigenmodes are needed to cover the frequency spectrum up to 33.0 Hertz. In the dynamic modal spectrum analysis, therefore, 13 additional eigenmodes beyond the cut-off frequency 33.0 Hertz were augmented. As far as the vertical components are concerned the superposition of 54% of the static responses is quite conservative.

After the adjustment of the dynamic responses due to the ZPA effect the dynamic reaction forces at the base of the FC increase significantly and the uplifting situation of the FC during a seismic event is worse. The number of down-holding nodes is reduced from 81 to 34. The total dynamic reaction force increased from 35,642 lbs. to 47,828 lbs.

3.2 Suggestions

The stress distribution and deformation of the FC are functions of the stiffness, mass distribution, and boundary conditions. In this scoping analysis the Plenum modeling is conservative but not as detailed as the rest of the model. Including the conceptual modification with heavy beams and columns in this model made the FC much stiffer and increased its fundamental frequency.

To have an understanding of the seismic capacity of the existing as-built FC, an analysis without the conceptual modification should be considered. This recommendation will provide an assessment of the seismic ruggedness of the existing FC. Also, as the results of the present model analysis indicate, the stress level and deformation are quite low. The existing FC with the same boundary conditions as the present model may be able to sustain the seismic excitations.

Since the overall stress and deformation of this model is low, and the actual base boundary condition does not hold every point to the rail-dolly as prescribed, a relaxation in boundary constraints, inclusion of nonlinear interfaces in the model, and a nonlinear dynamic time history analysis may be more realistic for the "as is" FC.

REFERENCES

1. Communications between DuPont and WSRC Engineers:
    1. May 8, 1987
        To: S. R. Norbutas (AED)
        From: J. M. Cahill (Allstates)
    2. December 2, 1987
        S. F. Petry: Filter Compartment Seismic Resistance.
    3. March 15, 1988
        To: R. S. Varney (AED/Allstates)
        From: J. M. Cahill (AED/Allstates)
    4. April 20, 1988
        To: R. D. Kelsch (AED)
        From: R.S. Varney (A/S)
    5. May 18, 1988
        To: R. D. Kelsch (AED)
        From: G. J. Tsavalas (AED)
    6. May 19, 1988
        To: A. C. McCullin / L. Golden (AED)
        From: R. D. Kelsch (AED)
    7. June 17, 1988
        To: G. C. Cambre
        From: R. J. Thomas / J. M. Cahill (A/S)
    9. November 16, 1989
        To: K. M. Vashi (WSRC)
        From: J. M. Cahill (DuPont)

2. March 20, 1990. Inter-Office Memorandum
    To: Chung Gong
    From: K. M Vashi

3. Shop drawings: BPF 211147, drawing number FD-405-001 to 026.

4. June 29, 1990. Inter-Office Memorandum
    To: Chung Gong
    From: K. M. Vashi

5. Seismic Qualification Program, Savannah River Site Reactor Facilities, Program Plan and Procedures, January 1990, Seismic Engineering, WSRC.

6. Chung Gong: Geometric Properties of cross-sections of Beams and Columns in the Seismic Analysis of Filter Compartment.

7. August 7, 1990. Inter-Office Memorandum EPD-SE-90-0018:63
To: Chung Gong
From: Ed Estochen

References [2], [4] and [7] are attached to this report in Appendix B.

ACKNOWLEDGEMENT

Dr. Kiranchandra M. Vashi of Seismic Engineering, suggested this problem and the general technical approaches in solving this problem as indicated in his memoranda [2], [4]. We sincerely appreciate his contribution in the analysis.

APPENDIX A

A.1 Test Runs

A.1.1 A complete half model with fixed base was used for testing the computer capacity and ABAQUS's reliability in Frequency Analysis. Several unanticipated problems arose when ABAQUS jobs were submitted. Initially, the UNICOS script file which submits ABAQUS jobs on the CRAY had to be optimized to handle the large memory requirements of this model. This took place only after a lengthy troubleshooting period. When this problem was solved, CPU intensity of the analysis emerged as a severe problem. This was affected by the large amount of input/output activity required by the model. A bug in the PATRAN to ABAQUS translator had added to this problem by translating the beam properties incorrectly. The approximately 60 unique properties were being translated into approximately 550 different property sets. The resolution of this problem required the creation of a supplementary FORTRAN program to compare these values and output a list of property sets which could be combined. This combination had to be done manually. A few successive runs indicated that ABAQUS was able to carry out the Frequency Analysis. Most of all, the test run produced confidence that even though the model was only half the real model, it was sufficient in structural details. The fundamental frequency was 2.3 Hertz which is quite reasonable under the given boundary conditions.

A.1.2 In this second test run, we adopt the same half model as was previously used. However, the boundary conditions are more realistic. The bottom of the FC is vertically restrained except at the location of the Guide Cone where the node is fixed in all three directions. The center plane which separates the whole model in halves along the two nozzle axes is prescribed with symmetric boundary conditions with respect to the Z-axis that is normal to the side walls of the FC. The nozzles are allowed to slide and rotate along their axes but otherwise they are continuous with the exhaust pipes from the reactor building wall.

The first three frequencies, namely 5.0918, 13.181, and 14.991 Hertz correspond to the first three symmetric modes. In this run, the Response Spectrum Analysis was performed to provide useful reference data for the Full Model Analysis.

A.1.3 **Dynamic Analysis of Full Model without MPC's**

This is the first complete FC finite element model with all the details except the MPC's which connect the shell elements with the beam and column elements. The calculation provides satisfactory results. This analysis virtually recaptures the symmetric modes obtained in the half model calculation. The Von Mises stresses in shell elements are well below 5 ksi.

APPENDIX B

3/20/90

TO:

DR. CHUNG GONG
SRL-773-42A

FROM: KIRAN VASHI
SEISMIC ENGINEERING

SUBJECT: GENERAL ANALYSIS REQUIREMENTS FOR CONFINEMENT FILTER

ENCLOSED PLEASE FIND A DOCUMENT ON THE REFERENCED SUBJECT. THIS DOCUMENT IS TO BE FOLLOWED IN THE FILTER DYNAMIC MODELLING AND ANALYSIS WORK THAT YOU ARE DOING FOR SEISMIC ENGINEERING. IF YOU HAVE ANY QUESTIONS, PLEASE CALL ME.

TRULY YOURS,
K.M.Vashi
7-9071

CC: M.W. BARLOW, 703-25C
R. BECKMEYER, SRL-773-42A

DRAFT

GENERAL ANALYSIS REQUIREMENTS
FOR
CONFINEMENT FILTERS

BY

KIRAN M. VASHI

MARCH 6, 1990

TABLE OF CONTENTS

1. INTRODUCTION

This document provides general analysis requirements for Savannah River Site (SRS) confinement filters. The filters are part of an Airborne Activity Confinement System (AACS). These filters absorb a significant amount of radioactive effluents in case of an incident before exhausting the filtered air to the atmosphere via the stack. The purpose of the analysis is to ascertain the seismic adequacy of the filters for a 0.2g Design Basis Earthquake (DBE).

2. SCOPE

The document specifies general analysis requirements for the SRS filters. The requirements encompass modelling, use of computer codes, modal response spectra analysis, modal combination, damping and output.

3. SEISMIC ANALYSIS

3.1 METHOD

The confinement filter shall be analyzed by the modal response spectrum method using the ABAQUS computer program.

3.2 MODELING

For the modal response spectrum method of analysis, a mathematical dynamic finite element model of the as-constructed (or as-built) filter shall be developed to represent and simulate dynamic interaction of the nozzles, outer shell, upper and lower compartments, filter frames, filters, access doors and supports system. The model shall be prepared with a sufficient amount of detail to permit evaluation of stresses in members of the confinement filter, loads in supports and possibility of effluent bypass around the filters. The model shall account for the following:

- Stiffness
- Mass
- Damping
- Boundary Conditions

These parameters shall be derived from the basic material properties, design and construction characteristics, drawings and other applicable documents and specifications.

3.2.1 STIFFNESS

The stiffness characteristics of various component parts of the filter shall be calculated using the applicable drawings. The component parts shall be represented by the appropriate finite elements of the ABAQUS program.

3.2.2 MASS

The mass properties shall be represented by the lumped mass and associated rotational inertia ← discretized at the nodes of the model. Alternatively, or in conjunction with the lumped mass approach, consistent mass formulation may be used.

Mass shall be lumped so that the total mass, and the location of the center of gravity are preserved both for the structure and its components. The number of dynamic degrees of freedom and hence the number of lumped masses shall be selected so that all modes of vibration with frequencies less than 33HZ are accurately accounted for.

3.2.3 DAMPING

In the modal spectra analysis of the filter, the seismic response spectra for 3% (Table 2.2-2 on page 10 of SEP-1 in Ref.1) modal damping shall be used. Modal interpolation shall use the specified scale on the spectrum plot (e.g. log-log,log-lin, lin-log, lin-lin).

3.2.4 BOUNDARY CONDITIONS

The model shall incorporate appropriate representation of constraints imposed on the boundary due to conical guides, nozzles, anchor hook, upper guide plate and other imposed boundary conditions.

3.3 MODAL RESPONSE SPECTRUM METHOD

3.3.1 UNIDIRECTIONAL SHOCK

Modal spectra seismic analysis shall be performed for each individual unidirectional shock as follows.

3.3.1.1 Multiply Supported System

Since the filter is seismically excited at multiple input points, the envelope of the spectra at all attachment points shall be used

3.3.1.2 Number of modes to be considered.

Modal responses for all modes below 33HZ shall be included in computing the resultant response.

3.3.1.3 Modal Combination

The modal responses for all modes below 33HZ shall be combined using the square-root-sum-of-squares (SRSS) procedure (paragraph E on page 6 of SEP-1 in Ref. 1).

3.3.1.4 Effect of Higher Modes

The effect of higher modes with frequencies greater than or equal to 33HZ shall be computed and accounted for using the Zero-Period-Acceleration (ZPA) method which uses the ZPA to perform static analysis in each direction of seismic shock. The ZPA is the spectral acceleration at 33HZ unless a different frequency is justified.

3.3.1.5 Combination of Responses from Lower and Higher Frequency Modes.
The resultant response of all lower modes from section 3.3.1.3 shall be combined with the resultant response of all higher modes from 3.3.1.4 using the SRSS procedure.

3.3.2 Combination of Earthquake Components
The three components of earthquake shock (two horizontal and the vertical) shall be considered to act simultaneously. The seismic response from section 3.3.1.5 for each individual unidirectional shock shall be combined by the SRSS procedure to obtain the response due to three components acting simultaneously.

4. ABAQUS COMPUTER PROGRAM

Controlled, verified and validated version of ABAQUS shall be used. The analysis results shall be certified to document use of such a version of the ABAQUS code.

5. DOCUMENTATION OF MODEL AND ANALYSIS RESULTS

The finite element model shall be validated and documented in terms of definition of nodes, elements and element and material properties. The input for the model shall be preserved and supplied in the form of plots, and data on hard copy and magnetic tape for future use. A general description of the model and its documentation shall be also provided.

The analysis results shall be documented in terms of the list and and purpose of runs, and validation of computer runs and the results. The results shall be supplied in the form of frequencies, mode shapes, stresses, displacements and forces and moments in the elements representing the structural members and supports of the filter.

6. REFERENCES

1. Seismic Qualification Program, Savannah River Site Reactor Facilities Program Plan and Procedures, January 1990, Seismic Engineering, WSRC.

OSR 3-4A-W (Rev 1-89)

WESTINGHOUSE SAVANNAH RIVER COMPANY

INTER-OFFICE MEMORANDUM

ENGINEERING AND PROJECTS DIVISION
SYSTEMS ENGINEERING DEPARTMENT

EPD-SE-90-0010:61

DATE: JUNE 29, 1990

TO: DR. CHUNG GONG, SRL

FROM: K. M. VASHI, 703-25C, 7-9071 K.M.V.

SUBJECT: SEISMIC ANALYSIS INPUT FOR FILTERS

With respect to the filters seismic analysis, this letter documents the analysis input as follows:

A. Weights of Filters
see Attachment #A

B. Seismic Spectra
see Attachment #B

* Please multiply the spectral accelerations in Attachment B by a factor of 0.6667 before inputting them to the model.

Please note the North (N) direction is perpendicular to the two rails for K and P reactors and is parallel to the two rails for L reactor. Therefore, to perform one conservative generic analysis for all three reactors, please envelope the spectra for North(N)-South(S) and East(E)-West(W) directions and then apply the resulting envelope spectrum in each of the two horizontal (ie. N-S and E-W) directions.

C Distance of Filter from Wall
Mr. R. Scherr has confirmed that the correct distance between the face of the wall and face of the filter is 6'3".

D. Boundary Conditions
* For each of the two nozzles at the nozzle-pipe interface, the translational displacement along the nozzle axis and the rotation about the nozzle axis are discontinuous. Rest of the

degrees of freedom at this interface are to be modelled as if the nozzle-pipe interface is continuous.

* For conservatism and linearization purposes, the restraint due to latch between the two nozzles, the upper guide and the dog legs (lower guides) is not to be included.

* At the interface between the filter base and rail-dolly the horizontal deflections along and perpendicular to the rails at each of the two guide cones is to be set to zero.

* Based on preliminary indication and for linearization purposes, the filter base locations, at which vertical deflection is to be set to zero, are as shown on Attachment C.

If you have any questions, please call me.

