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THE EVALUATION OF THE VERTICAL VIBRATION MODEL OF A PWR-4LOOP TYPE NUCLEAR REACTOR BUILDING

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ABSTRACT

Implementing a three-dimensional (3-D) FEM model, the vertical vibration properties of a Pressurized Water Reactor (PWR) type reactor building is studied. For design purposes, the assembling and calculation time of a 3-D FEM model are not practical. Therefore, a simplified lumped mass model is proposed in lieu of a 3-D FEM model and surveyed the vertical vibration properties comparing 3-D FEM model. From the analytical results, it has been found that the simplified lumped mass model can be used for the vertical design model of a PWR-4loop type reactor building.

1. INTRODUCTION

Study on advanced seismic design for Light Water Reactor (LWR) has been carried out by the Nuclear Power Engineering Corporation (NUPEC), under the sponsorship of the Ministry of International Trade and Industry (MITI) of Japan. In Japanese seismic design, a seismic load due to vertical ground motion has been treated as a static force. Nowadays dynamic evaluation of vertical ground motion can be analyzed by accumulating vertical observation records and the implementing computer technology. However the vertical seismic response model of a PWR type reactor building is not studied as much as the horizontal model. In this paper, the vertical seismic response model of a PWR-4Loop type reactor building is studied for deriving a reliable vertical design model. Primarily, a 3-D FEM model is assembled for realizing dynamic vibration characteristics and it is regarded as the reference model. Afterwards some multi lumped mass models with flexible base mat or rigid base mat are modeled and compared with the dynamic vibration characteristics of the 3-D FEM model.

2. ANALYTICAL CONDITIONS

(1) Outline of the Reactor Building

The PWR-4loop type reactor building consists of the Prestressed Concrete Containment Vessel (PCCV), Internal Concrete (I/C) and Reactor External Building (REB) on a 72.0m × 100.0m rectangular base mat and these are structurally isolated from each other. The plot plan (EL16.5m) and section (N-S Direction) are shown in Fig. 1. The reactor building is primarily made of reinforced concrete while the fuel handling building (FHB) in the REB is a steel structure. The reactor building is assumed to be founded on a rock ground surface without embedment.

(2) Seismic Ground Motion

The vertical input ground motion is an artificial earthquake with the phase angle sets of the EL Centro observed accelerogram, and it is simulated so as to fit the vertical target spectrum. The vertical target spectrum is generated by the horizontal design response spectrum with a magnitude of 6.5 and epicentral distance of 20 km, but the control point values of the vertical target spectrum are half of those of the horizontal design response spectrum. The acceleration time history and its acceleration response spectrum with 5% damping are shown in Fig. 2. The maximum acceleration is 143.08 gal.

(3) Material Properties
The physical properties of concrete and steel are shown in Table 1. In this study, two soil conditions with their shear wave velocities of 1000 m/s and 1500 m/s are considered. These soil properties are shown in Table 2.

3. ANALYTICAL MODELS

The reactor building form is almost symmetrical with respect to the N-S axis, but it is not symmetrical with respect to the E-W axis. The influence of eccentricity however, is small and the center of geometry and gravity are almost same. Therefore, symmetry of the reactor building with respect to E-W axis can be assumed. Based on this assumption, a quarter portion of building is modeled. Soil-structure interaction effect is evaluated applying the complex soil springs determined by the elastic half-space wave propagation theory. The following is an outline of the analytical models for to perform response analyses for vertical seismic ground motion as shown in Table 3.

· MODEL-A (3-D FEM Model)
MODEL-A is a reference model for realizing dynamic vibration characteristics. The base mat is modeled as solid and shell elements, and seismic walls, floor-slabs and roof-slab are modeled by shell elements. Steel beams and columns are modeled as beam elements. The soil interactive springs under the base mat are attached to he finite element mesh.

· MODEL-B (FEM Base Mat Model)
The walls of the PCCV and I/C are single stick lumped mass models. The floor slabs and steel columns of I/C are modeled as shear and axial springs. The seismic walls in the REB are modeled as three stick models with lumped masses. Roof and floor slabs are modeled as shear springs and columns are modeled as axial springs. Considering the flexibility of the base mat, it is modeled the same as MODEL-A. The soil interactive springs are modeled the same as MODEL-A.

