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SUBJECT: FINAL PROPOSAL FOR SEISMIC REANALYSIS OF CRITICAL STRUCTURES OF OYSTER CREEK NUCLEAR POWER STATION UNIT 1 FOR SEP

Based on NRC staff's comments on the original proposal of August 2, 1979 and my further research into the soil-structure interaction analysis methods, I have developed the final proposal for your review. Much of the proposed SSI approach has already been presented at the SSI panel meeting on September 26, 1979.

The checklist of requested information in Appendix A is a list of items that I have requested but for various reasons have not received so far. Obviously, some of the items are more crucial than others in affecting the timely completion of the reanalysis.

It is important to let NRC be aware of the status of the requested information and various constraints that exist in the way of progress.

The list of unresolved open items in Appendix A are those technical decisions that have to be made by the responsible people. These items could be effectively resolved by conference calls or by meetings of the people concerned.

Marshall Ma
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PROPOSAL FOR SEISMIC REANALYSIS
OF CRITICAL STRUCTURAL SYSTEMS
OF OYSTER CREEK NUCLEAR POWER
STATION UNIT 1 FOR THE SYSTEMATIC
EVALUATION PROGRAM (SEP)

S. M. MA
8 October 1979

1. INTRODUCTION

Presented herein is a proposal for seismic reanalysis of the critical structures of Oyster Creek Nuclear Power Station Unit 1 (referred to hereafter as OC plant) for the NRC Systematic Evaluation Program (SEP). This analysis is to be performed in the light of current knowledge in the area of seismic structural analysis.

The objective of the proposed analysis is to provide the required analytical data base for an overall reassessment of the critical structural components of OC plant under a safe shutdown condition. It is understood that in order to arrive at a reasonable reassessment, considerable engineering judgment and experience in addition to analytical efforts are required.

In the proposed analysis the seismic loads and responses used for the original design shall be compared with those derived from the present analysis. This comparison will help to identify critical areas of low margins which may require more detailed investigations.

Another objective of the structural system analysis is to provide in-structure response spectra to be used in the later phase of seismic re-evaluation of critical equipment/piping.

The scope of the analysis includes the following three major structures and two special items (see and overview in Figure 1).

- reactor building plus portion of the office building connected to the westside of the reactor building (referred to hereafter as office building annex) and other building internals which may affect building dynamic response.
- turbine building/control room - control room housing is situated on the N-E corner of the turbine building operating floor.
- ventilation stack
- condensate storage tank
- buried emergency service water lines (14 in. diameter)

The detailed analysis plan for each critical structure will be addressed spearately in the report. A list of unresolved open items and a checklist of requested information are given in Appendix A.

2. ANALYSIS GUIDES

NUREG/CR-0098, "Development of Criteria for Seismic Review of Selected Nuclear Power Plants", by Newmark and Hall (Ref. 1) will be used as the primary guide. Additional guides used mainly in the area of soil-structure interaction analysis, buried lifeline analysis, and the above-ground vertical storage tank analysis are found in the References.

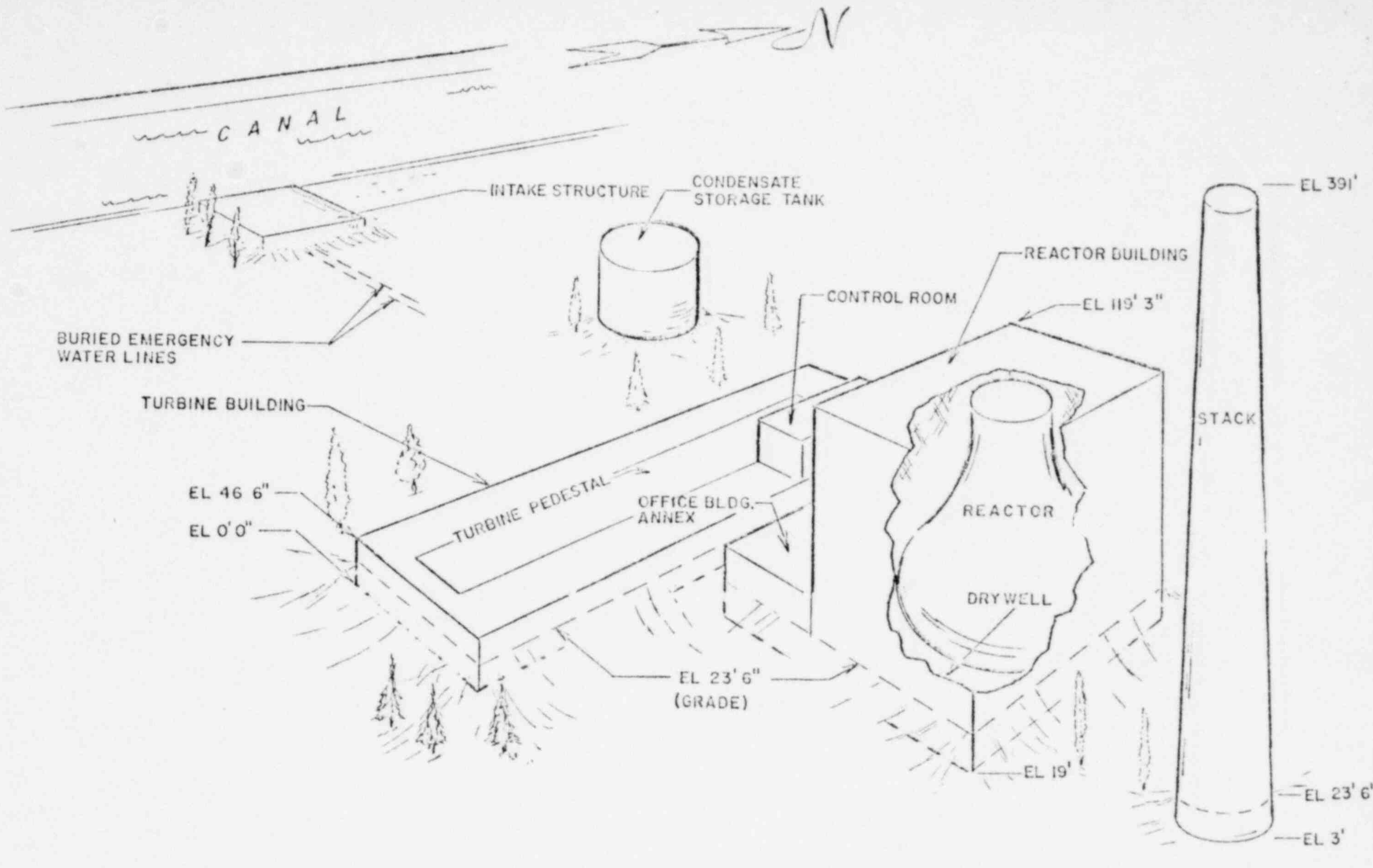

FIG. 1

OVERVIEW OF STRUCTURAL ITEMS UNDER CONSIDERATION

3. SEISMIC INPUT

The seismic input used in the analysis is defined by the SSE design spectra at the ground surface (normalized to 0.22g ZPA). The preliminary versions of site specific spectra at the Oyster Creek site have been developed by TERA (Ref. 2) and being evaluated by GSB/NRC. The final approved version is expected around mid-October this year. The standard design spectra (Reg. Guide 1.60) shall also be used for comparison.

Three (orthogonal) components of seismic motion shall be considered. The vertical component shall be taken as 2/3 of the horizontal across the entire frequency range (see Section 2.4, Ref. 1).

4. SITE SOIL PROPERTIES AND STRUCTURE FOUNDATION EMBEDMENTS

The soil profile underlying the Oyster Creek site shown in Fig. 2 is established from the descriptions in OC FSAR Section II.5.2. The bedrock is at a depth of about 1700 feet below grade (Ref. 2).

The elastic (Young's) moduli for the Oyster Creek Site reported in OC FSAR Section II.5.1 are:

Cape May Formation (~40' thick) E = 400 tons/ft.^{2} (5.55 x 10^3 psi)

Cohansey Formation (~180' thick) E = 800 tons/ft.^{2} (1.11 x 10^4 psi)

In addition, the field dynamic test data and boring logs are available at the proposed Fork River Nuclear Power Plant site which is about 1000 yards from the Oyster Creek site. The soil property data at this site, computed by Western Geophysical Engineers, are given below (Ref. 3):

Depth (Feet)	"P" Wave (Ft/Sec)	"S" Wave (Ft/Sec)	Poisson's Ratio	Young's Modulus E (psi)	Shear Modulus G (psi)
0-15	1400	600	.0.39	2.14 x 10^4	7.8 x 10^3
15-40	5200	1000	0.48	8.0 x 10^4	2.6 x 10^4
40-115	5600	1200	0.48	9.3 x 10^4	3.74 x 10^4
115-150	5900	1400	0.47	1.51 x 10^5	5.1 x 10^5

In the Blume's seismic analyses of reactor building and the more recently built radwaste building, the following values of E were used (source: Oyster Creek docket):

	E Elactic Modulus	Poisson's Ratio	Soil Under Foundation
Reactor Building	800 tons/ft^2 (1.11x10^4 psi)	0.20	Cohansey Sand
Radwaste Building	3540 ton/ft^2 (4.92 x 10^4 psi)	0.44	Compact backfill (4 feet thick)

