ATTACHMENT 1

COMBUSTION ENGINEERING

DEVELOPMENT DEPARTMENT

TEST REPORT

PALISADES CRDM DYNAMIC

ANALYSIS REPORT

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1.0 INTRODUCTION

The structural integrity of the Palisades CRDMs must be maintained during seismic disturbances of intensities as specified in Reference 1.

The purpose of this work was to determine the worst seismic response condition for the Palisades CRDM with existing seismic supports and to demonstrate the ability of the CRDM to meet the given seismic loads and to satisfy the scramability condition. The DBE event was considered. For this purpose a one-dimensional finite element model of the Palisades CRDM, as documented in Reference 2, was available. This model entails the dynamic characteristics of the free standing CRDM structure and, with some modifications, was used in this analysis.

The analysis technique for the Palisades CRDMs, which are tied together by seismic supports, was performed in accordance with the CRDM Seismic Review Plan given in Reference 3.

2.0 SUMMARY

A representative, two-dimensional finite element model of the Palisades CRDM rows was developed and analyzed for horizontal seismic loading. Each CRDM in a row was modeled by use of a simplified representation. Preliminary analyses of the CRDM rows allowed determination of the CRDM row with the worst response to seismic loadings. This row was analyzed in more detail by using a coupled finite element row presentation where two CRDMs were modeled in detail, and the effects of the other CRDMs were simulated by simplified models. The work performed and documented in this report demonstrates the CRDMs ability to meet all seismic requirements mentioned above. The results are summarized below.

The nozzle and flange connection are considered the most critical areas of the CRDMs.

- The maximum axial forces and moments of 18.17 kips and 37.07 in kips in the nozzle are less than allowable ones.
- The maximum stresses, of 8.4 ksi, in the flange bolts are also less than allowable ones.
- The maximum stress in the critical area of the seismic support was computed as 37.1 KSI and is less than an allowable stress of 47.16 KSI. Scramability of the CRDMs during the seismic event was demonstrated.

3.0 REDUCED AND DETAILED MODEL OF THE FREE STANDING PALISADES RACK & PINION DRIVE

In order to keep the problem size within acceptable limits (computer time) a simplified CRDM representation was developed from the standard, more detailed Palisades model documented in Reference 2. The SAP4 computer code (Reference 6) was used for this task and thirty-nine nodal points, which are combined by thirty-three beam elements, were used for the reduced model.

The assembly of the mathematical model is presented in Figure 1. The simplified CRDM model demonstrated good correlation with the standard CRDM model.

A comparison of the first three modal frequencies and bending moments (from a response spectrum analysis) is given in Tables 1 and 2. The deflection shapes for these modes are presented in Figure 2 through Figure 4.

A comparison of the above information confirms the acceptability of the reduced model. The detailed CRDM model basically is the standard Palisades model described in Reference 2. However, the piston tube and rod in this model were represented as separate structures (in the original model they were combined). Such a representation was chosen in order to determine the possibility of the rod to "hang-up" (due to large deflections), and to make an assessment of the CRDMs ability to scram during the postulated seismic intensities. The detailed model has one hundred-thirty nodes which are connected by one hundred-nineteen beam elements. The assembly of the detailed model with nodal coordinates is shown in Figure 5.

4.0 CRDM ROWS ANALYSIS AND DISCUSSION

The reactor vessel head of the Palisades plant has seven different CRDM rows. There are two types of rows. The first type of row combines seven CRDMs, and the second type of row combines five CRDMs. The location of nozzles on top of the reactor is given in Figure 6. Because of the symmetry, only four CRDM rows had to be considered. These rows are indicated in Figure 6, along with nozzle length information.

All four rows were anlayzed by using finite element models which contained the simplified model at each CRDM location. The CRDMs were tied together by seismic supports at an elevation of 44.25" above the reference point (Reference 4). The seismic supports were modeled by three beam elements each.

Since the supports were designed to transmit moment loads and to allow horizontal displacements between adjacent CRDMs, proper end release code techniques were used to model these boundary conditions. The CRDM, itself, is a stiff structure. The critical areas are the nozzle, the junction of CRDMs and nozzles, and the seismic supports. Therefore, the stressed state of these areas was determined to demonstrate the CRDMs ability to meet seismic loads. In order to verify the CRDM scramability, the deformed state of the mechanism had to be determined. The piston tube displacements were considered for this purpose.

A Response Spectrum analysis with an assumed spectrum level of 1 g (1 to 33 Hertz) was performed for each row of CRDMs. The worst combination of the maximum internal forces in the critical areas of the CRDMs are presented for each row in Table 3.

A review of the results given here, show that the worst combination of internal loads at the nozzle support (bending moment of 23.72 in kips and axial force of 1.66 kips per unit g) was developed in the CRDM with the longest nozzle length (Row #4). Maximum internal loads at the flange elevation (bending moment of 10.59 in kips and axial force of 10.66 kips per unit g) also occurred in that CRDM.

Similarly, review of the piston tube displacements demonstrated that the maximum displacement of .315" per 1g occurred in the same CRDM. Therefore, CRDM Row #4 was identified as the critical row, and was analyzed in more detail by using a more complex finite element model. For this, the two symmetrically located CRDMs with the longest nozzle lengths were represented by the detailed finite element model. A Response Spectrum analysis of this row was then performed for a uniform spectrum loading of 1g. The first fifteen modal frequencies are presented in Table 4. For comparison, the frequencies for each of the four analyzed CRDM rows are also given here.

The calculated maximum bending moments axial and shear forces at the CRDM nozzles, at the flange elevation, and in the ties are given in Table 5.

Maximum values of this data were used to determine stresses in the CRDM nozzle, in the flange bolts at the junction of CRDMs and nozzles, and in the seismic supports.

5.0 NOZZLE STRESSES

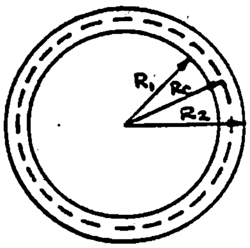
Nozzle stresses are determined in this section and compared to allowables.

