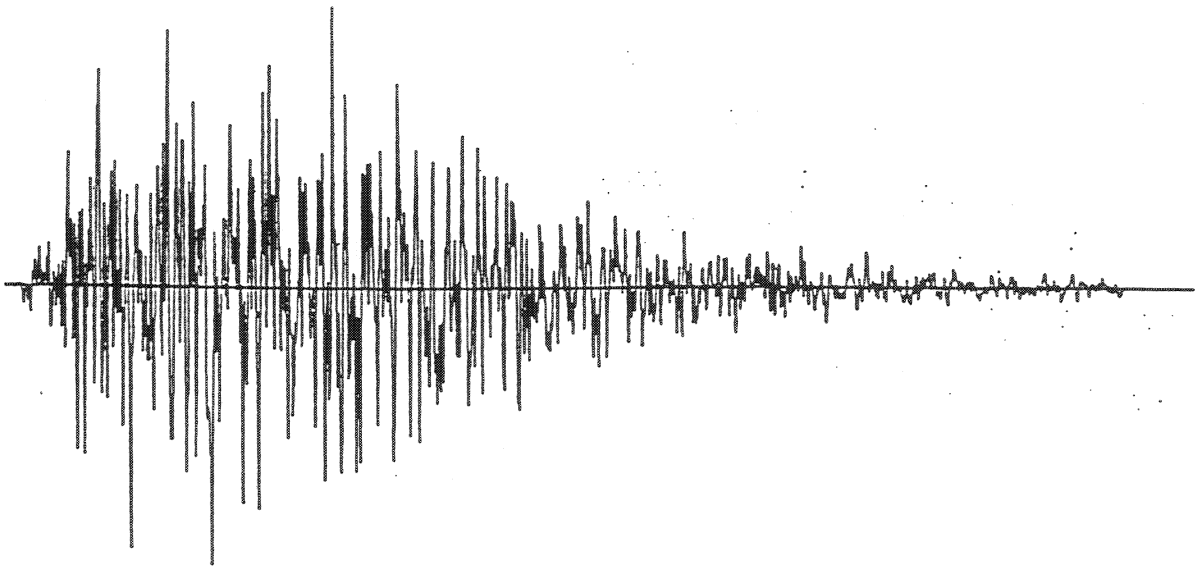
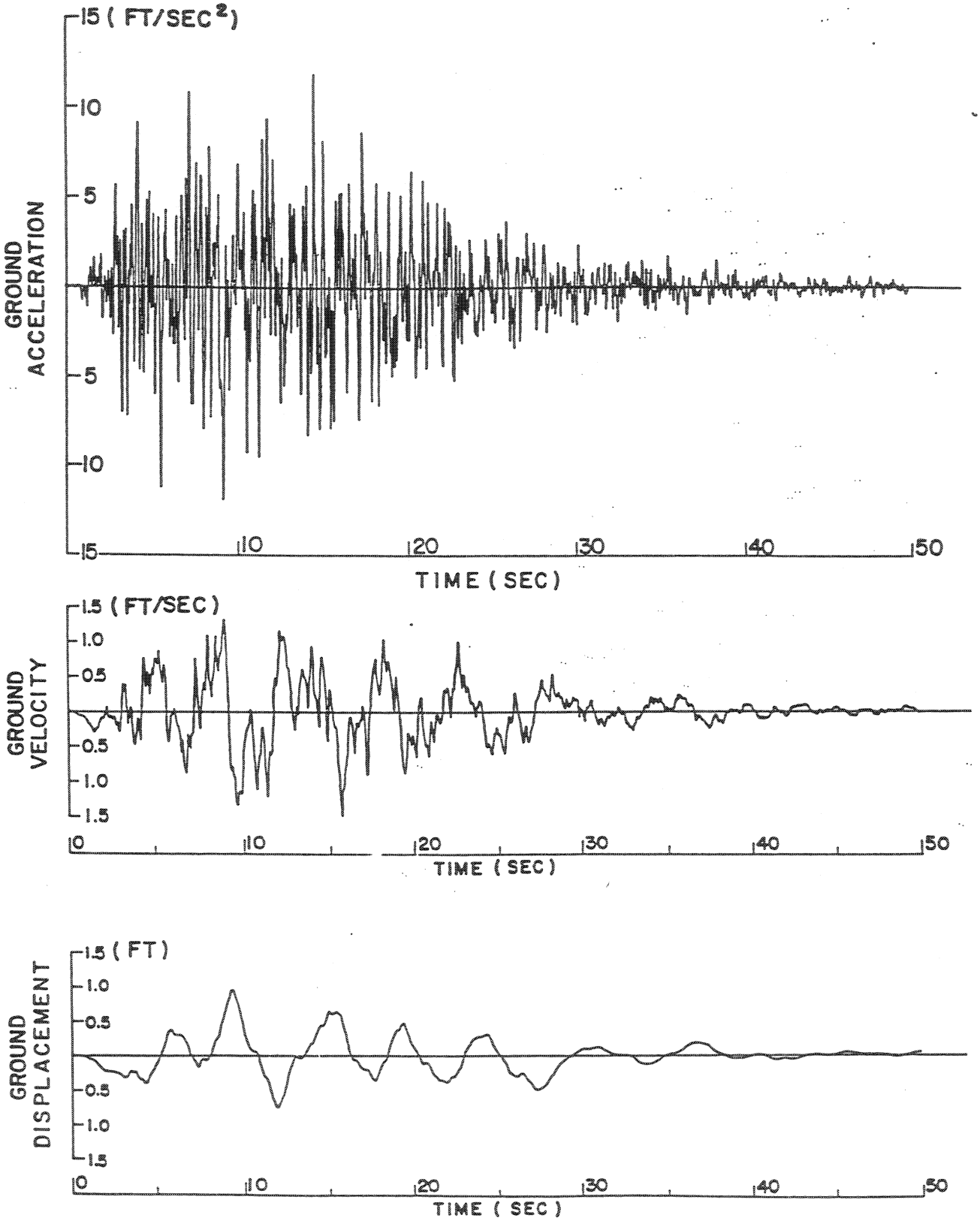
SEISMIC

SEISMIC DESIGN CRITERIA
for the
BaBar DETECTOR



Richard F Boyce
30 January 1996


15 (FT/SEC²)
10
5
5
10
15
GROUND ACCELERATION
10
20
30
40
50
TIME (SEC)
1.5 (FT/SEC)
1.0
0.5
0.5
1.0
1.5
GROUND VELOCITY
0
10
20
30
40
50
TIME (SEC)
1.5 (FT)
1.0
0.5
0.5
1.0
1.5
GROUND DISPLACEMENT
0
10
20
30
40
50
TIME (SEC)

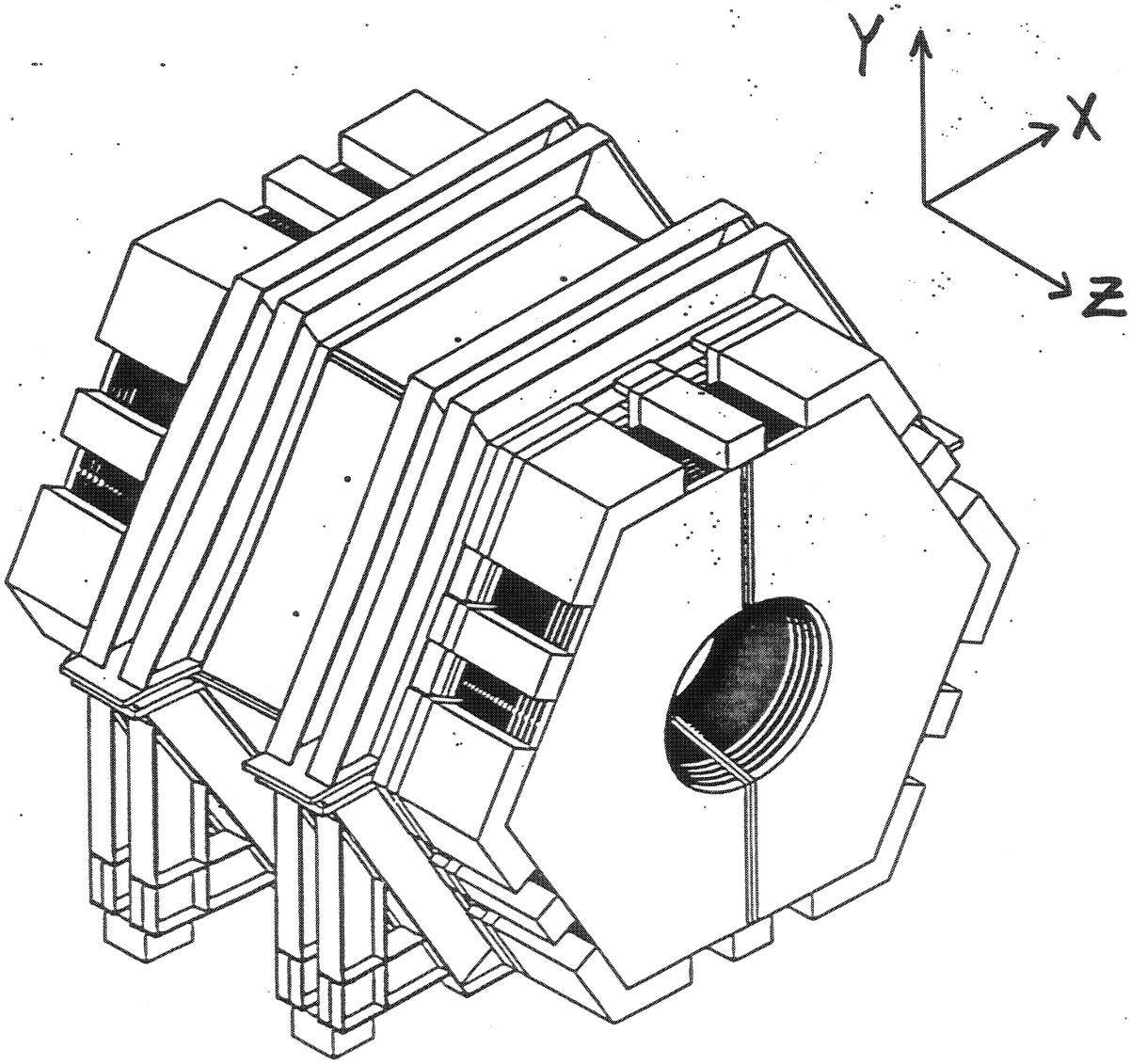
EARTHQUAKE

Forces caused by Maximum Credible Earthquake

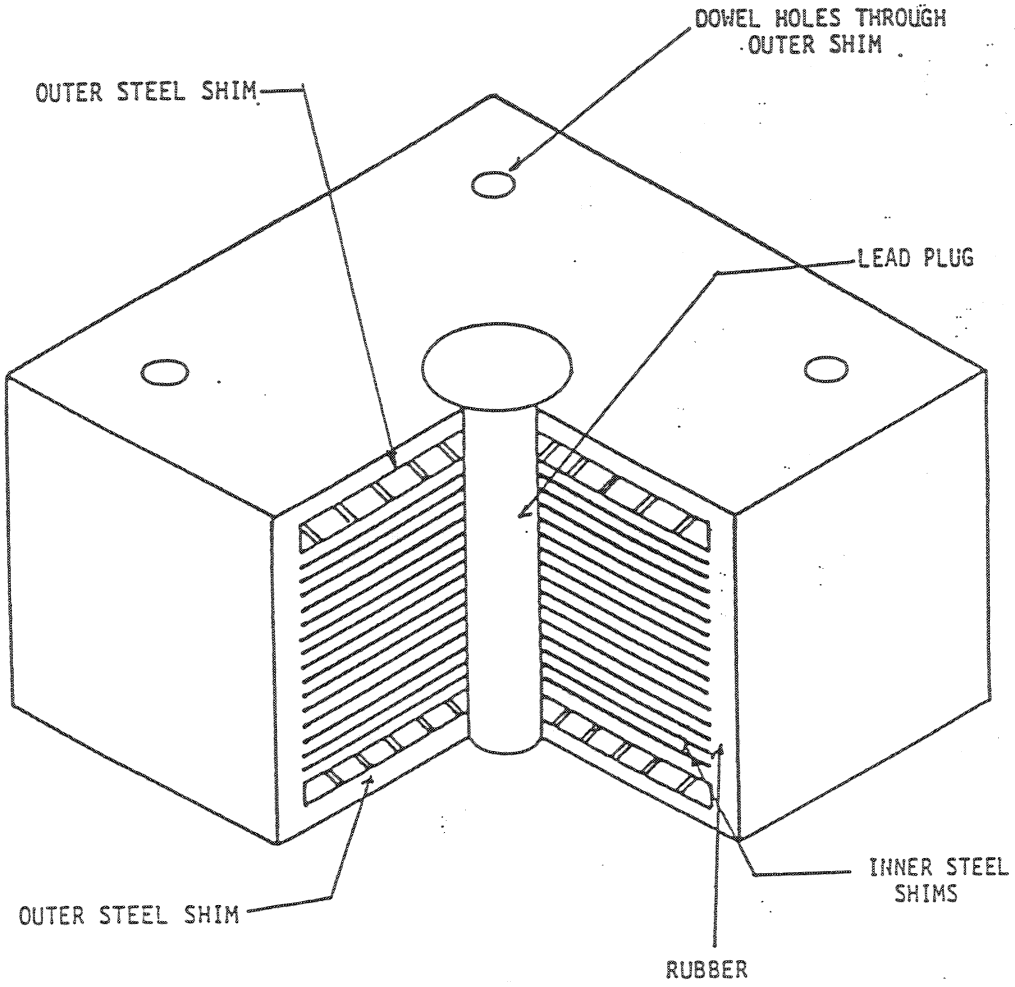
Case 1 Horizontal Force in the X direction, 0.3 g's
plus Gravity in the Y direction, -1.0 g's

Case 2 Horizontal Force in the X direction, 0.3 g's
plus Gravity in the Y direction, -1.0 g's

Case 3 Vertical Force in the Y direction, -1.3 g's
plus Gravity in the Y direction, -1.0 g's



LEAD-RUBBER ISOLATOR BEARINGS



```
*****************************************************************************************
*****************************************************************************************

  ----------------  L        EEEEEEE  AAAAAAAA  DDDDDDD   EEEEEEE   RRRRRR    ----------------
 ----------------  L        E        A      A  D      D  E         R     R   ----------------
----------------  L        E        A      A  D      D  E         R     R  ----------------
----------------  L        EEEEE    AAAAAAAA  D      D  EEEEE     RRRRRR   ----------------
----------------  L        E        A      A  D      D  E         R     R  ----------------
----------------  L        E        A      A  D      D  E         R     R  ----------------
----------------  LLLLLLLL EEEEEEEE A      A  DDDDDDDD EEEEEEE   R     R  ----------------

*****************************************************************************************
*****************************************************************************************
```

Copyright (C) 1994
DYNAMIC ISOLATION SYSTEMS, INC.
(510) 843-7233
All rights Reserved

DESIGN OF DIS SEISMIC ISOLATION BEARINGS
01-03-1996 17:27:54

The purpose of the procedures in this computer program is to aid in the evaluation of the impact that DIS Seismic Isolation Bearings have on the design of a structure. Seismic isolation design, energy dissipation design and force redistribution capabilities are incorporated in the program. The information set forth herein is based on technical data that DIS believes to be reliable. It is intended for use by persons having appropriate engineering skill, at their own discretion and risk. The entire and whole risk as to the quality, adequacy, correctness and applicability of the information is with the user. The licensee has agreed that results from this program will not be published in technical papers or articles without the prior written approval of DIS.

