MARTIN MARIETTA
FLUID VISCOUS DAMPER STUDY

OAK RIDGE PLANT
BUILDING X-330

by

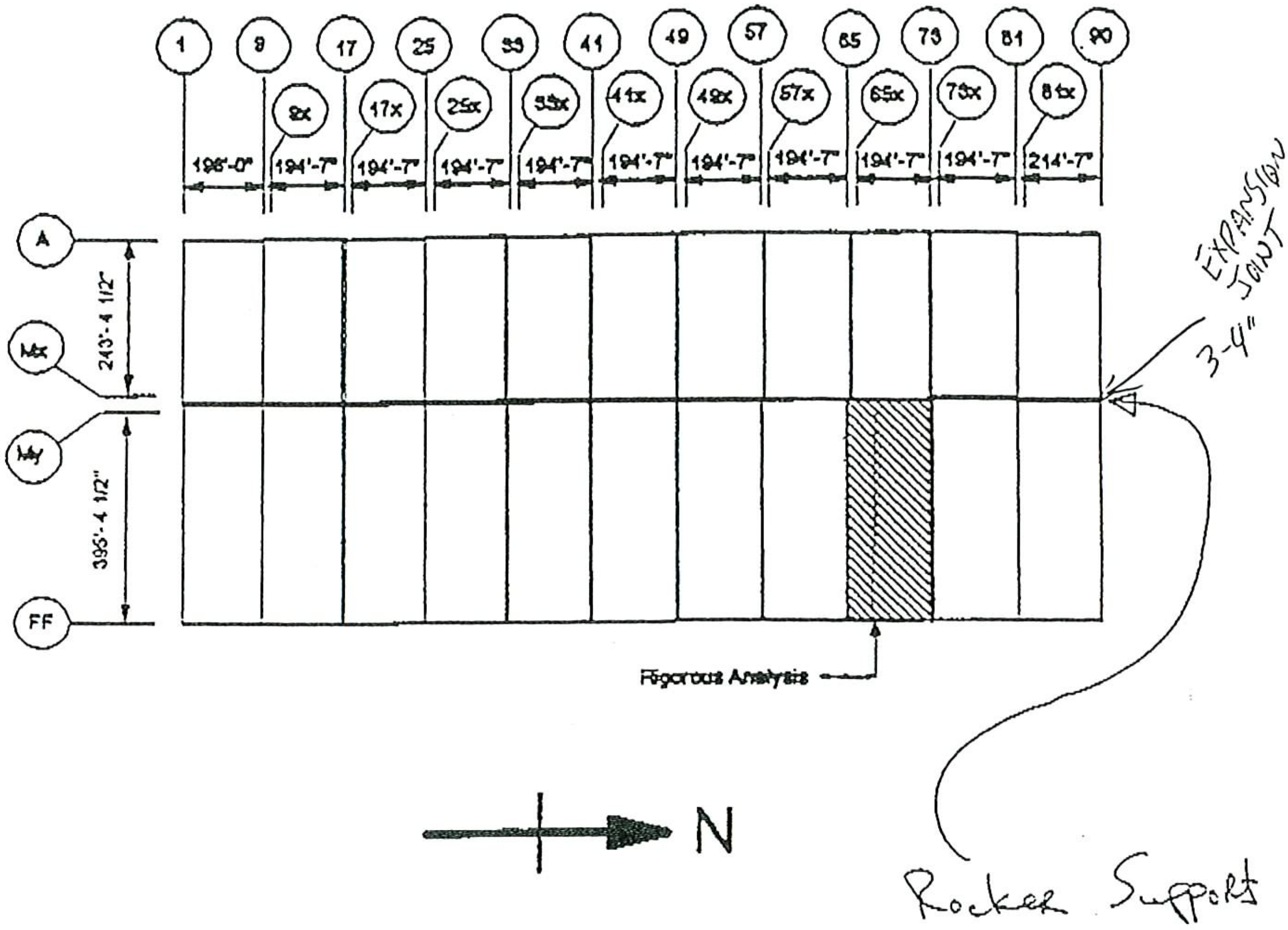
Craig Winters

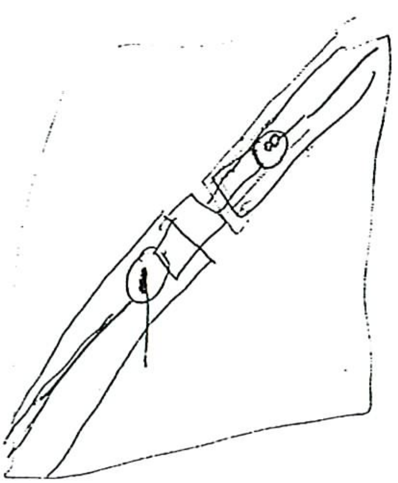
Taylor Devices, Inc.
90 Taylor Drive
P.O. Box 748
N. Tonawanda, NY 14120-0748

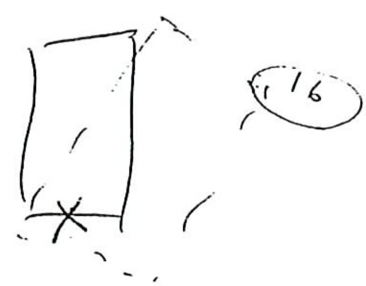
January 16, 1995

BUILDING INFORMATION

MARTIN MARIETTA
OAK RIDGE PLANT
BUILDING X-330







Plan View of Building X-330

Figure 1.2.2-1

Description	Approx. Elevation	Weight (kips)	% of Total
Cell Floor	694'-0"	14883	81.54
1st Mezzanine	708'-0"	1673	9.17
Roof	737'-3"	1697	9.30

Total Weight of Building = 18253 kips

Grade Elevation is at 671'-0"

Building X-330 Mass Distribution

Table 3.1.3-3

Horizontal Response

Based on 3-D Model of Building

Mode	Freq. (Hz.)	% Mass Part.	Dir.	% Mass Part.	Dir.
1.	0.309	73.39	N-S	0.00	E-W
2	0.892	6.98	N-S	0.53	E-W
3	0.928	0.00	N-S	98.01	E-W
4	0.964	8.05	N-S	0.00	E-W
5	1.039	2.70	N-S	0.00	E-W
6	1.460	2.35	N-S	0.00	E-W
7	1.559	4.96	N-S	0.00	E-W

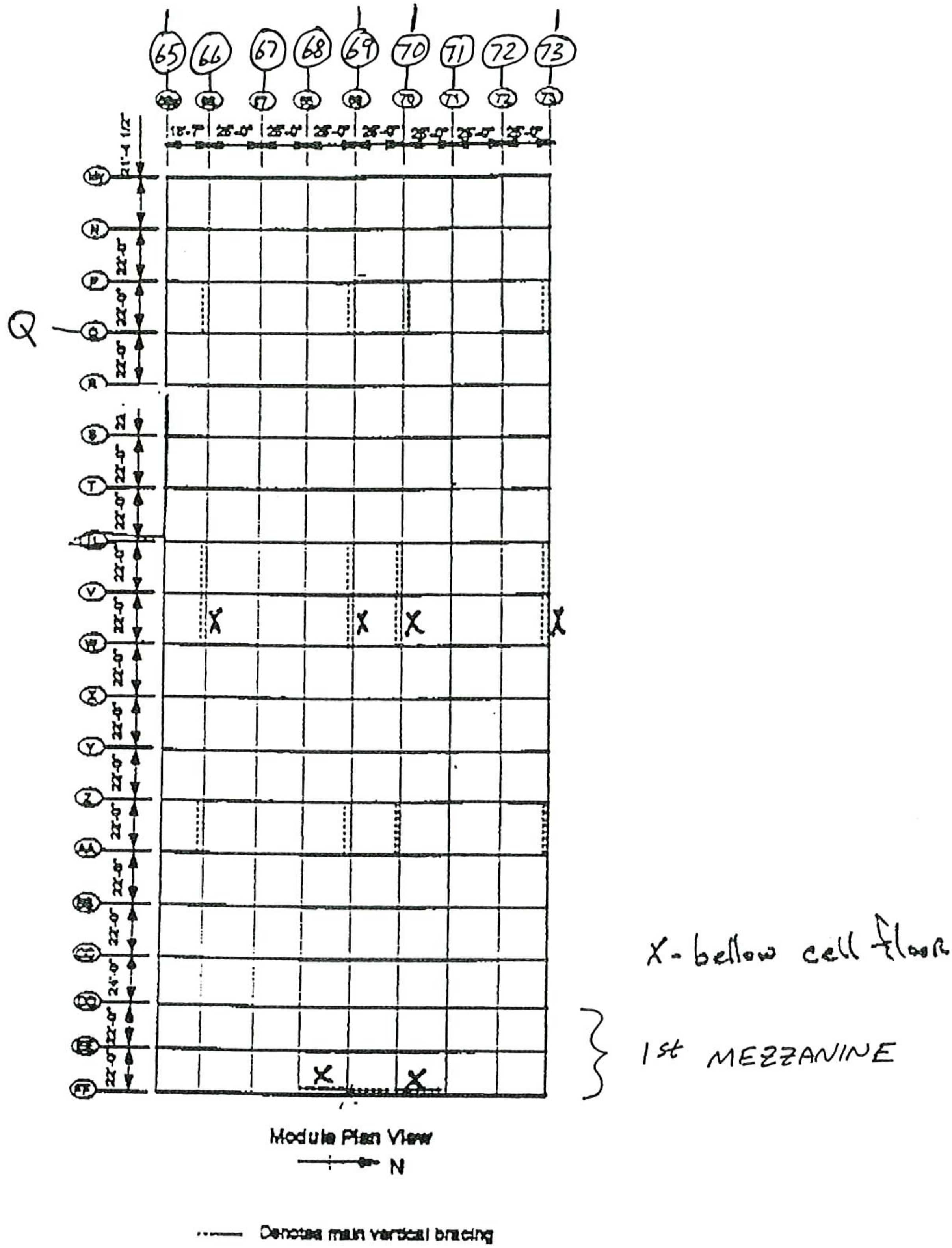
Vertical Response

Based on 2-D Section Along Column Line Q

Mode	Frequency (Hz.)	% Mass Part.
1	10.3	28.9
2	10.5	25.7
5	11.8	22.0
7	12.7	12.1
8	15.3	7.5

