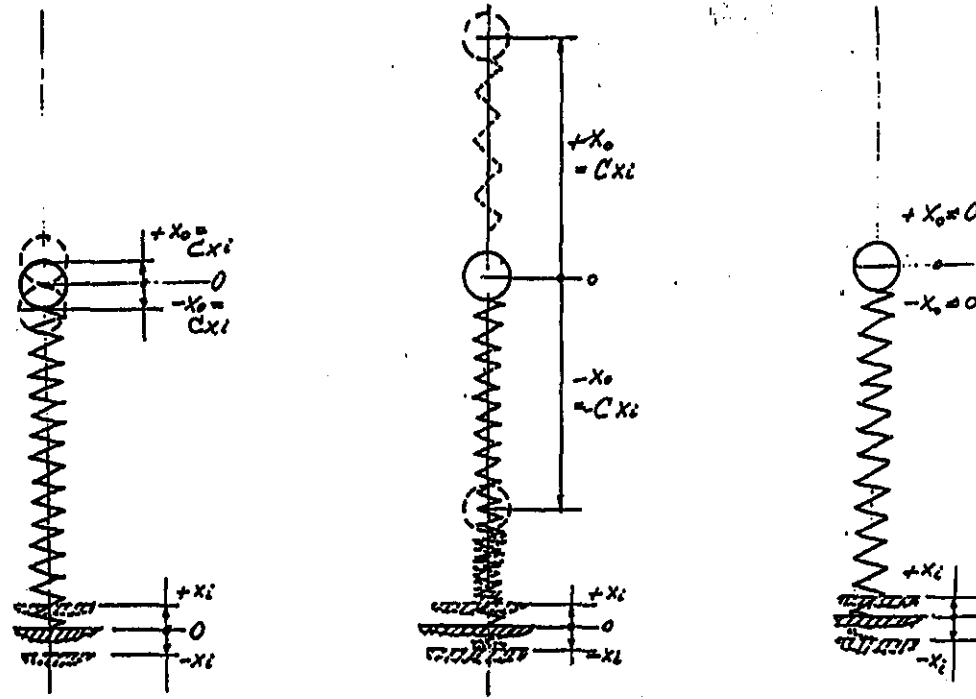
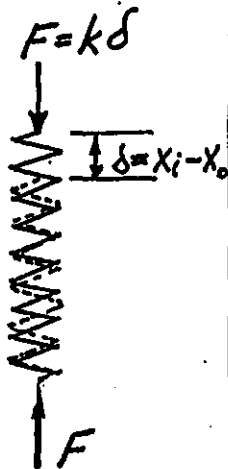


Fores on Spring



(a) At Very Low Frequency :

- $v/\omega = 0$
- Output = Input: $x_o = x_i$
- Amplification $C = x_o / x_i = 1$
- Change in spring length = $\delta = (x_o - x_i) = 0$
- Change of Force in spring due to vibration $\Delta F = 0$

(b) At Resonance :

- $v/\omega = 1$
- Output = Input: $x_o = C x_i$
- Amplification $C = x_o / x_i = 1/2\beta$
at $\beta = 5\%$, $C_s = 10$
at $\beta = 3\%$, $C_s = 16.67$
- Change in spring length = $\delta = (x_o - x_i) = (C - 1) x_i$
- Change of Force in spring due to vibration $\Delta F = k \delta = k \cdot (C - 1) x_i$

(c) At Very High Frequency :

- $v/\omega > 10$
- Output = $x_o = 0$
- Amplification $C = x_o / x_i = 0$
- Change in spring length = $\delta = (x_o - x_i) = (0 - 1) \cdot x_i = -x_i$
- Change of Force in spring due to vibration $\Delta F = k \cdot \delta = k x_i$

Response for Varied Frequency at Uniform Input Displacement

Displacements and Forces

Figure 4-1 Vibration Behaviour of a Simple Spring-Mass System

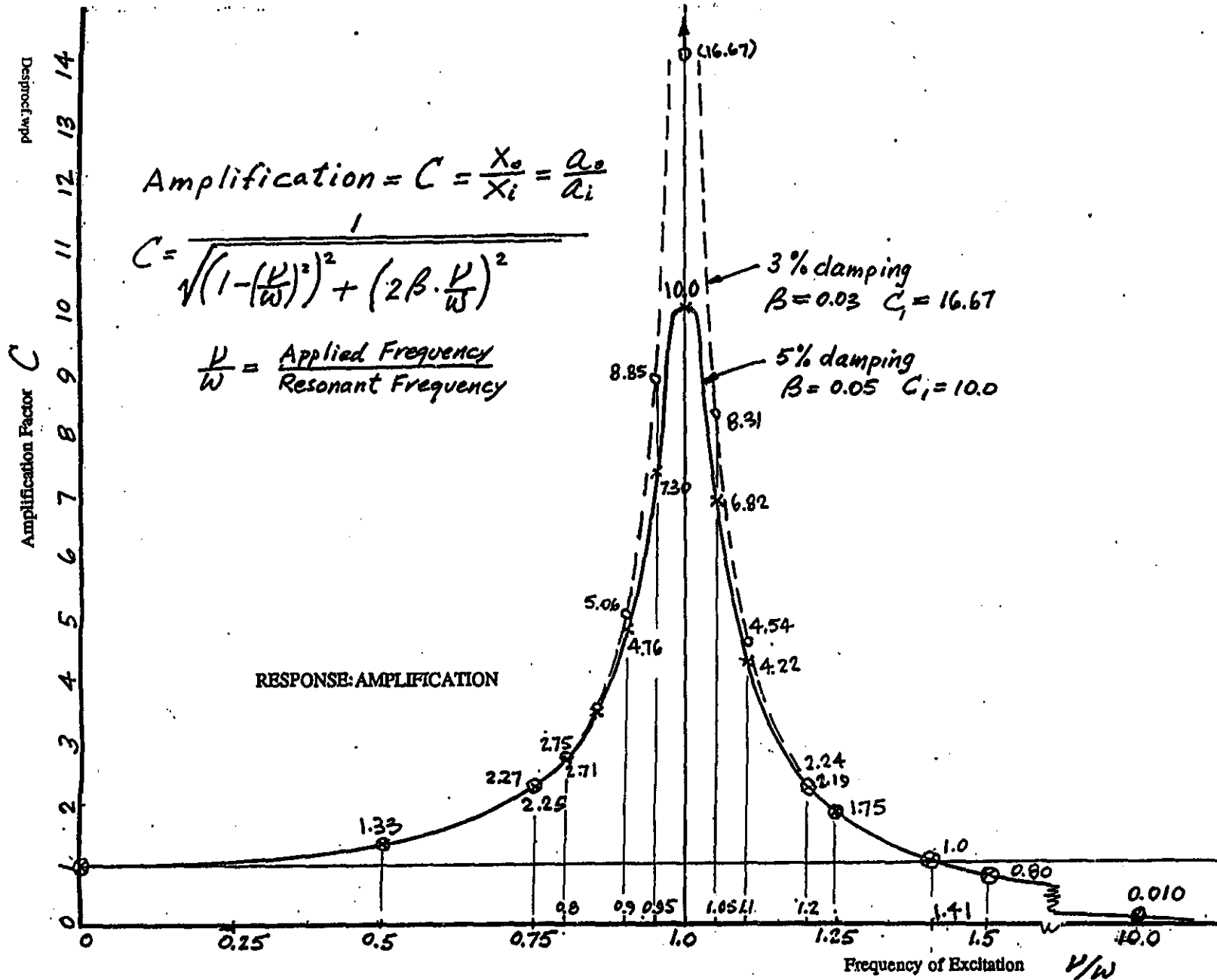
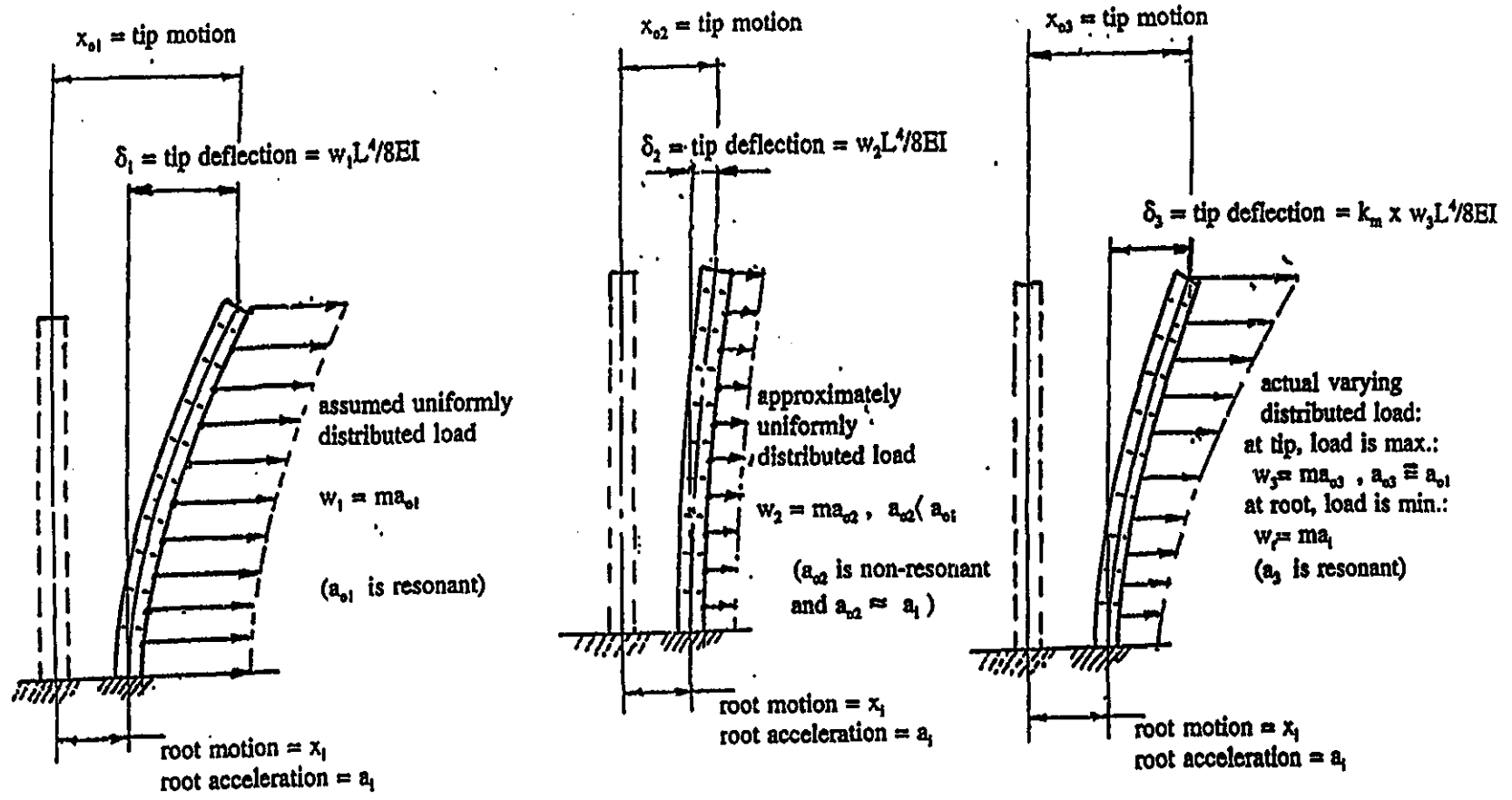


