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Project W-151, Tank 101-AZ, Waste Retrieval System		ECN No.

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ENGINEERING DATA TRANSMITTAL

Page 1 of 1
1. EDT 603351

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		2. Release	5. Post-Review	2. Approved w/comment	5. Reviewed w/comment
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1	1	Cog. Mgr. M.R. Lindquist	<i>[Signature]</i>	11/23/94	H5-70	F. Baxter	<i>[Signature]</i>	11/30/94	H5-70	1	1
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ANALYSTS S. Kauphal

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Performed Static Analysis of the
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DATE 11/29/94

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STRUCTURAL EVALUATION OF THERMOCOUPLE
PROBES FOR
241-AZ-101 WASTE TANK
PROJECT W-151

September 1994

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Westinghouse Hanford Company
Hanford Operations and Engineering contractor
for the
U. S. Department of Energy
Richland, Washington

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**STRUCTURAL EVALUATION OF THERMOCOUPLE
PROBES FOR
241-AZ-101 WASTE TANK
PROJECT W-151**

1.0 INTRODUCTION

This document reports on the structural analysis of the thermocouple probes (TCP) to be installed in the 241-AZ-101 waste tank as part of Project W-151. The thermocouple probes are analyzed for normal pump mixing operation and potential earthquake-induced loads required by the Hanford Site design criteria SDC-4.1 (DOE-RL 1989).

1.1 BACKGROUND

Waste tank 241-AZ-101 is 75 ft in diameter and approximately 50-ft deep. The 5.5-in.-diameter carbon steel (AISC 1026 cold drawn, ASTM A513) TCPs are inserted into the tank through 6-in.-diameter riser pipe fixed at the top of the tank. The riser pipe is approximately 18.25-ft long, and the TCP is approximately 57.5-ft long. The probe is connected at the top to the riser flange and to a device to adjust the submerged length of the probe. The TCPs are located in five places around the perimeter at a radius of 34.75 ft inside the tank.

1.2 SCOPE

The scope of this task requires that the structural adequacy of the TCP be evaluated for loads imposed on it by normal operation of the mixing pump and the site design criteria as specified in SDC-4.1 (DOE-RL 1989). Tank 241-AZ-101 waste contents are assumed to be homogenized. Two load conditions are considered. The normal operating load condition comprises the pump-induced hydraulic forces under steady-state conditions and the deadweight of the components. These loads also include the forces from the flow-induced vibrations (i.e., vortex shedding at resonance-condition). The extreme load conditions is defined to be the normal operative condition with the seismically induced forces, including the forces from vortex-induced resonance.

In addition, the weld between the probe and its mounting flange at the top is evaluated for worst-case loading conditions. The threads that hold the TCP to the adjusting device are also qualified for the worst-case loading.

To reduce bending in the TCP to a minimum, during installation handling this analysis determines the best location for the crane hooks that will be used to erect the TCP.

An evaluation of the tank risers and dome structure is not within the scope of this report.

1.3 DESIGN DATA FOR THE ANALYSIS

The following data are used in the calculations:

- The viscosity of the liquid in the tank is 5.0 centipoise (Ellingson 1993).
- The density of the liquid is 74.914 lb/ft³ (Waters 1993).
- The profile and cross section of the probe is per drawing, H-2-79344, Rev. 0. (WHC 1994).
- The maximum drag force that can be applied to a probe at any instant of time is 139 lbf (Waters 1993).

1.4 METHODS OF ANALYSIS

The TCP is analyzed as a vertical cantilever beam with a fixed-end condition at the flange of the tank riser when the TCP does not contact the riser, and as a vertical cantilever beam with a fixed end at the flange of the tank riser and spring supported in two lateral directions at the riser sleeve lip when the TCP does contact the riser-sleeve lip. Loadings from drag and lift forces are obtained from WHC-SD-W151-ER-001 (Waters 1993). The TCP is modeled and analyzed with the ANSYS computer program, version 5.0 (Swanson 1992). The probe is observed to touch the lip of the riser, which is 18.25 ft below the top, as a result of static drag force. Also the probe deflects to the extent that it touches the lip of the riser in the first mode of vibration. The analysis uses two unidirectional springs attached to the probe at the lip level of the riser. A spring constant of 1×10^6 lbf/in is assumed for those springs. The results are found not very sensitive on the values of the spring constants.

For the extreme load condition, the modes of vibration for the TCP, including the effects of added mass, are calculated by using the ANSYS finite-element program (Swanson 1992). All computer runs are recorded in Appendix A of this document.

Hydrodynamic loads induced by the earthquake cause sloshing of the tank contents. The forces induced by the impulsive and the convective components of the liquid motions are calculated from established semi-empirical relations. Detailed calculations for these forces are presented in Appendix B of this document.

A flow-induced vibration methodology was used to evaluate the TCP fatigue life should resonance occur. Checking the influence of vortex shedding on the probe indicates that, because the probe installed on risers 15L, 15C, and 15F are only 13.8 ft away from the jet, they may experience vortex-induced resonance at the third mode of vibration. Detailed calculations to check resonance amplitude and resonance stresses and the fatigue life of the system are documented in Appendix A.

1.5 DESIGN CRITERIA

The modal analyses of the TCP are based on the design spectrum for Safety Class 1 structures (0.2 g) as specified in SDC 4.1 (DOE-RL 1989). The impulsive and the convective forces are also based on Safety Class 1 response spectra. The seismic analysis is conservative as the probe is classified as a Safety Class 3 component. Component stresses are evaluated against the criteria specified by the American Institute of Steel Construction (AISC 1989).

2.0 SUMMARY

The peak static stresses caused by the drag and lift forces at the point where the TCP touches the lip of the riser are small. Combined seismic stresses from sloshing and the modal analysis of the TCP at the above location are 9.21 kip/in². The combined stresses are multiplied by 2.04 (Collins 1981) to account for the stress concentration at the key slot; the result is a total stress of 30.5 kip/in², which is less than the AISC allowable of 1.33 times 0.60 times the yield strength (55.86 kip/in²).

Peak stress caused by vortex-induced resonance is 10.29 kip/in² (Appendix A). Combined normal operating stresses and resonant stresses with an increase concentration factor of 2.04 are 32.5 kip/in² which is less than the normal AISC allowable of 0.6 times yield strength ($0.6 \times 70 = 42$ kip/in²).

The fatigue life of the probe for normal and vortex-induced resonance conditions is calculated as 11,090 cycles before any damage occurs, which is longer than the 9,048 cycles (waters 1993), i.e., the total number of cycles the probe will see throughout its operation.

3.0 RECOMMENDATION/CONCLUSIONS

The results of this analysis show that the TCP is good for both operating and extreme loading conditions. On the basis of the results of this analysis, we recommend that if vortex shedding occurs as predicted, the rotational speed of the pump should be increased to 0.15 r/min to increase the fatigue life of the TCP.

The size of the bottom penetration weld between the flange and the probe should be changed to 3/8 in. to prevent overstressing the weld.

For erection purposes, the crane hook should hold the probe at the top and at 38.92-ft from top for optimum deflection and moment.

4.0 DISCUSSION

There is some conservatism in the seismic evaluation of the TCP as described in Section 1.4 above. All stresses evaluated are on the extreme fibre whereas the concentration factor applies at the root of the notches

where the stresses are lower than those on the extreme fibre. In the evaluation of the sloshing stresses, the probe is considered as cantilever 57.5-ft long, whereas if the probe touches the riser tip in the sloshing mode, and the resulting stresses will be less.

The flow field is considered uniform around the TCP, a condition that will produce vortex-induced resonance. In reality, the distribution of the velocity pressure/drag force in both lateral and vertical directions is parabolic shape and not uniform.

The maximum number of fatigue cycles that the TCP will see for a two-pump or a single pump configuration is presented in Table 4.6 (Waters 1993). The total number of cycles for two-pump configurations (1B and 1D) is 9,048. The footnote to Table 4.6 recommends adding the forces or cycles for each pump and comparing them with two-pumps acting together, then taking the maximum of the two for the design. For a single pump, the drag force is maximum (122 lb) for one of the pumps and small (22 lb) for the other, though the total cycles are two times 9,048 cycles. For fatigue calculations, the operating cycles are determined by the two-pump configuration, as the drag and lift forces from one of the single pumps is small.

The allowable fatigue cycles are observed to be directly proportional to the rotational speed of the pump. A pump speed lower than 0.1 r/min may cause more fatigue cycles than expected (9,048 cycles). Also the fatigue cycles depend on the impingement angle at which the vortex-shedding resonance occurs. An impingement angle of 2.5 deg is assumed on the basis of an actual impingement angle of 1.9 deg, which will allow a certain degree of partial impingement before the center line of jet hits the center line of the TCP. However, increasing the pump rotational speed to 0.15 r/min will increase the fatigue life by a factor of 1.49.

5.0 REFERENCES

- AISC, 1989, *Manual of Steel Construction, Allowable Stress Design*, Ninth Edition, American Institute of Steel Construction, Chicago, Illinois.
- ARCO, 1968, *Thermocouple Probe Standard*, Drawing No. H-3-34304, Rev. 6, Atlantic Richfield Hanford Company, Richland, Washington.
- ASTM, 1989, *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, Pennsylvania.
- ASME, 1992, *Rules For Construction of Nuclear Power Plant Components*, ASME Section III, Division 1-Appendices, ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, New York, New York.
- Au-Yang, M. K., R. D. Blevins, and T. M. Mulcahy, 1991, *Flow-Induced Vibration Analysis to Tube Bundles - A Proposed Section III Appendix N Nonmandatory Code*, Journal of Pressure Vessel Technology.
- Blevins, R. B., 1990, *Flow-Induced Vibration*, Van Nostrand Reinhold Company, New York, New York.

- Collins, J. A., 1981, *Failure of Materials in Mechanical Design*, John Wiley and Sons, Inc., New York, New York.
- Crane, 1978, *Flow of Fluids*, Technical Paper No. 410, New York, New York.
- DOE-RL, 1989, *Standard Arch-Civil Design Criteria; Design Loads for Facilities*, SDC-4.1, Rev. 11, U. S. Department of Energy, Richland, Operations Office, Richland, Washington.
- Ellingson, S. D., 1993, *Specification for Waste Mobilization Mixer Pump*, Project W-151, Tank AZ-101 Waste Retrieval System, WHC-S-040, Westinghouse Hanford Company, Richland, Washington.
- Jones, F. D., and E. Oberg, 1974, *Machinery's Handbook*, Industrial Press, Inc., New York, New York.
- Robertson, J. A. and C. T. Crowe, 1985, *Engineering Fluid Mechanics*, Third Edition, Houghton Mifflin Company, Boston, Massachusetts.
- Swanson Analysis System, 1992, *ANSYS User's Manual*, for Rev. 5.0, Swanson Analysis Systems, Inc., Houston, Pennsylvania.
- Waters, E. D. and E. T. Heimberger, 1993, *Stress Cycle and Forces on In-Tank Components Resulting From Mixer Pump Operation in DST 101-AZ*, WHC-SD-W151-ER-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994, *TWRS Temperature Probe Housing Assembly 4 Details*, 1994, Drawing H-2-73-79344, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A
STRUCTURAL CALCULATIONS

TYPICAL CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed	Structural Evaluation of Thermocouple Probes fpr 241-AN-101 Waste Tank		
Author	S. K. Kanjilal		
Yes	No	N/A	
[✓]	[]	[]	Problem completely defined.
[✓]	[]	[]	Necessary assumptions explicitly stated and supported.
[✓]	[]	[]	Computer codes and data files documented.
[✓]	[]	[]	Data used in calculations explicitly stated in document.
[✓]	[]	[]	Data checked for consistency with original source information as applicable.
[✓]	[]	[]	Mathematical derivations checked including dimensional consistency of results.
[✓]	[]	[]	Models appropriate and used within range of validity or use outside range of established validity justified.
[✓]	[]	[]	Hand calculations checked for errors.
[✓]	[]	[]	Code run streams correct and consistent with analysis documentation.
[✓]	[]	[]	Code output consistent with input and with results reported in analysis documentation.
[✓]	[]	[]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[✓]	[]	[]	Safety margins consistent with good engineering practices.
[✓]	[]	[]	Conclusions consistent with analytical results and applicable limits.
[✓]	[]	[]	Results and conclusions address all points required in the problem statement.

MANDATORY

Software QA Log Number 94-046

Warcher
Reviewer

9-9-94
Date

09/22/93

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____
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 (7) Subject 241-AZ-101
 (8) Originator SK Gumbel Date 9-1-94
 (9) Checker NW Chen Date 9-9-94

(10)

DESIGN INPUT DATAS:

Outside diameter of probe = 5.5 in

Inside dia. of probe = 3.75 in.

Length of probe = 57.5' = 690 in.

$$\rho_{\text{steel}} = \text{density of steel} = 490 \frac{\text{lb}}{\text{ft}^3} = 0.2836 \frac{\text{lb}}{\text{in}^3}$$

$$= \frac{0.2836}{386.4} = 0.00073386 \frac{\text{lb sec}^2}{\text{in}^4}$$

$$\rho_{\text{water}} = \text{density of water} = 74.914 \frac{\text{lb}}{\text{ft}^3}$$

(Ref Water, 1993)

$$= 0.0001122877 \frac{\text{lb sec}^2}{\text{in}^4}$$

Submerged density of thermocouple probe

$$= 0.00073386 + 0.0001122877$$

$$= 0.00084615 \frac{\text{lb sec}^2}{\text{in}^4}$$

LOADING:

$$\text{Max. drag force} = 122 + 17 = 139 \text{ lb}$$

(refer Table 4.6, Water, 1993)

$$\text{Max. lift force} = 40\% \text{ of drag force}$$

$$= 0.4 \times 139 = 55.6 \text{ lb}$$

(Refer, Water, 1993)

DESIGN CALCULATION

WHC-SD-WISI-ANAL-001
REV-0

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 (8) Originator SK Guptha Date 9-1-96
 (9) Checker W. W. Chen Date 9-9-94

(10)

THERMOCOUPLE PROBE $5\frac{1}{2}" \Phi$.

ANSYS COMPUTER MODEL

FILE TCP.IN.

A-5

$$\begin{aligned}
 I_{xx} &= 10014 \cos 57.5 + .31 \times .38 \times (X_d)^2 \\
 &= 10014 + 2.52 \sin 57.5 \\
 &= 10014 + 2.125 \\
 &= 10016.125 \\
 I_{yy} &= 10014 \sin 57.5 + .31 \times .38 \times (Z_d)^2 \\
 &= 10014 + 2.125 \\
 &= 10016.125 \\
 I_{zz} &= 10014 \sin 57.5 + .31 \times .38 \times (Z_d)^2 \\
 &= 10014 + 2.125 \\
 &= 10016.125
 \end{aligned}$$

Moment of Inertia (MI)
Determine MI for each slot:

Probe length 0'-3'
Cross sectional Area = 11.29 in² (Auto Calc)

REF. DWG. H-2-79350.

VIEW A-A
X-SECTIONAL AREA = 11.2866 SQ.

SECTIONAL PROPERTIES.
THERMO COUPLE PROBE 5/2" Φ.

(10)

(1) Drawing	(2) Doc. No.	(3) Page	of
(4) Building	(5) Rev.	(6) Job No.	
(7) Subject	241-A2-101		
(8) Originator	MWT/Kos		
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DESIGN CALCULATION

REV - 0

W4 C-50-WISI-ANAL-001

DESIGN CALCULATION

WHC-SD-WISI-ANAL-00
REV-0

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(7) Subject 241-AZ-101
(8) Originator BRQ/whl Date 9-1-94
(9) Checker WVW/whl Date 9-9-94

(10)

THERMOCOUPLE PROBE - 5/2" ϕ

Slot (2)

$$X_d = 2.52 \sin 45 = 1.7819$$

$$Z_d = 2.52 \cos 45 = 1.7819$$

$$I_{xx} = .0014 \sin 45 + (.31 \times .38)(1.7819)^2$$

$$= 0.375 \text{ in}^4$$

$$I_{zz} = 0.375 \text{ in}^4$$

Slot (3)

$$X_d = 2.52 \sin 32.5 = 1.354$$

$$Z_d = 2.52 \cos 32.5 = 2.125$$

$$I_{xx} = .0014 \cos 32.5 + (.31 \times .38)(1.354)^2$$

$$= 0.2171 \text{ in}^4$$

$$I_{zz} = .0014 \sin 32.5 + (.31 \times .38)(2.125)^2$$

$$= 0.5327 \text{ in}^4$$

Slot (4)

$$I_{xx} = \frac{1}{12} \times .31 \times (.38)^3 = .0014 \text{ in}^4$$

$$I_{zz} = \frac{1}{12} \times .38 \times (.31)^3 + (.31 \times .38)(2.52)^2$$

$$= 0.749 \text{ in}^4$$

Slot 1(a)

$$X_d = 2.52 \sin 32.5 = 1.354$$

$$Z_d = 2.52 \cos 32.5 = 2.125$$

$$I_{xx} = 0.2171 \quad I_{zz} = 0.5327 \quad \left(\text{as in Slot (3)} \right)$$

Slot 2(a) Same as Slot 2

$$I_{xx} = I_{zz} = 0.375$$

A-b

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____
 (4) Building _____ (5) Rev. _____ (6) Job No. _____
 (7) Subject 24-AZ-101
 (8) Originator SKO Date 9-1-94
 (9) Checker W.W. Chen Date 9-9-94

(10)

Slot (3a) Same as slot (1)

$$I_{xx} = 0.5327 \quad I_{zz} = 0.2171$$

$$x_d = 2.52 \cos 30 = 2.1824$$

$$z_d = 2.52 \sin 30 = 1.26$$

$$I_{xx} = 10014 \sin^2 30 + (31 \times 38) (2.1824)^2$$

$$= 0.5618 \text{ in}^4$$

$$I_{zz} = 10014 \cos^2 30 + (31 \times 38) (1.26)^2$$

$$= 0.1882 \text{ in}^4$$

Slot (6), Same as Slot (5)

$$I_{xx} = 0.5618 \text{ in}^4 \quad I_{zz} = 0.1882 \text{ in}^4$$

$$\Sigma I_{xx} \text{ of all slots}$$

$$= [(0.5327 + 0.375 + 0.2171)^2 + 10014 + 2 \times 0.5618]$$

$$= 3.3746 \text{ in}^4 \sim 3.375 \text{ in}^4$$

$$\Sigma I_{zz} \text{ of all slots.}$$

$$= [2(0.2171 + 0.375 + 0.5327) + 1749 + 2 \times 0.1882]$$

$$= 3.375 \text{ in}^4$$

Moment of Inertia of whole section without slots

$$I_{xx} = I_{zz} = \pi/64 (5.54^4 - 3.75^4) = 35.21$$

DESIGN CALCULATION

WHC-SD-WIS1-ANAL-001
REV-0

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 (9) Checker W. Zhor Date 9-9-94

(10) THERMO COUPLE PROBE $5\frac{1}{2}" \Phi$.

Net Moment of Inertia
 $I_{xx} = I_{zz} = 35.21 - 3.375 = 31.83 \text{ in}^4$

SECTION BETWEEN $3'-0"$ & $18'-3\frac{1}{2}"$ / $19'-11"$ FOR
 PART NO. 3.

Slot No. 1 & 1(a) ends.

$A = 11.6083$ (Auto Cad)

$I_{xx} = 31.83 + (.5827 + .2171)$
 $= 32.58 \text{ in}^4$

$I_{zz} = 32.58 \text{ in}^4$

VIEW B-B

X-SECTIONAL AREA = 11.6083 SQ. IN.

SECTION BETWEEN $19'-11"$ & $31'-10"$ (PART NO. 3)

Slot No. 2 & 2(a) ends.

$A = 11.9274 \text{ in}^2$

$I_{xx} = I_{zz} = 32.58 + (.375)^2$
 $= 33.34 \text{ in}^4$

VIEW C-C

X-SECTIONAL AREA = 11.9274 SQ. IN.

A-8

DESIGN CALCULATION

WHC-SD-WISI-ANAL-001
REV-0

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 (9) Checker WV Chen Date 9-9-94

(10) THERMOCOUPLE PROBE 5/2" Φ

SECTION between 31'-10" &
11'-5 7/8" from bottom (VIEW DD)

$$A = 12.2416 \text{ in}^2$$

Slot 3 & 3(a) ends.

$$I_{xx} = 33.34 + (.2171 + .5327) \\ = 34.09 \text{ in}^4$$

$$I_{zz} = \text{Same as } I_{xx} = 34.09 \text{ in}^4$$

VIEW D-D

X-SECTIONAL AREA = 12.2416 SQ. IN.

SECTION BETWEEN BOTTOM
11'-5 7/8" TO 0'-8 7/8"

Slot 6 ends.

$$A = 12.399 \text{ in}^2$$

$$I_{xx} = 34.09 + .5618 = 34.65$$

$$I_{zz} = 34.09 + .1882 = 34.28$$

VIEW E-E

X-SECTIONAL AREA = 12.3990 SQ. IN.

LAST BOTTOM SECTION:

$$A = 12.5563 \text{ in}^2$$

$$I_{xx} = 34.65 + .5618 = 35.21 \text{ in}^4$$

$$I_{zz} = 34.28 + .1882 = 34.47 \text{ in}^4$$

VIEW F-F

X-SECTIONAL AREA = 12.5563 SQ. IN.

A-9

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(10)

STRESS CALCULATIONS:

A simplified ANSYS Computer model is made, the thermocouple probe is modelled as a simple cantilever beam and with sectional properties as calculated.

Drop & Lift forces are applied at Node[#] 7 as a point concentrated load (conservative)

Max deflection Δ_{max} at node[#] 7 = 16.03" Node[#] 7
 (refer comp. run CANT. OUT)
 Page 43, APP. A.

Max deflection at Node[#] 10, Top of tank where riser started = 2.317" (ref

Comp. run CANT. OUT)
 PAGE-42, APPENDIX-A

Inside dia. of riser pipe = 6"

Clearance between thermocouple probe & riser = $\left(\frac{6 - 5.5}{2}\right) = 0.25"$

As the deflection of the probe is 2.317" > 0.25", the probe touches the riser pipe.

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(10)

As the probe contacts the riser the behaviour of the probe changes from a cantilever beam to a supported cantilever.

To simulate this behaviour, two springs of assumed spring constants ($10^6 \frac{\text{lb}}{\text{in}}$) are used at node # 10, the end of riser point.

The moment & forces are obtained from this model to evaluate the stress in the probe:

Refer ANSYS FILE PSTATI.IN

Δ_{max} at node # 7 = 6.6" (Refer page 53, Appendix A)

Reactive forces at Node # 1, at flange connection. (Refer page 57, Appendix A)

$$F_x = 428 \text{ \#}$$

$$M_x = 12.8 \text{ K-in}$$

$$F_y = 2581 \text{ \#}$$

$$M_z = 32.0 \text{ K-in}$$

$$F_z = 171 \text{ \#}$$

$$\begin{aligned} \text{Resultant moment} &= \sqrt{(12.8)^2 + (32)^2} \\ &= 34.46 \text{ K-in} \end{aligned}$$

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(10)

Section Modulus at Node[#] 1

(See page 7)

$$= \frac{31.83}{5.5/2} = 11.57 \text{ in}^3$$

$$f_{bx2,1} = 34.46 / 11.57 = 2.98 \text{ ksi.}$$

Max. Static moment at Node[#] 10

$$M_{x2} = \sqrt{(25.63)^2 + (64.59)^2}$$

$$= 69.55 \text{ K-m.}$$

Section modulus at Node[#] 10

$$= 33.34 / 2.75 = 12.12 \text{ in}^3 \text{ (page-)}$$

$$f_{bx2,10} = \frac{69.55}{12.12} = 5.74 \text{ ksi.}$$

Axial & Shear stresses are small and neglected.

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(10)

SEISMIC STRESS:

Refer ANSYS Computer run TMOD11.IN &
 TMOD. OUT.

The results of the modal analysis
 are the following: (Used 0.2g response spectrum)

Node # 1 (Appendix A, Page 117)

$$F_x = 455 \text{ k}$$

$$M_x = 33.95 \text{ k-in}$$

$$F_y = 257 \text{ k}$$

$$M_z = 33.95 \text{ k-in}$$

$$F_z = 455 \text{ k}$$

$$M_{xz} = \sqrt{(33.95)^2 + (33.95)^2} = 48.01 \text{ k-in}$$

$$\sigma_{xz(\text{seis})} = \frac{48.01}{11.57} = 4.15 \text{ ksi.}$$

Seismic stress from fluid dynamics
 i.e. from sloshing etc. (Refer Appendix B, Page 29)

$$\text{Max. moment} = 53.45 \text{ k-in}$$

$$\sigma_{xz(\text{slosh})} = \frac{53.45}{11.57} = 4.62 \text{ ksi.}$$

SRSS of Seismic & sloshing stresses

$$\sigma_{xz(\text{seis} + \text{slosh})} = \sqrt{(4.15)^2 + (4.62)^2} = 6.21 \text{ ksi}$$

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(10)

Operating + Seismic stress:

$$\sum \text{stress} = \sum \sigma_{xz_1} = 2.98 + 6.21$$

(Node # 1)

$$= 9.19 \text{ ksi}$$

Check bending stresses at Node # 10

Seismic modal analysis results: (Tmodal, out)

$$\begin{aligned} F_x &= 452^{\#} \\ F_y &= 245^{\#} \\ F_z &= 452^{\#} \end{aligned}$$

$$M_x = 68.25 \text{ K-in}$$

$$M_z = 68.25 \text{ K-in}$$

$$M_{xz} = \sqrt{(68.25)^2 + (68.25)^2}$$

$$= 96.52 \text{ K-in}$$

$$\sum_{xz}(\sigma_{is}) = \frac{96.52}{12.12} = 7.96 \text{ ksi}$$

Add stresses due to sloshing (σ_{RSS})

$$\sigma_{xz}(\sigma_{is})_{\text{total}} = \sqrt{(7.96)^2 + (4.62)^2} = 9.21 \text{ ksi}$$

(NOTE: Sloshing forces at node # 10 will be less as the probe touches the riser, results conservative)

$$\sum \text{stress}_{10} (\text{operating} + \text{seismic}) = 5.74 + 9.21$$

$$= 14.95 \text{ ksi}$$

Axial & shear stresses are small, and neglected in this calculation.

DESIGN CALCULATION

WHC-SD-WISI-ANAL-001
REV-0

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(10)

Allowable stresses: (AISC 9th edition)

$$\text{Bending} = 0.6 \times F_y = 0.6 \times 70 = 42 \text{ ksi}$$

(F_y = yield stress of the material = 70 ksi)
 Increase in the allowable stress by 33%
 for seismic combination.

$$\text{INTERACTION} \\ \text{Node}^{\#} 1 = \frac{9.17}{1.33 \times 42} = 0.16$$

$$\text{Node}^{\#} 10 = \frac{14.95}{1.33 \times 42} = 0.267$$

Local stresses at notches can be estimated
 with a concentration factor of 2.5 (conservative)

$$\text{Factor acting at Node}^{\#} 1 = 0.16 \times 2.5 = 0.4$$

$$\text{do - Node}^{\#} 10 = 0.267 \times 2.5 = 0.67$$

< 1 OK

WHC-SD-WISI-ANAL-001
REV-0

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PROJECT W-151 TEMP PROBE/ RISER CONTACT
PROFILE T/C & STRAIN GAGE CONFIGURATION

WELD (2)

WELD (1)

WELD (5)

WELD (3)

WELD (4)

2.256"

47°

.563"

11.74°

106.25°

5.196

2.129"

44.36°

.812"

16.91°

5.87"

.282"

POINT "D"

500 UNSUPPORTED

POINT "C"

6" RISER
6.060 I.D.

PROBE
5.500 O.D.

THERMOCOUPLE
SLOT

GAP AT POINT "C"-.007
GAP AT POINT "D"-.017

CADFILE: FREDAN

WELD CONFIGURATION

A-16

DESIGN CALCULATION

WHC-SD-WISI-ANAL-00
REV-0

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(8) Originator SK Ouphal Date 9-1-94
(9) Checker WV Chan Date 9-9-94

(10)

CALCULATE WELD PROPERTIES:

WELD - 1.

$$r = 2.75''$$

$$\text{Length of weld} = 0.812''$$

$$\theta = \frac{16.91}{2} = 8.455^\circ$$

$$= \frac{8.455\pi}{180} = 0.1476 \text{ rad.}$$

$$e = \frac{r \sin \theta}{\theta} = 2.739''$$

$$I_{X'} = r^3 \left(\theta + \frac{\sin 2\theta}{2} \right) = 6.094 \text{ in}^3$$

$$I_{Y'} = r^3 \left(\theta - \frac{\sin 2\theta}{2} \right) = 0.045 \text{ in}^3$$

$$I_{X'Y'} = 0 - 0.812 \times 2.739 = -2.224$$

Transfer the moment of inertia $I_{X'}$, $I_{Y'}$ & $I_{X'Y'}$ along X & Y axis, $\phi = 14.325^\circ$

$$I_X = \frac{I_{X'} + I_{Y'}}{2} + \frac{I_{X'} - I_{Y'}}{2} \cos 2\phi - I_{X'Y'} \sin 2\phi$$

$$= 3.0695 + 2.6543 + (-) 1.0663$$

$$= 6.79$$

$$I_Y = \frac{I_{X'} + I_{Y'}}{2} - \frac{I_{X'} - I_{Y'}}{2} \cos 2\phi + I_{X'Y'} \sin 2\phi$$

$$= 3.0695 - 2.6543 - 1.0663 = 0.6511 \text{ (abs. value)}$$

$$I_{XY} = \frac{I_{X'} - I_{Y'}}{2} \sin 2\phi + I_{X'Y'} \cos 2\phi = -0.5016$$

A-17

DESIGN CALCULATION

WHC-SD-WISI-ANAL-001
REV-0

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(7) Subject 241-AZ-101
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(9) Checker W. W. Chai Date 9-9-94

(10)

WELD - 2

$$L = 2.256''$$

$$\theta = \frac{47}{2} = 23.5^\circ$$

Co-ordinate axis
X-Y is inclined
 0.64° from the
Centroidal axis to
the weld. This
small angle is
ignored and
the weld is assumed

to be concentric
with X & Y axis.

$$\theta = \frac{23.5 \times \pi}{180} = 0.4102 \text{ rad.}$$

$$e = \frac{r \sin \theta}{\theta} = 2.6732''$$

$$I_x = r^3 \left(\theta + \frac{\sin 2\theta}{2} \right)$$

$$= 16.14 \text{ in}^3$$

$$I_y = r^3 \left(\theta - \frac{\sin 2\theta}{2} \right) = 0.926 \text{ in}^3$$

$$I_{xy} = 0 + 2.256 \times 2.6732 = 6.03 \text{ in}^3$$

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 (9) Checker NW Zher Date 9-9-94

(10)

WELD - 3

$$I_x = r^3 \left(\theta - \frac{\sin 2\theta}{2} \right) = 9.78 \text{ in}^3$$

$$I_y = r^3 \left(\theta + \frac{\sin 2\theta}{2} \right) = 29.53 \text{ in}^3$$

$$I_{xy} = 0 + 5.196 \times 2.358 = 12.25 \text{ in}^3$$

WELD - 4 Same as WELD-2 except I_{xy}

$$I_x = 16.14 \text{ in}^3 \quad I_y = 0.926 \text{ in}^3$$

$$I_{xy} = -2.256 \times 2.6732 = -6.03 \text{ in}^3$$

WELD - 5 Same as WELD-1

$$I_x = 6.79 \text{ in}^3 \quad I_y = 0.651 \text{ in}^3$$

A-19

DESIGN CALCULATION

WHC-SD-WISI-ANAL-001
REV-0

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 (9) Checker W. R. Z. H. S. Date 9-9-94

(10)

Σ Moment of Inertia about X & Y Axis.

$$\begin{aligned}\Sigma I_{xx} &= 2 \times 6.79 + 2 \times 16.14 + 9.78 \\ &= 55.64 \text{ in}^3\end{aligned}$$

$$\begin{aligned}\Sigma I_{yy} &= 2 \times 9.26 + 2 \times 16.51 + 29.53 \\ &= 32.884\end{aligned}$$

$$\begin{aligned}\Sigma I_{xy} &= 2 \times (-) 5016 + 0 + 12.25 \\ &= 11.25 \text{ in}^3.\end{aligned}$$

find ϕ for min & max Moment of Inertia.

$$\tan 2\phi = \frac{2 \times 11.25}{32.884 - 55.64} =$$

$$\phi = -22.21^\circ$$

$$\begin{aligned}I_{xx}(\text{Max}) &= \frac{I_x + I_y}{2} \pm \sqrt{\left(\frac{I_x - I_y}{2}\right)^2 + I_{xy}^2} \\ &= 55.9 \text{ \& } 32.4\end{aligned}$$

A-20

DESIGN CALCULATION

WHC-SD-WLSI-ANAL-001
REV-0

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(9) Checker W. Chen Date 9-9-94

(10)

calculate weld stresses:

forces & moments at Node # 1, (See page 10 & 12)

Forces & Moments	Operating loads.	Seismic loads.	Total.
F_x	428 [#]	455 [#]	883 [#] = 0.88 K
F_y	2581 [#]	257 [#]	2838 [#] = 2.84 K
F_z	171 [#]	455 [#]	628 [#] = 0.63 K
M_{xz}	3446 K-in	$\sqrt{(48.01)^2 + (53.45)^2}$ K-in (Sloshing) = 71.85 K-in	106.30 K-in.