KMV/jb

cc: Roy Funderburk, SRL
Russ Beckmeyer, SRL
M. W. Barlow, 703-25C
R. Scherr, 707-C
M. E. Maryak, 703-25C
G. A. Antaki, 703-24C
R. S. Hoskins, 703-24C

ATTACHMENT # A

Westinghouse Savannah River Company
Inter-Office Memorandum

OPS-RSE-901264

June 20, 1990

To: Kirhan Vashni

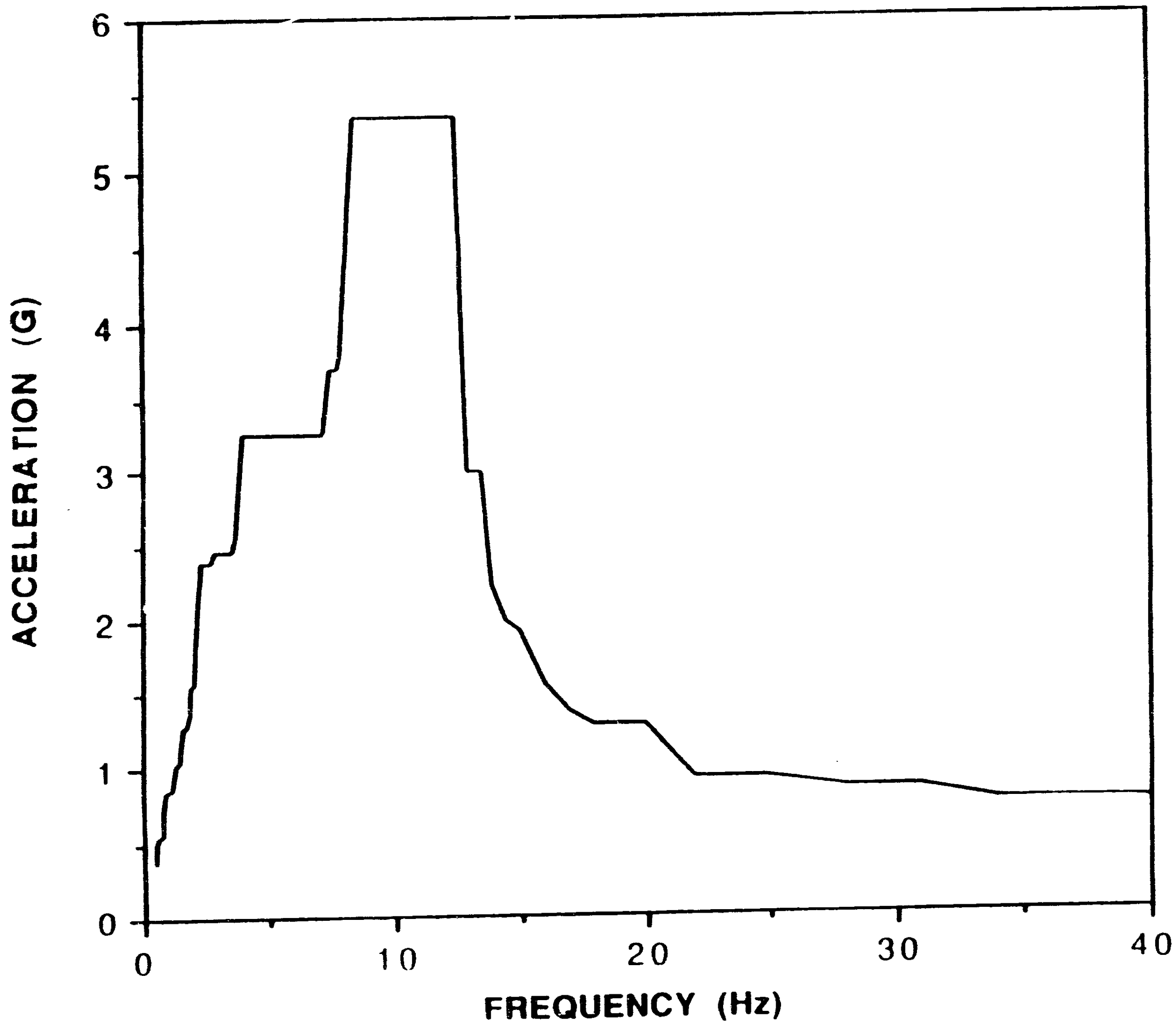
From: Rod W. Scherr

Weight of Filter Compartment Components

Component	SOURCE OF INFORMATION	VALUE
Carbon cell	Vendors QA Report	140 lbs
Particulate flt	Shipping Weight	50 lbs
Demister cell	Call to vendor	11 lbs

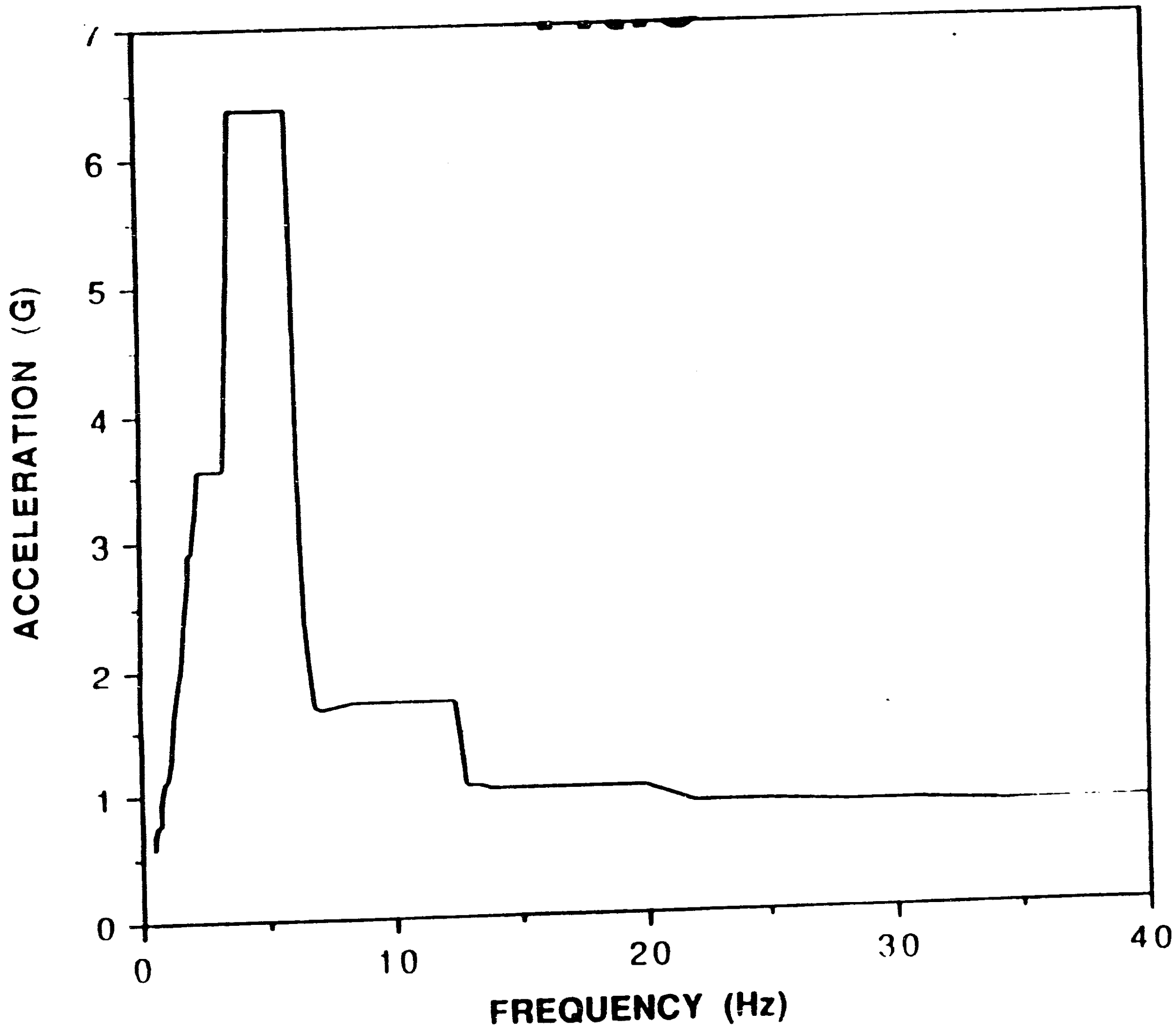
Attachment .
SE-SE-90-307
Page 3 of 3

PRELIMINARY SPECTRA FOR AACS FILTER COMPARTMENTS K,L, AND P 105 EXHAUST STACK, VERTICAL SMOOTHED FLOOR RESPONSE SPECTRA 3% DAMPING

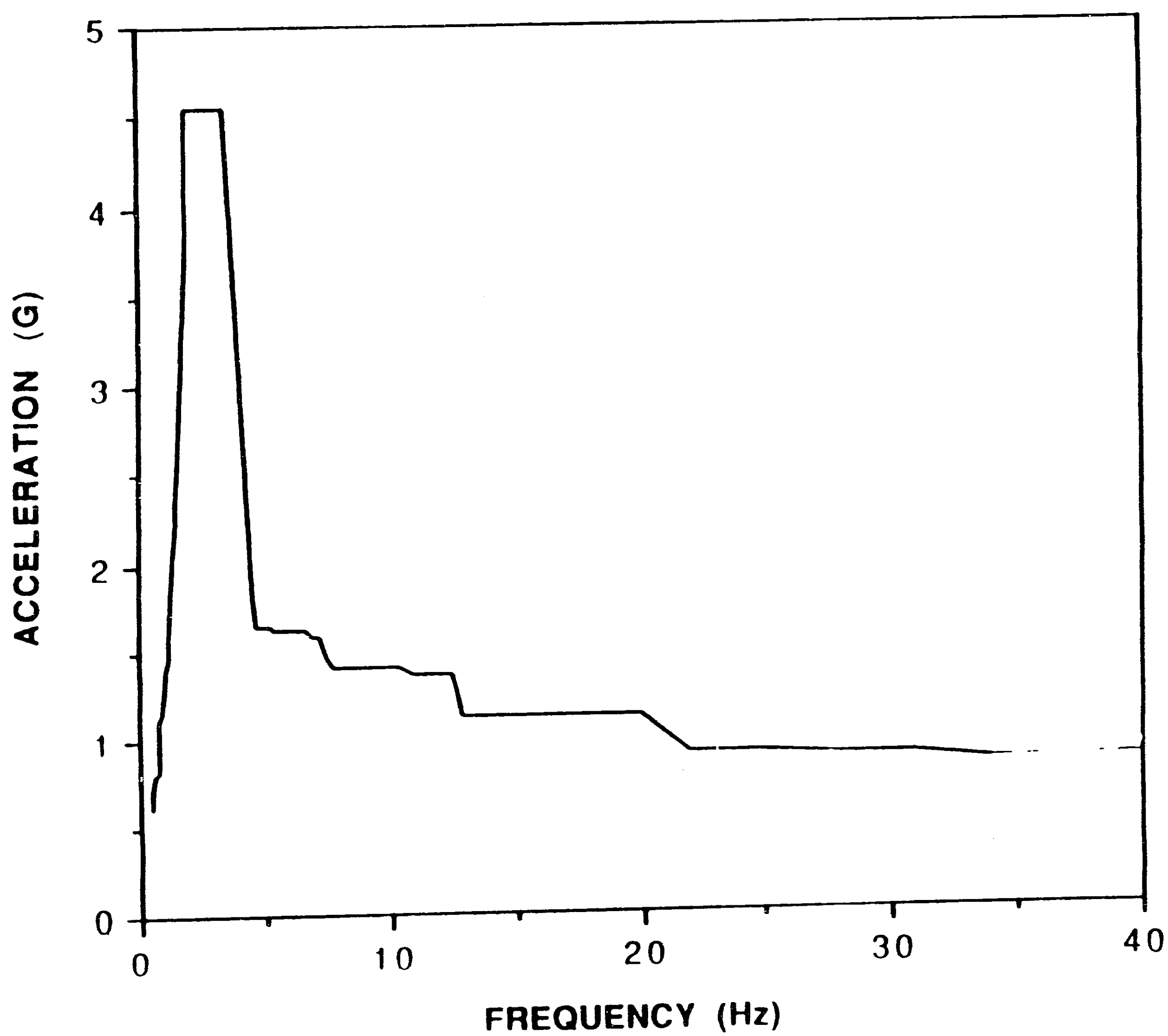


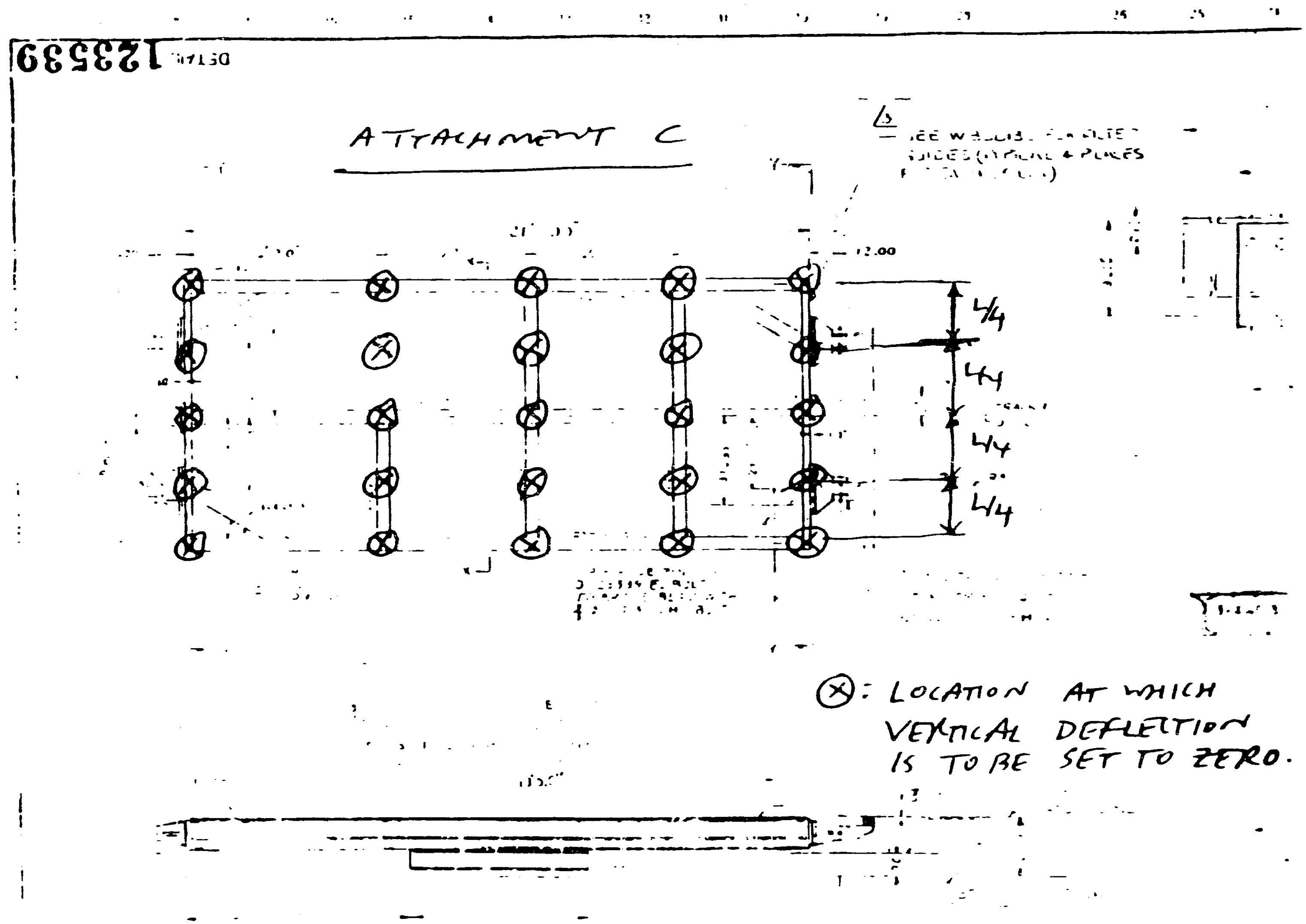
Attachment
SE-SE-90-307
Page 1 of 1

PRELIMINARY SPECTRA FOR AACS FILTER COMPARTMENTS K,L, AN P 105 EXHAUST STACK, E-W SMOOTHED FLOOR RESPONSE SPECTRA 3% DAMPING



PRELIMINARY SPECTRA FOR AACS FILTER COMPARTMENTS K, L, AND P 105 EXHAUST STACK, N-S SMOOTHED FLOOR RESPONSE SPECTRA 3% DAMPING




123539
DETAIL
ATTACHMENT C
12.00
L/4
L/4
L/4
L/4
⊗: LOCATION AT WHICH VERTICAL DEFLECTION IS TO BE SET TO ZERO.

ATTACHMENT B

WSR 3-4A-W (Rev 1-89)

WESTINGHOUSE SAVANNAH RIVER COMPANY

INTER-OFFICE MEMORANDUM

SE-SE-90-307

May 10, 1990

To: Stan Petry, SRL (773-41A)

From: R.S. Hoskins, (703-24C) RSH

AACS FILTER COMPARTMENTS

As agreed upon in our meeting of March 3, 1990 on the subject, the three attachments to this letter provide you with the information you need to set the requirements for the filter compartment.