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FIG. 2

UNDERLYING SOIL AT SITE

(SOURCE = OC FSAR SECT. 11.5.2)

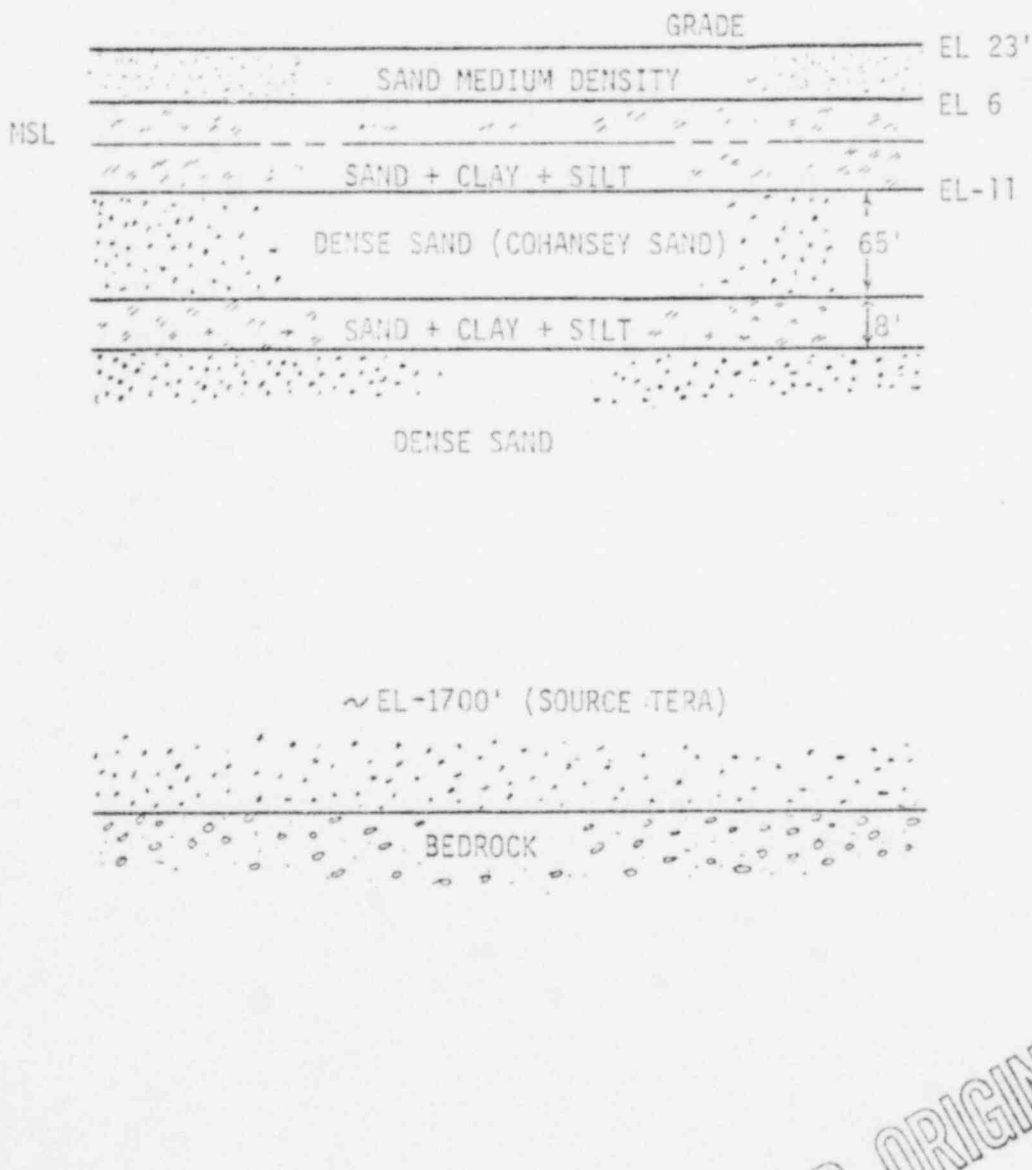
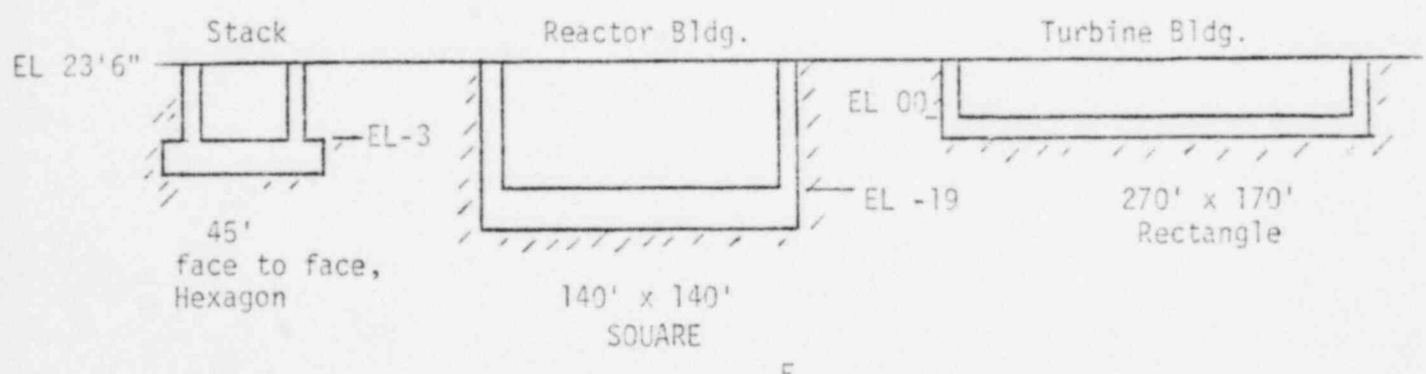


FIG. 3

FOUNDATION DIMENSIONS

	LEAST BASE DIMENSION b	EMBEDMENT E	$\frac{E}{b}$	FOUNDATION MAT THICKNESS
STACK	45'	33.5'	.740	7'
REACTOR BUILDING	140'	52.5'	.375	10'
TURBINE BUILDING	170'	29.5'	.173	6'



Deep embedment case: $\frac{E}{b} > 0.15$

(SRP 3.7.2)

Note that the foundation of the radwaste building is on grade and the building is located next to the east side of the reactor building.

The foundation embedment and the base dimensions of the stack, the reactor building, and the turbine building are depicted in Figure 3. The degree of embedment is generally represented by the ratio of the embedment length to the least base dimension (E/b). The present NRC SRP 3.7.2 considers a foundation is "deeply embedded" when

$\frac{E}{b} > 0.15$. Using this criterion, the foundations of these structures are all deep embedment cases.

5. OVERALL ANALYSIS PROCEDURE

5.1 Dynamic Analysis Method

The dynamic (seismic) analysis is to be solved in the time domain by using normal mode superposition. The immediate implication of this approach is that the damping of the dynamic system must be defined on the modal basis. Basically, the response spectral analysis method is to be used throughout. The time history analysis method employing normal modes shall be used only in generating floor response spectra. In this case the seismic input is the appropriate synthetic time history derived from Reg. Guide 1.60 spectra. (See Section 7)

5.2 Modal Combination Method

The seismic responses (shear, moments and displacements) are computed for each mode and combined by sum of square root of squares (SSRS). All the modes below 33 cps cutoff frequency shall be included.

5.3 Three Dimension (3D) Effects

Three dimensional stick models shall be used exclusively. The eccentricity between the center of mass and the center of rigidity is considered in the model to account for possible torsional responses.

5.4 Composite Modal Damping

The equipment composite damping for the r^{th} mode is determined by the following formula (Eq. (4), SRP 3.7.2):

$$\bar{\beta}_r = \frac{(\phi)^T (\bar{K}) (\phi)}{(\phi)^T (K) (\phi)} \qquad (1)$$

where

K = assembled stiffness matrix,

$\bar{\beta}_r$ = Equivalent modal damping ratio of the r^{th} mode.

$\bar{K}$ = the modified stiffness matrix constructed from element matrices formed by the product of the damping ratio βj for the element and its stiffness matrix

ϕ = r^{th} normalized modal vector.

The damping ratios ξ for different types of structure components are taken as the larger values given in Table 1 of NUREG/CR-0098 (Ref. 1) for materials at a just below yield point (since SSE condition is of concern here):

Stress Level	Type and Condition of Structure	Percent Critical Damping
At or just below yield point	a. Vital piping	2 to 3
	b. Welded Steel, prestressed concrete (without complete loss in prestress)	5 to 7
	c. Prestressed concrete with no prestress left	7 to 10
	d. Reinforced concrete	7 to 10
	e. Bolted and/or riveted steel, wood structures, with bolted joints	10 to 15
	f. Wood structures with nailed joints	15 to 20

The determination of soil damping ratios to be used in conjunction with Eq. (1) is described elsewhere in Section 6.2. As an approximation, only soil radiation damping effect is considered.