Weld properties.

$$A_w = \text{Area of weld} = 2 \times 8.12 + 2 \times 2.256 + 5.196 = 11.33"$$

$$\text{Moment of Inertia: Assume min. moment of Inertia} = 32.4 \text{ in}^3.$$

Weld stress

$$f_x = \frac{0.88}{11.33} = 0.078 \text{ K/in.}$$

$$f_y = \frac{2.84}{11.33} + \frac{106.3 \times 2.75}{32.4} = 9.27 \text{ K/in.}$$

$$f_z = \frac{0.63}{11.33} = 0.056 \text{ K/in.}$$

$$f_p (\text{resultant}) = \left[(0.078^2 + 9.27^2 + 0.056^2) \right]^{1/2} = 9.27 \text{ K/in.}$$

A-21

DESIGN CALCULATION

WHC-SD-WISI-ANAL-001
REV-0

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(7) Subject 241-AZ-101
(8) Originator SK Goyal Date 9-1-94
(9) Checker W. W. W. Date 9-9-94

(10)

Weld allowable stress = $1.33 \times 0.3 \times 72 = 28.73 \text{ Ksi}$
(stress increased for seismic)
Minimum throat thickness reqd.

$$= \frac{9.27}{28.73} = 0.323"$$

It is recommended to increase the size of
this weld to $\frac{3}{8}"$ penetration weld. $\approx 0.375"$
throat.

*Excerpted 9/1/94
Waters 9/9/94*

Forces on the Thermocouple probe at riser 15B, 15C, 15F relative to a 2-pump configuration (1B plus 1D). See Waters 1993, Table 4.6, for details.

riser := 1..4

P_{riser} :=

139·lbf
114·lbf
81·lbf
43·lbf

Probes installed in risers 15L, 15C, 15F, 13.8 ft. from pump
Probe in riser 15A, 16.7 ft. from pump 1A (by interpolation)
Probe in 15B, 20.4 ft from pump 1B
Probe in 15F, 37.4 ft. from pump 1B

The cone of influence on the thermocouple probe for a two pump configuration

x_{riser} :=

13.8·ft
16.7·ft
20.4·ft
37.4·ft

15L, 15C, 15F
15A
15B
15F

d_n := 0.5·ft

Dia. of nozzle on mixing pump

θ := 7.5·deg

Angle of influence for cone (Waters 1993)

$d_{\text{riser}} := 2 \cdot \left(x_{\text{riser}} \cdot \tan(\theta) + \frac{d_n}{2} \right)$

Length that uniform load is applied

$\frac{d_{\text{riser}}}{\text{ft}}$

4.134
4.897
5.871
10.348

15L, 15C, 15F
15A
15B
15F

*Sketched 9/1/94
Waters 9-9-94*

Define units:

cycle := 1

Hz := $\frac{\text{cycle}}{\text{sec}}$

fps := $\frac{\text{ft}}{\text{sec}}$

Cd := 1

**Cd = Drag coefficient
considered 1 for circular
cylinder**

$\rho_{\text{waste}} := 74.914 \cdot \frac{\text{lb}}{\text{ft}^3}$

**Density of waste after mixing
(Waters 1993)**

$\rho_{\text{waste}} = 1.123 \cdot 10^{-4} \cdot \text{lb} \cdot \frac{\text{sec}^2}{\text{in}^4}$

do := 5.5-in

**Outside diameter of the
Probe**

Drag forces per unit length on the thermocouple

$F_{\text{riser}} := \frac{P_{\text{riser}}}{d_{\text{riser}}}$

P_{riser} = Drag force on the Probe lbf. (Water,1993)

$\frac{F_{\text{riser}}}{\left(\frac{\text{lbf}}{\text{ft}}\right)}$

33.627
23.279
13.796
4.156

15L, 15C, 15F

15A

15B

15F

Velocity at thermocouple probes

$V_{\text{riser}} := \sqrt{\frac{2 \cdot F_{\text{riser}}}{Cd \cdot \rho_{\text{waste}} \cdot do}}$

$\frac{V_{\text{riser}}}{\text{fps}}$

7.938
6.605
5.085
2.791

15L, 15C, 15F

15A

15B

15F

Rev 0

$$\nu := 2.3076 \cdot 10^{-4} \frac{\text{ft}^2}{\text{sec}}$$

(Kinematic Viscosity, Waters 1993)

Example 21.194
Wells, 9/6/94

Determine the Reynolds Number

$$\text{Re}_{\text{riser}} := \frac{V_{\text{riser}} \cdot d_o}{\nu}$$

 Re_{riser}

$1.577 \cdot 10^4$
$1.312 \cdot 10^4$
$1.01 \cdot 10^4$
$5.543 \cdot 10^3$

15L, 15C, 15F

15A

15B

15F

Calculation for vortex-shedding lock-in band frequencies

 $s := 1..4$

Direct pump impingement on 15A, 15B, 15C, 15F

 $n := 1..4$

Modes 1 thru 4 (Refer ANSYS run) or mode 1 thru 8 due to symmetry

Vortex shedding frequency (circular cylinder)

$$f_{\text{riser}} := \frac{0.2 \cdot V_{\text{riser}}}{d_o}$$

0.2 = Strouhl Number for the Reynolds Number range and circular cylinder

 f_{riser}
Hz

3.464
2.882
2.219
1.218

15L, 15C, 15F

15A

15B

15F

$$f_n :=$$

0.643 Hz
4.306 Hz
12.334 Hz
22.67 Hz

mode 1 & 2

mode 3 & 4

mode 5 & 6

mode 7 & 8

Natural frequencies (Refer ANSYS run)

Signature
9/1/94
Wuzhen 9/1/94

$$V_s$$

$$\text{fps}$$

7.938
6.605
5.085
2.791

15L, 15C, 15F

15A

15B

15F

$$U_n := \frac{f_n \cdot d_o}{0.20}$$

$$U_n$$

$$(\text{fps})$$

1.474
9.868
28.265
51.952

Band of lock-in frequencies

$$0.7 \cdot f_n \leq f_{\text{riser}} \leq 1.3 \cdot f_n$$

$$0.7 \cdot f_n$$

$$\text{Hz}$$

0.45
3.014
8.634
15.869

$$1.3 \cdot f_n$$

$$\text{Hz}$$

0.836
5.598
16.034
29.471

mode 1

mode 2

mode 3

mode 4

*Reviewed and
checked 3/5/94*

From the above frequency bands it is observed that the vortex shedding frequency 3.464 Hz lies in between 3.014 Hz and 5.598 Hz in mode 3. Probes installed in 15L, 15C, and 15F which are 13.8 ft. away from the jet may see the resonance effects. All other probes are in off-resonance for the vortex induced vibrations.

The actual flow field is nonuniform. The distribution of velocity pressure in both lateral and vertical directions are parabolic and not uniform. Semi-empirical assessment is made by using the maximum response amplitudes to ratio the modal results obtained from the seismic analysis.

This is based on uniform flow at resonant frequencies across the full submerged length and is considered to be conservative when the flow field is nonuniform. A semi-empirical correlation for predicting resonant vortex-induced vibration amplitude is given in Blevins 1990.

*80 gumbel gillan
which 7/9/94*

Calculation of maximum amplitude and mode shape for the 3rd. mode
for the probe 15L, 15F, and 15C that are 13.8 ft. away from the major pump.

$$L := 690 \cdot \text{in}$$

L = Length of probe

$$L1 := 225.48 \cdot \text{in}$$

L1 = Length of the probe above the tank (not submerged)

$$Mt := .0093 \cdot \text{lb} \cdot \frac{\text{sec}^2}{\text{in}^2}$$

Mt = Mass of steel in thermocouple probe / inch
length

$$Ms := .012 \cdot \text{lb} \cdot \frac{\text{sec}^2}{\text{in}^2}$$

Ms = Submerged mass of the probe / inch length
(includes added mass)

$$L0 := 0 \cdot \text{in}$$

$$L2 := 49.6 \cdot \text{in}$$

L2 = Length over which the jet hits the probe

$$d := 5.5 \cdot \text{in}$$

d = Outer dia. of probe

$$\text{mass} := \text{lb} \cdot \frac{\text{sec}^2}{\text{in}^2} \quad \text{length} := \text{in}$$

$$\rho := 0.0001122877 \cdot \text{lb} \cdot \frac{\text{sec}^2}{\text{in}^4}$$

Density of liquid waste (Water, 1993)

$$v\psi := \text{READPRN}(\text{MODE})$$

Read ANSYS mode shape file

$$v_y := \text{READPRN}(\text{DIST})$$

$$v_s := \text{cspline}(v_y, v\psi)$$

$$\psi(y) := \text{interp}(v_s, v_y, v\psi, y)$$

$$y := 0, 36, 690$$

Mode shape three as a function of the
distance.

A-28

*Exemplar 2/1/94
Wurden 9/9/94*

Equivalent flow induced mass per unit length of the thermocouple submerged in the liquid waste (Blevins 1990 and Au-Yang 1991)

$$m_e := \frac{\int_{L0}^{L1} M_t \cdot \psi(y)^2 dy + \int_{L1}^L M_s \cdot \psi(y)^2 dy}{\int_{L2}^L \psi(y)^2 dy}$$

m_e = Equivalent flow induced mass for the 3rd. mode.

$$m_e = 0.012 \cdot \frac{\text{lbf} \cdot \text{sec}^2}{\text{in}^2}$$

The mode shape function

Γ is expressed as follows

$$\Gamma := \left[\frac{.2129 \cdot \left[\frac{\int_0^{690} \psi(y)^2 dy}{\int_0^{690} \psi(y)^4 dy} \right]^{\frac{1}{2}}}{.2129} \right]$$

$$\Gamma = 1.515$$

The peak resonant cylinder amplitude is expressed in terms of a single variable called the reduced damping coefficient

$$\delta_r := \frac{4 \cdot \pi \cdot m_e \cdot 1}{\rho \cdot d^2}$$

where δ_r is the reduced damping coefficient.

and damping of structure and fluid is assumed as 0.1
10 % damping is assumed based on energy dissipation
at the riser point where the probe will hit the riser pipe

$$\delta_r = 4.432$$

St. Germain 9/11/94
work 9/9/94

The maximum amplitude along the span for the third mode is expressed as

$$A = \frac{d \cdot 0.07 \cdot \Gamma}{(\delta r + 1.9) \cdot 2^2} \sqrt{0.30 + \frac{0.72}{(\delta r + 1.9) \cdot 0.2}}$$

where A = peak amplitude.

Γ = Mode shape function

(Refer Blevins 1990)

$$A = 2.146 \cdot \text{in}$$

Max. Amplitude along the span for mode 3

Modal deflections

$$u(y) = \frac{A \cdot \psi(y)}{\max(\psi)}$$

$\frac{u(y)}{\text{in}}$
0
0.035
0.11
0.187
0.23
0.199
0.06
-0.217
-0.583
-0.964
-1.288
-1.484
-1.514
-1.383
-1.1
-0.673
-0.113
0.551
1.277
2.022

Deflections
along the length
in inches

Distance from top of probe

*Sketched 9/11/94
W. Meta 9/9/94*

Calculation for modal moment

$$E := 29 \cdot 10^6 \frac{\text{lbf}}{\text{in}^2}$$

$$I := 33 \cdot \text{in}^4$$

$$M(y) := \frac{E \cdot I}{\text{in}^2} \left(\frac{d}{dy} \frac{d}{dy} u(y) \right)$$

where $u(y)$ is the displacement function

in^2 units are put in the denominator to calculate units for MATHCAD operations.

Moment in inch.lbf.

Distance from top

$M(y)$
lbf.in

$5.682 \cdot 10^4$
$2.926 \cdot 10^4$
$1.706 \cdot 10^3$
$-2.585 \cdot 10^4$
$-5.34 \cdot 10^4$
$-8.342 \cdot 10^4$
$-1.037 \cdot 10^5$
$-6.867 \cdot 10^4$
$-1.217 \cdot 10^4$
$4.466 \cdot 10^4$
$9.209 \cdot 10^4$
$1.191 \cdot 10^5$
$1.234 \cdot 10^5$
$1.17 \cdot 10^5$
$1.093 \cdot 10^5$
$9.475 \cdot 10^4$
$7.402 \cdot 10^4$
$4.778 \cdot 10^4$
$1.708 \cdot 10^4$
$-1.55 \cdot 10^4$

Modal nominal alternating bending stress due to resonance.

$$S := \frac{I}{\left(\frac{d}{2} \right)}$$

$$S = 12 \cdot \text{in}^3$$

$$\sigma(y) := \frac{M(y)}{S}$$

Excluded 9/11/94
Wash 9/9/94

$\frac{\sigma(y)}{\left(\frac{\text{lb}_f}{\text{in}^2}\right)}$

$4.735 \cdot 10^3$
$2.438 \cdot 10^3$
142.195
$-2.154 \cdot 10^3$
$-4.45 \cdot 10^3$
$-6.952 \cdot 10^3$
$-8.641 \cdot 10^3$
$-5.723 \cdot 10^3$
$-1.014 \cdot 10^3$
$3.722 \cdot 10^3$
$7.674 \cdot 10^3$
$9.927 \cdot 10^3$
$1.029 \cdot 10^4$
$9.751 \cdot 10^3$
$9.112 \cdot 10^3$
$7.896 \cdot 10^3$
$6.168 \cdot 10^3$
$3.982 \cdot 10^3$
$1.424 \cdot 10^3$
$-1.292 \cdot 10^3$

Distance from top (in)

Fatigue due to Vortex shedding from normal pump operation

**For the fatigue a fatigue concentration factor is applied to the stresses
(Peterson 1974 Figure 182 and Collins 1981)**

$p := 0.007225$

p = material constant based on Tensile strength of 80 ksi,
Figure 12.14 (Collins 1981)

$r := 0.13$

Contour radius of the notch root

$K := 2.04$

Stress concentration factor for the key slots (Peterson 1974)

$$K_1 := 1 + \left[\frac{K - 1}{1 + \sqrt{\frac{p}{r}}} \right]$$

$$K_1 = 1.842$$

Exhausted
9/1/94
crack 9/9/94

Refer ASME 1992 Section III, Division 1, Appendices as Figure I-9.1 (ASME 1992)

$$\sigma_{base} := 13500 \cdot \frac{\text{lbf}}{\text{in}^2}$$

Allowable Stress, Fatigue limit per ASME 1992
(Endurance limit)

$$K_1 = 1.842$$

$$\sigma_{shed}(y) := K_1 \cdot (\sigma(y))$$

$\sigma_{shed}(y)$

$\left(\frac{\text{lbf}}{\text{in}^2} \right)$

$8.719 \cdot 10^3$
$4.491 \cdot 10^3$
261.865
$-3.967 \cdot 10^3$
$-8.196 \cdot 10^3$
$-1.28 \cdot 10^4$
$-1.591 \cdot 10^4$
$-1.054 \cdot 10^4$
$-1.867 \cdot 10^3$
$6.854 \cdot 10^3$
$1.413 \cdot 10^4$
$1.828 \cdot 10^4$
$1.894 \cdot 10^4$
$1.796 \cdot 10^4$
$1.678 \cdot 10^4$
$1.454 \cdot 10^4$
$1.136 \cdot 10^4$
$7.333 \cdot 10^3$
$2.622 \cdot 10^3$
$-2.379 \cdot 10^3$

*SA Gueybol 9/1/94
Wmcler 9/4/94*

Max. bending stress with fatigue stress concentration factor = 18940 psi

For bending stress of 18.94 ksi, the allowable no. of cycles are 2,000,000

(Ref. ASME 1993, Fig. I-9.I)

Max. bending stress due to normal operation loads = 5.74 ksi

Allowable no. of cycles = more than 10,000,000 cycles

Max bending stress due to seismic and sloshing = 6.21 ksi

Allowable no of cycle = more than 20,000,000 cycles

$$\tan \theta_{\text{shed}} := \frac{\frac{d}{2}}{13.8 \cdot 12 \cdot \text{in}} \cdot 2$$

$$\tan \theta_{\text{shed}} = 1.903 \cdot \text{deg}$$

angle at which the thermocouple probe is exposed to vortex shedding. 13.8 ft is the shortest distance of the probe from pump

$$\theta_{\text{shed}} := 2.5 \cdot \text{deg}$$

$$\text{cycle} := 1$$

Assume angle of jet at which the thermocouple probe is exposed to vortex shedding in the third mode of vibration

$$\text{Hz} := \frac{\text{cycle}}{\text{sec}}$$

$$N_{\text{pro}} := 2 \cdot 10^6 \cdot \text{cycle}$$

Allowable No. of cycles for the operating stress including seismic

$$N_{\text{shed}} := 2 \cdot 10^5 \cdot \text{cycle}$$

Allowable No. of cycle for the resonant alternating stresses

$$\text{rev} := \frac{1 \cdot \text{rad}}{\text{cycle}}$$

$$\Omega_{\text{pump}} := 0.1 \cdot \frac{\text{rev}}{\text{min}}$$

$$T_{\text{shed}} := \frac{\theta_{\text{shed}} \cdot 1}{360 \cdot \text{deg} \cdot \Omega_{\text{pump}}}$$

$$T_{\text{shed}} = 4.167 \cdot \frac{\text{sec}}{\text{cycle}}$$

$$n_{\text{probe}} := \frac{1}{\left(\frac{1}{N_{\text{pro}}} \right) + 4.306 \cdot \text{Hz} \cdot \left(\frac{T_{\text{shed}}}{N_{\text{shed}}} \right)}$$

$$n_{\text{probe}} = 1.109 \cdot 10^4 \cdot \text{cycle}$$

Total allowable number of cycles that the thermocouple probe can withstand in riser 15L(1C,1A), 15C(1B,1D) 15F(1C,1A)

SK Querbach 9/19/94

$$\Omega_{\text{pump}} := 0.15 \frac{\text{rev}}{\text{min}}$$

$$T_{\text{shed}} := \frac{\theta_{\text{shed}}}{360 \cdot \deg \cdot \Omega_{\text{pump}}} \cdot 1$$

$$T_{\text{shed}} = 2.778 \cdot \text{time}$$

$$n_{\text{probe}} := \frac{1}{\left(\frac{1}{N_{\text{pro}}} \right) + 4.306 \cdot \text{Hz} \cdot \left(\frac{T_{\text{shed}}}{N_{\text{shed}}} \right)}$$

$$n_{\text{probe}} = 1.658 \cdot 10^4$$

Total allowable number of cycles for a pump speed of 0.15 rpm

APPENDIX A
COMPUTER PRINTOUTS

ANSYS FILENAME: CANT.IN

Sub : Static analysis of the thermocouple probe assuming the probe behaves as a cantilever. Both the drag and lift forces are considered in this analysis. Output file CANT.OUT is attached with this input file.

/title,Modal analysis of thermocouple tree with spring restraint

et,1,4

et,2,14,,1,

et,3,14,,3,

!

r,1,11.29,31.83,31.83,5.5,5.5,

r,2,11.608,32.58,32.58,5.5,5.5,

r,3,11.9274,33.34,33.34,5.5,5.5,

r,4,12.2416,34.09,34.09,5.5,5.5,,

r,5,12.399,34.65,34.28,5.5,5.5,

r,6,12.5563,35.21,34.47,5.5,5.5,

r,7,1e6

r,8,1e6

ex,1,29e6

dens,1,.00073386

nuxy,1,.3

ex,2,29e6

dens,2,.00084611

nuxy,2,.3

!

n,1,,,,

n,2,,,-36,,

n,3,,,-239,,

n,4,,,-382,,

n,5,,,-552.12,,

n,6,,,-681.125,,

n,7,,,-690,,

n,10,,,-225.48,,

!

mat,1

type,1

real,1

e,1,2

!

real,2

e,2,10

e,10,3

mat,2

type,1

real,3

e,3,4

!

real,4

```
e,4,5  
!  
real,5  
e,5,6  
!  
real,6  
e,6,7  
!  
d,1,all  
fini  
!  
!  
/solu  
outpr,all,all  
antype,static  
f,7,fx,139,,,  
f,7,fz,55.6,,,  
acel,,386.4,,  
lswrite  
solve  
finish
```

ANSYS FILE CANT. OUT

/INPUT FILE= cant.in LINE= 0

TITLE=
Static analysis of thermocouple tree

ELEMENT TYPE 1 IS BEAM4 3-D ELASTIC BEAM
KEYOPT(1-12)= 0 0 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

ELEMENT TYPE 2 IS COMBIN14 SPRING-DAMPER
KEYOPT(1-12)= 0 1 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

ELEMENT TYPE 3 IS COMBIN14 SPRING-DAMPER
KEYOPT(1-12)= 0 3 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

REAL CONSTANT SET 1 ITEMS 1 TO 6
11.290 31.830 31.830 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 2 ITEMS 1 TO 6
11.608 32.580 32.580 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 3 ITEMS 1 TO 6
11.927 33.340 33.340 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 4 ITEMS 1 TO 6
12.242 34.090 34.090 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 5 ITEMS 1 TO 6
12.399 34.650 34.280 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 6 ITEMS 1 TO 6
12.556 35.210 34.470 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 7 ITEMS 1 TO 6
0.10000E+07 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
0.00000E+00

REAL CONSTANT SET 8 ITEMS 1 TO 6
0.10000E+07 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
0.00000E+00

MATERIAL 1 EX = 0.2900000E+08

MATERIAL 1 DENS = 0.7338600E-03

MATERIAL 1 NUXY = 0.3000000

MATERIAL 2 EX = 0.2900000E+08

MATERIAL 2 DENS = 0.8461100E-03

MATERIAL 2 NUXY = 0.3000000

NODE 1 KCS= 0 X,Y,Z= 0.00000E+00 0.00000E+00 0.00000E+00

NODE 2 KCS= 0 X,Y,Z= 0.00000E+00 -36.000 0.00000E+00

NODE 3 KCS= 0 X,Y,Z= 0.00000E+00 -239.00 0.00000E+00

NODE 4 KCS= 0 X,Y,Z= 0.00000E+00 -382.00 0.00000E+00

NODE 5 KCS= 0 X,Y,Z= 0.00000E+00 -552.12 0.00000E+00

NODE 6 KCS= 0 X,Y,Z= 0.00000E+00 -681.13 0.00000E+00

NODE 7 KCS= 0 X,Y,Z= 0.00000E+00 -690.00 0.00000E+00

NODE 10 KCS= 0 X,Y,Z= 0.00000E+00 -225.48 0.00000E+00

MATERIAL NUMBER SET TO 1

ELEMENT TYPE SET TO 1

REAL CONSTANT NUMBER= 1

ELEMENT 1 1 2 0

REAL CONSTANT NUMBER= 2

ELEMENT 2 2 10 0

ELEMENT 3 10 3 0

MATERIAL NUMBER SET TO 2

ELEMENT TYPE SET TO 1

REAL CONSTANT NUMBER= 3

ELEMENT 4 3 4 0

REAL CONSTANT NUMBER= 4

ELEMENT 5 4 5 0

REAL CONSTANT NUMBER= 5

ELEMENT 6 5 6 0

REAL CONSTANT NUMBER= 6

ELEMENT 7 6 7 0

SPECIFIED CONSTRAINT UX FOR SELECTED NODES 1 TO 1 BY 1
REAL= 0.000000000E+00 IMAG= 0.000000000E+00
ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ

***** ROUTINE COMPLETED ***** CP = 2.490

***** ANSYS SOLUTION ROUTINE *****

PRINT ALL ITEMS WITH A FREQUENCY OF ALL
FOR ALL APPLICABLE ENTITIES

PERFORM A STATIC ANALYSIS
THIS WILL BE A NEW ANALYSIS

SPECIFIED NODAL LOAD FX FOR SELECTED NODES 7 TO 7 BY 1
REAL= 139.000000 IMAG= 0.000000000E+00

SPECIFIED NODAL LOAD FZ FOR SELECTED NODES 7 TO 7 BY 1
REAL= 55.600000 IMAG= 0.000000000E+00

ACEL= 0.00000E+00 386.40 0.00000E+00

WRITE ANSYS LOADS DATA AS FILE=skk.s01

***** ANSYS SOLVE COMMAND *****

SOLUTION OPTIONS

PROBLEM DIMENSIONALITY.3-D
DEGREES OF FREEDOM. UX UY UZ ROTX ROTY ROTZ
ANALYSIS TYPESTATIC (STEADY-STATE)

*** NOTE *** CP= 2.600 TIME= 14:27:20
Real constant set 7 is not used by any element types that require real constants.

*** NOTE *** CP= 2.610 TIME= 14:27:25
Real constant set 8 is not used by any element types that require real constants.

*** NOTE *** CP= 2.640 TIME= 14:27:29
Present time 0 is less than or equal to the previous time.
Time will default to 1.

LOAD STEP OPTIONS

LOAD STEP NUMBER.1
TIME AT END OF THE LOAD STEP.1.0000
NUMBER OF SUBSTEPS.1
STEP CHANGE BOUNDARY CONDITIONSNO
INERTIA LOADS X Y Z
ACEL0.00000E+00 386.40 0.00000E+00
PRINT OUTPUT CONTROLS
ITEM FREQUENCY COMPONENT
ALL ALL
DATABASE OUTPUT CONTROLS.ALL DATA WRITTEN
FOR THE LAST SUBSTEP

***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****

CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS = 6.6804

CENTROID	MOM. OF INERTIA ABOUT ORIGIN	MOM. OF INERTIA ABOUT CENTROID
XC = 0.00000E+00	IXX = 0.1116E+07	IXX = 0.2444E+06
YC = -361.26	IYY = 0.0000E+00	IYY = 0.0000E+00
ZC = 0.00000E+00	IZZ = 0.1116E+07	IZZ = 0.2444E+06

IXY =	0.0000E+00	IXY =	0.0000E+00
IYZ =	0.0000E+00	IYZ =	0.0000E+00
IZX =	0.0000E+00	IZX =	0.0000E+00

*** MASS SUMMARY BY ELEMENT TYPE ***

TYPE	MASS
1	6.68042

Range of element maximum matrix coefficients in global coordinates
Maximum= 460209577 at element 7.
Minimum= 19945535.1 at element 2.

*** ELEMENT MATRIX FORMULATION TIMES

TYPE	NUMBER	ENAME	TOTAL CP	AVE CP
------	--------	-------	----------	--------

1	7	BEAM4	0.030	0.004
---	---	-------	-------	-------

Time at end of element matrix formulation CP= 2.73000002.

Estimated number of active DOF= 42.
Maximum wavefront= 24.

Time at end of matrix triangularization CP= 2.80999994.
Equation solver maximum pivot= 120984606 at node 6 ROTZ.
Equation solver minimum pivot= 35.2859637 at node 7 UZ.

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****	
WEST. HANFORD VERSION=SGI IRIS4D 14:27:37 SEP 07, 1994 CP=	2.820
FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX	

*** PROBLEM STATISTICS

ACTUAL NO. OF ACTIVE DEGREES OF FREEDOM =	42
R.M.S. WAVEFRONT SIZE =	12.1

*** ANSYS BINARY FILE STATISTICS

BUFFER SIZE USED=	4096
0.031 MB WRITTEN ON ELEMENT MATRIX FILE:	skk.emat
0.016 MB WRITTEN ON ELEMENT SAVED DATA FILE:	skk.esav
0.016 MB WRITTEN ON TRIANGULARIZED MATRIX FILE:	skk.tri
0.047 MB WRITTEN ON RESULTS FILE:	skk.rst

FINISH SOLUTION PROCESSING

***** ROUTINE COMPLETED ***** CP = 3.040

***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER /SHOW,DEVICE-NAME TO ENABLE GRAPHIC DISPLAY
ENTER FINISH TO LEAVE POST1

*** NOTE *** CP= 3.250 TIME= 14:27:57
The element set contains elements that have only one structural degree of freedom per node. Viewing nodal displacements or forces in other than the nodal coordinate system may be invalid.

USE LOAD STEP 1 SUBSTEP 1 FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP= 1 SUBSTEP= 1 CUMULATIVE ITERATION= 1
TIME/FREQUENCY= 1.0000

PRODUCE DISPLACEMENT PLOT, KUND= 1

PRINT DOF NODAL SOLUTION PER NODE

***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

LOAD STEP= 1 SUBSTEP= 1
TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2	0.66158E-01	-0.27749E-03	0.26463E-01	-0.14572E-02	0.00000E+00	0.36429E-02
3	2.5830	-0.15631E-02	1.0332	-0.80573E-02	0.00000E+00	0.20143E-01
4	6.0564	-0.21911E-02	2.4226	-0.11178E-01	0.00000E+00	0.27945E-01
5	11.322	-0.26223E-02	4.5287	-0.13311E-01	0.00000E+00	0.33278E-01
6	15.724	-0.27292E-02	6.2900	-0.13841E-01	0.00000E+00	0.34587E-01
7	16.031	-0.27297E-02	6.4129	-0.13843E-01	0.00000E+00	0.34593E-01
10	2.3168	-0.14900E-02	0.92672	-0.76931E-02	0.00000E+00	0.19233E-01

MAXIMUM VALUES
 NODE 7 7 7 7 0 7
 VALUE 16.031 -0.27297E-02 6.4129 -0.13843E-01 0.00000E+00
 0.34593E-01

PRINT REACTION SOLUTIONS PER NODE

***** POST1 TOTAL REACTION SOLUTION LISTING *****

LOAD STEP= 1 SUBSTEP= 1
 TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
1	-139.00	2581.3	-55.600	38364.	0.00000E+00	-95910.

TOTAL VALUES
 VALUE -139.00 2581.3 -55.600 38364. 0.00000E+00 -95910.