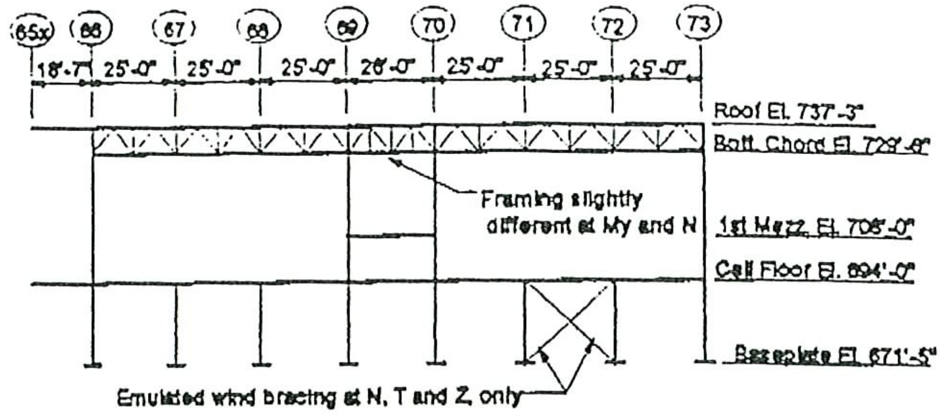
Building X-330 Seismic Response

Table 4.1.1-5

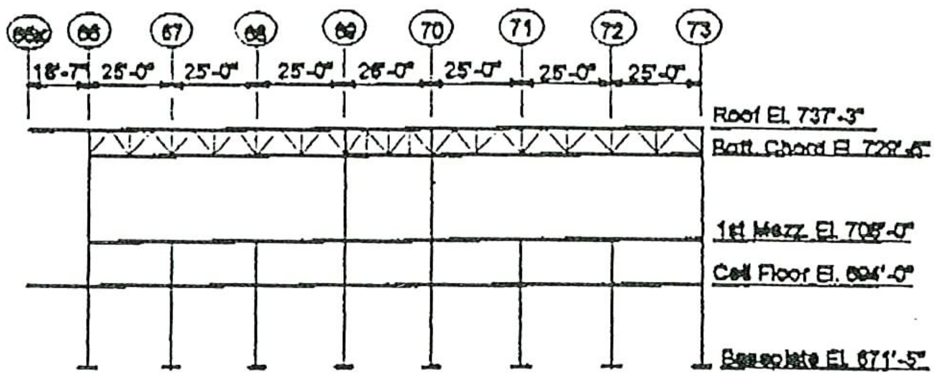


Building X-330 Typical Building Framing

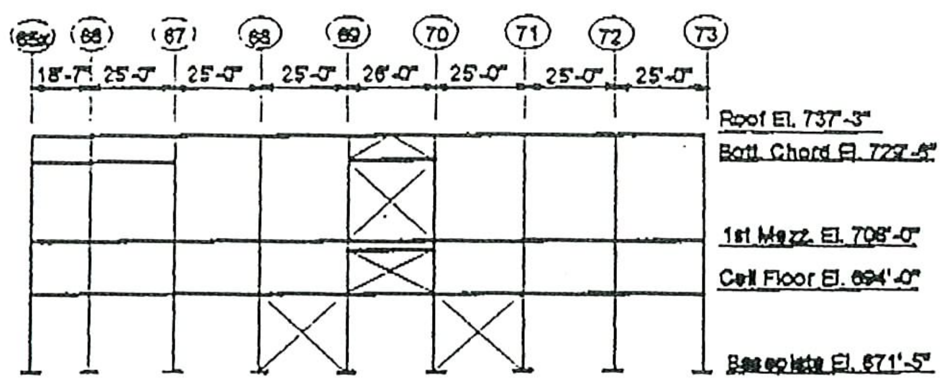
Figure 4.1.1-4



Typical N/S Section Along Column Lines
My, N, P, Q R, S, T, U, V, W, X, Y, Z, AA, BB and CC
(As noted)



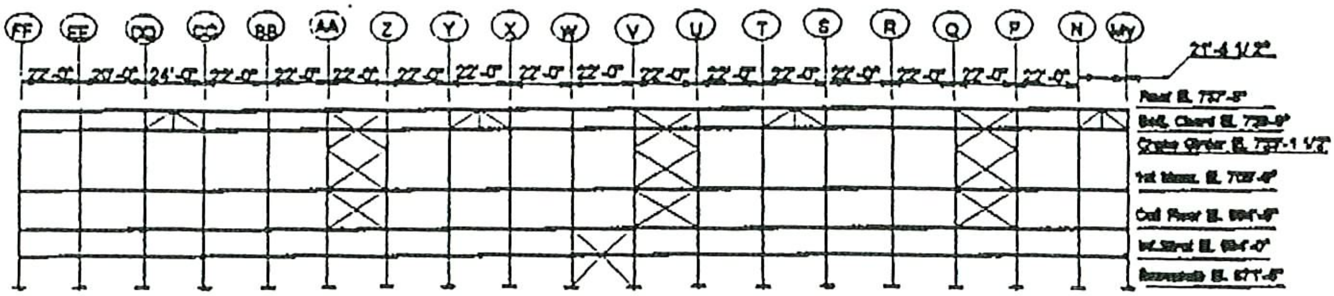
Typical N/S Sections Along Column Lines DD and EE



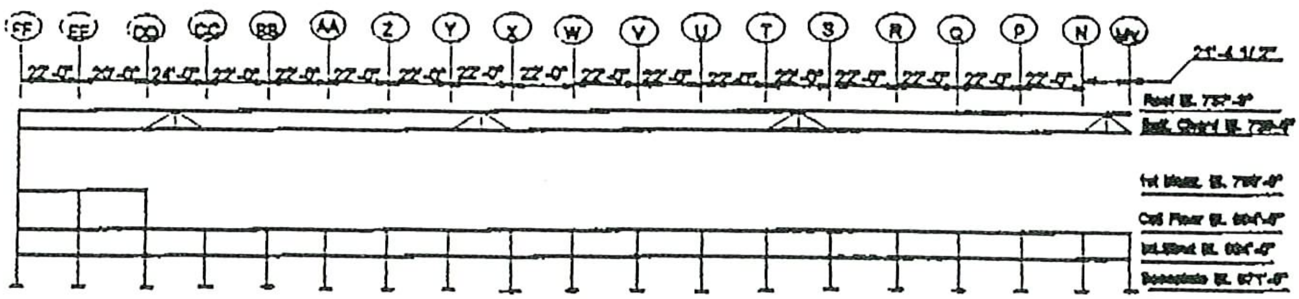
N/S Section Along Column Line FF

Building X-330 Typical Building Framing

Figure 4.1.1-4 (continued)