Figure 4.2 Response Amplitude for a Vibrating System

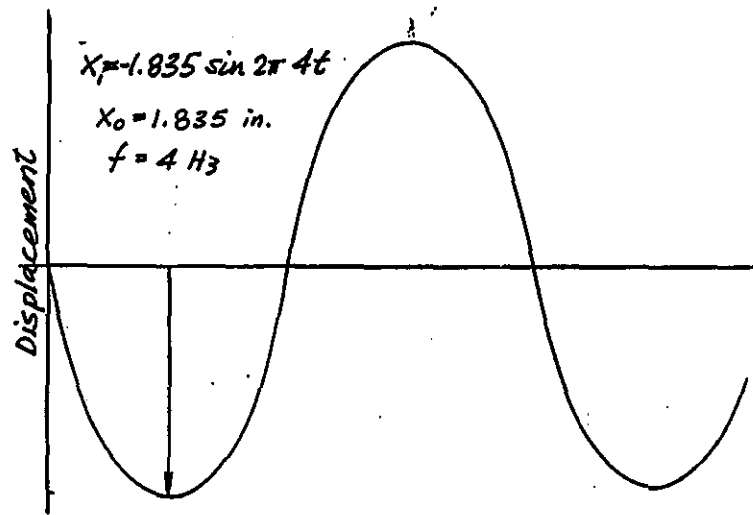
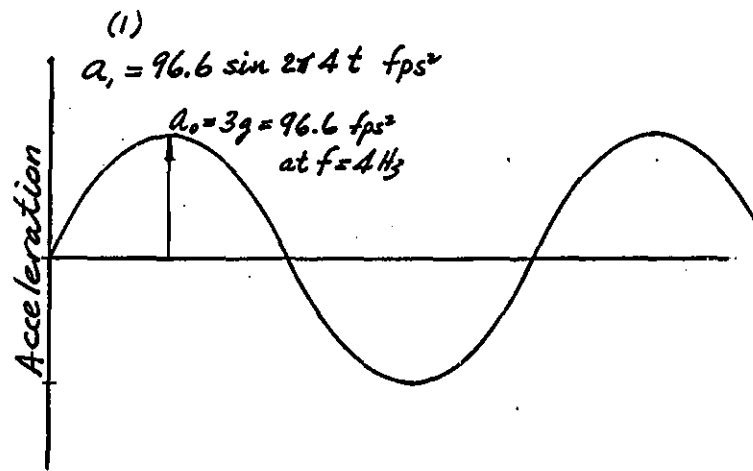


a) Tip Deflection for Uniformly Distributed Load

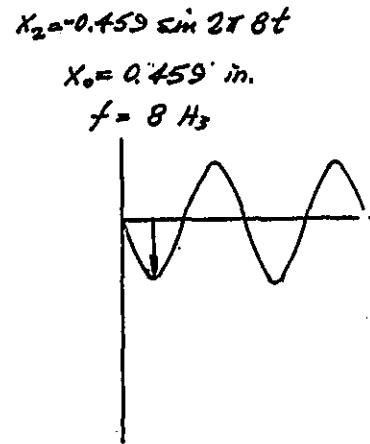
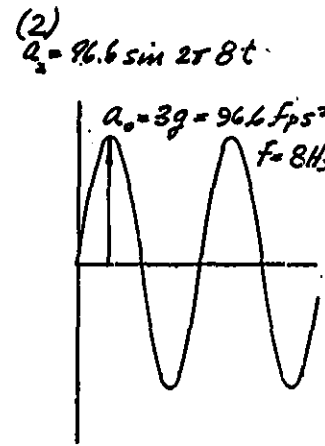
b) Tip Deflection for Whole-Body (Non-Resonant) Motion

c) Tip Deflection for Actual Varying Distributed Load

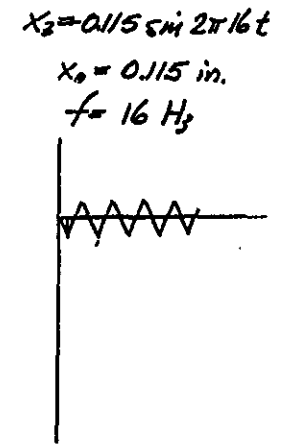
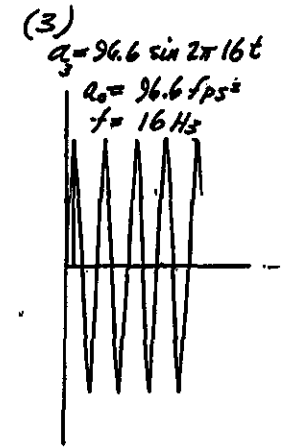
Figure 4-3 Response of a Vibrating Cantilever Beam



(1) $f_1 = 4 \text{ Hz}$ & $a_0 = 3 g = 96.6 \text{ f/s}^2$



(2) $f_2 = 8 \text{ Hz}$ & $a_0 = 3 g = 96.6 \text{ f/s}^2$

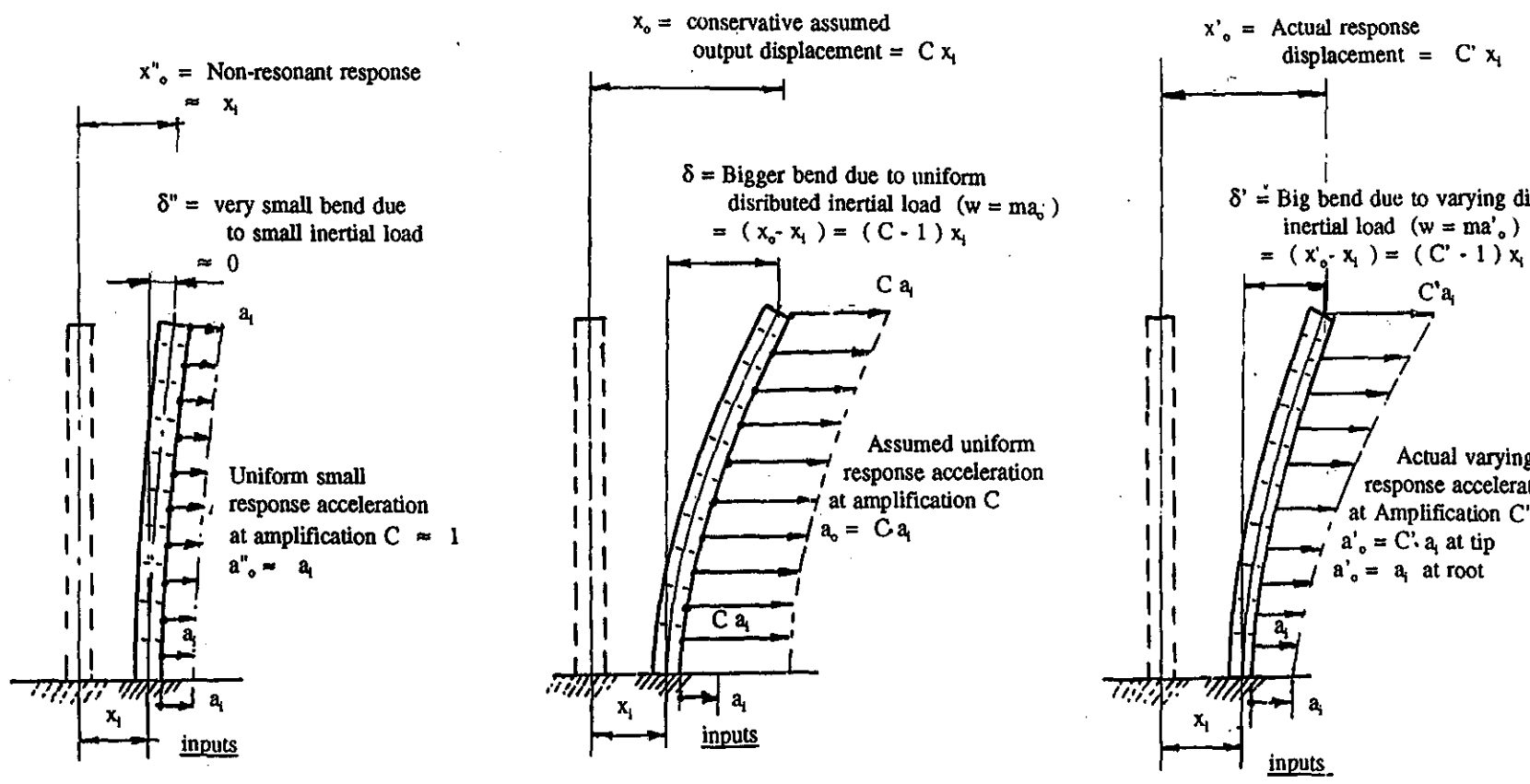


(3) $f_3 = 16 \text{ Hz}$
 & $a_0 = 3 g = 96.6 \text{ f/s}^2$

Displacement Generated by Sinusoidal Motion at Different Frequencies at Constant Acceleration

$$x = x_0 \sin 2\pi ft \quad a = x'' = -a_0 \sin 2\pi ft \quad a_0 = 4\pi^2 f^2 x_0 \quad \text{or} \quad x_0 = a_0 / 4\pi^2 f^2$$