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6. SOIL-STRUCTURE INTERACTION (SSI) ANALYSIS

The SSI analysis is solved in three steps (so called three step solution method (Ref. 4) see illustrations in Fig. 4):

STEP 1: Kinematic interaction analysis
(Determine motion of a massiveless foundation)

STEP 2: Determine impedance function (stiffness and damping) of the foundation accounting for embedment and layering

STEP 3: Inertia interaction analysis
(Dynamic structure analysis using seismic input from Step 1)

Since it is generally considered to be conservative to use the free field seismic ground motion in Step 3 in lieu of that from Step 1 (See Ref. 5), no kinematic interaction analysis shall be performed.

Step 2 involves the determination of soil spring constants and damping ratios to be used in Step 3. The details are presented in Sections 6.1 and 6.2.

The inertia interactim analysis in Step 3 is the dynamic analysis of the structural system including soil springs. From the dynamic analysis results, the structural interal forces and moments are computed and floor response spectra are generated.

The SSI analysis is a key step in the overall analysis procedure as illustrated in Figure 5. Due to the uncertainty in soil stiffness properties,

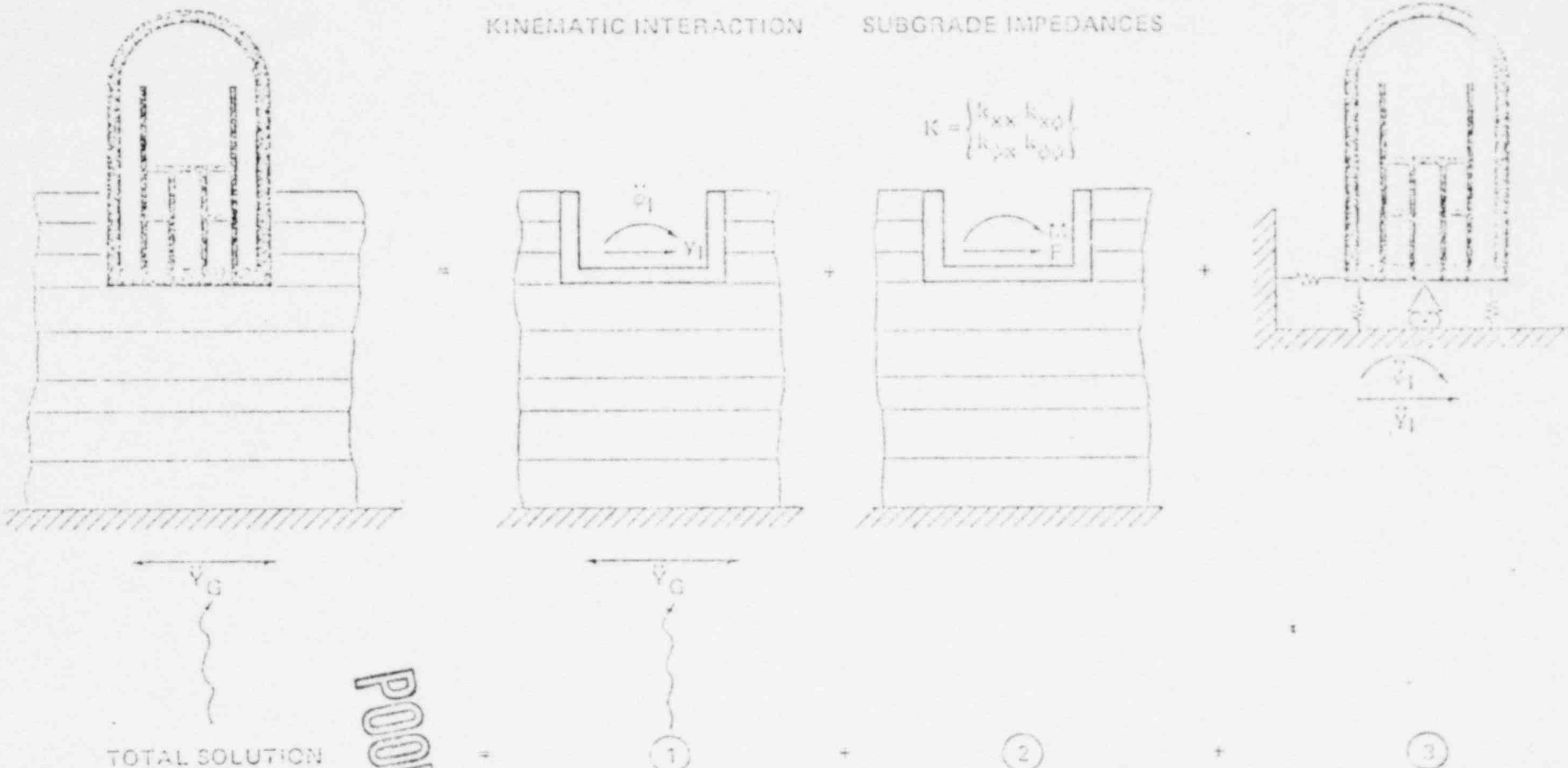
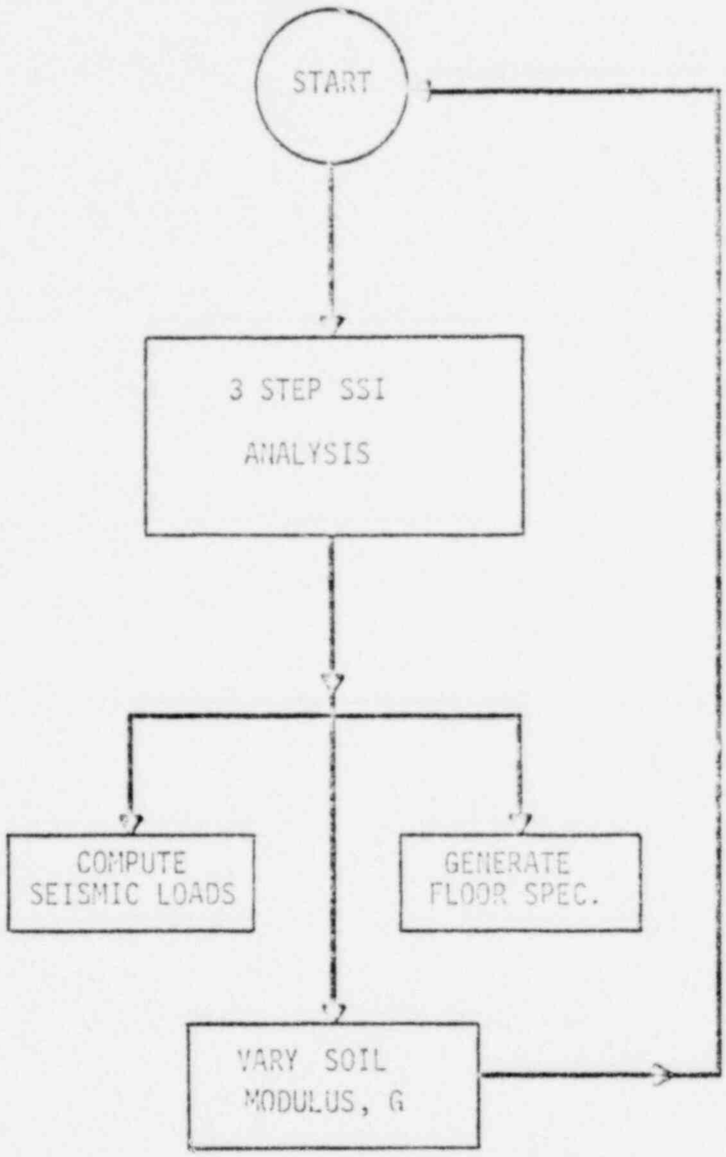


FIGURE 4
THE 3-STEP SOLUTION
(AFTER KAUSEL AND ROESSET, 1974)

FIG. 5
OVERALL ANALYSIS PROCEDURE



the analysis is to be repeated for the upper and lower limits of soil modules. These limits should be based on the existing soil data which are being compiled and examined by GSB/NRC.

6.1 DETERMINATION OF SUBGRADE STIFFNESS COEFFICIENTS

The complete set of soil stiffness coefficients for the six degrees of freedom at the foundation is shown in the matrix form in Figure 6. The off-diagonal terms indicate coupling between the rocking and the swaying (lateral) modes. For the ideal case of a rigid foundation on the surface of an elastic half space, a very good approximation is to use the static stiffness coefficients (referred to hereon as Whitman's spring contants, see formulas in Appendix B) for the diagonal terms and ignoring the off-diagonal terms.

For the structures of concern at the Oyster Creek site, the problem is complicated by the need to account for the embedment effects and possibly, the soil layering effect.

Since the Oyster Creek SSI problem is to be solved in the time domain, the stiffness coefficients in the matrix shown in Figure 6 must be frequency-independent constants.

Several proposals on approximating embedment effects using frequency-independent spring constants can be obtained in the works by Novak (Ref. 6), J. Hall (Ref. 7) and Kausel et al (Ref. 8). All of these approaches consider a homogeneous soil medium beneath the foundation. To investigate whether soil layers at Oyster Creek site can be approximated by a homogeneous layer of "averaged" properties, the technique proposed in BC-TOP-2 (Ref. 9) shall be used. This approach is outlined in Appendix C.