· MODEL-C (Multiple Bases Mat Model)
The PCCV, I/C and REB are modeled the same as MODEL-B, but they are two-dimensional models. Considering base mat flexibility, the base mat is separated into three rigid blocks because the structures on the base mat are structurally isolated from each other. These blocks have soil interactive springs. There are axial soil springs at the bottom surface of each block, and each block is connected by interactive shear springs. The soil interactive springs are reduced from the MODEL-A springs, and the shear springs have the reinforced concrete stiffness of each base mat block.

· MODEL-D (Rigid Base Mat Model)
The structures on the base mat are the same as MODEL-C, but the base mat is a rigid single mass model. The soil interactive spring is attached to the bottom center of the base mat.

· Model-E & MODEL-F (REB Single Stick Model)
Basically MODEL-E is the same as MODEL-C and MODEL-F is the same as MODEL-D, but the seismic walls in the REB of MODEL-E and MODEL-F are modeled as single stick lumped masses.

4. ANALYTICAL RESULTS

Concerning the two different soil conditions, both analytical results have similar tendencies. Therefore, the results of Vs=1500 m/s are mentioned below because it is similar to shear wave velocities at the typical site for PWR type power plants in Japan. Typical analytical results from the above mentioned analytical models are as follows:

(1) Transfer Function
Transfer functions from the ground surface to the top of the PCCV (EL 65.1m), the edge of I/C slab (EL 16.5m) and the center of the FHB roof (EL 30.2m) are shown in Fig. 3.

In general, the transfer function shapes of every lumped mass model are in fairly good agreement with the result of the 3-D FEM model, but no lumped mass model can express the shape in the high frequency range over 20.0 Hz. Also, the lumped mass models cannot express the transfer function shape of the edge of the I/C slab at about 15.0Hz. There is no obvious difference between the results of the flexible base mat and rigid base mat.

(2) Maximum Response Value
Maximum response acceleration distribution of each analysis model is shown in Fig. 4. A numerical comparison table of the maximum response values of acceleration and displacement at typical locations is shown in Table 4. The maximum response acceleration values at the top of the PCCV of the lumped mass models are a little larger than those of MODEL-A. The acceleration values of the rigid base mat model (MODEL-D and F) are especially larger than those of others. However the acceleration values at the other locations of the lumped mass models are in good agreement with the values of MODEL-A.

The maximum response displacement value at the top of the PCCV and the I/C of MODEL-B are a little larger than those of MODEL-A, but the other lumped mass models show nearly the same value of MODEL-A.

(3) Floor Response Spectrum
Acceleration floor response spectrum (FRS) at the top of the PCCV, the edge of the I/C slab and the center of the FHB roof slab are compared in Fig. 5. The maximum peak point values at the top of the PCCV lumped mass models are a little larger than those of MODEL-A. The values at the the edge of the I/C slab and the center of the FHB roof slab lumped mass models are a little smaller than those of MODEL-A. But the FRS shapes of lumped mass models are in good agreement with those of MODEL-A.

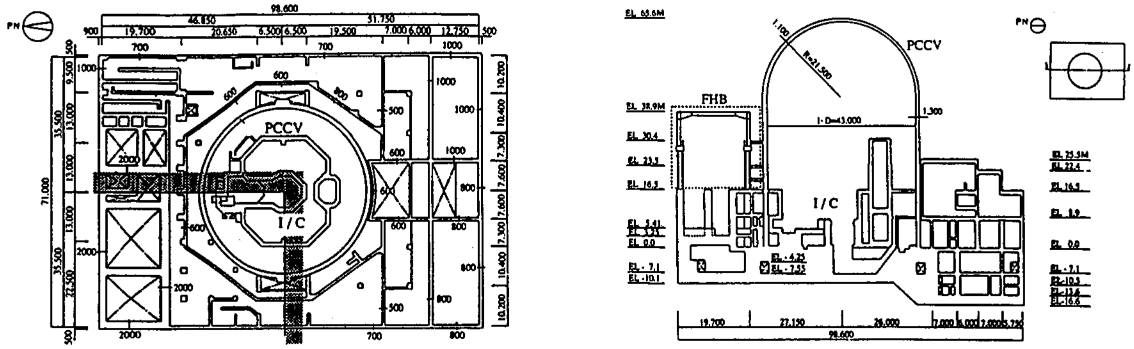
5. CONCLUSION

In order to survey the simplified lumped mass model for the vertical response analysis of the PWR 4loop type reactor building, the dynamic vertical characteristics of the lumped mass models are compared to those of the 3-D FEM model. The conclusions of seismic response analysis are summarized as follows:

(1) In the cases when soil shear wave velocities are 1000 m/s and 1500 m/s, there are no obvious influences due to the flexibility of the base mat.