Figure 4-4 Simple Harmonic Motion



(1) Non-Resonant Response

(2) Amplified Response for Assumed Uniform Response Acceleration

(3) Amplified Response for Actual Varied Response Acceleration

Figure 4-5 Displacement and Deflection on a Vibration Cantilever Beam

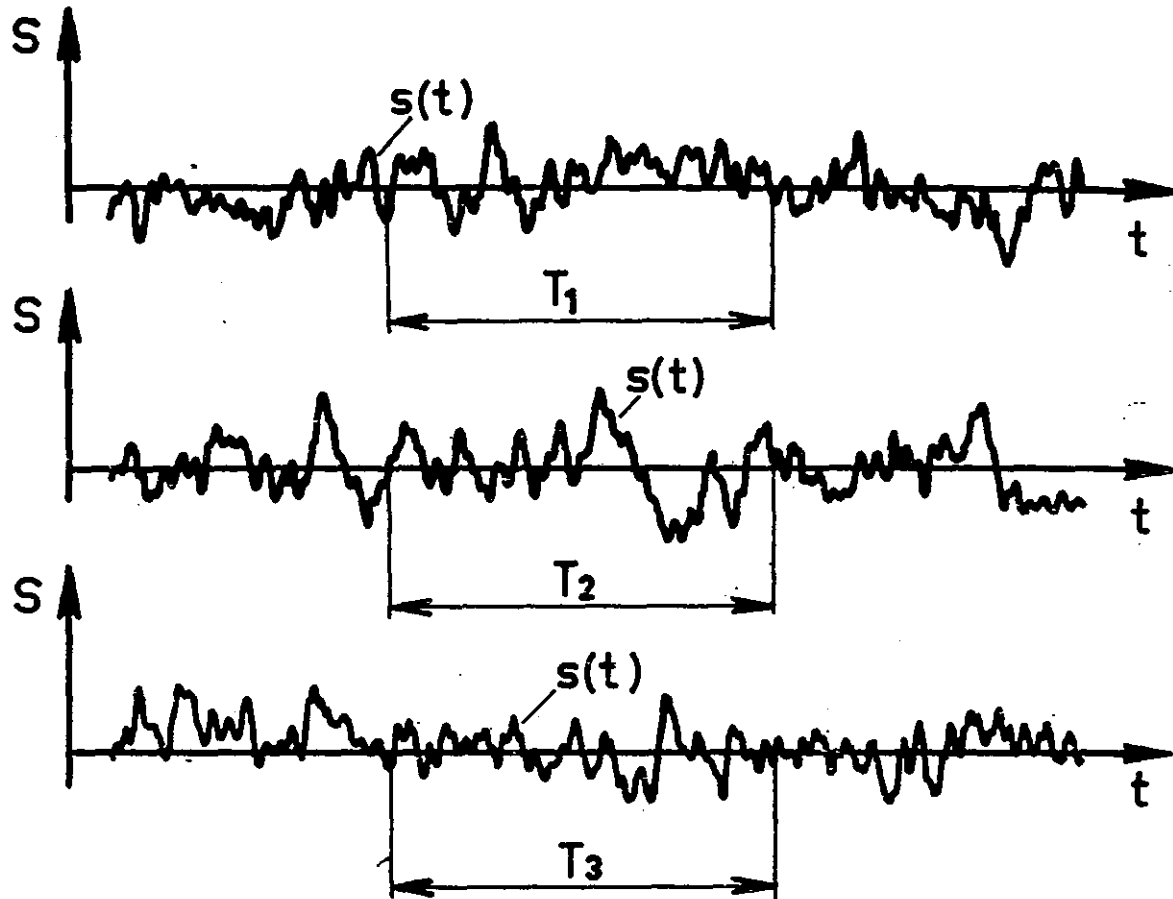


Figure 4-6 Time-History of Typical Complex Vibration

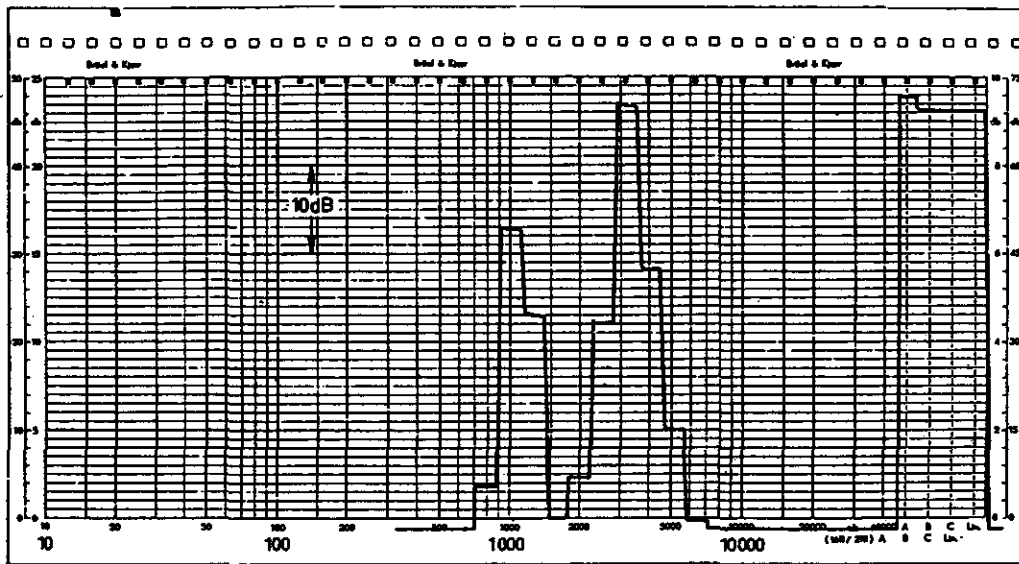
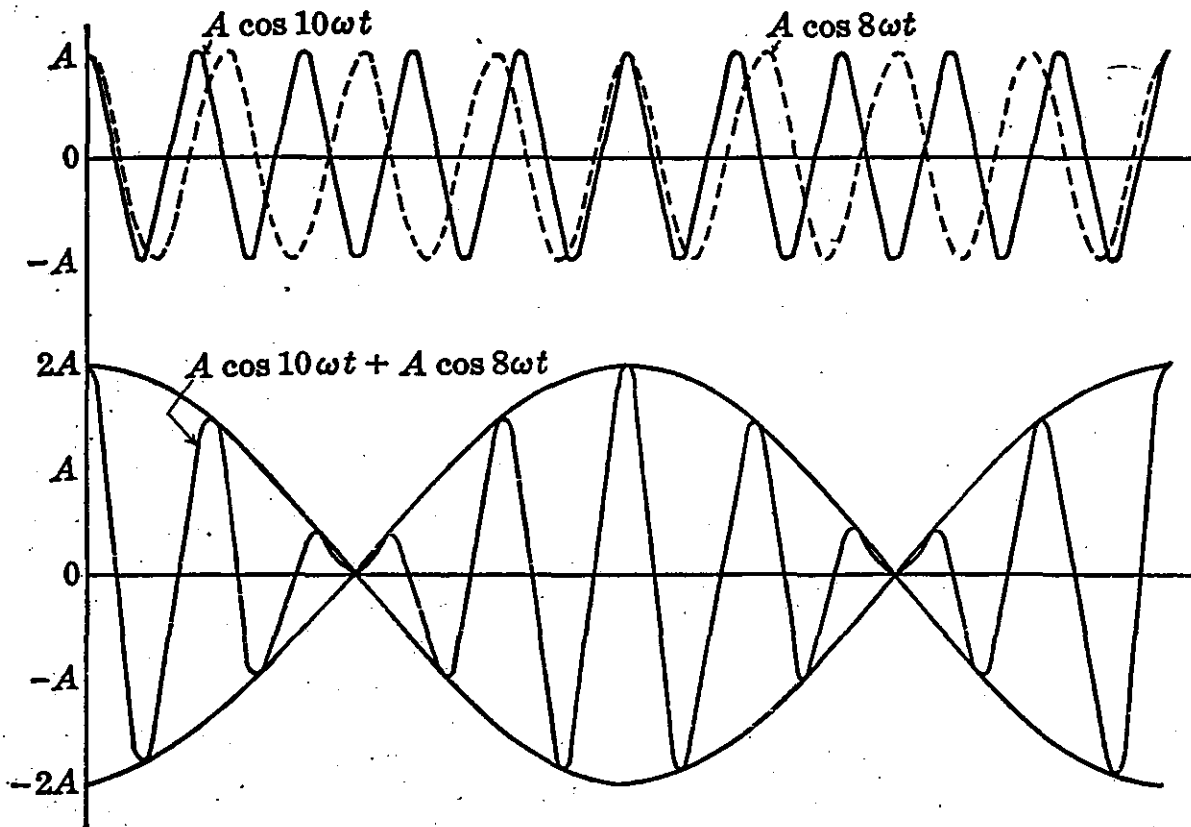
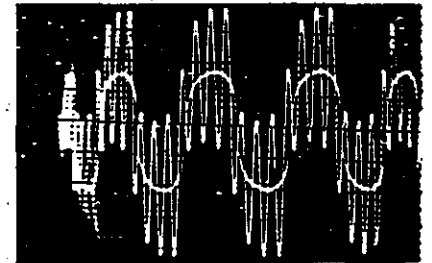
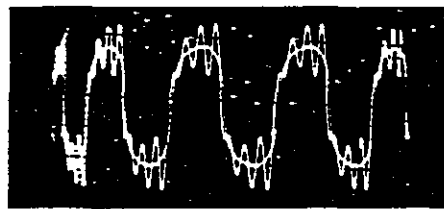
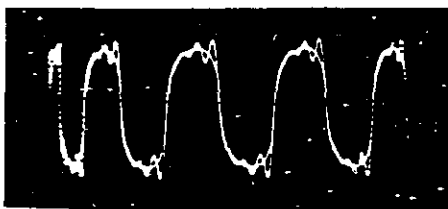


Figure 4-7 Output Recording of a Frequency-Spectrum Analyser using filter bandwidth = 1/3 octave