PRINT F ELEMENT SOLUTION PER ELEMENT

***** POST1 ELEMENT NODE TOTAL FORCE LISTING *****

LOAD STEP= 1 SUBSTEP= 1
 TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

ELEM=	1	FX	FY	FZ
1	139.00	-2581.3	55.600	
2	-139.00	2466.1	-55.600	

ELEM=	2	FX	FY	FZ
2	139.00	-2466.1	55.600	
10	-139.00	1842.4	-55.600	

A-45

ELEM=	3	FX	FY	FZ
10	139.00	-1842.4	55.600	
3	-139.00	1797.9	-55.600	

ELEM=	4	FX	FY	FZ
3	139.00	-1797.9	55.600	
4	-139.00	1240.2	-55.600	

ELEM=	5	FX	FY	FZ
4	139.00	-1240.2	55.600	
5	-139.00	559.38	-55.600	

ELEM=	6	FX	FY	FZ
5	139.00	-559.38	55.600	
6	-139.00	36.433	-55.600	

ELEM=	7	FX	FY	FZ
6	139.00	-36.433	55.600	
7	-139.00	0.79652E-11	-55.600	

PRINT M ELEMENT SOLUTION PER ELEMENT

***** POST1 ELEMENT NODE TOTAL FORCE LISTING *****

LOAD STEP= 1 SUBSTEP= 1

TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

ELEM=	1	MX	MY	MZ
1	-38364.	0.00000E+00	95910.	
2	36362.	0.00000E+00	-90906.	

ELEM=	2	MX	MY	MZ
2	-36362.	0.00000E+00	90906.	
10	25827.	0.00000E+00	-64568.	

ELEM=	3	MX	MY	MZ
-------	---	----	----	----

10	-25827.	0.00000E+00	64568.
3	25076.	0.00000E+00	-62689.
ELEM= 4 MX MY MZ			
3	-25076.	0.00000E+00	62689.
4	17125.	0.00000E+00	-42812.
ELEM= 5 MX MY MZ			
4	-17125.	0.00000E+00	42812.
5	7666.1	0.00000E+00	-19165.
ELEM= 6 MX MY MZ			
5	-7666.1	0.00000E+00	19165.
6	493.45	0.00000E+00	-1233.6
ELEM= 7 MX MY MZ			
6	-493.45	0.00000E+00	1233.6
7	-0.17695E-07	0.00000E+00	0.10617E-06

EXIT THE ANSYS POST1 DATABASE PROCESSOR

***** ROUTINE COMPLETED ***** CP = 4.190

PURGE ALL SOLUTION AND POST DATA
SAVE ALL MODEL DATA

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= skk.db
FOR POSSIBLE RESUME FROM THIS POINT

NUMBER OF WARNING MESSAGES ENCOUNTERED=	0
NUMBER OF ERROR MESSAGES ENCOUNTERED=	0

ANSYS FILE NAME : PSTAT1.IN

Sub: Static analysis of thermocouple probe with springs in both lateral directions at the point where the tank rises meets the tank dome.

/title,Modal analysis of thermocouple tree with spring restraint

et,1,4

et,2,14,,1,

et,3,14,,3,

!

r,1,11.29,31.83,31.83,5.5,5.5,

r,2,11.608,32.58,32.58,5.5,5.5,

r,3,11.9274,33.34,33.34,5.5,5.5,

r,4,12.2416,34.09,34.09,5.5,5.5,,

r,5,12.399,34.65,34.28,5.5,5.5,

r,6,12.5563,35.21,34.47,5.5,5.5,

r,7,1e6

r,8,1e6

ex,1,29e6

dens,1,.00073386

nuxy,1,.3

ex,2,29e6

dens,2,.00084611

nuxy,2,.3

!

n,1,,,,

n,2,, -36,,

n,3,, -239,,

n,4,, -382,,

n,5,, -552.12,,

n,6,, -681.125,,

n,7,, -690,,

n,8,, -225.48,,

n,9,, -225.48,,

n,10,, -225.48,,

!

mat,1

type,1

real,1

e,1,2

!

real,2

e,2,10

e,10,3

mat,2

type,1

real,3

```
e,3,4
!
real,4
e,4,5
!
real,5
e,5,6
!
real,6
e,6,7
!
type,2
real,7
e,10,8
!
type,3
real,8
e,10,9
!
d,1,all
d,8,all
d,9,all
fini
!
/solu
outpr,all,all
antype,static
f,7,fx,139,,,
f,7,fz,55.6,,,
acel,,386.4,,
lswrite
solve
finish
```

ANSYS FILE NAME: PSTAT1.OUT

Output file for PSTAT1.in

/INPUT FILE= pstat1.in LINE= 0

TITLE=

Modal analysis of thermocouple tree with spring restraint

ELEMENT TYPE 1 IS BEAM4 3-D ELASTIC BEAM
KEYOPT(1-12)= 0 0 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

ELEMENT TYPE 2 IS COMBIN14 SPRING-DAMPER
KEYOPT(1-12)= 0 1 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

ELEMENT TYPE 3 IS COMBIN14 SPRING-DAMPER
KEYOPT(1-12)= 0 3 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

REAL CONSTANT SET 1 ITEMS 1 TO 6
11.290 31.830 31.830 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 2 ITEMS 1 TO 6
11.608 32.580 32.580 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 3 ITEMS 1 TO 6
11.927 33.340 33.340 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 4 ITEMS 1 TO 6

12.242 34.090 34.090 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 5 ITEMS 1 TO 6
12.399 34.650 34.280 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 6 ITEMS 1 TO 6
12.556 35.210 34.470 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 7 ITEMS 1 TO 6
0.10000E+07 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
0.00000E+00

REAL CONSTANT SET 8 ITEMS 1 TO 6
0.10000E+07 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
0.00000E+00

MATERIAL 1 EX = 0.2900000E+08

MATERIAL 1 DENS = 0.7338600E-03

MATERIAL 1 NUXY = 0.3000000

MATERIAL 2 EX = 0.2900000E+08

MATERIAL 2 DENS = 0.8461100E-03

MATERIAL 2 NUXY = 0.3000000

NODE 1 KCS= 0 X,Y,Z= 0.00000E+00 0.00000E+00 0.00000E+00

NODE 2 KCS= 0 X,Y,Z= 0.00000E+00 -36.000 0.00000E+00

NODE 3 KCS= 0 X,Y,Z= 0.00000E+00 -239.00 0.00000E+00

NODE 4 KCS= 0 X,Y,Z= 0.00000E+00 -382.00 0.00000E+00

NODE 5 KCS= 0 X,Y,Z= 0.00000E+00 -552.12 0.00000E+00

NODE 6 KCS= 0 X,Y,Z= 0.00000E+00 -681.13 0.00000E+00

NODE 7 KCS= 0 X,Y,Z= 0.00000E+00 -690.00 0.00000E+00

NODE 8 KCS= 0 X,Y,Z= 0.00000E+00 -225.48 0.00000E+00

NODE 9 KCS= 0 X,Y,Z= 0.00000E+00 -225.48 0.00000E+00

NODE 10 KCS= 0 X,Y,Z= 0.00000E+00 -225.48 0.00000E+00

MATERIAL NUMBER SET TO 1
 ELEMENT TYPE SET TO 1
 REAL CONSTANT NUMBER= 1
 ELEMENT 1 1 2 0

REAL CONSTANT NUMBER= 2
 ELEMENT 2 2 10 0
 ELEMENT 3 10 3 0

MATERIAL NUMBER SET TO 2
 ELEMENT TYPE SET TO 1
 REAL CONSTANT NUMBER= 3
 ELEMENT 4 3 4 0

REAL CONSTANT NUMBER= 4
 ELEMENT 5 4 5 0
 REAL CONSTANT NUMBER= 5
 ELEMENT 6 5 6 0

REAL CONSTANT NUMBER= 6
 ELEMENT 7 6 7 0
 ELEMENT TYPE SET TO 2
 REAL CONSTANT NUMBER= 7

ELEMENT 8 10 8
 ELEMENT TYPE SET TO 3
 REAL CONSTANT NUMBER= 8
 ELEMENT 9 10 9

SPECIFIED CONSTRAINT UX FOR SELECTED NODES 1 TO 1 BY 1
 REAL= 0.00000000E+00 IMAG= 0.00000000E+00
 ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ

SPECIFIED CONSTRAINT UX FOR SELECTED NODES 8 TO 8 BY 1
 REAL= 0.000000000E+00 IMAG= 0.000000000E+00
 ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ

SPECIFIED CONSTRAINT UX FOR SELECTED NODES 9 TO 9 BY 1
 REAL= 0.000000000E+00 IMAG= 0.000000000E+00
 ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ

***** ROUTINE COMPLETED ***** CP = 2.150

***** ANSYS SOLUTION ROUTINE *****

PRINT ALL ITEMS WITH A FREQUENCY OF ALL
 FOR ALL APPLICABLE ENTITIES

PERFORM A STATIC ANALYSIS
 THIS WILL BE A NEW ANALYSIS

SPECIFIED NODAL LOAD FX FOR SELECTED NODES 7 TO 7 BY 1
 REAL= 139.000000 IMAG= 0.000000000E+00

SPECIFIED NODAL LOAD FZ FOR SELECTED NODES 7 TO 7 BY 1
 REAL= 55.600000 IMAG= 0.000000000E+00

ACEL= 0.00000E+00 386.40 0.00000E+00

WRITE ANSYS LOADS DATA AS FILE=skk.s01

***** ANSYS SOLVE COMMAND *****

SOLUTION OPTIONS

PROBLEM DIMENSIONALITY.3-D
 DEGREES OF FREEDOM. UX UY UZ ROTX ROTY ROTZ
 ANALYSIS TYPESTATIC (STEADY-STATE)

*** NOTE *** CP= 2.260 TIME= 08:49:33
 Present time 0 is less than or equal to the previous time.
 Time will default to 1.

LOAD STEP OPTIONS

LOAD STEP NUMBER.1
 TIME AT END OF THE LOAD STEP.1.0000
 NUMBER OF SUBSTEPS.1

STEP CHANGE BOUNDARY CONDITIONS NO
 INERTIA LOADS X Y Z
 ACEL 0.00000E+00 386.40 0.00000E+00
 PRINT OUTPUT CONTROLS
 ITEM FREQUENCY COMPONENT
 ALL ALL
 DATABASE OUTPUT CONTROLS. ALL DATA WRITTEN
 FOR THE LAST SUBSTEP

***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****

CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS = 6.6804

CENTROID	MOM. OF INERTIA ABOUT ORIGIN	MOM. OF INERTIA ABOUT CENTROID
XC = 0.00000E+00	IXX = 0.1116E+07	IXX = 0.2444E+06
YC = -361.26	IYY = 0.0000E+00	IYY = 0.0000E+00
ZC = 0.00000E+00	IZZ = 0.1116E+07	IZZ = 0.2444E+06
	IXY = 0.0000E+00	IXY = 0.0000E+00
	IYZ = 0.0000E+00	IYZ = 0.0000E+00
	IZX = 0.0000E+00	IZX = 0.0000E+00

*** MASS SUMMARY BY ELEMENT TYPE ***

TYPE	MASS
1	6.68042

Range of element maximum matrix coefficients in global coordinates
 Maximum= 460209577 at element 7.
 Minimum= 1000000 at element 8.

*** ELEMENT MATRIX FORMULATION TIMES

TYPE	NUMBER	ENAME	TOTAL CP	AVE CP
1	7	BEAM4	0.040	0.006
2	1	COMBIN14	0.000	0.000
3	1	COMBIN14	0.000	0.000

Time at end of element matrix formulation CP= 2.38000011.

Estimated number of active DOF= 42.
 Maximum wavefront= 24.

Time at end of matrix triangularization CP= 2.45000005.
Equation solver maximum pivot= 115052394 at node 7 ROTZ.
Equation solver minimum pivot= 2409.57319 at node 5 UX.

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
WEST. HANFORD VERSION=SGI IRIS4D 08:49:41 SEP 08, 1994 CP= 2.470
FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** DEGREE OF FREEDOM SOLUTION ***** TIME = 1.0000
LOAD STEP= 1 SUBSTEP = 1 CUM. ITER.= 1

NOTE - ALL VECTOR DOFS ARE IN NODAL COORDINATE SYSTEMS.

NODE	UX	UY	UZ	ROTX
1	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
2	-0.188550E-01	-0.277490E-03	-0.754199E-02	0.378913E-03
3	0.590023E-01	-0.156313E-02	0.236009E-01	-0.191005E-02
4	1.33471	-0.219114E-02	0.533885	-0.503080E-02
5	3.98558	-0.262233E-02	1.59423	-0.716381E-02
6	6.40521	-0.272921E-02	2.56256	-0.769324E-02
7	6.57581	-0.272966E-02	2.63085	-0.769543E-02
8	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
9	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
10	0.567270E-03	-0.149003E-02	0.226908E-03	-0.154585E-02

MAXIMUMS
NODE 7 7 7 7
0 7
VALUE 6.57581 -0.272966E-02 2.63085 -0.769543E-02
0.000000E+00 0.192243E-01
1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 08:49:41 SEP 08, 1994 CP= 2.490
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** ELEMENT SOLUTION ***** TIME = 1.0000
 LOAD STEP= 1 SUBSTEP = 1 CUM. ITER.= 1

EL= 7 NODES= 6 7 MAT= 2

		BEAM4				
LOCATION	SDIR	SBYT	SBYB	SBZT	SBZB	
1 (I)	2.9016	-96.350	96.350	-39.367	39.367	
2 (J)	-0.52458E-12	0.62555E-08	-0.62555E-08	-0.37150E-10	0.37150E-10	
		BEAM4				
LOCATION	SMAX	SMIN				
1 (I)	138.62	-132.82				
2 (J)	0.62922E-08	-0.62932E-08				
		BEAM4				
LOCATION	EPELDIR	EPELBYT	EPELBYB	EPELBZT	EPELBZB	
1 (I)	0.000000	-0.000003	0.000003	-0.000001	0.000001	
2 (J)	0.000000	0.000000	0.000000	0.000000	0.000000	
STATIC LOAD ON NODE		6	139.000	-36.4329	55.6000	
-493.450	0.000000E+00	1233.63				
STATIC LOAD ON NODE		7	-139.000	-0.658673E-11	-55.6000	
0.465661E-09	0.000000E+00	0.800937E-07				
ELEM 7 POTENTIAL ENERGY= 0.256889E-02						

EL= 6 NODES= 5 6 MAT= 2

		BEAM4				
LOCATION	SDIR	SBYT	SBYB	SBZT	SBZB	
1 (I)	45.115	-1521.1	1521.1	-614.99	614.99	
2 (J)	2.9384	-97.907	97.907	-39.585	39.585	
		BEAM4				
LOCATION	SMAX	SMIN				
1 (I)	2181.2	-2090.9				
2 (J)	140.43	-134.55				
		BEAM4				
LOCATION	EPELDIR	EPELBYT	EPELBYB	EPELBZT	EPELBZB	
1 (I)	0.000002	-0.000052	0.000052	-0.000021	0.000021	
2 (J)	0.000000	-0.000003	0.000003	-0.000001	0.000001	
STATIC LOAD ON NODE		5	139.000	-559.379	55.6000	
-7666.13	0.000000E+00	19165.3				
STATIC LOAD ON NODE		6	-139.000	36.4329	-55.6000	
493.450	0.000000E+00	-1233.63				
ELEM 6 POTENTIAL ENERGY= 9.77186						

EL= 5 NODES= 4 5 MAT= 2

		BEAM4				
LOCATION	SDIR	SBYT	SBYB	SBZT	SBZB	
1 (I)	101.31	-3453.6	3453.6	-1381.4	1381.4	

2 (J)	45.695	-1546.0	1546.0	-618.42	618.42
LOCATION	SMAX	SMIN			
1 (I)	4936.3	-4733.7			
2 (J)	2210.2	-2118.8			
LOCATION	EPELDIR	EPELBYT	EPELBYB	EPELBZT	EPELBZB
1 (I)	0.000003	-0.000119	0.000119	-0.000048	0.000048
2 (J)	0.000002	-0.000053	0.000053	-0.000021	0.000021
STATIC LOAD ON NODE		4	139.000	-1240.24	55.6000
-17124.8	0.000000E+00	42812.0			
STATIC LOAD ON NODE		5	-139.000	559.379	-55.6000
7666.13	0.000000E+00	-19165.3			
ELEM	5	POTENTIAL ENERGY=	100.688		

EL= 4 NODES= 3 4 MAT= 2

				BEAM4	
LOCATION	SDIR	SBYT	SBYB	SBZT	SBZB
1 (I)	150.73	-5170.8	5170.8	-2068.3	2068.3
2 (J)	103.98	-3531.3	3531.3	-1412.5	1412.5
LOCATION	SMAX	SMIN			
1 (I)	7389.9	-7088.4			
2 (J)	5047.8	-4839.8			
LOCATION	EPELDIR	EPELBYT	EPELBYB	EPELBZT	EPELBZB
1 (I)	0.000005	-0.000178	0.000178	-0.000071	0.000071
2 (J)	0.000004	-0.000122	0.000122	-0.000049	0.000049
STATIC LOAD ON NODE		3	139.000	-1797.87	55.6000
-25075.6	0.000000E+00	62689.0			
STATIC LOAD ON NODE		4	-139.000	1240.24	-55.6000
17124.8	0.000000E+00	-42812.0			
ELEM	4	POTENTIAL ENERGY=	242.002		

EL= 3 NODES= 10 3 MAT= 1

				BEAM4	
LOCATION	SDIR	SBYT	SBYB	SBZT	SBZB
1 (I)	158.72	-5450.1	5450.1	-2180.0	2180.0
2 (J)	154.88	-5291.4	5291.4	-2116.6	2116.6
LOCATION	SMAX	SMIN			
1 (I)	7788.8	-7471.4			
2 (J)	7562.9	-7253.1			
LOCATION	EPELDIR	EPELBYT	EPELBYB	EPELBZT	EPELBZB
1 (I)	0.000005	-0.000188	0.000188	-0.000075	0.000075
2 (J)	0.000005	-0.000182	0.000182	-0.000073	0.000073
STATIC LOAD ON NODE		10	139.000	-1842.37	55.6000
-25827.3	0.000000E+00	64568.3			
STATIC LOAD ON NODE		3	-139.000	1797.87	-55.6000
25075.6	0.000000E+00	-62689.0			
ELEM	3	POTENTIAL ENERGY=	33.6706		

EL= 9 NODES= 10 9 FORC= -226.91 STRETCH= -0.000227
 RATE= 0.100000E+07 COMBIN14
 STATIC LOAD ON NODE 10 -226.908

STATIC LOAD ON NODE 9 226.908
ELEM 9 POTENTIAL ENERGY= 0.257436E-01

EL= 8 NODES= 10 8 FORC= -567.27 STRETCH= -0.000567
RATE= 0.100000E+07 COMBIN14
STATIC LOAD ON NODE 10 -567.270
STATIC LOAD ON NODE 8 567.270
ELEM 8 POTENTIAL ENERGY= 0.160897

EL= 2 NODES= 2 10 MAT= 1

LOCATION	SDIR	SBYT	SBYB	BEAM4 SBZT	SBZB
1 (I)	212.45	1399.5	-1399.5	559.80	-559.80
2 (J)	158.72	-5450.1	5450.1	-2180.0	2180.0
LOCATION	SMAX	SMIN			
1 (I)	2171.7	-1746.9			
2 (J)	7788.8	-7471.4			
LOCATION	EPELDIR	EPELBYT	EPELBYB	EPELBZT	EPELBZB
1 (I)	0.000007	0.000048	-0.000048	0.000019	-0.000019
2 (J)	0.000005	-0.000188	0.000188	-0.000075	0.000075
STATIC LOAD ON NODE 2		-428.270		-2466.06	-171.308
6632.10	0.000000E+00	-16580.2			
STATIC LOAD ON NODE 10		428.270		1842.37	171.308
25827.3	0.000000E+00	-64568.3			
ELEM 2	POTENTIAL ENERGY= 132.101				

EL= 1 NODES= 1 2 MAT= 1

LOCATION	SDIR	SBYT	SBYB	BEAM4 SBZT	SBZB
1 (I)	228.64	2764.5	-2764.5	1105.8	-1105.8
2 (J)	218.43	1432.5	-1432.5	572.99	-572.99
LOCATION	SMAX	SMIN			
1 (I)	4099.0	-3641.7			
2 (J)	2223.9	-1787.0			
LOCATION	EPELDIR	EPELBYT	EPELBYB	EPELBZT	EPELBZB
1 (I)	0.000008	0.000095	-0.000095	0.000038	-0.000038
2 (J)	0.000008	0.000049	-0.000049	0.000020	-0.000020
STATIC LOAD ON NODE 1		-428.270		-2581.32	-171.308
12799.2	0.000000E+00	-31998.0			
STATIC LOAD ON NODE 2		428.270		2466.06	171.308
-6632.10	0.000000E+00	16580.2			
ELEM 1	POTENTIAL ENERGY= 14.1432				

***** ENERGY BY MATERIAL *****

MATERIAL POTENTIAL

1	179.91
2	352.65

TOTAL= 532.57

*** ELEMENT RESULT CALCULATION TIMES

TYPE	NUMBER	ENAME	TOTAL CP	AVE CP
1	7	BEAM4	0.080	0.011
2	1	COMBIN14	0.000	0.000
3	1	COMBIN14	0.000	0.000

*** NODAL LOAD CALCULATION TIMES

TYPE	NUMBER	ENAME	TOTAL CP	AVE CP
1	7	BEAM4	0.000	0.000
2	1	COMBIN14	0.000	0.000
3	1	COMBIN14	0.010	0.010

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 08:49:42 SEP 08, 1994 CP= 2.600
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** REACTION SOLUTION ***** TIME = 1.0000
 LOAD STEP= 1 SUBSTEP = 1 CUM. ITER.= 1

NOTE - ALL VECTOR DOFS ARE IN NODAL COORDINATE SYSTEMS.

MY	NODE	FX	FY	FZ	MX
	1	428.270	2581.32	171.308	-12799.2
0.000000E+00		31998.0			
	8	-567.270	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00		0.000000E+00			
	9	0.000000E+00	0.000000E+00	-226.908	0.000000E+00
0.000000E+00		0.000000E+00			
TOTAL		-139.000	2581.32	-55.6000	-12799.2
0.000000E+00		31998.0			

*** NOTE *** CP= 2.600 TIME= 08:49:42
 Totals may not be correct if any reaction nodes are in a rotated nodal coordinate system.

*** LOAD STEP 1 SUBSTEP 1 COMPLETED. CUM ITER = 1
 *** TIME = 1.00000 TIME INC = 1.00000 NEW TRIANG MATRIX

A-59

*** PROBLEM STATISTICS
 ACTUAL NO. OF ACTIVE DEGREES OF FREEDOM = 42
 R.M.S. WAVEFRONT SIZE = 12.1

*** ANSYS BINARY FILE STATISTICS
 BUFFER SIZE USED= 4096
 0.031 MB WRITTEN ON ELEMENT MATRIX FILE: skk.emat
 0.016 MB WRITTEN ON ELEMENT SAVED DATA FILE: skk.esav
 0.016 MB WRITTEN ON TRIANGULARIZED MATRIX FILE: skk.tri
 0.047 MB WRITTEN ON RESULTS FILE: skk.rst

FINISH SOLUTION PROCESSING

***** ROUTINE COMPLETED ***** CP = 2.700

***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER /SHOW,DEVICE-NAME TO ENABLE GRAPHIC DISPLAY
 ENTER FINISH TO LEAVE POST1

*** NOTE *** CP= 2.920 TIME= 08:50:52
 The element set contains elements that have only one structural degree
 of freedom per node. Viewing nodal displacements or forces in other
 than the nodal coordinate system may be invalid.

USE LOAD STEP 1 SUBSTEP 1 FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP= 1 SUBSTEP= 1 CUMULATIVE ITERATION= 1
 TIME/FREQUENCY= 1.0000

PRODUCE DISPLACEMENT PLOT, KUND= 0

PRODUCE DISPLACEMENT PLOT, KUND= 1

PRINT DOF NODAL SOLUTION PER NODE

***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

LOAD STEP= 1 SUBSTEP= 1
 TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2	-0.18855E-01	-0.27749E-03	-0.75420E-02	0.37891E-03		
3	0.59002E-01	-0.15631E-02	0.23601E-01	-0.19101E-02	0.00000E+00	
4	1.3347	-0.21911E-02	0.53388	-0.50308E-02	0.00000E+00	
5	3.9856	-0.26223E-02	1.5942	-0.71638E-02	0.00000E+00	
6	6.4052	-0.27292E-02	2.5626	-0.76932E-02	0.00000E+00	
7	6.5758	-0.27297E-02	2.6308	-0.76954E-02	0.00000E+00	
8	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	
9	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	
10	0.56727E-03	-0.14900E-02	0.22691E-03	-0.15459E-02	0.00000E+00	

MAXIMUM VALUES

NODE	7	7	7	7	0	7
VALUE	6.5758	-0.27297E-02	2.6308	-0.76954E-02	0.00000E+00	

PRINT REACTION SOLUTIONS PER NODE

***** POST1 TOTAL REACTION SOLUTION LISTING *****

LOAD STEP= 1 SUBSTEP= 1

TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
1	428.27	2581.3	171.31	-12799.	0.00000E+00	31998.
8	-567.27	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	

9 0.00000E+00 0.00000E+00 -226.91 0.00000E+00 0.00000E+00
0.00000E+00

TOTAL VALUES
VALUE -139.00 2581.3 -55.600 -12799. 0.00000E+00 31998.

PRINT F ELEMENT SOLUTION PER ELEMENT

***** POST1 ELEMENT NODE TOTAL FORCE LISTING *****

LOAD STEP= 1 SUBSTEP= 1
TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

ELEM=	1	FX	FY	FZ
	1	-428.27	-2581.3	-171.31
	2	428.27	2466.1	171.31

ELEM=	2	FX	FY	FZ
	2	-428.27	-2466.1	-171.31
	10	428.27	1842.4	171.31

ELEM=	3	FX	FY	FZ
	10	139.00	-1842.4	55.600
	3	-139.00	1797.9	-55.600

ELEM=	4	FX	FY	FZ
	3	139.00	-1797.9	55.600
	4	-139.00	1240.2	-55.600

ELEM=	5	FX	FY	FZ
	4	139.00	-1240.2	55.600
	5	-139.00	559.38	-55.600

ELEM=	6	FX	FY	FZ
	5	139.00	-559.38	55.600
	6	-139.00	36.433	-55.600

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ELEM=	7	FX	FY	FZ
6	139.00	-36.433	55.600	
7	-139.00	-0.65867E-11	-55.600	

ELEM=	8	FX
10	-567.27	
8	567.27	

ELEM=	9	FZ
10	-226.91	
9	226.91	

PRINT M ELEMENT SOLUTION PER ELEMENT

***** POST1 ELEMENT NODE TOTAL FORCE LISTING *****

LOAD STEP= 1 SUBSTEP= 1
 TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

ELEM=	1	MX	MY	MZ
1	12799.	0.00000E+00	-31998.	
2	-6632.1	0.00000E+00	16580.	

ELEM=	2	MX	MY	MZ
2	6632.1	0.00000E+00	-16580.	
10	25827.	0.00000E+00	-64568.	

ELEM=	3	MX	MY	MZ
10	-25827.	0.00000E+00	64568.	
3	25076.	0.00000E+00	-62689.	

ELEM=	4	MX	MY	MZ
3	-25076.	0.00000E+00	62689.	
4	17125.	0.00000E+00	-42812.	

ELEM=	5	MX	MY	MZ
	4	-17125.	0.00000E+00	42812.
	5	7666.1	0.00000E+00	-19165.
ELEM=	6	MX	MY	MZ
	5	-7666.1	0.00000E+00	19165.
	6	493.45	0.00000E+00	-1233.6
ELEM=	7	MX	MY	MZ
	6	-493.45	0.00000E+00	1233.6
	7	0.46566E-09	0.00000E+00	0.80094E-07

EXIT THE ANSYS POST1 DATABASE PROCESSOR

***** ROUTINE COMPLETED ***** CP = 3.470

PURGE ALL SOLUTION AND POST DATA
SAVE ALL MODEL DATA

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= skk.db
FOR POSSIBLE RESUME FROM THIS POINT

NUMBER OF WARNING MESSAGES ENCOUNTERED=	0
NUMBER OF ERROR MESSAGES ENCOUNTERED=	0

ANSYS FILE: PSEIS1.IN

Description of file: The probe is modelled as a cantilever and run for first two modes. Seismic response of the probe is evaluated and is seen that the probe hits the the riser in the first mode.

```
/title,Modal analysis of thermocouple tree with spring restraint
et,1,4
!
r,1,11.29,31.83,31.83,5.5,5.5,
r,2,11.608,32.58,32.58,5.5,5.5,
r,3,11.9274,33.34,33.34,5.5,5.5,
r,4,12.2416,34.09,34.09,5.5,5.5,,
r,5,12.399,34.65,34.28,5.5,5.5,
r,6,12.5563,35.21,34.47,5.5,5.5,
ex,1,29e6
dens,1,.00073386
nuxy,1,.3
ex,2,29e6
dens,2,.00084611
nuxy,2,.3
!
n,1,,,
n,2,, -36,,
n,3,, -239,,
n,4,, -382,,
n,5,, -552.12,,
n,6,, -681.125,,
n,7,, -690,,
!
mat,1
type,1
real,1
e,1,2
!
real,2
e,2,3
mat,2
type,1
real,3
e,3,4
!
real,4
e,4,5
!
```

```
real,5
e,5,6
!
real,6
e,6,7
!
d,1,all
fini
!
/solu
outpr,all,all
antype,modal
modopt,redu
m,2,ux,7,1,uy,uz,rotx,roty,rotz
save
solve
finish
!
/solu
expass,on
mxpand,2,.01,10,yes
solve
finish
!
/solu
antype,spectr
spopt,sprs,2,on
svtype,2,386.4
sed,1,0,0
freq,0.16,0.4,1.1,1.64,8,12,20,33,100
sv,,0.026,0.104,0.283,0.420,0.420,0.340,0.26,0.2,0.2
mcomb,srss,0.0001
solve
!
sed,0,1,0
freq
freq,0.16,0.4,1.1,1.64,8,12,20,33,100
sv,,0.0156,0.0624,0.1698,0.252,0.252,0.204,0.156,0.12,0.12
solve
!
sed,0,0,1
freq
freq,0.16,0.4,1.1,1.64,8,12,20,33,100
sv,,0.026,0.104,0.283,0.420,0.420,0.340,0.26,0.2,0.2
solve
!
finish
```


ANSYS FILE: PSEIS1.OUT

This output file is used to find the displacement of node number 3, The displacement shows that the probe hits the riser pipe at the first mode of vibration.