The information contained is insufficient for the specification of DIS Seismic Isolation Bearings. Materials and quality control procedures unique to the DIS product are inherent in the use of this program. DIS will, at the time of purchase, complete the design and provide relevant information for the project plans and specifications.

PROJECT	:	SLAC - Babar Detector - Increased Kvert
Design Acceleration Level	:	0.80
UBC Soil Profile Type	:	1

OVERALL SEISMIC PERFORMANCE

Seismic performance has been calculated assuming rigid substructure below and rigid superstructure above the bearings. Superstructure and/or substructure flexibility will result in an isolated period longer than that estimated from these procedures. The rigid assumption provides a reasonably accurate estimate of seismic forces. The values of isolated period, center of rigidity displacement and elastic base shear coefficient are based on the nonlinear response spectra developed for the specified acceleration level and soil profile type. The procedure is a single mode spectral analysis method where it is assumed that the dominant mode is the deformation of the bearings, and the elastic base shear coefficient is calculated from the period of this mode. The nonlinear spectra allow the additional damping from the lead cores to be accounted for in calculating forces and displacements.

DESIGN LEVEL : 0.80 g Soil Profile Type 1 (UBC Spectral Shape)
(Qd: 0.114)

Isolated Period (sec.) :	1.58
Center of Rigidity Disp. (in.):	7.15
Elastic Base Shear Coefficient:	0.294

.6 hertz Natural freq.

.3 g's Max Lateral Acc.

PERFORMANCE FOR OTHER ACCELERATION LEVELS :

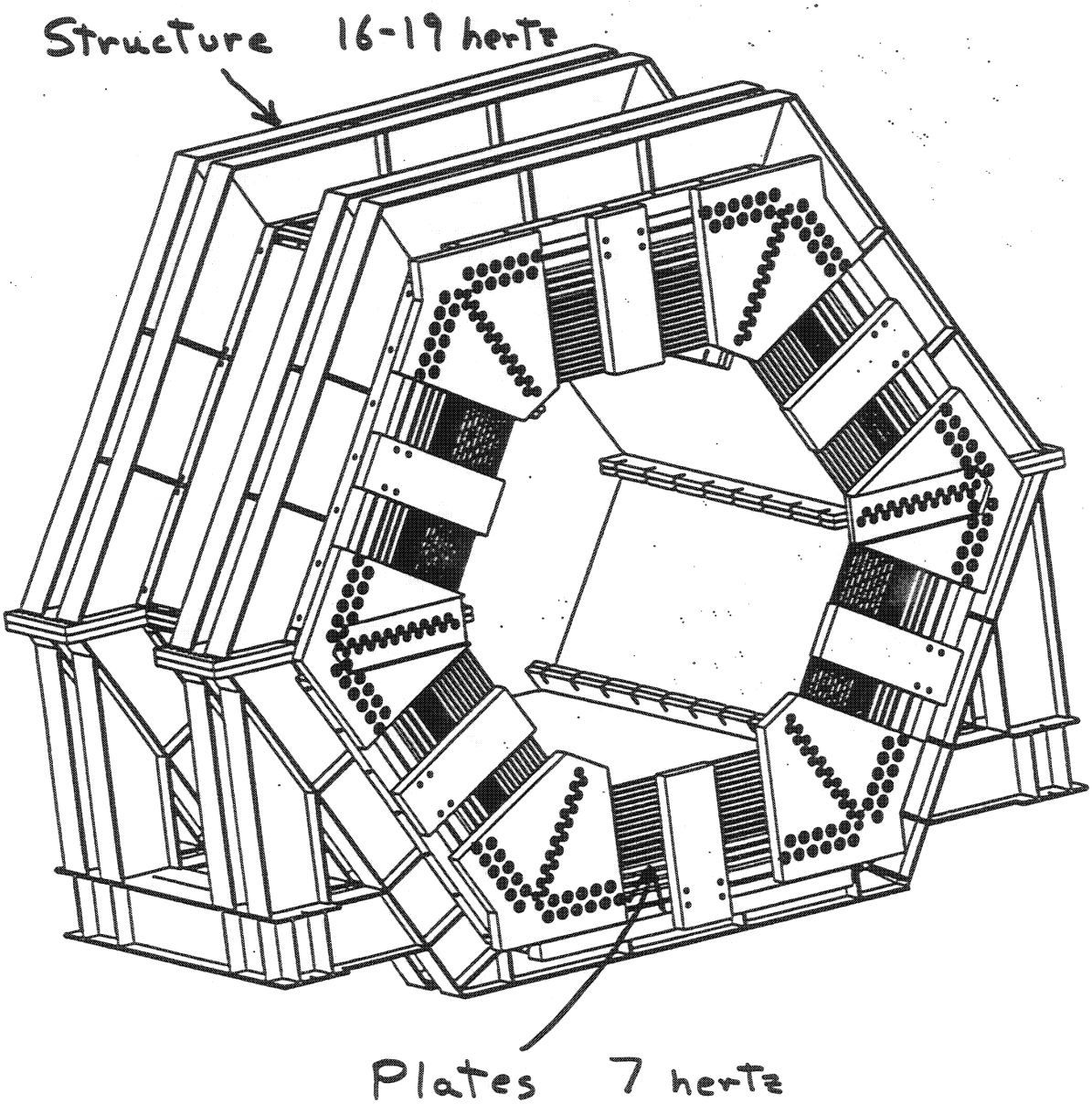
	EARTHQUAKE G LEVEL				
	0.60G	0.70G	0.80G	0.90G	1.00G
Isolated Period (sec.) :	1.47	1.52	1.58	1.62	1.67
Center of Rigidity Disp. (in.):	5.08	6.02	7.15	8.36	9.74
Elastic Base Shear Coefficient:	0.242	0.266	0.294	0.325	0.359

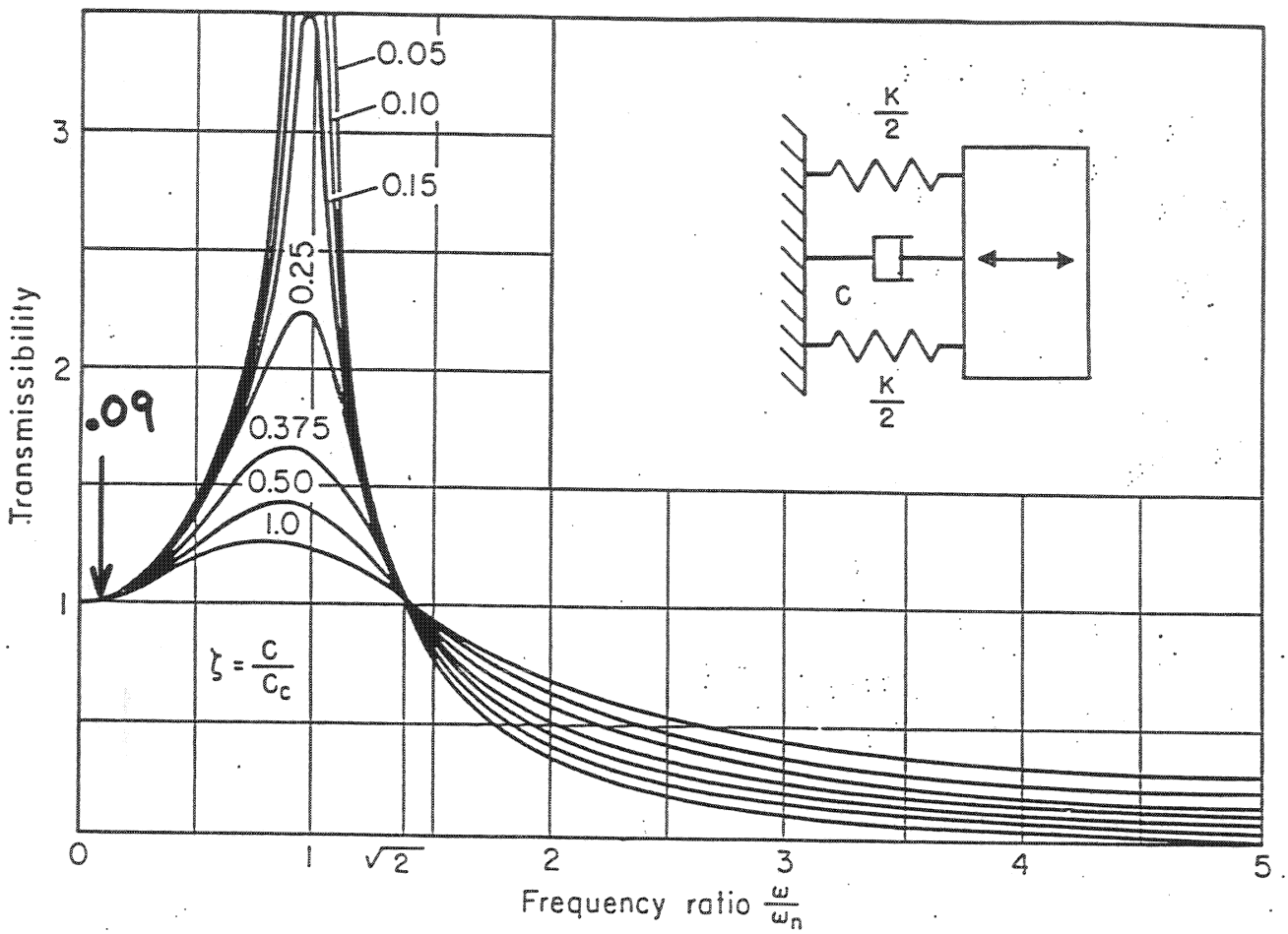
********** WARNING **********
Design has inadequate Factor of Safety for EQ load.

EARTHQUAKE EFFECTIVE STIFFNESSES (Keff) (Units: kip, in.)

BEARING	EQ Disp.	Effective Stiffness
C16-35.1-5.50	7.15	4.30
C35.5-15.4-7.00	7.15	20.09

Lowest Natural freq.





Driving freq. $\omega = .6$ hertz

Lowest Natural freq $\omega_n = 7$ hertz

Ratio $\frac{.6}{7} = .09$

No Resonance

Structure acts as a Rigid Body

STANFORD LINEAR ACCELERATOR CENTER

SLAC BABAR DETECTOR
SITE-SPECIFIC RESPONSE SPECTRA

for:

Stanford Linear Accelerator Center
2575 Sand Hill Road
Menlo Park, California

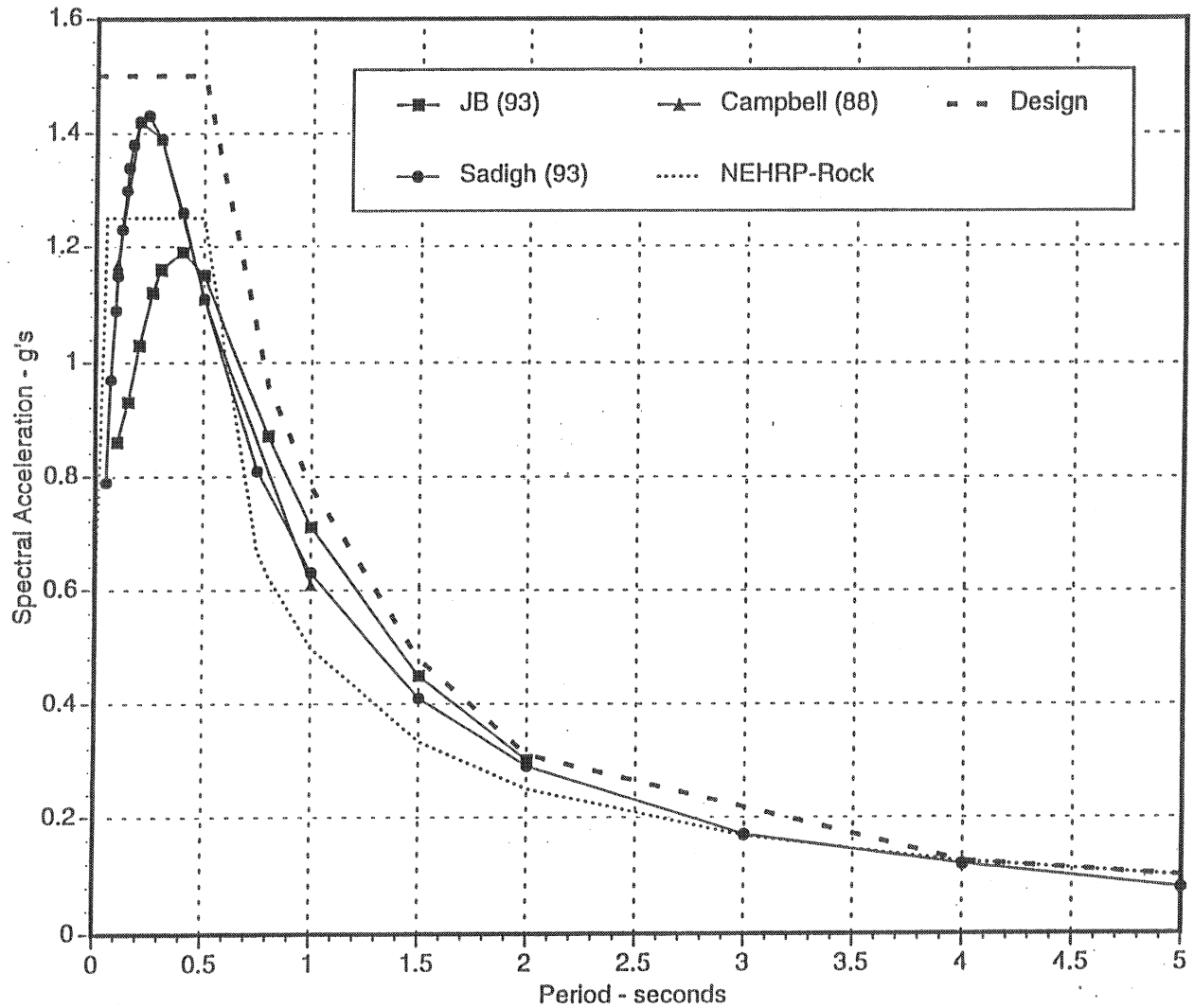
by:

ESA Consultants Inc.
201 San Antonio Circle, Suite 102
Mountain View, California 94040

Project No. 117.9501

April, 1995

Recent →



ESA Consultants Inc.
Mountain View, California

SLAC BABAR DETECTOR

SPECTRAL ACCELERATIONS - DAMPING = 5%
MAGNITUDE 7.7-7.9 EVENT - DISTANCE = 4.75KM

Checked By ____ Date ____	Project No.	Figure No.
Approved By ____ Date ____	117.9501	5

TABLE 3. RECOMMENDED DAMPING VALUES

Stress Level	Type and Condition of Structure	Percentage Critical Damping
Working stress, no more than about ½ yield point	• Vital piping	1 to 2
	• Welded steel, prestressed concrete, well reinforced concrete (only slight cracking)	2 to 3
	• Reinforced concrete with considerable cracking	3 to 5
	• Bolted and/or riveted steel, wood structures with nailed or bolted joints	5 to 7 ←
At or just below yield point	• Vital piping	2 to 3
	• Welded steel, prestressed concrete (without complete loss in prestress)	5 to 7
	• Prestressed concrete with no prestress left	7 to 10
	• Reinforced concrete	7 to 10
	• Bolted and/or riveted steel, wood structures, with bolted joints	10 to 15 ←
	• Wood structures with nailed joints	15 to 20