Design requirements:

Design Pressure:	2.5 ksi (real 2.23 ksi)
Design Temperature:	$650^{\circ}F$
Material:	SA-182
Allowable Sm:	18.0 ksi
Weight (WT):	1.906 kips
Vertical Force for the DBE Case Calculated as .21 WT*	.40 kips V_F = 18.57 kips
Axial Force	1.73 x 10.5 = 18.17 kips

* Spec. No. 70P-008, Rev. 2; No-Loss-of-Function seismic loads are defined as 1.73g horizontal and .21g vertical accelerations.

Cross section of nozzle



R_1 = 1.364 IN

R_2 = 1.750 IN

R_c = 1.557 IN

t = .386 IN

$$A = \pi R^2 = \pi(R_2^2 - R_1^2) = 3.774 \text{ IN}^2 \quad (1)$$

$$I = \frac{\pi}{4}R^4 = \frac{\pi}{4}(R_2^4 - R_1^4) = 4.645 \text{ IN} \quad (2)$$

<u>Faulted Condition</u>

$$\sigma_x = \frac{PR_1^2}{2R_c t} \pm \frac{V_F}{A} - \frac{WT}{A} \pm \frac{M \cdot R_c}{I} \quad (3)$$

$$(\sigma_x)_{MAX} = \frac{2.5(1.364^2)}{2(1.557)(.386)} + \frac{18.57}{3.774} - \frac{1.906}{3.774} + \frac{M(1.5)}{4.645} \quad (4)$$

$$(\sigma_x)_{MAX} = 8.285 + .323 M \quad (5)$$

$$(\sigma_x)_{MIN} = \frac{2.5(1.364^2)}{2(1.557)(.386)} - \frac{18.57}{3.774} - \frac{1.906}{3.774} - \frac{M(1.5)}{4.645} \quad (6)$$

$$(\sigma_x)_{MIN} = -1.556 - .323 M \quad (7)$$

$$\sigma_\theta = \frac{PR_1}{t} = \frac{2.5(1.125)}{.386} = 7.286 \text{ KSI} \quad (8)$$

$$\sigma_r = \frac{P}{2} = -\frac{2.5}{2} = -1.25 \text{ KSI AVERAGE} \quad (9)$$

Since tangential stresses in the given directions (X, θ, Z) are small ($\tau = \frac{F_{shear}}{A} = \frac{1.03}{3.744} = .3$ ksi), it was accepted that these directions are principal and stress tensor components in these directions are principal stresses.

Then:

$$\sigma_x - \sigma_\phi = \begin{cases} (\sigma_x)_{MAX} - \sigma_\phi = 1.0 + .323M & (10) \\ (\sigma_x)_{MIN} - \sigma_\phi = 8.842 - .323M & (11) \end{cases}$$

$$\sigma_x - \sigma_r = \begin{cases} (\sigma_x)_{MAX} - \sigma_r = 9.535 + .323M & (12) \\ (\sigma_x)_{MIN} - \sigma_r = .306 - .323M & (13) \end{cases}$$

$$\sigma_\theta - \sigma_r = 8.536 \text{ KSI}$$

(S.I.)max = 2.4Sm, for faulted allowable per paragraph 4.1.4.2.4 of project Spec. No. 00000-PE-110, Rev. 4, where $S_m = .95\ S_m$ to allow for a five percent factor of safety. Therefore,

$$(S.I.)_{MAX} = 41.04 \text{ KSI} \qquad (14)$$

The maximum bending moment was calculated in the Row #4 for the CRDM with the longest nozzle, and is

$$(Mb)_{MAX} = 1.73 \times 21.43 = 37.07 \text{ IN}/\text{KIPS} \qquad (15)$$

Then,

$$41.04 \text{ KSI} > \left| 9.535 + .323M \right| = 21.51 \text{ KSI} \qquad (16)$$

The maximum allowable bending moment at the nozzle can be obtained as the following:

$$M_{\substack{MAX \\ ALLOWABLE}} \leq \frac{41.04 - 9.535}{.323} = 97.54 \text{ IN/KIPS} \quad (17)$$

A comparison of the maximum computed bending moment at the nozzle to the allowable value is shown below.

$$97.54 \text{ IN/KIPS} \gg 37.07 \text{ IN/KIPS} \quad (18)$$

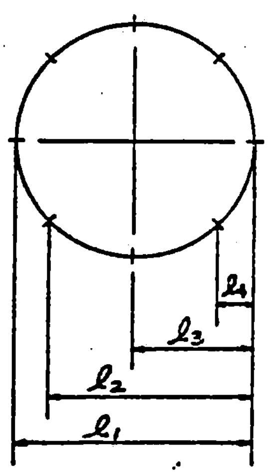
6.0 STRESSES IN THE BOLTS

The goal of this analysis was to determine stresses in the bolts of the flange which connects nozzle and mechanism upper housing.

Design requirements:

Design Pressure (Pr):	2.5 ksi (real 2.485 ksi)
Design Temperature:	650°F
Material:	SA-193-B7
Allowable Sm	27.0 ksi
Bolts	1" x 8
Number of Bolts (n)	8

Bolt locations



$\ell_1 = 7.0$ IN

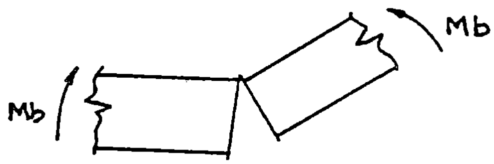
$\ell_2 = 5.975$ IN

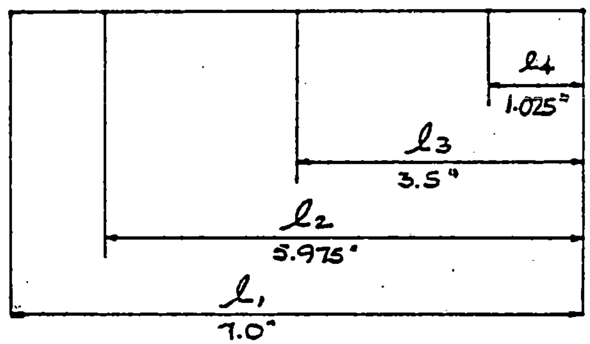
$\ell_3 = 3.50$ IN

$\ell_4 = 1.025$ IN

The worst combination of internal forces, which occurred at the flange elevation, (for the DBE event bending moment and axial force equal $1.73 \cdot 13.96 = 24.15$ in kips, $1.73 \cdot 10.04 = 17.37$ kips) was obtained in the Row #4 for the CRDM with the longest nozzle.