Typical E/W Sections Along Column Lines 66, 69, 70 and 73



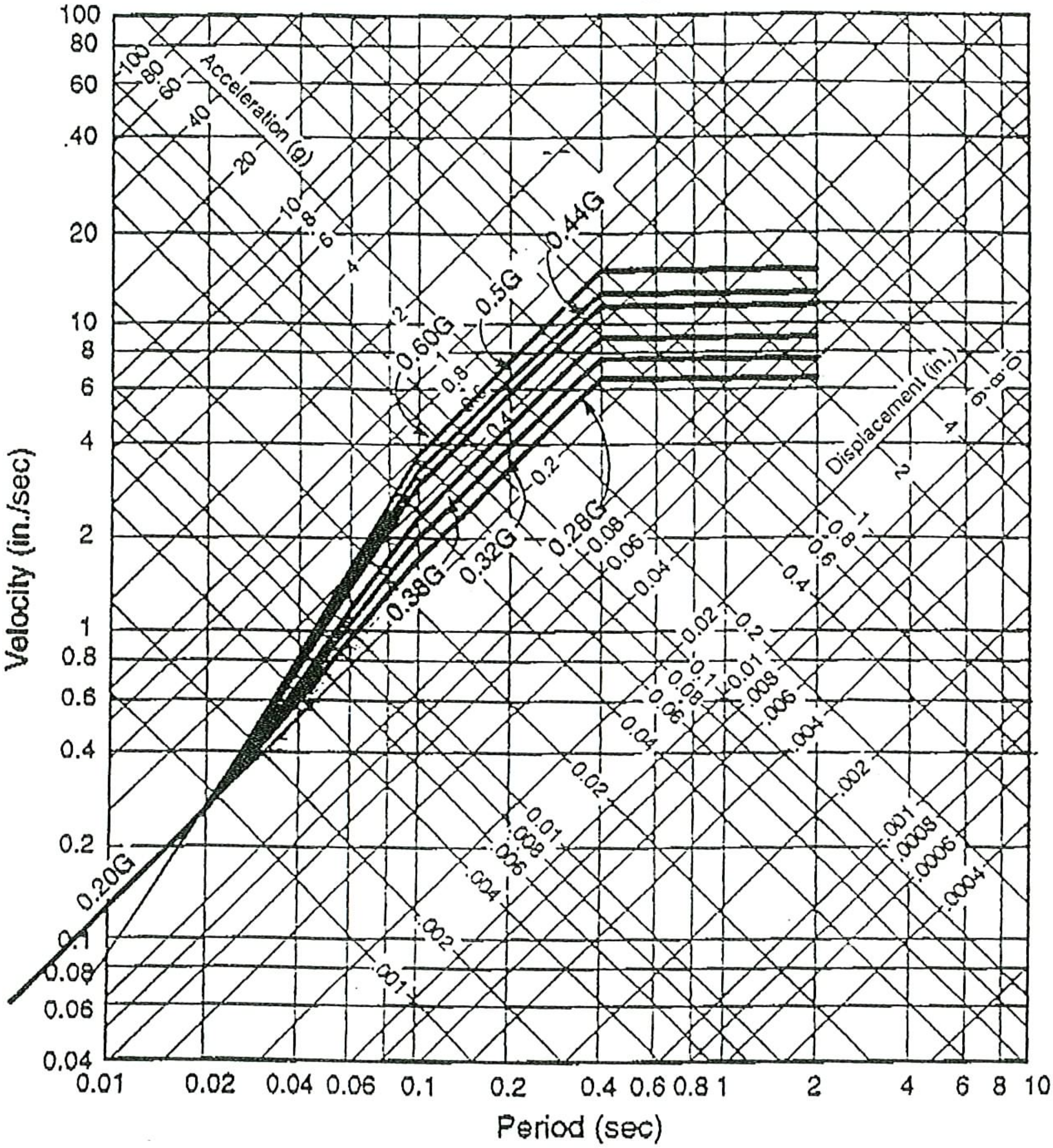
Typical E/W Sections Along Column Lines 67, 68, 71 and 72

Building X-330 Typical Building Framing

Figure 4.1.1-4 (continued)

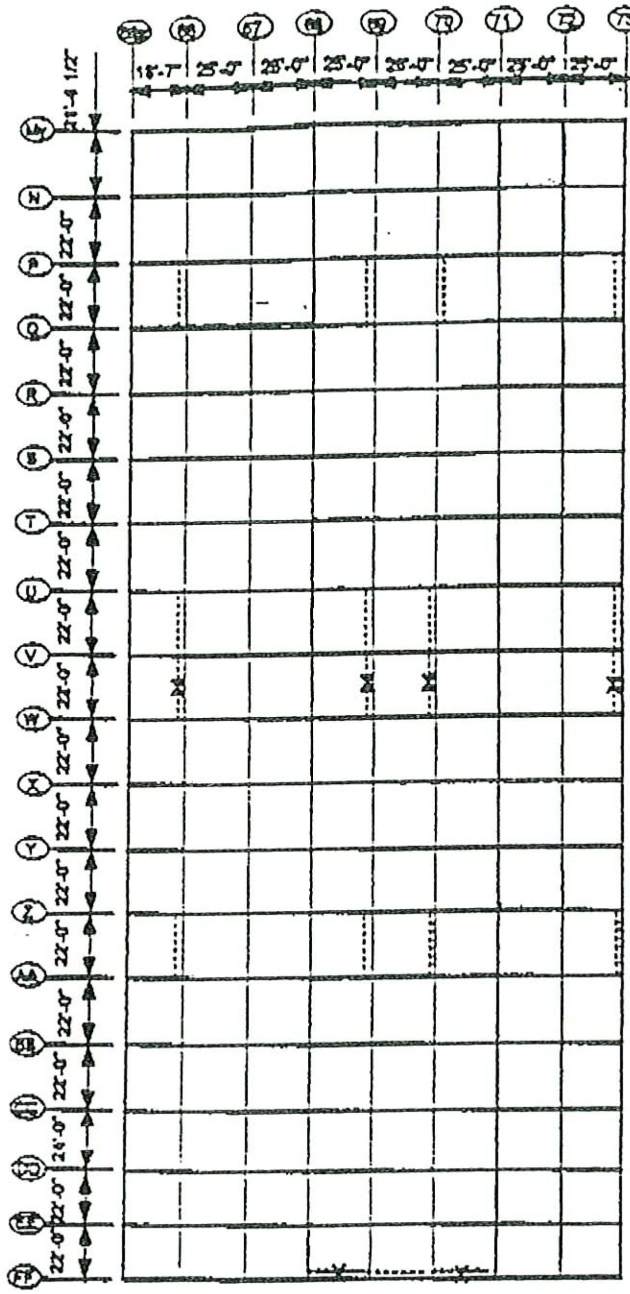
evaluated at.

Damping Ratios – 2, 5, 7, 10, 12, and 15%



PADUCAH - 500 YEAR UNIFORM HAZARD GROUND SURFACE RESPONSE SPECTRA - HORIZONTAL MOTION

Y-GA 94-57 lhm



Module Plan View

N

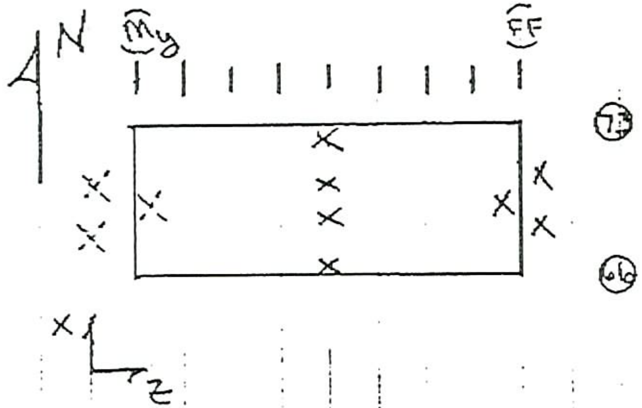
······· Denotes main vertical bracing above cell floor

--X-- Denotes main vertical bracing below cell floor

Typical Building Framing

GENERAL DESIGN AND COMPUTATION SHEET

JOB: S-331 MOD STUDY
ESO NO.: CE848401
COMPUTED: RLW
DATE:
CHECKED BY:
SHEET: of



.2g input spectra 500 yR

x - exsiting cross bracing

⁑ - added cross bracing

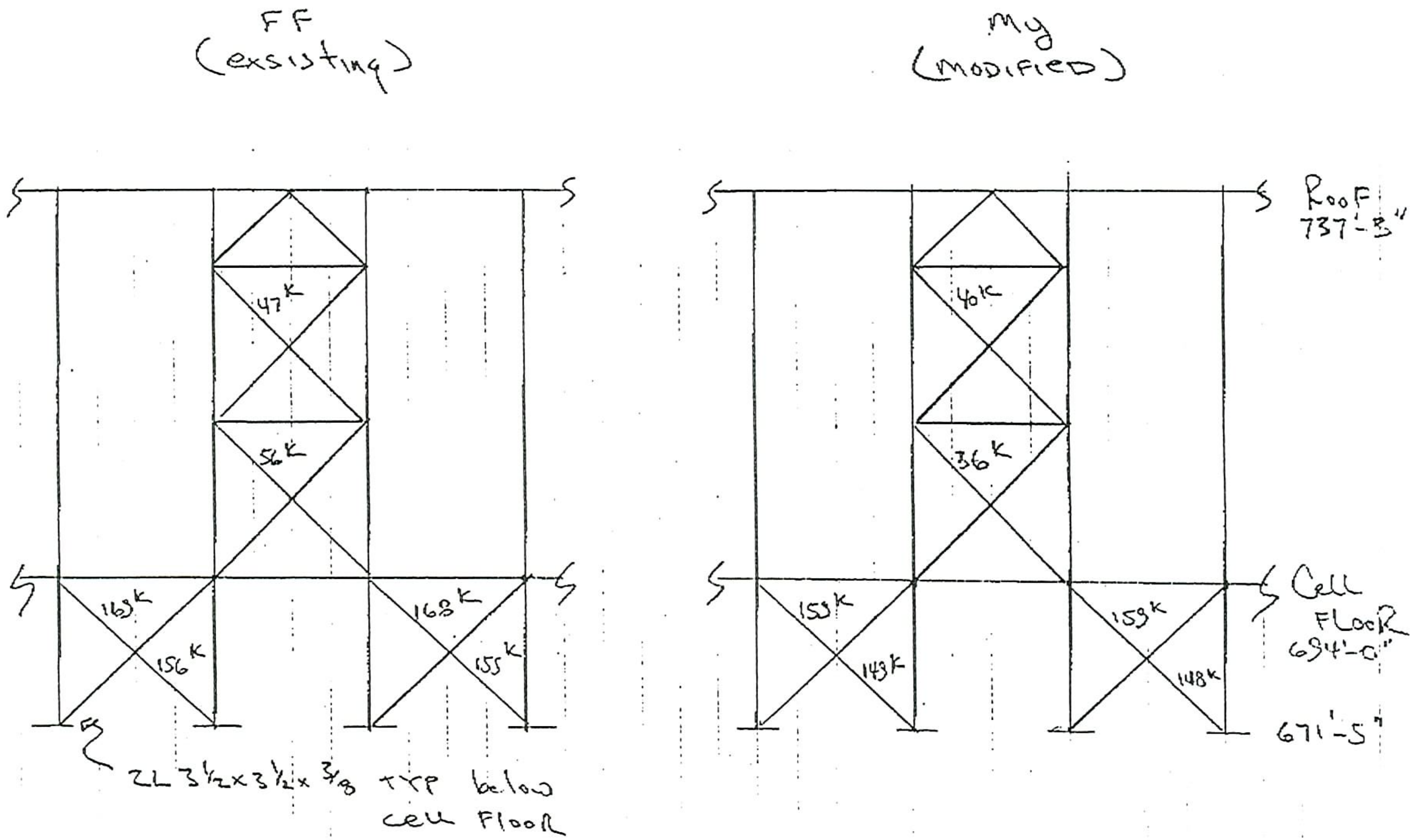
Condition	As-built	My braced to cell floor	My braced to Roof	My braced to Roof + 30% damped input spectra X & Z direction
Displ (SRSS) Roof	11.7"	7.3"	4.4"	2.23"
Displ (SRSS) Cell	6.2"	2.1"	2.1"	1.1"
Base Reaction (N-S)	160k ↑	297k ↑	328k ↑	137k ↑
Base React (E-W)	770k ↑	596k ↑	601k ↑	257k ↑
Bracing (N-S)	368k	581k	609k	325k
Bracing (E-W)	1244k	997k	1002k	523k
Bracing (N-S)	146k	180k	216k	112k
Bracing (E-W)				