/INPUT FILE= pseis1.in LINE= 0

TITLE=

Modal analysis of thermocouple tree as cantilever

ELEMENT TYPE 1 IS BEAM4 3-D ELASTIC BEAM
KEYOPT(1-12)= 0 0 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

REAL CONSTANT SET 1 ITEMS 1 TO 6
11.290 31.830 31.830 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 2 ITEMS 1 TO 6
11.608 32.580 32.580 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 3 ITEMS 1 TO 6
11.927 33.340 33.340 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 4 ITEMS 1 TO 6
12.242 34.090 34.090 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 5 ITEMS 1 TO 6
12.399 34.650 34.280 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 6 ITEMS 1 TO 6
12.556 35.210 34.470 5.5000 5.5000
0.00000E+00

MATERIAL	1	EX	=	0.2900000E+08
MATERIAL	1	DENS	=	0.7338600E-03
MATERIAL	1	NUXY	=	0.3000000
MATERIAL	2	EX	=	0.2900000E+08
MATERIAL	2	DENS	=	0.8461100E-03
MATERIAL	2	NUXY	=	0.3000000
NODE	1	KCS=	0	X,Y,Z= 0.00000E+00 0.00000E+00 0.00000E+00
NODE	2	KCS=	0	X,Y,Z= 0.00000E+00 -36.000 0.00000E+00
NODE	3	KCS=	0	X,Y,Z= 0.00000E+00 -239.00 0.00000E+00
NODE	4	KCS=	0	X,Y,Z= 0.00000E+00 -382.00 0.00000E+00
NODE	5	KCS=	0	X,Y,Z= 0.00000E+00 -552.12 0.00000E+00
NODE	6	KCS=	0	X,Y,Z= 0.00000E+00 -681.13 0.00000E+00
NODE	7	KCS=	0	X,Y,Z= 0.00000E+00 -690.00 0.00000E+00
MATERIAL NUMBER SET TO 1				
ELEMENT TYPE SET TO 1				
REAL CONSTANT NUMBER= 1				
ELEMENT	1	1	2	0
REAL CONSTANT NUMBER= 2				
ELEMENT	2	2	3	0
MATERIAL NUMBER SET TO 2				
ELEMENT TYPE SET TO 1				
REAL CONSTANT NUMBER= 3				
ELEMENT	3	3	4	0
REAL CONSTANT NUMBER= 4				
ELEMENT	4	4	5	0

REAL CONSTANT NUMBER= 5

ELEMENT 5 5 6 0

REAL CONSTANT NUMBER= 6

ELEMENT 6 6 7 0

SPECIFIED CONSTRAINT UX FOR SELECTED NODES 1 TO 1 BY 1
 REAL= 0.00000000E+00 IMAG= 0.00000000E+00
 ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ

***** ROUTINE COMPLETED ***** CP = 2.040

***** ANSYS SOLUTION ROUTINE *****

PRINT ALL ITEMS WITH A FREQUENCY OF ALL
 FOR ALL APPLICABLE ENTITIES

PERFORM A MODAL ANALYSIS
 THIS WILL BE A NEW ANALYSIS

USE HOUSEHOLDER METHOD
 EXTRACT AS MANY MODES AS THERE ARE MDOF
 PRINT 0 REDUCED MODES
 NORMALIZE THE MODE SHAPES TO THE MASS MATRIX

MASTER DOF UX FOR SELECTED NODES IN RANGE 2 TO 7 IN STEPS OF 1
 ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ
 NUMBER OF MASTER DOF= 36

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= skk.db
 FOR POSSIBLE RESUME FROM THIS POINT

***** ANSYS SOLVE COMMAND *****

SOLUTION OPTIONS

PROBLEM DIMENSIONALITY.3-D
 DEGREES OF FREEDOM. UX UY UZ ROTX ROTY ROTZ
 ANALYSIS TYPEMODAL
 EXTRACTION METHOD.REDUCED
 NUMBER OF MODES TO EXTRACT.ALL MDOF
 NUMBER OF REDUCED MODES TO PRINT. 0

NUMBER OF MASTER DOF. 36

L O A D S T E P O P T I O N S

LOAD STEP NUMBER. 1

***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****

CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS = 6.6804

CENTROID	MOM. OF INERTIA ABOUT ORIGIN	MOM. OF INERTIA ABOUT CENTROID
XC = 0.00000E+00	IXX = 0.1115E+07	IXX = 0.2433E+06
YC = -361.26	IYY = 0.0000E+00	IYY = 0.0000E+00
ZC = 0.00000E+00	IZZ = 0.1115E+07	IZZ = 0.2433E+06
	IXY = 0.0000E+00	IXY = 0.0000E+00
	IYZ = 0.0000E+00	IYZ = 0.0000E+00
	IZX = 0.0000E+00	IZX = 0.0000E+00

*** MASS SUMMARY BY ELEMENT TYPE ***

TYPE	MASS
1	6.68042

Range of element maximum matrix coefficients in global coordinates
 Maximum= 460209577 at element 6.
 Minimum= 18617142.9 at element 2.

*** ELEMENT MATRIX FORMULATION TIMES

TYPE	NUMBER	ENAME	TOTAL CP	AVE CP
------	--------	-------	----------	--------

1	6	BEAM4	0.030	0.005
---	---	-------	-------	-------

Time at end of element matrix formulation CP= 2.27999997.

Estimated number of active DOF= 36.
 Maximum wavefront= 37.
 Number of Master DOF= 36.

Time at end of matrix triangularization CP= 2.36999989.

***** EIGENVALUE (NATURAL FREQUENCY) SOLUTION *****

MODE FREQUENCY (CYCLES/TIME)

1	0.354119676
2	0.354120856
3	2.28545116
4	2.28565943
5	6.60086786
6	6.60400787
7	13.3054824
8	13.3197914
9	23.4440446
10	23.4707953
11	36.6827577
12	36.7354640
13	41.2646960
14	51.9074046
15	51.9690478
16	66.3375305
17	77.5336886
18	77.5837532
19	127.079107
20	127.663752
21	133.836818
22	215.793211
23	253.030960
24	253.720045
25	253.720326
26	383.804728
27	407.923701
28	467.909040
29	618.866253
30	753.599407
31	2563.16405
32	2584.97521
33	3855.38180
34	6217.43760
35	13247.5832
36	13299.3373

***** REDUCED MASS DISTRIBUTION *****

ROW NODE DIR VALUE

1	2	UX	0.97621
---	---	----	---------

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2	2	UY	0.96407
3	2	UZ	0.97621
7	3	UX	1.5862
8	3	UY	1.5862
9	3	UZ	1.5862
13	4	UX	1.6026
14	4	UY	1.6026
15	4	UZ	1.6026
19	5	UX	1.5577
20	5	UY	1.5577
21	5	UZ	1.5577
25	6	UX	0.72383
26	6	UY	0.72383
27	6	UZ	0.72383
31	7	UX	0.47144E-01
32	7	UY	0.47144E-01
33	7	UZ	0.47144E-01

MASS(X,Y,Z) = 6.494 6.482 6.494

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***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 15:29:36 SEP 07, 1994 CP= 2.580
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** PARTICIPATION FACTOR CALCULATION ***** X DIRECTION

MODE MASS	CUMULATIVE FREQUENCY MASS FRACTION	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE
1	0.354120	2.8239	-1.1289	0.648740	1.27440
	0.196251				
2	0.354121	2.8239	1.7401	1.000000	3.02805
	0.662555				
3	2.28545	0.43755	-0.39064E-07	0.000000	
0.152601E-14	0.662555				
4	2.28566	0.43751	-1.0935	0.628419	1.19581
	0.846704				
5	6.60087	0.15150	-0.64551E-09	0.000000	
0.416688E-18	0.846704				
6	6.60401	0.15142	0.60683	0.348728	0.368246
	0.903412				

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7	13.3055	0.75157E-01	0.24721E-09	0.000000	
0.611148E-19	0.903412				
8	13.3198	0.75076E-01	-0.42364	0.243452	0.179469
	0.931049				
9	23.4440	0.42655E-01	-0.10670E-09	0.000000	
0.113841E-19	0.931049				
10	23.4708	0.42606E-01	0.40703	0.233911	0.165677
	0.956562				
11	36.6828	0.27261E-01	0.20714E-10	0.000000	
0.429083E-21	0.956562				
12	36.7355	0.27222E-01	-0.34085	0.195879	0.116182
	0.974454				
13	41.2647	0.24234E-01	-0.22102E-12	0.000000	
0.488482E-25	0.974454				
14	51.9074	0.19265E-01	0.19109E-09	0.000000	
0.365167E-19	0.974454				
15	51.9690	0.19242E-01	0.24648	0.141644	
0.607522E-01	0.983809				
16	66.3375	0.15074E-01	0.11531E-12	0.000000	
0.132966E-25	0.983809				
17	77.5337	0.12898E-01	-0.91297E-09	0.000000	
0.833517E-18	0.983809				
18	77.5838	0.12889E-01	-0.14316	0.082271	
0.204955E-01	0.986966				
19	127.079	0.78691E-02	-0.44159E-14	0.000000	
0.194999E-28	0.986966				
20	127.664	0.78331E-02	0.22858E-01	0.013136	
0.522467E-03	0.987046				
21	133.837	0.74718E-02	-0.44772E-13	0.000000	
0.200451E-26	0.987046				
22	215.793	0.46341E-02	0.22191E-13	0.000000	
0.492429E-27	0.987046				
23	253.031	0.39521E-02	-0.27753E-11	0.000000	
0.770203E-23	0.987046				
24	253.720	0.39414E-02	0.31900E-02	0.001833	
0.101761E-04	0.987048				
25	253.720	0.39413E-02	0.29002	0.166663	
0.841090E-01	1.000000				
26	383.805	0.26055E-02	0.32583E-14	0.000000	
0.106164E-28	1.000000				
27	407.924	0.24514E-02	0.30760E-14	0.000000	
0.946189E-29	1.000000				
28	467.909	0.21372E-02	-0.14859E-14	0.000000	
0.220795E-29	1.000000				
29	618.866	0.16159E-02	0.50919E-14	0.000000	
0.259272E-28	1.000000				
30	753.599	0.13270E-02	-0.11858E-14	0.000000	
0.140607E-29	1.000000				

31	2563.16	0.39014E-03	0.35265E-17	0.000000
0.124360E-34		1.000000		
32	2584.98	0.38685E-03	0.11503E-04	0.000007
0.132313E-09		1.000000		
33	3855.38	0.25938E-03	0.22904E-14	0.000000
0.524609E-29		1.000000		
34	6217.44	0.16084E-03	-0.23616E-16	0.000000
0.557710E-33		1.000000		
35	13247.6	0.75485E-04	0.13639E-16	0.000000
0.186010E-33		1.000000		
36	13299.3	0.75192E-04	-0.19673E-06	0.000000
0.387032E-13		1.000000		

SUM OF EFFECTIVE MASSES= 6.49372

***** PARTICIPATION FACTOR CALCULATION ***** Y DIRECTION

MODE MASS	CUMULATIVE FREQUENCY MASS FRACTION	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE
1	0.354120	2.8239	0.72695E-13	0.000000	
0.528456E-26		0.815320E-27			
2	0.354121	2.8239	-0.55349E-13	0.000000	
0.306356E-26		0.128798E-26			
3	2.28545	0.43755	-0.89972E-13	0.000000	
0.809504E-26		0.253691E-26			
4	2.28566	0.43751	0.12572E-12	0.000000	
0.158053E-25		0.497540E-26			
5	6.60087	0.15150	0.67157E-13	0.000000	
0.451009E-26		0.567124E-26			
6	6.60401	0.15142	0.27735E-13	0.000000	
0.769227E-27		0.578991E-26			
7	13.3055	0.75157E-01	-0.40999E-13	0.000000	
0.168088E-26		0.604925E-26			
8	13.3198	0.75076E-01	-0.66038E-13	0.000000	
0.436102E-26		0.672208E-26			
9	23.4440	0.42655E-01	-0.26495E-13	0.000000	
0.701971E-27		0.683038E-26			
10	23.4708	0.42606E-01	-0.36956E-13	0.000000	
0.136573E-26		0.704109E-26			
11	36.6828	0.27261E-01	0.91466E-13	0.000000	
0.836611E-26		0.833184E-26			
12	36.7355	0.27222E-01	-0.30230E-13	0.000000	
0.913835E-27		0.847283E-26			
13	41.2647	0.24234E-01	-0.35231E-13	0.000000	
0.124119E-26		0.866433E-26			

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14	51.9074	0.19265E-01	-0.11615E-12	0.000000	
0.134918E-25		0.107459E-25			
15	51.9690	0.19242E-01	-0.39980E-13	0.000000	
0.159843E-26		0.109925E-25			
16	66.3375	0.15074E-01	2.3533	1.000000	5.53824
	0.854458				
17	77.5337	0.12898E-01	0.58574E-13	0.000000	
0.343096E-26		0.854458			
18	77.5838	0.12889E-01	0.59289E-14	0.000000	
0.351516E-28		0.854458			
19	127.079	0.78691E-02	0.85763E-14	0.000000	
0.735530E-28		0.854458			
20	127.664	0.78331E-02	-0.35632E-15	0.000000	
0.126962E-30		0.854458			
21	133.837	0.74718E-02	0.10321E-13	0.000000	
0.106514E-27		0.854458			
22	215.793	0.46341E-02	0.69139	0.293791	0.478022
	0.928209				
23	253.031	0.39521E-02	0.11401E-13	0.000000	
0.129975E-27		0.928209			
24	253.720	0.39414E-02	0.11427E-13	0.000000	
0.130582E-27		0.928209			
25	253.720	0.39413E-02	0.50100E-15	0.000000	
0.251003E-30		0.928209			
26	383.805	0.26055E-02	0.45421E-15	0.000000	
0.206304E-30		0.928209			
27	407.924	0.24514E-02	0.41388	0.175870	0.171300
	0.954638				
28	467.909	0.21372E-02	0.48323E-14	0.000000	
0.233515E-28		0.954638			
29	618.866	0.16159E-02	-0.25198	0.107073	
0.634940E-01		0.964434			
30	753.599	0.13270E-02	0.48013	0.204020	0.230524
	1.000000				
31	2563.16	0.39014E-03	0.83389E-16	0.000000	
0.695378E-32		1.000000			
32	2584.98	0.38685E-03	0.15839E-16	0.000000	
0.250862E-33		1.000000			
33	3855.38	0.25938E-03	-0.38422E-14	0.000000	
0.147625E-28		1.000000			
34	6217.44	0.16084E-03	-0.27837E-04	0.000012	
0.774913E-09		1.000000			
35	13247.6	0.75485E-04	-0.67569E-17	0.000000	
0.456563E-34		1.000000			
36	13299.3	0.75192E-04	0.21656E-19	0.000000	
0.468987E-39		1.000000			

SUM OF EFFECTIVE MASSES= 6.48158

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***** PARTICIPATION FACTOR CALCULATION ***** Z DIRECTION

MODE MASS	CUMULATIVE FREQUENCY MASS FRACTION	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE
1	0.354120	2.8239	1.7401	1.000000	3.02804
	0.466303				
2	0.354121	2.8239	1.1289	0.648740	1.27439
	0.662552				
3	2.28545	0.43755	-1.0935	0.628387	1.19568
	0.846682				
4	2.28566	0.43751	0.23575E-06	0.000000	
0.555760E-13	0.846682				
5	6.60087	0.15150	0.60672	0.348665	0.368110
	0.903369				
6	6.60401	0.15142	0.65207E-08	0.000000	
0.425200E-16	0.903369				
7	13.3055	0.75157E-01	-0.42357	0.243415	0.179414
	0.930998				
8	13.3198	0.75076E-01	-0.16838E-09	0.000000	
0.283521E-19	0.930998				
9	23.4440	0.42655E-01	0.40693	0.233853	0.165595
	0.956498				
10	23.4708	0.42606E-01	0.20039E-10	0.000000	
0.401577E-21	0.956498				
11	36.6828	0.27261E-01	-0.34090	0.195906	0.116214
	0.974395				
12	36.7355	0.27222E-01	-0.18565E-10	0.000000	
0.344655E-21	0.974395				
13	41.2647	0.24234E-01	0.33732E-14	0.000000	
0.113786E-28	0.974395				
14	51.9074	0.19265E-01	0.24712	0.142013	
0.610688E-01	0.983799				
15	51.9690	0.19242E-01	0.37601E-10	0.000000	
0.141387E-20	0.983799				
16	66.3375	0.15074E-01	-0.62560E-13	0.000000	
0.391376E-26	0.983799				
17	77.5337	0.12898E-01	-0.14336	0.082386	
0.205526E-01	0.986964				
18	77.5838	0.12889E-01	-0.54376E-09	0.000000	
0.295675E-18	0.986964				
19	127.079	0.78691E-02	0.23077E-01	0.013262	
0.532556E-03	0.987046				
20	127.664	0.78331E-02	-0.23311E-13	0.000000	
0.543422E-27	0.987046				
21	133.837	0.74718E-02	0.12118E-14	0.000000	
0.146836E-29	0.987046				

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22	215.793	0.46341E-02	0.38934E-14	0.000000
0.151583E-28		0.987046		
23	253.031	0.39521E-02	-0.48563E-11	0.000000
0.235832E-22		0.987046		
24	253.720	0.39414E-02	0.29002	0.166664
0.841097E-01		0.999998		
25	253.720	0.39413E-02	-0.31900E-02	0.001833
0.101762E-04		1.000000		
26	383.805	0.26055E-02	0.32063E-16	0.000000
0.102805E-32		1.000000		
27	407.924	0.24514E-02	-0.20568E-14	0.000000
0.423046E-29		1.000000		
28	467.909	0.21372E-02	0.20677E-15	0.000000
0.427547E-31		1.000000		
29	618.866	0.16159E-02	-0.10652E-13	0.000000
0.113465E-27		1.000000		
30	753.599	0.13270E-02	0.16435E-15	0.000000
0.270108E-31		1.000000		
31	2563.16	0.39014E-03	0.11713E-04	0.000007
0.137205E-09		1.000000		
32	2584.98	0.38685E-03	-0.19520E-15	0.000000
0.381024E-31		1.000000		
33	3855.38	0.25938E-03	-0.42396E-14	0.000000
0.179740E-28		1.000000		
34	6217.44	0.16084E-03	-0.18606E-15	0.000000
0.346167E-31		1.000000		
35	13247.6	0.75485E-04	0.19828E-06	0.000000
0.393154E-13		1.000000		
36	13299.3	0.75192E-04	-0.24895E-15	0.000000
0.619777E-31		1.000000		

SUM OF EFFECTIVE MASSES= 6.49372

*** PROBLEM STATISTICS

ACTUAL NO. OF ACTIVE DEGREES OF FREEDOM = 1

R.M.S. WAVEFRONT SIZE = 0.0

NUMBER OF MASTER DEGREES OF FREEDOM = 36

*** ANSYS BINARY FILE STATISTICS

BUFFER SIZE USED= 4096

0.016 MB WRITTEN ON ELEMENT MATRIX FILE: skk.emat

0.016 MB WRITTEN ON ELEMENT SAVED DATA FILE: skk.esav

0.016 MB WRITTEN ON TRIANGULARIZED MATRIX FILE: skk.tri

0.047 MB WRITTEN ON MODAL MATRIX FILE: skk.mode

FINISH SOLUTION PROCESSING

***** ROUTINE COMPLETED ***** CP = 2.700

***** ANSYS SOLUTION ROUTINE *****

PERFORM AN EXPANSION PASS

NUMBER OF MODES TO EXPAND= 2
IN THE FREQUENCY RANGE 0.10000E-01 TO 10.000
CALCULATE ELEMENT RESULTS AND NODAL DOF SOLUTION

***** ANSYS SOLVE COMMAND *****

SOLUTION OPTIONS

PROBLEM DIMENSIONALITY.3-D
DEGREES OF FREEDOM. UX UY UZ ROTX ROTY ROTZ
ANALYSIS TYPEMODAL
EXTRACTION METHOD.REDUCED
EXPANSION PASSON
NUMBER OF MODES TO EXPAND2
MODAL EXPANSION RANGE0.10000E-01 TO 10.000
ELEMENT RESULTS CALCULATIONON

LOAD STEP OPTIONS

LOAD STEP NUMBER.1
PRINT OUTPUT CONTROLS
ITEM FREQUENCY COMPONENT
ALL ALL
DATABASE OUTPUT CONTROLS.ALL DATA WRITTEN

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
WEST. HANFORD VERSION=SGI IRIS4D 15:29:36 SEP 07, 1994 CP= 2.750
FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

***** ANSYS SOLUTION ROUTINE *****

PERFORM A SPECTRUM ANALYSIS
THIS WILL BE A NEW ANALYSIS

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*** NOTE ***

CP= 3.020 TIME= 15:29:37

Some analysis options have been reset to their defaults. Please verify current settings or respecify as required.

USE SINGLE POINT EXCITATION RESPONSE SPECTRUM
USE THE FIRST 2 MODES FROM THE MODAL ANALYSIS
INCLUDE STRESS RESPONSES IN THE CALCULATIONS

SPECTRUM TYPE KEY= 2 FACTOR= 386.400

SEISMIC EXCITATION DIRECTION = 1.0000 0.00000E+00 0.00000E+00

FREQ= 0.160 0.400 1.10 1.64 8.00 12.0 20.0
33.0 100.

NUMBER OF FREQUENCIES IN TABLE = 9

DAMPING= 0.00000E+00 SV= 0.26000E-01 0.10400 0.28300
0.42000 0.42000 0.34000
0.26000 0.20000 0.20000

COMBINE MODES USING THE SRSS METHOD
WHOSE SIGNIFICANCE LEVEL EXCEEDS THE THRESHOLD OF 0.10000E-03

***** ANSYS SOLVE COMMAND *****

SOLUTION OPTIONS

PROBLEM DIMENSIONALITY. 3-D
DEGREES OF FREEDOM. UX UY UZ ROTX ROTY ROTZ
ANALYSIS TYPE SPECTRUM
SPECTRUM TYPE. SINGLE POINT
NUMBER OF MODES TO BE USED. 2
ELEMENT RESULTS CALCULATION ON

LOAD STEP OPTIONS

LOAD STEP NUMBER. 1
SPECTRUM LOADING TYPE ACCELERATION
EXCITATION DIRECTION. 1.0000 0.00000E+00 0.00000E+00
MODE COMBINATION TYPE SRSS
SIGNIFICANCE LEVEL FOR COMBINATIONS. 0.10000E-03
PRINT OUTPUT CONTROLS
ITEM FREQUENCY COMPONENT
ALL ALL
DATABASE OUTPUT CONTROLS. ALL DATA WRITTEN

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***** REDUCED MASS DISTRIBUTION *****

ROW	NODE	DIR	VALUE
1	2	UX	0.97621
2	2	UY	0.96407
3	2	UZ	0.97621
7	3	UX	1.5862
8	3	UY	1.5862
9	3	UZ	1.5862
13	4	UX	1.6026
14	4	UY	1.6026
15	4	UZ	1.6026
19	5	UX	1.5577
20	5	UY	1.5577
21	5	UZ	1.5577
25	6	UX	0.72383
26	6	UY	0.72383
27	6	UZ	0.72383
31	7	UX	0.47144E-01
32	7	UY	0.47144E-01
33	7	UZ	0.47144E-01

MASS(X,Y,Z) = 6.494 6.482 6.494

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 15:29:41 SEP 07, 1994 CP= 3.080
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** RESPONSE SPECTRUM CALCULATION SUMMARY *****

MODE RATIO	FREQUENCY EFFECTIVE MASS	CUMULATIVE SV MASS FRACTION	PARTIC.FACTOR	MODE COEF.	M.C.
1	0.3541	33.421	-1.129	-7.621	
0.648741	1.27440		0.296203		
2	0.3541	33.421	1.740	11.75	
1.000000	3.02805		1.00000		

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SUM OF EFFECTIVE

MASSSES= 4.30245
1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
WEST. HANFORD VERSION=SGI IRIS4D 15:29:41 SEP 07, 1994 CP= 3.110
FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

SIGNIFICANCE FACTOR FOR COMBINING MODES = 0.10000E-03

SIGNIFICANT MODE COEFFICIENTS (INCLUDING DAMPING)

MODE	FREQUENCY	DAMPING	SV	MODE COEF.
1	0.3541	0.0000	33.421	-7.621
2	0.3541	0.0000	33.421	11.75

MODAL COMBINATION COEFFICIENTS

MODE=	1	FREQUENCY=	0.354	COUPLING COEF.=	1.000
MODE=	2	FREQUENCY=	0.354	COUPLING COEF.=	1.000

SRSS COMBINATION INSTRUCTIONS WRITTEN ON FILE skk.mcom

*** PROBLEM STATISTICS

ACTUAL NO. OF ACTIVE DEGREES OF FREEDOM = 1
R.M.S. WAVEFRONT SIZE = 0.0
NUMBER OF MASTER DEGREES OF FREEDOM = 36

*** ANSYS BINARY FILE STATISTICS

BUFFER SIZE USED= 4096

SEISMIC EXCITATION DIRECTION = 0.00000E+00 1.0000 0.00000E+00

FREQ= 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00 0.000E+00

SPECTRUM TABLE INITIALIZED

FREQ=	0.160	0.400	1.10	1.64	8.00	12.0	20.0
	33.0	100.					

NUMBER OF FREQUENCIES IN TABLE = 9

DAMPING= 0.00000E+00 SV= 0.15600E-01 0.62400E-01 0.16980
 0.25200 0.25200 0.20400
 0.15600 0.12000 0.12000

***** ANSYS SOLVE COMMAND *****

LOAD STEP OPTIONS

LOAD STEP NUMBER. 2
 SPECTRUM LOADING TYPE ACCELERATION
 EXCITATION DIRECTION. 0.00000E+00 1.0000 0.00000E+00
 MODE COMBINATION TYPE SRSS
 SIGNIFICANCE LEVEL FOR COMBINATIONS. 0.10000E-03
 PRINT OUTPUT CONTROLS
 ITEM FREQUENCY COMPONENT
 ALL ALL
 DATABASE OUTPUT CONTROLS. ALL DATA WRITTEN

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 15:29:41 SEP 07, 1994 CP= 3.170
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** RESPONSE SPECTRUM CALCULATION SUMMARY *****

MODE RATIO	FREQUENCY EFFECTIVE MASS	CUMULATIVE SV MASS FRACTION	PARTIC.FACTOR	MODE COEF.	M.C.
1	0.3541 20.053	0.7269E-13	0.2945E-12		
1.000000	0.528456E-26	0.633024			
2	0.3541 20.053	-0.5535E-13	-0.2242E-12		
0.761392	0.306356E-26	1.00000			

SUM OF EFFECTIVE

MASSSES= 0.834812E-26

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 15:29:41 SEP 07, 1994 CP= 3.180
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

SIGNIFICANCE FACTOR FOR COMBINING MODES = 0.10000E-03

SIGNIFICANT MODE COEFFICIENTS (INCLUDING DAMPING)

MODE	FREQUENCY	DAMPING	SV	MODE COEF.
1	0.3541	0.0000	20.053	0.2945E-12
2	0.3541	0.0000	20.053	-0.2242E-12

MODAL COMBINATION COEFFICIENTS

MODE=	1	FREQUENCY=	0.354	COUPLING COEF.=	1.000
MODE=	2	FREQUENCY=	0.354	COUPLING COEF.=	1.000

SRSS COMBINATION INSTRUCTIONS WRITTEN ON FILE skk.mcom

SEISMIC EXCITATION DIRECTION = 0.00000E+00 0.00000E+00 1.0000

FREQ= 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00 0.000E+00

SPECTRUM TABLE INITIALIZED

FREQ= 0.160 0.400 1.10 1.64 8.00 12.0 20.0
33.0 100.

NUMBER OF FREQUENCIES IN TABLE = 9

DAMPING=	0.00000E+00	SV=	0.26000E-01	0.10400	0.28300
			0.42000	0.42000	0.34000
			0.26000	0.20000	0.20000

***** ANSYS SOLVE COMMAND *****

LOAD STEP OPTIONS

LOAD STEP NUMBER. 3
SPECTRUM LOADING TYPE ACCELERATION
EXCITATION DIRECTION. 0.00000E+00 0.00000E+00 1.0000
MODE COMBINATION TYPE SRSS
SIGNIFICANCE LEVEL FOR COMBINATIONS. 0.10000E-03
PRINT OUTPUT CONTROLS
ITEM FREQUENCY COMPONENT
ALL ALL

DATABASE OUTPUT CONTROLS. ALL DATA WRITTEN

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 15:29:41 SEP 07, 1994 CP= 3.230
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** RESPONSE SPECTRUM CALCULATION SUMMARY *****

MODE RATIO	FREQUENCY EFFECTIVE MASS	CUMULATIVE SV MASS FRACTION	PARTIC.FACTOR	MODE COEF.	M.C.
1	0.3541	33.421	1.740	11.75	
1.000000	3.02804		0.703797		
2	0.3541	33.421	1.129	7.621	
0.648739	1.27439		1.00000		
					SUM OF EFFECTIVE
MASSES= 4.30243					
1					

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 15:29:41 SEP 07, 1994 CP= 3.240
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

SIGNIFICANCE FACTOR FOR COMBINING MODES = 0.10000E-03

SIGNIFICANT MODE COEFFICIENTS (INCLUDING DAMPING)

MODE	FREQUENCY	DAMPING	SV	MODE COEF.
1	0.3541	0.0000	33.421	11.75
2	0.3541	0.0000	33.421	7.621

MODAL COMBINATION COEFFICIENTS

MODE= 1 FREQUENCY= 0.354 COUPLING COEF.= 1.000

A-85

MODE= 2 FREQUENCY= 0.354 COUPLING COEF.= 1.000

SRSS COMBINATION INSTRUCTIONS WRITTEN ON FILE skk.mcom

FINISH SOLUTION PROCESSING

***** ROUTINE COMPLETED ***** CP = 3.270

***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER /SHOW,DEVICE-NAME TO ENABLE GRAPHIC DISPLAY
ENTER FINISH TO LEAVE POST1

/INPUT FILE= skk.mcom LINE= 0
ANSYS REVISION 5.0 A 15:29:41 09/07/1994
skk.mcom

CURRENT LOAD SET IN DATABASE IS ERASED

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 1 COMPLEX= 0
FILE= skk.rst
Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO -7.6210

COPY LOAD CASE 1 FROM FILE TO DATABASE

SQUARE THE CURRENT LOAD SET IN DATABASE

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 2 COMPLEX= 0
FILE= skk.rst
Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 11.747

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= 11.747 ABS= 0
MULTIPLIED BY LOAD CASE= 1 FACTOR= 11.747 ABS= 0

TAKE SQRT OF CURRENT LOAD SET IN DATABASE
ANSYS REVISION 5.0 A 15:29:41 09/07/1994
skk.mcom

SQUARE THE CURRENT LOAD SET IN DATABASE

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LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 1 COMPLEX= 0
 FILE= skk.rst
 Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 0.29445E-12

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= 0.29445E-12 ABS= 0
 MULTIPLIED BY LOAD CASE= 1 FACTOR= 0.29445E-12 ABS= 0

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 2 COMPLEX= 0
 FILE= skk.rst
 Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO -0.22419E-12

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= -0.22419E-12 ABS= 0
 MULTIPLIED BY LOAD CASE= 1 FACTOR= -0.22419E-12 ABS= 0

TAKE SQRT OF CURRENT LOAD SET IN DATABASE
 ANSYS REVISION 5.0 A 15:29:41 09/07/1994
 skk.mcom

SQUARE THE CURRENT LOAD SET IN DATABASE

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 1 COMPLEX= 0
 FILE= skk.rst
 Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 11.747

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= 11.747 ABS= 0
 MULTIPLIED BY LOAD CASE= 1 FACTOR= 11.747 ABS= 0

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 2 COMPLEX= 0
 FILE= skk.rst
 Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 7.6210

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= 7.6210 ABS= 0
 MULTIPLIED BY LOAD CASE= 1 FACTOR= 7.6210 ABS= 0

TAKE SQRT OF CURRENT LOAD SET IN DATABASE

PRODUCE DISPLACEMENT PLOT, KUND= 1

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PRINT DOF NODAL SOLUTION PER NODE

***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

CALCULATED LOAD CASE= 0

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2	0.49828E-01	0.34669E-13	0.49828E-01	0.27346E-02	0.28755E-13	
3	1.8662	0.20436E-12	1.8662	0.14128E-01	0.10435E-12	
4	4.2292	0.23045E-12	4.2291	0.18468E-01	0.92067E-13	
5	7.5829	0.23813E-12	7.5828	0.20505E-01	0.71800E-13	
6	10.249	0.24218E-12	10.249	0.20728E-01	0.58225E-13	
7	10.433	0.23865E-12	10.433	0.20728E-01	0.58462E-13	
MAXIMUM VALUES						
NODE	7	6	7	7	3	7
VALUE	10.433	0.24218E-12	10.433	0.20728E-01	0.10435E-12	

PRINT REACTION SOLUTIONS PER NODE

***** POST1 TOTAL REACTION SOLUTION LISTING *****

CALCULATED LOAD CASE= 0

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
1	-143.79	-0.31530E-06	-143.79	-72705.	-0.56716E-06	-72705.