It is assumed that the flange is not deformed under given loads condition.





Then,

$$Mb = F_a \ell_1 + 2F_b \ell_2 + 2F_c \ell_3 + 2F_d \ell_4 \qquad (19)$$

$$P_a : P_b : P_c : P_d = \ell_1 : \ell_2 : \ell_3 : \ell_4 \qquad (20)$$

$$P_b = P_a \frac{\ell_2}{\ell_1} = .854\, P_a \qquad (21)$$

$$P_c = P_a \frac{\ell_3}{\ell_1} \cdot 5\, P_a \qquad (22)$$

$$P_d = .146\, P_a \qquad (23)$$

$$M_b = P_a(\ell_1 + 1.708\,\ell_2 + \ell_3 + .292\,\ell_4) = 21.0046\,P_a \quad (24)$$

$$P_a = \frac{M_b}{21.0046} = 1.150 \text{ kips} \quad (25)$$

$$P_b = .981 \text{ kips} \quad (26)$$

$$P_c = .574 \text{ kips} \quad (27)$$

$$P_d = .168 \text{ kips} \quad (28)$$

Stresses in the bolts can be calculated as follows:

$$\sigma_b = \frac{P_a}{A} + \frac{V_F}{nA} \quad (29)$$

WHERE $A = \frac{\pi}{4}\left(OD - \frac{.9743}{m}\right)^{*} = .7854\left(1 - \frac{.9743}{8}\right) = .6897 \text{ IN}^2$

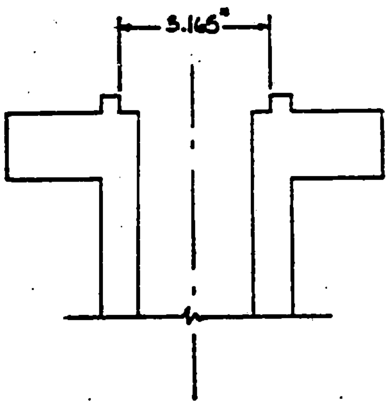
m - is number of threads per inch

OD = 1"

n = 8 number of bolts

V_F - vertical force which combines pressure and axial forces.

Pressure forces at the flange bolts



Pr = 2.5 ksi

Area = 7.863 in^2

F = PA = 19.6588 (30)

* Manual of Steel Construction, Seventh Edition, American Institute of Steel Construction, pp. 5-20.

Then vertical force equals:

$$V_F = 19.659 + 17.37 = 37.029 \text{ kips}$$

Maximum stresses in the bolts equals:

$$\sigma_b = \frac{1.150}{.6897} + \frac{37.029}{8(.6897)} = 8.378 \text{ ksi} \qquad (31)$$

and are less than the allowable stresses

$$8.378 < 27.0$$

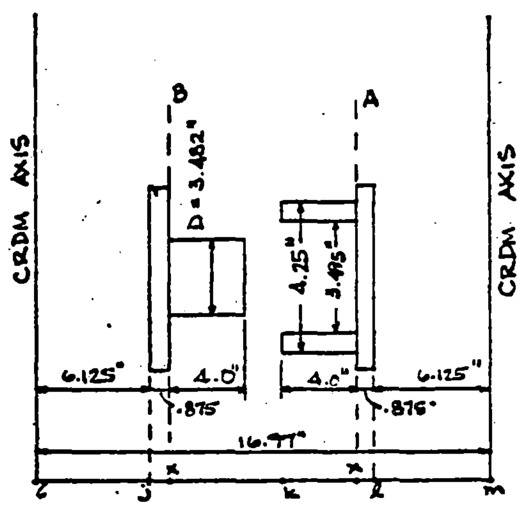
7.0 STRESSES IN THE SEISMIC SUPPORTS

Stresses in the ties (Reference 7) are obtained in this section of the report and compared to the allowables.

Design requirements:

Design Temperature:	250°F
Material:	AISA-4130
Allowable S_m	= 20.55 ksi

The critical areas of the seismic support structure are indicated as sections A and B, below.



The nodal point positions in the mathematical model of the structure are also shown here. A linear bending moment distribution is assumed along each beam element.

Then the maximum bending moment in the critical section (A or B) was determined through nodal bending moment values as follows:

$$M_x = \left(M_k + \frac{M_j - M_k}{L_{jk}} \cdot L_{xk}\right) K \tag{32}$$

where,

L_{jk}, L_{xk} = lengths between j,k and x,k points.

κ = 1.73 seismic loads coefficient for the DBE event.

Then,

$$M_x = \left(65.18 + \frac{93.11 - 65.18}{4.72} \cdot 3.845\right) 1.73 = 152.12 \text{ IN/KIPS} \tag{33}$$

Stresses in the A and B sections were calculated as follows:

$$\sigma_a = \frac{M_x}{W_a}; \quad \sigma_b = \frac{M_x}{W_b}; \tag{34}$$

WHERE $$W_A = \frac{\pi D^3}{32}\left(1 - \frac{d^4}{D^4}\right) = \frac{3.14(4.25^3)}{32}\left(1 - \frac{3.495^4}{4.25^4}\right) = 4.09 \text{ IN}^3 \tag{35}$$

$$W_B = \frac{\pi D^3}{32} = \frac{3.14(3.482^3)}{32} = 4.142 \text{ IN}^3 \tag{36}$$

$$\sigma_a = \frac{152.12}{4.09} = 37.19 \text{ KSI} \tag{37}$$

$$\sigma_b = \frac{152.12}{4.142} = 36.72 \text{ KSI} \tag{38}$$

σ_a and σ_b stresses are less than allowable stresses which, for DBE event, were determined as $2.4S_m = 2.4 \cdot 20.55 = 49.33$ ksi.

$$37.19 \ll 49.33 \qquad (39)$$

$$36.72 \ll 49.33 \qquad (40)$$

8.0 THE ABILITY OF THE PALISADES CRDM TO SCRAM

In order to address the question whether or not the CRDMs under seismic loading, maintain their ability to scram, deflection of the piston tube in comparison with the deflection of the rod was considered. Since the maximum deflections of the piston tube were determined in the CRDM with the longest nozzle (Row #4), these CRDMs were modelled in detail. A maximum displacement of .244" per 1g for the piston tube was calculated for critical mode #1 (RSS displacement per 1 g equals .247") and .298" per 1g for critical mode #1 for the rod (RSS displacement per 1g equals .307"). These displacements occurred at an elevation of 133" above the reference point.