* The first attachment presents the amplified floor response spectra for E-W Horizontal, N-S Horizontal, and Vertical accelerations at El. 55' for the 105-K Stack Building. The input was a 0.2g ZPA. R.G. 1.60 Ground Spectra with an amplication of factor 2.0. being applied. A amplication factor of 2.0 was used to provide margin for a potential increase of the ground response spectra to a ZPA = 0.3g, a seismic motion input at a higher elevation (El.66') on the inlet & outlet nozzles, and the differences in the response spectra in L & P Reactors. This assures the spectra given will envelope all possible contingent cases for the filters.

The second attachment presents SEP-22 which invokes IEEE-344-1987 as the seismic qualification methodology standard to be used. This procedure provides the exceptions to the standard permitted for the SRS Reactors.

The third attachment is provided for information purposes explaining the approach used by SRL for performing a finite element analysis using the ABAQUS Computer Code.

The fourth attachment provides the seismic qualification approach to be used for the redesign of the filter housings.

If you have any questions regarding this matter, please feel free to contact me at x7-6422 for help on this subject.

CC: M.W. Barlow, 703-25C
G.A. Antaki, 703-24C
File 16.8

Attachments

* NOTE: ONLY ATTACHMENT 1 TO THIS LETTER IS ENCLOSED

OSR3-4A-W(Rev1-89)

WESTINGHOUSE SAVANNAH COMPANY

INTER-OFFICE MEMORANDUM

ENGINEERING & PROJECTS DIVISION
SYSTEMS ENGINEERING DEPARTMENT

EPD-SE-90-0018:63

DATE: August 7, 1990

TO: Chung Gong SRL

FROM: Ed Estochen BTC-B15

It is not necessary to do an equivalent static run, using the filter compartment finite element model, to obtain the higher mode participation. Including more modes in the spectral analysis will satisfactorily duplicate the combination of the dynamic stresses with the equivalent static component representing the contribution from the higher modes. The number of modes included should be such that at least 90% of the filter compartment's total mass is participating in the response. Per our meeting (8/6) approximately 40 of 45 (88%) total filter mass units were participating in the response due to the inclusion of 19 modes. If the number of modes is increased from 19 to 25, the 90% requirement should be met. If after this increase the requirement is still not met, continue to increase the number of contributing modes until more than 40.5 of the total 45 mass units are participating. This dynamic analysis should be performed on the initial model, for which stresses have already been obtained, before pursuing an analysis using the updated PATRAN model. The desired results from this analysis are the maximum stresses in the beam elements for which the "section points" were specified. These results should be directed to myself and Dick Hoskins at your earliest convenience.

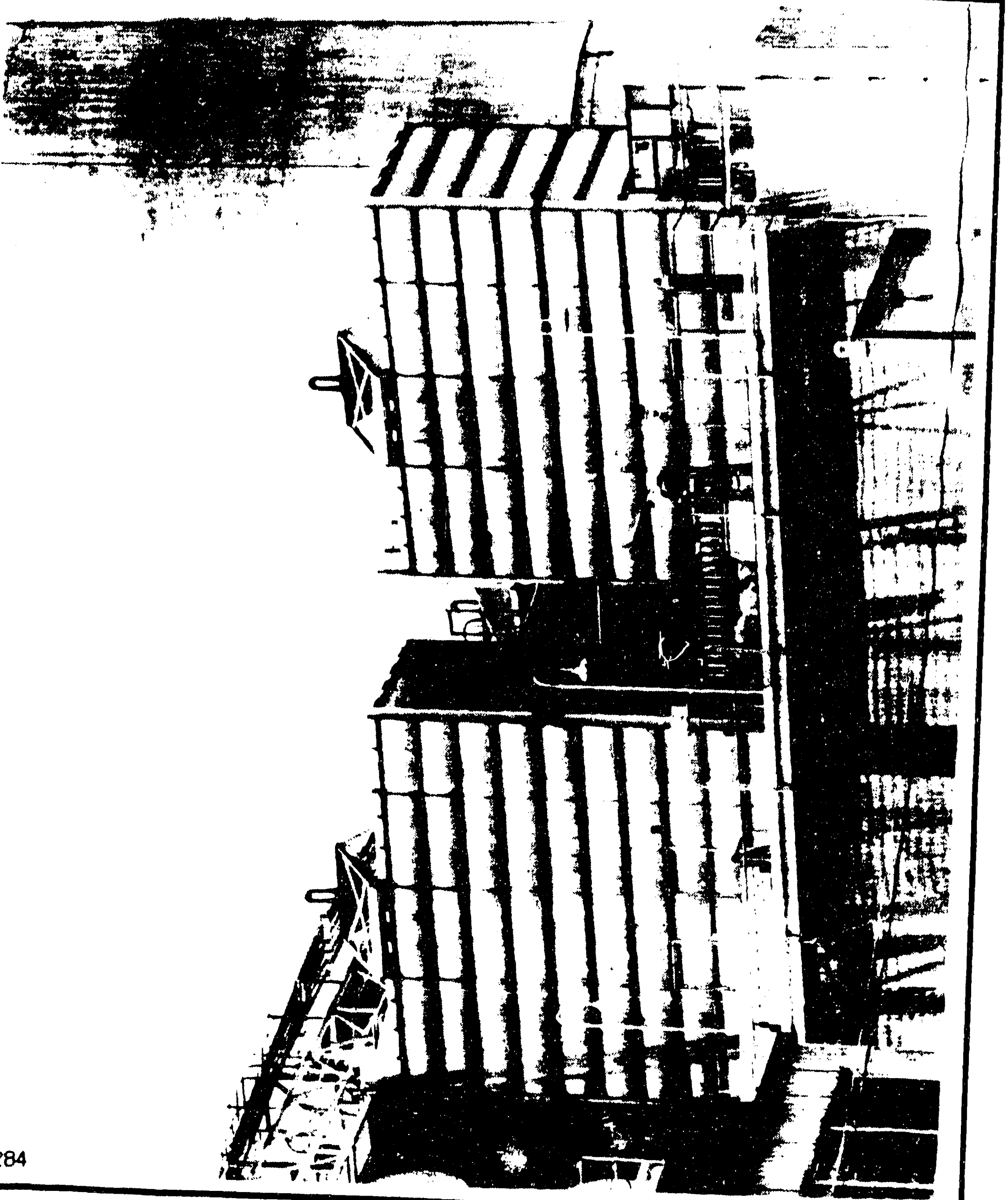
I appreciate you patience and perseverance and hope that this modeling strategy will facilitate the project's completion.

cc:

R. Hoskins, 703-24C
B. Gutierrez, 703-41A
M. Barlow, 703-25C
W. Kennedy, BTC-B15
K. Vashi, 703-25C
R. Beckmeyer, 773-42A
File 16.8

FIGURES

Reactor Air Filters



0284

Figure 1

Computer Application Technology

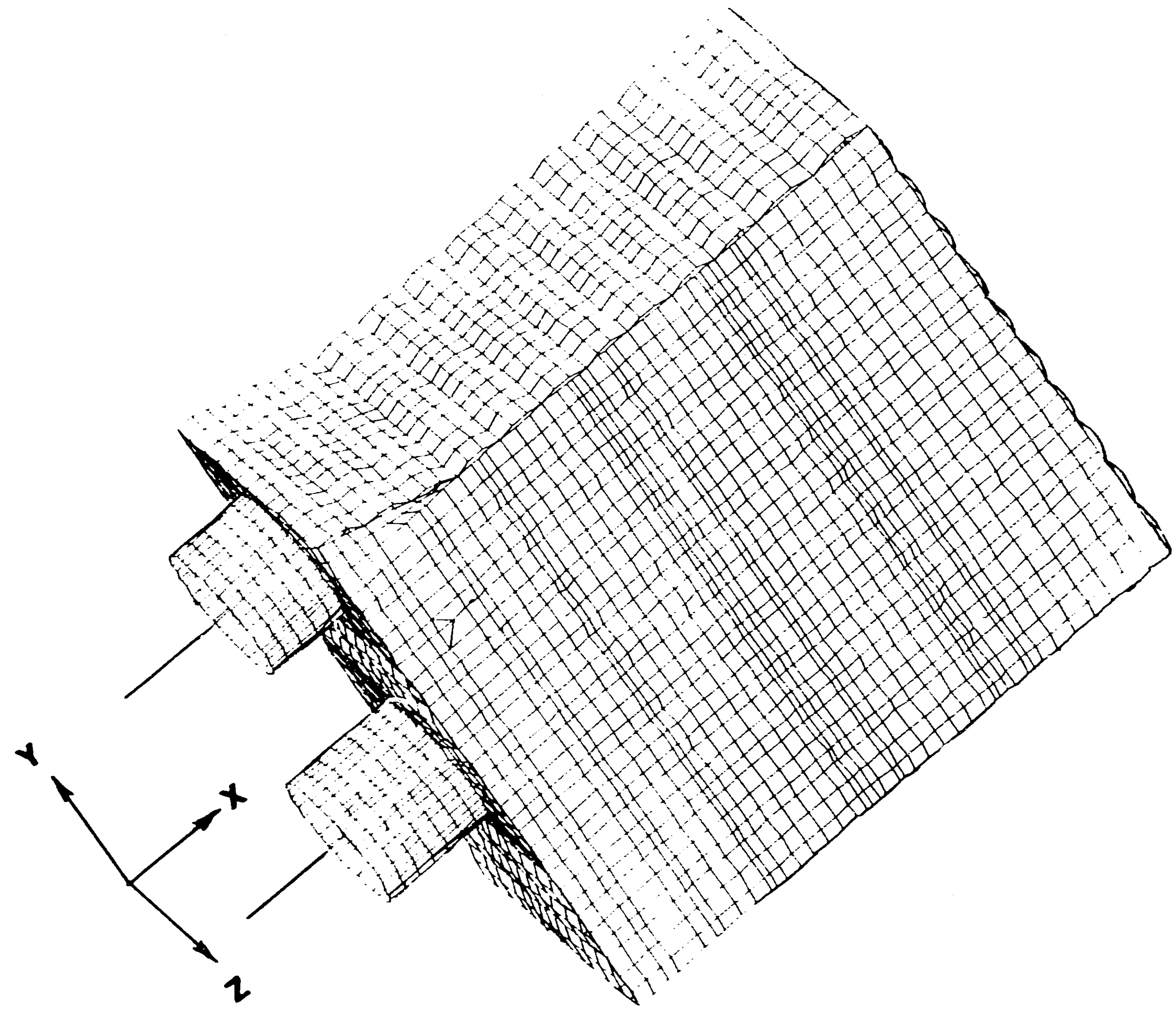


Figure 2

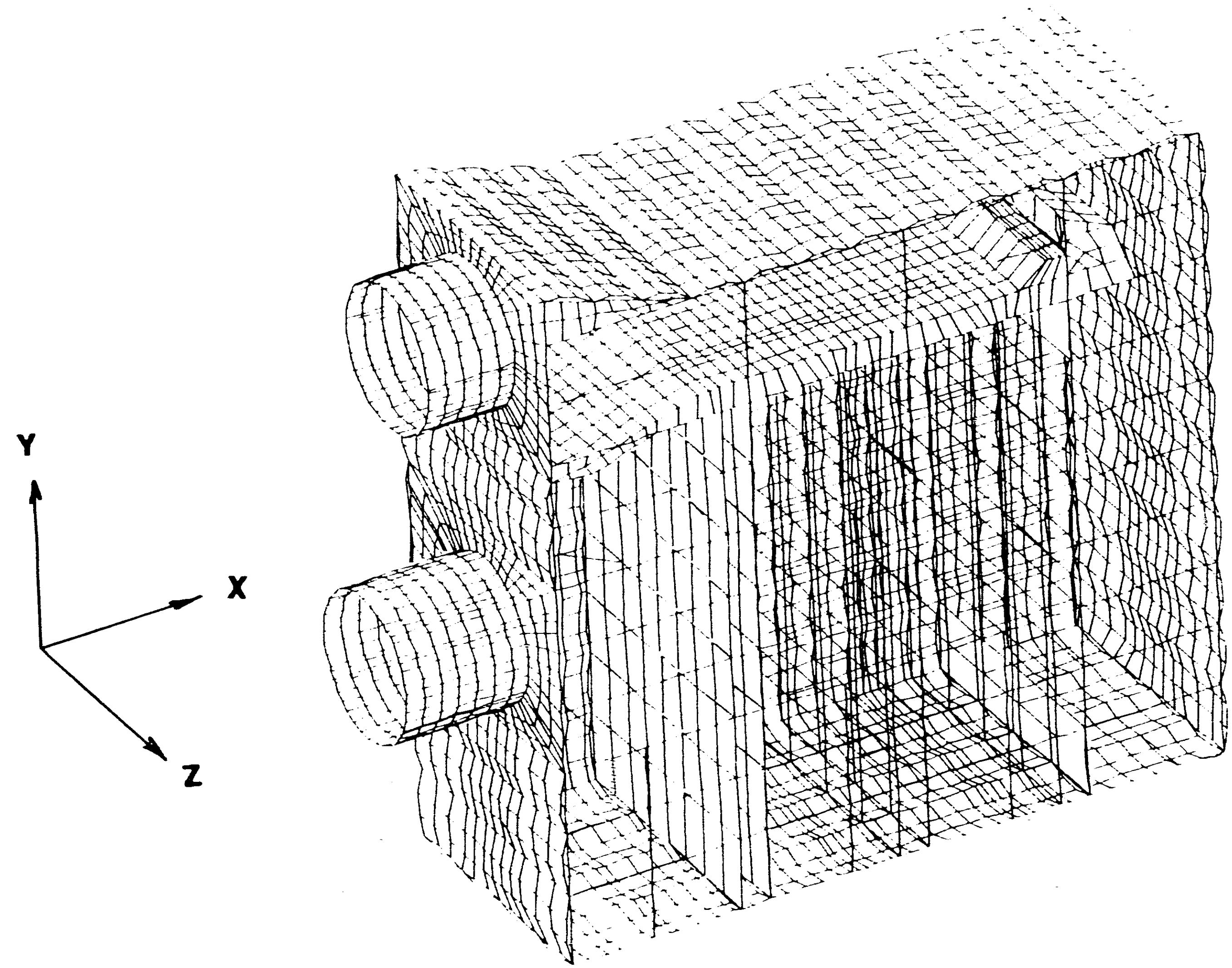


Figure 3

PRELIMINARY SPECTRA FOR AACS FILTER COMPARTMENTS K,L, AND P 105 EXHAUST STACK, VERTICAL SMOOTHED FLOOR RESPONSE SPECTRA 3% DAMPING