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TOTAL VALUES
 VALUE -143.79 -0.31530E-06 -143.79 -72705. -0.56716E-06 -72705.

PRINT F ELEMENT SOLUTION PER ELEMENT

***** POST1 ELEMENT NODE TOTAL FORCE LISTING *****

CALCULATED LOAD CASE= 0

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

ELEM=	1	FX		FY		FZ
	1	143.79		0.31530E-06		143.79
	2	143.79		0.31530E-06		143.79
ELEM=	2	FX		FY		FZ
	2	142.07		0.28187E-06		142.07
	3	142.07		0.28187E-06		142.07
ELEM=	3	FX		FY		FZ
	3	128.21		0.76809E-07		128.21
	4	128.21		0.76809E-07		128.21
ELEM=	4	FX		FY		FZ
	4	93.118		0.47109E-07		93.118
	5	93.118		0.47109E-07		93.118
ELEM=	5	FX		FY		FZ
	5	36.478		0.37853E-07		36.478
	6	36.478		0.37853E-07		36.478
ELEM=	6	FX		FY		FZ
	6	2.4251		0.19160E-06		2.4251
	7	2.4251		0.19160E-06		2.4251

PRINT M ELEMENT SOLUTION PER ELEMENT

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***** POST1 ELEMENT NODE TOTAL FORCE LISTING *****

CALCULATED LOAD CASE= 0

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

ELEM=	1	MX	MY	MZ
	1	72705.	0.56716E-06	72705.
	2	67528.	0.56716E-06	67528.

ELEM=	2	MX	MY	MZ
	2	67450.	0.27078E-06	67450.
	3	38609.	0.27078E-06	38609.

ELEM=	3	MX	MY	MZ
	3	38507.	0.64994E-07	38507.
	4	20172.	0.64994E-07	20173.

ELEM=	4	MX	MY	MZ
	4	19762.	0.91364E-07	19762.
	5	3921.2	0.91364E-07	3921.2

ELEM=	5	MX	MY	MZ
	5	4066.1	0.81128E-07	4066.1
	6	639.70	0.81128E-07	639.70

ELEM=	6	MX	MY	MZ
	6	17.946	0.71048E-07	17.947
	7	3.5763	0.71048E-07	3.5763

EXIT THE ANSYS POST1 DATABASE PROCESSOR

***** ROUTINE COMPLETED ***** CP = 4.700

PURGE ALL SOLUTION AND POST DATA
SAVE ALL MODEL DATA

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*** NOTE ***

CP= 4.750 TIME= 15:31:15

NEW BACKUP FILE NAME= skk.dbb.

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= skk.db
FOR POSSIBLE RESUME FROM THIS POINT

NUMBER OF WARNING MESSAGES ENCOUNTERED=	0
NUMBER OF ERROR MESSAGES ENCOUNTERED=	0

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ANSYS FILE : TMOD.IN

Description of file: The probe is modelled with two springs one on each X and Z directions at node # 10 which is approximately the end of the riser pipe. This model is used to evaluate the seismic response of the probe.

/title,Modal analysis of thermocouple tree with spring restraint

et,1,4

et,2,14,,1,

et,3,14,,3,

!

r,1,11.29,31.83,31.83,5.5,5.5,

r,2,11.608,32.58,32.58,5.5,5.5,

r,3,11.9274,33.34,33.34,5.5,5.5,

r,4,12.2416,34.09,34.09,5.5,5.5,,

r,5,12.399,34.65,34.28,5.5,5.5,

r,6,12.5563,35.21,34.47,5.5,5.5,

r,7,1e6

r,8,1e6

ex,1,29e6

dens,1,.00073386

nuxy,1,.3

ex,2,29e6

dens,2,.00084611

nuxy,2,.3

!

n,1,,,,

n,2,,,-36,,

n,10,,,-225.48

n,3,,,-239,,

n,4,,,-382,,

n,5,,,-552.12,,

n,6,,,-681.125,,

n,7,,,-690,,

n,9,,,-225.48,1

n,8,1,-225.48,,

!

mat,1

type,1

real,1

e,1,2

!

real,2

e,2,10

e,10,3

```
mat,2
type,1
real,3
e,3,4
!
real,4
e,4,5
!
real,5
e,5,6
!
real,6
e,6,7
!
type,2
real,7
e,10,8
!
type,3
real,8
e,10,9
!
d,1,all
d,8,all
d,9,all
fini
!
!
/solu
outpr,all,all
antype,modal
modopt,redu
m,2,ux,7,1,uy,uz,rotx,roty,rotz
save
solve
finish
!
/solu
expass,on
mxpand,20,.01,150,yes
solve
finish
!
/solu
antype,spectr
spopt,sprs,20,on
svtype,2,386.4
sed,1,0,0
freq,0.16,0.4,1.1,1.64,8,12,20,33,100
sv,,0.026,0.104,0.283,0.420,0.420,0.340,0.26,0.2,0.2
```

```

mcomb,srss,0.0001
solve
!
sed,0,1,0
freq
freq,0.16,0.4,1.1,1.64,8,12,20,33,100
sv,,0.0156,0.0624,0.1698,0.252,0.252,0.204,0.156,0.12,0.12
solve
!
sed,0,0,1
freq
freq,0.16,0.4,1.1,1.64,8,12,20,33,100
sv,,0.026,0.104,0.283,0.420,0.420,0.340,0.26,0.2,0.2
solve
!
finish

```

ANSYS FILE : TMOD.OUT

Description of the file: This is the output file for the input file TMOD.IN. The results obtained from this modal analysis is used to evaluate the probe.

/INPUT FILE= tmod.in LINE= 0

TITLE=

Modal analysis of thermocouple tree with spring restraint

ELEMENT TYPE 1 IS BEAM4 3-D ELASTIC BEAM
KEYOPT(1-12)= 0 0 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

ELEMENT TYPE 2 IS COMBIN14 SPRING-DAMPER
KEYOPT(1-12)= 0 1 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

ELEMENT TYPE 3 IS COMBIN14 SPRING-DAMPER
KEYOPT(1-12)= 0 3 0 0 0 0 0 0 0 0 0 0

CURRENT NODAL DOF SET IS UX UY UZ ROTX ROTY ROTZ
THREE-DIMENSIONAL MODEL

REAL CONSTANT SET 1 ITEMS 1 TO 6
11.290 31.830 31.830 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 2 ITEMS 1 TO 6
11.608 32.580 32.580 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 3 ITEMS 1 TO 6
11.927 33.340 33.340 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 4 ITEMS 1 TO 6
12.242 34.090 34.090 5.5000 5.5000
0.00000E+00

REAL CONSTANT SET 5 ITEMS 1 TO 6
 12.399 34.650 34.280 5.5000 5.5000
 0.00000E+00

REAL CONSTANT SET 6 ITEMS 1 TO 6
 12.556 35.210 34.470 5.5000 5.5000
 0.00000E+00

REAL CONSTANT SET 7 ITEMS 1 TO 6
 0.10000E+07 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00

REAL CONSTANT SET 8 ITEMS 1 TO 6
 0.10000E+07 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00

MATERIAL 1 EX = 0.2900000E+08

MATERIAL 1 DENS = 0.7338600E-03

MATERIAL 1 NUXY = 0.3000000

MATERIAL 2 EX = 0.2900000E+08

MATERIAL 2 DENS = 0.8461100E-03

MATERIAL 2 NUXY = 0.3000000

NODE 1 KCS= 0 X,Y,Z= 0.00000E+00 0.00000E+00 0.00000E+00

NODE 2 KCS= 0 X,Y,Z= 0.00000E+00 -36.000 0.00000E+00

NODE 10 KCS= 0 X,Y,Z= 0.00000E+00 -225.48 0.00000E+00

NODE 3 KCS= 0 X,Y,Z= 0.00000E+00 -239.00 0.00000E+00

NODE 4 KCS= 0 X,Y,Z= 0.00000E+00 -382.00 0.00000E+00

NODE 5 KCS= 0 X,Y,Z= 0.00000E+00 -552.12 0.00000E+00

NODE 6 KCS= 0 X,Y,Z= 0.00000E+00 -681.13 0.00000E+00

NODE 7 KCS= 0 X,Y,Z= 0.00000E+00 -690.00 0.00000E+00

NODE 9 KCS= 0 X,Y,Z= 0.00000E+00 -225.48 1.0000

NODE 8 KCS= 0 X,Y,Z= 1.0000 -225.48 0.00000E+00

MATERIAL NUMBER SET TO 1

ELEMENT TYPE SET TO 1
 REAL CONSTANT NUMBER= 1
 ELEMENT 1 1 2 0

REAL CONSTANT NUMBER= 2
 ELEMENT 2 2 10 0
 ELEMENT 3 10 3 0

MATERIAL NUMBER SET TO 2
 ELEMENT TYPE SET TO 1
 REAL CONSTANT NUMBER= 3
 ELEMENT 4 3 4 0

REAL CONSTANT NUMBER= 4
 ELEMENT 5 4 5 0
 REAL CONSTANT NUMBER= 5
 ELEMENT 6 5 6 0

REAL CONSTANT NUMBER= 6
 ELEMENT 7 6 7 0
 ELEMENT TYPE SET TO 2
 REAL CONSTANT NUMBER= 7

ELEMENT 8 10 8
 ELEMENT TYPE SET TO 3
 REAL CONSTANT NUMBER= 8
 ELEMENT 9 10 9

SPECIFIED CONSTRAINT UX	FOR SELECTED NODES	1 TO	1 BY	1
REAL= 0.000000000E+00	IMAG= 0.000000000E+00			
ADDITIONAL DOFS= UY	UZ ROTX ROTY ROTZ			

SPECIFIED CONSTRAINT UX	FOR SELECTED NODES	8 TO	8 BY	1
REAL= 0.000000000E+00	IMAG= 0.000000000E+00			

ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ

SPECIFIED CONSTRAINT UX FOR SELECTED NODES 9 TO 9 BY 1
 REAL= 0.000000000E+00 IMAG= 0.000000000E+00
 ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ

***** ROUTINE COMPLETED ***** CP = 2.540

***** ANSYS SOLUTION ROUTINE *****

PRINT ALL ITEMS WITH A FREQUENCY OF ALL
 FOR ALL APPLICABLE ENTITIES

PERFORM A MODAL ANALYSIS
 THIS WILL BE A NEW ANALYSIS

USE HOUSEHOLDER METHOD
 EXTRACT AS MANY MODES AS THERE ARE MDOF
 PRINT 0 REDUCED MODES
 NORMALIZE THE MODE SHAPES TO THE MASS MATRIX

MASTER DOF UX FOR SELECTED NODES IN RANGE 2 TO 7 IN STEPS OF 1
 ADDITIONAL DOFS= UY UZ ROTX ROTY ROTZ
 NUMBER OF MASTER DOF= 36

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= skk.db
 FOR POSSIBLE RESUME FROM THIS POINT

***** ANSYS SOLVE COMMAND *****

*** WARNING *** CP= 2.690 TIME= 09:17:20
 Nodes I and J of element 8 (COMBIN14) are not coincident.

*** WARNING *** CP= 2.700 TIME= 09:17:22
 Nodes I and J of element 9 (COMBIN14) are not coincident.

*** NOTE *** CP= 2.700 TIME= 09:17:25
 The model data was checked and warning messages were found.
 Please review output or errors file (file.err) for these warning
 messages.

SOLUTION OPTIONS

PROBLEM DIMENSIONALITY.3-D
 DEGREES OF FREEDOM. UX UY UZ ROTX ROTY ROTZ

ANALYSIS TYPE MODAL
 EXTRACTION METHOD. REDUCED
 NUMBER OF MODES TO EXTRACT. ALL MDOF
 NUMBER OF REDUCED MODES TO PRINT. 0
 NUMBER OF MASTER DOF. 36

LOAD STEP OPTIONS

LOAD STEP NUMBER. 1

***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****

CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS = 6.6804

CENTROID	MOM. OF INERTIA ABOUT ORIGIN	MOM. OF INERTIA ABOUT CENTROID
XC = 0.00000E+00	IXX = 0.1116E+07	IXX = 0.2444E+06
YC = -361.26	IYY = 0.0000E+00	IYY = 0.0000E+00
ZC = 0.00000E+00	IZZ = 0.1116E+07	IZZ = 0.2444E+06
	IXY = 0.0000E+00	IXY = 0.0000E+00
	IYZ = 0.0000E+00	IYZ = 0.0000E+00
	IZX = 0.0000E+00	IZX = 0.0000E+00

*** MASS SUMMARY BY ELEMENT TYPE ***

TYPE	MASS
1	6.68042

Range of element maximum matrix coefficients in global coordinates
 Maximum= 460209577 at element 7.
 Minimum= 1000000 at element 9.

*** ELEMENT MATRIX FORMULATION TIMES

TYPE	NUMBER	ENAME	TOTAL CP	AVE CP
------	--------	-------	----------	--------

1	7	BEAM4	0.040	0.006
2	1	COMBIN14	0.000	0.000
3	1	COMBIN14	0.000	0.000

Time at end of element matrix formulation CP= 2.8599999.

Estimated number of active DOF= 42.
 Maximum wavefront= 54.

Number of Master DOF= 36.

Time at end of matrix triangularization CP= 2.97000003.
Equation solver maximum pivot= 129147168 at node 10 ROTZ.
Equation solver minimum pivot= 5589421.97 at node 10 UZ.

***** EIGENVALUE (NATURAL FREQUENCY) SOLUTION *****

MODE	FREQUENCY (CYCLES/TIME)
1	0.643136961
2	0.643146106
3	4.30660436
4	4.30808690
5	12.3340326
6	12.3498537
7	22.6622033
8	22.6792063
9	31.4179569
10	31.4617889
11	41.2646960
12	49.1721226
13	49.2498623
14	66.3375305
15	76.0304895
16	76.0808005
17	126.762817
18	127.349021
19	133.836818
20	215.793211
21	239.341984
22	239.342729
23	253.030960
24	347.476172
25	347.476871
26	383.804728
27	407.923701
28	467.909040
29	618.866253
30	753.599407
31	2563.28893
32	2585.10084
33	3855.38180
34	6217.43760
35	13247.7148
36	13299.4694

***** REDUCED MASS DISTRIBUTION *****

ROW	NODE	DIR	VALUE
1	6	UX	0.72383
2	6	UY	0.72383
3	6	UZ	0.72383
7	7	UX	0.47144E-01
8	7	UY	0.47144E-01
9	7	UZ	0.47144E-01
13	5	UX	1.5577
14	5	UY	1.5577
15	5	UZ	1.5577
19	4	UX	1.6026
20	4	UY	1.6026
21	4	UZ	1.6026
25	3	UX	0.94232
26	3	UY	1.5862
27	3	UZ	0.94232
34	2	UZ	0.42110
35	2	UY	0.96407
36	2	UX	0.42110

MASS(X,Y,Z) = 5.295 6.482 5.295

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
WEST. HANFORD VERSION=SGI IRIS4D 09:17:36 SEP 08, 1994 CP= 3.190
FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** PARTICIPATION FACTOR CALCULATION ***** X DIRECTION

MODE MASS	CUMULATIVE FREQUENCY MASS FRACTION	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE
1	0.643137	1.5549	0.57031E-04	0.000032	
0.325255E-08	0.614301E-09				
2	0.643146	1.5549	1.7893	1.000000	3.20150
	0.604659				
3	4.30660	0.23220	-0.42162E-08	0.000000	
0.177759E-16	0.604659				

A-101

4	4.30809	0.23212	-0.93940	0.525019	0.882478
	0.771330				
5	12.3340	0.81076E-01	0.21758E-09	0.000000	
0.473430E-19	0.771330				
6	12.3499	0.80973E-01	0.47841	0.267375	0.228874
	0.814557				
7	22.6622	0.44126E-01	0.43832E-11	0.000000	
0.192124E-22	0.814557				
8	22.6792	0.44093E-01	0.23610E-01	0.013195	
0.557425E-03	0.814662				
9	31.4180	0.31829E-01	-0.42101E-11	0.000000	
0.177246E-22	0.814662				
10	31.4618	0.31785E-01	-0.54501	0.304599	0.297036
	0.870762				
11	41.2647	0.24234E-01	0.10553E-12	0.000000	
0.111365E-25	0.870762				
12	49.1721	0.20337E-01	0.44871E-10	0.000000	
0.201343E-20	0.870762				
13	49.2499	0.20305E-01	0.50279	0.281003	0.252798
	0.918508				
14	66.3375	0.15074E-01	0.68192E-12	0.000000	
0.465012E-24	0.918508				
15	76.0305	0.13153E-01	-0.28175E-08	0.000000	
0.793851E-17	0.918508				
16	76.0808	0.13144E-01	-0.45211	0.252679	0.204404
	0.957113				
17	126.763	0.78887E-02	-0.52332E-14	0.000000	
0.273867E-28	0.957113				
18	127.349	0.78524E-02	0.84963E-01	0.047485	
0.721874E-02	0.958476				
19	133.837	0.74718E-02	-0.67233E-13	0.000000	
0.452033E-26	0.958476				
20	215.793	0.46341E-02	-0.27515E-14	0.000000	
0.757064E-29	0.958476				
21	239.342	0.41781E-02	-0.32557E-04	0.000018	
0.105995E-08	0.958476				
22	239.343	0.41781E-02	0.35442	0.198078	0.125610
	0.982200				
23	253.031	0.39521E-02	-0.10067E-12	0.000000	
0.101337E-25	0.982200				
24	347.476	0.28779E-02	-0.13367E-02	0.000747	
0.178667E-05	0.982200				
25	347.477	0.28779E-02	0.30699	0.171574	
0.942448E-01	1.000000				
26	383.805	0.26055E-02	0.54204E-14	0.000000	
0.293810E-28	1.000000				
27	407.924	0.24514E-02	0.69177E-14	0.000000	
0.478547E-28	1.000000				
28	467.909	0.21372E-02	0.13820E-14	0.000000	
0.190988E-29	1.000000				

29	618.866	0.16159E-02	-0.24070E-16	0.000000
0.579356E-33	1.000000			
30	753.599	0.13270E-02	0.19590E-14	0.000000
0.383766E-29	1.000000			
31	2563.29	0.39012E-03	0.41950E-15	0.000000
0.175979E-30	1.000000			
32	2585.10	0.38683E-03	0.76405E-04	0.000043
0.583777E-08	1.000000			
33	3855.38	0.25938E-03	-0.13632E-15	0.000000
0.185820E-31	1.000000			
34	6217.44	0.16084E-03	0.12023E-15	0.000000
0.144554E-31	1.000000			
35	13247.7	0.75485E-04	-0.13825E-17	0.000000
0.191122E-35	1.000000			
36	13299.5	0.75191E-04	-0.12994E-05	0.000001
0.168853E-11	1.000000			

SUM OF EFFECTIVE MASSES= 5.29472

***** PARTICIPATION FACTOR CALCULATION ***** Y DIRECTION

MODE MASS	CUMULATIVE FREQUENCY MASS FRACTION	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE
1	0.643137	1.5549	-0.15802E-12	0.000000	
0.249692E-25	0.385233E-26				
2	0.643146	1.5549	-0.38302E-12	0.000000	
0.146706E-24	0.264866E-25				
3	4.30660	0.23220	0.18650E-12	0.000000	
0.347809E-25	0.318528E-25				
4	4.30809	0.23212	-0.63146E-13	0.000000	
0.398748E-26	0.324680E-25				
5	12.3340	0.81076E-01	0.17939E-12	0.000000	
0.321816E-25	0.374330E-25				
6	12.3499	0.80973E-01	-0.20041E-12	0.000000	
0.401636E-25	0.436296E-25				
7	22.6622	0.44126E-01	0.39871E-13	0.000000	
0.158970E-26	0.438749E-25				
8	22.6792	0.44093E-01	-0.80133E-12	0.000000	
0.642132E-24	0.142945E-24				
9	31.4180	0.31829E-01	0.60233E-13	0.000000	
0.362799E-26	0.143505E-24				
10	31.4618	0.31785E-01	-0.15101E-11	0.000000	
0.228036E-23	0.495327E-24				
11	41.2647	0.24234E-01	0.29765E-12	0.000000	
0.885973E-25	0.508996E-24				

12	49.1721	0.20337E-01	0.42492E-12	0.000000	
0.180556E-24		0.536853E-24			
13	49.2499	0.20305E-01	-0.19484E-11	0.000000	
0.379634E-23		0.112257E-23			
14	66.3375	0.15074E-01	2.3533	1.000000	5.53824
	0.854458				
15	76.0305	0.13153E-01	-0.74030E-12	0.000000	
0.548042E-24		0.854458			
16	76.0808	0.13144E-01	0.14628E-11	0.000000	
0.213980E-23		0.854458			
17	126.763	0.78887E-02	-0.14582E-12	0.000000	
0.212626E-25		0.854458			
18	127.349	0.78524E-02	0.66396E-12	0.000000	
0.440843E-24		0.854458			
19	133.837	0.74718E-02	0.66910E-13	0.000000	
0.447688E-26		0.854458			
20	215.793	0.46341E-02	0.69139	0.293791	0.478022
	0.928209				
21	239.342	0.41781E-02	0.29806E-15	0.000000	
0.888394E-31		0.928209			
22	239.343	0.41781E-02	0.47978E-14	0.000000	
0.230186E-28		0.928209			
23	253.031	0.39521E-02	-0.23801E-13	0.000000	
0.566471E-27		0.928209			
24	347.476	0.28779E-02	0.16734E-15	0.000000	
0.280016E-31		0.928209			
25	347.477	0.28779E-02	-0.59138E-15	0.000000	
0.349736E-30		0.928209			
26	383.805	0.26055E-02	0.38009E-14	0.000000	
0.144466E-28		0.928209			
27	407.924	0.24514E-02	0.41388	0.175870	0.171300
	0.954638				
28	467.909	0.21372E-02	-0.28876E-13	0.000000	
0.833839E-27		0.954638			
29	618.866	0.16159E-02	-0.25198	0.107073	
0.634940E-01		0.964434			
30	753.599	0.13270E-02	0.48013	0.204020	0.230524
	1.000000				
31	2563.29	0.39012E-03	-0.32473E-15	0.000000	
0.105448E-30		1.000000			
32	2585.10	0.38683E-03	0.31692E-14	0.000000	
0.100441E-28		1.000000			
33	3855.38	0.25938E-03	0.45450E-16	0.000000	
0.206571E-32		1.000000			
34	6217.44	0.16084E-03	-0.27837E-04	0.000012	
0.774913E-09		1.000000			
35	13247.7	0.75485E-04	-0.16385E-16	0.000000	
0.268470E-33		1.000000			
36	13299.5	0.75191E-04	-0.11950E-15	0.000000	
0.142804E-31		1.000000			

SUM OF EFFECTIVE MASSES= 6.48158

***** PARTICIPATION FACTOR CALCULATION ***** Z DIRECTION

MODE MASS	CUMULATIVE FREQUENCY MASS FRACTION	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE
1	0.643137	1.5549	1.7893	1.000000	3.20145
	0.604649				
2	0.643146	1.5549	-0.57031E-04	0.000032	
0.325250E-08	0.604649				
3	4.30660	0.23220	-0.93924	0.524933	0.882174
	0.771262				
4	4.30809	0.23212	0.22170E-07	0.000000	
0.491513E-15	0.771262				
5	12.3340	0.81076E-01	0.47852	0.267440	0.228981
	0.814509				
6	12.3499	0.80973E-01	0.10008E-09	0.000000	
0.100150E-19	0.814509				
7	22.6622	0.44126E-01	0.21876E-01	0.012226	
0.478564E-03	0.814600				
8	22.6792	0.44093E-01	0.43793E-10	0.000000	
0.191781E-20	0.814600				
9	31.4180	0.31829E-01	-0.54421	0.304156	0.296169
	0.870536				
10	31.4618	0.31785E-01	-0.69400E-09	0.000000	
0.481637E-18	0.870536				
11	41.2647	0.24234E-01	0.16214E-12	0.000000	
0.262903E-25	0.870536				
12	49.1721	0.20337E-01	0.50344	0.281366	0.253448
	0.918404				
13	49.2499	0.20305E-01	0.50510E-11	0.000000	
0.255131E-22	0.918404				
14	66.3375	0.15074E-01	-0.77493E-14	0.000000	
0.600523E-28	0.918404				
15	76.0305	0.13153E-01	-0.45256	0.252934	0.204814
	0.957087				
16	76.0808	0.13144E-01	0.97259E-10	0.000000	
0.945931E-20	0.957087				
17	126.763	0.78887E-02	0.85719E-01	0.047907	
0.734770E-02	0.958475				
18	127.349	0.78524E-02	-0.15309E-12	0.000000	
0.234371E-25	0.958475				
19	133.837	0.74718E-02	-0.97228E-14	0.000000	
0.945336E-28	0.958475				

20	215.793	0.46341E-02	-0.33322E-13	0.000000	
0.111034E-26	0.958475				
21	239.342	0.41781E-02	0.35443	0.198085	0.125617
	0.982200				
22	239.343	0.41781E-02	0.32558E-04	0.000018	
0.106001E-08	0.982200				
23	253.031	0.39521E-02	-0.15060E-12	0.000000	
0.226804E-25	0.982200				
24	347.476	0.28779E-02	0.30699	0.171576	
0.942453E-01	1.000000				
25	347.477	0.28779E-02	0.13367E-02	0.000747	
0.178668E-05	1.000000				
26	383.805	0.26055E-02	0.51776E-15	0.000000	
0.268072E-30	1.000000				
27	407.924	0.24514E-02	-0.13197E-13	0.000000	
0.174170E-27	1.000000				
28	467.909	0.21372E-02	-0.85488E-15	0.000000	
0.730818E-30	1.000000				
29	618.866	0.16159E-02	0.22950E-14	0.000000	
0.526707E-29	1.000000				
30	753.599	0.13270E-02	-0.33510E-16	0.000000	
0.112289E-32	1.000000				
31	2563.29	0.39012E-03	0.77813E-04	0.000043	
0.605483E-08	1.000000				
32	2585.10	0.38683E-03	0.35585E-15	0.000000	
0.126631E-30	1.000000				
33	3855.38	0.25938E-03	0.76870E-16	0.000000	
0.590907E-32	1.000000				
34	6217.44	0.16084E-03	0.14799E-14	0.000000	
0.219007E-29	1.000000				
35	13247.7	0.75485E-04	0.13097E-05	0.000001	
0.171525E-11	1.000000				
36	13299.5	0.75191E-04	-0.32197E-16	0.000000	
0.103663E-32	1.000000				

SUM OF EFFECTIVE MASSES= 5.29472

*** PROBLEM STATISTICS

ACTUAL NO. OF ACTIVE DEGREES OF FREEDOM = 6
 R.M.S. WAVEFRONT SIZE = 39.5
 NUMBER OF MASTER DEGREES OF FREEDOM = 36

*** ANSYS BINARY FILE STATISTICS

BUFFER SIZE USED= 4096
 0.016 MB WRITTEN ON ELEMENT MATRIX FILE: skk.emat
 0.016 MB WRITTEN ON ELEMENT SAVED DATA FILE: skk.esav
 0.016 MB WRITTEN ON TRIANGULARIZED MATRIX FILE: skk.tri
 0.047 MB WRITTEN ON MODAL MATRIX FILE: skk.mode

FINISH SOLUTION PROCESSING

***** ROUTINE COMPLETED ***** CP = 3.330

*** NOTE *** CP= 5.530 TIME= 09:17:41
A total of 2 warnings and errors written to file.err.

***** ANSYS SOLUTION ROUTINE *****

PERFORM A SPECTRUM ANALYSIS
THIS WILL BE A NEW ANALYSIS

*** NOTE *** CP= 5.550 TIME= 09:17:44
Some analysis options have been reset to their defaults. Please verify current settings or respecify as required.

USE SINGLE POINT EXCITATION RESPONSE SPECTRUM
USE THE FIRST 20 MODES FROM THE MODAL ANALYSIS
INCLUDE STRESS RESPONSES IN THE CALCULATIONS

SPECTRUM TYPE KEY= 2 FACTOR= 386.400

SEISMIC EXCITATION DIRECTION = 1.0000 0.00000E+00 0.00000E+00

FREQ= 0.160 0.400 1.10 1.64 8.00 12.0 20.0
33.0 100.