Ref. Newmark and Hall

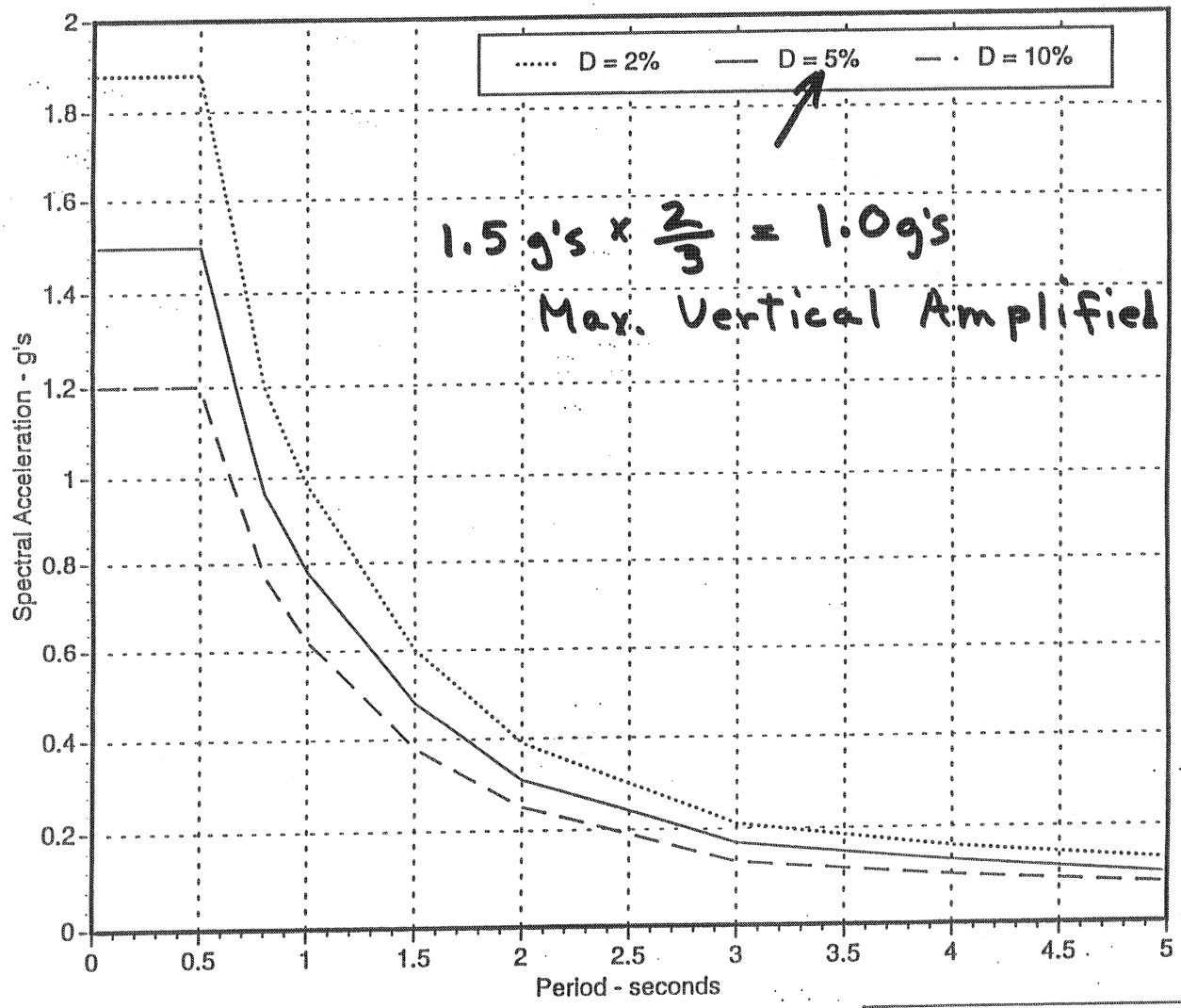
"Earthquake Spectra and Design" 1982

sections for this area are included in Appendix A and indicate that the materials underlying the LR Hall consists mainly of dense to very dense poorly cemented sands with Standard Penetration Test (SPT) blow counts in the range of 75 to 100 blows per foot. In addition, results of a geophysical crosshole survey conducted in Borings 3-5-1, 3-5-2 , and 3-5-3 by Dames & Moore in 1977 are also included in Appendix A together with the boring logs for these holes. Review of these logs indicate that the materials at this location are classified as poorly cemented sandstones with SPT blow counts somewhat greater than those measured in Boring 2-2 drilled right at the LR Hall location. A profile of shear and compressional wave velocities versus depth developed from the crosshole survey is included in Appendix A. This plot indicates that at the depths corresponding to the elevation of the LR Hall floor, values of shear wave velocities are on the order of 2000 ft/sec. Thus, one would expect somewhat similar velocities below the foundation of the LR Hall. On the basis of this information we have classified the site as a soft rock site from the standpoint of seismic response and local site effects.

Peak Ground Accelerations

Peak horizontal ground accelerations were estimated using a number of attenuation relationships proposed by several investigators (Campbell, 1988; Joyner and Boore, 1993, 1994; Sadigh and others, 1993; Idriss, 1985), and are presented in Table 1. Values obtained from the Joyner and Boore relationship correspond to both a soft rock site with an average shear wave velocity (V_s) within the upper 100 feet of 750 m/sec (2500 ft/sec), and a hard to stiff soil site with an average shear wave velocity ranging between 360 m/sec (1200 ft/sec) and 750 m/sec. The other relationships apply to rock and rock-like sites without any consideration of the shear wave velocity characteristics of the site. Mean and mean plus one standard deviation values of acceleration were computed for both a M7 and M7.7-7.9 event on the nearby San Andreas fault zone (distance = 4.75 km). For the rock and rock-like site conditions the mean values of acceleration range between 0.43 g to 0.56 g. Based on the ratios of peak horizontal to peak vertical accelerations recorded on rock sites during both the 1989 Loma Prieta and the 1994 Northridge earthquakes, values of peak vertical accelerations can be taken as two-thirds of the peak horizontal values.

Values of peak ground accelerations of themselves are not adequate to establish appropriate site-specific response spectra for use in seismic analysis. The shape of the response spectrum depends no only on the peak ground acceleration, but also on the individual spectral values at the various periods of interest. Scaling of the entire spectrum by the peak ground acceleration value which has often been done in the past due to a scarcity of strong ground motion data is not entirely correct, especially at intermediate and long periods. In addition, the magnitude of the earthquake and the site-specific local geologic conditions affect the shape of the spectrum. All of these factors need to be taken into consideration when developing an appropriate site-specific response spectrum for use in seismic design.



ESA Consultants Inc.
Mountain View, California

SLAC BABAR DETECTOR
DESIGN SPECTRAL ACCELERATIONS
MAGNITUDE 7.7-7.9 EVENT - DISTANCE = 4.75KM

Checked By	Date	Project No.	Figure No.
Approved By	Date	117.9501	7

UCRL-53582, Rev. 1
Distribution Category UC-11

Natural Phenomena Hazards Modeling Project: Seismic Hazard Models for Department of Energy Sites

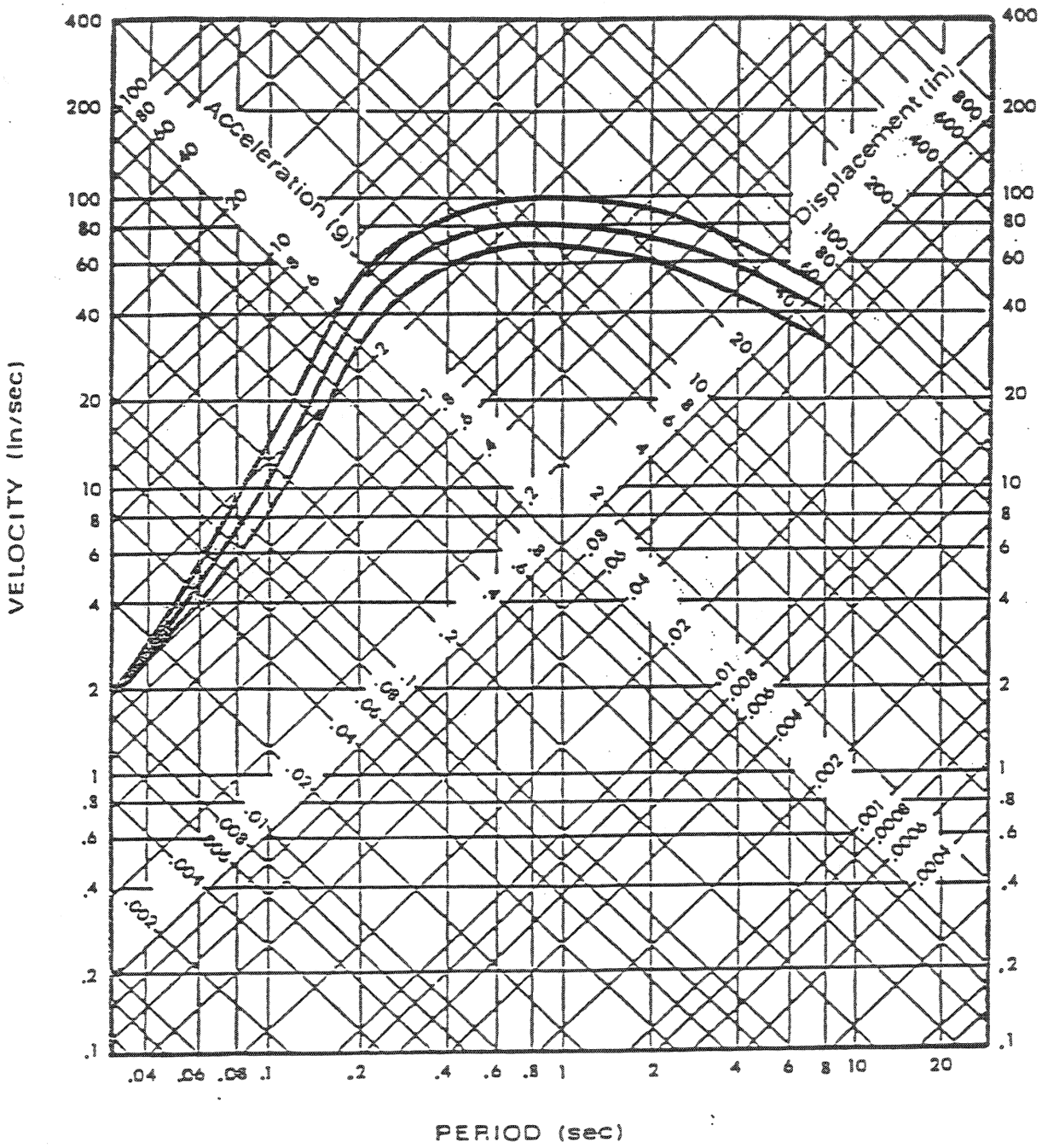
D. W. Coats

R. C. Murray

Manuscript date: November 1984

LAWRENCE LIVERMORE NATIONAL LABORATORY
University of California • Livermore, California • 94550

Available from: National Technical Information Service • U.S. Department of Commerce
5285 Port Royal Road • Springfield, VA 22161 • $11.50 per copy • (Microfiche $4.50)



Design Response Spectrum Scaled to 1.0 g
(2%, 5%, and 10% of Critical Damping)
Stanford Linear Accelerator Center, California

TABLE 1

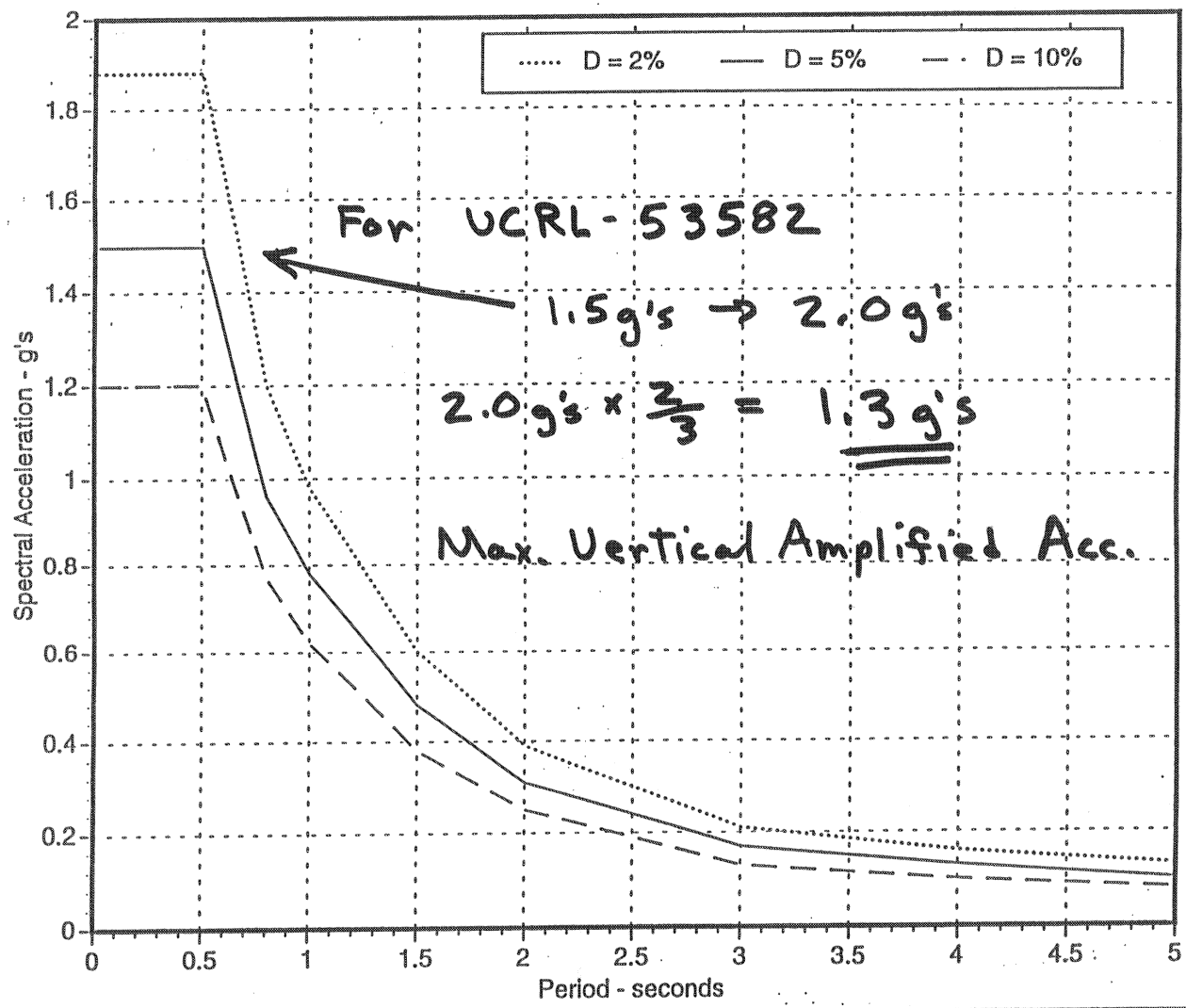
Summary of Peak Horizontal Ground Acceleration (g) - Rock and Hard to Stiff Soil Sites

Earthquake on Nearby San Andreas Fault Zone

Distance = 4.75 km

Max. Credible Eqk.		Rock and Rock-like Site Conditions						Joyner & Boore (1993)			
		Campbell (1988)		Idriss (1987)		Sadigh et al (1993)		Soft rock; Vs = 750 m/sec		Hard to stiff soils: Vs>360 & <750 m/sec	
Ms	Mw	mean	mean + 1σ	mean	mean + 1σ	mean	mean + 1σ	mean	mean + 1σ	mean	mean + 1σ
7.2	7.0	0.53	0.89	0.49	0.84	0.53	0.94	0.40	0.65	0.46	0.71
8.3	7.9	0.60	0.96	0.60	0.95	0.60	0.89	0.57	0.82	0.66	0.91

1. Magnitudes listed are moment magnitude (Mw) or surface wave magnitude (Ms) unless otherwise indicated.
2. All attenuation relationships presented are based on a statistical analysis of historic earthquake data.
3. Joyner & Boore (1993) relationship for the larger of two horizontal components. Acceleration values correspond to a site class B site which is a soft rock/stiff soil site where the average shear wave velocity (Vs) within the upper 100 feet is in the range of Vs>360 m/sec & <750 m/sec, and a rock site with an average Vs = 750 m/sec.
This relationsahip only applies for magnitudes . 5 and < 7.7 and for distances < 100 km..
A maximum value of M = 7.7 used in JB (93) relationship.
4. Campbell (1987) & Sadigh et al. (1989) relationships consider fault type.
5. Idriss (1987), Campbell (1988) and Sadigh et al (1993) relationships are for rock-like sites.