Above Cell Floor
Below Cell Floor

UCN-4002A
(5 2-54)

GENERAL DESIGN AND COMPUTATION SHEET

JOB: C-331 MOD STUDY
DATE:
SHEET: of
ESO NO.: CE848401
COMPUTED: [illegible]
CHECKED BY:



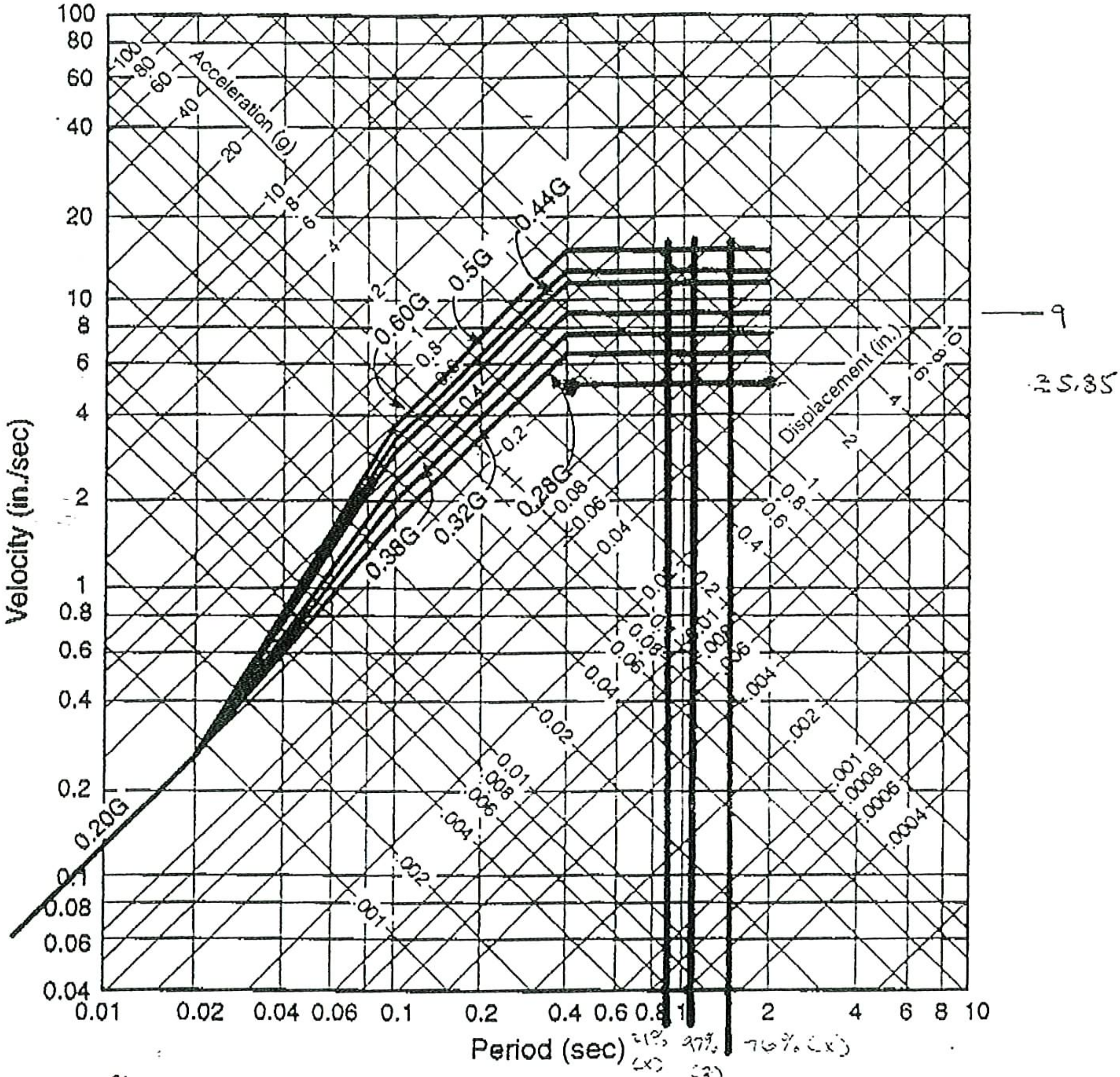
MODE	FREQ (HZ)	PERIOD (SEC)	PART FACT.	10% DAMP acc (g)	30% DAMP acc (g)
1	.70	1.43	76.1	.09	.058
2	.97	1.03	1.6	.15	
3	1.21	0.83	20.5	.18	.094

10% to 30% ≥ 35% Reductions

V@10% = 9 in/sec

V@30% ≥ 5.9 in/sec

Damping Ratios – 2, 5, 7, 10, 12, and 15%



[illegible]	% mass	10% Acc (g)
[illegible]	[illegible]	.10
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.16

PADUCAH - 500 YEAR UNIFORM HAZARD GROUND SURFACE RESPONSE SPECTRA - HORIZONTAL MOTION

Y-GA 94-57 lhm

My [illegible] to roof

11/29/94

INITIAL REVIEW

DAMPING VS. ISOLATING STUDY

MARTIN MARIETTA OAK RIDGE PLANT
BLDG X-330

CRAIG W. WINTERS

11/29/94
CWW

OAK RIDGE Y-12 PLANT

BUILDING X-330

① CONSIDER N-S DIRECTION

FIRST MODE ⇒ 1 f = 0.309 HZ 73.39% MA

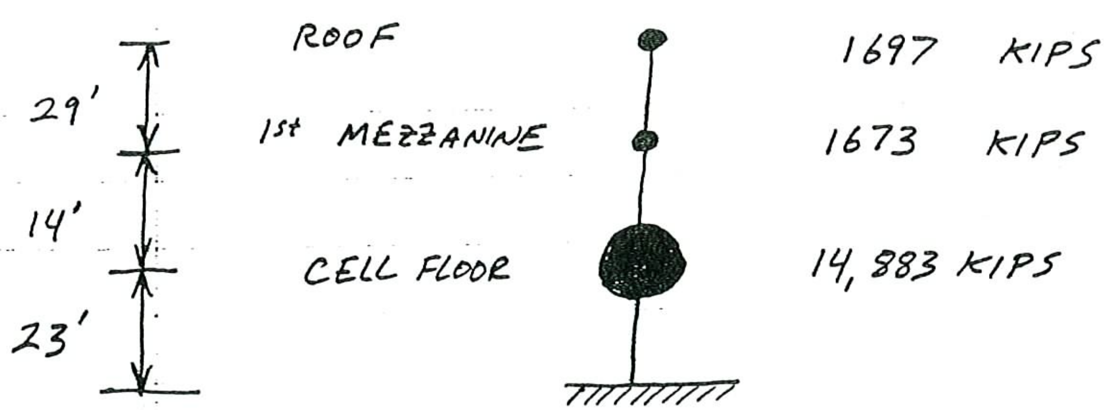
SECOND MODE ⟹ 4 f = 0.964 HZ 8.05% MA

MOST EFFECT FROM MODE 1

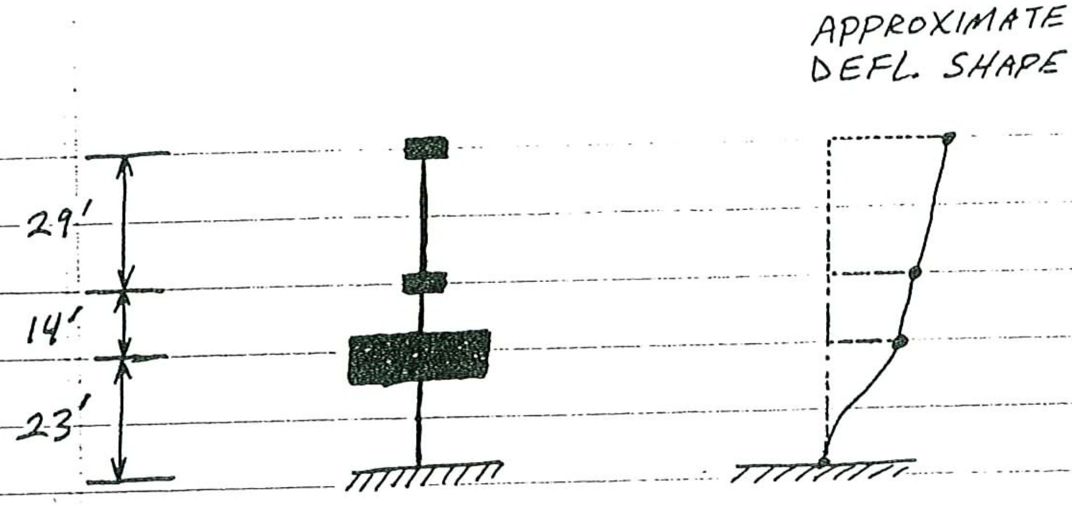
$T_1 = \frac{1}{0.309} = 3.24$ SEC

W_{TOTAL} = 18,253 KIPS

BUT, LETS LOOK AT WEIGHT DISTRIBUTION:



16" DEFLECTION



BASE ISOLATION UNNECESSARY
PERIOD = 3.24 SEC

* NOT APPROPRIATE TO SHIFT PERIOD HIGHER SINCE WE ARE ALREADY AT OR ABOVE TYPICAL PERIODS THAT AN ISOLATION SYSTEM WILL SHIFT THE STRUCTURE TO.

∴ STRUCTURE NEEDS DAMPING!

MOST DAMPERS WILL BE PLACED IN DIAGONAL BRACING FROM BASE TO FIRST FLOOR - CELL FLOOR.

SOME DAMPERS PLACED BETWEEN 1st MEZZANINE AND ROOF DUE TO THE HEIGHT (29') MAYBE ONLY A FEW

SMALL AMOUNT OR NO DAMPERS PLACED BETWEEN CELL FLOOR AND 1st MEZZANINE. SUSPECT LITTLE RELATIVE DISPLACEMENT + VELOCITIES HERE

(2) CONSIDER E-W DIRECTION

FIRST MODE $\Longrightarrow$ 3 $f = 0.928$ 98.01% MASS

EFFECTS COMING COMPLETELY FROM THIS FIRST MODE

$$T_1 = \frac{1}{0.928} = 1.08 \text{ SEC}$$

AGAIN, SAME WEIGHT DISTRIBUTION AS N-S DIRECTION

* PERIOD IS SUFFICIENTLY HIGH

$\therefore$ PROVIDE DAMPING

- AGAIN, DAMPERS PLACED IN LEVELS AS BEFORE
- MAY WANT TO PROVIDE HIGHER DAMPING IN THIS DIRECTION SINCE OUR PERIOD IS 1/3 THAT OF THE N-S DIRECTION

1/10/95

DAMPING ANALYSIS

PROVIDE 20% OF CRITICAL DAMPING WITH FLUID VISCOUS DAMPERS

HAND CALCULATIONS USING THEORY FROM NCEER-92-0032 REPORT. PERTINENT PAGES INCLUDED AT END OF THIS SECTION

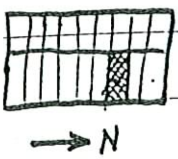
MARTIN MARIETTA OAK RIDGE PLANT
BLDG X-330

CRAIG W. WINTERS

MARTIN - MARIETTA

OAK RIDGE Y-12 PLANT BLDG X-330 — 1/13/95 CWN

ANALYSIS

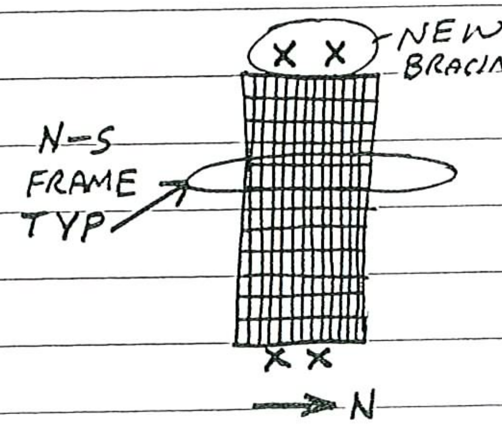


BUILDING LAYOUT COMPOSED OF 22 SIMILAR SUBFRAMES SEPARATED BY FLEXIBLE INTERFACES.

ASSUMPTION 1: NO INTERACTION BETWEEN SUBFRAMES

∴ CONSIDER 1 SUBFRAME ONLY AND PROVIDE RQ'D DAMPIN

N - S DIRECTION



WITH NEW BRACING,

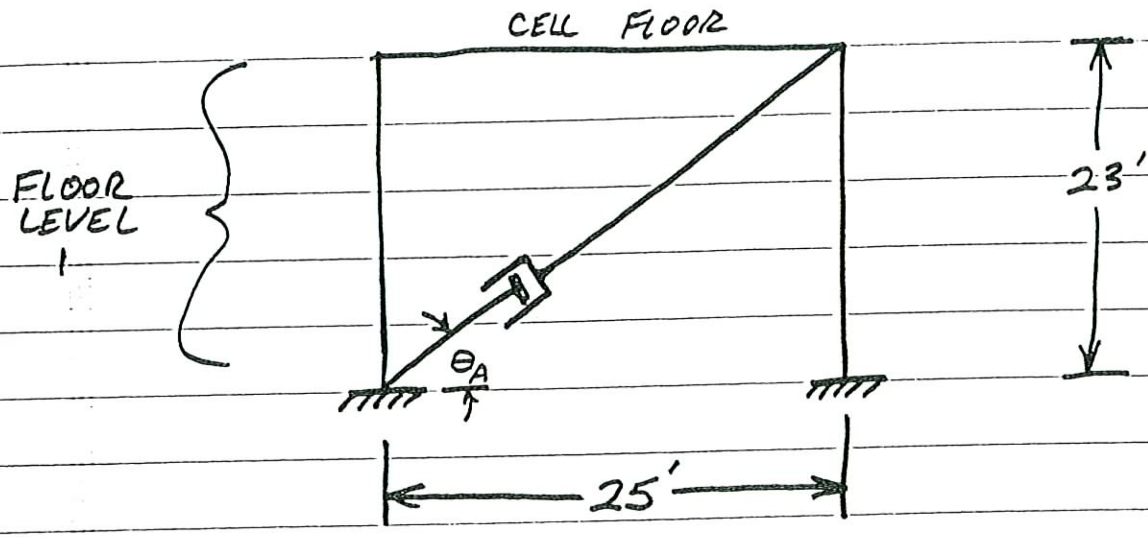
$T_1 = 1.21$ SEC

$\omega_1 = 2\pi f_1 = 2\pi \frac{1}{T_1} = 5.19$ rad/sec

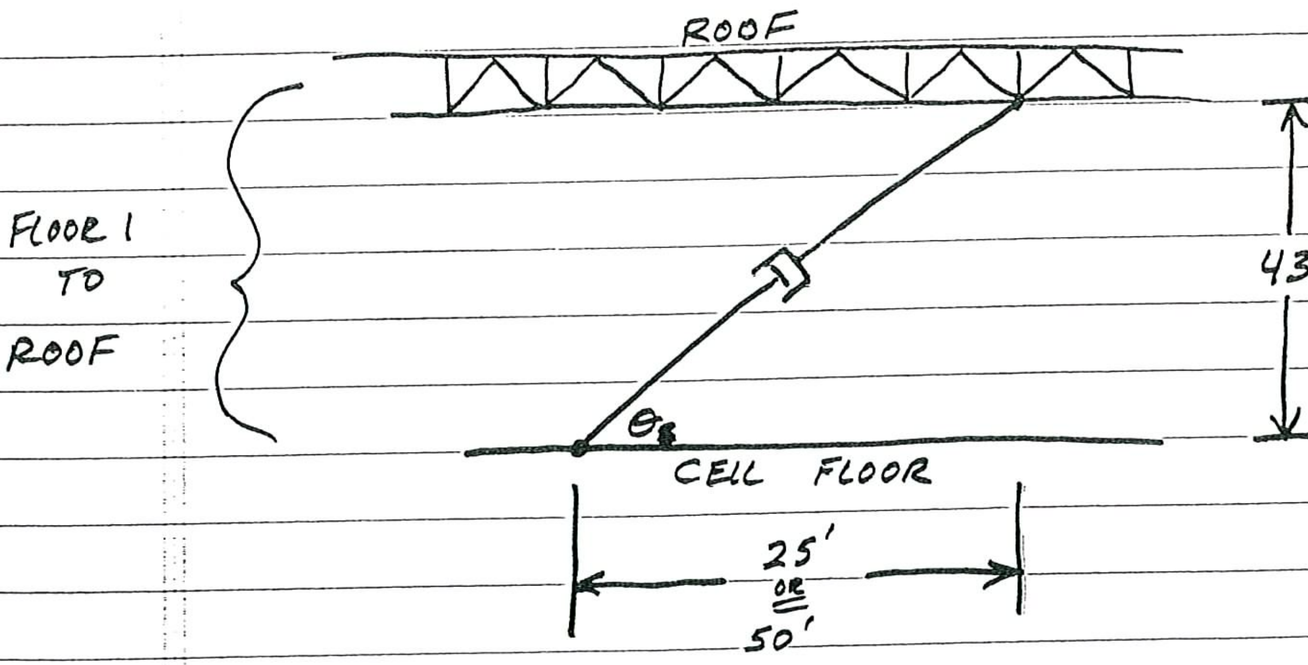
		NORMALIZED ϕ_1	W_1	m_1
FLOOR 3	ROOF	+1.0000	1697^k	4.39 $\frac{KIP \cdot s^2}{in}$
FLOOR 2	1st MEZZANINE	+0.6058	1673^k	4.33 "
FLOOR 1	CELL FLOOR	+0.3947	$14,833^k$	38.39 "

$$\sum_j m_j \phi_j^2 = 4.39 + 1.59 + 5.98 = 11.96 \ \frac{KIP \cdot sec^2}{in}$$