The deformation-based scramability criterion can be described as follows. (The force-based criterion is not taken into account because of its negligible value):

$$U_r^L \leq R_p + U_p^L - R_r \qquad (41)$$

where

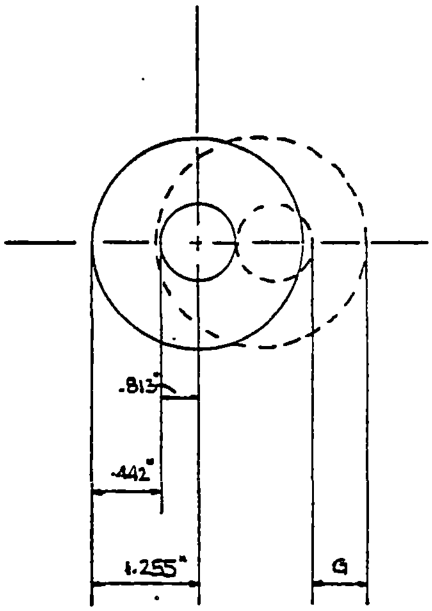
U_r^L = maximum rod deflection at the elevation "L".

U_p^L = piston tube deflection at the elevation "L".

R_p = 1.255" piston tube radius

R_r = .813" rod radius

Schematically, the above given criterion can be presented as follows:



deformed positions
of the piston tube and the rod.

initial positions
of the piston tube and the rod.

Here, "G" is a gap between the piston tube housing and the rod surface.

For the DBE event, U_r and U_p are:

Note: Both rod and piston tube deflect in same direction.

$$U_r^{\ell} = 1.73 \times .287'' = .497'' \qquad (42)$$

$$U_p^{\ell} = 1.73 \times .244'' = .422'' \qquad (43)$$

For the deformed state, a minimum "G" was positive and equalled .367", which indicates the CRDM scramability.

The same result was obtained by using the inequality given above,

$$.467'' \leq 1.255'' + .422'' - .813'' = .864'' \qquad (44)$$

and thus verifies the ability of the CRDM to scram.

9.0 CONCLUSION

All representative rows of Palisades CRDMs were analyzed for horizontal seismic loads of 1.73 g's. The maximum forces at the CRDM junction point to the reactor vessel head are within the allowables, stipulated in Reference 5.

The stresses in the flange bolts which connects the CRDMs and nozzles are within allowables.

The seismically supported Palisades CRDMs can accept seismic forces as required.

CRDM deflections are small. Therefore, the CRDMs are capable of scramming during OBE and DBE events of the referenced intensities.

10.0 REFERENCES

1. Engineering Specification for a Control Rod Drive Mechanism, Specification No. 70P-008, Revision 2, April, 1968.

2. Calculation No. 606110-CD-CEDM-054, "Omaha-Palisades Rack & Pinion Drive mechanism Free Standing SAP4 Computer Model."

3. K. H. Haslinger to J. Davison, "Palisades CRDMs Seismic Review," P-ESE-003, March 19, 1981.

4. C-E Drawing CRDM Installation Drawing, 2966-E-3011.

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6. K. J. Bathe, E. L. Wilson, and F. T. Peterson, "SAPIV, A Structural Analysis Program for Static and Dynamic Response of Linear Systems," Earthquake Engineering Research Center, Report No. 73-11, Revised April, 1974, University of California, Berkeley, California.