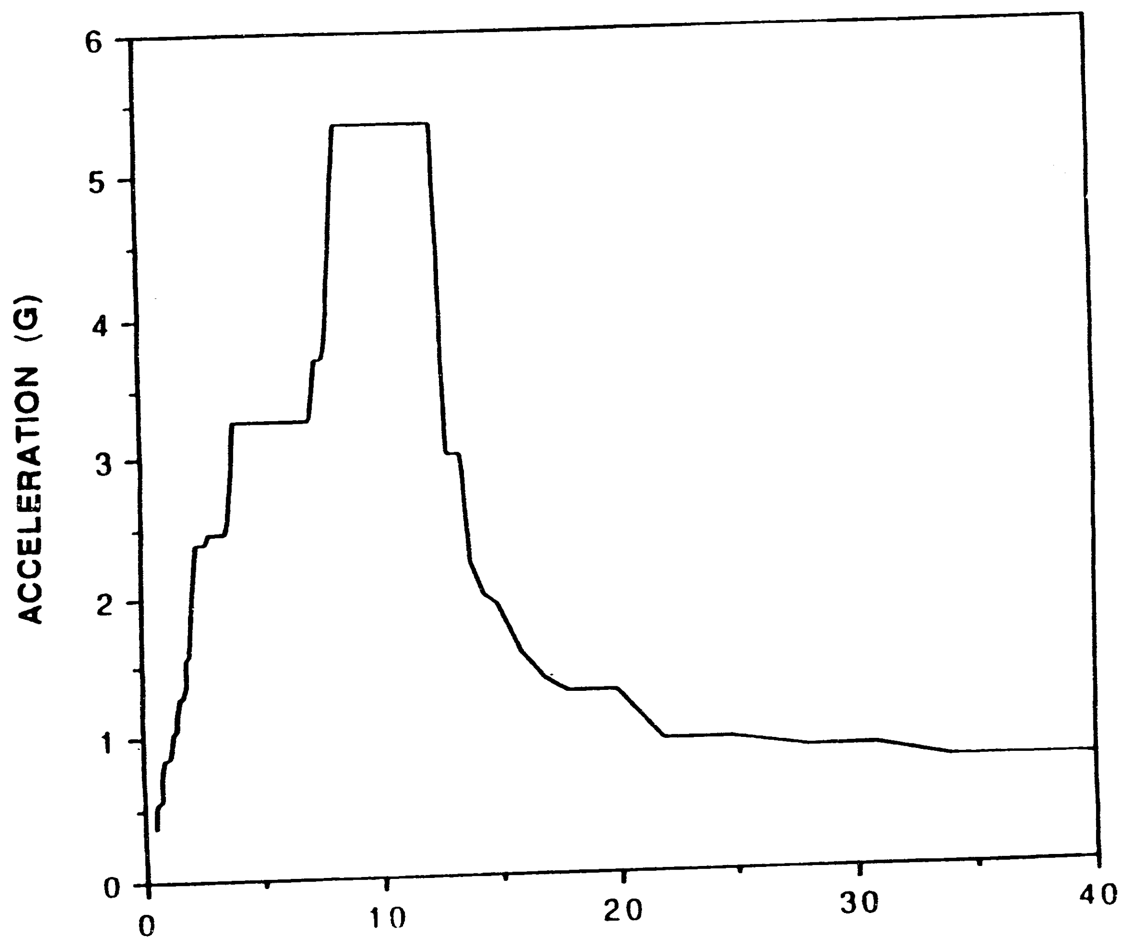


Figure 4

PRELIMINARY SPECTRA FOR AACS FILTER COMPARTMENTS K,L, AN P 105 EXHAUST STACK, E-W SMOOTHED FLOOR RESPONSE SPECTRA 3% DAMPING

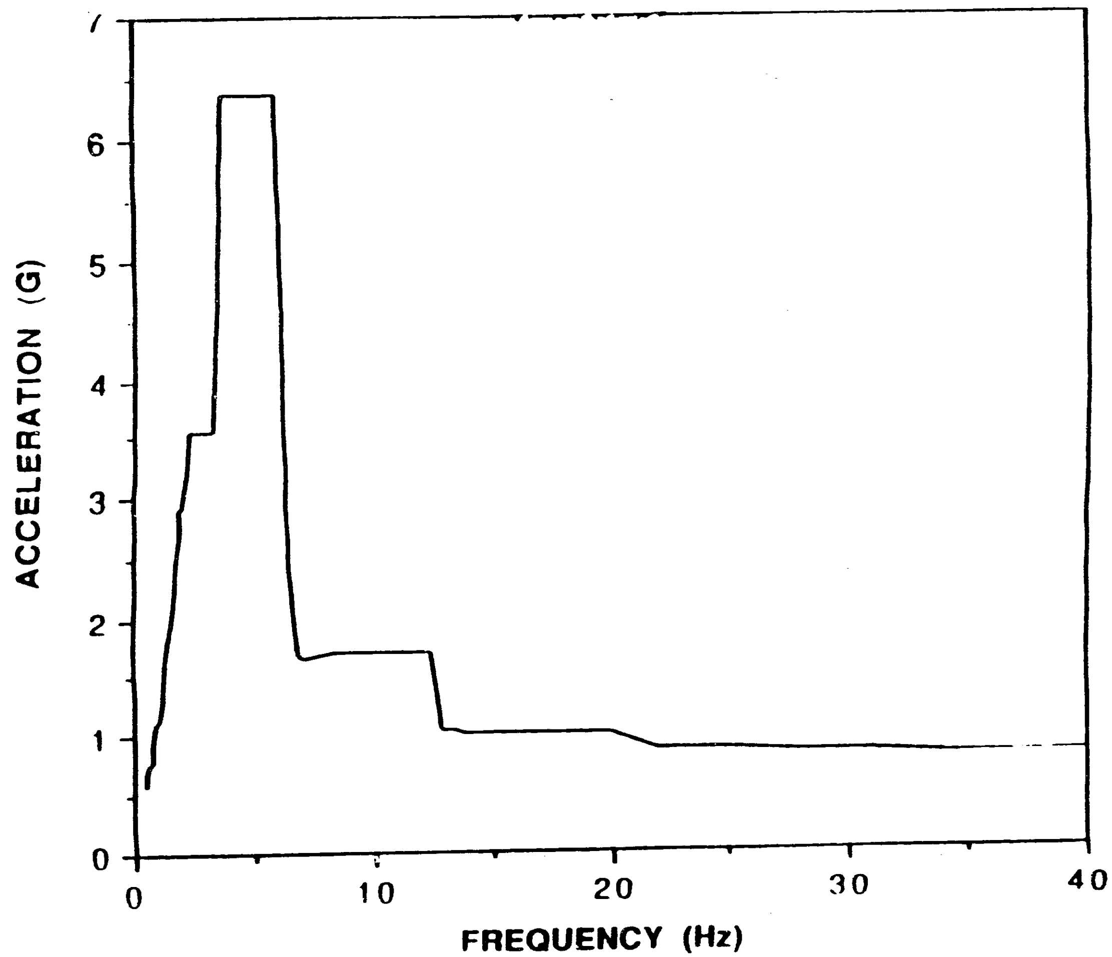


Figure 5

Attachment :
SE-SE-90-307
Page 2 of 3

PRELIMINARY SPECTRA FOR AACS FILTER COMPARTMENTS K, L, AND P 105 EXHAUST STACK, N-S SMOOTHED FLOOR RESPONSE SPECTRA 3% DAMPING

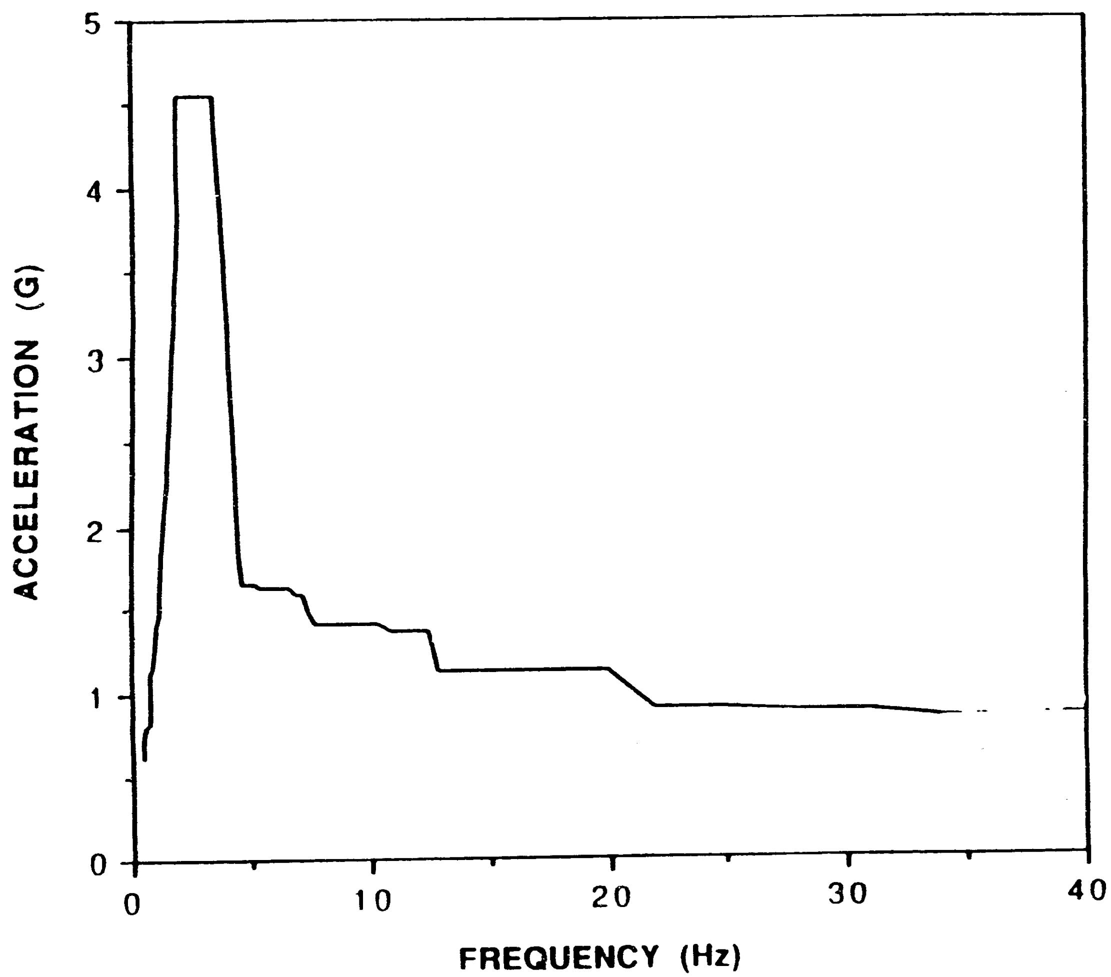


Figure 6

Digitized Vertical Smoothed Floor Response Spectrum

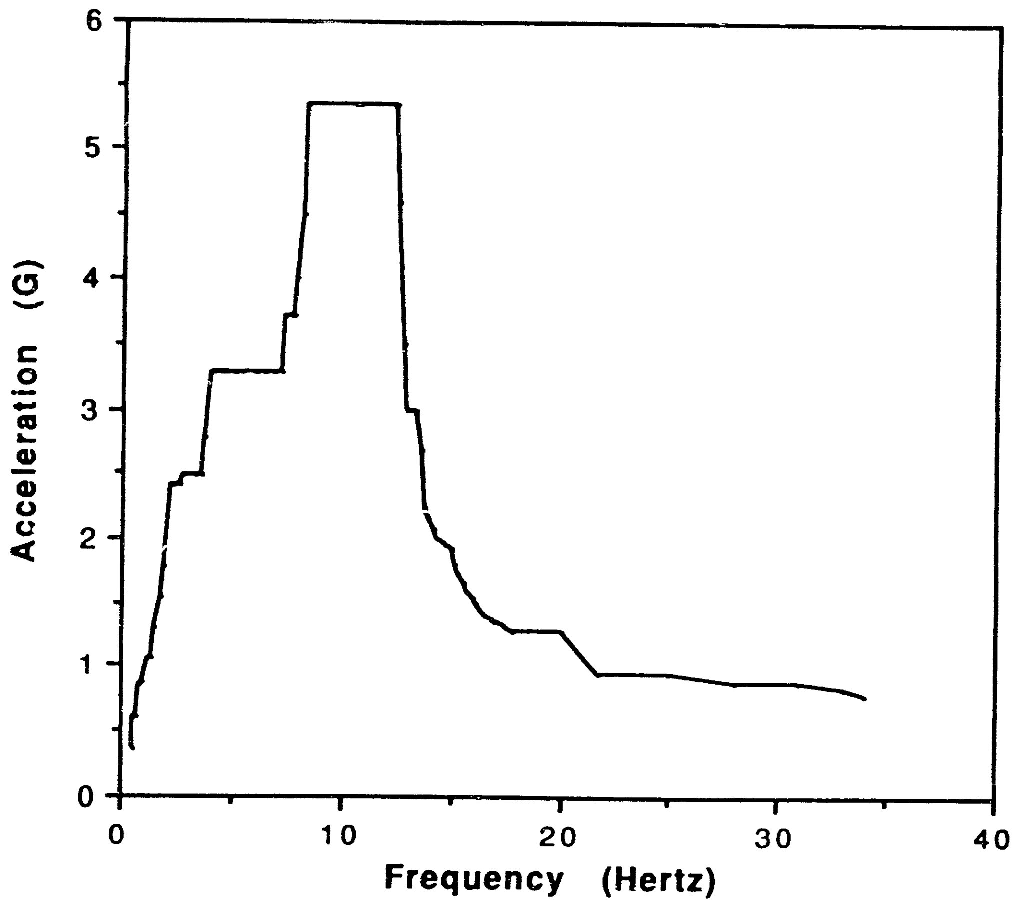
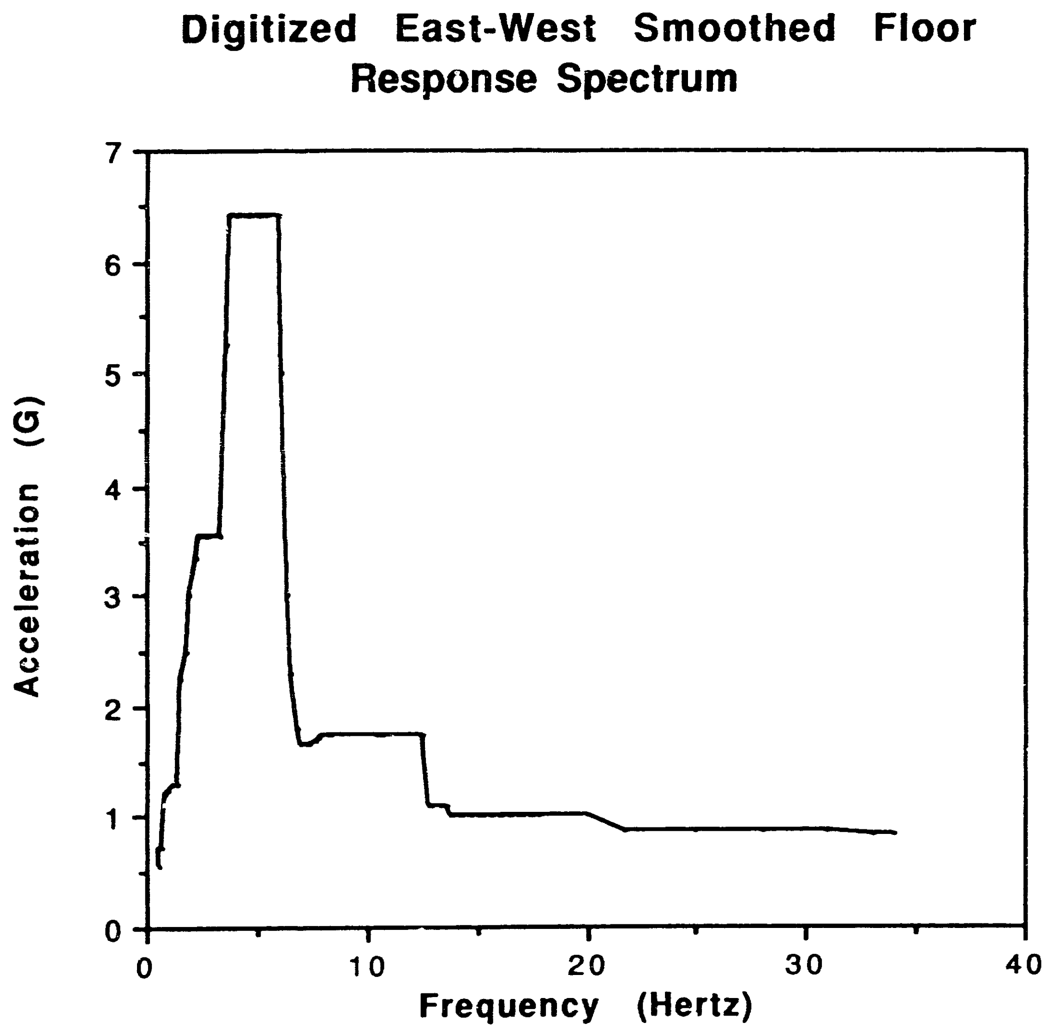