NUMBER OF FREQUENCIES IN TABLE = 9

DAMPING= 0.00000E+00	SV= 0.26000E-01	0.10400	0.28300
	0.42000	0.42000	0.34000
	0.26000	0.20000	0.20000

COMBINE MODES USING THE SRSS METHOD
WHOSE SIGNIFICANCE LEVEL EXCEEDS THE THRESHOLD OF 0.10000E-03

***** ANSYS SOLVE COMMAND *****

SOLUTION OPTIONS

PROBLEM DIMENSIONALITY.3-D
DEGREES OF FREEDOM. UX UY UZ ROTX ROTY ROTZ
ANALYSIS TYPE.SPECTRUM
SPECTRUM TYPE.SINGLE POINT
NUMBER OF MODES TO BE USED.20
ELEMENT RESULTS CALCULATIONON

LOAD STEP OPTIONS

LOAD STEP NUMBER. 1
 SPECTRUM LOADING TYPE ACCELERATION
 EXCITATION DIRECTION. 1.0000 0.00000E+00 0.00000E+00
 MODE COMBINATION TYPE SRSS
 SIGNIFICANCE LEVEL FOR COMBINATIONS. 0.10000E-03
 PRINT OUTPUT CONTROLS
 ITEM FREQUENCY COMPONENT
 ALL ALL
 DATABASE OUTPUT CONTROLS. ALL DATA WRITTEN

***** REDUCED MASS DISTRIBUTION *****

ROW	NODE	DIR	VALUE
1	6	UX	0.72383
2	6	UY	0.72383
3	6	UZ	0.72383
7	7	UX	0.47144E-01
8	7	UY	0.47144E-01
9	7	UZ	0.47144E-01
13	5	UX	1.5577
14	5	UY	1.5577
15	5	UZ	1.5577
19	4	UX	1.6026
20	4	UY	1.6026
21	4	UZ	1.6026
25	3	UX	0.94232
26	3	UY	1.5862
27	3	UZ	0.94232
34	2	UZ	0.42110
35	2	UY	0.96407
36	2	UX	0.42110

1 MASS(X,Y,Z) = 5.295 6.482 5.295

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 09:17:48 SEP 08, 1994 CP= 5.610
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** RESPONSE SPECTRUM CALCULATION SUMMARY *****

MODE RATIO	FREQUENCY EFFECTIVE MASS	CUMULATIVE SV MASS FRACTION	PARTIC.FACTOR	MODE COEF.	M.C.
1	0.6431	64.293	0.5703E-04	0.2245E-03	
0.000032	0.325255E-08		0.640914E-09		
2	0.6431	64.294	1.789	7.045	
1.000000	3.20150		0.630854		
3	4.307	162.29	-0.4216E-08	-0.9345E-09	
0.000000	0.177759E-16		0.630854		
4	4.308	162.29	-0.9394	-0.2081	
0.029535	0.882478		0.804746		
5	12.33	129.50	0.2176E-09	0.4692E-11	
0.000000	0.473430E-19		0.804746		
6	12.35	129.41	0.4784	0.1028E-01	
0.001460	0.228874		0.849845		
7	22.66	94.097	0.4383E-11	0.2034E-13	
0.000000	0.192124E-22		0.849845		
8	22.68	94.060	0.2361E-01	0.1094E-03	
0.000016	0.557425E-03		0.849955		
9	31.42	79.295	-0.4210E-11	-0.8567E-14	
0.000000	0.177246E-22		0.849955		
10	31.46	79.237	-0.5450	-0.1105E-02	
0.000157	0.297036		0.908486		
11	41.26	77.280	0.1055E-12	0.1213E-15	
0.000000	0.111365E-25		0.908486		
12	49.17	77.280	0.4487E-10	0.3633E-13	
0.000000	0.201343E-20		0.908486		
13	49.25	77.280	0.5028	0.4058E-03	
0.000058	0.252798		0.958300		
14	66.34	77.280	0.6819E-12	0.3033E-15	
0.000000	0.465012E-24		0.958300		
15	76.03	77.280	-0.2818E-08	-0.9541E-12	
0.000000	0.793851E-17		0.958300		
16	76.08	77.280	-0.4521	-0.1529E-03	
0.000022	0.204404		0.998578		
17	126.8	77.280	-0.5233E-14	-0.6375E-18	
0.000000	0.273867E-28		0.998578		
18	127.3	77.280	0.8496E-01	0.1026E-04	
0.000001	0.721874E-02		1.000000		
19	133.8	77.280	-0.6723E-13	-0.7348E-17	
0.000000	0.452033E-26		1.000000		
20	215.8	77.280	-0.2751E-14	-0.1157E-18	
0.000000	0.757064E-29		1.000000		

SUM OF EFFECTIVE

MASSES= 5.07487

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 09:17:48 SEP 08, 1994 CP= 5.640
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

SIGNIFICANCE FACTOR FOR COMBINING MODES = 0.10000E-03

SIGNIFICANT MODE COEFFICIENTS (INCLUDING DAMPING)

MODE	FREQUENCY	DAMPING	SV	MODE COEF.
2	0.6431	0.0000	64.294	7.045
4	4.308	0.0000	162.29	-0.2081
6	12.35	0.0000	129.41	0.1028E-01
10	31.46	0.0000	79.237	-0.1105E-02

MODAL COMBINATION COEFFICIENTS

MODE=	2	FREQUENCY=	0.643	COUPLING COEF.=	1.000
MODE=	4	FREQUENCY=	4.308	COUPLING COEF.=	1.000
MODE=	6	FREQUENCY=	12.350	COUPLING COEF.=	1.000
MODE=	10	FREQUENCY=	31.462	COUPLING COEF.=	1.000

SRSS COMBINATION INSTRUCTIONS WRITTEN ON FILE skk.mcom

*** PROBLEM STATISTICS

ACTUAL NO. OF ACTIVE DEGREES OF FREEDOM = 6
 R.M.S. WAVEFRONT SIZE = 39.5
 NUMBER OF MASTER DEGREES OF FREEDOM = 36

*** ANSYS BINARY FILE STATISTICS

BUFFER SIZE USED= 4096

SEISMIC EXCITATION DIRECTION = 0.00000E+00 1.0000 0.00000E+00

FREQ= 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
 0.000E+00 0.000E+00

SPECTRUM TABLE INITIALIZED

FREQ= 0.160 0.400 1.10 1.64 8.00 12.0 20.0
 33.0 100.
 NUMBER OF FREQUENCIES IN TABLE = 9

DAMPING= 0.00000E+00 SV= 0.15600E-01 0.62400E-01 0.16980
 0.25200 0.25200 0.20400
 0.15600 0.12000 0.12000

***** ANSYS SOLVE COMMAND *****

LOAD STEP OPTIONS

LOAD STEP NUMBER. 2
 SPECTRUM LOADING TYPE ACCELERATION
 EXCITATION DIRECTION. 0.00000E+00 1.0000 0.00000E+00
 MODE COMBINATION TYPE SRSS
 SIGNIFICANCE LEVEL FOR COMBINATIONS. 0.10000E-03
 PRINT OUTPUT CONTROLS
 ITEM FREQUENCY COMPONENT
 ALL ALL
 DATABASE OUTPUT CONTROLS. ALL DATA WRITTEN

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 09:17:48 SEP 08, 1994 CP= 5.720
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

***** RESPONSE SPECTRUM CALCULATION SUMMARY *****

MODE RATIO	FREQUENCY EFFECTIVE MASS	CUMULATIVE SV MASS FRACTION	PARTIC.FACTOR	MODE COEF.	M.C.
1	0.6431 38.576	-0.1580E-12	-0.3733E-12		
0.000000	0.249692E-25	0.415028E-26			
2	0.6431 38.576	-0.3830E-12	-0.9048E-12		
0.000000	0.146706E-24	0.285352E-25			
3	4.307 97.373	0.1865E-12	0.2480E-13		
0.000000	0.347809E-25	0.343164E-25			
4	4.308 97.373	-0.6315E-13	-0.8392E-14		
0.000000	0.398748E-26	0.349791E-25			
5	12.33 77.697	0.1794E-12	0.2321E-14		
0.000000	0.321816E-25	0.403282E-25			
6	12.35 77.645	-0.2004E-12	-0.2584E-14		
0.000000	0.401636E-25	0.470041E-25			
7	22.66 56.458	0.3987E-13	0.1110E-15		
0.000000	0.158970E-26	0.472683E-25			

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8	22.68	56.436	-0.8013E-12	-0.2227E-14
0.000000	0.642132E-24		0.154001E-24	
9	31.42	47.577	0.6023E-13	0.7354E-16
0.000000	0.362799E-26		0.154604E-24	
10	31.46	47.542	-0.1510E-11	-0.1837E-14
0.000000	0.228036E-23		0.533638E-24	
11	41.26	46.368	0.2977E-12	0.2053E-15
0.000000	0.885973E-25		0.548364E-24	
12	49.17	46.368	0.4249E-12	0.2064E-15
0.000000	0.180556E-24		0.578375E-24	
13	49.25	46.368	-0.1948E-11	-0.9435E-15
0.000000	0.379634E-23		0.120939E-23	
14	66.34	46.368	2.353	0.6281E-03
1.000000	5.53824		0.920545	
15	76.03	46.368	-0.7403E-12	-0.1504E-15
0.000000	0.548042E-24		0.920545	
16	76.08	46.368	0.1463E-11	0.2968E-15
0.000000	0.213980E-23		0.920545	
17	126.8	46.368	-0.1458E-12	-0.1066E-16
0.000000	0.212626E-25		0.920545	
18	127.3	46.368	0.6640E-12	0.4808E-16
0.000000	0.440843E-24		0.920545	
19	133.8	46.368	0.6691E-13	0.4387E-17
0.000000	0.447688E-26		0.920545	
20	215.8	46.368	0.6914	0.1744E-04
0.027764	0.478022		1.00000	

SUM OF EFFECTIVE

MASSES= 6.01626

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 09:17:48 SEP 08, 1994 CP= 5.740
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

SIGNIFICANCE FACTOR FOR COMBINING MODES = 0.10000E-03

*** WARNING *** CP= 5.750 TIME= 09:17:48
 Mode 20 was not expanded and cannot be included in the combination,
 even though its mode coefficient ratio of 2.776394606E-02 is larger
 than the significance factor.

SIGNIFICANT MODE COEFFICIENTS (INCLUDING DAMPING)

MODE	FREQUENCY	DAMPING	SV	MODE COEF.
------	-----------	---------	----	------------

14 66.34 0.0000 46.368 0.6281E-03

MODAL COMBINATION COEFFICIENTS

MODE= 14 FREQUENCY= 66.338 COUPLING COEF.= 1.000

SRSS COMBINATION INSTRUCTIONS WRITTEN ON FILE skk.mcom

SEISMIC EXCITATION DIRECTION = 0.00000E+00 0.00000E+00 1.0000

FREQ= 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00 0.000E+00

SPECTRUM TABLE INITIALIZED

FREQ= 0.160 0.400 1.10 1.64 8.00 12.0 20.0
33.0 100.

NUMBER OF FREQUENCIES IN TABLE = 9

DAMPING= 0.00000E+00	SV=	0.26000E-01	0.10400	0.28300
		0.42000	0.42000	0.34000
		0.26000	0.20000	0.20000

***** ANSYS SOLVE COMMAND *****

LOAD STEP OPTIONS

LOAD STEP NUMBER. 3
SPECTRUM LOADING TYPE ACCELERATION
EXCITATION DIRECTION. 0.00000E+00 0.00000E+00 1.0000
MODE COMBINATION TYPE SRSS
SIGNIFICANCE LEVEL FOR COMBINATIONS. 0.10000E-03
PRINT OUTPUT CONTROLS
ITEM FREQUENCY COMPONENT
ALL ALL
DATABASE OUTPUT CONTROLS. ALL DATA WRITTEN

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
WEST. HANFORD VERSION=SGI IRIS4D 09:17:55 SEP 08, 1994 CP= 5.820
FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

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***** RESPONSE SPECTRUM CALCULATION SUMMARY *****

MODE RATIO	FREQUENCY EFFECTIVE MASS	CUMULATIVE SV MASS FRACTION	PARTIC.FACTOR	MODE COEF.	M.C.
1	0.6431 64.293		1.789	7.045	
1.000000	3.20145		0.630845		
2	0.6431 64.294		-0.5703E-04	-0.2245E-03	
0.000032	0.325250E-08		0.630845		
3	4.307 162.29		-0.9392	-0.2082	
0.029550	0.882174		0.804677		
4	4.308 162.29		0.2217E-07	0.4910E-08	
0.000000	0.491513E-15		0.804677		
5	12.33 129.50		0.4785	0.1032E-01	
0.001465	0.228981		0.849797		
6	12.35 129.41		0.1001E-09	0.2151E-11	
0.000000	0.100150E-19		0.849797		
7	22.66 94.097		0.2188E-01	0.1015E-03	
0.000014	0.478564E-03		0.849892		
8	22.68 94.060		0.4379E-10	0.2029E-12	
0.000000	0.191781E-20		0.849892		
9	31.42 79.295		-0.5442	-0.1107E-02	
0.000157	0.296169		0.908252		
10	31.46 79.237		-0.6940E-09	-0.1407E-11	
0.000000	0.481637E-18		0.908252		
11	41.26 77.280		0.1621E-12	0.1864E-15	
0.000000	0.262903E-25		0.908252		
12	49.17 77.280		0.5034	0.4076E-03	
0.000058	0.253448		0.958194		
13	49.25 77.280		0.5051E-11	0.4076E-14	
0.000000	0.255131E-22		0.958194		
14	66.34 77.280		-0.7749E-14	-0.3447E-17	
0.000000	0.600523E-28		0.958194		
15	76.03 77.280		-0.4526	-0.1533E-03	
0.000022	0.204814		0.998552		
16	76.08 77.280		0.9726E-10	0.3289E-13	
0.000000	0.945931E-20		0.998552		
17	126.8 77.280		0.8572E-01	0.1044E-04	
0.000001	0.734770E-02		1.00000		
18	127.3 77.280		-0.1531E-12	-0.1848E-16	
0.000000	0.234371E-25		1.00000		
19	133.8 77.280		-0.9723E-14	-0.1063E-17	
0.000000	0.945336E-28		1.00000		
20	215.8 77.280		-0.3332E-13	-0.1401E-17	
0.000000	0.111034E-26		1.00000		

SUM OF EFFECTIVE

MASSES= 5.07486

1

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***** ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 5.0A *****
 WEST. HANFORD VERSION=SGI IRIS4D 09:17:55 SEP 08, 1994 CP= 5.870
 FOR SUPPORT CALL BRAD COVERDELL PHONE (509) 376-1921 FAX

Modal analysis of thermocouple tree with spring restraint

SIGNIFICANCE FACTOR FOR COMBINING MODES = 0.10000E-03

SIGNIFICANT MODE COEFFICIENTS (INCLUDING DAMPING)

MODE	FREQUENCY	DAMPING	SV	MODE COEF.
1	0.6431	0.0000	64.293	7.045
3	4.307	0.0000	162.29	-0.2082
5	12.33	0.0000	129.50	0.1032E-01
9	31.42	0.0000	79.295	-0.1107E-02

MODAL COMBINATION COEFFICIENTS

MODE=	1	FREQUENCY=	0.643	COUPLING COEF.=	1.000
MODE=	3	FREQUENCY=	4.307	COUPLING COEF.=	1.000
MODE=	5	FREQUENCY=	12.334	COUPLING COEF.=	1.000
MODE=	9	FREQUENCY=	31.418	COUPLING COEF.=	1.000

SRSS COMBINATION INSTRUCTIONS WRITTEN ON FILE skk.mcom

FINISH SOLUTION PROCESSING

***** ROUTINE COMPLETED ***** CP = 5.910

*** NOTE *** CP= 5.910 TIME= 09:17:55
 A total of 3 warnings and errors written to file.err.

***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER /SHOW,DEVICE-NAME TO ENABLE GRAPHIC DISPLAY
 ENTER FINISH TO LEAVE POST1

*** NOTE *** CP= 6.200 TIME= 09:19:14
 The element set contains elements that have only one structural degree of freedom per node. Viewing nodal displacements or forces in other than the nodal coordinate system may be invalid.

/INPUT FILE= skk.mcom LINE= 0
ANSYS REVISION 5.0 A 09:17:48 09/08/1994
skk.mcom

CURRENT LOAD SET IN DATABASE IS ERASED

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 2 COMPLEX= 0
FILE= skk.rst
Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 7.0448

COPY LOAD CASE 1 FROM FILE TO DATABASE

SQUARE THE CURRENT LOAD SET IN DATABASE

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 4 COMPLEX= 0
FILE= skk.rst
Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO -0.20807

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR=-0.20807 ABS= 0
MULTIPLIED BY LOAD CASE= 1 FACTOR=-0.20807 ABS= 0

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 6 COMPLEX= 0
FILE= skk.rst
Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 0.10282E-01

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= 0.10282E-01 ABS= 0
MULTIPLIED BY LOAD CASE= 1 FACTOR= 0.10282E-01 ABS= 0

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 10 COMPLEX= 0
FILE= skk.rst
Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO -0.11051E-02

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR=-0.11051E-02 ABS= 0
MULTIPLIED BY LOAD CASE= 1 FACTOR=-0.11051E-02 ABS= 0

TAKE SQRT OF CURRENT LOAD SET IN DATABASE
ANSYS REVISION 5.0 A 09:17:48 09/08/1994
skk.mcom

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SQUARE THE CURRENT LOAD SET IN DATABASE

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 14 COMPLEX= 0
 FILE= skk.rst
 Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 0.62810E-03

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= 0.62810E-03 ABS= 0
 MULTIPLIED BY LOAD CASE= 1 FACTOR= 0.62810E-03 ABS= 0

TAKE SQRT OF CURRENT LOAD SET IN DATABASE
 ANSYS REVISION 5.0 A 09:17:55 09/08/1994
 skk.mcom

SQUARE THE CURRENT LOAD SET IN DATABASE

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 1 COMPLEX= 0
 FILE= skk.rst
 Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 7.0448

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= 7.0448 ABS= 0
 MULTIPLIED BY LOAD CASE= 1 FACTOR= 7.0448 ABS= 0

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 3 COMPLEX= 0
 FILE= skk.rst
 Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO -0.20818

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR=-0.20818 ABS= 0
 MULTIPLIED BY LOAD CASE= 1 FACTOR=-0.20818 ABS= 0

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 5 COMPLEX= 0
 FILE= skk.rst
 Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO 0.10318E-01

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR= 0.10318E-01 ABS= 0
 MULTIPLIED BY LOAD CASE= 1 FACTOR= 0.10318E-01 ABS= 0

LOAD CASE 1 IS LOAD STEP 1 SUBSTEP 9 COMPLEX= 0
 FILE= skk.rst

Modal analysis of thermocouple tree with spring restraint

LOAD CASE 1 FACTOR SET TO-0.11074E-02

LCOPER OPERATION ADD USING LOAD CASE= 1 FACTOR=-0.11074E-02 ABS= 0
MULTIPLIED BY LOAD CASE= 1 FACTOR=-0.11074E-02 ABS= 0

TAKE SQRT OF CURRENT LOAD SET IN DATABASE

PRODUCE DISPLACEMENT PLOT, KUND= 1

PRINT DOF NODAL SOLUTION PER NODE

***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

CALCULATED LOAD CASE= 0

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2	0.19999E-01	0.28236E-04	0.19999E-01	0.10045E-02	0.12425E-13	0.10046E-02
3	0.62450E-01	0.17579E-03	0.62448E-01	0.50424E-02	0.81140E-13	0.50425E-02
4	1.3628	0.25854E-03	1.3628	0.12425E-01	0.12715E-12	0.12426E-01
5	3.8492	0.32012E-03	3.8491	0.16144E-01	0.18637E-12	0.16144E-01
6	5.9656	0.33604E-03	5.9659	0.16600E-01	0.22937E-12	0.16596E-01
7	6.1124	0.33611E-03	6.1128	0.16600E-01	0.23328E-12	0.16596E-01
8	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10	0.69058E-03	0.16596E-03	0.69054E-03	0.40877E-02	0.76563E-13	0.40878E-02

MAXIMUM VALUES

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
7	6.1124	0.33611E-03	6.1128	0.16600E-01	0.23328E-12	0.16596E-01

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PRINT REACTION SOLUTIONS PER NODE

***** POST1 TOTAL REACTION SOLUTION LISTING *****

CALCULATED LOAD CASE= 0

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
1	-455.24	-256.80	-455.22	-33950.	-0.24507E-06	-33951.
8	-690.58	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9	0.00000E+00	0.00000E+00	-690.54	0.00000E+00	0.00000E+00	0.00000E+00
TOTAL VALUES						
VALUE	-1145.8	-256.80	-1145.8	-33950.	-0.24507E-06	-33951.

PRINT F ELEMENT SOLUTION PER ELEMENT

***** POST1 ELEMENT NODE TOTAL FORCE LISTING *****

CALCULATED LOAD CASE= 0

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

ELEM=	1	FX	FY	FZ
1	455.24	256.80	455.22	
2	455.24	256.80	455.22	
ELEM=	2	FX	FY	FZ
2	452.44	244.68	452.42	
10	452.44	244.68	452.42	
ELEM=	3	FX	FY	FZ
10	259.19	244.68	259.15	
3	259.19	244.68	259.15	

ELEM=	4	FX	FY	FZ
3	234.04	200.17	234.02	
4	234.04	200.17	234.02	

ELEM=	5	FX	FY	FZ
4	163.11	128.50	163.10	
5	163.11	128.50	163.10	

ELEM=	6	FX	FY	FZ
5	93.601	44.387	93.610	
6	93.601	44.387	93.610	

ELEM=	7	FX	FY	FZ
6	8.3234	2.7527	8.3278	
7	8.3234	2.7527	8.3278	

ELEM=	8	FX
10	690.58	
8	690.58	

ELEM=	9	FZ
10	690.54	
9	690.54	

PRINT M ELEMENT SOLUTION PER ELEMENT

***** POST1 ELEMENT NODE TOTAL FORCE LISTING *****

CALCULATED LOAD CASE= 0

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

ELEM=	1	MX	MY	MZ
1	33950.	0.24507E-06	33951.	
2	17566.	0.24507E-06	17566.	

ELEM=	2	MX	MY	MZ
-------	---	----	----	----

2	17478.	0.24601E-06	17478.
10	68252.	0.24601E-06	68254.
ELEM= 3 MX MY MZ			
10	68252.	0.24601E-06	68254.
3	65207.	0.24601E-06	65208.
ELEM= 4 MX MY MZ			
3	64959.	0.23930E-06	64961.
4	37266.	0.23930E-06	37268.
ELEM= 5 MX MY MZ			
4	36889.	0.26554E-06	36891.
5	12404.	0.26554E-06	12404.
ELEM= 6 MX MY MZ			
5	10699.	0.25850E-06	10698.
6	1418.0	0.25850E-06	1418.1
ELEM= 7 MX MY MZ			
6	61.754	0.34210E-06	61.722
7	12.156	0.34210E-06	12.149

EXIT THE ANSYS POST1 DATABASE PROCESSOR

***** ROUTINE COMPLETED ***** CP = 7.430

*** NOTE *** CP= 7.430 TIME= 09:20:16
A total of 3 warnings and errors written to file.err.

PURGE ALL SOLUTION AND POST DATA
SAVE ALL MODEL DATA

*** NOTE *** CP= 7.470 TIME= 09:20:22
NEW BACKUP FILE NAME= skk.dbb.

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= skk.db
FOR POSSIBLE RESUME FROM THIS POINT

NUMBER OF WARNING MESSAGES ENCOUNTERED= 3
NUMBER OF ERROR MESSAGES ENCOUNTERED= 0

```

/title,Erection of Thermocouple Probe.k
et,1,4
!
r,1,11.29,31.83,31.83,5.5,5.5,
r,2,11.608,32.58,32.58,5.5,5.5,
r,3,11.9274,33.34,33.34,5.5,5.5,
r,4,12.2416,34.09,34.09,5.5,5.5,,
r,5,12.399,34.65,34.28,5.5,5.5,
r,6,12.5563,35.21,34.47,5.5,5.5,
ex,1,29e6
dens,1,.00073386
nuxy,1,.3
!
n,1,,,
n,2,-1,,
ngen,690,1,1,2,1,-1,,
!
mat,1
type,1
real,1
e,1,2
egen,36,1,-1
!
real,2
e,36,37
egen,203,1,-1
!
real,3
e,239,240,
egen,143,1,-1
!
real,4
e,382,383
egen,170,1,-1
!
real,5
e,552,553
egen,129,1,-1
!
real,6
e,681,682
egen,9,1,-1
!
!
d,1,ux,,,467,466,roty
finish

```

Displacement plot of thermocouple probe

Moment diagram of thermocouple probe

WHC-SD-WISI-ANAL-001
REV-0

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____
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 (8) Originator _____ Date _____
 (9) Checker _____ Date _____

(10)

MAJOR DIA. OF EXTERNAL THREAD
 $8\frac{3}{4}'' \phi$

$$\text{Tolerance} = .05 p = .05 \times 1.5 = .075''$$

$$\text{Min. major dia} = 8.75 - .075 = 8.675''$$

Thread geometric shear areas:

$$A_{ss} = 3.1416 n L_e \cdot K_n(\max) \left[\frac{1}{2n} + 0.57735 \right] \quad (E_{\min} - K_n(\max))$$

L_e = Length of engagement

$K_n(\max)$ = Maximum minor dia of internal threads.

n = number of threads/in.

$E_{\min}$ = Minimum pitch dia of external threads.

DESIGN CALCULATION

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REV-0

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____
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 (9) Checker _____ Date _____

(10)

forces & Moments transferred through threads.

Same loads as welds in Node[#] 1.

$$F_x = 0.88 \text{ K}$$

$$M_{x2} = 82.47 \text{ K-in.}$$

$$F_y = 2.84 \text{ K}$$

$$F_z = 0.63 \text{ K}$$

$$\text{Tension/Comp from moment} = \frac{M_{x2}}{D}$$

$$D = \text{Min. major dia.} = 8.675"$$

$$\text{Tension/Comp} = \frac{82.47}{8.675} = 9.507 \text{ Kips.}$$

$$\Sigma \text{Tension/Comp} = 9.507 + 2.84 = 12.347 \text{ Kips.}$$

$$\text{assume } L_e = 1"$$

$$n = \frac{1}{\text{pitch}} = \frac{1}{1.5} = 0.6667$$

$$\text{Pitch dia.} = 8.75 - 2 \times \frac{P}{4} = 8.75 - 2 \times \frac{11.5}{4}$$

$$= 8.00$$

$$\text{Pitch dia. tolerance} = .008 \sqrt{D}$$

(Table-6, ANSI B1.5-1973, Acme
- Screw Threads)

$$= .008 \sqrt{8.75} = .0237$$

$$E_s(\text{min}) = 8.0 - 2 \times .0237 = 7.9526"$$

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DESIGN CALCULATION

WH C-SD-W151-ANAL-001
REV-0

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____
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(9) Checker _____ Date _____

(10)

$$K_n = \text{Nominal minor dia} - \text{Tol.}$$

$$= (8.75 - .1) + 2(0.03 \times P) = 8.75 - 2 \times \frac{1.5}{2} + 2(0.05 \times 1.5)$$

$$= 7.40'' \quad (\text{For Tol. refer Table 2})$$

ANSI B1.5
-1973

$$A_{S_s} = 3.1416 \times 0.6667 \times 1 \times 8.675 \left[\frac{1}{2 \times 0.6667} + 0.57735 (7.9526 - 7.40) \right]$$

$$= 19.42 \text{ in}^2$$

Shear Capacity / in of engagement =

$$= 0.5 S_t \cdot A_{S_s}$$

Where S_t = Ultimate tensile strength of material

$$= 80 \text{ ksi}$$

$$\text{or Shear strength} = 0.5 \times 80 \times 19.42$$

$$= 776.8 \text{ kips} \gg 12.3 \text{ k}$$

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____
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(10)

Internal Thread Qualification
 Shear area

$$A_{sn} = \pi n L_e D_{smin} \left[\frac{1}{2n} + 0.57735 (D_{smin} - E_{nmax}) \right]$$

$$D_{s(min)} = \text{Minimum } \phi \text{ major dia. of external thread.}$$

$$= 8.75 - 0.05P = 8.075"$$

$$E_n(max) = \text{Max pitch dia of internal thread.}$$

$$= 8.75 - 2 \times \frac{P}{4} + 2 \times 0.008\sqrt{D}$$

$$= 7.9526"$$

$$= \pi \times 1.6667 \times 1 \times 8.075 \left[\frac{1}{2 \times 1.6667} + 0.57735 (8.075 - 7.9526) \right]$$

$$= 23.74 \text{ in}^2$$

Shear capacity f_u of encasement

$$= 0.5 \times 80 \times 23.47$$

$$= 949.9 \text{ Kips. } \gg 12 \text{ k}$$

Ok.

WHC-SD-W151-ANAL-001

Rev 0 B1

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APPENDIX B

HYDRODYNAMIC LOADS ON THERMOCOUPLE PROBES IN 241-AZ-101 WASTE TANK FOR A DESIGN BASIS EARTHQUAKE

B-1

TYPICAL CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed WHC-SD-W151-ANAL-001

Author J. L. Julyk

Yes No N/A

☒	☐	☐	Problem completely defined.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☐	☐	☒	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☒	☐	☐	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors.
☒	☐	☐	Code run streams correct and consistent with analysis documentation.
☒	☐	☐	Code output consistent with input and with results reported in analysis documentation.
☒	☐	☐	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.

MANDATORY

Software QA Log Number N/A

SK Julyk
Reviewer

9/19/94
Date

DESIGN CALCULATION

(1) Drawing H-2-78862, H-2-79344 (2) Doc. No. WHC-SD-W151-ANAL-001 (3) Page 1 of 30
(4) Building 241AZ101 (5) Rev. 0 (6) Job. No. D23D3
(7) Subject Structural Evaluation of Thermocouple Probes Installed in Tank 241-AZ-101 (Sloshing)
(8) Originator John L. Julyk *John Julyk* Date 8/19/94
(9) Checker *SA [signature]* Date 9/12/94
(10)

HYDRODYNAMIC LOADS ON THERMOCOUPLE PROBES IN 241-AZ-101 WASTE TANK FOR A DESIGN BASIS EARTHQUAKE

1.0 INTRODUCTION

The objective of this analysis is to determine the dynamic behavior of the fluid waste during a seismic event, in the 241AZ101 tank, and the fluids effect on the thermocouple (TCP) probes installed in the tank to monitor the temperature of the waste. The analysis addresses the hydrodynamic pressures and forces and associated liquid motions induced by earthquake ground motions in the 241AZ101 waste-storage tank. An evaluation of the T/C probes installed in the tank, under hydrodynamic loads, is addressed in the analysis.

The thermocouple probes are classified as safety class (SC) 3. To be conservative the sloshing analysis will consider the TCP as a SC1 component. To determine the dynamic behavior of the fluid for seismic activity, resulting from ground excitations occurring in the 200 Area, an analysis of a 0.20-g seismic event is performed with a 0.5% slosh damping and 2% tank damping.

2.0 BACKGROUND DESCRIPTION

The content of the 241AZ101 tank is 28.33 ft of liquid waste and 20 in. of sludge for a total waste height of 30 ft (see drawing H-2-78862, rev. 0). Utilizing 2 or 4-mixing pumps the contents is mixed into a homogenous fluid. The tank is 75 ft in diameter and approximately 50 ft deep (see H-2-78862, rev. 0). The T/C probes are submerged in the waste 29.75 ft and 3 inches from the bottom of the tank's primary steel liner. The modified 5.5-in. carbon steel (AISI 1026 Cold Drawn, ASTM A513) T/C probes are 60 ft in length and at a perimeter radius of 34.75 ft from the center line of the tank, worst case senerio (H-2-78862, Rev. 0). The waste has a dynamic viscosity of 5 centipoise and a specific gravity of 1.2 (Water 1993).

The fluid mixture is considered homogeneous, inviscid, irrotational, and incompressible. The wave amplitudes are sufficiently small in comparision with the wavelengths and depths to permit nonlinear effects to be neglected. The influence of the surrounding atmosphere and surface tension is also negligible.

The hydrodynamic effects induced by the horizontal component of ground shaking is expressed as the sum of the impulsive and convective (sloshing) components. The impulsive component represents the effects of the liquid that may be considered to move in synchronism with the tank wall as a rigidly attached mass. The convective component represents the action of the liquid near the surface that experiences sloshing or rocking motion.

The added mass concept deals with the structural component (T/C probes) vibration in a viscous fluid. The presence of the fluid gives rise to a fluid reaction force which can be interpreted as an added mass effect and a damping contribution to the dynamic response of the thermocouple probes.

3.0 ANALYSIS DESCRIPTION

The analysis determines the following for a design basis earthquake (DBE) event occurring in the north-south direction:

1. The sloshing modes for a 0.2-g acceleration at 0.5% damping (DOE 1993, Table 3.2).
2. The fundamental natural frequency of the tank-liquid (impulsive) and (convective) mode of vibration for an anchored storage tank.
3. The natural frequency of the thermocouple at 5% damping with and without the added mass effect.
4. The fundamental natural frequency of the tank at 2% damping.
5. The hydrodynamic loads imposed on the thermocouple probes and the tank walls from the interaction with the fluid waste.

The hydrodynamic loading effects include:

1. The sloshing displacements and velocities (radial and tangential).
2. The drag force acting on the T/C probes in the waste tank.
3. The moment and shear reaction forces at the T/C probes critical location.