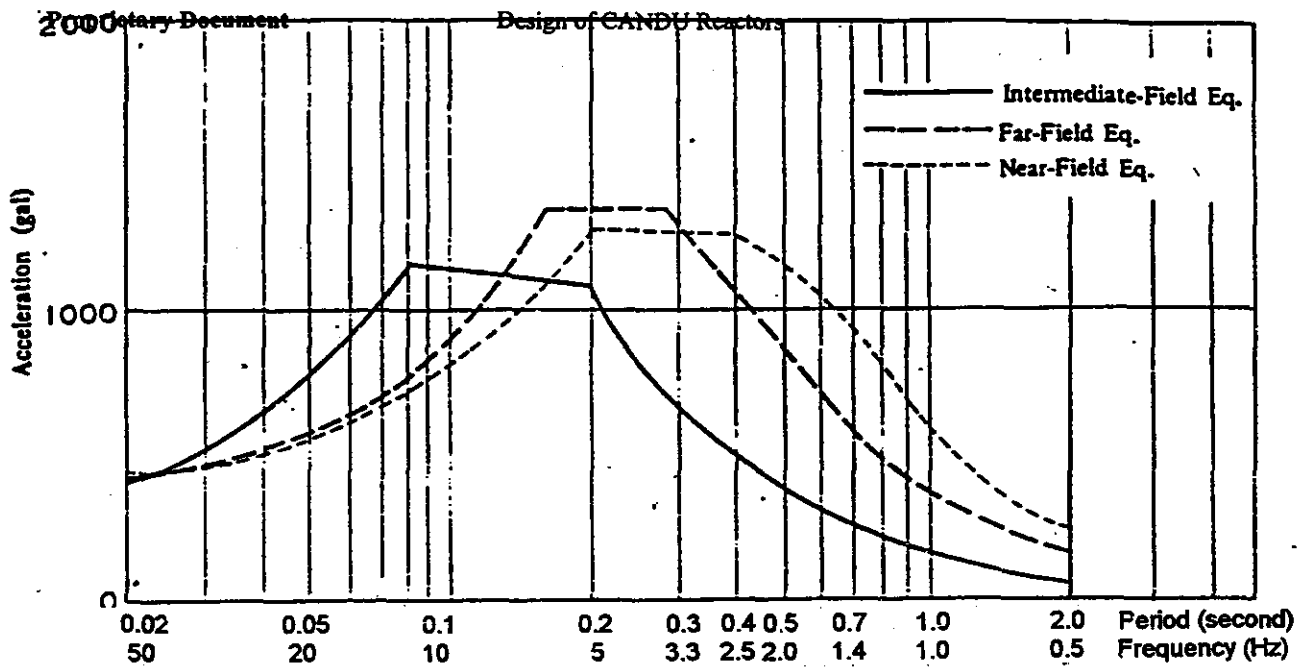


(i) Addition of two signals with the same amplitude but different frequencies

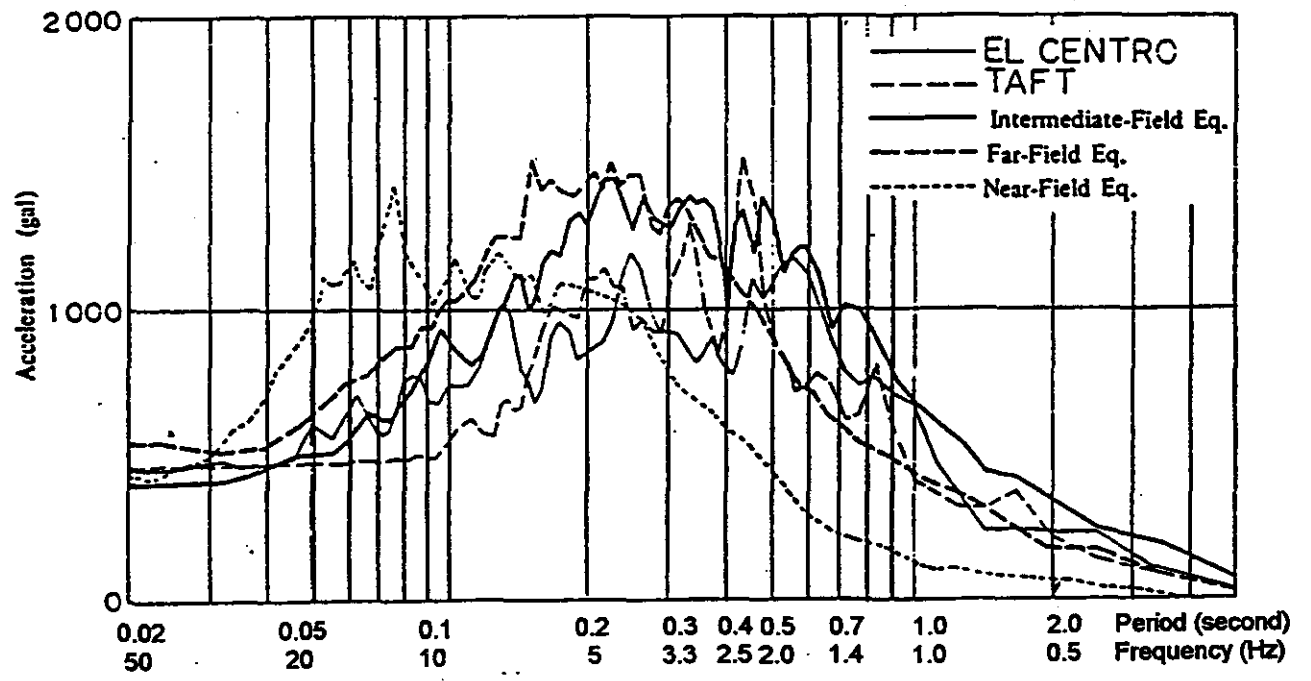


(ii) Three recordings showing the addition of high frequency waves to a low frequency wave, where the amplitude of the second wave is much smaller than, 1/4 as big as, and equal to that of the first wave. The first wave is also shown in each case, for reference.

Figure 4-8 Addition of Two Vibrations of Different Frequencies



(a) Smoothed envelope curve used for design



(b) Acceleration response spectra for recorded and synthesized earthquakes

Figure 4-9 Design Response Spectra for Recorded Earthquakes
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System response curve = *product* of sub-system response curves

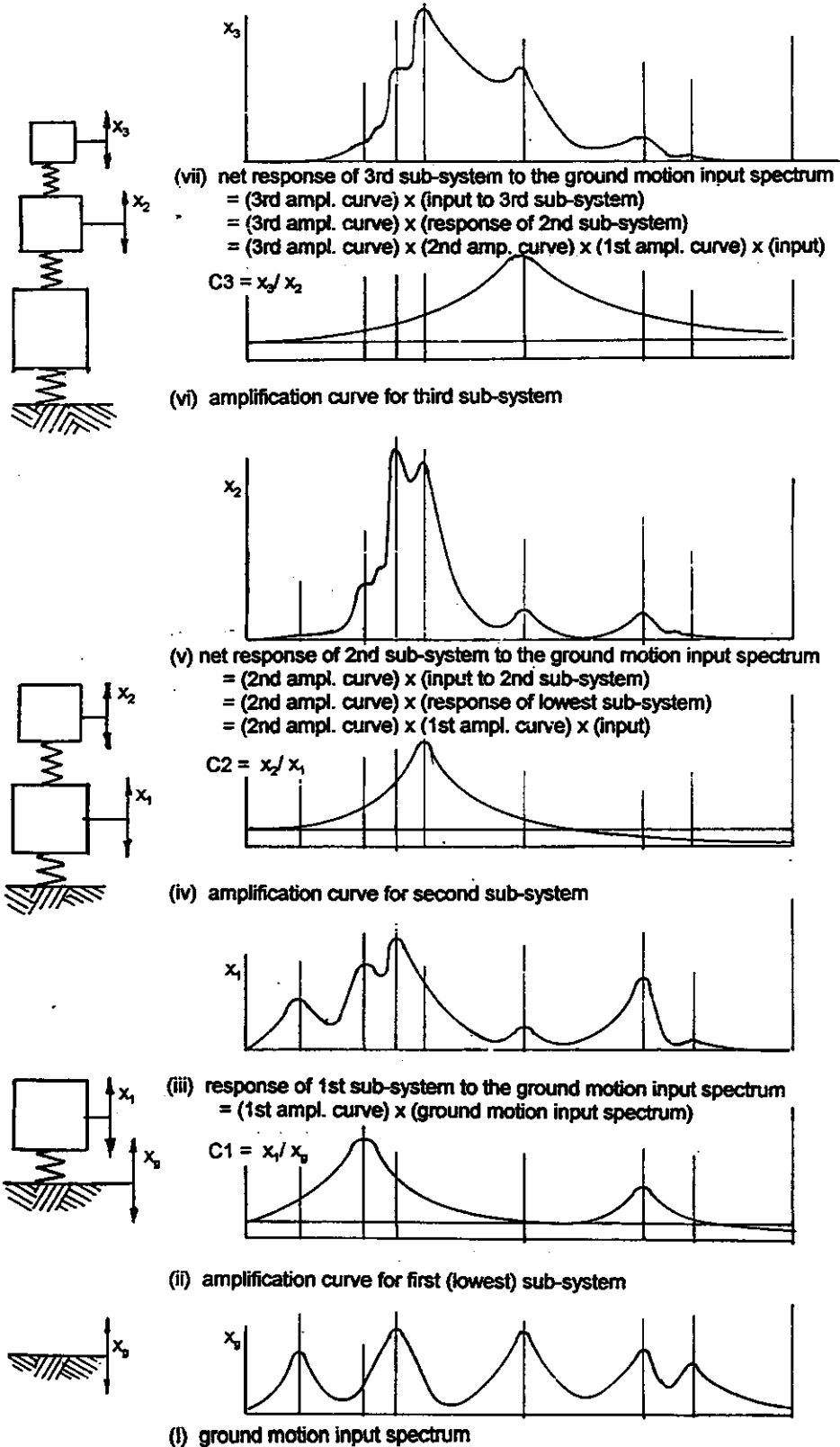


Figure 4-10 Added Responses for a Simplified Representation of a Complex Structure