CALCULATE DAMPER ANGLES OF ORIENTATION



$$\theta_A = \tan^{-1}\frac{23}{25} = 42.6^\circ \qquad \cos^2\theta_A = 0.5418$$



$$\theta_B = \tan^{-1}\frac{43}{25} = 59.8^\circ \Longleftarrow \text{TRY THIS}$$

$$\tan^{-1}\frac{43}{50} = 40.7^\circ$$

$$\cos^2\theta_B = 0.2530$$

PER EQUATION (6-11) P 6-20 NCEER-92-0032
APPLY 30% OF CRITICAL DAMPING TO STRUCTURE
WITH ASSUMPTION THAT BUILDING PROVIDES 10%
OF CRITICAL DAMPING.

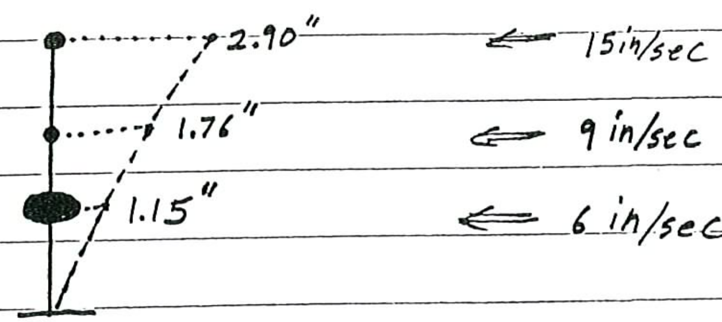
$$30\% = 10\% + \frac{1}{2}\,\frac{\sum_j C_j\left[(0.5418)(.3947)^2 + (.2530)(.6053)^2 \ldots\right]}{\left(5.19\,\frac{rad}{sec}\right)\left(11.96\,\frac{k\cdot s^2}{in}\right)}$$

$$.20 = \frac{1}{2}\,\frac{.1771\,C_j}{62.07}$$

$$C_j = 140.2\ \frac{KIP\cdot sec}{in}$$

CALCULATE REQ'D OUTPUT FORCE + VELOCITY
($F = CV$)

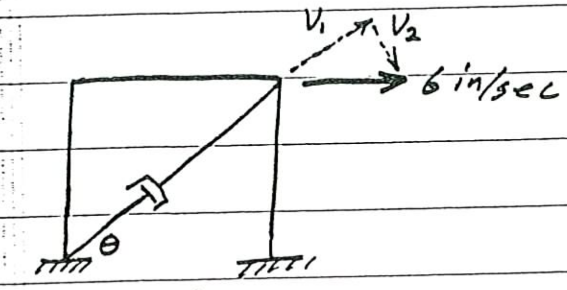
N-S
DISPLACEMENT
PROFILE



PSEUDO VELOCITY $= \omega_1 \Delta$
$= (5.19)(\Delta)$

FIND VELOCITY ALONG DAMPER DIRECTION

(CELL)
FIRST FLOOR



$\theta = 42.6°$

$\cos\theta = \frac{V_1}{6\,in/sec}$

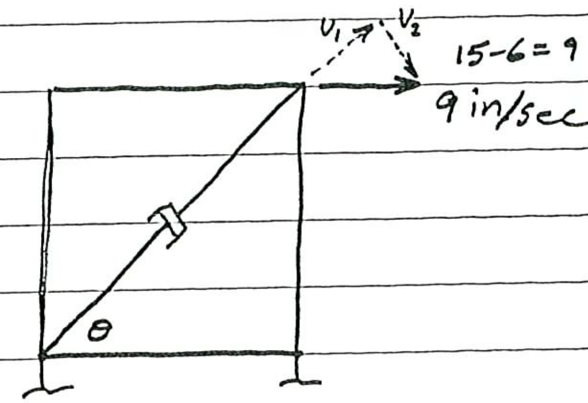
$V_1 = 4.4$ in/sec

$F = CV$

$F = (140.2)(4.4) = 620$ KIPS

USE 13pcs 50KIP DAMPER
WITH $C = 140.2\ \frac{k\cdot s}{in}$

CELL FLOOR TO ROOF



$\theta = 59.8°$

$\cos\theta = \frac{V_1}{9\,in/sec}$

$V_1 = 4.5$ in/sec

$F = CV$

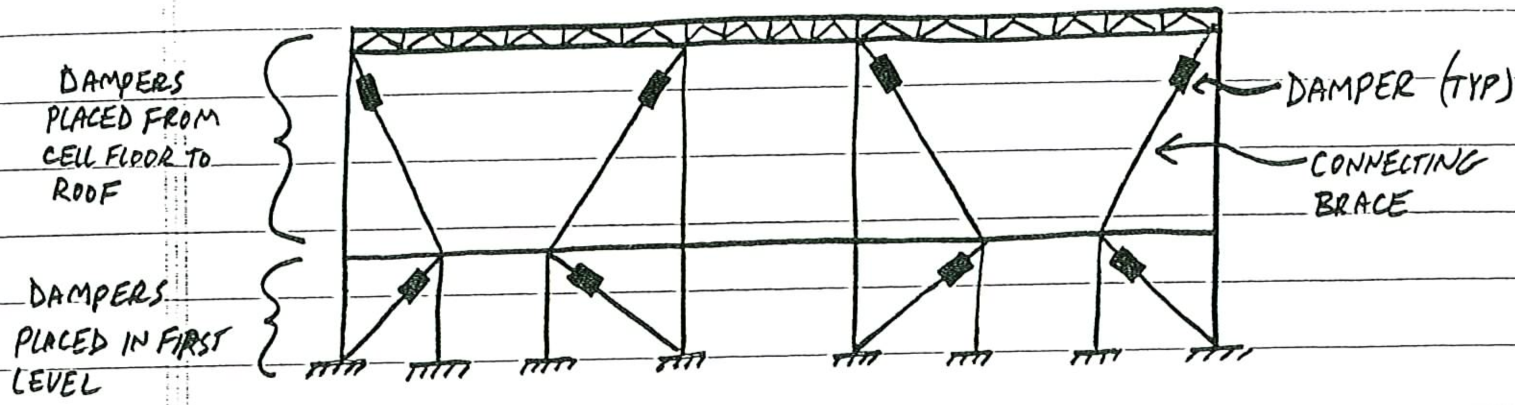
$F = (140.2)(4.5) = 630$ KIPS

USE 13pcs 50KIP
WITH $C = 140.2\ \frac{k\cdot s}{in}$

TOTAL = 26pcs 50KIP DAMPERS SET WITH $C = 140.2\ \frac{k\cdot s}{in}$
$V_{max} \approx 4.5$ in/sec STROKE = ±2"

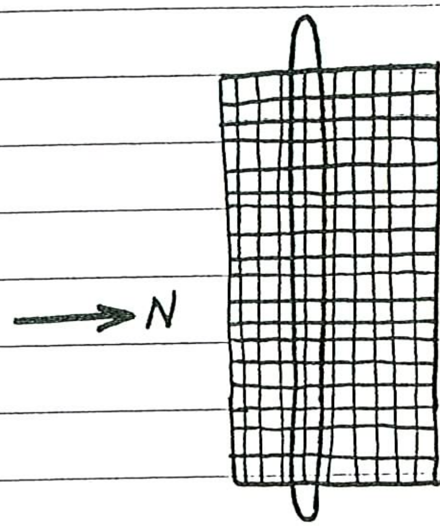
USE ±2" SET @ MID-STROKE

STROKE: $(2.90-1.15)\cos 59.8 = 0.88"$ $1.15\cos 42.6 = 0.85"$


DAMPERS PLACED FROM CELL FLOOR TO ROOF
DAMPERS PLACED IN FIRST LEVEL
DAMPER (TYP)
CONNECTING BRACE

N-S FRAME

E - W DIRECTION



E-W FRAME

$T_1 = 1.04$ SEC

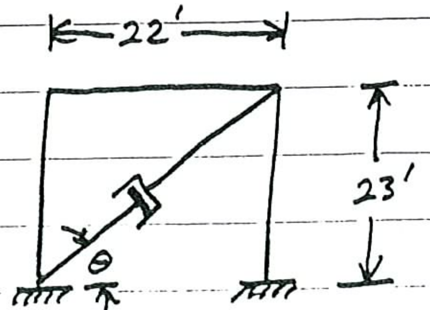
$\omega_1 = 2\pi \frac{1}{T_1} = 6.04$ rad/sec

BASED ON MODE SHAPES,
WE HAVE SEVERE SOFT FIRST STORY.
∴ PLACE ALL DAMPERS IN FIRST STORY DIAGONAL BRACING.