The analysis considers only the dynamic behavior of the liquid under a design basis earthquake. The hydrodynamic loads imposed on the T/C probes are from the interaction of the liquid waste and the T/C probes. The analysis does not consider the response of the T/C probes (i.e., the ground excitations at higher frequencies imposed to the T/C probes and modal combination of the modes) and the loads and stresses produced at the higher modes on the T/C probes. The analysis of the thermocouple probes vibrations are discussed in appendix A of this report.

FIGURE B1. SKETCH OF TANK AND THERMOCOUPLE PROBE

ANALYSIS OF TANK WASTE UNDER SEISMIC (DESIGN BASIS EARTHQUAKE):

Given information on the tanks waste and dimensions (see H-2-78862 rev.0, H-2-79344 rev. 0, and Waters 1993)

$$g := 32.17 \cdot \frac{\text{ft}}{\text{sec}^2}$$

acceleration of gravity

$$g = 386.04 \cdot \frac{\text{in}}{\text{sec}^2}$$

$$\text{Hz} := \frac{1}{\text{sec}} \quad \text{rad} := 1$$

$$\text{cp} := 0.00067197 \cdot \frac{\text{lb}}{\text{ft} \cdot \text{sec}}$$

centipoise conversion (cp)

$$\rho_{\text{waste}} := 74.914 \cdot \frac{\text{lb}}{\text{ft}^3}$$

mass density of waste (Waters 1993)

$$\mu := 5 \cdot \text{cp}$$

absolute or dynamic viscosity (Waters 1993)

$$\nu := \frac{\mu}{\rho_{\text{waste}}}$$

kinematic viscosity

$$\nu = 4.4849 \cdot 10^{-5} \cdot \frac{\text{ft}^2}{\text{sec}}$$

$$\rho_{\text{concrete}} := 150 \cdot \frac{\text{lb}}{\text{ft}^3}$$

density of concrete shield plug @ 3,000 lbf/in² (H-2-79344)

$$h := 30 \cdot \text{ft}$$

The total depth of waste inside the tank
(considered fully mixed fluid waste)

$$h_{\text{TC}} := h - 3 \cdot \text{in}$$

height of thermocouple probes inside tank waste

$$h_{\text{TC}} = 29.75 \cdot \text{ft}$$

$$R := 37.5 \cdot \text{ft}$$

inside radius of tank

$$L := 60 \cdot \text{ft}$$

length of thermocouple probes probe from fixed
mounting point (flange connection)

$$R_{\text{TC}} := 34.75 \cdot \text{ft}$$

radial location of thermocouple probe, worst case.

$$t_{\text{tank}} := 0.5 \cdot \text{in}$$

average wall thickness of steel primary tank

$$E := 29 \cdot 10^6 \cdot \frac{\text{lb}}{\text{in}^2}$$

Youngs modulus for steel primary tank

$$\rho_{\text{steel}} := 489.2 \cdot \frac{\text{lb}}{\text{ft}^3}$$

density of steel primary tank and Thermocouple probes

$$F_y := 70000 \cdot \frac{\text{lb}}{\text{in}^2}$$

minimum yield strength for ASTM A513, AISI 1026 carbon steel
(ASTM 1989)

$$F_{ab} := \frac{4}{3} \cdot 0.60 \cdot F_y$$

allowable bending stress (AISC 1989) $F_{ab} = 56000 \cdot \frac{\text{lb}}{\text{in}^2}$

$$F_{as} := \frac{4}{3} \cdot 0.40 \cdot F_y$$

allowable shear stress (AISC 1989) $F_{as} = 37333 \cdot \frac{\text{lb}}{\text{in}^2}$

Note: The 4/3 accounts for seismic activity (AISC 1989)

CALCULATION OF SLOSHING NATURAL FREQUENCIES AND MODE SHAPES:

(see Blevins 1979, Table 13-6, Circular form and Abramowitz 1966, Table 9.5 for additional values):

$i := 0..6$ number of nodal diameters
 $j := 0..6$ number of nodal circles

$\lambda_{i,j} \Rightarrow$ roots $J'_i(\lambda_{i,j}) = 0$ where J_i is Bessel function of the first kind and i order

$$\lambda = \begin{bmatrix} 0 & 3.83171 & 7.01559 & 10.17347 & 13.32369 & 16.47063 & 19.61586 \\ 1.84118 & 5.33144 & 8.53632 & 11.70600 & 14.86359 & 18.01553 & 21.16437 \\ 3.05424 & 6.70613 & 9.96947 & 13.17037 & 16.34752 & 19.51291 & 22.67158 \\ 4.20119 & 8.01524 & 11.34592 & 14.58585 & 17.78875 & 20.97248 & 24.14490 \\ 5.31755 & 9.28240 & 12.68191 & 15.96411 & 19.19603 & 22.40103 & 25.58976 \\ 6.41562 & 10.51986 & 13.98719 & 17.31284 & 20.57551 & 23.80358 & 27.01031 \\ 7.50127 & 11.73494 & 15.26818 & 18.63744 & 21.93172 & 25.18393 & 28.40978 \end{bmatrix} \quad (1)$$

Natural frequency, $f_{i,j}$ (Hz)

$$f_{i,j} := \frac{1}{2 \cdot \pi} \cdot \left(\frac{\lambda_{i,j} \cdot g}{R} \cdot \tanh \left(\frac{\lambda_{i,j} \cdot h}{R} \right) \right)^{\frac{1}{2}} \quad (2)$$

$$f = \begin{bmatrix} 0 & 0.2879 & 0.3904 & 0.4702 & 0.5381 & 0.5983 & 0.6529 \\ 0.1898 & 0.3403 & 0.4307 & 0.5044 & 0.5683 & 0.6257 & 0.6782 \\ 0.2557 & 0.3817 & 0.4654 & 0.535 & 0.596 & 0.6512 & 0.7019 \\ 0.3018 & 0.4173 & 0.4965 & 0.563 & 0.6217 & 0.6751 & 0.7243 \\ 0.3399 & 0.4491 & 0.525 & 0.589 & 0.6459 & 0.6977 & 0.7457 \\ 0.3734 & 0.4781 & 0.5513 & 0.6134 & 0.6687 & 0.7192 & 0.7661 \\ 0.4037 & 0.505 & 0.576 & 0.6364 & 0.6903 & 0.7398 & 0.7857 \end{bmatrix} \cdot \text{Hz}$$

Circular natural frequency, $\omega_{i,j}$ (rad/sec)

$$\omega_{i,j} := 2 \cdot \pi \cdot f_{i,j} \quad (3)$$

$$\omega = \begin{bmatrix} 0 & 1.8091 & 2.4532 & 2.9542 & 3.3808 & 3.7589 & 4.1022 \\ 1.1924 & 2.1382 & 2.7061 & 3.1689 & 3.5709 & 3.9313 & 4.261 \\ 1.6065 & 2.3985 & 2.9245 & 3.3613 & 3.7449 & 4.0914 & 4.4101 \\ 1.8962 & 2.6222 & 3.1198 & 3.5373 & 3.9065 & 4.2416 & 4.5512 \\ 2.1354 & 2.8219 & 3.2984 & 3.7007 & 4.058 & 4.3837 & 4.6854 \\ 2.3459 & 3.0041 & 3.464 & 3.8538 & 4.2013 & 4.5189 & 4.8137 \\ 2.5367 & 3.1729 & 3.6191 & 3.9986 & 4.3376 & 4.6481 & 4.9368 \end{bmatrix} \cdot \frac{\text{rad}}{\text{sec}}$$

The pressure, velocity, and displacement of the fluid in the tank are expressed in terms of $\phi_{i,j}$ using the formulas in Blevins (1979).

Mode shape of potential function, $\phi_{i,j}$

$$\phi(r, \theta, i, j) := J_n\left(i, \lambda_{i,j} \cdot \frac{r}{R}\right) \cdot \cos(i \cdot \theta) \quad (4)$$

$$\phi'_{i,j} := \phi(R, 0, i, j) \quad \text{at } r = R = 37.5 \text{ ft, } \theta = 0$$

$$\phi' = \begin{bmatrix} 1 & -0.4028 & 0.3001 & -0.2497 & 0.2184 & -0.1965 & 0.1801 \\ 0.5819 & -0.3461 & 0.2733 & -0.2333 & 0.207 & -0.188 & 0.1735 \\ 0.4865 & -0.3135 & 0.2547 & -0.2209 & 0.1979 & -0.181 & 0.1678 \\ 0.4344 & -0.2912 & 0.2407 & -0.211 & 0.1904 & -0.175 & 0.163 \\ 0.3997 & -0.2744 & 0.2296 & -0.2028 & 0.184 & -0.1699 & 0.1587 \\ 0.3741 & -0.2611 & 0.2204 & -0.1958 & 0.1785 & -0.1653 & 0.1548 \\ 0.3541 & -0.2502 & 0.2126 & -0.1898 & 0.1736 & -0.1613 & 0.1514 \end{bmatrix}$$

Modal wave speed, $c_{i,j}$

$$c_{i,j} := \omega_{i,j} \cdot \frac{R}{\lambda_{i,j}} \quad (5)$$

$$c = \begin{bmatrix} 0 & 17.7052 & 13.113 & 10.8895 & 9.5154 & 8.5583 & 7.8422 \\ 24.2855 & 15.0395 & 11.8879 & 10.1517 & 9.0091 & 8.1831 & 7.5499 \\ 19.7248 & 13.4121 & 11.0003 & 9.5707 & 8.5904 & 7.8629 & 7.2946 \\ 16.9251 & 12.2682 & 10.3115 & 9.0944 & 8.2351 & 7.5843 & 7.0685 \\ 15.0591 & 11.4002 & 9.7532 & 8.693 & 7.9275 & 7.3385 & 6.8661 \\ 13.7122 & 10.7087 & 9.287 & 8.3475 & 7.6571 & 7.119 & 6.6831 \\ 12.6815 & 10.1391 & 8.8889 & 8.0454 & 7.4166 & 6.9212 & 6.5164 \end{bmatrix} \cdot \frac{\text{ft}}{\text{sec}}$$

$$\theta = 0, \frac{2 \cdot \pi}{20} \dots 2 \cdot \pi$$

FIGURE B2-1. MODE SHAPES AS A FUNCTION OF θ FOR $r=R$

FIGURE B2-2. MODE SHAPES AS A FUNCTION OF θ FOR $r=R$

$$N := 20 \quad n := 0..N \quad r_n := \frac{n}{N} \cdot R$$

FIGURE B3-1. MODE SHAPES AS A FUNCTION OF r FOR $\theta = 0$

FIGURE B3-2. MODE SHAPES AS A FUNCTION OF r FOR $\theta = 0$

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$N := 20$
 $m := 0..N$
 $n := 0..N$

$$r_n := \frac{n}{N} \cdot R \quad \theta_m := \frac{m}{N} \cdot 2 \cdot \pi$$

FIGURE B4. MODE SHAPES AS A FUNCTION OF r AND θ

$$M01_{n,m} := \phi(r_n, \theta_m, 0, 1)$$

M01

$$M02_{n,m} := \phi(r_n, \theta_m, 0, 2)$$

M02

$$M03_{n,m} := \phi(r_n, \theta_m, 0, 3)$$

M03

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FIGURE B5. MODE SHAPES AS A FUNCTION OF r AND θ

$$M10_{n,m} := \phi(r_n, \theta_m, 1, 0)$$

M10

$$M11_{n,m} := \phi(r_n, \theta_m, 1, 1)$$

M11

$$M12_{n,m} := \phi(r_n, \theta_m, 1, 2)$$

M12

$$M13_{n,m} := \phi(r_n, \theta_m, 1, 3)$$

M13

Following Blevins approach for sloshing in tanks, the sloshing mode is described by a potential function (see Blevins 1979, Section 13.5)

$$\Phi(r, \theta, z, t) = \frac{A \cdot g}{\omega} \frac{\cosh\left[\frac{\omega}{c} \cdot (h + z)\right]}{\cosh\left(\frac{\omega \cdot h}{c}\right)} \cdot \phi(r, \theta) \cdot \sin(\omega \cdot t + \psi)$$

The potential function for multi-modal free vibration becomes

$$\Phi(r, \theta, z, t) = \sum_i \left[\sum_j \frac{A_{i,j} \cdot g}{\omega_{i,j}} \frac{\cosh\left[\frac{\omega_{i,j}}{c_{i,j}} \cdot (h + z)\right]}{\cosh\left(\frac{\omega_{i,j} \cdot h}{c_{i,j}}\right)} \cdot \phi(r, \theta, i, j) \cdot \sin(\omega_{i,j} \cdot t + \psi_{i,j}) \right]$$

or

$$\Phi(r, \theta, z, t) = \sum_i \left[\sum_j \frac{A_{i,j} \cdot g}{\omega_{i,j}} \frac{\cosh[k_{i,j} \cdot (h + z)]}{\cosh(k_{i,j} \cdot h)} \cdot \phi(r, \theta, i, j) \cdot \sin(\omega_{i,j} \cdot t + \psi_{i,j}) \right] \quad (6)$$

where

$$k_{i,j} = \frac{\omega_{i,j}}{c_{i,j}} = \frac{\lambda_{i,j}}{R} \quad k = \begin{bmatrix} 0 & 0.1022 & 0.1871 & 0.2713 & 0.3553 & 0.4392 & 0.5231 \\ 0.0491 & 0.1422 & 0.2276 & 0.3122 & 0.3964 & 0.4804 & 0.5644 \\ 0.0814 & 0.1788 & 0.2659 & 0.3512 & 0.4359 & 0.5203 & 0.6046 \\ 0.112 & 0.2137 & 0.3026 & 0.389 & 0.4744 & 0.5593 & 0.6439 \\ 0.1418 & 0.2475 & 0.3382 & 0.4257 & 0.5119 & 0.5974 & 0.6824 \\ 0.1711 & 0.2805 & 0.373 & 0.4617 & 0.5487 & 0.6348 & 0.7203 \\ 0.2 & 0.3129 & 0.4072 & 0.497 & 0.5848 & 0.6716 & 0.7576 \end{bmatrix} \cdot \frac{1}{ft} \quad (7)$$

$A_{i,j}$ (amplitude in ij mode) and $\psi_{i,j}$ (phase angle, considered at 0 degrees) are determined from boundary conditions

$$\vec{v} \cdot \vec{n} = 0 \quad \eta = \frac{1}{g} \frac{d}{dt} \Phi \quad \text{at } z = 0 \quad (8)$$

where

$$\begin{aligned} \vec{v} &= -\nabla \Phi && \text{fluid velocity} \\ \vec{n} &&& \text{unit outward normal to the sides and bottom of tank} \\ \eta &&& \text{wave amplitude at free surface of fluid} \\ \frac{d}{dt} \Phi &&& \text{partial derivative of potential with respect to time} \end{aligned}$$

The velocity components in cylindrical coordinates are given by the following partial derivatives of the potential

$$v_r = -\frac{d}{dr} \Phi \quad v_\theta = -\frac{1}{r} \frac{d}{d\theta} \Phi \quad v_z = -\frac{d}{dz} \Phi \quad (9)$$

and the pressure in the liquid is the sum of a dynamic component and the static head

$$p = \rho \frac{d}{dt} \Phi - \rho \cdot g \cdot z = \rho \cdot g \cdot (\eta - z) \quad (10)$$

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DEVELOPMENT OF 0.5% RESPONSE SPECTRA CURVE AT DBE ZPA

Horizontal Response Spectra Control Points - Median Centered
 Newmark-Hall (SDC-4.1 1989, Rev. 11, Table 3 or Figure 3)

DOE, 1984, *Natural Phenomena Hazards Modeling Project: Seismic Hazard Models for Department of Energy Sites*, UCRL-53582, Rev. 1, D. W. Coats and R. C. Murry, Lawrence Livermore National Laboratory, Livermore, California, for U.S. Department of Energy.

ZPA := 0.20 DBE seismic zero period acceleration (g) or peak ground acceleration $kk := 0..7$

$$A(\beta) := 3.21 - 0.68 \cdot \ln(\beta) \quad g_c := \frac{g}{\left(\frac{\text{in}}{\text{sec}^2}\right)}$$

$$V(\beta) := 2.31 - 0.41 \cdot \ln(\beta)$$

$$D(\beta) := 1.82 - 0.27 \cdot \ln(\beta)$$

$$a_g := \text{ZPA} (g) \quad v_g := 48 \cdot a_g \left(\frac{\text{in}}{\text{s}}\right) \quad d_g := 36 \cdot a_g (\text{in})$$

$$a_{\max}(\beta) := a_g \cdot A(\beta) \quad v_{\max}(\beta) := v_g \cdot V(\beta) \quad d_{\max}(\beta) := d_g \cdot D(\beta)$$

$$f_E(\beta) := 0.1$$

$$S_{aC}(\beta) := a_{\max}(\beta)$$

Damping (%)

$$f_B(\beta) := 8$$

$$S_{aB}(\beta) := a_{\max}(\beta)$$

$\beta_{kk} :=$	$A(\beta_{kk})$	$V(\beta_{kk})$	$D(\beta_{kk})$
0.5	3.68	2.59	2.01
1	3.21	2.31	1.82
2	2.74	2.03	1.63
3	2.46	1.86	1.52
5	2.12	1.65	1.39
7	1.89	1.51	1.29
10	1.64	1.37	1.2
20	1.17	1.08	1.01

$$f_A(\beta) := 33$$

$$S_{aA}(\beta) := a_g$$

$$f_{A'}(\beta) := 100$$

$$S_{aA'}(\beta) := a_g$$

$$f_D(\beta) := \frac{v_{\max}(\beta)}{2 \cdot \pi \cdot d_{\max}(\beta)}$$

$$S_{aE}(\beta) := \frac{0.395}{g_c} \cdot d_{\max}(\beta)$$

$$f_C(\beta) := \frac{g_c \cdot a_{\max}(\beta)}{2 \cdot \pi \cdot v_{\max}(\beta)}$$

$$S_{aD}(\beta) := \frac{v_{\max}(\beta)^2}{g_c \cdot d_{\max}(\beta)}$$

$kk := 0..5$

$$f_{\text{ZPA}2\%kk} := S_{a\text{ZPA}2\%kk}$$

$f_{\text{ZPA}2\%kk}$	$S_{a\text{ZPA}2\%kk}$
$f_E(2)$	$S_{aE}(2)$
$f_D(2)$	$S_{aD}(2)$
$f_C(2)$	$S_{aC}(2)$
$f_B(2)$	$S_{aB}(2)$
$f_A(2)$	$S_{aA}(2)$
$f_{A'}(2)$	$S_{aA'}(2)$

$$f_{\text{ZPA}0.5\%kk} := S_{a\text{ZPA}0.5\%kk}$$

$f_{\text{ZPA}0.5\%kk}$	$S_{a\text{ZPA}0.5\%kk}$
$f_E(0.5)$	$S_{aE}(0.5)$
$f_D(0.5)$	$S_{aD}(0.5)$
$f_C(0.5)$	$S_{aC}(0.5)$
$f_B(0.5)$	$S_{aB}(0.5)$
$f_A(0.5)$	$S_{aA}(0.5)$
$f_{A'}(0.5)$	$S_{aA'}(0.5)$

$$\log f_{\text{ZPA}2\%} := \log(f_{\text{ZPA}2\%})$$

$$\log f_{\text{ZPA}0.5\%} := \log(f_{\text{ZPA}0.5\%})$$

$$\log S_{a\text{ZPA}2\%} := \log(S_{a\text{ZPA}2\%})$$

$$\log S_{a\text{ZPA}0.5\%} := \log(S_{a\text{ZPA}0.5\%})$$

$\beta - 13$

$$vS_{aZPA2\%}(f) := 10^{\text{interp}(\log f_{ZPA2\%}, \log S_{aZPA2\%}, \log(f))} \quad vS_{aZPA0.5\%}(f) := 10^{\text{interp}(\log f_{ZPA0.5\%}, \log S_{aZPA0.5\%}, \log(f))}$$

FIGURE B6 Horizontal Response Spectra Control Points
- Median Centered Newmark-Hall

Resulting spectral acceleration (g) scaled to design ZPA at 0.5% damping for sloshing modes. ZPA = 0.2

$$S_{a_{i,j}} := \text{if} \left[(i=0) \cdot (j=0), 0 \cdot g, g \cdot vS_{aZPA0.5\%} \left(\frac{f_{i,j}}{\text{Hz}} \right) \right]$$

$\frac{S_a}{g}$	0	0.1167	0.1583	0.1906	0.2181	0.2425	0.2646
	0.0532	0.1379	0.1746	0.2044	0.2304	0.2536	0.2749
	0.0966	0.1547	0.1887	0.2168	0.2416	0.2639	0.2845
	0.1223	0.1692	0.2013	0.2282	0.252	0.2736	0.2936
	0.1378	0.182	0.2128	0.2387	0.2618	0.2828	0.3023
	0.1513	0.1938	0.2235	0.2486	0.271	0.2915	0.3105
	0.1636	0.2047	0.2335	0.258	0.2798	0.2999	0.3185

$$\frac{S_{a_{1,0}}}{g} = 0.0532$$

CONVECTIVE (SLOSHING) AND IMPULSIVE MODES OF VIBRATION IN THE LIQUID

The corresponding variation of the pressure associated with the sloshing modes of vibration in the liquid (maximum at the surface).

$$C_{i,j} := \frac{2}{(\lambda_{i,j})^2 - 1} \quad (\text{DOE 1993, section 4.3.2, Eq. 4.4})$$

$$C = \begin{bmatrix} -2 & 0.1462 & 0.0415 & 0.0195 & 0.0113 & 0.0074 & 0.0052 \\ 0.8368 & 0.0729 & 0.0278 & 0.0147 & 0.0091 & 0.0062 & 0.0045 \\ 0.2401 & 0.0455 & 0.0203 & 0.0116 & 0.0075 & 0.0053 & 0.0039 \\ 0.1201 & 0.0316 & 0.0157 & 0.0094 & 0.0063 & 0.0046 & 0.0034 \\ 0.0733 & 0.0235 & 0.0125 & 0.0079 & 0.0054 & 0.004 & 0.0031 \\ 0.0498 & 0.0182 & 0.0103 & 0.0067 & 0.0047 & 0.0035 & 0.0027 \\ 0.0362 & 0.0146 & 0.0086 & 0.0058 & 0.0042 & 0.0032 & 0.0025 \end{bmatrix}$$

Maximum modal vertical displacement (ft) of the free surface (Haroun 1981) at $\theta = 0$, $z = 0$ (surface of liquid waste) and $r = R = 37.5$ ft (at tank wall).

$$\eta_{\max_{i,j}} := C_{i,j} \cdot R \cdot \frac{S_{a_{i,j}}}{g} \quad (\text{Haroun 1981})$$

$$\frac{\eta_{\max}}{\text{ft}} = \begin{bmatrix} 0 & 0.6398 & 0.2462 & 0.1395 & 0.0927 & 0.0673 & 0.0517 \\ 1.6706 & 0.3772 & 0.1822 & 0.1127 & 0.0786 & 0.0588 & 0.0461 \\ 0.8701 & 0.2639 & 0.1438 & 0.0943 & 0.0681 & 0.0521 & 0.0416 \\ 0.551 & 0.2006 & 0.1182 & 0.0808 & 0.0599 & 0.0468 & 0.0378 \\ 0.3788 & 0.1603 & 0.0998 & 0.0705 & 0.0534 & 0.0424 & 0.0347 \\ 0.2826 & 0.1325 & 0.0861 & 0.0624 & 0.0481 & 0.0387 & 0.032 \\ 0.2221 & 0.1123 & 0.0754 & 0.0559 & 0.0437 & 0.0355 & 0.0296 \end{bmatrix}$$

The maximum wave amplitude (ft) for each convective mode shapes is obtained by combining equations (11) and (12) on pg. 14 at $z = 0$, $\theta = 0$, $\psi = 0$, $r = R$, and solving for $A_{c_{ij}}$.

$$A_{c_{i,j}} := \frac{\eta_{\max_{i,j}}}{\frac{\cosh[k_{i,j} \cdot (h + 0 \cdot \text{ft})]}{\cosh(k_{i,j} \cdot h)} \cdot \phi(R, 0, i, j)} \quad (13)$$

$$\frac{A_c}{\text{ft}} = \begin{bmatrix} 0 & -1.5884 & 0.8202 & -0.5585 & 0.4244 & -0.3425 & 0.2872 \\ 2.8711 & -1.0899 & 0.6666 & -0.4831 & 0.3795 & -0.3127 & 0.2659 \\ 1.7885 & -0.8417 & 0.5645 & -0.4269 & 0.3438 & -0.288 & 0.2478 \\ 1.2685 & -0.689 & 0.4909 & -0.3831 & 0.3147 & -0.2672 & 0.2322 \\ 0.9478 & -0.5843 & 0.4349 & -0.3479 & 0.2903 & -0.2493 & 0.2185 \\ 0.7555 & -0.5076 & 0.3907 & -0.3188 & 0.2696 & -0.2338 & 0.2065 \\ 0.6271 & -0.4489 & 0.3548 & -0.2943 & 0.2518 & -0.2202 & 0.1958 \end{bmatrix}$$

$i := 1..1$ $j := 0..6$ (Number of modes used)

Dropping the time dependent terms from Eqn (6) the potential function becomes (for maximum response):

$$\Phi_1(r, \theta, z, i, j) := \text{if} \left[(i=0) \cdot (j=0), 0, \frac{ft^2}{\sec} \cdot \frac{A_{c_{i,j}} \cdot g}{\omega_{i,j}} \cdot \frac{\cosh[k_{i,j} \cdot (h+z)]}{\cosh(k_{i,j} \cdot h)} \cdot \phi(r, \theta, i, j) \right] \quad (11)$$

From Eqn (6), (7), and (8), differentiate first and then dropping time dependent terms the free surface displacement becomes (Eqn 12).

$$\eta_1(r, \theta, z, i, j) := \text{if} \left[(i=0) \cdot (j=0), 0, ft \cdot \frac{\omega_{i,j}}{g} \cdot \Phi_1(r, \theta, z, i, j) \right] \quad (12)$$

$$\eta(r, \theta, z) := \sqrt{\sum_i \sum_j \eta_1(r, \theta, z, i, j)^2}$$

Convective component function (DOE 1993, section 4.3.2, equation 4.4)

$$c_{cl}(r, \theta, z, i, j) := C_{i,j} \cdot \frac{\cosh[k_{i,j} \cdot (h+z)]}{\cosh(k_{i,j} \cdot h)}$$

$$c_c(r, \theta, z) := \sum_j c_{cl}(r, \theta, z, 1, j) = 1 - C_c(r, \theta, z)$$

Impulsive component function (DOE 1993, section 4.3.2, equation 4.7)

$$c_i(r, \theta, z) := 1 - \sum_j c_{cl}(r, \theta, z, 1, j)$$

$$z_n := -\frac{n}{N} \cdot h$$

FIGURE B7. CONVECTIVE AND IMPULSIVE FUNCTIONS

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FUNDAMENTAL NATURAL FREQUENCY OF TANK-LIQUID SYSTEM

Values of Coefficients in Expressions for Fundamental Impulsive Frequencies for Lateral Mode of Vibration of Roofless Steel Tank Filled with Water (DOE 1993, Table 4.3)

 $\alpha_{nn} := 0..16$

h/R	Top Support Condition		
	Free	Roller	Hinged
$\alpha_{nn} :=$	$vC_{irF,nn} :=$	$vC_{irR,nn} :=$	$vC_{irH,nn} :=$
0.20	0.0516	0.0521	0.0539
0.25	0.0561	0.0569	0.0589
0.30	0.0600	0.0613	0.0634
0.35	0.0635	0.0653	0.0675
0.40	0.0666	0.0690	0.0712
0.45	0.0694	0.0724	0.0747
0.50	0.0719	0.0758	0.0781
0.55	0.0742	0.0789	0.0812
0.60	0.0762	0.0820	0.0843
0.65	0.0781	0.0850	0.0873
0.70	0.0799	0.0880	0.0901
0.75	0.0815	0.0909	0.0930
0.80	0.0829	0.0937	0.0957
0.85	0.0843	0.0966	0.0984
0.90	0.0855	0.0993	0.1011
0.95	0.0865	0.1020	0.1037
1.00	0.0875	0.1047	0.1062

$$C_{irF}(\alpha) := \text{linterp}(v\alpha, vC_{irF}, \alpha)$$

$$C_{irR}(\alpha) := \text{linterp}(v\alpha, vC_{irR}, \alpha)$$

$$C_{irH}(\alpha) := \text{linterp}(v\alpha, vC_{irH}, \alpha)$$

FIGURE B8. LATERAL MOTION VS. LIQUID WASTE HEIGHT/TANK RADIUS RATIO

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Recalling the following information previously stated.

$$\begin{aligned} h &= 30 \cdot \text{ft} & E &= 2.9 \cdot 10^7 \cdot \frac{\text{lb}}{\text{in}^2} & \rho_{\text{waste}} &= 74.914 \cdot \frac{\text{lb}}{\text{ft}^3} \\ R &= 37.5 \cdot \text{ft} \\ t_{\text{tank}} &= 0.5 \cdot \text{in} \\ \alpha &:= \frac{h}{R} & \alpha &= 0.8 & (\text{per } h/R \text{ in DOE 1993, Table 4.3}) \end{aligned}$$

Fundamental natural frequency of tank-liquid system for impulsive vibration mode per DOE 1993, section 4.3.2.2, equation 4.13 and 4.15.

$$f_{iF} := \frac{1}{2 \cdot \pi} \cdot \frac{C_{iF}(\alpha)}{h} \cdot \sqrt{127 \cdot \frac{t_{\text{tank}}}{R} \cdot \frac{\rho_{\text{steel}}}{\rho_{\text{waste}}} \cdot \frac{E}{\rho_{\text{steel}}}} \quad f_{iF} = 6.9966 \cdot \text{Hz}$$

$$f_{iR} := \frac{1}{2 \cdot \pi} \cdot \frac{C_{iR}(\alpha)}{h} \cdot \sqrt{127 \cdot \frac{t_{\text{tank}}}{R} \cdot \frac{\rho_{\text{steel}}}{\rho_{\text{waste}}} \cdot \frac{E}{\rho_{\text{steel}}}} \quad f_{iR} = 7.9081 \cdot \text{Hz}$$

$$f_{iH} := \frac{1}{2 \cdot \pi} \cdot \frac{C_{iH}(\alpha)}{h} \cdot \sqrt{127 \cdot \frac{t_{\text{tank}}}{R} \cdot \frac{\rho_{\text{steel}}}{\rho_{\text{waste}}} \cdot \frac{E}{\rho_{\text{steel}}}} \quad f_{iH} = 8.0769 \cdot \text{Hz}$$

Fundamental natural frequency of anchored tanks - horizontal earthquake excitation tank-liquid system for antimitric vibration mode per Rammerstorfer 1990.

(F. G. Rammerstorfer, K. Scharf and F. D. Fisher, Storage Tanks under Earthquake Loading, Applied Mechanics Review, vol 43, no. 11, November 1990.)