ESA Consultants Inc.
Mountain View, California

SLAC BABAR DETECTOR
DESIGN SPECTRAL ACCELERATIONS
MAGNITUDE 7.7-7.9 EVENT - DISTANCE = 4.75KM

Checked By ____ Date ____	Project No.	Figure No.
Approved By ____ Date ____	117.9501	7

BEARING PROPERTIES (Sheet 1 of 1) Units: kip, in.

		C16-35.1-5.50	C35.5-15.4-7.00
DIMENSIONAL PROPERTIES			
Shape Factor	:	3.75	42.50
Gross Bonded Area	:	176.71	907.92
Plug Area	:	23.76	38.48
Rubber Shear Area	:	177.30	951.31
Total Rubber Thickness	:	30.000	8.800
STRENGTH AND STIFFNESS PROPERTIES			
Yielded Stiffness	:	0.71	14.27
Elastic Stiffness	:	12.02	137.78
Characteristic Strength	:	25.71	41.65
Yield Strength	:	27.32	46.46
Yield Displacement	:	2.273	0.337
Inner Layer Stiffness	:	1272	1030091
Vertical Stiffness	:	46	25752
VERTICAL LOAD CAPACITIES (Strain Limits)			
Zero Rotation on Bearing			
At 0 Shear Disp.	:	126	7689
At EQ Disp.	:	151	14409
STABILITY LIMIT STATES			
Rollover Displacement	:	Bolted	Bolted
Buckling Load At 0 Disp.	:	40	24609
Buckling Load At EQ Disp	:	17	18065

WARNING Design has inadequate Factor of Safety for D+L load.

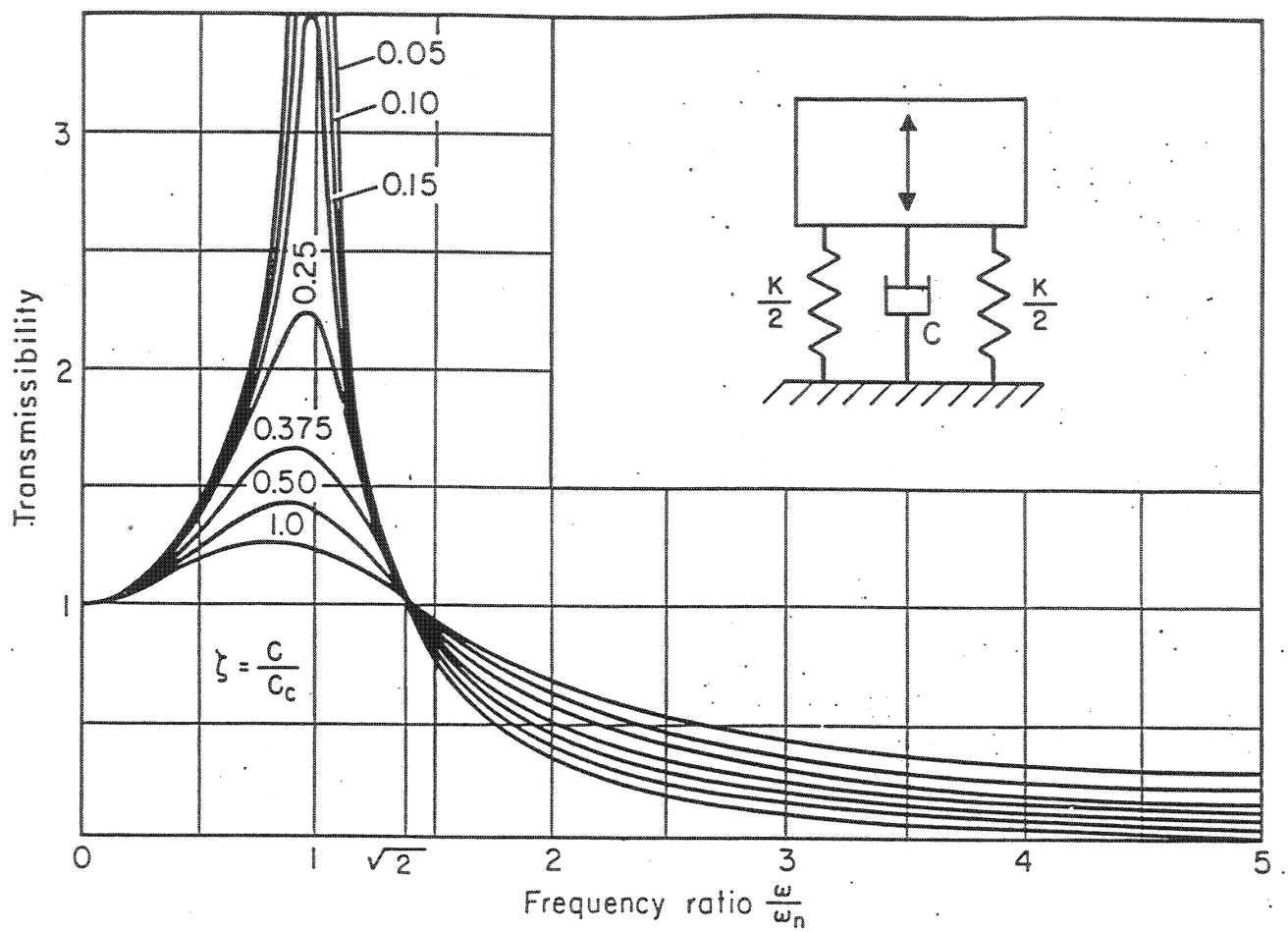
Vertical Spring Rate =

$4 \times 25{,}752{,}000$ lbs/inch

Deflection =

$$\frac{1{,}200{,}000}{4 \times 25{,}752{,}000} = .012''$$

$$\text{Natural freq} = \frac{1}{2\pi}\sqrt{\frac{386}{.012}} = 29 \text{ hertz}$$



Driving freq $\omega = 29$ hertz

Structure Natural freq $\omega_n = 19$ hertz

Ratio $\frac{29}{19} = 1.5 > \sqrt{2}$

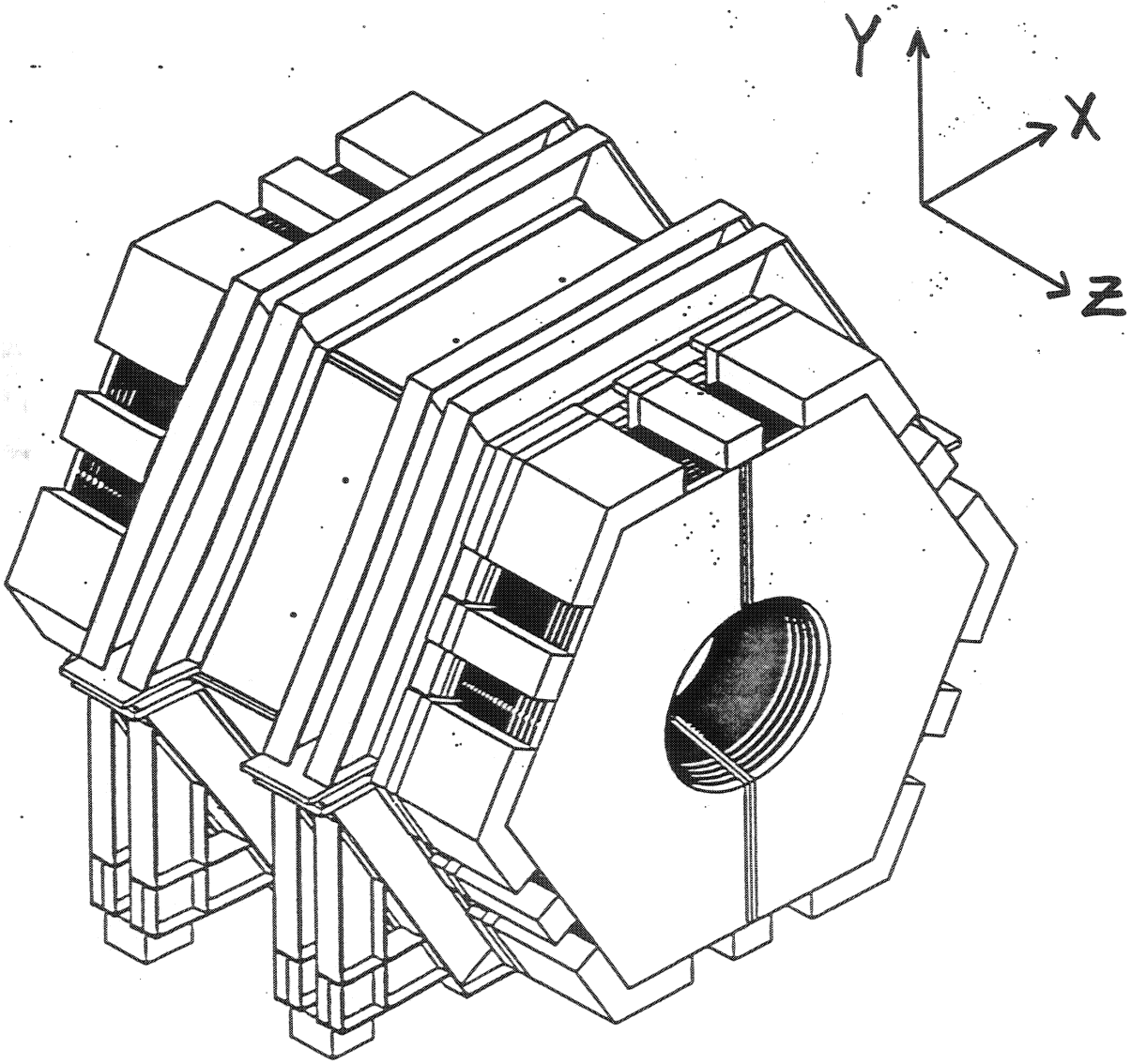
No Resonance Vertically

Forces caused by Maximum Credible Earthquake

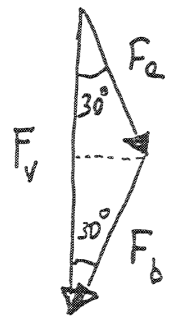
Case 1 Horizontal Force in the X direction, 0.3 g's
plus Gravity in the Y direction, -1.0 g's

Case 2 Horizontal Force in the X direction, 0.3 g's
plus Gravity in the Y direction, -1.0 g's

Case 3 Vertical Force in the Y direction, -1.3 g's
plus Gravity in the Y direction, -1.0 g's



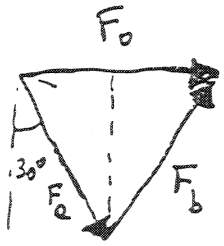
FORCES COMPOSITION



$$\frac{F_v}{2} = F_a \cos 30°$$

$$F_a = F_b = \frac{F_v}{2 \cos 30°} = 0.577\, F_v$$

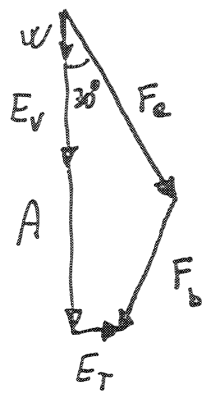
F_a = 4 FEET POUNDS



$$\frac{F_o}{2} = F_a \cos 60°$$

$$F_a = F_b = \frac{F_o}{2 \cos 60°} = F_o$$

MAX RADIAL FORCES



	F_v (Ton)	F_φ (Ton)
W = 18	7.8	
E_V = 1.68	12.5	
A =	20	
	40.3	
E_T =		0.28 1.56
		1.56

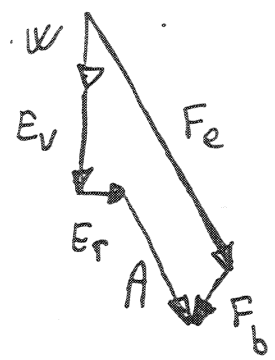
$$F_a = 0.577 \cdot F_V + F_o = 0.577 \cdot 40.3 + 1.56 = 24.8$$

$$F_b = 0.577 \cdot F_V - F_o = 0.577 \cdot 40.3 - 1.56 = 21.7 \text{ T}$$

if $\vec{E_T} = -\vec{E_T} \rightarrow F_a = 21.7$ Ton $\quad F_b = 24.8$ Ton

- both F_a and F_b is supported by 4 Tie rod

MAX RADIAL FORCES



	F_v (Ton)	F_r (Ton)
$W = 1g$	7.8	
$E_v = 1.6g$	12.5	
	20.3	
$A =$		20
$E_r =$		0.2g 1.56
		21.6

$$F_a = 0.577 * 20.3 + F_o = 0.577 * 20.3 + 21.56 = 33T$$

$$F_b = 0.577 * 20.3 - 1.56 = 10.1\ T$$

MAX- AXIAL FORCES

$$F_a = 25 + 0.2g = 25 + 1.56 = 26.6$$

RADIAL TIE RODS

$$A_{TOT\ CORE} = \frac{F_{max}}{\sigma_{max}} = \frac{33300}{50} = 660\ mm^2$$

$\sigma_{TENS} = 0.5$ INSTEAD OF 0.375 REQUIRED BY INPN (ANOMAL)

$$A_{TIE\ ROD\ CORE} = \frac{660}{4} = 165\ mm^2$$

$$\phi_{TIE\ ROD\ CORE} = 14.50\ mm$$

$$\phi_{TIE\ ROD} = M16$$

$$A_{TIE\ ROD} = 200\ mm^2$$

$$A_{TOT\ TIE\ ROD} = 800\ mm^2$$

$$\sigma_{NORM} = \frac{20000}{800} = 25\ \frac{Kg}{mm^2} = 0.25 \cdot \sigma_{TENSILE}$$