(2) Concerning the lumped mass models, there is no obvious influence due to the REB modeling differences, and even the most simplified rigid base mat lumped mass model (MODEL-F) can approximately express the vertical vibration characteristics. Therefore the lumped mass model is suitable for the vertical design model of a PWR-4loop type reactor building.

ACKNOWLEDGEMENT This work was supported by "Committee on advanced seismic design for LWR" of NUPEC. The authors wish to express their gratitude for the cooperation and valuable suggestions given by the members of Committee.



(a)PLAN(EL16.5m) (b)SECTION (N-S)

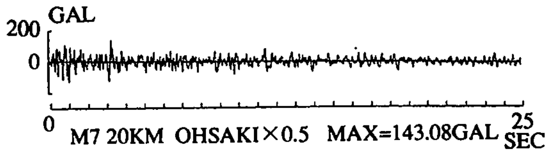
Fig.1 Plan and Cross Section

Table 1 Material Properties of Structure

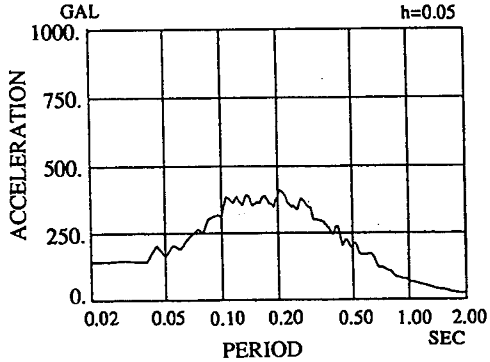
		PCCV	I/C, Base Mat REB (RC)	REB (Steel)
Young's Modules	$(10^5 kgf/cm^2)$	3.15	2.57	21.00
Shear Modules	$(10^5 kgf/cm^2)$	1.35	1.10	8.10
Compressive Strength	(kgf/cm^2)	450	300	—
Damping Factor		0.03	0.03	0.02

Table 2 Material Properties of Soil

Shear Wave Velocity	Vs(m/s)	1000	1500
Unit Weight	(t/m^3)	2.0	2.3
Poisson's Ratio		0.40	0.38
Shear Module	$(10^5 t/m^2)$	2.04	5.28