Sakai, et al, correction factor, F_S

$$F_{sS}(\alpha) := \frac{1}{(0.46 - 0.15 \cdot \alpha + 0.017 \cdot \alpha^2)} \quad F_{sS}(\alpha) = 2.85$$

$$f_{\text{tankS}} := \frac{1}{2 \cdot F_{sS}(\alpha) \cdot R} \cdot \sqrt{\frac{E}{\rho_{\text{waste}}} \cdot \frac{t_{\text{tank}}}{h}} \quad f_{\text{tankS}} = 7.3838 \cdot \text{Hz}$$

Rammerstorfer, et al, correction factor, F_S

$$F_{sR}(\alpha) := 1.49 + \alpha + 0.157 \cdot \alpha^2 \quad F_{sR}(\alpha) = 2.3905$$

$$f_{\text{tankR}} := \frac{1}{2 \cdot F_{sR}(\alpha) \cdot R} \cdot \sqrt{\frac{E}{\rho_{\text{waste}}} \cdot \frac{t_{\text{tank}}}{h}} \quad f_{\text{tankR}} = 8.8032 \cdot \text{Hz}$$

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Consider $f_{\text{tank}} := f_{iH}$ $f_{\text{tank}} = 8.0769 \cdot \text{Hz}$

Liquid containing metal tanks (impulsive mode at a response level 1, conservative) (DOE 1993, Table 3.2)

$$S_{ai} := g \cdot v S_{aZPA2\%} \left(\frac{f_{\text{tank}}}{\text{Hz}} \right) \quad \frac{S_{ai}}{g} = 0.544$$

$$A_i := \frac{S_{ai}}{\phi(R, 0, 1, 0)}$$

A_i is the impulsive component of the instantaneous pseudoacceleration induced by the DBE motion and refers to the fundamental frequency of the tank vibration including the impulsive component of liquid mass.

$$N := 20 \quad m := 0..N \quad n := 0..N \quad r_n := \frac{n}{N} \cdot R \quad \theta_m := \frac{m}{N} \cdot \frac{\pi}{2} \quad z := 0 \cdot \text{ft}$$

$$\eta'_{n,m} := \frac{\eta(r_n, \theta_m, z)}{\text{ft}}$$

$$\begin{aligned} R &= 37.5 \cdot \text{ft} && \text{tank radius} \\ h &= 30 \cdot \text{ft} && \text{fluid height} \\ i &= 1 && j \end{aligned}$$

0
1
2
3
4
5
6

FIGURE B9. FREE SURFACE DISPLACEMENT AS A FUNCTION OF r AND θ

$$z_n := -\frac{n}{N} \cdot h$$

η'

HYDRODYNAMIC WALL PRESSURE (DOE 1993, Section 4.3.2)

Dynamic pressure (convective and impulsive)

$$p_{dc}(r, \theta, z) := \rho_{\text{waste}} \cdot g \cdot \eta(r, \theta, z)$$

(convective pressure)

$$p_{di}(r, \theta, z) := \rho_{\text{waste}} \cdot c_i(r, \theta, z) \cdot \phi(r, \theta, 1, 0) \cdot A_i \cdot r$$

(impulsive pressure)

Static pressure

$$p_s(z) := -\rho_{\text{waste}} \cdot g \cdot z$$

Total pressure

$$p_T(r, \theta, z) := p_{dc}(r, \theta, z) + p_{di}(r, \theta, z) + p_s(z)$$

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Hydrodynamic pressure at surface
of waste at tank wall

$$p_s(0 \cdot ft) = 0 \cdot \frac{lbf}{in^2}$$

$$p_{dc}(R, 0, 0 \cdot ft) = 0.8996 \cdot \frac{lbf}{in^2}$$

$$p_{di}(R, 0, 0 \cdot ft) = 0.2966 \cdot \frac{lbf}{in^2}$$

$$p_T(R, 0, 0 \cdot ft) = 1.1962 \cdot \frac{lbf}{in^2}$$

$$P_{dc_{m,n}} := \frac{p_{dc}(R, \theta_m, z_n)}{\left(\frac{lbf}{in^2}\right)}$$

FIGURE B10. DYNAMIC CONVECTIVE PRESSURE
AT $r=R$ AS A FUNCTION OF z AND θ

Hydrodynamic pressure at bottom
of waste at tank wall

$$p_s(-h) = 15.6051 \cdot \frac{lbf}{in^2}$$

$$p_{dc}(R, 0, -h) = 0.3786 \cdot \frac{lbf}{in^2}$$

$$p_{di}(R, 0, -h) = 6.7211 \cdot \frac{lbf}{in^2}$$

$$p_T(R, 0, -h) = 22.7048 \cdot \frac{lbf}{in^2}$$

$$P_{di_{m,n}} := \frac{p_{di}(R, \theta_m, z_n)}{\left(\frac{lbf}{in^2}\right)}$$

FIGURE B11. DYNAMIC IMPULSIVE PRESSURE
AT $r=R$ AS A FUNCTION OF z AND θ

CALCULATION OF WASTE MODAL AND COMPONENT VELOCITIES

(see equation (9) stated previously in the analysis for details)

Radial velocity of fluid

$$v_{rl}(r, \theta, z, i, j) := -\frac{d}{dr} \Phi_l(r, \theta, z, i, j)$$

r-modal component velocity
(general eq. for modes)

$$v_r(r, \theta, z) := \sqrt{\sum_i \sum_j v_{rl}(r, \theta, z, i, j)^2}$$

r-component velocity
(Modal combination, SRSS)

Circumferential velocity of fluid

$$v_{\theta l}(r, \theta, z, i, j) := \text{if} \left(r = 0 \cdot \text{ft}, 0 \cdot \frac{\text{ft}}{\text{sec}}, -\frac{1}{r} \cdot \frac{d}{d\theta} \Phi_l(r, \theta, z, i, j) \right) \quad \begin{array}{l} \theta\text{-Modal component velocity} \\ \text{(general eq. for modes)} \end{array}$$

$$v_{\theta}(r, \theta, z) := \sqrt{\sum_i \sum_j v_{\theta l}(r, \theta, z, i, j)^2} \quad \begin{array}{l} \theta\text{-component velocity} \\ \text{(Modal combination, SRSS)} \end{array}$$

Vertical velocity of fluid

$$v_{z l}(r, \theta, z, i, j) := -\frac{d}{dz} \Phi_l(r, \theta, z, i, j) \quad \begin{array}{l} z\text{-modal component velocity} \\ \text{(general eq. for modes)} \end{array}$$

$$v_z(r, \theta, z) := \sqrt{\sum_i \sum_j v_{z l}(r, \theta, z, i, j)^2} \quad \begin{array}{l} z\text{-component velocity} \\ \text{(Modal combination, SRSS)} \end{array}$$

Resultant in-plane fluid velocity

$$v(r, \theta, z) := \sqrt{v_r(r, \theta, z)^2 + v_{\theta}(r, \theta, z)^2}$$

CALCULATION OF WASTE DISPLACEMENTS

displacement of liquid waste based on the velocity of the fluid

$$\delta = \int_0^t v \, dt = \frac{v}{\omega}$$

Radial modal displacement of the liquid

$$\delta_{r l}(r, \theta, z, i, j) := \text{if} \left[(i=0) \cdot (j=0), 0 \cdot \text{ft}, \frac{1}{\omega_{i,j}} \cdot v_{r l}(r, \theta, z, i, j) \right]$$

$$\delta_r(r, \theta, z) := \sqrt{\sum_i \sum_j \delta_{r l}(r, \theta, z, i, j)^2} \quad \text{r-component displacement}$$

Circumferential modal displacement of the liquid

$$\delta_{\theta l}(r, \theta, z, i, j) := \text{if} \left[(i=0) \cdot (j=0), 0 \cdot \text{ft}, \frac{1}{\omega_{i,j}} \cdot v_{\theta l}(r, \theta, z, i, j) \right]$$

$$\delta_{\theta}(r, \theta, z) := \sqrt{\sum_i \sum_j \delta_{\theta l}(r, \theta, z, i, j)^2} \quad \theta\text{-component displacement}$$

Vertical modal displacement of the liquid

$$\delta_{z1}(r, \theta, z, i, j) := \text{if} \left[(i=0) \cdot (j=0), 0 \cdot \text{ft}, \frac{1}{\omega_{i,j}} \cdot v_{z1}(r, \theta, z, i, j) \right]$$

$$\delta_z(r, \theta, z) := \sqrt{\sum_i \sum_j \delta_{z1}(r, \theta, z, i, j)^2} \quad \text{z-component displacement}$$

$$\delta(r, \theta, z) := \sqrt{\delta_r(r, \theta, z)^2 + \delta_\theta(r, \theta, z)^2} \quad \text{Resultant in-plane fluid displacement}$$

The calculated velocity and displacements of the liquid waste fluid inside the waste storage tank for the first i,j slosh modes (results based on the information given on the previous pages)

R = 37.5 · ft tank radius
h = 30 · ft fluid height

(modes used) i = 1 j

0
1
2
3
4
5
6

boundary conditions for maximum displacement and velocity

r := R θ := 0 · rad z := 0 · ft

r = distance from the center line of the tank out.

θ = angle direction from the north-west direction

z = depth from the waste surface to the bottom of the tank.

r := 0 · ft θ := 0 · rad z := 0 · ft

r := R θ := $\frac{\pi}{2}$ · rad z := 0 · ft

r := 0 · ft θ := 0 · rad z := -h

r := R_{TC} θ := 0 · rad z := 0 · ft

results for maximum boundary conditions

η_R := η(r, θ, z) η_R = 20.7526 · in

vertical disp. and vel. at surface

δ_z(r, θ, z) = 20.7526 · in

v_z(r, θ, z) = 2.2715 · $\frac{\text{ft}}{\text{sec}}$

radial disp. and vel. at surface

δ_r(r, θ, z) = 21.0877 · in

v_r(r, θ, z) = 2.7445 · $\frac{\text{ft}}{\text{sec}}$

circumferential disp. and vel. at surface

δ_θ(r, θ, z) = 12.1293 · in

v_θ(r, θ, z) = 1.2134 · $\frac{\text{ft}}{\text{sec}}$

radial disp. and vel. at bottom

δ_r(r, θ, z) = 8.3384 · in

v_r(r, θ, z) = 0.829 · $\frac{\text{ft}}{\text{sec}}$

resultant in-plane disp. and vel. at surface (T/C location)

δ(r, θ, z) = 3.4548 · in

v(r, θ, z) = 0.6834 · $\frac{\text{ft}}{\text{sec}}$

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$$N := 20 \quad m := 0..N \quad n := 0..N$$

$$r_n := \frac{n}{N} \cdot R \quad z_m := -\frac{m}{N} \cdot h \quad \theta := 0$$

$$V_{r,n,m} := \frac{v_r(r_n, \theta, z_m)}{\left(\frac{\text{ft}}{\text{sec}}\right)}$$

FIGURE B12. RADIAL VELOCITY AT $\theta=0$ AS A FUNCTION OF r AND z

$$\theta_n := \frac{n}{N} \cdot \frac{\pi}{2} \quad z_m := -\frac{m}{N} \cdot h$$

$$V_{\theta,n,m} := \frac{v_\theta(R_{TC}, \theta_n, z_m)}{\left(\frac{\text{ft}}{\text{sec}}\right)}$$

FIGURE B14. CIRCUMFERENTIAL VELOCITY AT $r=R_{TC}$ AS A FUNCTION OF θ AND z

$$R = 37.5 \cdot \text{ft}$$

tank radius

$$h = 30 \cdot \text{ft}$$

fluid height

$$i = 1 \quad j$$

(modes used)

0
1
2
3
4
5
6

FIGURE B13. RADIAL ($\theta=0$) AND CIRCUMFERENTIAL ($\theta=\pi/2$) VELOCITY AT $r=R_{TC}$, AS A FUNCTION OF z

$$V_{n,m} := \frac{v(R_{TC}, \theta_n, z_m)}{\left(\frac{\text{ft}}{\text{sec}}\right)}$$

FIGURE B15. IN-PLANE VELOCITY AT $r=R_{TC}$ AS A FUNCTION OF θ AND z

R = 37.5 · ft tank radius

h = 30 · ft fluid height

(modes used) i = 1 j

0
1
2
3
4
5
6

FIGURE B16. IN-PLANE VELOCITY AT $r=R_{TC}$, $\theta=0$ and $\pi/2$ AS A FUNCTION OF z

$$\frac{v_r(R_{TC}, 0, 0 \cdot ft)}{\left(\frac{ft}{sec}\right)} = 0.6834$$

$$\frac{v_\theta(R_{TC}, 0, 0 \cdot ft)}{\left(\frac{ft}{sec}\right)} = 0$$

$$\frac{v(R_{TC}, 0, 0 \cdot ft)}{\left(\frac{ft}{sec}\right)} = 0.6834$$

FIGURE B17. DIAGRAM OF VELOCITIES BASED ON LOCATION OF TC IN A DESIGN BASIS EARTHQUAKE (NORTH-SOUTH DIRECTION)

NATURAL FREQUENCY OF THERMOCOUPLE TREE

(assumed thermocouple probes is close to the fluid)

$$d_o := 5.5 \cdot \text{in}$$

Outside diameter of pipe

$$d_i := 3.75 \cdot \text{in}$$

inside pipe diameter

$$A_{TC} := \frac{\pi}{4} \cdot (d_o^2 - d_i^2)$$

area of thermocouple probe pipes

$$A_{TC} = 12.7136 \cdot \text{in}^2$$

$$I_{TC} := \frac{\pi}{64} \cdot (d_o^4 - d_i^4)$$

moment of inertia of thermocouple probes

$$I_{TC} = 35.2108 \cdot \text{in}^4$$

$$A_{\text{remove}} := 3 \cdot ((0.31 \cdot \text{in}) \cdot (0.38 \cdot \text{in}) + (0.57 \cdot \text{in}) \cdot (0.075 \cdot \text{in})) + 2 \cdot ((0.437 \cdot \text{in}) \cdot (0.375 \cdot \text{in}) + (0.075 \cdot \text{in}) \cdot (1.635 \cdot \text{in}))$$

metal surface area removed for 3 thermocouples and 6 strain gages, total of 9 key slots. (see H-2-79344)

$$A_e := A_{TC} - A_{\text{remove}}$$

equivalent surface area of thermocouple probe pipe with slots

$$A_e = 11.0035 \cdot \text{in}^2$$

$$d_e := \sqrt{\frac{4 \cdot A_e}{\pi} + d_i^2}$$

effective outside diameter of thermocouple probes (used in stress calc.)

$$d_e = 5.2984 \cdot \text{in}$$

$$I_e := \frac{\pi}{64} \cdot (d_e^4 - d_i^4)$$

effective moment of inertia of thermocouple probes (used in stress calc.)

$$I_e = 28.977 \cdot \text{in}^4$$

$$m_{\text{pipe}} := \frac{\rho_{\text{steel}} \cdot A_e}{g}$$

$$\text{mass of thermocouple probes pipe } m_{\text{pipe}} = 1.162 \cdot \frac{\text{lbf} \cdot \text{sec}^2}{\text{ft}^2}$$

$$m_{TC} := m_{\text{pipe}} \cdot (1 + 0.10)$$

assume 10% increase in mass for instrumentation and additional metal plates welded to pipe

$$m_{TC} = 1.2782 \cdot \frac{\text{lbf} \cdot \text{sec}^2}{\text{ft}^2}$$

Fixed-free beam natural frequency in vacuum

$$f_{TC_vacuum} := \frac{1.87510407^2}{2 \cdot \pi \cdot L^2} \cdot \sqrt{\frac{E \cdot I_e}{m_{TC}}}$$

$$f_{TC_vacuum} = 0.3321 \cdot \text{Hz}$$

displaced fluid mass per unit length

$$M := \rho_{\text{waste}} \cdot \pi \cdot \frac{d_o^2}{4}$$

$$M = 12.3599 \cdot \frac{\text{lb}}{\text{ft}}$$

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ADDED MASS COEFFICIENT FOR VISCOUS FLUID

S. S. Chen, M. W. Wambsganss, and J. A. Jendrzejczyk, *Added Mass and Damping of a Vibrating Rod in Confined Viscous Fluid*, Journal of Applied Mechanics, June 1976, pp. 325-329.

$$S := \frac{\omega_{1,0} \cdot d_o^2}{\nu}$$

At sloshing mode (first mode dominates)

$$S = 5584.9392$$

$$\alpha := \sqrt{i \cdot S}$$

Reynolds No. times Strouhal No.

$$\alpha = 52.8438 + 52.8438i$$

$$H = 1 + \frac{4 \cdot \text{Kn}(1, \alpha)}{\alpha \cdot \text{Kn}(0, \alpha)}$$

where $\text{Kn}(1, \alpha)$ and $\text{Kn}(0, \alpha)$ are modified Bessel functions of order 1 and 0, respectively.

$$C_M = \text{Re}(H)$$

Added mass coefficient

$$C_M := 1.04$$

Static deflection shape function for uniformly loaded cantilever beam and partial uniformly loaded to account for the added mass of the fluid. (see Roarks 4th edition)

FIGURE B18. STATIC LOADING DIAGRAM FOR CANTILEVER BEAM (THERMOCOUPLE PROBE)

STATIC DEFLECTION SHAPE FUNCTIONS FOR UNIFORMLY LOADED AND PARTIAL CANTILEVER BEAM EQUATIONS TO ACCOUNT FOR THE ADDED MASS OF THE FLUID:

$$\xi_1(x) := (L - x)^4 + 4 \cdot L^3 \cdot x - L^4$$

$$\xi''_1(x) := 12 \cdot (L - x)^2$$

$$\xi_2(x) := 2 \cdot h_{TC} \cdot \left[x^2 \cdot (6 \cdot L - 3 \cdot h_{TC} - 2 \cdot x) \right]$$

$$\xi''_2(x) := 2 \cdot h_{TC} \cdot (12 \cdot L - 6 \cdot h_{TC} - 12 \cdot x)$$

$$\xi_3(x) := h_{TC} \cdot \left[6 \cdot x^2 \cdot (2 \cdot L - h_{TC}) - 4 \cdot x^3 \right] + (x + h_{TC} - L)^4$$

$$\xi''_3(x) := h_{TC} \cdot (24 \cdot L - 12 \cdot h_{TC} - 24 \cdot x) + 12 \cdot (x + h_{TC} - L)^2$$

$$\xi_{12}(x) := \xi_1(x) + \xi_2(x)$$

$$\xi''_{12}(x) := \xi''_1(x) + \xi''_2(x)$$

$$\xi_{13}(x) := \xi_1(x) + \xi_3(x)$$

$$\xi''_{13}(x) := \xi''_1(x) + \xi''_3(x)$$

Natural frequency of thermocouple probe with added mass by approximate Rayleigh-Ritz method.

$$f_{TC} := \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{E \cdot I_e \cdot \left(\int_{0 \cdot ft}^{L - h_{TC}} \xi''_{12}(x)^2 dx + \int_{L - h_{TC}}^L \xi''_{13}(x)^2 dx \right)}{m_{TC} \cdot \int_{0 \cdot ft}^{L - h_{TC}} \xi_{12}(x)^2 dx + (m_{TC} + C_M \cdot M) \cdot \int_{L - h_{TC}}^L \xi_{13}(x)^2 dx}}$$

$$f_{TC} = 0.2922 \cdot \text{Hz}$$

$$\frac{f_{TC}}{f_{TC_vacuum}} = 0.8798$$

However, per the analysis in appendix A the thermocouple probes probe natural frequency, with added mass, for the first and second modes of vibration is (see appendix C)

$$f_{TC} := 0.354 \cdot \text{Hz}$$

Therefore, this natural frequency of the T/C probes, with added mass, will be used in the folloing calculations.

$Re_{II} := 0..36$

$Re_{II} := C_{d_{II}} :=$

.05	100
.07	74
.1	56
.2	34
.3	24
.5	16.5
.7	13.3
1	10.5
2	6.8
3	5.2
5	3.7
7	3.2
10	2.7
20	2.20
40	1.75
100	1.40
200	1.20
400	1.00
700	0.95
1000	0.90
1500	0.88
2000	0.87
3000	0.90
10000	1.12
20000	1.27
40000	1.37
70000	1.40
100000	1.38
130000	1.35
180000	1.30
250000	1.12
300000	1.00
400000	0.70
500000	0.42
520000	0.34
700000	0.36
1000000	0.36

LOG-LOG INTERPOLATION OF DRAG COEFFICIENT AS A FUNCTON OF REYNOLDS NUMBER

(Daugherty and Franzini 1977, figure 10.13)

$$\logRey := \overrightarrow{\log(Rey)}$$

$$\logCd := \overrightarrow{\log(C_d)}$$

$$vC_d(Rey) := 10^{\text{interp}(\logRey, \logCd, \log(Rey))}$$

FIGURE B19. Drag Coefficient for Infinte Cylinder
vs
Reynolds Number

Calculation of the moment and shear for an angle parallel to the earthquake (zero degrees):

$\theta := 0 \cdot \text{rad}$	location of T/C probes (angle)	(modes used) $i = 1$	j
$r := R_{TC}$	location of T/C probes (radial)	$r = 34.75 \cdot \text{ft}$	0
$z := 0 \cdot \text{ft}$	at the surface of the fluid		1
$h_{TC} = 29.75 \cdot \text{ft}$	height of thermocouple probes submerged in the fluid		2
$\delta(r, \theta, z) = 3.4548 \cdot \text{in}$	liquid waste displacement at surface (resultant in-plane)		3
			4
			5
			6

Determine the drag force on the thermocouple probes probe in the waste tank

$$v = 0.0000448494 \cdot \frac{\text{ft}^2}{\text{sec}} \quad \text{kinematic viscosity}$$

$$v(r, \theta, z) = 0.6834 \cdot \frac{\text{ft}}{\text{sec}} \quad \text{liquid waste velocity at surface (resultant in-plane)}$$

$$\text{Rey}(r, \theta, z) := \frac{v(r, \theta, z) \cdot d_o}{v} \quad \text{Reynolds number at surface}$$

$$\text{Rey}(r, \theta, z) = 6983.8851$$

$$C_d(r, \theta, z) := v C_d(\text{Rey}(r, \theta, z)) \quad \text{Drag coefficient for circular cylinder at surface}$$

$$C_d(r, \theta, z) = 1.0493$$

Drag force per unit length on circular cylinder (thermocouple probes probe)

$$F_d(r, \theta, z) := C_d(r, \theta, z) \cdot \rho_{\text{waste}} \cdot \frac{v(r, \theta, z)^2}{2} \cdot d_o$$

$$F_d(r, \theta, z) = 0.2615 \cdot \frac{\text{lbf}}{\text{ft}}$$

Buoyancy force per unit length due to acceleration of waste for impulsive mode

$$F_{sb}(r, \theta, z) := \rho_{\text{waste}} \cdot \frac{\pi}{4} \cdot d_o^2 \cdot c_i(r, \theta, z) \cdot \phi(r, \theta, 1, 0) \cdot A_i = \frac{\pi}{4} \cdot d_o^2 \cdot \frac{p_{di}(r, \theta, z)}{r}$$

$$F_{sb}(r, \theta, -h) = 4.2308 \cdot \frac{\text{lbf}}{\text{ft}}$$

$$\zeta := 0.05$$

Structural slosh damping (DOE 1993)

$$f_{1,0} = 0.1898 \cdot \text{Hz}$$

Minimum Sloshing frequency (forced vibration)

$$f_{TC} = 0.354 \cdot \text{Hz}$$

Minimum thermocouple frequency (natural vibration with added mass)

Dynamic amplification load factor (Biggs 1964)

$$\text{DLF} := \frac{1}{\sqrt{\left[1 - \left(\frac{f_{1,0}}{f_{TC}}\right)^2\right]^2 + \left(2 \cdot \zeta \cdot \frac{f_{1,0}}{f_{TC}}\right)^2}} \quad \text{DLF} = 1.3993$$

Total sloshing induced load per unit length

$$F_s(r, \theta, z) := \text{DLF} \cdot F_d(r, \theta, z) + F_{sb}(r, \theta, z)$$

**FIGURE B20. FORCE DISTRIBUTION ALONG PROPE
AT $r=R_{TC}$, $\theta=0$ AS A FUNCTION OF z**

$$\theta = 0$$

$$z_m := -\frac{m}{N} \cdot h_{TC}$$

**FIGURE B21. FIXED CANTILEVER BEAM
(THERMOCOUPLE TREE)**

Shear at flange connection

$$V(r, \theta) := - \int_{0 \cdot \text{ft}}^{-h_{TC}} F_s(r, \theta, z) dz$$

$$V(r, \theta) = 92.9703 \cdot \text{lbf}$$

Moment at flange connection

$$M(r, \theta) := - \int_{0 \cdot \text{ft}}^{-h_{TC}} (L - h_{TC} - z) \cdot F_s(r, \theta, z) dz$$

$$M(r, \theta) = 53452.536 \cdot \text{in} \cdot \text{lbf}$$

Axial stress at flange connection (use effective area)

$$\sigma_a := \frac{g \cdot m_{TC} \cdot L + \rho_{\text{concrete}} \cdot \frac{\pi}{4} \cdot d_i^2 \cdot 5 \cdot \text{ft}}{A_e} - \rho_{\text{waste}} \cdot g \cdot h_{TC}$$

$$\sigma_a = 213.969 \cdot \frac{\text{lbf}}{\text{in}^2}$$

Bending stress at flange connection (use effective moment of inertia)

$$\sigma_b(r, \theta) := \frac{M(r, \theta) \cdot \frac{d_o}{2}}{I_e}$$

$$\sigma_b(r, \theta) = 5072.793 \cdot \frac{\text{lbf}}{\text{in}^2}$$

Shear stress at flange (use effective area)

$$\tau(r, \theta) := \frac{V(r, \theta)}{A_e}$$

$$\tau(r, \theta) = 8.449 \cdot \frac{\text{lbf}}{\text{in}^2}$$

 $\leq$ allowable shear stress
(AISC 1989)

$$F_{as} = 37333 \cdot \frac{\text{lbf}}{\text{in}^2}$$

Axial and bending stress at flange

$$\sigma(r, \theta) = \sigma_b(r, \theta) + \sigma_a \quad \sigma(r, \theta) = 5286.762 \cdot \frac{\text{lb}_f}{\text{in}^2} \leq \text{allowable bending stress (AISC 1989)} \quad F_{ab} = 56000 \cdot \frac{\text{lb}_f}{\text{in}^2}$$

4.0 RESULTS AND CONCLUSIONS

The analysis considers only the hydrodynamic effects of the liquid on the thermocouple (T/C) probes and tank walls. For calculation of the dynamic behavior of the fluid on the T/C probes only the fundamental sloshing mode ($i=1$, $j=0..6$) is considered to contribute to the dynamically activated loads acting on the thermocouple probes and tank wall vibration. The higher order modes lead to smaller mode participation factors and smaller dynamic amplification load factors.

The fundamental natural frequency of the T/C probe (with added mass), sloshing (convective mode), and tank-liquid-system (impulsive vibration mode) are 0.354, 0.1898, and 8.0769 Hz, respectively.

The analysis considers a north-south seismic earthquake with the TC probe 34.75 ft from the center and located at 0 degrees relative to the north-west direction of the tank, worst case senerio per WHC 1994 conclusions. The results are summarized in a Table B1. Where the maximum values occur at the surface of the homogenous liquid waste.

The following data remains constant regardless of T/C location: the kinematic viscosity is 0.00004485 ft²/sec, the slosh damping is 0.5%, the minimum fundamental frequency for the sloshing and thermocouple probe (added mass) is 0.1898 and 0.354 Hz, and the height of the thermocouple probes submerged in the fluid is 29.75 ft.

**TABLE B1. ANGULAR LOCATION OF THERMOCOUPLE TREE
RELATIVE TO THE NORTH-SOUTH (DBE) EARTHQUAKE**

<u>Maximum Hydrodynamic results</u>	<u>0 degrees</u>
Fluid waste velocity (ft/sec)	
1. Resultant in-plane (@ T/C)	0.6834
2. Vertical (@ tank wall, r=R)	1.2134
Waste Displacements (in)	
1. Resultant in-plane (@ T/C)	2.2715
2. Vertical (@ tank wall, r=R)	20.7526
Forces on TC at surface (lb _f /ft)	
1. Drag force	0.2615
2. Buoyancy force (impulsive)	4.2308
3. Total sloshing force (convective)	4.5810
Reaction Forces on T/C at flange	
1. Shear force (lb _f)	93
2. Moment (in-lb _f)	53,453
Stresses on T/C at flange (lb _f /in ²)	
1. Axial stress	214
2. Bending stress	5,073
3. Shear stress	8.5
4. Axial and bending stress	5,287

Table B1 indicate that for a (DBE) earthquake occuring in the north-south direction (x-axis) the stresses due to hydrodynamic loads on the T/C probes are less than the allowable AISC stress requires for bending and shear. Therefore, the thermocouple probes are adequate to withstand hydrodynamic loads produced from the sloshing of the liquid waste in the 241AZ101 storage tank. However, this analysis does not consider the ground response interaction with the TCP at higher modes (modal combinations). In fact stresses and loads will increase when the ground motion interaction is considered. The response of the T/C probe due to ground motion is discussed in appendix A of this report.

5.0 REFERENCES

- AISC, 1989, *AISC Manual of Steel Construction*, 9th ed., American Institute of Steel Construction, Inc., Chicago, Illinois.
- ASTM, 1989, *Annual Book of ASTM Standards*, Vol. 01.01, Steel Pipping, Tubing, Fittings, American Society for Testing and Materials, Philadelphia, Pennsylvania.
- Biggs, John M., 1964, *Introduction to Structural Dynamics*, McGraw-Hill Book Company, New York, New York.
- Blevins, Robert B., 1979, *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Company, New York.
- Daugherty, Robert L. and Joseph B. Franzini, 1977, *Fluid Mechanics with Engineering Applications*, 7th ed., McGraw-Hill, New York.
- DOE, 1993, *Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Storage Tanks and Appurtenances*, Tank Seismic Expert Panel, Brookhaven National Laboratory Associated Universities, Inc., Upton, New York, January 1993.
- DOE-RL, 1989, *Standard Arch-Civil Design Criteria; Design Loads for Facilities*, SDC-4.1, Rev. 11, U.S. Department of Energy, Richland operations office, Richland, Washington.
- Epstein, Howard I., 1976, *Seismic Design of Liquid-Storage Tanks*, ASCE Journal of the Structural Division.
- F. G. Rammerstorfer, K. Scharf and F. D. Fisher, 1990, *Storage Tanks under Earthquake Loading*, Applied Mechanics Review, vol 43, no. 11, November 1990.
- Harris, Cyril M. and Charles E. Crede, 1976, *Shock and Vibration Handbook*, 2nd ed., McGraw-Hill, New York, New York.
- Haroun, Medhat A., 1981, *Behavior of Unanchored Oil Storage Tanks: Imperial Valley Earthquake*, ASCE International Convention and Exposition, Held in New York, New York, May 22, 1981.
- M. Abramowitz and I. A. Stegun, 1966, *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*, National Bureau of Standards Applied Mathematics Series 55, 5th ed., U. S. Department of Commerce.
- Roark, Raymond J., 1965, *Formulas for Stress and Strain*, 4th ed., McGraw-Hill Book Company, New York, New York.
- S. S. Chen, M. W. Wambsganss, and J. A. Jendrzeczyk, 1976 *Added Mass and Damping of a Vibrating Rod in Confined Viscous Fluid*, Journal of Applied Mechanics, June 1976.
- E. D. Waters and D. T. Heimberger, 1993 *Stress Cycles and Forces on In-Tank Components Resulting From Mixer Pump Operation in DST 101-AZ*, WHC-SD-W151-ER-001, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994, *Structural Evaluation of Tank 241-AN-107 Internal Components for Caustic Addition Mixing Operations*, WHC-SD-WM-ANAL-018, Westinghouse Hanford Company, Richland, Washington.

Displacement plot of thermocouple probe

Moment diagram of thermocouple probe

WHC-SD-WISI-ANAL-001
 REV-0

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