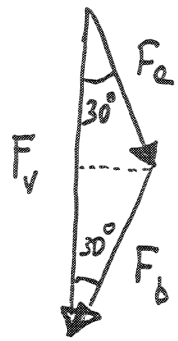
$$\varepsilon = \frac{\sigma}{E} = \frac{25}{11500} = 2174\ \mu\varepsilon$$

$$\Delta L = L \cdot \varepsilon = 668 \times 0.002174 = 1.45\ mm \quad O.K.$$

$$\sigma_{NORM\ CORE} = \frac{20000}{660} = 30\ \frac{Kg}{mm^2} = 0.30\ \sigma_{TENS.}$$

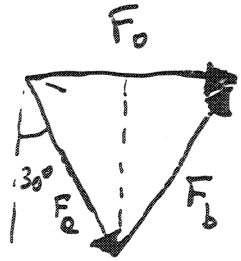
INSTEAD OF 0.25 REQUIRED BY INPN (NORMAL)

FORCES COMPOSITION



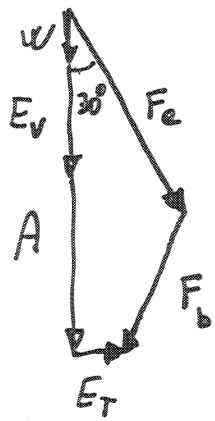
$$\frac{F_v}{2} = F_a \cos 30^\circ$$

$$F_a = F_b = \frac{F_v}{2 \cos 30^\circ} = 0.577\, F_v$$



$$\frac{F_o}{2} = F_a \cos 60^\circ$$

$$F_a = F_b = \frac{F_o}{2 \cos 60^\circ} = F_o$$



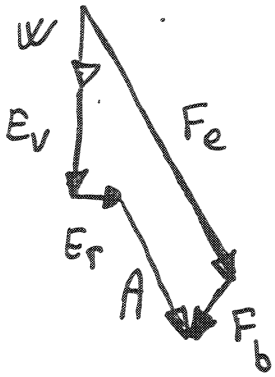
F_v (Ton)	F_T (Ton)
$W = 18$ 7.8	
$E_v = 1.68$ 12.5	
$A =$ 20	
40.3	
$E_T =$	0.28 1.56
	1.56

$$F_a = 0.577 * F_v + F_o = 0.577 * 40.3 + 1.56 = 24.8\ T$$

$$F_b = 0.577 * F_v - F_o = 0.577 * 40.3 - 1.56 = 21.7\ T$$

if $\vec{E_T} = -\vec{E_T} \rightarrow F_a = 21.7$ Ton $F_b = 24.8$ Ton

- both F_a and F_b is supported by 4 Tie rods



F_v (Ton)		F_p (Ton)
$W = 1g$	7.8	
$E_v = 1.6g$	12.5	
	20.3	
$A =$		20
$E_r =$		0.2g 1.56
		21.6

$$F_a = 0.577 * 20.3 + F_o = 0.577 * 20.3 + 21.56 = 33T$$

$$F_b = 0.577 * 20.3 - 1.56 = 10.1\ T$$

MAX- AXIAL FORCES

$$F_a = 25 + 0.2g = 25 + 1.56 = 26.61$$

$$A_{TOT\ CORE} = \frac{F_{MAX}}{\sigma_{MAX}} = \frac{33300}{50} = 660\ mm^2$$

$\sigma_{TENS} = 0.5$
INSTEAD OF 0.375
REQUIRED BY INPN
(ANOMAL)

$$A_{TIE\ ROD\ CORE} = \frac{660}{4} = 165\ mm^2$$

$$\phi_{TIE\ ROD\ CORE} = 14.50\ mm$$

$$\phi_{TIE\ ROD} = M\,16$$

$$A_{TIE\ ROD} = 200\ mm^2$$

$$A_{TOT\ TIE\ ROD} = 800\ mm^2$$

$$\sigma_{NORM} = \frac{20'000}{800} = 25\ \frac{Kg}{mm^2} = 0.25 \cdot \sigma_{TENSILE}$$

$$\varepsilon = \frac{\sigma}{E} = \frac{25}{11500} = 2174\ \mu\varepsilon$$

$$\Delta L = L \cdot \varepsilon = 668 \times 0.002174 = 1.45\ mm \quad O.K.$$

$$\sigma_{NORM\ CORE} = \frac{20'000}{660} = 30\ \frac{Kg}{mm^2} = 0.30\ \sigma_{TENS.}$$

INSTEAD OF 0.25
REQUIRED BY INPN
(NORMAL)

CALCULATION

Lawrence Livermore National Laboratory

APPLIED RESEARCH ENGINEERING DIVISION

DAVID HITLING

Post Office Box 808, L-287
Livermore, California 94551-9900 U.S.A.

Telephone No. (510) 423-7533
FTS No. 8 (510) 423-7533

Fax No. (510) 422-6747
FTS No. 8 (510) 422-6747

Telecopy Transmittal Sheet

R. Penco + P. Valente 011-39-10-655-6985

To: P. Fabbricatore 011-39-10-31-3358

Date: June 2, 96

Address:

Telecopier Phone #:

Telecopier Verification #:

Total Pages Including Cover: 28

From: Tom O'Connor

Telephone No.: (510) 423-8781

Message:

Please see the attached seismic analysis of the cold mass tie rods. Pages 1-23 are the first report where the vertical load is shared by 4 tie rods at each end. The stress in the tie rods is 29.8 kg/mm² (see page 5) this stress is quite large. The second report (Pages 24-27, dated May 23, 96) assumes the vertical load is shared by 8 rods at each end and that all the tie rods are pre loaded to ½ the Allowable stress. In this case there does not appear to be a problem with the seismic loads on the tie rods. Please review both reports.

FAX TRANSMITTAL 53

WON NUOVO FAX DEC 25/96 [illegible]

(1)

ROLAND L. SHARPE, S.E. Consulting Structural Engineer
Cupertino, CA 408-255-4510, 415-941-7131: Fax408-725-8585

20 May 1996

Memo to: Tom O'Connor
SLAC BaBar Detector Project

From: Roland L. Sharpe

Subject: Preliminary Analysis of "Cold Mass" Support Bolts in Cryostat

Tom:

We have completed our preliminary seismic analysis of the bolts supporting the "cold mass" within the Cryostat. Following is a summary of the analyses and the resulting forces/stresses in the support bolts.

1. Assumptions;

   a. The "cold mass" and cryostat vacuum cylinder are essentially rigid, i.e., we did not make a detailed model of either one.

   è una smodo

   b. Longitudinally the cold mass is supported by three bolts at each end. The bolts are effective only in tension. Transversely the cold mass is supported by eight bolts at each end. The four bolts in tension at any time are the only ones considered effective.

   c. The bolt spring constants were calculated using the properties of the titanium bolts at 4 degrees Kelvin.

   Sono di INCONEL

   d. The connections supporting the cryostat to the detector barrel are assumed as rigid; we do not have details of these connections.

   e. The cryostat vacuum cylinder is the support for the cold mass.

   f. The input motions are about 10 percent larger than those used by DIS in their lateral frce calculations for the Detector.

   Fy = 35.1 33 = 3/8 bolt

   g. The material properties for the bolts are:
      Axial bolts: E = 11,500 kg/mm2 ; Dia. = ~~17.96~~ mm; Fy = 83 kg/mm2; Fa = ~~32.9~~ kg/mm2 (normal operation, 0.4Fy): Same values for radial bolts except, Dia = 15.96 mm and Fa = 25 kg/mm2 (0.3 Fy). Fy = 41.6 Fc =

2. The frequency of the cold mass system (cold mass supported by bolts) in the longitudinal (axial) direction was calculated and compared to that of the Detector barrel in this direction. A generic floor amplification curve was used to determine the amplification, if any, of the previously calculated accelerations at the horizontal centerline of the Detector barrel.

   The acceleration thus determined was used as a static seismic force to determine the tensile force in the axial bolts.

(2)

ROLAND L. SHARPE, S.E. Consulting Structural Engineer
Cupertino, CA 408-255-4510, 415-941-7131: Fax408-725-8585

A similar procedure was followed for the radial bolts. Note: the transverse and vertical input motions are different because of the isolator system characteristics.

3. Results:

a. Longitudinal Response:
T= 0.042 sec
Seismic tension/bolt = 1430 kg (Detector door open)
Seismic tension/bolt = 1000 kg (Detector door closed)

b. Transverse Response:
T= 0.069 sec
Seismic tension/bolt = 1205 kg (Detector door open - governing case)

c. Vertical Response:
T = 0.0396 sec
Seismic tension/bolt = 5960 kg (Detector door open - governing case)*
Gravity load + seismic = 7169 kg

* The vertical response is magnified by 3.4 because the ratio of equpment vertical period to Detector vertical period equals 0.61; from Figure 12-2 (see attachment to calculations), MF = 3.4. This value is conservative, but a more exact (detailed) analysis would require modifying the 3D model of the detector so as to include the cryostat. This would take six to eight days effort. A simpler solution might be to increase the bolt diameter.

Roland Sharpe

Encl: 17 pages calculations + 3 pages of attachments

COLLABORATIVE
ENGINEERING
SERVICE, INC.

(3)

BY _____ DATE _____ PROJECT _____ PAGE _____ OF _____

CHKD. BY _____ DATE _____ SUBJECT _____ JOB NO. _____

SLAC

SOLENOID

May 19, 1996

COLLABORATIVE ENGINEERING SERVICE, INC.

(4)

BY mcc DATE 5/17/96 PROJECT SLAC PAGE 1 OF

CHKD. BY DATE SUBJECT SOLENOID Seismic Analysis JOB NO.

OBJECTIVE: Perform simplified analysis to determine the seismic forces of supporting bolts for the solenoid cold mass.

General Note:

1. Longitudinally, the solenoid cylinder is supported by 3 bolts at each end. Hand calculations are performed to determine the seismic forces.

2. Transversely, the cylinder is supported by 8 bolts at each end, and only the 4 bolts in tension are considered being effective. The cylinder is modeled as a rigid ring supported by bolts. The total length of bolt is used for modeling.

3. Material

Axial Rod E: ~~11500~~ NO kg/mm²

ϕ: 17.96 mm

Fy: ~~83~~ kg/mm²

83 is to YIELD for the SOLENOID PER INCONEL 153

Fa: 32.9 kg/mm² Normal operation (0.4 Fy) O.K. 0.22 Fracture

Obtained $\frac{3}{8}\sigma_{fracture} = 0.375\,\sigma_{fracture} = 0.375 \cdot 143 = 53.6$

Normal $0.25\,\sigma_{fracture} = 0.25 \cdot 143 = 35.8$

Radial Rod E: ~~11500~~ NO kg/mm²

ϕ: 15.96 mm

Fy = ~~83~~ kg/mm²

Fa = 25 kg/mm² Normal operation (0.3 Fy) OK 0.17 Fracture

(5)

COLLABORATIVE ENGINEERING SERVICE, INC.

BY MCC DATE 5/19/96 PROJECT SLAC PAGE 2 OF

CHKD. BY DATE SUBJECT SOLENOID Seismic Analysis JOB NO.

Conclusions:

1. Under Longitudinal Response

T = 0.042 S. NO.055

Tension per bolt = 1930 kg under No door Condition

stress per bolt = 5.7 kg/mm² << 1.33 x 32.9 = 43.8 kg/mm² OK

Tension per bolt = 1000 kg w/ door, Not govern.

stress per bolt = 3.95 kg/mm²

2. Under Transverse Response

T = 0.069 S.

Tension per bolt = 1205 kg, No door

stress per bolt = 6.03 kg/mm² < 1.33 x 25 = 33.25 kg/mm² OK

3. Under Vertical Response

T = 0.0396 S.

Tension per bolt / due to Vert. EQ = 5960 kg No door

Stress per bolt / due to Vert. EQ = 29.8 kg/mm²

Tension due to DL = 1209 kg

Stress per bolt due to DL = 6.1 kg/mm²

Combined Vert EQ + DL.

Tension per bolt = 7169 kg

stress per bolt = 35.9 kg/mm² > 33.25 kg/mm² N.G.

mm² kg. mm

(6)

COLLABORATIVE ENGINEERING SERVICE, INC.

BY MCC DATE 5/19/96 PROJECT SLAC PAGE 3 OF

CHKD. BY DATE SUBJECT SOLENOID JOB NO.

Seismic Analysis

Longitudinal Response

Axial tie rod : 486 mm O.K.

Diameter D : 17.96 mm O.K.

Total 3 @ each end

E : 11500 kg/mm² 21793 kg·m/s²

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (17.96)^2}{4} = 253 \text{ mm}^2 \quad \text{O.K.}$$

Equivalent Stiffness per rod 58.7 N/m

$$K = \frac{AE}{l} = \frac{253 \times 11500}{486} = 5987 \text{ kg/mm} = 5.87 \times 10^7 \text{ N/M}$$

21793

Cold mass wt. = 7.8 Ton = 7800 kg

$$T_a = 2\pi\sqrt{\frac{m}{K}} = 2\pi\sqrt{\frac{7800}{3 \times 5.87 \times 10^7}} = 0.042 \text{ sec.}$$

$$f = \frac{1}{T} = 24 \text{ cps.}$$

In the longitudinal direction, the barrel is on the isolator ; the period & base shear

w/ door (p. 4/8/96 presentation to SLAC)

T = 1.59 s.

V = 0.35 W

w/o Door

T = 1.04 s. (File: BAR3NDXZ)

V = 0.5 W (p. 4/8/96 to SLAC)

(7)

COLLABORATIVE ENGINEERING SERVICE, INC.

BY MCC DATE 5/19/96 PROJECT SLAC PAGE 4 OF

CHKD. BY DATE SUBJECT SOLENOID Seismic Analysis JOB NO.

For design purpose, a 10% increase will be used for adjusting the R.S. curve

W/ Door case

$\frac{T_a}{T} = \frac{0.042}{1.59} = 0.026$ $\frac{0.04}{1.59} = 0.03$

The magnification factor

$MF = 1.0$

$V = 1.1 \times 0.35 \times W_p = 0.385 W_p$

$= 0.385 \times 7800 = 3003$ kg

Tension @ Tie Rod (Only 3 working as Tension)

$F = \frac{V}{3} = 1000$ kg/each. $f_a = F/A = 3.95$ kg/mm²

W/o Door Case

$\frac{T_a}{T} = \frac{0.042}{1.04} = 0.04$

M.F. = 1.0 to 0.2

$V = 1.1 \times 0.5 W_p = 0.55 W_p$

$= 0.55 \times 7800 = 4290$ kg

Tension @ Tie Rod

$F = \frac{V}{3} = \frac{4290}{3} = 1430$ kg/each. > 1000 kg

Governing

COLLABORATIVE ENGINEERING SERVICE, INC.

(8)

BY MLC DATE 5/19/96 PROJECT SLAC PAGE 5 OF

CHKD. BY DATE SUBJECT SOLENOID Seismic Analysis JOB NO.

Stress @ Rod

$f_a = \frac{F}{A} = \frac{1430}{253} = 5.7\ kg/mm^2$ Solo Terminated

Allowable stress = 1.33 × Work condition

$= 1.33 \times 32.9 = 43.8\ kg/mm^2$

$\gg 5.7\ kg/mm^2$ OK

(7)

COLLABORATIVE ENGINEERING SERVICE, INC.

(9)

BY mcc DATE 5/19/96 PROJECT SLAC PAGE 6 OF

CHKD. BY DATE SUBJECT SOLENOID Seismic Analysis JOB NO.