Depending on the outcome of the layering effect approximation analysis different analysis methods are proposed for computing soil stiffness coefficients considering the embedment effects:

Case		Proposed Method for Determining Stiffness Coefficients
1.	All subgrade soil can be approximated by a single layer	KAUSEL
2.	Only soil beneath foundation can be approximated by a single layer	NOVAK
3.	Neither 1. or 2. (Not likely, by examining Fork River site data)	CLASSI (Frequency domain analysis)

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Kausel's and Novak's formulas are for swaying and rocking coefficients only, i.e., K_{xx}, $K_{\phi\phi}$, and $K_{x\phi}$ (Fig. 6). For the vertical vibration mode, it is proposed to use Whitman's static spring, (K_z, appendix B) plus 67.5% of the lateral spring (K_{xx})*. For the torsional mode, Whitman's spring (K_t) times the ratio between the foundation/soil contact area and the base area shall be used.

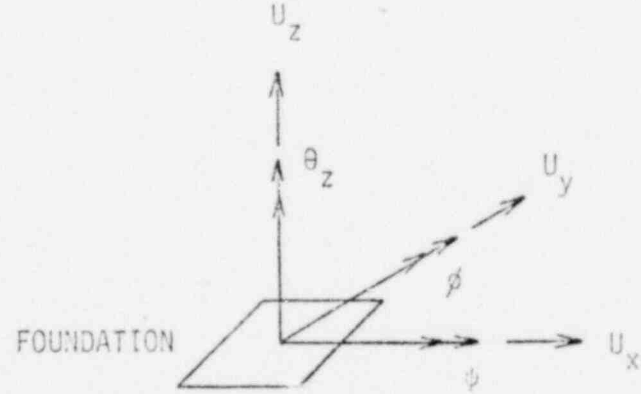
In constructing the soil spring model the coupling term $K_{x\phi}$ can be eliminated by placing the lateral spring a distance $h(= \frac{K_{x\phi}}{K_{xx}})$ from the foundation base

*See Ref. 10

Fig. 6

SUBGRADE STIFFNESS MATRIX

U_x	ϕ	U_y	ψ	θ_z	U_z
K_{xx}	$K_{x\phi}$				
$K_{\phi x}$	$K_{\phi\phi}$				
		K_{yy}	$K_{y\psi}$		
		$K_{\psi y}$	$K_{\psi\psi}$		
	(sym.)			k_t	
					k_z



line as shown in Fig. 7. As a consequency, the rocking spring constant should be modified as follows:

$$K'_{\phi} = \left(K_{\phi} - \frac{K^2_{x\phi}}{K_{xx}} \right) \text{ or } \left(K_{\phi} - h^2 K_{xx} \right)$$

Generally, the term $h^2 K_{xx}$ is small comparing to K_{ϕ} .

6.2 SOIL DAMPING

The soil damping effects shall be included in computing the equivalent composite model damping ratio per Eq. 1, Sect. 5.4 As an approximation soil internal hysteretic damping is ignored and only radiation damping effects are considered. The formulas for estimating radiation damping coefficients are given in Ref. 11. These damping coefficients can be converted to the form of damping ratios (percent critical damping) by considering structures as rigid bodies on flexible foundation. The formulations for computing these ratios are given in the Appendix of Ref. 11. These damping ratios represent viscous coefficients $\beta_{v\phi}$ and β_{vx} in Fig. 8 where the details of matrix operation in Eq. 1 (Sect. 5.4) are illustrated. The equivalent soil damping ratios to be used in Eq. 1 are determined by multiplying $\beta_{v\phi}$ and β_{vx} respectively by the frequency ratios $\frac{\omega_r}{\omega_\phi}$ and $\frac{\omega_r}{\omega_x}$.

It is a generally-accepted practice to limit the soil damping ratio under a certain reasonable and realistic cut-off value. In the present analysis, a 30% cut-off damping ratio is proposed.

7. GENERATION OF FLOOR RESPONSE SPECTRA

The floor response spectra shall be generated directly from the ground design spectra using the dynamic (modal) properties of the structure. The The available LLL computer program based on Singh's approach (Ref. 12) shall be used. For comparison purposes, another set of floor response spectra shall be generated from a time history analysis using the appropriate Reg. Guide 1.60 synthetic time history as the input.

8. STRUCTURE DYNAMIC MODELS

Since the reactor building, the turbine building and the stack are physically separated, they were modeled independently by the 2D stick models shown in Fig. 9 in the original Blume's analysis. In this figure, the calculated natural periods and frequencies are also listed. The two buildings and the stack are all reinforced concrete structures. Their foundation and embedment dimensions are shown in Fig. 3. Reactor building has a setback on the westside, where a portion of office building (office building annex) is located. The control room is situated at the NE corner of the turbine building except for sharing a common foundation with the building.

The proposed analytical models for the reactor building, the turbine building and the stack (Fig.'s 10, 11, and 12) are essentially the same as Blume's original 2D models except that they are 3D models which account for eccentricities between the center of rigidity and the center of masses at

Fig. 7

PLACEMENT OF SOIL SPRINGS

IN AN EMBEDMENT CASE

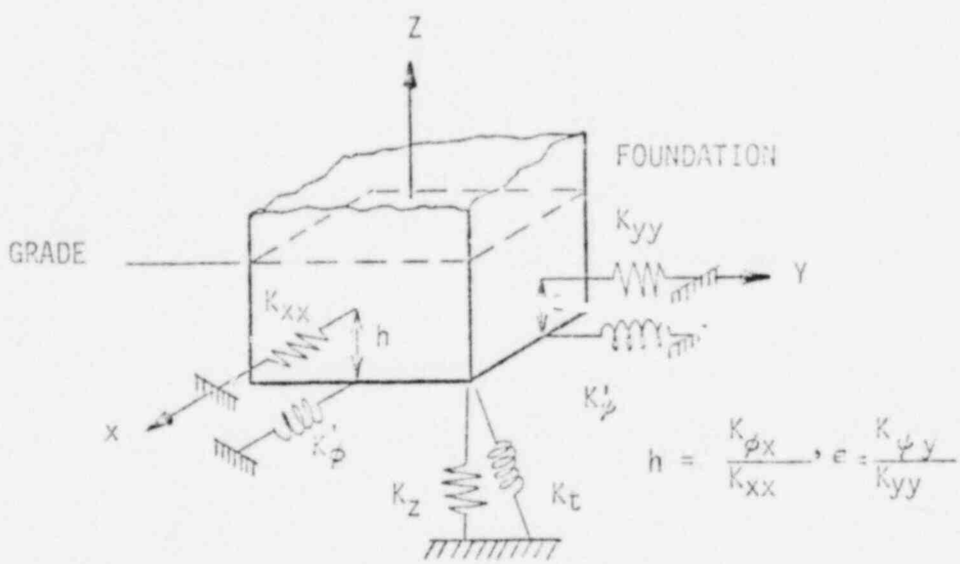
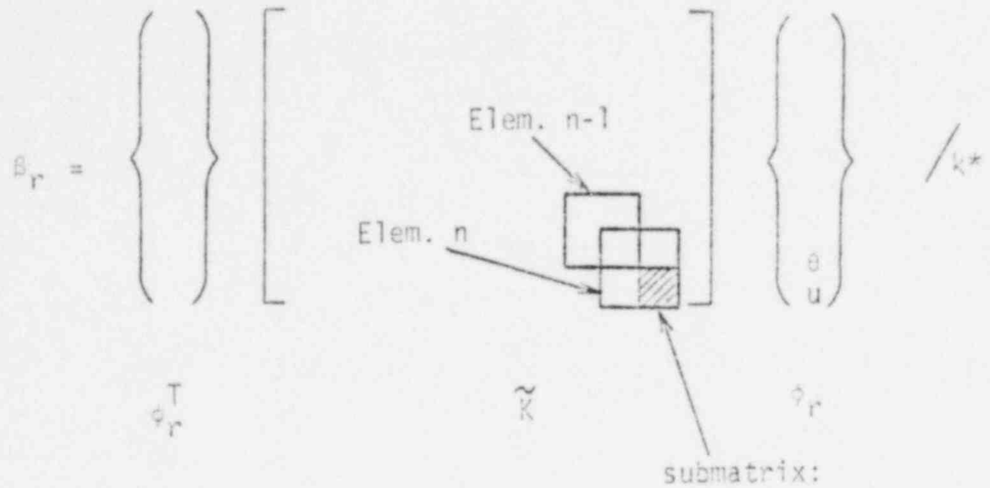
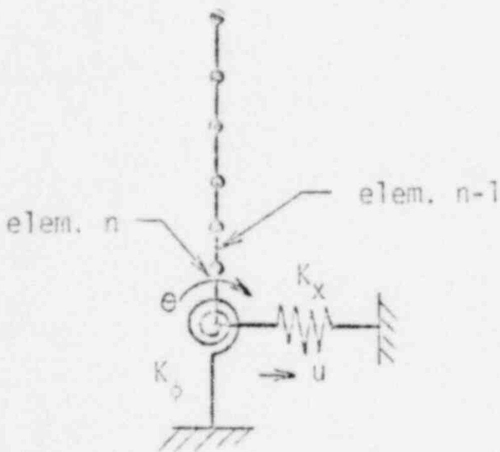