		NORMALIZED ϕ	W_1	m_1
FLOOR 3	ROOF	1.0000	1697^k	4.39
FLOOR 2	1st MEZZANINE	0.9487	1673^k	4.33
FLOOR 1	CELL FLOOR	0.9096	$14{,}833^k$	38.39

$\sum_j m_j \phi_j^2 = 4.39 + 3.90 + 31.76 = 40.05 \frac{\text{kip} \cdot \text{sec}^2}{\text{in}}$

DAMPER ANGLE OF ORIENTATION:



$\theta = \tan^{-1} \frac{23}{22} = 46.3°$

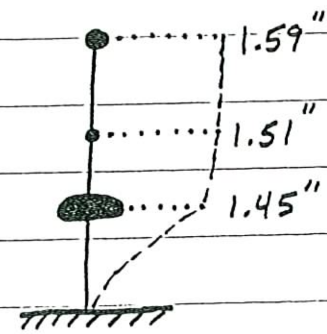
$\cos^2\theta = 0.4773$

USING EQ (6-11),

$$30\% = 10\% + \frac{1}{2}\,\frac{\sum C_j\left[(0.4773)(0.9096)^2\right]}{\left(6.04\ \frac{rad}{sec}\right)\left(40.05\ \frac{KIP \cdot sec^2}{in}\right)}$$

$$C_j = 245.0\ \frac{KIP \cdot sec}{in}$$

E-W
DISPLACEMENT
PROFILE



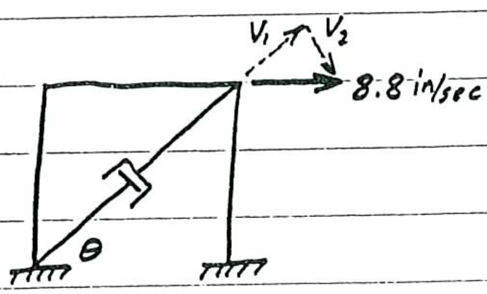
9.60 in/sec

9.12 in/sec

8.78 in/sec

PSEUDO VELOCITY = $\omega_1 \Delta$ = $(6.04)\Delta$

FIRST (CELL) FLOOR DAMPERS ONLY – FIND VELOCITY ALONG DAMPER DIRECTION:



$$\cos\theta = \frac{V_1}{8.8\ in/sec}$$

$$V_1 = 6.0\ in/sec$$

$\theta = 46.3°$

$F = CV$

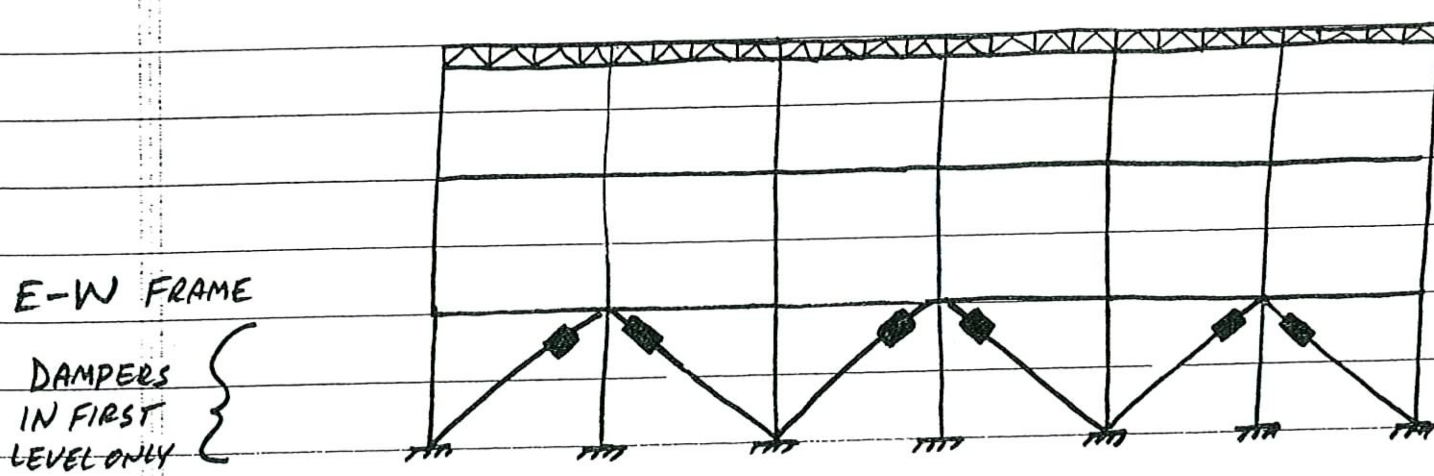
$F = (245)(6.0) = 1470$ KIPS

STROKE REQUIRED:

$\Delta = 1.45'' \cos 46.3 = 1.002''$ ∴ NEED $\pm 1.002''$

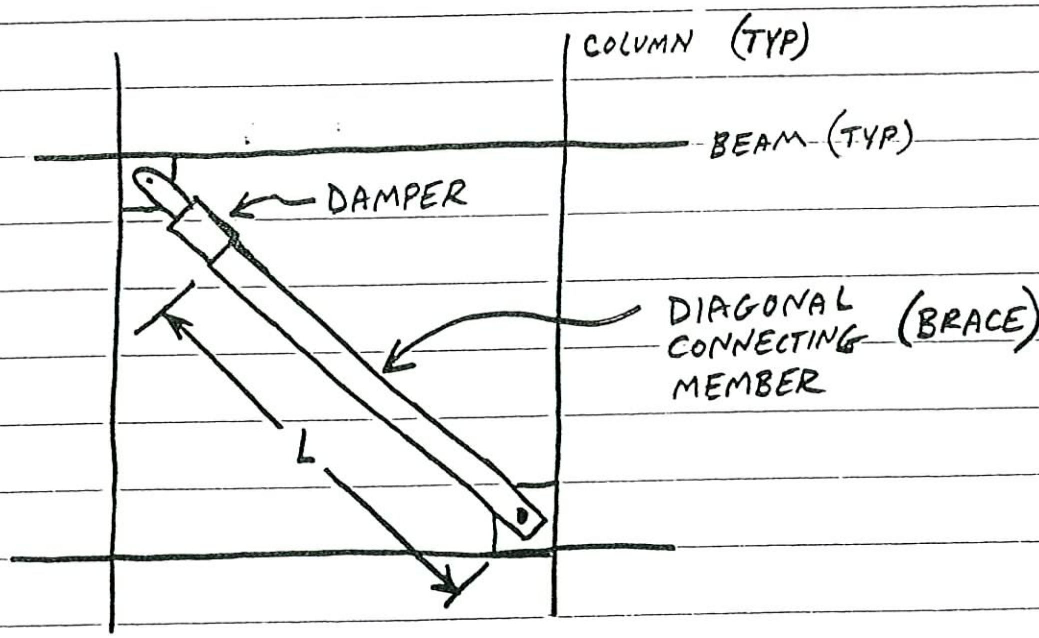
PROVIDE $\pm 2''$, USE MIDDLE OF STROKE

USE:	30pcs 50 KIP DAMPERS SET WITH	
	$C = 245 \frac{K \cdot S}{in}$	$V_{max} = 6.0$ in/sec
		$\pm 2''$ STROKE



① THE PREVIOUS ANALYSIS ASSUMES DAMPING IN BOTH DIRECTIONS. THEREFORE, DIAGONAL CONNECTING MEMBERS FOR BEAM-COLUMN JOINTS TO DAMPERS MUST BE SUFFICIENTLY LARGE TO PREVENT BUCKLING. ALSO, X-SECTION MUST BE LARGE SUCH THAT THE STRAIN IN THE CONNECTING BRACE IS NEGLIGIBLE COMPARED WITH THE DAMPER STROKE USED. GENERALLY, KEEP STRAIN BELOW 5% OF STROKE; $0.05 * 0.8'' = .04''$

$$\therefore \quad \Delta L_{BRACE} \le 0.04''$$



$$L \Rightarrow \sqrt{25^2 + 23^2} - 2' = 32' = 384''$$
$$\sqrt{25^2 + 43^2} - 2' = 47\tfrac{1}{2}' = 570''$$
$$\sqrt{22^2 + 23^2} - 2' = 30' = 360''$$

$$\epsilon = \frac{\Delta L}{L} = \frac{.04''}{570''} = 7.02 \times 10^{-5} \qquad \text{(WORST CASE)}$$

USING 50 KIP DAMPER, CALCULATE X-SECTION AREA REQUIRED:

$$\sigma = E\epsilon$$

$$\frac{P}{A} = E\epsilon$$

$$\frac{50\ \text{KIP}}{A} = (29{,}000\ \text{ksi})(7.02 \times 10^{-5})$$

$A = 24.6\ in^2$ FOR LONGEST BRACE (WORST CASE)

(10" DIA, SCHED 120 PIPE WORKS)

$A = 16.6\ in^2$ OKAY FOR OTHER TWO BRACES

(8" DIA, SCHED 120 PIPE WORKS)

BRACES ARE FAIRLY LARGE, BUT NECESSARY FOR DAMPER TO UTILIZE MAXIMUM DEFLECTION OF STRUCTURE.