REACTOR BUILDING @ 0.04 DAMPING
GRADE FLOOR EL. 100 M HOR. A/C DIRECTION

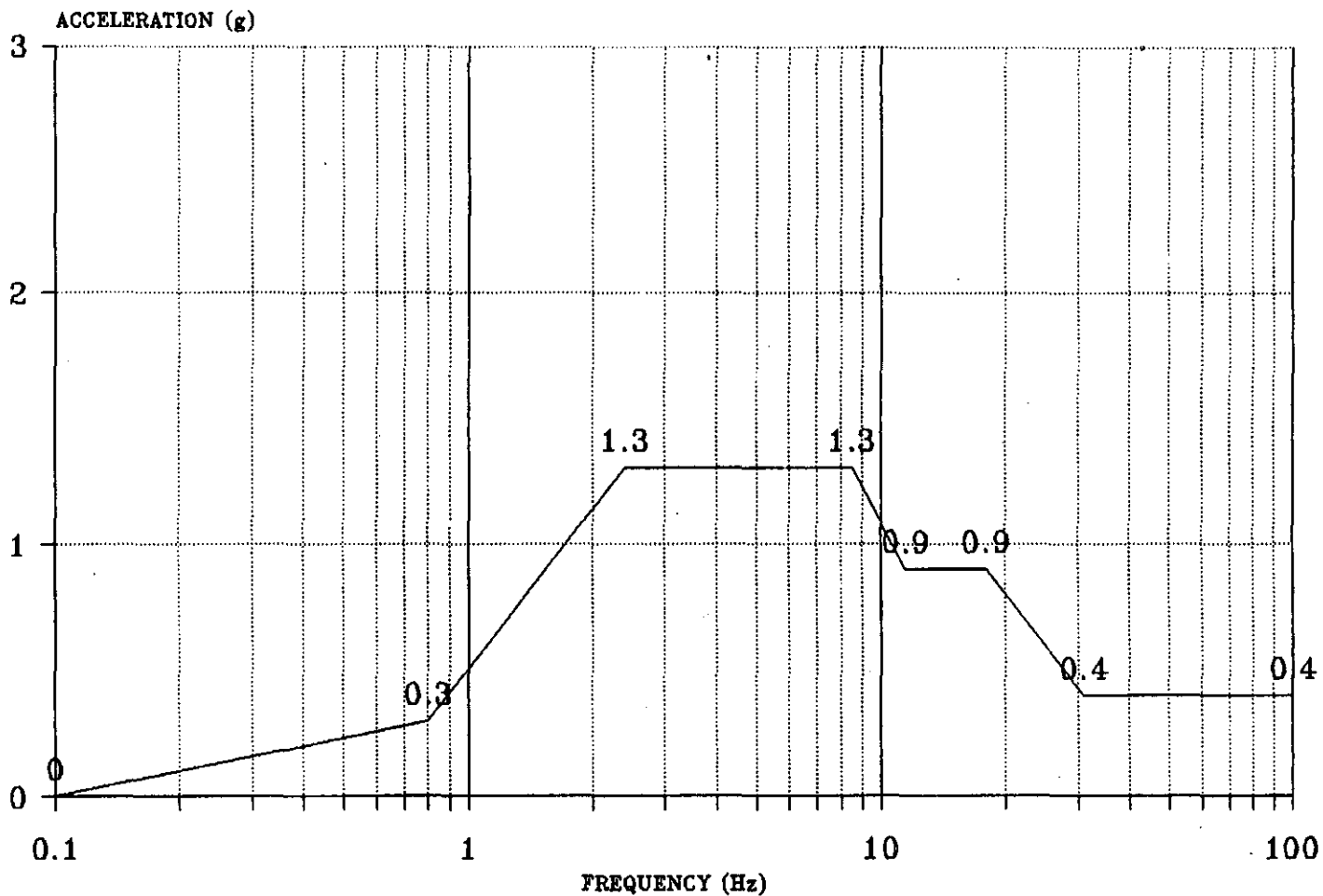


Figure 4-11 Floor Response Spectrum for CANDU 6 Reactor Structure

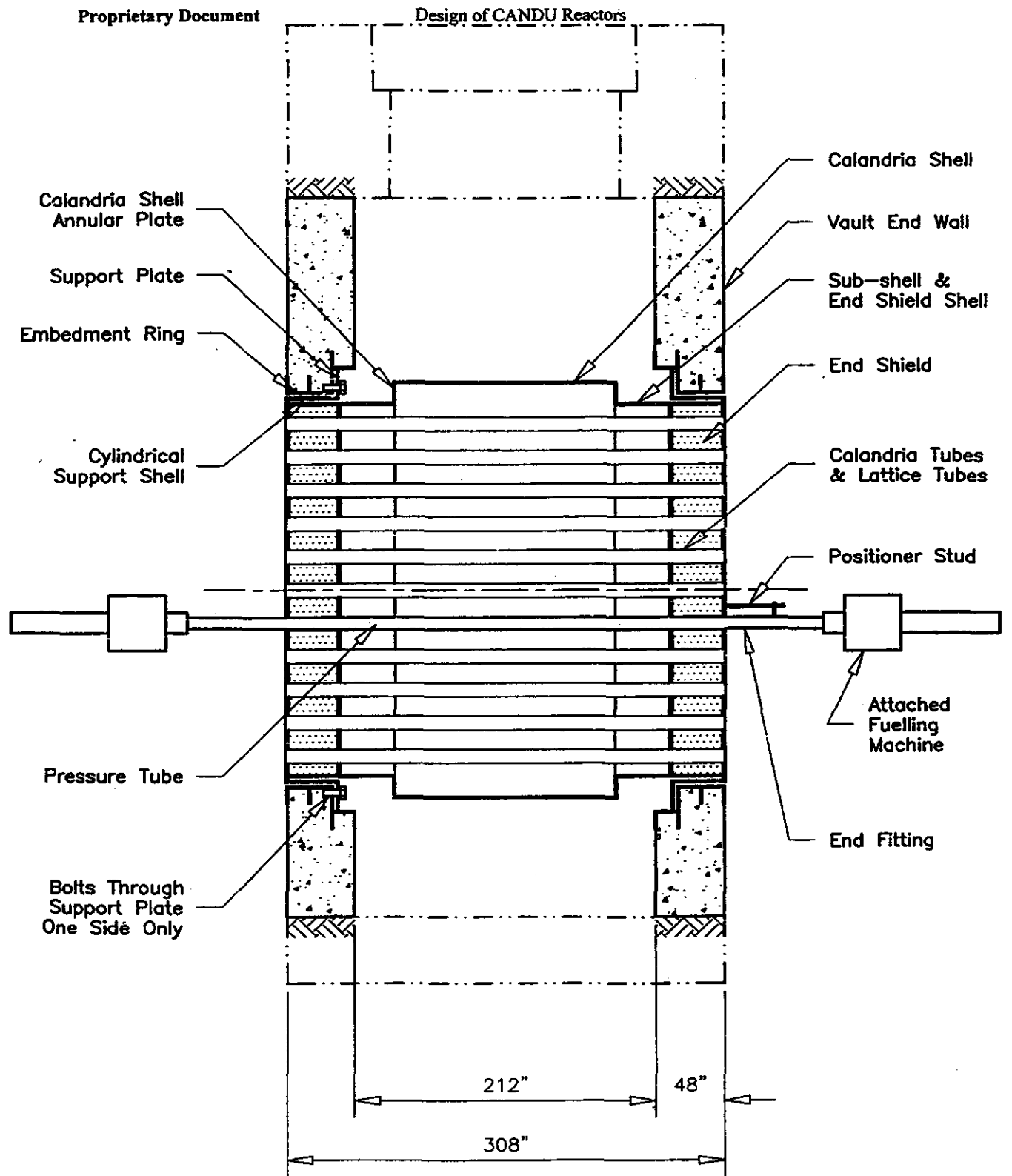


Figure 4-12 Structure Schematic of Present CANDU 6 Reactor Assembly

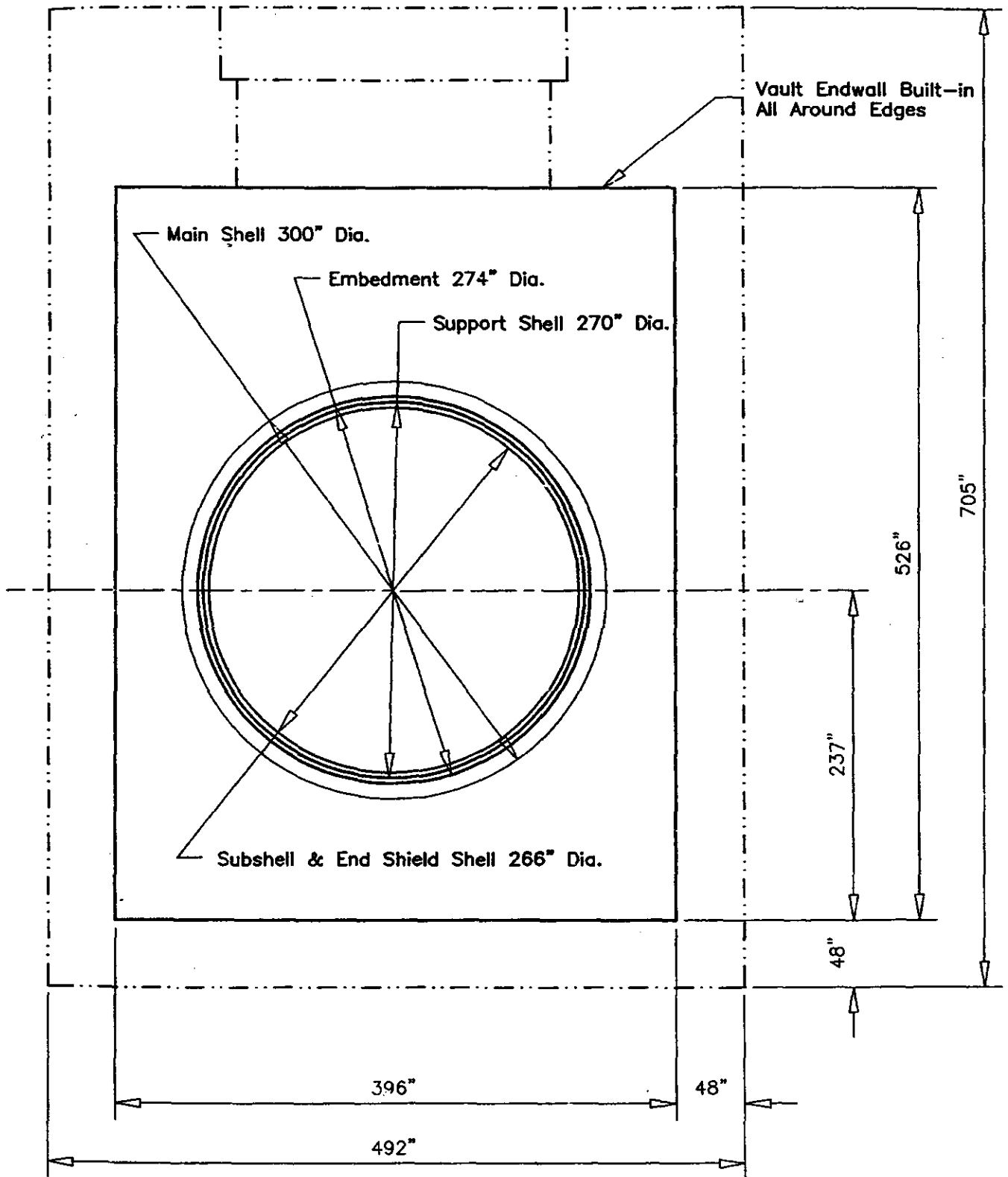
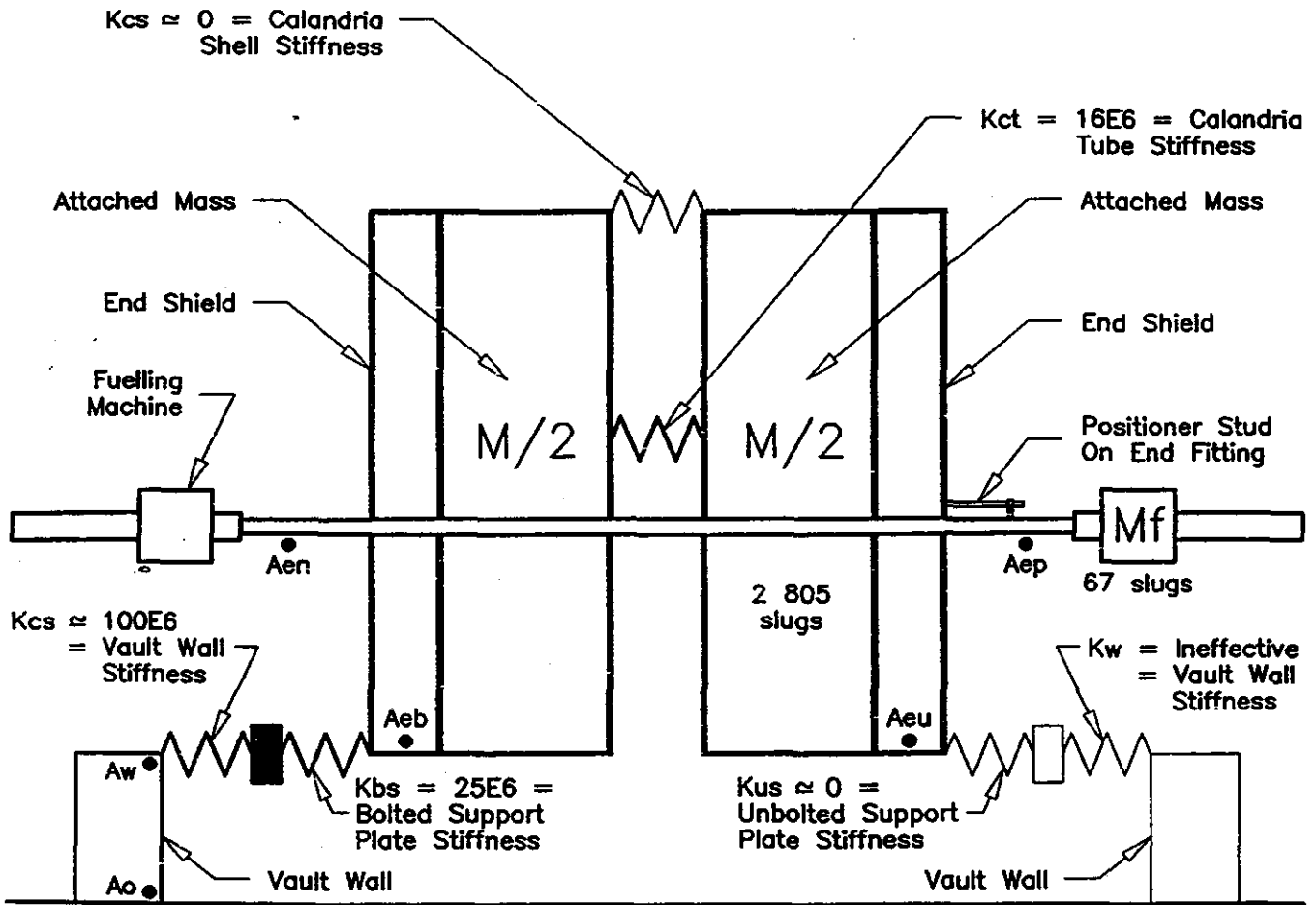
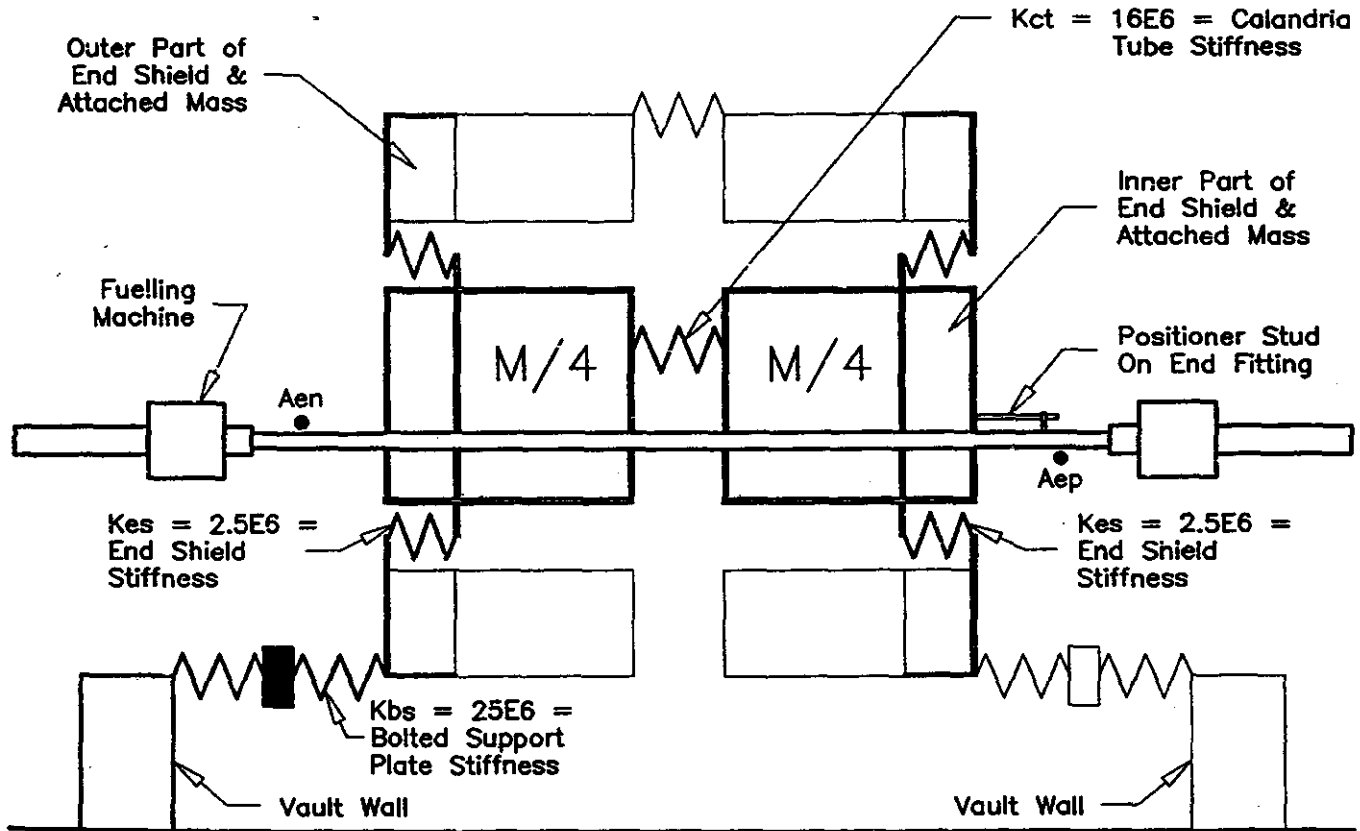