Figure 7



Digitized East-West Smoothed Floor Response Spectrum
Acceleration (G)
0
1
2
3
4
5
6
7
0
10
20
30
40
Frequency (Hertz)

Figure 8

Digitized North-South Smoothed Floor Response Spectrum

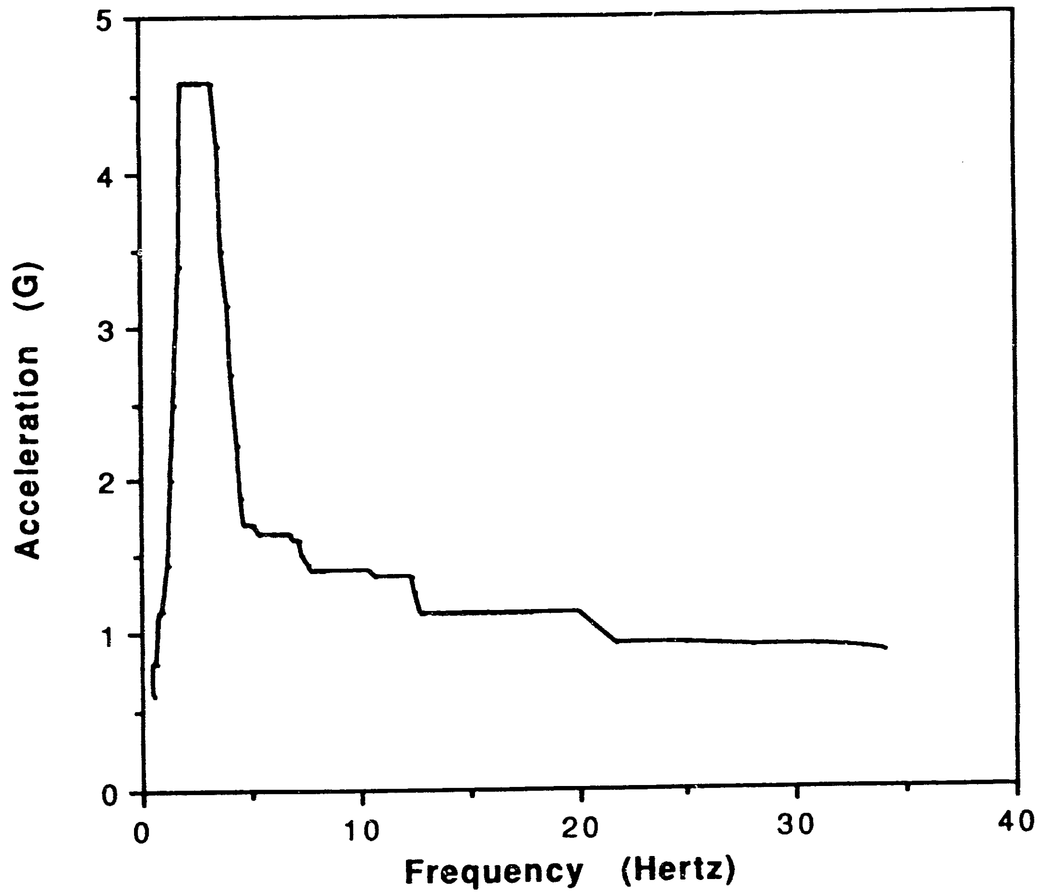


Figure 9

Envelope of the Digitized East-West and North-South Floor Response Spectra

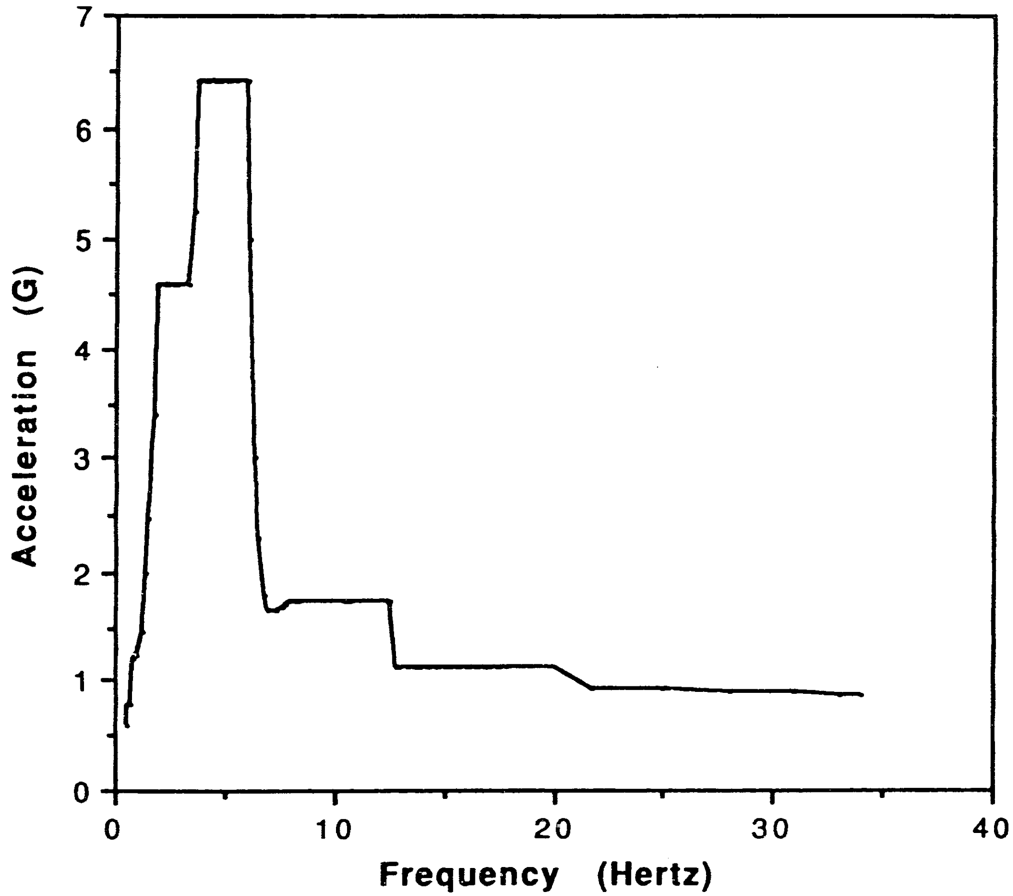


Figure 10

VON MISES STRESS IN SHELL ELEMENTS

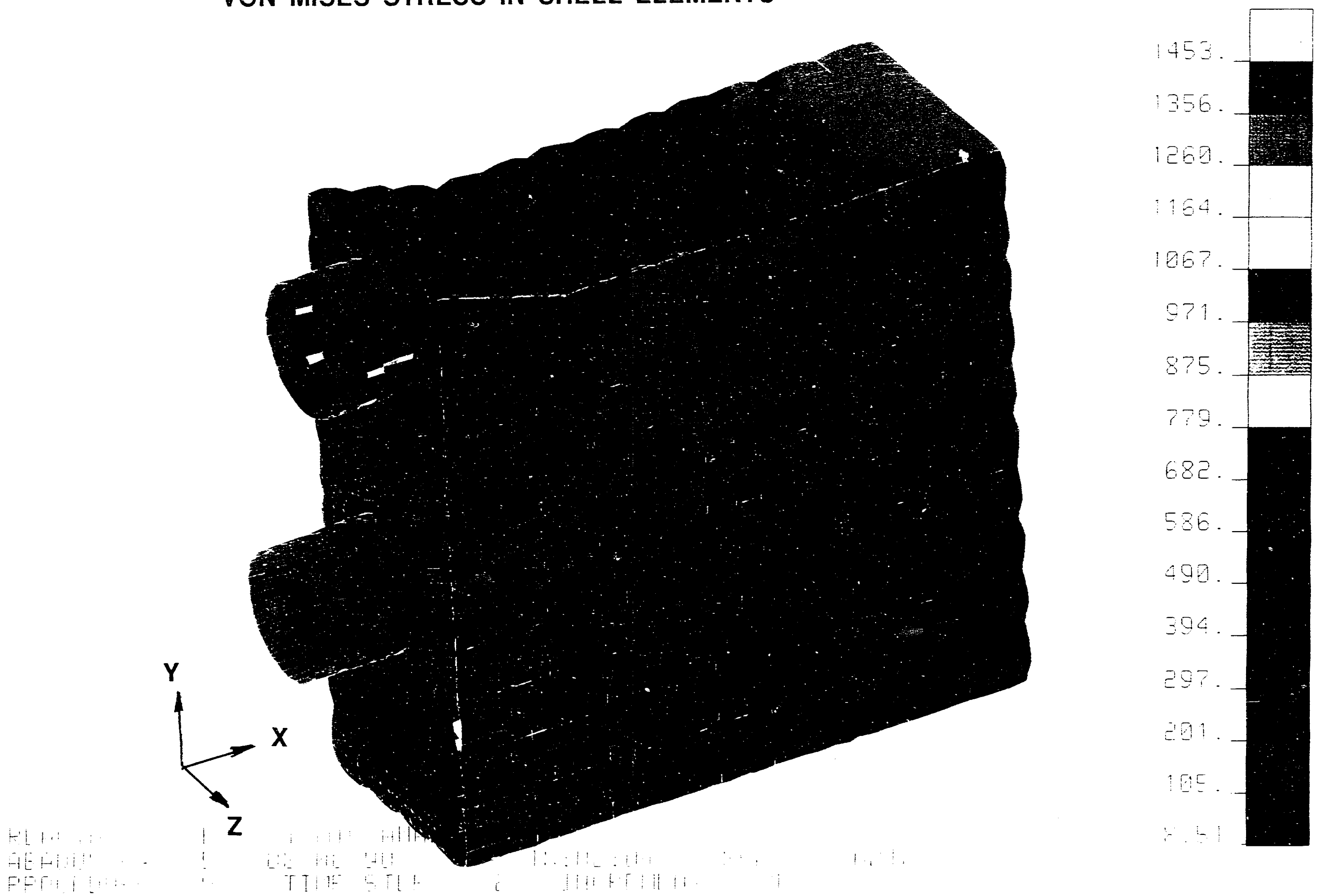


Figure 11

VON MISES STRESS IN SHELL ELEMENTS

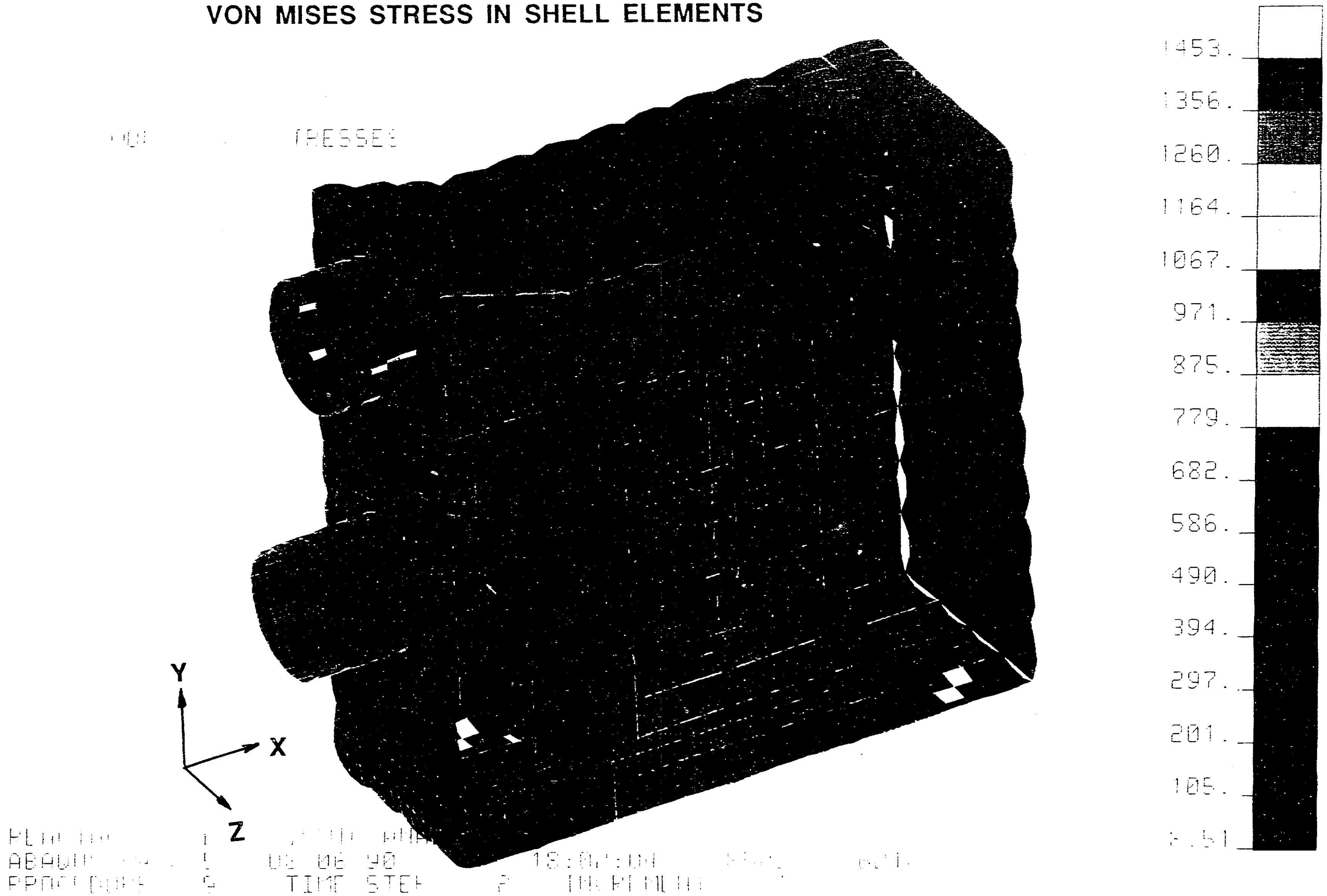


Figure 12

VON MISES STRESS IN SHELL ELEMENTS

Figure 13

TABLES

Table 1 SECTIONAL PROPERTIES

MEMBER NUMBER	SHAPE	AREA INCH**2	Ixx INCH**4	Iyy INCH**4	J INCH**4	MATERIAL ALUMINUM	PAGE
1	SIMPLE-I	1.766	4.309	0.037	0.156	6061-T6	1
2	SIMPLE-T	1.711	0.673	0.476	0.031	6061-T6	2
3	SIMPLE-Ia	2.156	8.728	0.182	0.058	6061-T6	4
4	T and BAR	1.836	0.673	0.486	0.031	6061-T6	5
5	HALF-T	1.398	0.662	0.203	0.023	6061-T6	7
6	HALF-T-BAR	1.523	0.662	0.214	0.023	6061-T6	10
7	HALF-T-L	1.628	0.682	0.224	0.024	6061-T6	11
8	2HALF-T-L-B	3.152	1.344	0.438	0.047	6061-T6	12
9	2-L-1X1	0.460	0.042	0.042	0.003	6061-T6	13
10	BAR	1.406	0.046	0.593	0.150	6061-T6	14
11	2-BAR	2.813	0.092	1.186	0.301	6061-T6	14
12	L-6X4-Ixy	4.740	16.950	6.010	0.420	6061-T6	15
13	2-I-BAR	4.469	4.522	4.376	0.138	6061-T6	16
14	2-I-BAR-L	7.319	11.672	6.306	0.279	6061-T6	17
15	HALF-Ia	1.883	6.887	0.089	0.047	6061-T6	18
16	2-HALF-Ia	3.766	13.773	0.179	0.094	6061-T6	20
17	SIMPLE-I-B	2.703	4.485	0.068	0.246	6061-T6	21
18	NOZZLE-TOP	15.156	19.030	53.578	4.946	6061-T6	22
19	NOZZLE-BTM	10.000	1.302	53.333	4.639	6061-T6	24
20	HALF-Ia-BAR	11.883	1.391	60.220	4.686	6061-T6	25
21	DOOR-FRAME	6.313	0.775	8.080	2.383	6061-T6	26
22	2-L-6X4 BOX	9.480	33.900	12.020	0.840	6061-T6	15
23	2-L-DOOR-FR	16.793	34.680	21.433	3.244	6061-T6	29
24	DR-FR-BOTTM	13.631	12.447	14.386	2.662	6061-T6	31
25	DR-FR-TOP	8.078	0.812	12.389	2.540	6061-T6	32
26	L-6X4-PLT-Ixy	5.740	16.955	7.343	0.441	6061-T6	36
27	2-L-BOX-PL	10.480	33.905	13.353	0.861	6061-T6	37
28	2-SIMPLE-I	3.531	8.618	0.074	0.313	6061-T6	38
29	DR-FR-BTT-R	10.781	5.297	12.456	3.271	6061-T6	39
30	NOZZLE RIB	3.438	8.665	0.112	0.412	6061-T6	40
31	DR-FR-Half T	7.711	0.978	8.741	2.406	6061-T6	28
32	2-I-BAR-RT14	7.319	6.306	11.672	0.279	6061-T6	17
33	DOOR-FR-RT21	6.313	8.080	0.775	2.383	6061-T6	26
34	2-L-DR-FR-RT23	16.793	21.433	34.680	3.244	6061-T6	29
35	DR-FR-BT-RT24	13.631	14.386	12.447	2.662	6061-T6	31
36	DR-FR-TP-RT25	8.078	12.389	0.812	2.540	6061-T6	32
37	DR-FR-TP-RT31	7.711	8.741	0.978	2.406	6061-T6	28
38	BAR-4"X1"	4.000	5.333	0.333	1.124	6061-T6	46
39	SIMPLE-I-BAR	4.766	4.371	9.037	0.406	6061-T6	47
40	BAR-6"X0.5"	3.000	0.063	9.000	0.250	6061-T6	47
41	L-6X4-P-R26-Ixy	5.740	7.343	16.955	0.441	6061-T6	36
42	DR-FR-BTT-R-Y	10.781	12.456	5.279	2.521	6061-T6	49
43	2-I-BAR-RT13	4.469	4.376	4.522	0.138	6061-T6	16
44	SIMPLE-Ia-RT3	2.156	0.182	8.728	0.056	6061-T6	4
45	SIMPLE-Ia-PLT	3.641	4.543	8.736	0.089	6061-T6	50

Table 1 SECTIONAL PROPERTIES

MEMBER	SHAPE	AREA	Ixx	Iyy	J	MATERIAL	PAGE
NUMBER		INCH**2	INCH**4	INCH**4	INCH**4	ALUMINUM	
46	2-HALF-Ia-RT16	3.766	0.179	13.773	0.094	6061-T6	20
47	2-SIMPLE-Ia	4.313	8.911	8.911	0.115	6061-T6	51
48	T-PLATE	2.789	2.344	0.482	0.053	6061-T6	52
49	T-DEEP-PLATE	1.897	0.486	0.673	0.031	6061-T6	53
50	RACK-BAR	0.625	0.020	0.052	0.050	6061-T6	55
51	2-RACK-BARS	1.250	0.041	0.104	0.099	6061-T6	55
52	2-HALF-T	3.152	0.438	1.344	0.047	6061-T6	56
53	SIMPLE-T-RT2	1.711	0.476	0.673	0.031	6061-T6	2
54	WF-5"	5.672	23.813	7.832	0.266	6061-T6	78
55	WF-8"	9.281	115.188	33.558	0.435	6061-T6	79
56	PLENUM BAR	4.000	5.333	0.333	1.124	3003-H-16	84
57	MOD-T & RKBAR	3.297	4.236	0.913	0.175	6061-T6	88
58	NOZZLE-BEAM	44.768	18181.630	18181.630	36363.260	3003-H112	89
	Ixy = 5.769 in**4						

Table 2 SPECTRA

	A	B	C	D	E	F
1	PRELIMINARY SPECTRA FOR FILTER COMPARTMENT					
2						
3	POINT	FREQUENCY	VERTICAL	EAST-WEST	NORTH-SOUTH	E-W & N-S
4		HERTZ	G	G	G	G
5						
6	1	0.50	0.37	0.55	0.60	0.60
7	2	0.55	0.60	0.73	0.80	0.80
8	3	0.70	0.60	0.73	0.80	0.80
9	4	0.80	0.85	1.20	1.13	1.20
10	5	1.00	0.87	1.25	1.14	1.25
11	6	1.20	1.05	1.28	1.45	1.45
12	7	1.40	1.07	1.30	2.00	2.00
13	8	1.60	1.30	2.25	2.48	2.48
14	9	1.80	1.55	2.50	3.40	3.40
15	10	2.00	1.78	3.00	4.58	4.58
16	11	2.20	2.40	3.35	4.58	4.58
17	12	2.40	2.40	3.55	4.58	4.58
18	13	2.60	2.40	3.55	4.58	4.58
19	14	2.80	2.48	3.55	4.58	4.58
20	15	3.40	2.48	3.55	4.58	4.58
21	16	3.60	2.48	5.25	4.18	5.25
22	17	3.80	2.78	6.40	3.50	6.40
23	18	4.00	3.28	6.40	3.13	6.40
24	19	4.20	3.28	6.40	2.70	6.40
25	20	4.40	3.28	6.40	2.22	6.40
26	21	4.60	3.28	6.40	1.88	6.40
27	22	4.80	3.28	6.40	1.71	6.40
28	23	5.00	3.28	6.40	1.71	6.40
29	24	5.20	3.28	6.40	1.71	6.40
30	25	5.40	3.28	6.40	1.64	6.40
31	26	6.00	3.28	6.40	1.64	6.40
32	27	6.20	3.28	5.00	1.64	5.00
33	28	6.40	3.28	3.00	1.64	3.00
34	29	6.60	3.28	2.30	1.64	2.30
35	30	6.80	3.28	1.80	1.64	1.80
36	31	7.00	3.28	1.66	1.60	1.66