FIGURE 8

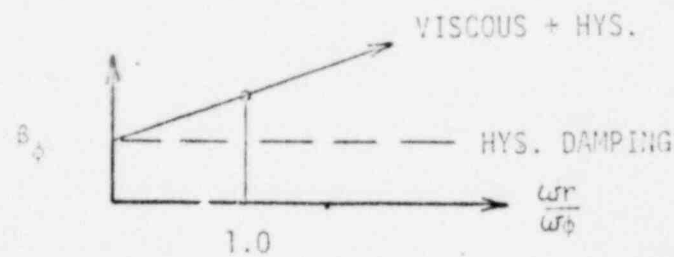
MATRICES FOR ESTABLISHING

EQUIVALENT COMPOSITIE MODAL DAMPING





$$\beta_n \begin{bmatrix} \frac{4EI}{\ell} & \frac{-6EI}{\ell^2} \\ \frac{-6EI}{\ell^2} & \frac{12EI}{\ell^3} \end{bmatrix} + \begin{bmatrix} \beta_\phi K_\phi & 0 \\ 0 & \beta_x K_x \end{bmatrix}$$



$$\beta_\phi = (\underbrace{\beta_{v\phi}\frac{\omega_r}{\omega_\phi}}_{\frac{C_\phi}{2K_\phi}\omega_r} + \cancelto{0}{\beta_{H\phi}}) \qquad \beta_x = (\underbrace{\beta_{vx}\frac{\omega_r}{\omega_x}}_{\frac{C_x}{2K_x}\omega_r} + \cancelto{0}{\beta_{Hx}})$$

ω_r = rth mode frequency; ω_ϕ, ω_x = rigid body, rocking, translat. frequencies.

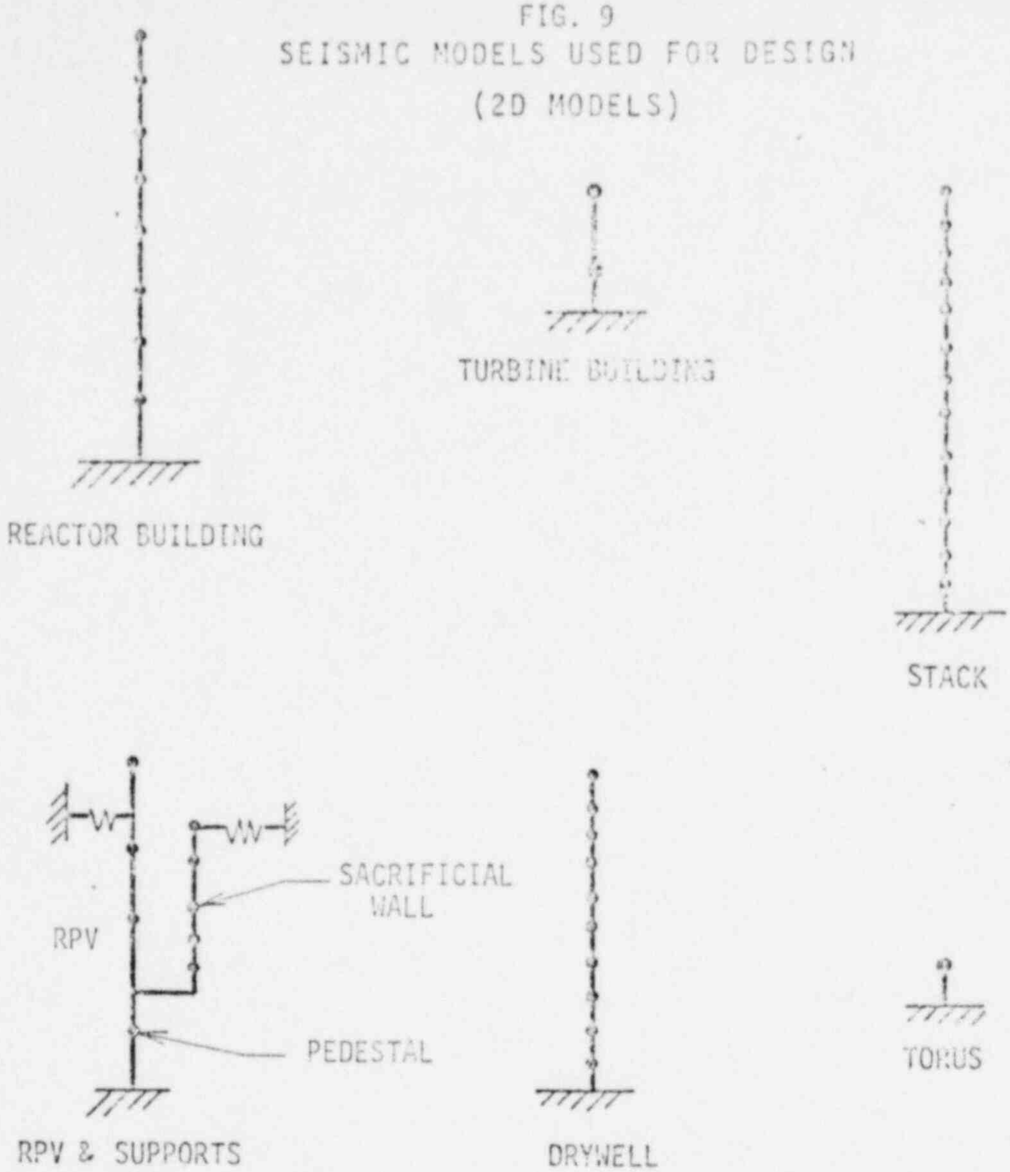
β_v = viscous (radiation) damping ratio.

β_H = soil internal (linear hysteretic) damping ratio.

FIG. 9

SEISMIC MODELS USED FOR DESIGN

(2D MODELS)



COMPUTED NATURAL PERIOD (T) and Freq (f)	T (Seconds)			f(cps)		
	T_1	T_2	T_3	f_1	f_2	f_3
REACTOR BUILDING	0.256	0.162	0.054	3.9	6.2	18.5
TURBINE BUILDING	0.091	0.033		11.0	30.3	
STACK	1.63	0.52	0.23	0.61	1.9	4.4
DRYWELL	0.076	0.032	0.017	13.2	13.2	58.8
TORUS	0.142			7.1		
RPV SYS	0.129			7.8		

Fig. 10

PROPOSED BUILDING MODEL (3D)

REACTOR BUILDING

(Eccentricities are exaggerated for Illustration Purpose)

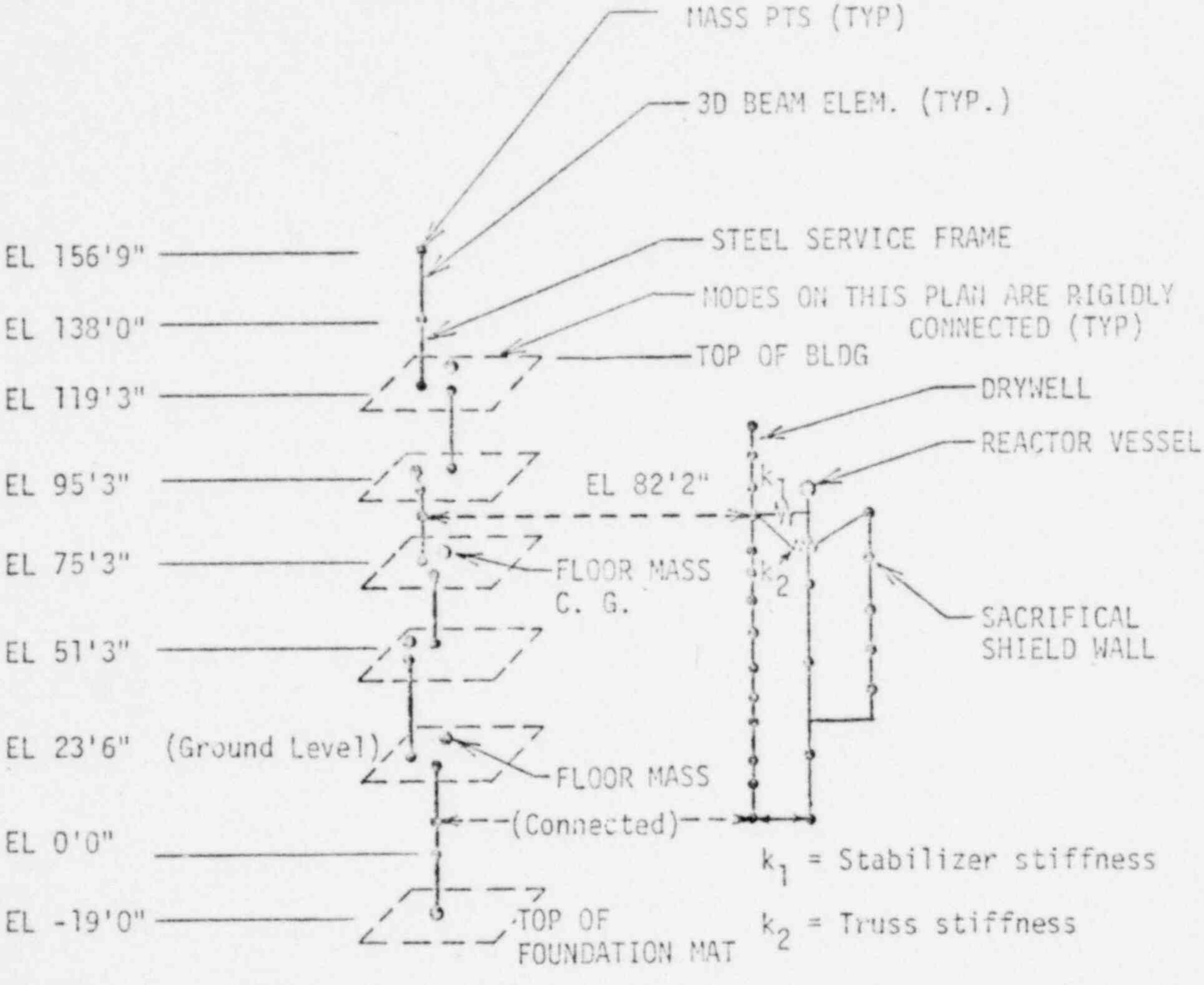


Fig. 11

PROPOSED BUILDING MODEL (3D)