7. C-E Drawing CRDM Shock Mount Assembly, #2966-E-2869.

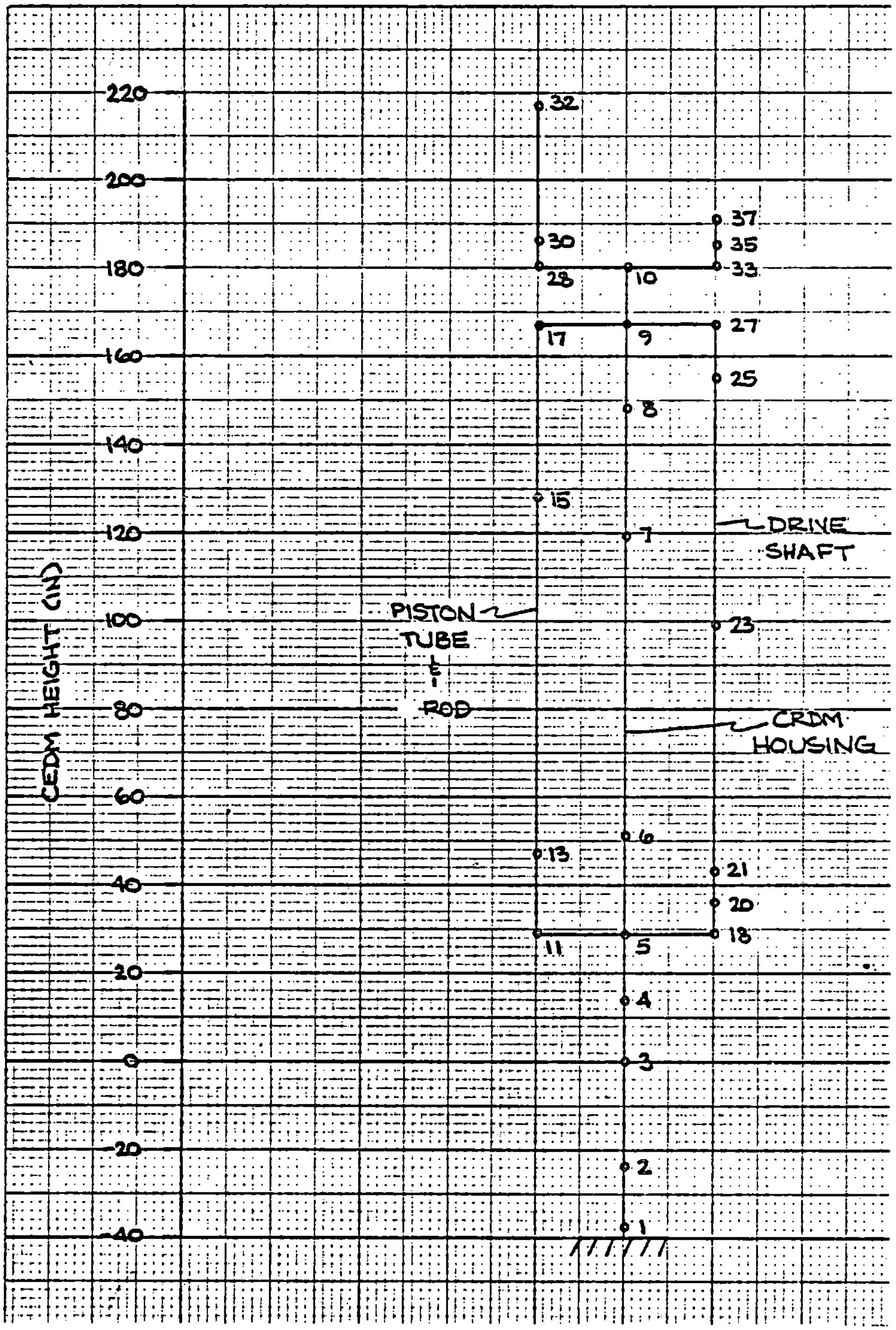


FIGURE 1

REDUCED FINITE ELEMENT CRDM MODEL

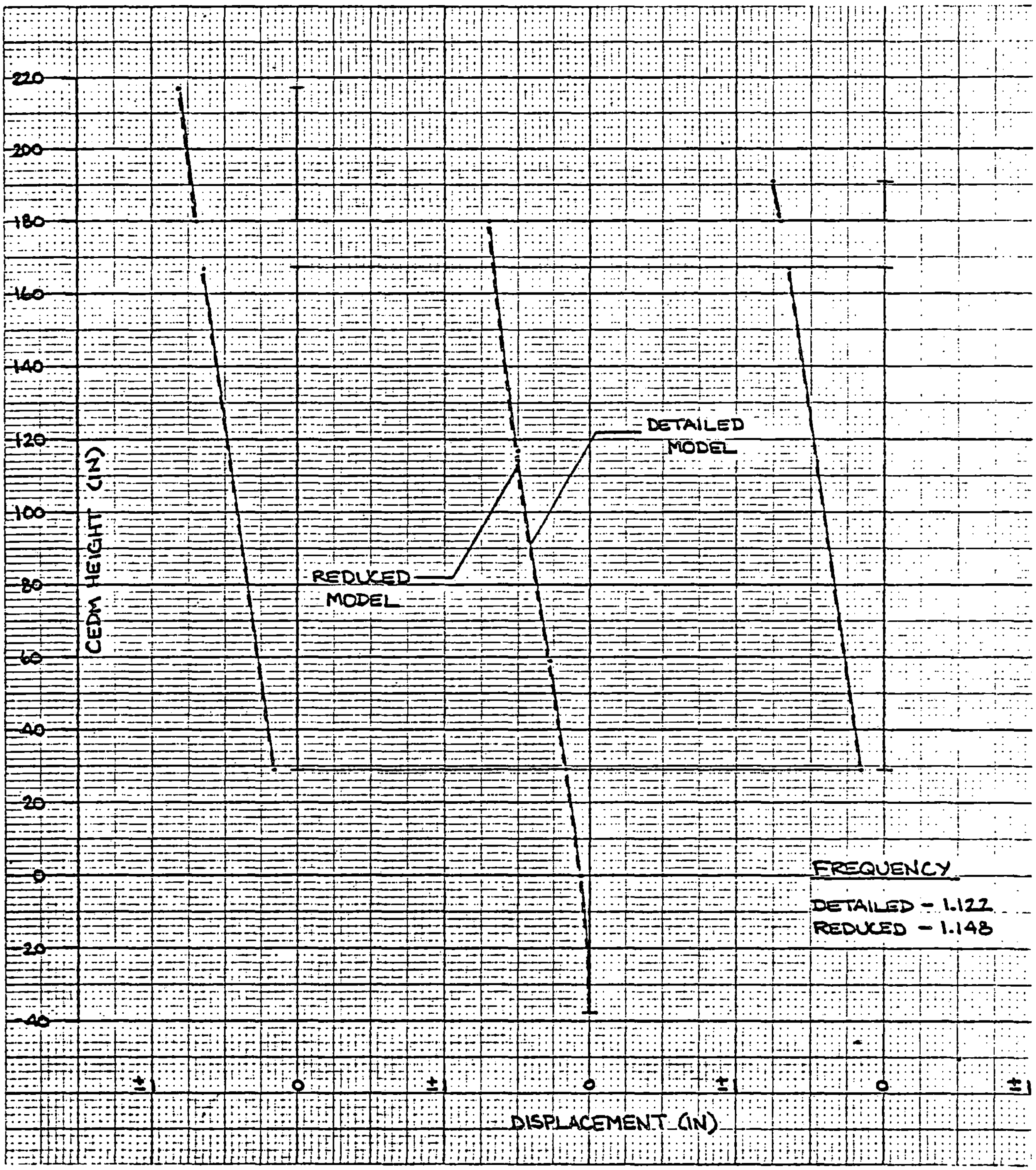