Figure 4-13 Dimensions of Present CANDU 6 Reactor Assembly



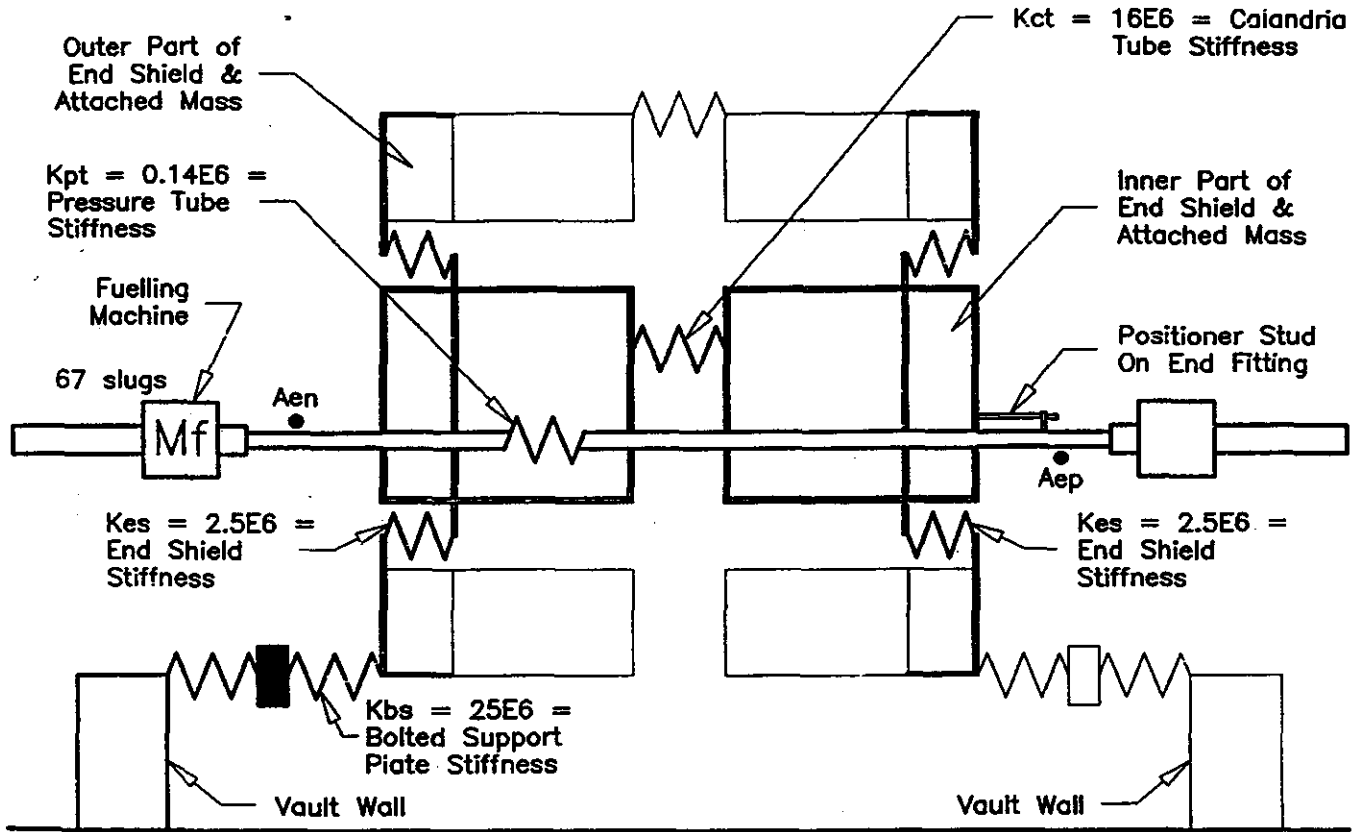
$f_1 = \text{half-mass mode} = 11.7 \text{ Hz}, A_1 = 0.9 \text{ g}$
 $f_2 = \text{whole-mass mode} = 10.6 \text{ Hz}, A_2 = 1.0 \text{ g}$

Figure 4-14 Seismic Schematic of Present Reactor Assembly - Basic Response Modes and Frequencies



$f_3 = \text{end shield mode} = 6.6 \text{ Hz}, A_3 = 1.3 \text{ g}$

Figure 4-15 Seismic Schematic of Present Reactor Assembly - End Shield Response Mode and Frequency



$$f_4 = 7.4 \text{ Hz}, A_4 = 1.3 \text{ g}$$

Figure 4-16 Seismic Schematic of Present Reactor Assembly
- Fuel Channel Response Mode and Frequency

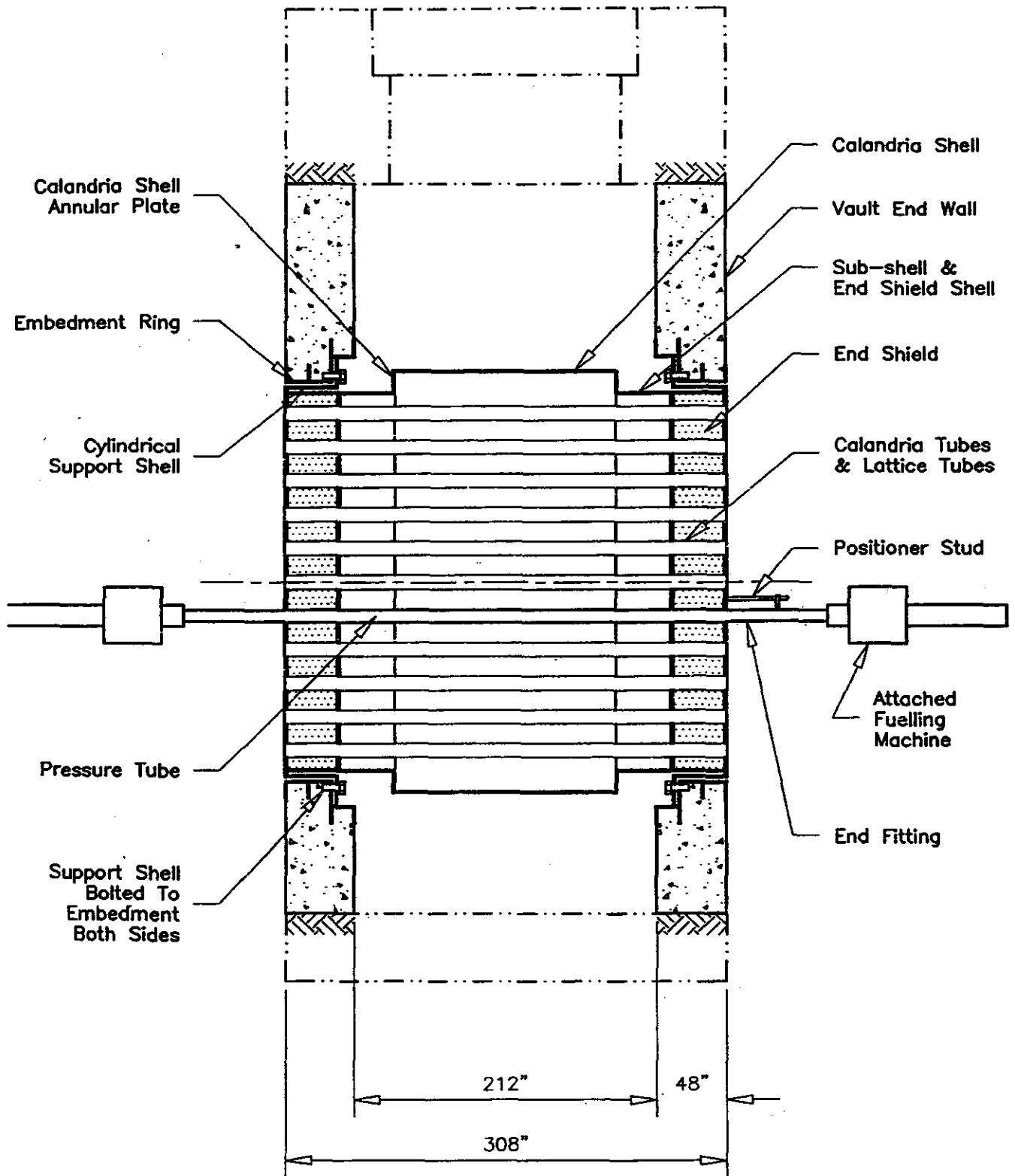


Figure 4-17 Structure Schematic of Modified Reactor Assembly - Axial Support by Bolts at *Both* Ends