37	32	7.20	3.28	1.65	1.60	1.65
38	33	7.40	3.72	1.66	1.50	1.66
39	34	7.60	3.72	1.70	1.44	1.70
40	35	7.80	3.72	1.72	1.41	1.72
41	36	8.00	4.00	1.74	1.41	1.74
42	37	8.20	4.50	1.74	1.41	1.74
43	38	8.40	5.35	1.74	1.41	1.74
44	39	10.40	5.35	1.74	1.41	1.74
45	40	10.60	5.35	1.74	1.39	1.74
46	41	10.80	5.35	1.74	1.37	1.74
47	42	12.40	5.35	1.74	1.37	1.74

Table 2 SPECTRA

	A	B	C	D	E	F
48	43	12.60	4.60	1.74	1.27	1.74
49	44	12.80	3.50	1.10	1.13	1.13
50	45	13.00	3.00	1.10	1.13	1.13
51	46	13.40	3.00	1.10	1.13	1.13
52	47	13.60	2.68	1.10	1.13	1.13
53	48	13.80	2.24	1.00	1.13	1.13
54	49	14.00	2.16	1.00	1.13	1.13
55	50	14.20	2.08	1.00	1.13	1.13
56	51	14.40	2.00	1.00	1.13	1.13
57	52	14.60	1.98	1.00	1.13	1.13
58	53	14.80	1.95	1.00	1.13	1.13
59	54	15.00	1.93	1.00	1.13	1.13
60	55	15.20	1.80	1.00	1.13	1.13
61	56	15.40	1.73	1.00	1.13	1.13
62	57	15.60	1.66	1.00	1.13	1.13
63	58	15.80	1.58	1.00	1.13	1.13
64	59	16.00	1.55	1.00	1.13	1.13
65	60	16.20	1.50	1.00	1.13	1.13
66	61	16.40	1.43	1.00	1.13	1.13
67	62	16.60	1.40	1.00	1.13	1.13
68	63	16.80	1.38	1.00	1.13	1.13
69	64	17.00	1.36	1.00	1.13	1.13
70	65	17.20	1.34	1.00	1.13	1.13
71	66	17.40	1.32	1.00	1.13	1.13
72	67	17.60	1.30	1.00	1.13	1.13
73	68	17.80	1.28	1.00	1.13	1.13
74	69	20.00	1.28	1.00	1.13	1.13
75	70	21.80	0.93	0.88	0.92	0.92
76	71	25.00	0.93	0.88	0.92	0.92
77	72	28.00	0.87	0.86	0.90	0.90
78	73	31.00	0.87	0.86	0.90	0.90
79	74	33.00	0.81	0.84	0.88	0.88
80	75	34.00	0.77	0.83	0.86	0.86

Table 3

FOUR CORNER POINTS OF CROSS SECTIONS								
MEMBER NUMBER	X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)	X(4)	Y(4)
1	0.313	2.313	0.313	-2.313	-0.313	2.313	-0.313	-2.313
2	1.125	1.687	1.125	-1.687	-1.125	1.687	-1.125	-1.687
3	0.750	2.750	0.750	-2.750	-0.750	2.750	-0.750	-2.750
4	1.125	1.812	1.125	-1.812	-1.125	1.812	-1.125	-1.812
5	1.125	1.687	1.125	-1.687	-1.125	1.687	-1.125	-1.687
6	1.125	1.812	1.125	-1.812	-1.125	1.812	-1.125	-1.812
7	1.125	2.687	1.125	-2.687	-1.125	2.687	-1.125	-2.687
8	1.438	2.687	1.438	-2.687	-1.438	2.687	-1.438	-2.687
9	1.000	1.000	1.000	-1.000	-1.000	1.000	-1.000	-1.000
10	1.125	0.313	1.125	-0.313	-1.125	0.313	-1.125	-0.313
11	1.125	0.625	1.125	-0.625	-1.125	0.625	-1.125	-0.625
12	3.030	4.040	3.030	-4.040	-3.030	4.040	-3.030	-4.040
13	4.000	6.000	4.000	-6.000	-4.000	6.000	-4.000	-6.000
14	4.000	6.000	4.000	-6.000	-4.000	6.000	-4.000	-6.000
15	0.750	2.750	0.750	-2.750	-0.750	2.750	-0.750	-2.750
16	1.063	2.750	1.063	-2.750	-1.063	2.750	-1.063	-2.750
17	0.313	3.813	0.313	-3.813	-0.313	3.813	-0.313	-3.813
18	4.000	6.000	4.000	-6.000	-4.000	6.000	-4.000	-6.000
19	4.000	0.625	4.000	-0.625	-4.000	0.625	-4.000	-0.625
20	4.000	1.542	4.000	-1.542	-4.000	1.542	-4.000	-1.542
21	2.125	1.500	2.125	-1.500	-2.125	1.500	-2.125	-1.500
22	3.030	4.040	3.030	-4.040	-3.030	4.040	-3.030	-4.040
23	3.030	5.540	3.030	-5.540	-3.030	5.540	-3.030	-5.540
24	2.313	5.000	2.313	-5.000	-2.313	5.000	-2.313	-5.000
25	2.313	2.250	2.313	-2.250	-2.313	2.250	-2.313	-2.250
26	3.030	4.290	3.030	-4.290	-3.030	4.290	-3.030	-4.290
27	3.030	4.290	3.030	-4.290	-3.030	4.290	-3.030	-4.290
28	0.625	2.313	0.625	-2.313	-0.625	2.313	-0.625	-2.313
29	3.083	7.000	3.083	-7.000	-3.083	5.000	-3.083	-5.000
30	0.313	2.750	0.313	-2.750	-0.313	2.750	-0.313	-2.750
31	2.500	2.250	2.500	-2.250	-2.500	2.250	-2.500	-2.250
32	6.000	4.000	6.000	-4.000	-6.000	4.000	-6.000	-4.000
33	1.500	2.125	1.500	-2.125	-1.500	2.125	-1.500	-2.125
34	5.540	3.030	5.540	-3.030	-5.540	3.030	-5.540	-3.030
35	5.000	2.313	5.000	-2.313	-5.000	2.313	-5.000	-2.313
36	2.250	2.313	2.250	-2.313	-2.250	2.313	-2.250	-2.313
37	2.250	2.500	2.250	-2.500	-2.250	2.500	-2.250	-2.500
38	0.500	2.000	0.500	-2.000	-0.500	2.000	-0.500	-2.000
39	6.000	4.500	6.000	-4.500	-6.000	4.500	-6.000	-4.500
40	3.000	0.250	3.000	-0.250	-3.000	0.250	-3.000	-0.250
41	4.290	3.030	4.290	-3.030	-4.290	3.030	-4.290	-3.030
42	7.000	3.083	5.000	-3.083	-7.000	3.083	-5.000	-3.083
43	6.000	4.000	6.000	-4.000	-6.000	4.000	-6.000	-4.000
44	2.750	0.750	2.750	-0.750	-2.750	0.750	-2.750	-0.750

Table 3

FOUR CORNER POINTS OF CROSS SECTIONS								
MEMBER	X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)	X(4)	Y(4)
NUMBER								
45	5.500	6.000	5.500	-6.000	-5.500	6.000	-5.500	-6.000
46	2.750	1.063	2.750	-1.063	-2.750	1.063	-2.750	-1.063
47	5.500	5.500	5.500	-5.500	-5.500	5.500	-5.500	-5.500
48	1.125	6.000	1.125	-6.000	-1.125	6.000	-1.125	-6.000
49	2.750	3.000	2.750	-3.000	-2.750	3.000	-2.750	-3.000
50	0.500	0.313	0.500	-0.313	-0.500	0.313	-0.500	-0.313
51	0.500	0.625	0.500	-0.625	-0.500	0.625	-0.500	-0.625
52	3.000	1.200	3.000	-1.200	-3.000	1.200	-3.000	-1.200
53	1.687	1.125	1.687	-1.125	-1.687	1.125	-1.687	-1.125
54	2.500	2.563	2.500	-2.563	-2.500	2.563	-2.500	-2.563
55	4.250	4.250	4.250	-4.250	-4.250	4.250	-4.250	-4.250
56	0.500	2.000	0.500	-2.000	-0.500	2.000	-0.500	-2.000
57	2.375	2.563	2.375	-2.563	-2.375	2.563	-2.375	-2.563
58	28.625	28.625	28.625	-28.625	-28.625	28.625	-28.625	-28.625