FIGURE 2

FIRST MODE DISPLACEMENTS FOR THE REDUCED CRDM MODEL

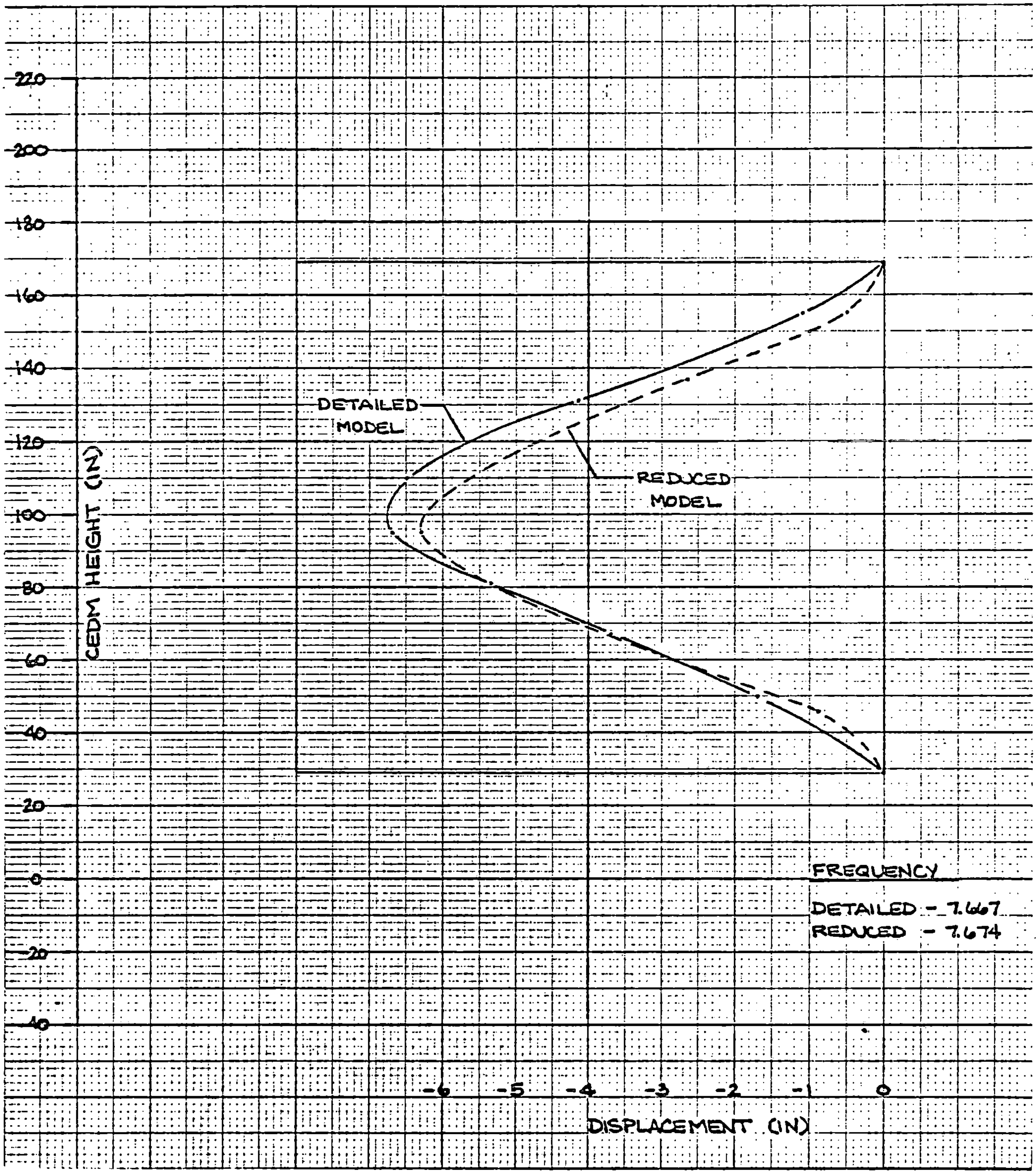


FIGURE 3

SECOND MODE DISPLACEMENTS FOR THE REDUCED CRDM MODEL