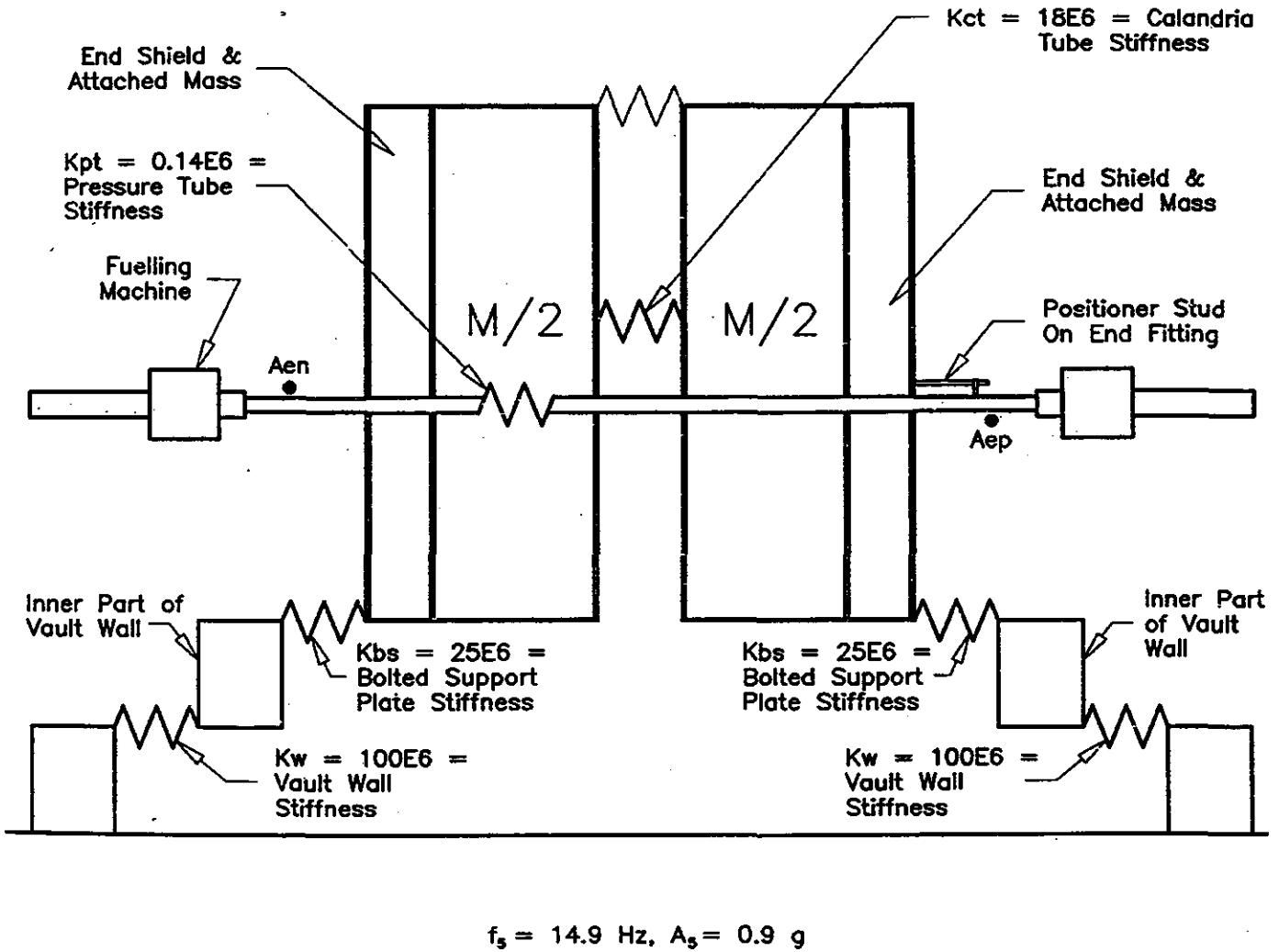


Figure 4-18 Seismic Schematic of Modified Reactor Assembly
- Basic Response Modes and Frequencies

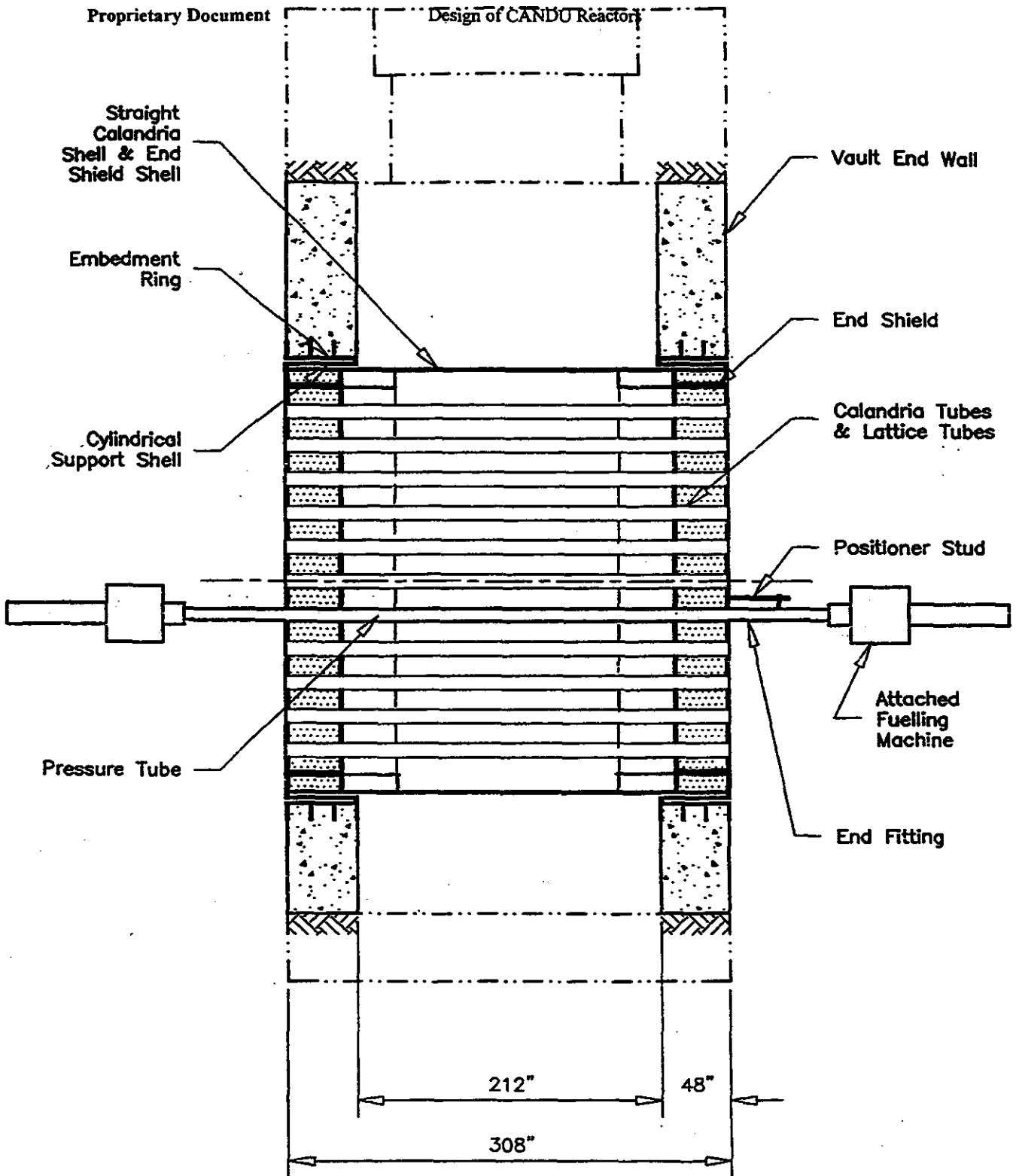


Figure 4-19 Structure Schematic of Straight-shell Reactor Assembly - Axially Rigid Joint Direct to Vault at Both Ends

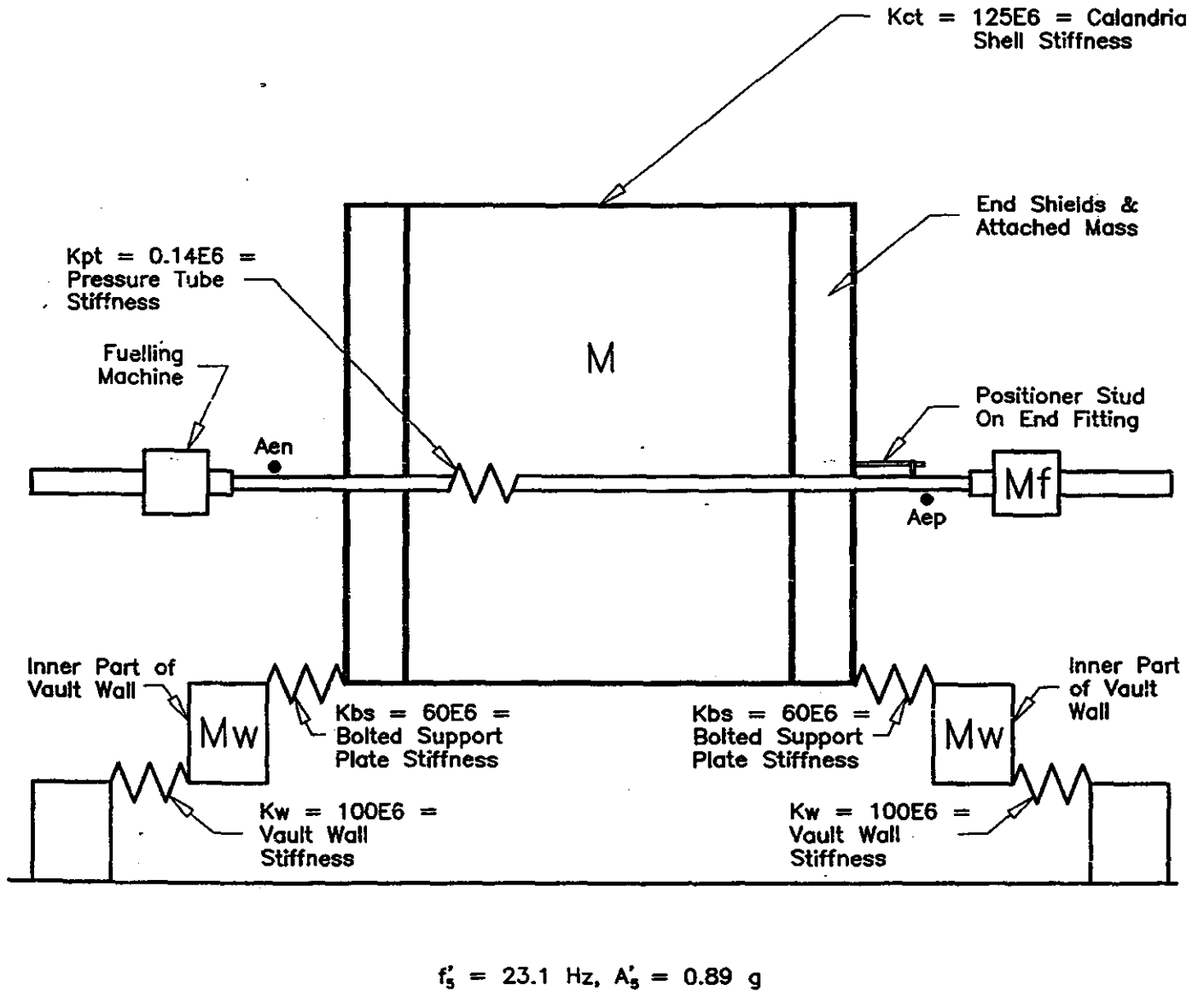


Figure 4-20 Seismic Schematic of Straight-shell Reactor Assembly - Basic Response Modes and Frequencies