Transverse & Vertical Response

Radial Tie Rod $D = 15.96$ mm

$l = 668$ mm / $\cos 6° = 671.7$ mm

(only 268 mm)

$E = 11500$ kg/mm²

8 @ Each End, Total 16

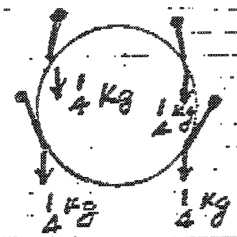
$F_z = 46.3$ ton

$k = 3.17 \times 10^4$ kg/mm $= 3.1 \times 10^8$ N/m

$A = \frac{\pi}{4} \times (15.96)^2 = 200$ mm²

$T_a = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{28\,m}{3.1\times10^8}} = 0.031$

a. Under Vertical load



Considering 4 Tension bolts only. The deflection w/ 1 kg at one end of cylinder ($\frac{1}{4}$ kg at each bolt locations).

$\Delta = 0.1 \times 10^{-3}$ mm (File: SOLENDV)

$K = \frac{AE}{L} = \frac{200 \times 11500}{668} = 6520$ kg/mm $= 6520$ N/m

$K = \frac{P}{\Delta} = 1.0 \times 10^4$ kg/mm $= 1 \times 10^7$ kg/m $= 9.8 \times 10^7$ N/m per end

$T_a = 2\pi\sqrt{\frac{m}{K}} = 2\pi\sqrt{\frac{7.8 \times 1000}{(9.8 \times 10^7 \times 2)}} = 0.0396$ s

$f_a = 25$ cps

The Vertical period

$T = 0.065$ s. $f = 15.4$ cps 2D-model

or $= 0.074$ s. $f = 13.5$ cps 3-D model

(4/8/96 SLAC meeting)

$\frac{T_a}{T} = \frac{0.0396}{0.065} = 0.61$

or $\frac{T_a}{T} = \frac{0.0396}{0.074} = 0.54$

(10)

COLLABORATIVE ENGINEERING SERVICE, INC.

BY MCC DATE 5/19/96 PROJECT SLAC PAGE 7 OF

CHKD. BY DATE SUBJECT SOLENOID Seismic Analysis JOB NO.

From Fig. 12-2,

$$M.F. = 1.0 + \frac{(0.6)-0.5)}{0.3} \times (7.5-1) = 3.4$$

(?) Floor accel. = 1.45g from Vert. R.S @ f = 13.5 cps

Equip Acc. = 3.4 x 1.45 = 4.93g

Total Vert. EQ Force

V = 4.93 x 7.8 x 1000 = 38,454 kg.

(?) From Computer File : SOLENDV-F3F

under 1 kg at each end, the max. bolt tension

f = 0.31 kg

Seismic force per bolt

$$F_{EQ} = \frac{38,454}{2} \times 0.31 = 5960 \text{ kg.}$$

Stress @ each bolt due to EQ

$$(f_a)_{EQ} = \frac{F}{A} = \frac{5960}{200} = 29.8 \text{ kg/mm}^2$$

DL per bolt

$$F_{DL} = \frac{7.8 \times 1000}{2} \times 0.31 = 1209 \text{ kg}$$

Stress due to DL per bolt

$$(f_a)_{DL} = \frac{1209}{200} = 6.1 \text{ kg/mm}^2 < 25 \text{ kg/mm}^2$$

allowable working stress under Normal operation

Combined DL + EQ

$$f_a = 29.8 + 6.1 = 35.9 \text{ kg/mm}^2$$

$$> 25 \times 1.33 = 33.25 \text{ kg/mm}^2$$

(11)

COLLABORATIVE ENGINEERING SERVICE, INC.

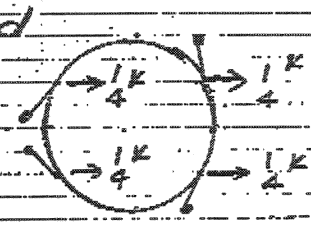
BY Mcc DATE 5/19/96 PROJECT SLAC PAGE 8 OF

CHKD. BY DATE SUBJECT Solenoid Seismic Analysis JOB NO.

b. Under Transverse Load

Consider tension only, 4 bolt effective

The deflection w/ 1 kip at one end of cylinder



$\Delta = 0.3 \times 10^{-3}$ mm

$K' = \frac{P}{\Delta} = \frac{1}{0.3\times10^{-3}} = 3333$ kg/mm

$= 3.27\times10^{7}$ N/M /per end

$T_a = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{7.8\times1000}{3.27\times10^{7}\times2}} = 0.069$ S.

$f_a = 14.6$ cps

$F_z = 26.1$ $\Delta z = 0.087$

$K = 3.66\times10^{5}\ \frac{kg}{m} = 3.0\times10^{8}\ \frac{N}{m}$

$f_a = 2\pi\sqrt{\frac{m}{K}} = \sqrt{\frac{3.66}{7.8\times10^{5}}} = 0.0\ldots$

The transverse response is on isolator

$T = 1.55$ S.

$\frac{T_a}{T} = \frac{0.069}{1.55} = 0.045$

M.F. = 1.0 (from Fig. 2-12)

w/o door Case (governing Case)

$V = 1.1\times0.5\ W_p = 0.55\ W_p = 0.55\times7.8\times1000 = 4290$ kg.

Under 1 kg at one end of cylinder, the max. bolt tension

$f = 0.562$ kg

Seismic force per bolt

$F_{EQ} = \frac{4290}{2}\times0.562 = 1205$ kg

Stress per bolt

$(f_a)_{EQ} = 1205/200 = 6.03$ kg/mm $\ll 25\times1.33 = 33.25$ kgf/mm²

COLLABORATIVE ENGINEERING SERVICE, INC.

(12)

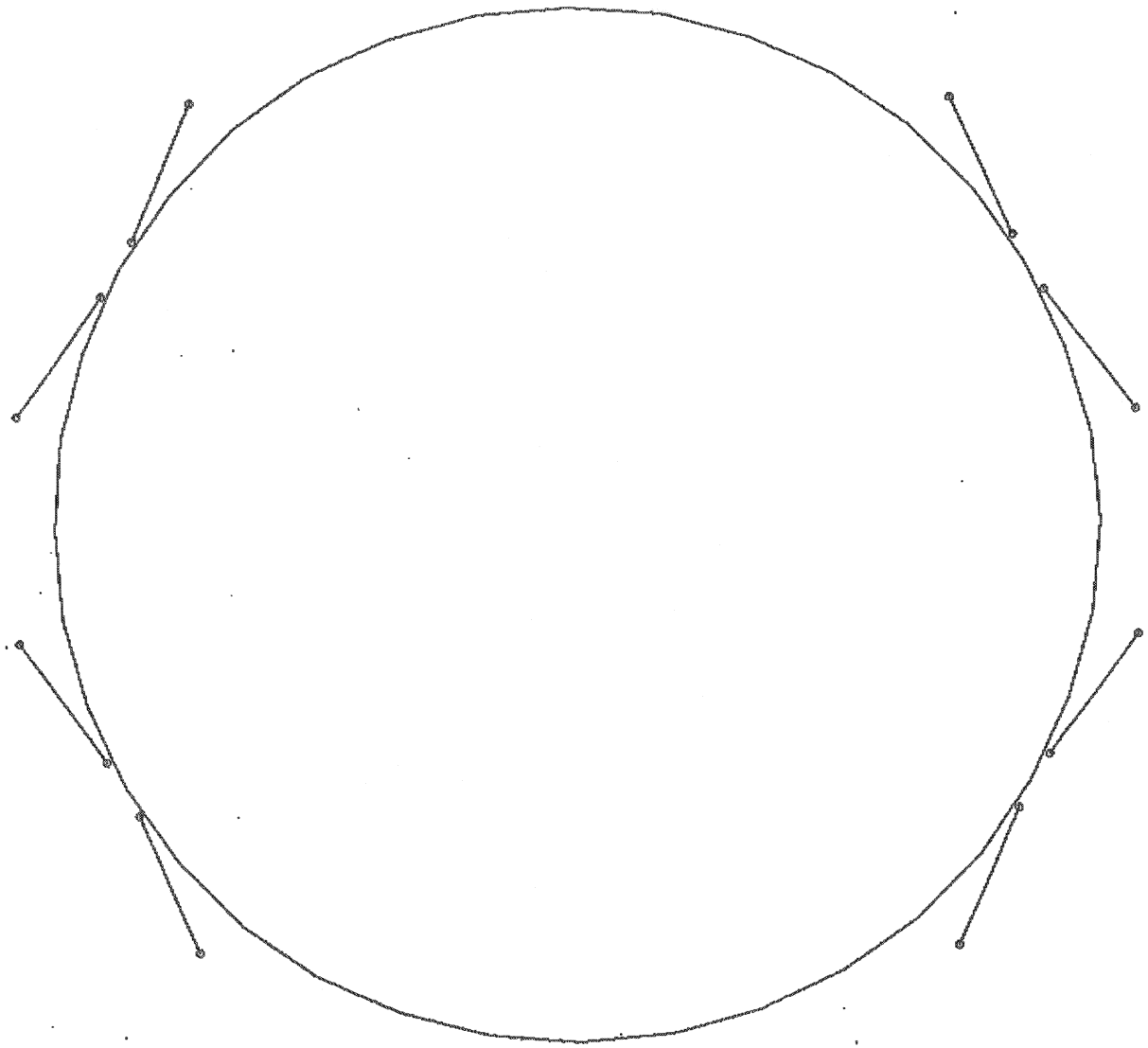
BY MCC DATE 5/19/96 PROJECT SLAC PAGE 9 OF

CHKD. BY DATE SUBJECT SOLENOID Seismic Analysis JOB NO.

Under Combined EQ

1. The bolts for two horizontal directions are de-coupled; therefore no combination of horizontal EQ's is needed.

2. Vertical & Horizontal EQ's need not be combined per criteria.



MODEL

X

Z

SOLEND

UNDEFORMED SHAPE

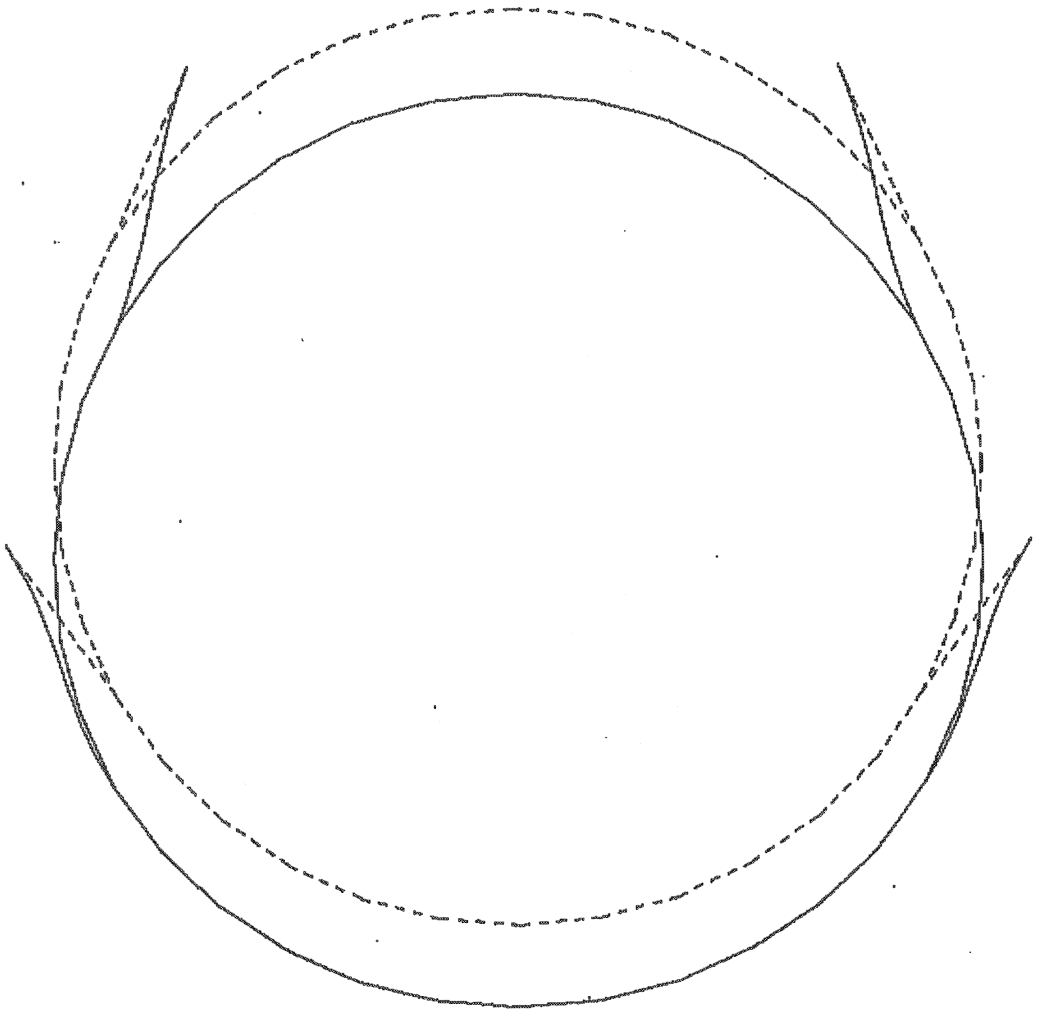
OPTIONS

ELEMENT PINS
WIRE FRAME

SAP90

P.10

13



VERTICAL LOAD

X
Z

SOLENDV

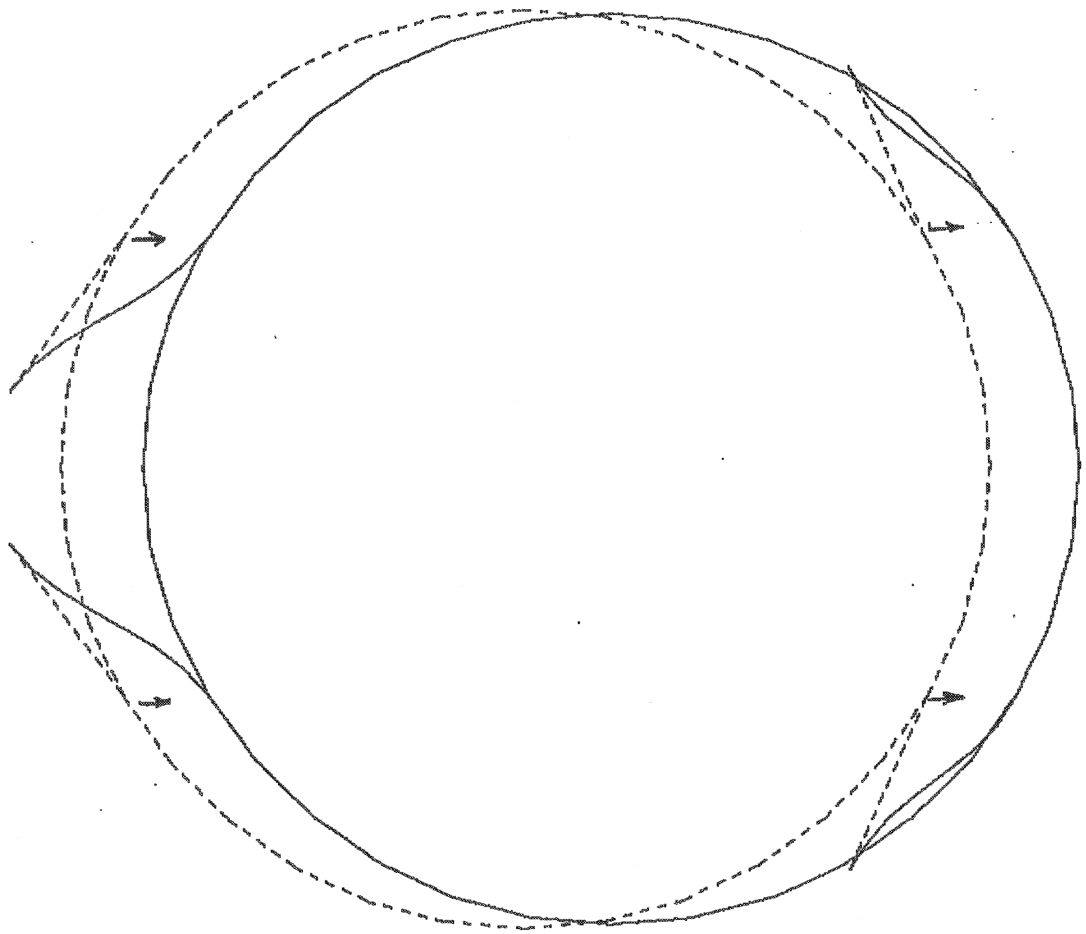
DEFORMED
SHAPE

LOAD 1

MINIMA
X-0.4586E-05
Y 0.0000E+00
Z 0.0000E+00
MAXIMA
X 0.4586E-05
Y 0.0000E+00
Z 0.1002E-03

SAP90

Fig. 11 (14)