	A	B	C	D	E	F	G
1	PID	SHAPE	AREA	Ixx	Iyy	J	X
2			INCH**2	INCH**4	INCH**4	INCH**4	INCHES
3	1	SIMPLE-I	1.766	4.309	0.037	0.156	0.313
4	2	SIMPLE-T	1.711	0.673	0.476	0.031	1.125
5	3	SIMPLE-Ia	2.156	8.728	0.182	0.058	0.750
6	9	2-L-1X1	0.460	0.042	0.042	0.003	1.000
7	11	2-BAR	2.813	0.092	1.186	0.301	1.125
8	18	NOZZLE-TOP	15.156	19.030	53.578	4.946	4.000
9	19	NOZZLE-BTM	10.000	1.302	53.333	4.639	4.000
10	20	HALF-Ia-BAR	11.883	1.391	60.220	4.686	4.000
11	28	2-SIMPLE-I	3.531	8.618	0.074	0.313	0.625
12	30	NOZZLE RIB	3.438	8.665	0.112	0.412	0.313
13	32	2-I-BAR-RT14	7.319	6.306	11.672	0.279	6.000
14	33	DOOR-FR-RT21	6.313	8.080	0.775	2.383	1.500
15	34	2-L-DR-FR-RT23	16.793	21.433	34.680	3.244	5.540
16	35	DR-FR-BT-RT24	13.631	14.386	12.447	2.662	5.000
17	36	DR-FR-TP-RT25	8.078	12.389	0.812	2.540	2.250
18	37	DR-FR-TP-RT31	7.711	8.741	0.978	2.406	2.250
19	38	BAR-4"X1"	4.000	5.333	0.333	1.124	0.500
20	39	SIMPLE-I-BAR	4.766	4.371	9.037	0.406	6.000
21	40	BAR-6"X0.5"	3.000	0.063	9.000	0.250	3.000
22	41	L-6X4-P-R26-Ixy	5.740	7.343	16.955	0.441	4.290
23	42	DR-FR-BTT-R-Y	10.781	12.456	5.279	2.521	7.000
24	43	2-I-BAR-RT13	4.469	4.376	4,522	0.138	6.000
25	44	SIMPLE-Ia-RT3	2.156	0.182	8.728	0.056	2.750
26	45	SIMPLE-Ia-PLT	3.641	4.543	8.736	0.089	5.500
27	46	2-HALF-Ia-RT16	3.766	0.179	13.773	0.094	2.750
28	47	2-SIMPLE-Ia	4.313	8.911	8.911	0.115	5.500
29	48	T-PLATE	2.789	2.344	0.482	0.053	1.125
30	49	T-DEEP-PLATE	1.897	0.486	0.673	0.031	2.750
31	50	RACK-BAR	0.625	0.020	0.052	0.050	0.500
32	51	2-RACK-BARS	1.250	0.041	0.104	0.099	0.500
33	52	2-HALF-T	3.152	0.438	1.344	0.047	3.000
34	53	SIMPLE-T-RT2	1.711	0.476	0.673	0.031	1.687
35	54	WF-5"	5.672	23.813	7.832	0.266	2.500
36	55	WF-8"	9.281	115.188	33.558	0.435	4.250
37	56	PLENUM BAR	4.000	5.333	0.333	1.124	0.500
38	58	NOZZLE-BEAM	44.768	18181.630	18181.630	36363.260	28.625

Table 4

	H	I	J	K	L	M	N
1	Y	R	AXIAL FORCE	SHEAR 2	SHEAR 1	MOMENT 1	MOMENT 2
2	INCHES	INCHES	POUNDS	POUNDS	POUNDS	INCH-LBS	INCH-LBS
3	2.313	2.334	735.800	117.700	64.260	1960.000	19.570
4	1.687	2.028	268.000	30.150	4.061	284.300	30.780
5	2.750	2.850	129.400	24.430	5.216	776.300	11.300
6	1.000	1.414	124.600	36.920	24.490	15.160	24.810
7	0.625	1.287	317.600	18.110	307.000	9.943	535.800
8	6.000	7.211	112.100	23.380	32.930	311.700	679.300
9	0.625	4.049	117.900	20.120	70.640	34.270	1820.000
10	1.542	4.287	160.000	9.145	29.340	36.880	1004.000
11	2.313	2.395	326.200	92.870	32.900	1660.000	28.420
12	2.750	2.768	120.600	77.350	24.450	1225.000	17.240
13	4.000	7.211	2032.000	130.600	215.000	577.000	491.500
14	2.125	2.601	635.300	56.070	28.550	572.600	73.210
15	3.030	6.314	2718.000	68.820	107.600	378.500	830.500
16	2.313	5.509	1648.000	48.790	103.100	319.800	254.800
17	2.313	3.226	285.800	57.170	45.720	1288.000	72.520
18	2.500	3.363	1777.000	106.200	19.420	946.300	53.450
19	2.000	2.062	170.400	92.310	16.130	903.500	37.130
20	4.500	7.500	536.500	80.190	22.050	161.600	81.450
21	0.250	3.010	118.200	1.821	19.850	9.294	46.530
22	3.030	5.252	1957.000	93.230	205.400	438.400	756.100
23	3.083	7.649	2089.000	260.100	219.800	1397.000	476.100
24	4.000	7.211	1514.000	94.360	185.100	433.500	393.100
25	0.750	2.850	225.000	10.770	18.970	20.910	1100.000
26	6.000	8.139	2445.000	106.100	26.790	371.900	382.400
27	1.063	2.948	204.100	3.824	25.660	12.100	1331.000
28	5.500	7.778	10.570	7.748	13.050	61.440	91.000
29	6.000	6.105	326.200	64.810	8.633	928.900	30.260
30	3.000	4.070	236.700	25.920	7.373	56.190	254.600
31	0.313	0.590	190.900	2.359	18.270	2.966	19.560
32	0.625	0.800	156.800	0.964	17.150	2.166	8.542
33	1.200	3.231	162.000	14.110	173.400	8.634	223.400
34	1.125	2.028	204.900	39.130	56.740	44.870	227.500
35	2.563	3.580	597.900	307.800	56.650	3165.000	473.300
36	4.250	6.010	1379.000	314.600	183.600	6850.000	939.900
37	2.000	2.062	96.170	11.470	17.040	466.100	38.420
38	28.625	40.482	0.000	221.200	1635.000	11670.000	70940.000

Table 4

	O	P	Q	R	S	T
1	TORSION	P/A	SHEAR 2/A	SHEAR 1/A	SHEAR 1,2/A	T*R/J
2	INCH-LBS	PSI	PSI	PSI	PSI	PSI
3	47.940	416.648	66.648	36.387	75.934	717.108
4	1.948	156.634	17.621	2.373	17.780	127.418
5	1.848	60.019	11.331	2.419	11.587	90.821
6	0.319	270.870	80.261	53.239	96.313	150.425
7	11.450	112.904	6.438	109.136	109.326	48.988
8	274.600	7.396	1.543	2.173	2.665	400.358
9	278.000	11.790	2.012	7.064	7.345	242.615
10	231.900	13.465	0.770	2.469	2.586	212.146
11	22.030	92.382	26.301	9.317	27.903	168.601
12	61.060	35.079	22.499	7.112	23.596	410.184
13	21.660	277.634	17.844	29.376	34.371	559.830
14	59.500	100.634	8.882	4.522	9.967	64.945
15	54.340	161.853	4.098	6.407	7.606	105.773
16	64.770	120.901	3.579	7.564	8.368	134.038
17	28.550	35.380	7.077	5.660	9.062	36.266
18	54.610	230.450	13.773	2.518	14.001	76.341
19	51.160	42.600	23.078	4.033	23.427	93.834
20	68.050	112.568	16.825	4.627	17.450	1257.081
21	13.440	39.400	0.607	6.617	6.644	161.839
22	158.700	340.941	16.242	35.784	39.298	1890.057
23	61.490	193.767	24.126	20.388	31.587	186.567
24	10.690	338.778	21.114	41.419	46.490	558.599
25	8.489	104.360	4.995	8.799	10.118	432.096
26	5.801	671.588	29.143	7.359	30.058	533.522
27	1.212	54.195	1.015	6.814	6.889	38.012
28	1.797	2.451	1.797	3.026	3.519	121.467
29	5.774	116.957	23.237	3.095	23.442	664.302
30	7.129	124.776	13.664	3.887	14.206	926.931
31	7.938	305.440	3.774	29.232	29.475	94.554
32	2.149	125.440	0.771	13.720	13.742	17.387
33	0.833	51.396	4.477	55.013	55.195	57.435
34	4.099	119.755	22.870	33.162	40.283	268.115
35	12.870	105.415	54.268	9.988	55.179	173.298
36	25.310	148.579	33.896	19.782	39.246	349.662
37	56.440	24.043	2.868	4.260	5.135	103.518
38	0.000	0.000	4.941	36.522	36.855	0.000

Table 4

	U	V	W	X	Y	Z
1	TOTAL SHEAR	BENDING S1	BENDING S2	TOTAL AXIAL S	MAX SHEAR	MAX AXIAL S
2	PSI	PSI	PSI	PSI	PSI	PSI
3	793.042	1051.868	165.287	1633.803	1138.527	1955.429
4	145.199	712.651	72.747	942.031	492.888	963.904
5	102.407	244.595	46.566	351.179	203.271	378.861
6	246.738	360.952	590.714	1222.536	659.188	1270.456
7	158.314	67.548	508.242	688.694	378.996	723.343
8	403.022	98.276	50.715	156.388	410.538	488.732
9	249.960	16.451	136.501	164.742	263.183	345.553
10	214.732	40.876	66.689	121.029	223.096	283.610
11	196.504	445.434	240.034	777.850	435.748	824.673
12	433.779	388.777	48.103	471.958	493.812	729.791
13	594.200	366.001	252.656	896.290	744.250	1192.395
14	74.912	150.591	141.697	392.921	210.258	406.719
15	113.379	53.509	132.669	348.031	207.693	381.708
16	142.406	51.407	102.354	274.662	197.836	335.167
17	45.328	240.415	200.948	476.743	242.643	481.015
18	90.342	270.650	122.968	624.068	324.849	636.883
19	117.261	338.813	55.696	437.108	248.024	466.578
20	1274.531	166.369	54.078	333.015	1285.362	1451.869
21	168.483	37.176	15.510	92.086	174.662	220.705
22	1929.354	180.900	191.310	713.152	1962.028	2318.604
23	218.154	345.811	631.313	1170.890	624.770	1210.215
24	605.089	396.252	521.583	1256.614	872.297	1500.604
25	442.214	86.168	346.586	537.113	517.374	785.930
26	563.580	491.173	240.751	1403.512	900.047	1601.803
27	44.901	71.823	265.755	391.774	200.967	396.854
28	124.986	37.924	56.170	96.544	133.984	182.256
29	687.744	2370.093	70.696	2565.745	1455.594	2738.466
30	941.136	346.852	1040.342	1511.970	1207.166	1963.151
31	124.029	45.558	187.776	538.774	296.568	565.955
32	31.129	33.270	41.002	199.711	104.595	204.451
33	112.630	23.655	498.661	573.711	308.175	595.030
34	308.398	106.048	570.271	796.073	503.530	901.567
35	228.477	340.581	151.084	597.080	375.936	674.476
36	388.908	252.738	119.036	520.353	467.912	728.089
37	108.653	174.788	57.630	256.460	168.073	296.303
38	36.855	18.373	111.687	130.060	74.748	139.778

Table 4

Table 5 BASE REACTION FORCES

	A	B	C	D	E	F	G
1		Modal Dynamic	Modal Dynamic	Static	Difference	Uplift	Downhold
2	Node	Without ZPA	with ZPA	Dead Weight	Dynamic-Static	Force	Force
3		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
4	642	156.00	162.52	12.07	150.45	150.45	
5	644	17.85	24.86	12.98	11.88	11.88	
6	647	2133.00	2647.89	953.50	1694.39	1694.39	
7	707	18.38	20.09	3.17	16.92	16.92	
8	710	10.08	11.55	2.72	8.83	8.83	
9	714	74.51	80.10	10.36	69.74	69.74	
10	768	12.66	14.17	2.79	11.38	11.38	
11	771	1.40	3.19	3.31	-0.13		-0.13
12	774	51.52	54.47	5.46	49.01	49.01	
13	825	32.19	51.07	34.96	16.11	16.11	
14	826	13.63	15.97	4.33	11.64	11.64	
15	829	3.89	6.37	4.58	1.79	1.79	
16	885	661.30	885.72	415.60	470.12	470.12	
17	887	3.04	5.40	4.37	1.03	1.03	
18	890	2.46	5.29	5.23	0.06	0.06	
19	942	100.40	113.34	23.97	89.37	89.37	
20	945	33.60	35.06	2.71	32.35	32.35	
21	948	3.51	4.72	2.24	2.48	2.48	
22	986	1015.00	1400.78	714.40	686.38	686.38	
23	1001	5.73	7.45	3.18	4.27	4.27	
24	1002	28.24	29.53	2.38	27.14	27.14	
25	1042	69.40	73.05	6.76	66.29	66.29	
26	1058	7.28	9.45	4.01	5.44	5.44	
27	1060	13.52	15.63	3.91	11.72	11.72	
28	1075	19.68	21.02	2.48	18.54	18.54	
29	1105	7.99	11.74	6.94	4.79	4.79	
30	1121	4.91	6.45	2.84	3.60	3.60	
31	1124	14.62	16.42	3.33	13.09	13.09	
32	1176	614.80	772.43	291.90	480.53	480.53	
33	1182	31.86	31.88	-0.04	31.92	31.92	
34	1195	36.95	39.63	4.96	34.67	34.67	
35	1245	93.51	112.73	35.60	77.13	77.13	
36	1247	427.60	701.06	506.40	194.66	194.66	
37	1263	76.30	358.02	521.70	-163.68		-163.68
38	1274	14.50	16.28	3.30	12.98	12.98	
39	1298	47.41	47.70	0.54	47.16	47.16	
40	1316	2459.00	2980.86	966.40	2014.46	2014.46	
41	1319	419.90	744.82	601.70	143.12	143.12	
42	1333	69.17	411.69	634.30	-222.61		-222.61
43	1379	74.22	97.92	43.88	54.04	54.04	
44	1384	29.92	33.38	6.40	26.97	26.97	
45	1400	63.02	67.37	8.06	59.31	59.31	
46	1437	10.08	15.79	10.57	5.22	5.22	
47	1440	6.96	8.90	3.60	5.30	5.30	