TURBINE BUILDING

(Eccentricities are exaggerated for Illustration Purpose)

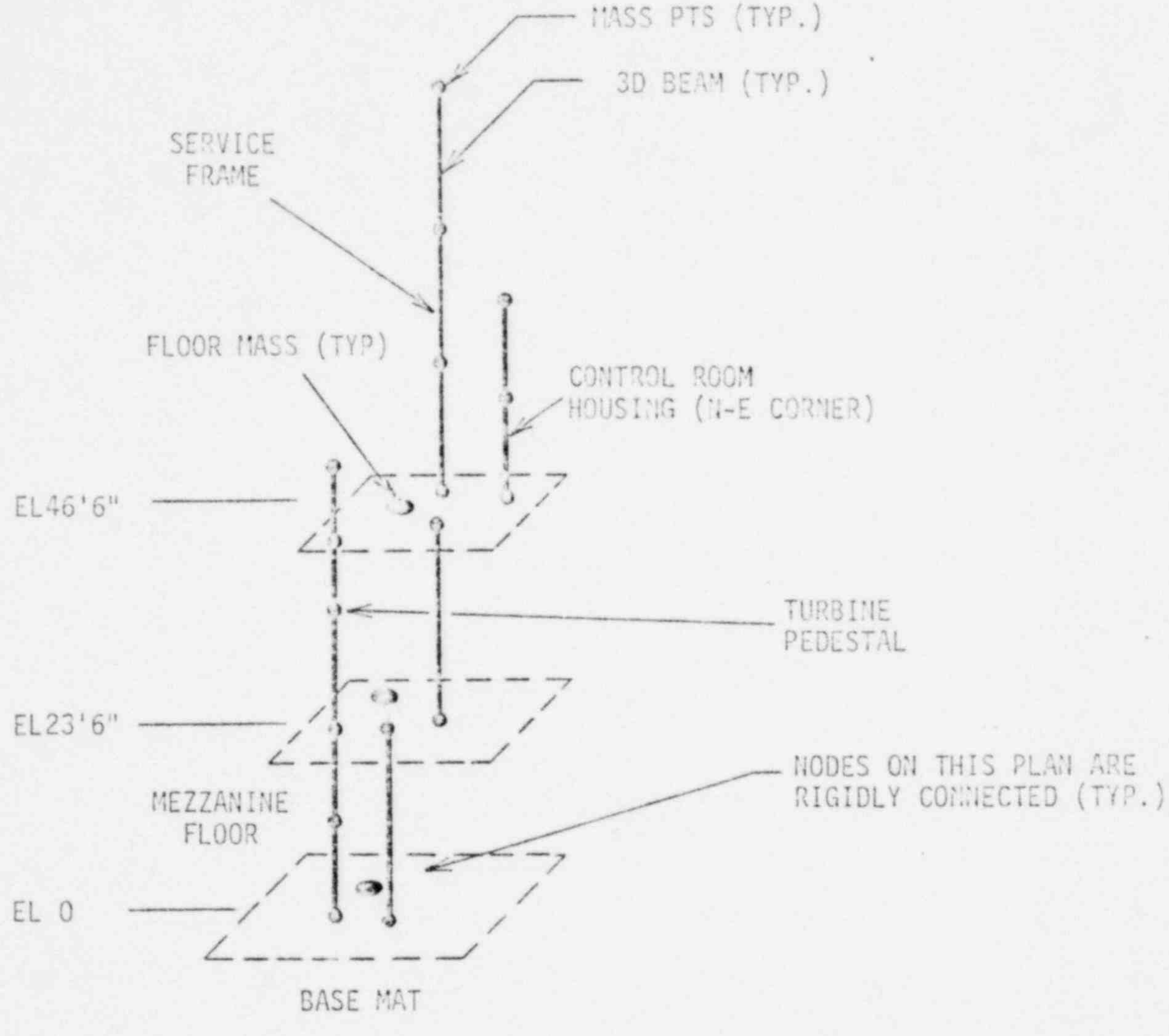


Fig. 12

PROPOSED 3D STACK MODEL

each floor elevation.

Additionally, the reactor building model (Fig. 10) includes the models for drywell, and RPV (reactor pressure vessel) with the shield wall and the RPV support pedestal. These equipment models are identical to those used by Blume (Fig. 9).

The spring constants K_1 and K_2 shown in Fig. 10 represent respectively the connecting element stiffness from RPV to the drywell and that from shield wall to the drywell. They are determined from Blume's original analysis. A rigid connection (gap closed condition) is assumed at about El. 82' between the drywell and the reactor building. The mass of the office building annex will be included in the reactor building model.

In the turbine building model (Fig. 11), the control room housing is represented by a separate branch of the stick model on the operating floor (El. 46' 6"). Similarly, separate branches were used to represent the overhead service frame and the turbine pedestal.

The model for the stack (Fig. 12) is a single 3D stick model.

The method of deriving composite modal damping ratios for the model made of reinforced concrete and steel components has been discussed in Sect. 5.4, and for the inclusion of soil damping effects, in Sect. 6.2.

The soil springs for the six foundation d.o.f.'s are not shown in Fig's 10, 11, and 12. The method of determining these spring constant and attaching these springs to the model has been described in Sect. 6.1.

9. CONDENSATE STORAGE TANK

The seismic analysis of this tank was reported in AM. 38 to OC FSAR (Pages 5-10 and 5-11). The analysis considered both impulsive and convective modes of water, and the base overturning moment and shear were computed. The analysis indicated these findings under a 0.22g SSE loading:

1. Anchor bolts are not capable of resisting the induced base shear if no reliance is placed upon the interfact friction between the bottom of the tank and the foundation.
2. Tank shell is safe from buckling.
3. The upward forces on the roof because of the sloshing liquid will be negligible and can be ignored.

The proposed reanalysis shall examine the up-to-date tank base anchorage configuration. The analysis shall also include the vertical response mode in addition to impulsive and convective modes of water. The methology will be adopted from Ref.'s 13 and 16. The particular areas of concern are:

1. Possibility of uplifting
2. Shell buckling at the base
3. Base anchorage strength against overturning and shear
4. Tank shell hoop tension stress due to hydrodynamic and static fluid pressures.
5. Roof integrity against sloshing liquid forces

10. BURIED EMERGENCY SERVICE WATER LINES

The analysis is reported in Ref. 17 by J.A. Blume Associates in November, 1967. Only the bending stresses were calculated and no considerations were given to determine axial stresses due to passage of seismic waves.

The reanalysis of buried pipeline will follow the guidelines given in NUREG/CR-0098, Sect. 8.3 and those given in Ref's 18 to 23.

Information is needed on the exact layout (routing) of the buried emergency service water lines (i.e., referenced drawings in Ref. 17) and their connections to the intake and turbine buildings. Critical areas are then to be identified and appropriate formulas shall be used to check pipe axial and bending stresses due to passage of seismic waves and building displacements.

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APPENDIX A

- Checklist of Information Required for Seismic Reanalysis
- Unresolved Open Items

o CHECKLIST OF INFORMATION REQUIRED FOR SEISMIC REANALYSIS

/ / Equipment weight and distribution information for establishing the 3D turbine building, reactor building and turbine pedestal dynamic models.

/ / Structure and equipment weight information on the office building annex attached to the reactor building. For example, B & R dwg's 4063-1, 2, 3, and 4.

/ / Structure drawings required to verify and to determine the amount of physical separation at important elevations of the following buildings:

- Office building and reactor building
- Reactor building and turbine building
- Machine shop and turbine building
- Radwaste building and reactor building

/ / Data on compacted backfill useful for establishing soil elastic properties

/ / Locations of the RPV stabilizer attachment points

/ / Referenced drawings in Blume's report on Buried Emergency Service Water Lines B & R dwg's 2192-5, 2193-6, 2194-5, 2195-3, 2196-4, 2117-4 and 2120-5

/ / Condensate storage tank structure details including dome geometry, shell thickness variation, base anchorage details, and foundation details.