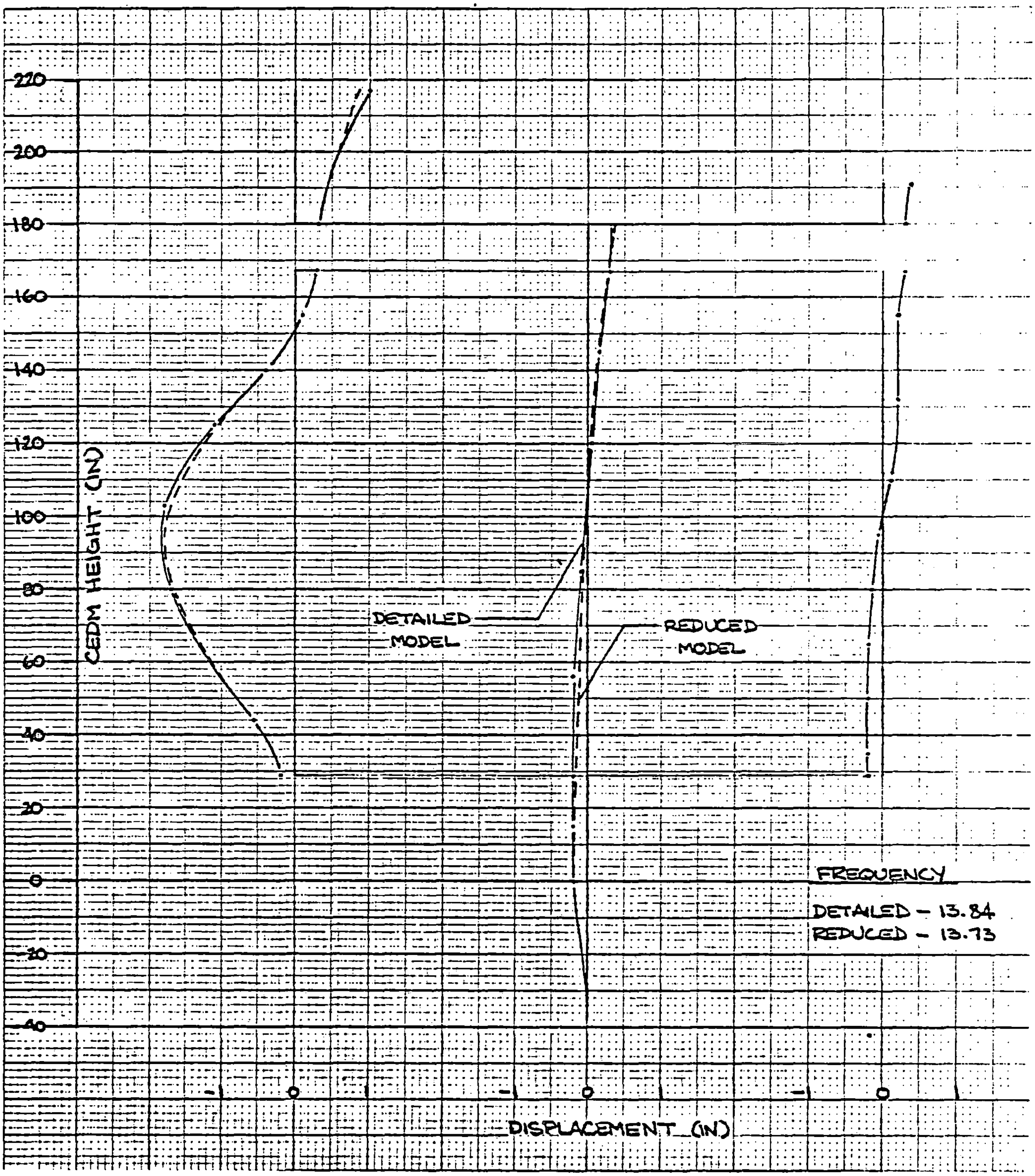


FIGURE 4

THIRD MODE DISPLACEMENTS FOR THE REDUCED CRDM MODEL

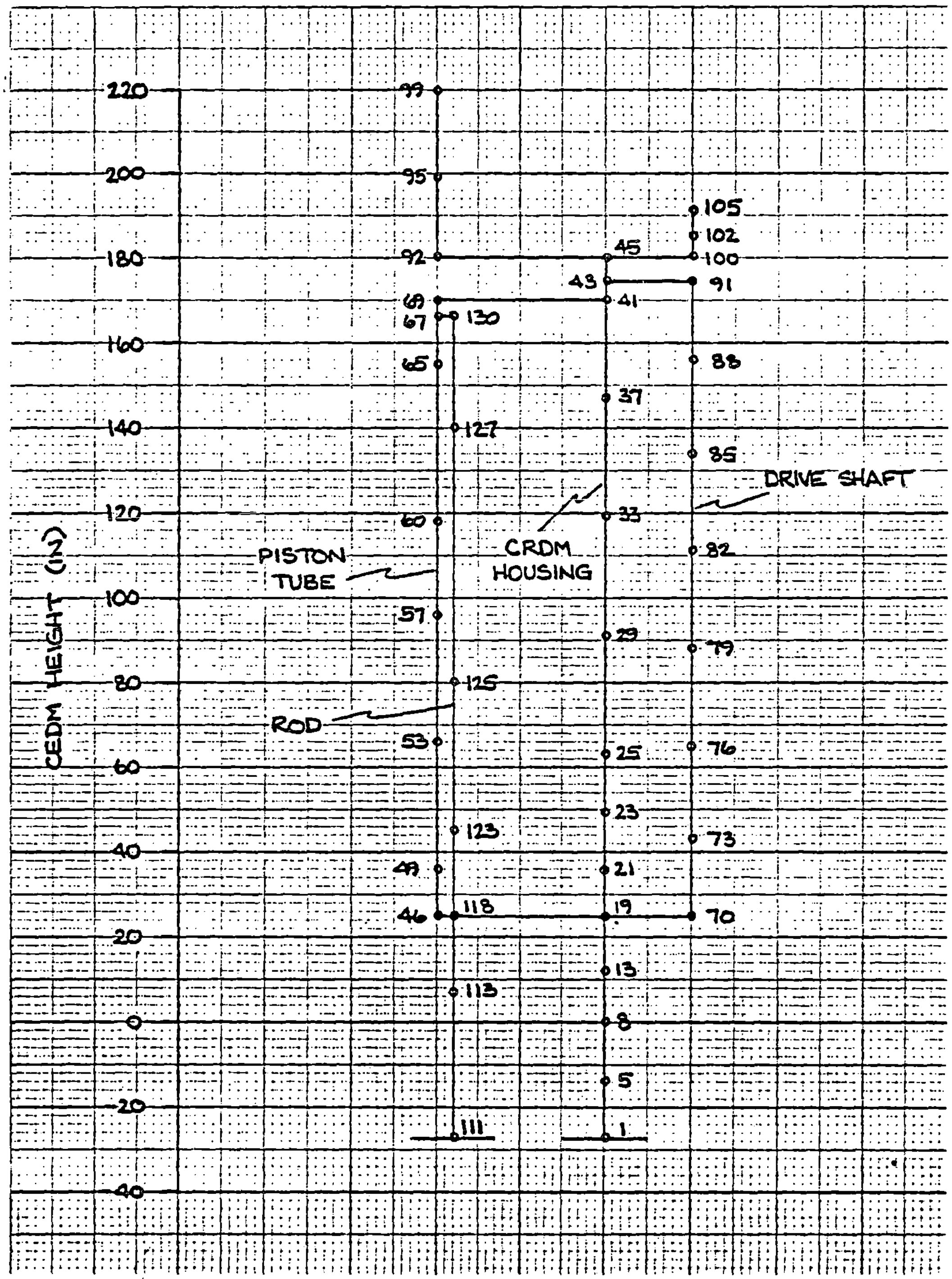
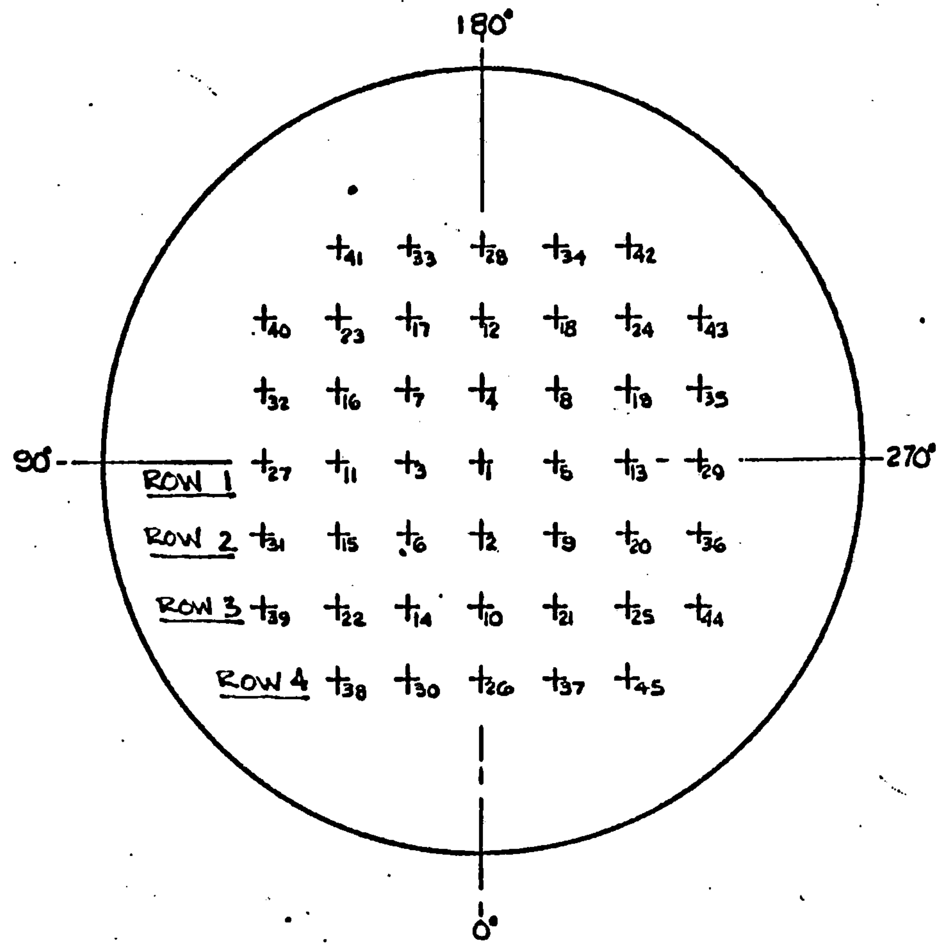