DESIGN OPTION	Half-Body Mode		Whole-Body Mode		End Shield Mode		FM/PT Mode		Positioner Assembly End		Non-Positioner Assembly End		CT Stress (Net)
	f_1	A_1	f_2	A_2	f_3	A_3	f_4	A_4	1.2 Aep	P_{PA}	1.2 Aen	P_{RI}	
STANDARD CANDU 6	11.7 Hz		f_2	A_2	6.6 Hz	1.3 g	7.4 Hz	1.3 g	2.25 g	58100 lb	2.74 g	70800 lb	Outer 145 Comp
		0.9 g	1.0 g	Inner 1450 Tens									
BOLTED BOTH ENDS	n/a		f_3	A_3	6.6 Hz	1.3 g	7.4 Hz	1.3 g	1.90 g	49100 lb	2.46 g	63500 lb	Outer 190 Comp
		0.9 g	1.3 g	Inner 1080 Tens									
STRAIGHT CALANDRIA SHELL	n/a		f'_3	A'_3	6.6 Hz	1.3 g	7.4 Hz	1.3 g	1.83 g	47400 lb	2.40 g	62300 lb	Outer 1000 Tens
		0.8 g	1.3 g	Inner 2000 Tens σ cal shell = 6000 Comp									

Figure 4-21 Comparison of Present and Proposed Designs

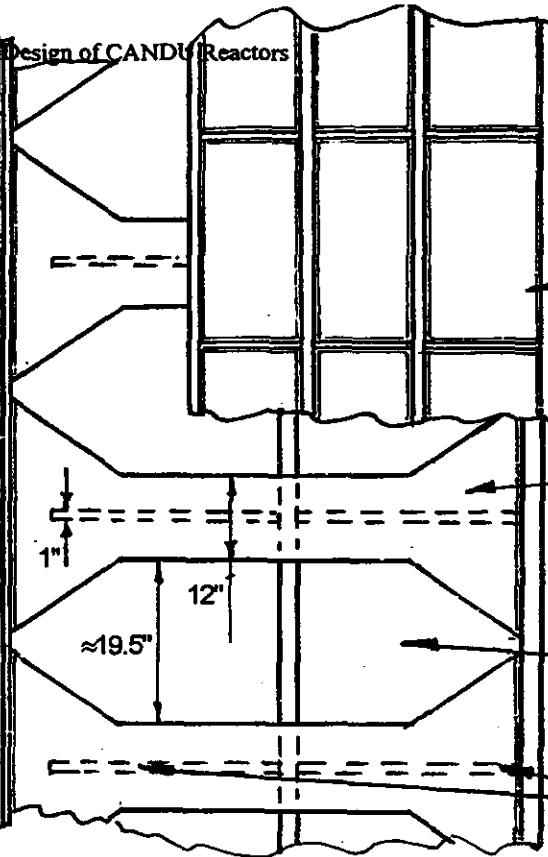
Proprietary Document

Design of CANDU Reactors

WELD SEQUENCE

- (*) 2-sided full penetration
- (@) 1-sided full penetration
- (#) 2-sided fillets

- 1* End Shield Shell to 2 Tubesheets
- 2* Sub-shell to Tubesheet
- 3* Webs to ES Shell & Tubesheets
- 4* Gusset to Tubesheet
- 5* Ext'n Bars to Tubesheets, Webs & Gussets
- 6* Embed't Inner PI to Support Shell
- 7@ Support Shell to F Tubesheet
- 8* Sub Ass Embed't Ring
- 9* & 10@ Embed't S/A to Embed't Inner PI
- 11* Annular PI to Main Shell
- 12* Annular PI to Ext Bars & Sub-Shell



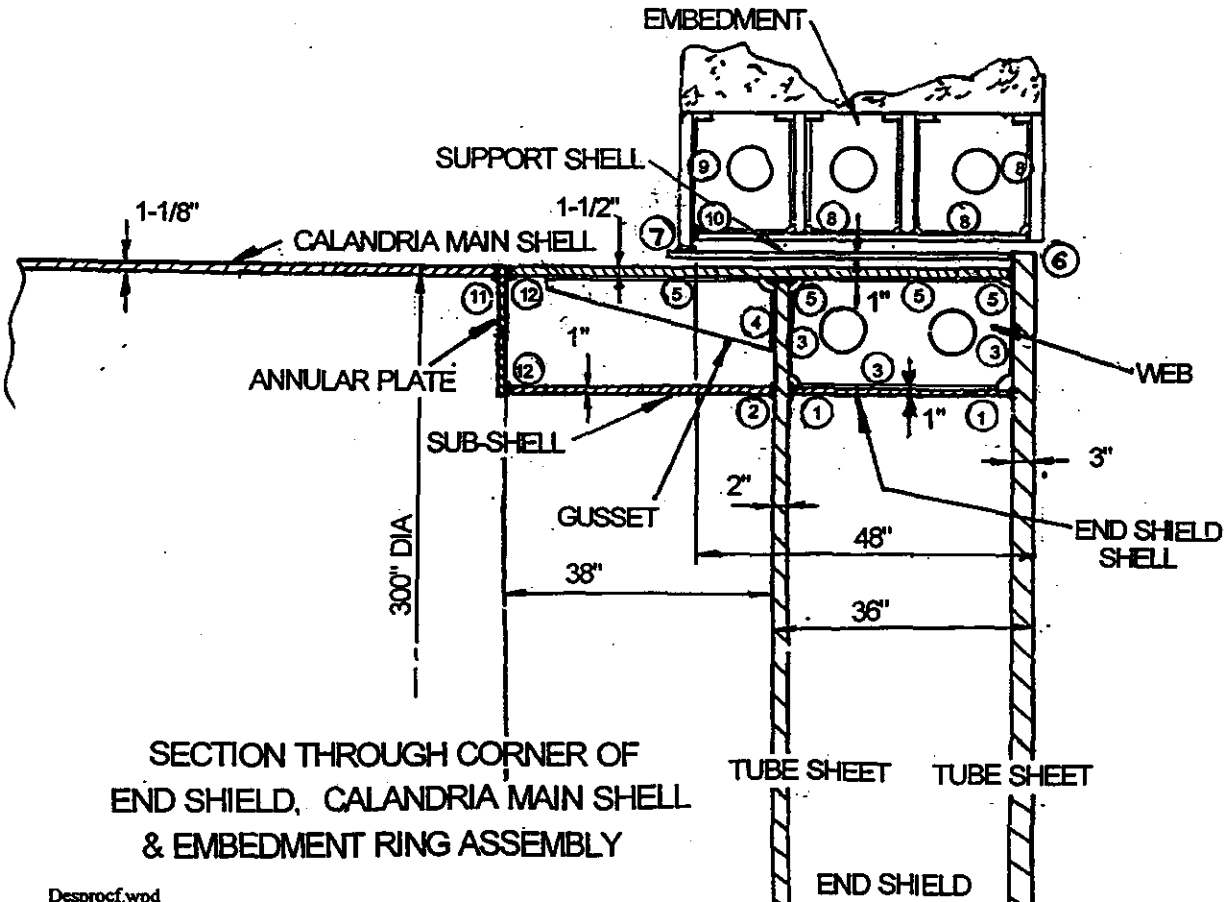
EMBEDMENT RING

MAINSHELL EXTENSION BARS ('DOGBONES')

ACCESS FOR INTERNAL WELD

30 WEBS & GUSSE @ 12" PITCH ($\approx 31.4"$ PITCH)

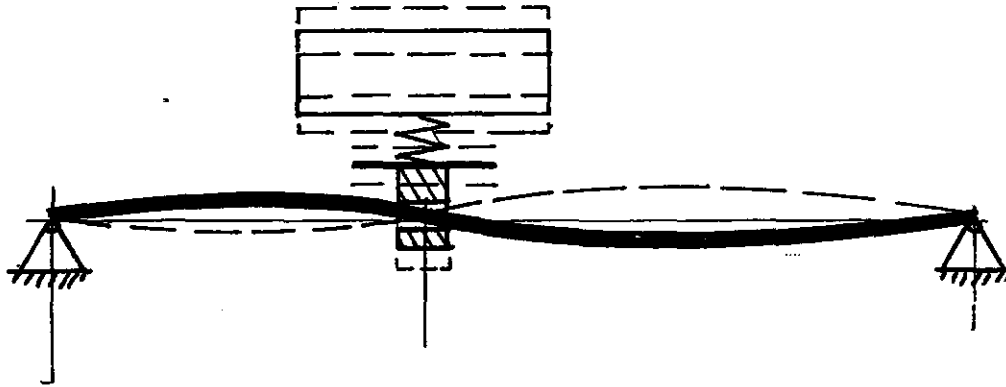
VIEW FROM TOP (CONCRETE REMOVED)



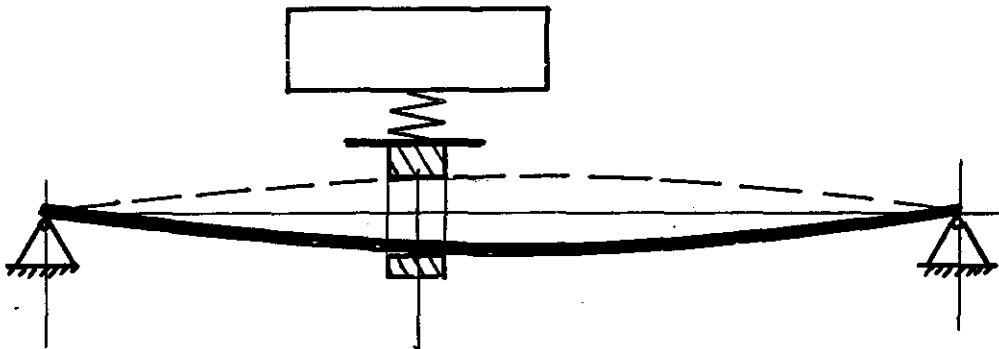
SECTION THROUGH CORNER OF END SHIELD, CALANDRIA MAIN SHELL & EMBEDMENT RING ASSEMBLY

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Figure 4-22 Details of Area of Structure at Reactor Support for Straight-shell Design



(b) Behaviour when response amplitude becomes bigger than gap
- beam has 3-point support, coupling it to downstream sub-system



(a) Behaviour when response amplitude is less than gap
- beam is simply supported and decoupled from downstream sub-system

Figure 4-23 Vibration Behaviour of a System with a Gap

Simply supported beam with a large gap at mid-span at connection to the downstream sub-system