/ / Soil data beneath the tank foundation

/ / Liquid level in the tank

UNRESOLVED OPEN ITEMS

/ / Decision on cut-off soil (modal) damping ratios

/ / Consideration of site soil elastic property variations

/ / Conflicting soil data at the OC site vs. that at the Fork River site

/ / Estimation of the maximum ground velocity associated with the site (this data is needed in the buried pipe analysis)

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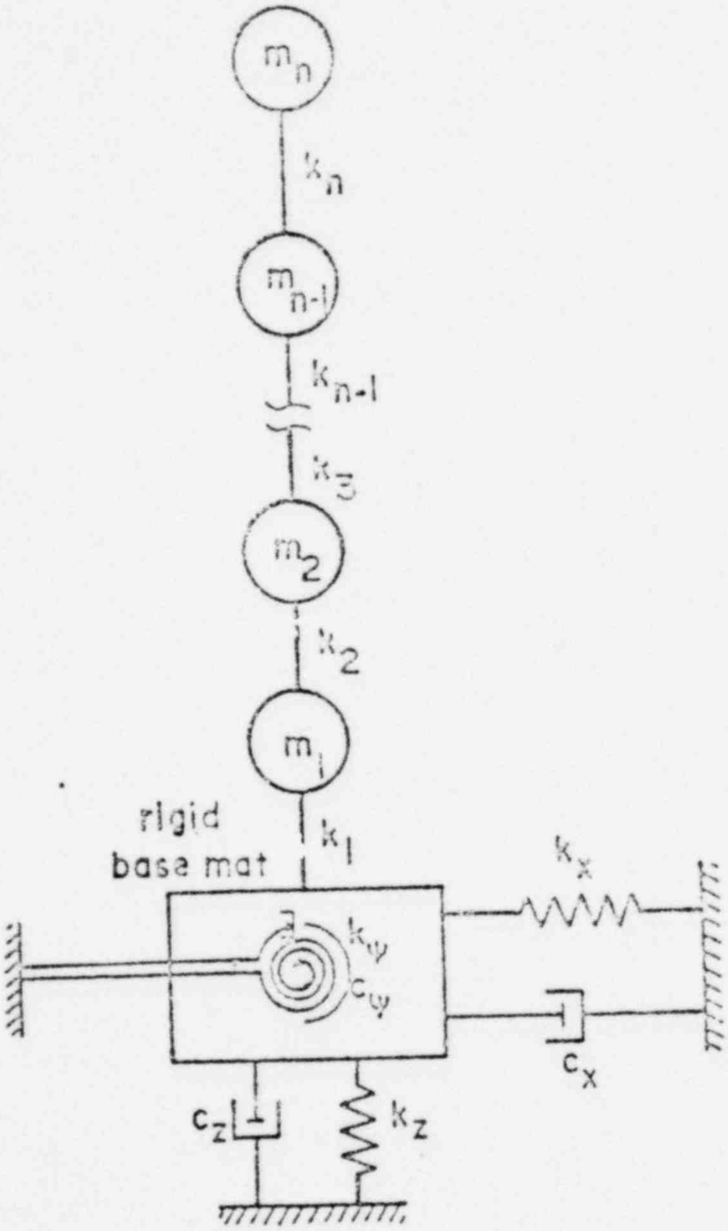
APPENDIX B

WHITMAN'S SPRING CONSTANTS FOR STRUCTURES ON ELASTIC HALF SPACE



m_n
k_n
m_n-1
k_n-1
k_3
m_2
k_2
m_1
k_1
rigid
base mat
k_x
k_ψ
c_ψ
c_x
c_z
k_z

(b) Rectangular Base

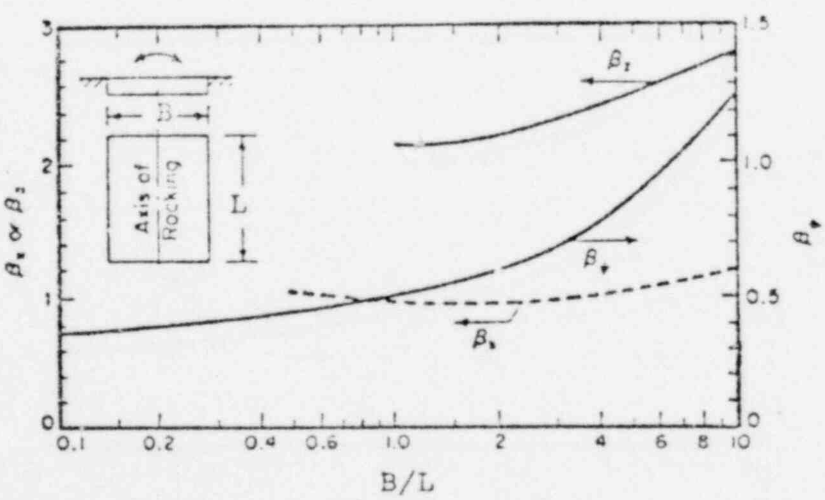
Motion	Equivalent Spring Constant	Equivalent Damping Coefficient
Horizontal	$k_x = 2(1+\nu)G\beta_x\sqrt{BL}$	Use the formulas for circular base having an equivalent radius R defined by Table 3-2(c).
Rocking	$k_\psi = \frac{G}{1-\nu}\beta_\psi B^2L$	
Vertical	$k_z = \frac{G}{1-\nu}\beta_z\sqrt{BL}$	
Torsion	Use Table 3-2(a) for $R = \sqrt[4]{BL(B^2+L^2)/6\pi}$	

in which ν and G are as defined previously, and

B = width of the base mat in the plane of horizontal excitation;

L = length of the base mat perpendicular to the plane of horizontal excitation;

$\beta_x, \beta_\psi, \beta_z$ = constants that are functions of the dimensional ratio, B/L. (After Fig. 10-16 in Ref. 3-6.)



Constants β_x, β_ψ and β_z for Rectangular Bases

(a) Circular Base

Motion	Equivalent Spring Constant	Equivalent Damping Coefficient
Horizontal	$k_x = \frac{32(1-\nu)GR}{7-8\nu}$	$c_x = 0.576 k_x R \sqrt{\rho/G}$
Rocking	$k_\psi = \frac{8GR^3}{3(1-\nu)}$	$c_\psi = \frac{0.30}{1+B_\psi} k_\psi R \sqrt{\rho/G}$
Vertical	$k_z = \frac{4GR}{1-\nu}$	$c_z = 0.85 k_z R \sqrt{\rho/G}$
Torsion	$k_t = 16\ GR^3/3$	$c_t = \frac{\sqrt{k_t I_t}}{1+2I_t/\rho R^5}$

in which

ν = Poisson's ratio of foundation medium,

G = shear modulus of foundation medium,

R = radius of the circular base mat,

ρ = density of foundation medium,

$$B_\psi = \frac{3(1-\nu)I_o}{8\rho R^5},$$

I_o = total mass moment of inertia of structure and base mat about the rocking axis at the base.

I_t = polar mass moment of inertia of structure and base mat.

(c) Equivalent Radius For Rectangular Base

For a rectangluar base having a dimension of BxL (B = width of base in the plane of horizontal vibration), the equivalent radius R is taken to be the smallest of the parameters R_x, R_ψ and R_z defined below:

$$R_x = \frac{(1+\nu)(7-8\nu)\beta_x\sqrt{BL}}{16(1-\nu)} \quad \text{OR} \quad \sqrt{BL/\pi}$$

$$R_\psi = \sqrt[3]{3\beta_\psi B^2 L/8} \quad \text{OR} \quad \sqrt[4]{BL^3/3\pi}$$

$$R_z = \beta_z\sqrt{BL}/4$$

APPENDIX C

LAYERING EFFECT SIMPLIFICATION PROCEDURE FROM REF. 8

structures having an embedment less than the base radius for circular bases or one half of the shorter dimension for rectangular bases, and the effect of embedment is taken into account according to Section 3.3.1. On the other hand, the finite element representation is generally used for structures having an embedment to base dimension ratio exceeding the limit defined above or for sites having more complicated foundation conditions. The embedment is defined as the vertical distance from the bottom of the structural base slab to the grade. Reference (2-6) and Appendix B discuss the distinction between, and the applicability of, these two methods for interaction representation.

Horizontal layering is usually present at the plant sites. In engineering applications, the layering of the foundation medium can be simplified to some extent without significantly affecting the accuracy of the structural response calculations. This is possible either because of small contrasts in the material properties of the layers, or because of a certain relationship between the layer thickness, base slab dimension and wave velocity variation.

The following two steps may be used for the layering simplification, irrespective of the subsequent methods of analysis:

<u>Layering Simplification Criterion (A)</u> - Layering indicated by the initial soil reports is first simplified with reference to the degree of material property variation across each layer boundary. It is sufficient to examine only the wave velocity variation and to neglect the variation in density because the latter is relatively small.