TRANSVERSE LOAD

X
Z

SOLENDT

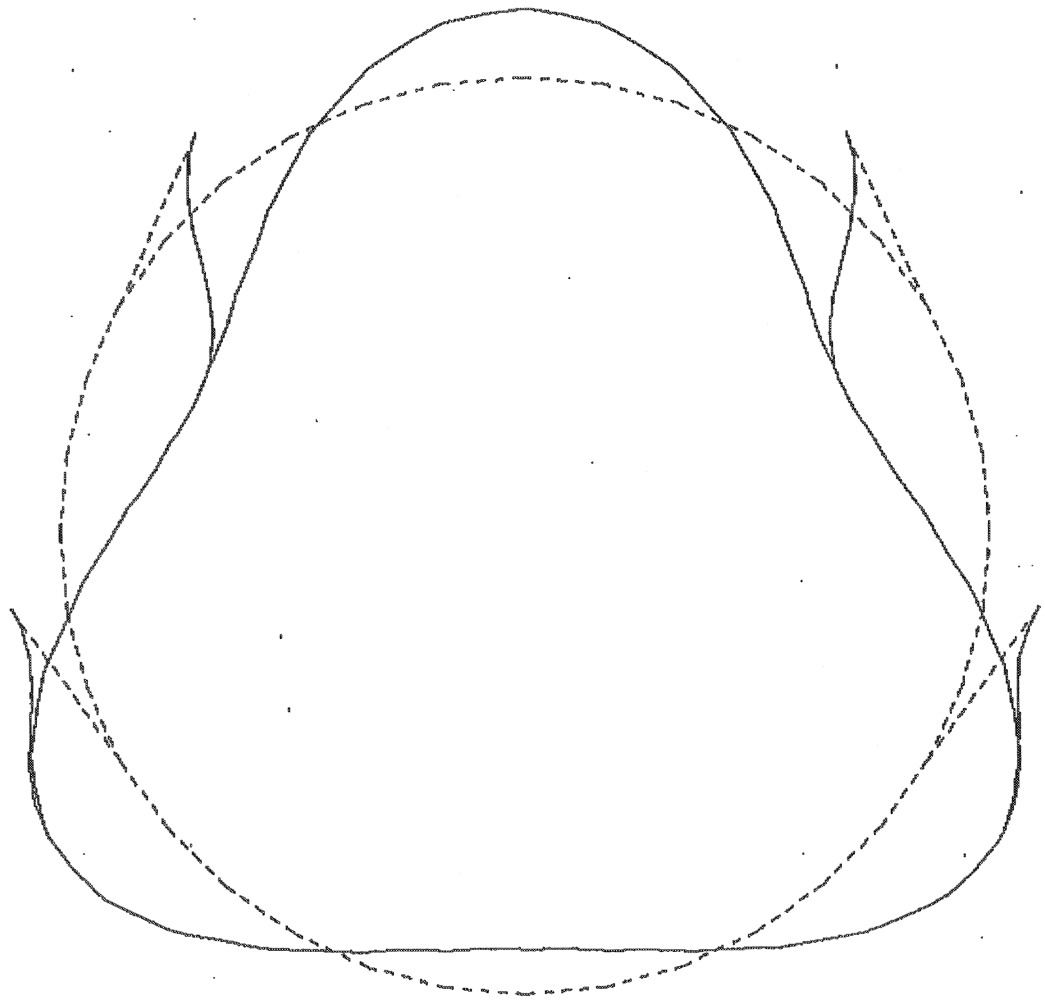
DEFORMED
SHAPE

LOAD 1

MINIMA
X 0.0000E+00
Y 0.0000E+00
Z-0.1322E-04
MAXIMA
X 0.3002E-03
Y 0.0000E+00
Z 0.1322E-04

SAP90

P.12 (15)



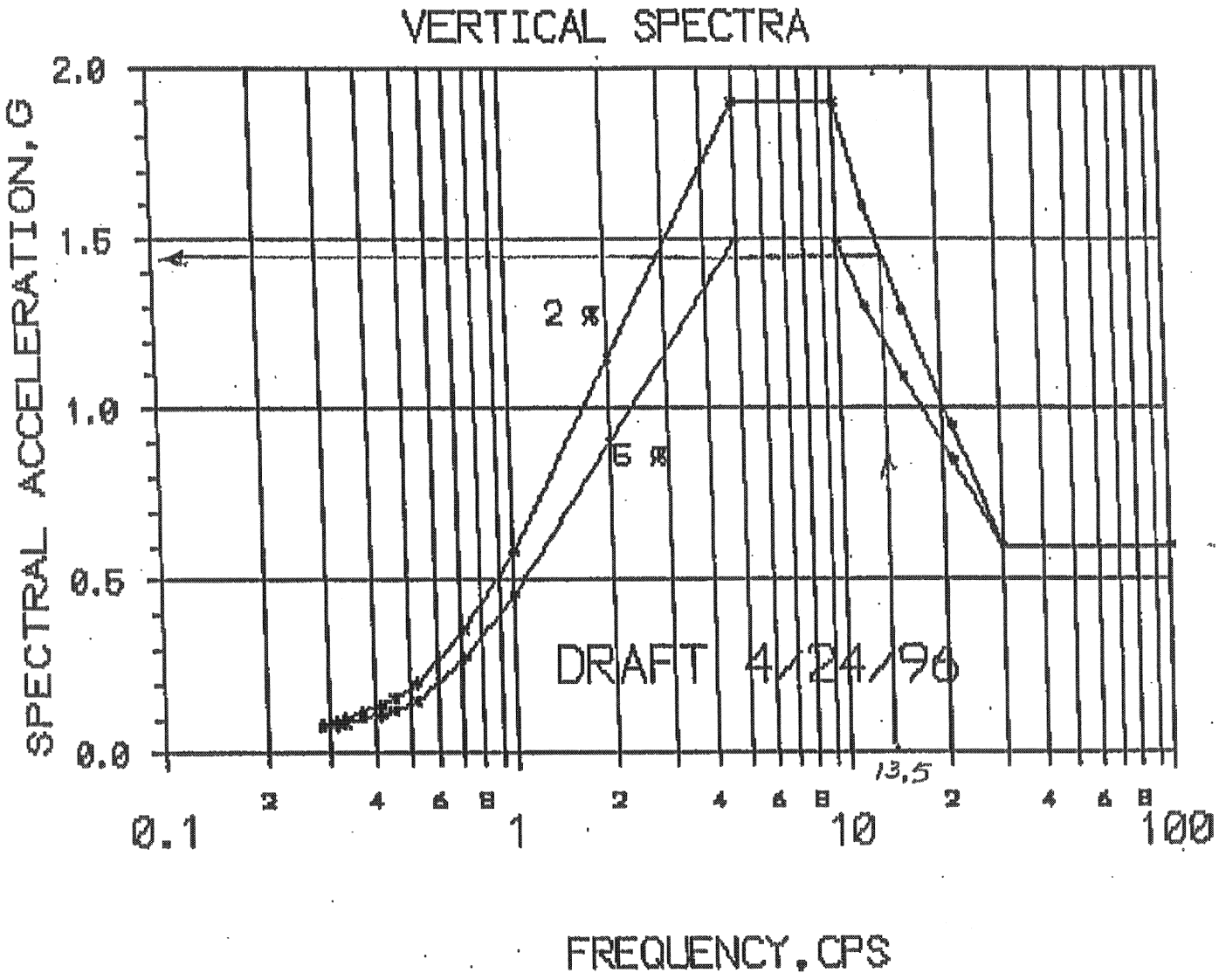
LOCAL DEFORMATION (Qualitative)

X
Z

SOLENOV
DEFORMED SHAPE
LOAD 1

MINIMA
X-0.3827E-03
Y 0.0000E+00
Z-0.2983E-03
MAXIMA
X 0.3827E-03
Y 0.0000E+00
Z 0.3209E-03

SAP90


VERTICAL SPECTRA
SPECTRAL ACCELERATION, G
2.0
1.5
1.0
0.5
0.0
2 %
5 %
DRAFT 4/24/96
13.5
0.1
1
10
100
FREQUENCY, CPS

P.14

17

(18)
P.15

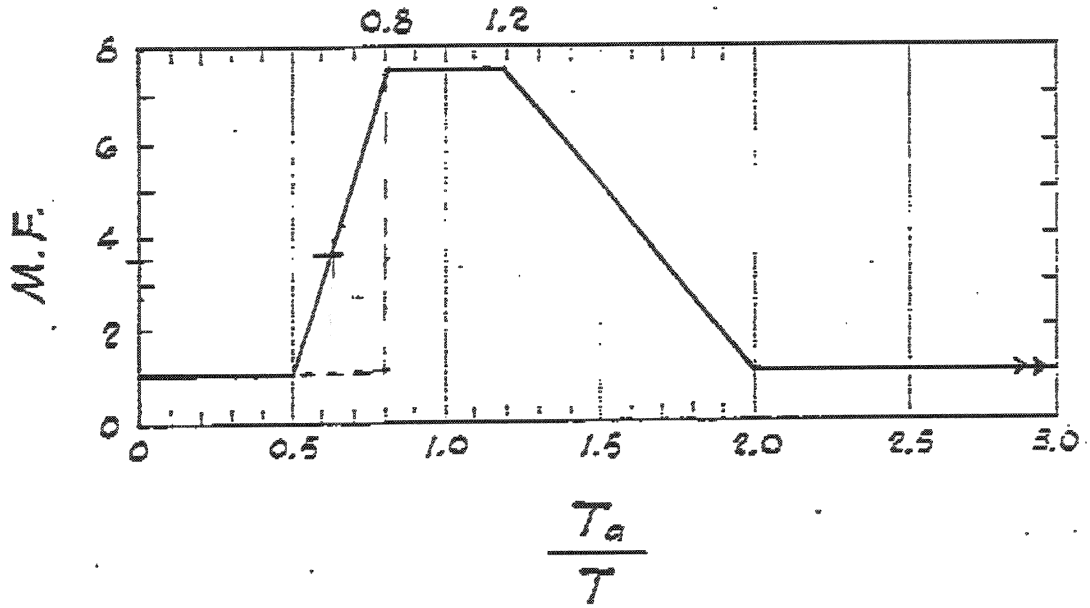


Figure 12-2. Design MF vs period ratio

(19)
P16

ROLAND L. SHARPE, S.E.
Cupertino, CA

Consulting Structural Engineer

FIGURE 2
ANALYTICAL CHECK RESULTS

1. Developed Two Models

2D - For mode shapes and vertical response, see attached.

3D - Global - For horizontal forces - check on stresses at selected points, se attached.

2. Response Spectrum Analysis

Used DIS spectral curve, do not have precise data to modify curve in longer period range
For purposes of this check analysis, DIS curve was deemed adequate. See attached figure.

Base Shear w/o Doors, V = 0.5g [DIS, V = 0.49g]

Base Shear w/ Doors, V = 0.35g [DIS, V = 0.34g]

System Period, T = 1.59 sec Longitudinal, [1.6 sec]
T = 1.55 sec Transverse

3. Vertical Analysis

2D Model, Frequency Analysis, T = 0.065 sec, f = 15.38 Hz

3D Model T = 0.074 sec, f = 13.5 Hz

Effect on Equipment: Possible resonant range = 11 to 18 Hz

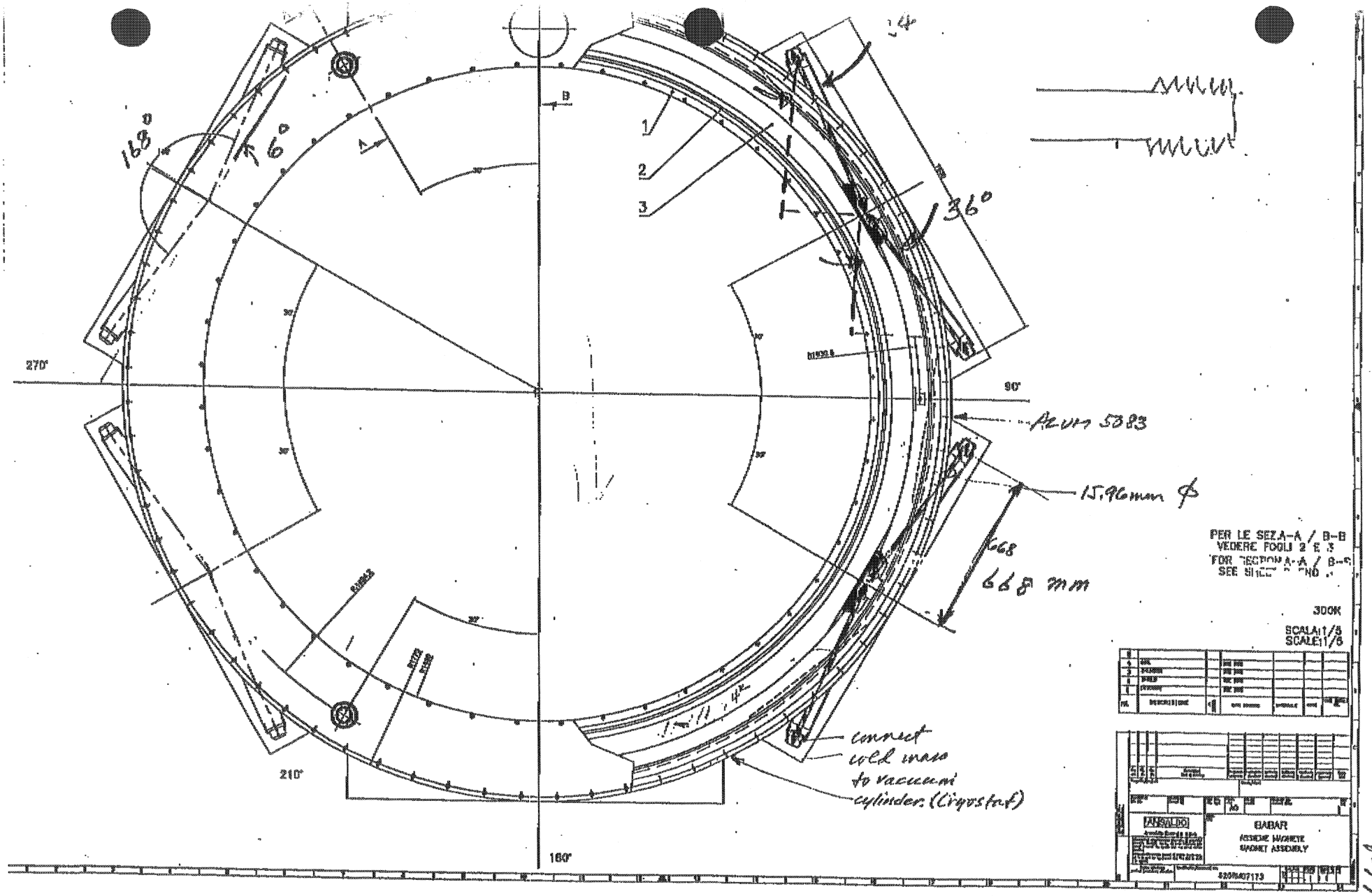
Vertical P = +/- 1.07 W

4. Stress Analysis

Support legs: Axial stress = 12.9 ksi

Bending stress = 24.4 ksi

Combined = 37.3 ksi


270°
90°
180°
210°
168°
16°
36°
14°
1
2
3
B
A
Acum 5383
15.96mm ϕ
668
668 mm
connect
cold mass
to vacuum
cylinder (Cryostat)
PER LE SEZ.A-A / B-B
VEDERE FOGLI 2 E 3
FOR SECTION A-A / B-B
SEE SHEET 2 AND 3
300K
SCALA:1/5
SCALE:1/5
ANSALDO
BABAR
ASSIEME MAGNETE
MAGNET ASSEMBLY
820/5407173