Table 5 BASE REACTION FORCES

	A	B	C	D	E	F	G
48		Modal Dynamic	Modal Dynamic	Static	Difference	Uplift	Downhold
49	Node	Without ZPA	with ZPA	Dead Weight	Dynamic-Static	Force	Force
50		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
51	1455	12.16	13.67	2.79	10.88	10.88	
52	1491	6.83	13.77	12.85	0.92	0.92	
53	1494	2.80	4.73	3.58	1.15	1.15	
54	1497	4.75	6.36	2.99	3.37	3.37	
55	1548	10.12	26.67	30.64	-3.97		-3.97
56	1551	3.47	5.22	3.25	1.97	1.97	
57	1554	2.90	4.41	2.81	1.61	1.61	
58	1613	508.00	727.67	406.80	320.87	320.87	
59	1616	3.06	4.03	1.80	2.23	2.23	
60	1619	4.31	5.19	1.62	3.57	3.57	
61	1691	98.89	108.01	16.88	91.13	91.13	
62	1694	0.43	1.21	1.45	-0.23		-0.23
63	1697	4.30	5.01	1.31	3.70	3.70	
64	1761	672.10	1040.38	682.00	358.38	358.38	
65	1764	0.27	1.16	1.65	-0.49		-0.49
66	1767	2.89	3.78	1.66	2.12	2.12	
67	1784	99.66	104.98	9.86	95.13	95.13	
68	1846	1.74	3.12	2.55	0.57	0.57	
69	1849	1.02	2.43	2.60	-0.17		-0.17
70	1863	8.70	10.03	2.47	7.56	7.56	
71	1941	5.93	7.62	3.14	4.48	4.48	
72	1944	5.90	7.21	2.42	4.79	4.79	
73	1958	37.06	64.09	50.05	14.04	14.04	
74	2052	18.72	53.22	63.89	-10.67		-10.67
75	2055	13.06	71.76	108.70	-36.94		-36.94
76	2068	19.59	33.45	25.67	7.78	7.78	
77	2071	15.53	16.71	2.18	14.53	14.53	
78	2139	24.08	25.39	2.42	22.97	22.97	
79	2155	62.69	291.54	423.80	-132.26		-132.26
80	2156	15.04	276.13	483.50	-207.37		-207.37
81	2167	368.40	652.22	525.60	126.62	126.62	
82	2266	17.06	18.33	2.36	15.97	15.97	
83	2268	24.55	26.00	2.69	23.31	23.31	
84	2280	22.60	39.86	31.97	7.89	7.89	
85	2360	2.59	4.56	3.64	0.92	0.92	
86	2364	5.96	7.85	3.49	4.36	4.36	
87	2373	1.56	7.50	11.00	3.50		-3.50
88	2449	2.32	4.25	3.58	0.67	0.67	
89	2452	2.44	4.19	3.24	0.95	0.95	
90	2454	19.87	27.29	13.74	13.55	13.55	
91	2528	4.53	6.17	3.04	3.13	3.13	
92	2530	0.94	2.40	2.71	-0.31		-0.31
93	2532	6.77	22.34	28.83	-6.49		-6.49
94	2611	0.81	1.75	1.75	0.00	0.00	

Table 5 BASE REACTION FORCES

	A	B	C	D	E	F	G
95		Modal Dynamic	Modal Dynamic	Static	Difference	Uplift	Downhold
96	Node	Without ZPA	with ZPA	Dead Weight	Dynamic-Static	Force	Force
97		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
98	2614	1.04	1.95	1.68	0.27	0.27	
99	2616	326.70	534.71	385.20	149.51	149.51	
100	2674	1.65	2.54	1.66	0.88	0.88	
101	2677	0.79	1.53	1.36	0.16	0.16	
102	2679	183.30	192.00	16.11	175.89	175.89	
103	2724	0.88	1.76	1.63	0.13	0.13	
104	2727	0.68	1.55	1.60	-0.05		-0.05
105	2729	639.00	1007.50	682.40	325.10	325.10	
106	2750	192.10	196.98	9.03	187.95	187.95	
107	2776	2.10	3.47	2.54	0.93	0.93	
108	2778	1.04	2.40	2.52	-0.12		-0.12
109	2799	17.50	18.59	2.03	16.57	16.57	
110	2831	2.87	4.28	2.61	1.67	1.67	
111	2833	1.03	2.28	2.31	-0.03		-0.03
112	2842	75.41	103.75	52.48	51.27	51.27	
113	2881	3.52	26.76	43.04	-16.28		-16.28
114	2882	8.60	42.57	62.91	-20.34		-20.34
115	2890	76.01	90.10	26.10	64.00	64.00	
116	2903	18.44	19.49	1.94	17.55	17.55	
117	2923	17.61	18.71	2.04	16.67	16.67	
118	2932	102.00	230.95	238.80	-7.85		-7.85
119	2933	70.01	187.03	216.70	-29.67		-29.67
120	2940	640.20	767.26	235.30	531.96	531.96	
121	2974	54.95	56.88	3.58	53.31	53.31	
122	2977	9.39	11.59	4.07	7.52	7.52	
123	2985	63.63	78.84	28.17	50.67	50.67	
124	3009	16.46	19.04	4.78	14.26	14.26	
125	3013	7.18	9.36	4.04	5.32	5.32	
126	3018	206.50	211.14	8.60	202.54	202.54	
127	3043	25.09	27.36	4.20	23.16	23.16	
128	3045	23.72	26.08	4.36	21.71	21.71	
129	3047	1206.00	1623.47	773.10	850.37	850.37	
130	3060	0.40	9.80	17.41	-7.61		-7.61
131	3073	0.03	5.15	9.49	-4.34		-4.34
132	3076	12.38	14.59	4.09	10.50	10.50	
133	3089	181.50	194.92	24.86	170.06	170.06	
134	3102	19.30	21.31	3.72	17.59	17.59	
135	3105	22.13	24.01	3.49	20.53	20.53	
136	3117	2440.00	2756.44	586.00	2170.44	2170.44	
137	3133	84.91	92.84	14.69	78.15	78.15	
138	3134	195.90	202.65	12.50	190.15	190.15	
139	3852	88.50	97.10	15.93	81.17	81.17	
140	3855	3221.00	3758.35	995.10	2763.25	2763.25	
141	3915	12.32	14.10	3.30	10.80	10.80	

Table 5 BASE REACTION FORCES

	A	B	C	D	E	F	G
142		Modal Dynamic	Modal Dynamic	Static	Difference	Uplift	Downhold
143	Node	Without ZPA	with ZPA	Dead Weight	Dynamic-Static	Force	Force
144		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
145	3919	264.80	272.04	13.40	258.64	258.64	
146	3973	48.62	49.89	2.35	47.54	47.54	
147	3976	133.10	139.07	11.06	128.01	128.01	
148	4025	0.13	18.61	34.23	-15.62		-15.62
149	4028	0.60	6.21	10.39	-4.18		-4.18
150	4082	380.40	601.37	409.20	192.17	192.17	
151	4086	59.18	61.46	4.21	57.24	57.24	
152	4136	188.10	200.21	22.42	177.79	177.79	
153	4141	28.82	30.18	2.52	27.66	27.66	
154	4177	871.60	1250.57	701.80	548.77	548.77	
155	4192	12.07	13.83	3.26	10.57	10.57	
156	4229	153.30	155.43	3.95	151.48	151.48	
157	4245	20.21	22.18	3.65	18.53	18.53	
158	4260	12.41	12.58	0.31	12.27	12.27	
159	4284	3.02	6.15	5.79	0.36	0.36	
160	4300	5.73	7.44	3.16	4.28	4.28	
161	4344	736.10	891.94	288.60	603.34	603.34	
162	4350	55.53	55.80	-0.49	56.29	56.29	
163	4408	120.70	139.35	34.53	104.82	104.82	
164	4410	377.90	650.76	505.30	145.46	145.46	
165	4435	32.90	34.59	3.12	31.46	31.46	
166	4474	2511.00	3029.40	960.00	2069.40	2069.40	
167	4477	377.40	701.45	600.10	101.35	101.35	
168	4534	78.83	101.41	41.82	59.59	59.59	
169	4539	29.92	33.36	6.37	26.99	26.99	
170	4589	21.79	26.36	8.46	17.90	17.90	
171	4592	6.20	8.14	3.59	4.55	4.55	
172	4640	4.68	10.56	10.88	-0.32		-0.32
173	4643	3.98	5.91	3.58	2.33	2.33	
174	4692	28.58	44.26	29.04	15.22	15.22	
175	4695	4.98	6.69	3.18	3.51	3.51	
176	4752	486.40	704.40	403.70	300.70	300.70	
177	4755	2.60	3.55	1.75	1.80	1.80	
178	4816	107.40	116.27	16.42	99.85	99.85	
179	4819	1.23	2.11	1.64	0.47	0.47	
180	4882	641.70	1007.87	678.10	329.77	329.77	
181	4885	1.17	2.17	1.85	0.32	0.32	
182	4904	119.50	123.80	7.97	115.83	115.83	
183	4957	1.23	2.43	2.23	0.20	0.20	
184	4973	16.16	16.64	0.89	15.75	15.75	
185	5038	6.01	7.60	2.94	4.66	4.66	
186	5054	36.22	62.57	48.80	13.77	13.77	
187	5138	17.75	52.37	64.11	-11.74		-11.74
188	5153	17.91	30.93	24.11	6.82	6.82	

Table 5 BASE REACTION FORCES

	A	B	C	D	E	F	G
189		Modal Dynamic	Modal Dynamic	Static	Difference	Uplift	Downhold
190	Node	Without ZPA	with ZPA	Dead Weight	Dynamic-Static	Force	Force
191		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
192	5156	12.29	13.46	2.17	11.29	11.29	
193	5234	57.13	285.87	423.60	-137.73		-137.73
194	5245	355.20	637.13	522.10	115.03	115.03	
195	5339	19.37	20.63	2.34	18.30	18.30	
196	5352	4.91	21.17	30.11	-8.94		-8.94
197	5429	2.63	4.60	3.65	0.95	0.95	
198	5441	8.11	12.95	8.97	3.98	3.98	
199	5514	2.68	4.61	3.59	1.03	1.03	
200	5518	16.79	23.16	11.80	11.36	11.36	
201	5589	4.68	6.32	3.04	3.28	3.28	
202	5592	11.87	26.57	27.23	-0.66		-0.66
203	5666	0.76	1.71	1.75	-0.05		-0.05
204	5670	334.90	542.10	383.70	158.40	158.40	
205	5725	1.13	2.02	1.65	0.37	0.37	
206	5729	144.80	153.06	15.30	137.76	137.76	
207	5771	0.92	1.82	1.66	0.16	0.16	
208	5775	655.60	1022.37	679.20	343.17	343.17	
209	5796	152.70	156.73	7.46	149.27	149.27	
210	5819	1.33	2.66	2.46	0.19	0.19	
211	5841	10.49	10.75	0.48	10.27	10.27	
212	5866	4.19	5.65	2.71	2.95	2.95	
213	5876	66.97	94.66	51.27	43.39	43.39	
214	5912	6.51	29.62	42.79	-13.17		-13.17
215	5920	59.42	72.79	24.76	48.03	48.03	
216	5933	22.54	23.64	2.03	21.61	21.61	
217	5959	90.81	219.49	238.30	-18.81		-18.81
218	5966	479.20	605.02	233.00	372.02	372.02	
219	5999	14.22	16.13	3.54	12.59	12.59	
220	6009	41.73	55.69	25.85	29.84	29.84	
221	6032	9.15	11.70	4.72	6.98	6.98	
222	6040	50.31	54.01	6.86	47.15	47.15	
223	6064	3.30	5.71	4.47	1.24	1.24	
224	6067	1347.00	1760.37	765.50	994.87	994.87	
225	6080	88.15	92.89	8.79	84.11	84.11	
226	6092	0.89	3.45	4.74	-1.29		-1.29
227	6107	89.60	100.78	20.70	80.08	80.08	
228	6119	17.77	19.84	3.83	16.01	16.01	
229	6133	1975.00	2290.20	583.70	1706.50	1706.50	
230	6148	38.37	46.48	15.02	31.46	31.46	
231							
232	TOTAL	35642.44	47828.32	22565.37	25262.92	26350.54	-1087.62

Table 6

E I G E N V A L U E   O U T P U T

MODE NO	EIGENVALUE	FREQUENCY (RAD/TIME)	FREQUENCY (CYCLES/TIME)	GENERALIZED MASS	COMPOSITE MODAL DAMPING
1	1023.8	31.997	5.0925	9.60100E-02	0.00000
2	6859.7	82.823	13.182	5.73065E-02	0.00000
3	8001.4	89.451	14.237	0.11077	0.00000
4	8869.9	94.180	14.989	2.59414E-02	0.00000
5	13604.	116.64	18.563	13.434	0.00000
6	16112.	126.93	20.202	4.47262E-02	0.00000
7	20982.	144.85	23.054	0.90275	0.00000
8	23686.	153.90	24.494	0.12751	0.00000
9	24859.	157.67	25.094	0.11967	0.00000
10	25835.	160.73	25.581	2.57125E-02	0.00000
11	27299.	165.22	26.296	3.55854E-02	0.00000
12	28583.	169.06	26.907	5.84450E-02	0.00000
13	32753.	180.98	28.803	0.10534	0.00000
14	33063.	181.83	28.939	8.0273	0.00000
15	35175.	187.55	29.850	0.18324	0.00000
16	38372.	195.89	31.177	2.7328	0.00000
17	40174.	200.43	31.900	0.15720	0.00000
18	41378.	203.41	32.374	1.7521	0.00000
19	44034.	209.84	33.397	0.88491	0.00000
20	46449.	215.52	34.301	0.54147	0.00000
21	48677.	220.63	35.114	0.13295	0.00000
22	49554.	222.61	35.429	0.17095	0.00000
23	52048.	228.14	36.310	0.32650	0.00000
24	54070.	232.53	37.008	2.59198E-02	0.00000
25	55585.	235.76	37.523	1.3436	0.00000
26	55895.	236.42	37.628	1.1823	0.00000
27	57474.	239.74	38.155	0.22723	0.00000
28	60438.	245.84	39.127	0.42773	0.00000
29	64139.	253.26	40.307	1.3270	0.00000
30	67510.	259.83	41.353	0.88204	0.00000

Table 7

E I G E N V A L U E   O U T P U T

MODE NO	EIGENVALUE	FREQUENCY (RAD/TIME)	FREQUENCY (CYCLES/TIME)	GENERALIZED MASS	COMPOSITE MODAL DAMPING
1	8793.7	93.775	14.925	2.62936E-02	0.00000
2	14145.	118.93	18.929	12.323	0.00000
3	15583.	124.83	19.868	4.30897E-02	0.00000
4	21089.	145.22	23.113	0.57097	0.00000
5	24075.	155.16	24.695	0.12383	0.00000
6	24900.	157.80	25.114	2.73802E-02	0.00000
7	26272.	162.09	25.797	0.17333	0.00000
8	27093.	164.60	26.197	3.42565E-02	0.00000
9	34621.	186.07	29.614	7.6344	0.00000
10	38096.	195.18	31.064	3.1606	0.00000
11	40173.	200.43	31.900	0.15708	0.00000
12	42029.	205.01	32.628	1.3865	0.00000
13	43059.	207.51	33.026	0.13249	0.00000
14	43878.	209.47	33.338	0.10150	0.00000
15	46213.	214.97	34.214	0.20249	0.00000
16	48082.	219.28	34.899	1.9523	0.00000
17	48659.	220.59	35.108	0.13264	0.00000
18	51896.	227.81	36.257	0.96601	0.00000
19	54052.	232.49	37.002	2.61662E-02	0.00000
20	55762.	236.14	37.583	2.0119	0.00000
21	55902.	236.44	37.630	1.1139	0.00000
22	58022.	240.88	38.337	0.21475	0.00000
23	60350.	245.66	39.098	0.27398	0.00000
24	64122.	253.22	40.302	1.3248	0.00000
25	67852.	260.48	41.457	0.60548	0.00000
26	68250.	261.25	41.579	0.58364	0.00000
27	68790.	262.28	41.743	0.64368	0.00000
28	69193.	263.05	41.865	2.3220	0.00000
29	70744.	265.98	42.332	0.40882	0.00000
30	71027.	266.51	42.416	0.67598	0.00000

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