Referring to Fig. 3-1(a), let h_i and V_i be the thickness and shear wave velocity, respectively, of the i-th layer from the initial site soil data. Starting from the very top layer (i=1), compute the following velocity ratio successively for each layer:

$$r_v = \frac{|V_i - V_{i+1}|}{\text{the lesser of } V_i \text{ and } V_{i+1}} \quad (3-5)$$

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The boundary between layers i and i+1 is retained if r_v exceeds 0.25 (uncertainties in field measurements are generally above this level). Otherwise, these two layers are combined into one new layer, i, having a new thickness $(h_i)_{new}$ and new shear wave velocity $(V_i)_{new}$ as computed below:

$$(h_i)_{new} = h_i + h_{i+1}$$

$$(V_i)_{new} = \frac{(h_i)_{new}}{h_i/V_i + h_{i+1}/V_{i+1}} \quad (3-6)$$

Proceeding downward, this test is applied successively to each layer boundary until either the shear wave velocity exceeds 4000 ft/sec, or the boundary is at a vertical distance below the base slab exceeding six times the base radius R, whichever takes place first. For rectangular bases, use an equivalent radius defined by Table 3-2(c).

<u>Layering Simplification Criterion (B)</u> - The layering condition is further simplified for those layers recognized under Criterion (A).

Criterion (B) is established based on a study of the lateral vibration of a circular rigid plate on the surface of a single elastic layer overlying another uniform elastic half space (3-5). In this study, different combinations of the parameters: h_1/R (top layer thickness/base radius), shear wave velocity, density and Poisson's

ratio were considered in the response computation. The results were then compared with those for the limiting case of an infinitely thick top layer; the latter is equivalent to a uniform half space. The study indicated that, in general, the layering effect becomes negligible when the following idealized relation is met:

$$V_1/V_2 + h_1/8R > 1 \qquad (3\text{-}7)$$

in which V_1 and V_2 are the shear wave velocities in the top layer and the underlying uniform half space, respectively.

The above conclusion derived from the study of the single-layered case is modified for multiple-layered sites, as follows: The upper boundary of the top layer (j=1) considered in this criterion starts at the elevation of the bottom of the structure base slab. See Fig. 3-1(b). Let there be a total of N' layers below the base slab after Criterion (A) is applied. Compute the following parameters: 2

$$\left.\begin{aligned} D_j &= h_1 + \ldots + h_j \\ &= \text{vertical distance of the lower boundary of of layer } j \text{ from the base mat.} \\ \bar{V}_j &= \frac{D_j}{h_1/V_1 + \ldots + h_j/V_j} \\ \bar{V}_{j+1} &= \left\{\begin{aligned} &\frac{h_{j+1} + \ldots + h_{N'}}{h_{j+1}/V_{j+1} + \ldots + h_{N'}/V_{N'}} \quad \text{if } j<N' \\ &= V_{N'+1} \;\ldots\ldots\ldots\ldots\ldots\ldots \text{ if } j=N' \end{aligned}\right. \end{aligned}\right\} \qquad (3\text{-}8)$$

Both layers j and j+1 are retained if

$$\frac{\bar{V}_j}{\bar{V}_{j+1}} + \frac{D_j}{8R} \geq 1 \qquad (3\text{-}9)$$

or, graphically, if the point defined by the coordinates $\bar{V}_j/\bar{V}_{j+1}$ and h_j/R falls inside the shaded triangle shown in Figure 3-2. Otherwise, layers j and j+1 are combined into one new layer having a new thickness and wave velocity computed according to Eq. (3-6). 2

For rectangular bases, use an equivalent radius established according to Table 3-2([illegible]).

3.3.1 Lumped Parameter Representation

In using the lumped parameter representation, the effect of the foundation medium is represented by the foundation impedances. In general, the foundation impedances are complex functions of the base mat, embedment depth, elastic properties of the foundation medium and forcing frequencies. Whether or not frequency dependent, they can always be represented by a mechanical analog composed of equivalent springs and dampers. The equivalent dampers represent the radiation effect of the seismic wave energy away from the structural base. The material damping of the foundation medium is neglected in the lumped parameter representation if it is small compared with radiation damping. 2

Figure 3-3 shows a schematic lumped parameter model of the structure-foundation system, with the equivalent foundation springs, k_x and k_ψ, and radiation dampers, c_x and c_ψ, representing the foundation impedances for horizontal seismic excitation. The foundation is represented by k_z and c_z for vertical motion, and k_t and c_t for torsion. These impedance functions are the superposition of the effect due to the foundation medium below the base slab elevation and the effect due to the structural embedment. Various tests indicated that the embedment has the effect of increasing both the equivalent spring stiffnesses and the radiation damping (e.g., 3-10, 3-11). For simplicity of analysis,

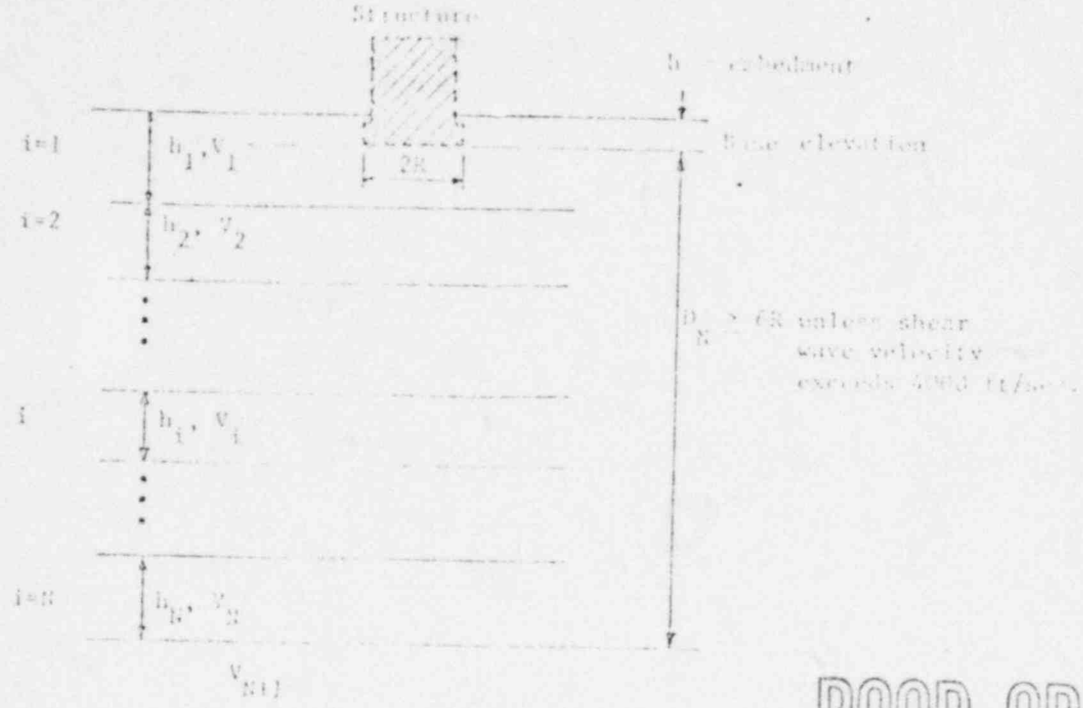

Figure 3-1(a) Notations for Layering Criterion (A) Applied to Original Soil Data

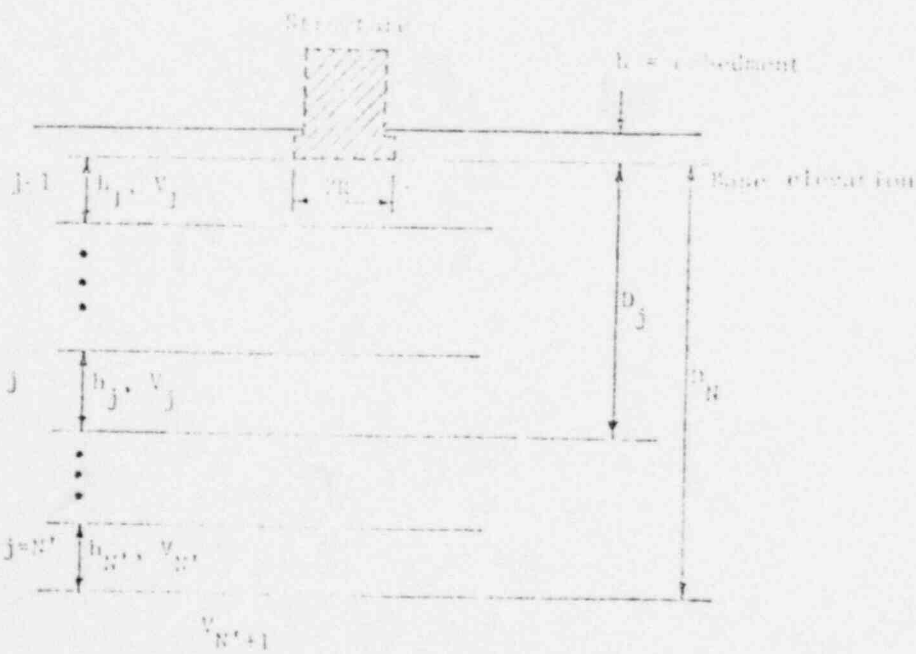

Figure 3-1(b) Notations for Layering Criterion (B) Applied to Layers Recognized by Criterion (A)