21
F 18

ARMY TM 5-809-10
NAVY NAVFAC P-355
AIR FORCE AFM 88-3, Chap 13

TECHNICAL MANUAL

SEISMIC DESIGN FOR BUILDINGS

DRAFT VERSION

For

SEISMIC DESIGN WORKSHOP
November 1991

DEPARTMENTS OF THE ARMY, THE NAVY, AND THE AIR FORCE
October 1991

P19 (22)

d. Appendage magnification factor. The appendage magnification factor (MF) is the ratio of the peak motion of the appendage (in this case, equipment) to the peak motion of the floor level that it is mounted on. A theoretical value of the MF is generally based on steady-state motion due to the floor responding as a uniform sine wave. However, buildings that are responding to earthquakes move in a somewhat random fashion and thereby do not generate magnification factors as large as calculated by theoretical steady-state response. Following are discussions of the steady-state response and of an approximate method for estimating appendage magnification factors.

(1) The magnification factor for an idealized single mass oscillator, with a period T_a and damping characteristics at 2 percent of critical damping, responding to a steady-state sinusoidal acceleration having a period T, is plotted in figure 12-1. If T_a is essentially equal to T, MF equals 25. In other words, at a condition of resonance, the maximum acceleration of the oscillator mass will be 25 times the peak acceleration of the forcing motion. This idealized condition depends on the fine-tuning of the two periods, the linearity of the oscillator spring, the uniformity of the input sinusoidal motion, and the length of time of the input motion (at least 25 cycles).

(2) If the oscillator represents the equipment, the floor response represents the steady-state input motion, and the product ZC_p (0.4 x 0.75) equal to 0.30 is assumed to be the floor acceleration, the peak acceleration for the equipment is 25 times 0.30g = 7.5g. In other words, the horizontal force on the equipment is seven and one-half times its own weight. However, due to the actual nonlinear characteristics of equipment and buildings and particularly the finite duration of earthquake motion, it is highly unlikely that such a magnification could actually occur to a 2 percent damped equipment appendage.

(3) In order to approximate a realistic value for a design MF, it is assumed that the periods T_a and T will differ by at least 5 percent; that buildings are not perfectly linearly elastic, especially at high amplitudes of response; that the floor response is not an exact, uniform sine wave; and that the number of high amplitude floor response cycles is substantially less than 25.

(4) The design MF curve shown in figure 12-2 is presented as an aid to estimating the design response of single-degree-of-freedom appendages, in lieu of more rigorous analysis methods. The peak MF of 25 is reduced to 7.5 by reducing the effectiveness of the period tuning, the peak floor response amplitude, and the number of continuous cycles to roughly two-thirds of the idealized values (i.e., 25 x 2/3 x 2/3 x 2/3 = 7.5). The width of the magnification factor is broadened to account for uncertainty of actual period ratios.

e. Equivalent static force. The equivalent static force for the anchorage of flexible and flexibly mounted equipment is given by the equation

$$F_p = ZI_pA_pC_pW_p \qquad \text{(eq 12-2)}$$

which is a modification of the SEAOC rigid equipment equation 1-10, where A_p is the amplification factor for a value of C_p = 0.75. The value of A_p is related to the MF values of figure 12-2; however, the

P20
(28)

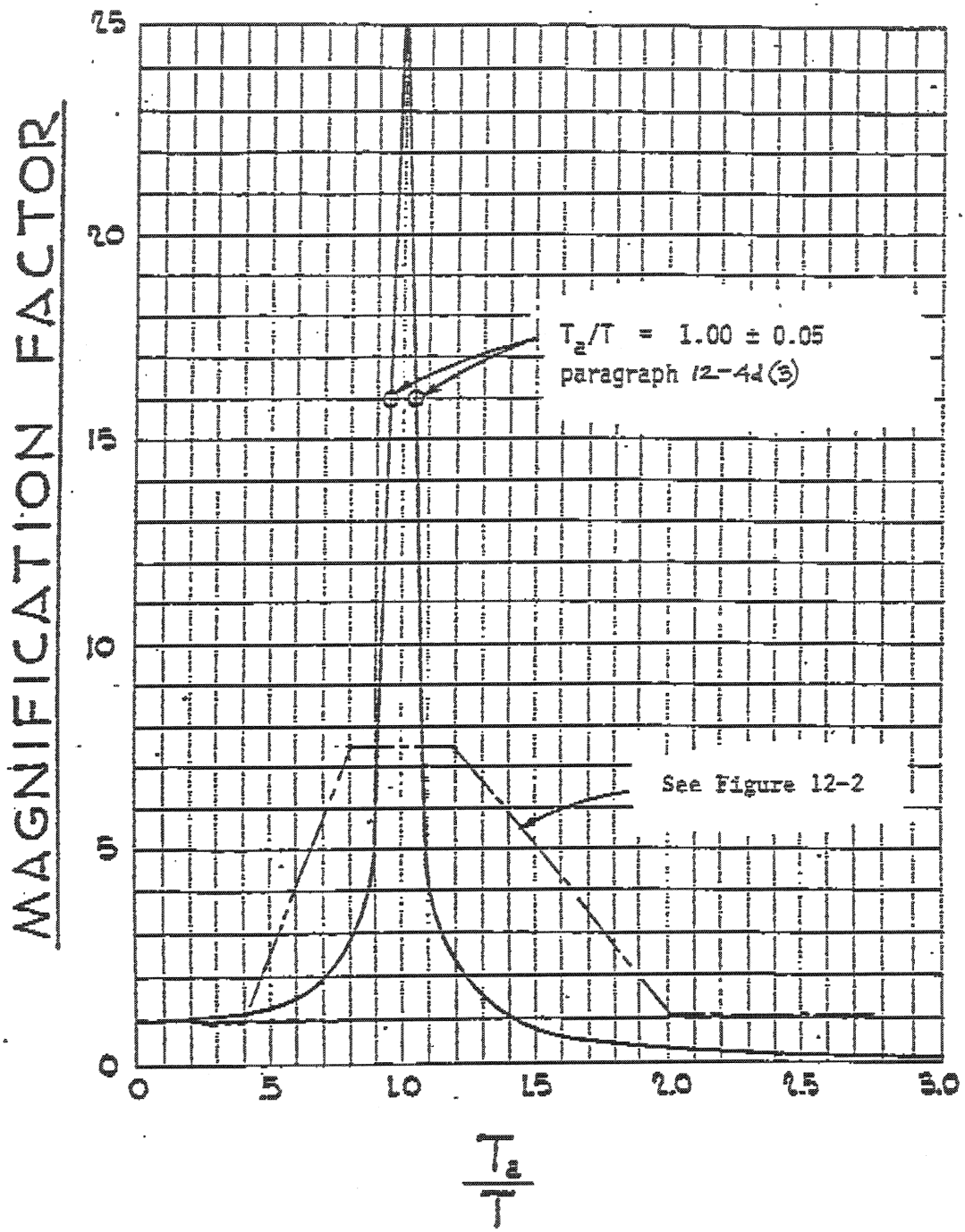


Figure 12-1. Idealized acceleration magnification factor vs period ratio at 2 percent of critical damping

(24)

ROLAND L. SHARPE, S.E. **Consulting Structural Engineer**
Cupertino, CA 408-255-4510, 415-941-7131: Fax408-725-8585

23 May 1996

Memo to: Tom O'Connor
SLAC BaBar Detector Project

From: Roland L. Sharpe

Subject: Additional Preliminary Analyses of "Cold Mass" Support Bolts in Cryostat

Tom:

Enclosed are copies of Tables 1, 2, and 3 which present results of reanalyses for the solenoid (Cold Mass) assuming the longitudinal and radial bolts are prestressed. We made these reanalyses for two materials, titanium and inconel bolts. We assumed the prestress was equal to 1/2 F_a.

Roland L. Sharpe

No prestress.

25

TABLE 1 - SOLENOID SUPPORTS W/ PRESTRESSED LONGITUDINAL BOLTS

DATE : 5/23/96

	TITANIUM	INCONEL
ULTIMATE STRENGTH, Fu, Kg/mm^2	100	126 — 113
YIELD STRENGTH, Fy, Kg/mm^2	83	105 — 123
MODULUS OF ELASTICITY, E, Kg/mm^2	11500	21000 22793
BOLT DIAMETER, mm	17.96	17.96
AREA OF BOLT, mm^2 (*)	253.2	253.2
BOLT LENGTH, mm	486	486
ALLOWABLE TENSILE STRESS, Fa, Kg/mm^2 (1/4 Fu, or 2/3 Fy)	25	31.5 35 -53 normal clamped
PERIOD (FREQUENCY) OF SOLENOID	Ta=0.03 S. Fa=33 CPS	Ta=0.022 S. 0.055 Fa=45 CPS
PERIOD (FREQUECY) OF BARREL N ISOLATOR, W/O DOOR)	Ta=1.04 S. Fa=0.96 CPS	Ta=1.04 S. Fa=0.96 CPS
Ta/T	0.029	0.021
MF, MAGNIFICATION FACTOR	1	1
BASE SHEAR COEFFICIENT OF BARREL	0.55	0.55 ? use 0.2
WT OF SOLENOID, Kg	7800	7800
TOTAL EQ FORCE OF SOLENOID, Kg	4290	4290 — 2560
EQ FORCE PER BOLT (TOTAL 6), Kg	715	715 520
TENSILE STRESS DUE EQ, Kg/mm^2	2.82	2.82
PRESTRESS, 1/2 ALLOWABLE(Fa), mm^2	12.5	15.75
TOTAL STRESS (EQ+PRESTRESS), Kg/mm^2	15.32	18.57
	<1.33*25=33.25, OK	<1.33*31.5=41.9 OK

* ASSUMING UPSET BOLT

~~PRESTRESS~~ + EQ + NORMAL LOAD < F_a clamped

~~"~~ + NORMAL < F_a normal

(26)

TABLE 2 - SOLENOID VERTICAL SUPPORTS W/ PRESTRESSED RADIAL BOLTS

DATE : 5/23/96

	TITANIUM	INCONEL
ULTIMATE STRENGTH, Fu, Kg/mm^2	100	126 143
YIELD STRENGTH, Fy, Kg/mm^2	83	105 123
MODULUS OF ELASTICITY, E, Kg/mm^2	11500	21000 21253
BOLT LENGTH, mm	668	668
BOLT DIAMETER, mm	15.96	15.96 NO LOAD AREA
AREA OF BOLT, mm^2 (*)	200.0	200.0
ALLOWABLE TENSILE STRESS, Fa, Kg/mm^2 (1/4 Fu or 2/3 Fy)	25	31.5 NC
PERIOD (FREQUENCY) OF SOLENOID	Ta=0.028 S. Fa=36 CPS	Ta=0.021 S. 0.031 Fa=47 CPS
PERIOD (FREQUECY) OF BARREL	Ta=0.065 S. Fa=15.4 CPS	Ta=0.065 S. Fa=15.4 CPS
T-/T	0.43	0.32 0.48
M, MAGNIFICATION FACTOR	1	1
FLOOR ACCELERATION, g	1.45	1.45
WT OF SOLENOID, Kg	7800	7800
TOTAL EQ FORCE OF SOLENOID, Kg	11310	11310
MAX. BOLT FORCE UNDER 1 Kg EA. END	0.155	0.155
EQ FORCE PER BOLT (TOTAL 8), Kg	877	877
TENSILE STRESS DUE EQ, Kg/mm^2	4.39	4.39
PRESTRESS, 1/2 ALLOWABLE(Fa), mm^2	12.5	15.75
TOTAL STRESS (EQ+PRESTRESS), Kg/mm^2	16.89	20.14
	<1.33*25=33.25, OK	<1.33*31.5=41.9 OK

* ASSUMING UPSET BOLT

27

TABLE 3 - SOLENOID TRANSVERSE SUPPORTS W/ PRESTRESSED RADIAL BOLTS

DATE : 5/23/96

	TITANIUM	INCONEL
ULTIMATE STRENGTH,Fu,Kg/mm^2	100	126
YIELD STRENGTH,Fy,Kg/mm^2	83	105
MODULUS OF ELASTICITY,E,Kg/mm^2	11500	21000
BOLT LENGTH,mm	668	668
BOLT DIAMETER,mm	15.96	15.96
AREA OF BOLT,mm^2(*)	200.0	200.0
ALLOWABLE TENSILE STRESS,Fa,Kg/mm^2 (1/4 Fu or 2/3 Fy)	25	31.5
PERIOD (FREQUENCY) OF SOLENOID	Ta=0.048 S. Fa=21 CPS	Ta=0.036 S. Fa=28 CPS
PERIOD (FREQUECY) OF BARREL (ON ISOLATOR,NO DOOR)	Ta=1.04 S. Fa=0.96 CPS	Ta=1.04 S. Fa=0.96 CPS
Ta/T	0.046	0.034
MAGNIFICATION FACTOR	1	1
BASE SHEAR COEFFICIENT	0.55	0.55
WT OF SOLENOID,Kg	7800	7800
TOTAL EQ FORCE OF SOLENOID,Kg	4290	4290
MAX. BOLT FORCE UNDER 1 Kg EA. END	0.289	0.289
EQ FORCE PER BOLT (TOTAL 8),Kg	620	620
TENSILE STRESS DUE EQ,Kg/mm^2	3.10	3.10
PRESTRESS,1/2 ALLOWABLE(Fa),mm^2	12.5	15.75
TOTAL STRESS (EQ+PRESTRESS),Kg/mm^2	15.60	18.85
	<1.33*25=33.25,OK	<1.33*31.5=41.9 OK

* ASSUMING UPSET BOLT