N-S

Generalized mass (k-sec^2/in)./ 4.9965E+00
Generalized stiffness (k/in)../ 1.5850E+03

Mode shape: 1

	Floor	Ordinate	$(\phi_i - \phi_{i-1})$	
GRD			0.3947	
CELL	01	+0.3947	0.2111	0.6053
1st MEZ.	02	+0.6058	0.3742	
ROOF	03	+1.0000		

Mode shape: 2

Floor	Ordinate
01	-0.2956
02	+0.0389
03	+1.0000

Mode shape: 3

Floor	Ordinate
01	-0.0923
02	+1.0000
03	-0.2777

Mode number: 1

Floor	Floor Disp(in.)	Floor Force(kips)	Story Shear(kips)	Floor Acc(g's)	Story Drift(in.)

E-W

Generalized mass (k-sec^2/in)./ 5.0103E+00
Generalized stiffness (k/in)../ 1.4736E+04

Mode shape: 1

$(\phi_i - \phi_{i-1})$

	Floor	Ordinate	
GND			0.9096
CELL	01	+0.9096	
1st MEZ	02	+0.9487	0.0904
ROOF	03	+1.0000	

Mode shape: 2

Floor	Ordinate
01	-0.1514
02	+0.2218
03	+1.0000

Mode shape: 3

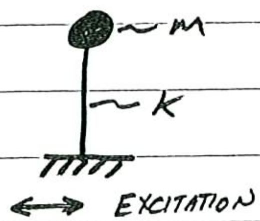
Floor	Ordinate
01	-0.0770
02	+1.0000
03	-0.3209

Mode number: 1

Floor	Floor Disp(in.)	Floor Force(kips)	Story Shear(kips)	Floor Acc(g's)	Story Drift(in.)

ANALYSIS CHECK

E-W DIRECTION (CAN EASILY BE SDOF MODEL)



$W = 1697 + 1673 + 14833 = 18{,}203$

$m = \frac{W}{g} = 47.11 \ \frac{k \cdot sec^2}{in}$

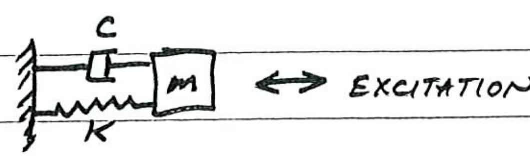
$T = 1.04 \ sec \implies \omega = 6.04 \ rad/sec$

$$\xi = \frac{c}{2m\omega}$$

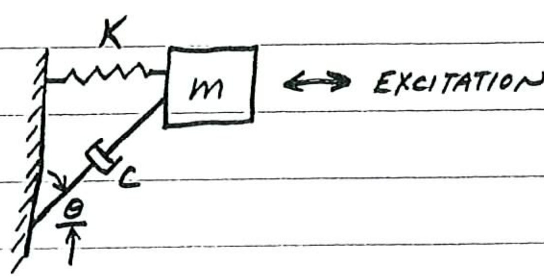
$$\xi = \frac{245 \frac{k \cdot s}{in}}{2\left(47.11 \frac{k \cdot s^2}{in}\right)\left(6.04 \ rad/s\right)} = 43\% \text{ OF CRITICAL}$$

BUT, THIS EQUATION DOES NOT TAKE INTO ACCOUNT THE ∡ θ.

ABOVE EQ ASSUMES:



BUT WE HAVE:



∴ MUST MULTIPLY BY $\cos^2\theta$

$\theta = 46.3° \implies \cos^2\theta = (0.69)^2$
$= 0.4773$

$\xi = 0.4773(43\%) = 20.5\%$ ✓

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
State University of New York at Buffalo

Experimental and Analytical Investigation of Seismic Response of Structures with Supplemental Fluid Viscous Dampers

by

M. C. Constantinou and M. D. Symans
State University of New York at Buffalo
Department of Civil Engineering
Buffalo, New York 14260

Technical Report NCEER-92-0032

December 21, 1992

This research was conducted at the State University of New York at Buffalo and was partially supported by the National Science Foundation under Grant No. BCS 90-25010 and the New York State Science and Technology Foundation under Grant No. NEC-91029.

The application of the response spectrum analysis method requires that estimates of the structural properties are available.

6.3.1 Approximate Determination of Structural Properties

Approximate methods for the determination of the frequencies, mode shapes and damping ratios of non-classically damped structures have been successfully applied in problems involving soil-structure interaction (e.g., Novak 1983; Constantinou 1987). Veletsos (1986) presented a comprehensive treatment of the method.

The method starts with the assumption that frequencies and mode shapes of the non-classically damped structure are identical to those of the undamped structure. Typically, these quantities are determined in a standard eigenvalue analysis.

The modal damping ratios are determined from an analysis involving energy considerations. The damping ratio in the k-th mode of vibration may be expressed as

$$\xi_k = \xi_{str_k} + \frac{W_k}{4\pi L_k} \qquad (6\text{-}6)$$

where ξ_{str_k} is the damping ratio due to damping inherent to the structure, W_k is the work done by the dampers in a single cycle of motion, and L_k is the maximum strain energy. W_k may be expressed as

$$W_k = \sum_j \int_0^{T_k} P_j d(u_j - u_{j-1}) \qquad (6\text{-}7)$$

where P_j is the horizontal component of the force in the dampers at the j-th story, and u_j is the modal displacement of the j-th floor. For the case of purely viscous dampers, it can be shown that

$$P_j = C_j \cos^2\theta_j (\phi_j - \phi_{j-1}) \omega_k \cos(\omega_k t) \qquad (6\text{-}8)$$

where C_j is the combined damping coefficient of the dampers at the j-th story, θ_j is the angle of inclination of the dampers at the j-th story, ϕ_j is the modal displacement of the j-th floor in the k-th mode of vibration, and ω_k is the frequency of vibration in the k-th mode. Combining Equations 6-7 and 6-8, W_k can be written as

$$W_k = \pi \omega_k \sum_j C_j \cos^2\theta_j (\phi_j - \phi_{j-1})^2 \qquad (6\text{-}9)$$

The maximum strain energy is equal to the maximum kinetic energy, so that

$$L_k = (KE)_{MAX} = \frac{1}{2} \sum_j m_j \phi_j^2 \omega_k^2 \qquad (6\text{-}10)$$

Combining Equations 6-6, 6-9 and 6-10, the damping ratio of the structure in the k-th mode of vibration is determined to be

$$\xi_k = \xi_{str_k} + \frac{1}{2} \frac{\sum_j C_j \cos^2\theta_j (\phi_j - \phi_{j-1})^2}{\omega_k \sum_j m_j \phi_j^2} \qquad (6\text{-}11)$$

It is clear from Equation 6-11 that in order to have the greatest contribution to the modal damping ratio, the dampers should be placed at story levels where the modal interstory drift $(\phi_j - \phi_{j-1})$ is maximum.

The accuracy of the simple energy approach in determining the damping ratios of the tested structures is demonstrated in Tables 6-I and 6-II. The tables include the damping ratios calculated by the complex eigenvalue approach of Section 4 wherein the calibrated rigorous Maxwell model is utilized for the fluid dampers. The calculation was repeated by utilizing the simple viscous model and,

TABLE 6-I Comparison of Damping Ratios of One-Story Model Structure

STRUCTURE	NUMBER OF DAMPERS	RIGOROUS METHOD MAXWELL MODEL	RIGOROUS METHOD VISCOUS MODEL	ENERGY APPROACH VISCOUS MODEL
UNSTIFFENED	2	0.284	0.280	0.280
STIFFENED		0.193	0.192	0.192
UNSTIFFENED	4	0.577	0.554	0.554
STIFFENED		0.374	0.363	0.363

TABLE 6-II Comparison of Damping Ratios of 3-story Model Structure

NUMBER OF DAMPERS	RIGOROUS METHOD MAXWELL MODEL			RIGOROUS METHOD VISCOUS MODEL			ENERGY APPROACH VISCOUS MODEL		
	MODE 1	MODE 2	MODE 3	MODE 1	MODE 2	MODE 3	MODE 1	MODE 2	MODE 3
2	0.099	0.147	0.050	0.100	0.154	0.049	0.100	0.149	0.051
4	0.177	0.319	0.113	0.183	0.326	0.081	0.183	0.291	0.098
6	0.194	0.447	0.380	0.193	0.428	0.490	0.193	0.428	0.490

thus, solving exactly the eigenvalue problem of the non-classically damped structure (λ was set equal to zero). Finally, the procedure of Equation 6-11 was employed.

The results demonstrate that the damping in the fundamental mode is predicted very well by the energy approach. In addition, the energy approach provides reasonable approximations to the damping ratios of the higher modes. The error in the calculation of the higher mode damping ratios is due to neglect of the stiffening effect of the tested fluid dampers at frequencies exceeding about 4 Hz.

6.3.2 Determination of Peak Response

The determination of the peak structural response to an excitation described by a response spectrum requires that the peak response in each significant mode of vibration be evaluated first (Clough 1975). The required mode shapes, frequencies and damping ratios are determined by the procedures described in Section 6.3.1. The calculated peak modal responses are then combined by an appropriate combination rule to give estimates of the peak response.

The only complexity in the application of this approach is that of constructing high damping response spectra from the usually specified 5%-damped spectra. A recent study on this problem has been reported by Wu (1989). However, it may be appropriate to include de-amplification factors of design spectra at high damping in future design requirements of structures with supplemental damping devices. This will ensure uniformity, reasonable conservatism and avoidance of gross errors.