FIGURE 5

DETAILED FINITE ELEMENT CRDM MODEL



ROW NO.		MECH. NO.		NOZZLE LENGTH
1		27		26.67
		11		18.03
		3		13.408
		1		11.6875
2		31		28.51
		15		19.687
		6		14.7838
		2		13.408
3		39		34.33
		22		24.78
		14		19.687
		10		18.03
4		38		34.33
		30		28.51
		26		26.67

FIGURE 6

LOCATION OF THE NOZZLES FOR THE PALISADES PLANT

TABLE 1

LIST OF FREQUENCIES - PALISADES CRDMs

FREE STANDING MODELS

MODE NO.	DETAILED MODEL	REDUCED MODEL
1	1.122	1.148
2	7.667	7.674
3	13.84	13.73

TABLE 2

BENDING MOMENT AT NOZZLE - PALISADES CRDMs

FREE STANDING MODELS

MODE NO.	LOAD	DETAILED MODEL	REDUCED MODEL	% ERROR
1	1g	256.7	262.0	
2	1g	.011	.010	
3	1g	2.446	1.000	
RSS	1g	256.8	262.1	2%

TABLE 3

MAXIMUM INTERNAL FORCES - CRITICAL AREAS OF CRDMS

(Worst Combinations)

		NOZZLE			FLANGE			TIE	
ROW NO.	MECH. NO.	AXIAL	SHEAR	Mb	AXIAL	SHEAR	Mb	SHEAR	Mb
1	27	9.601	1.104	18.44	9.600	1.099	3.512	9.575	144.2
2	31	9.730	1.131	19.51	9.729	1.125	5.009	9.703	148.3
3	39	10.23	1.222	23.51	10.23	1.212	10.01	10.20	161.6
4	38	10.66	1.247	23.72	10.66	1.231	10.59	10.63	159.6

TABLE 4

LIST OF FREQUENCIES FOR CRDMS ROWS

MODE NO.	REDUCED MODELS				DETAILED MODEL
	ROW 1	ROW 2	ROW 3	ROW 4	ROW 4
1	5.980	5.876	5.548	5.491	5.627
2	5.981	5.877	5.550	5.538	5.672
3	7.341	7.279	7.085	6.795	6.791
4	7.403	7.341	7.105	7.134	7.135
5	7.554	7.529	7.391	7.566	7.564
6	7.606	7.600	7.571	7.696	7.696
7	7.624	7.622	7.613	7.696	7.697
8	7.703	7.701	7.696	7.745	7.744
9	7.703	7.701	7.696	7.802	7.803
10	7.866	7.835	7.781	8.456	8.450
11	7.920	7.872	7.787	14.04	11.37
12	8.287	8.175	7.921	14.04	11.37
13	8.903	8.794	8.456	14.08	13.98
14	9.496	9.412	9.153	14.10	14.01
15	14.07	14.06	14.04	14.14	14.11

TABLE 5

MAXIMUM LOADS FOR THE PALISADES CRDM'S (WORST COMBINATIONS)

ROW 4 - DETAILED MODEL/MECH. NOS. 45 & 38

LOCATION	AXIAL (kips)	SHEAR (kips)	Mb (in/kips)
NOZZLE	10.01	1.03	21.43
FLANGE	10.01	1.03	13.96
SEISMIC SUPPORTS		10.01	93.11