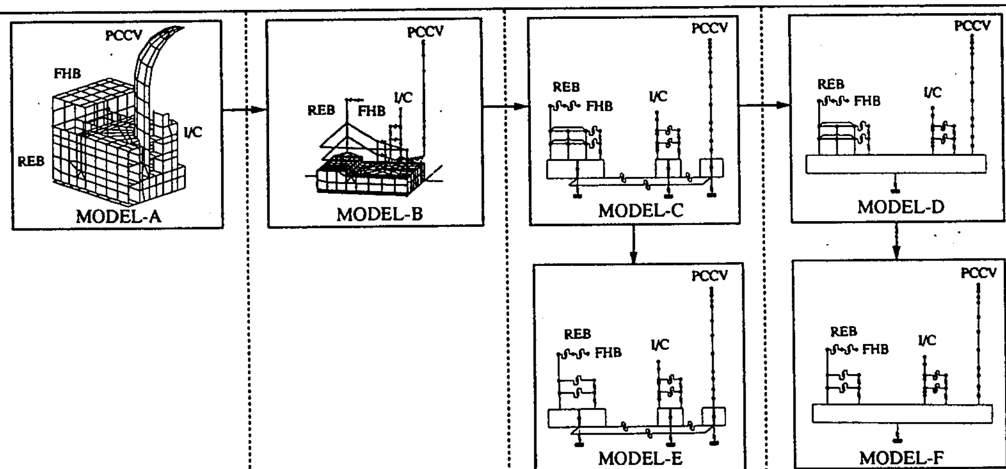
(a)Acceleration Time History

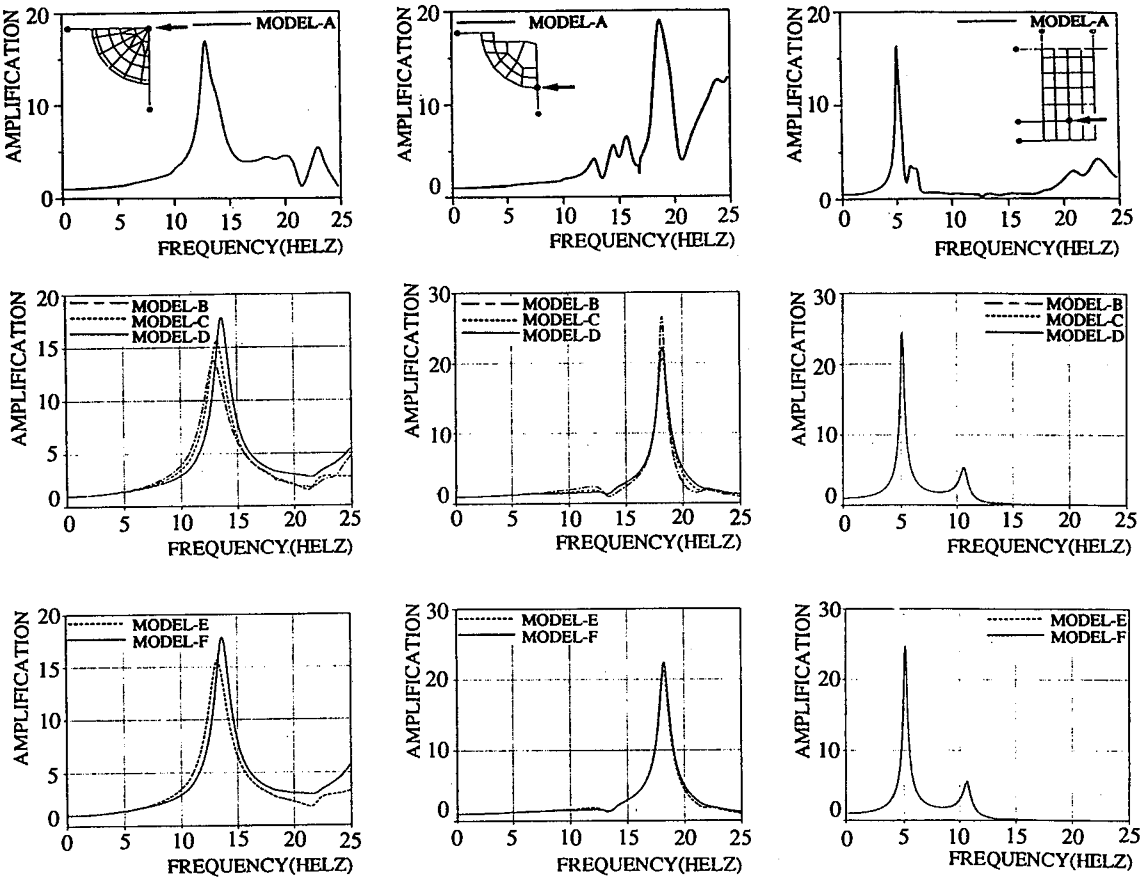


(b)Acceleration Response Spectrum

Fig.2 Input Seismic Motion

Table 3 Vertical Analysis Models

Reactor Building 1/4 Model				
Structures on the Base Mat	FEM Elements	The PCCV,I/C and REB are stick lumped mass models. The seismic walls in theREB are modeled by three sticks at the MODEL-D, MODEL-C and MODEL-D,and the sticks are combined one stick at the MODEL-E and MODEL-F.		
Base Mat	FEM Elements	FEM Elements	Multiple Bases	Single Rigid Base
Soil Spring	Attached to the nodes at the bottom surface of base mat FEM mesh		Combined with the base mat stiffness from FEM model and calculated interaction springs	Unit



(a)Top of PCCV (EL 65.1m) (b)Edge of I/C Slab (EL16.5m) (c)Center of FHB Roof Slab (EL30.2m)

Fig.3 Comparison of Transfer Functions (Vs=1500m/s)

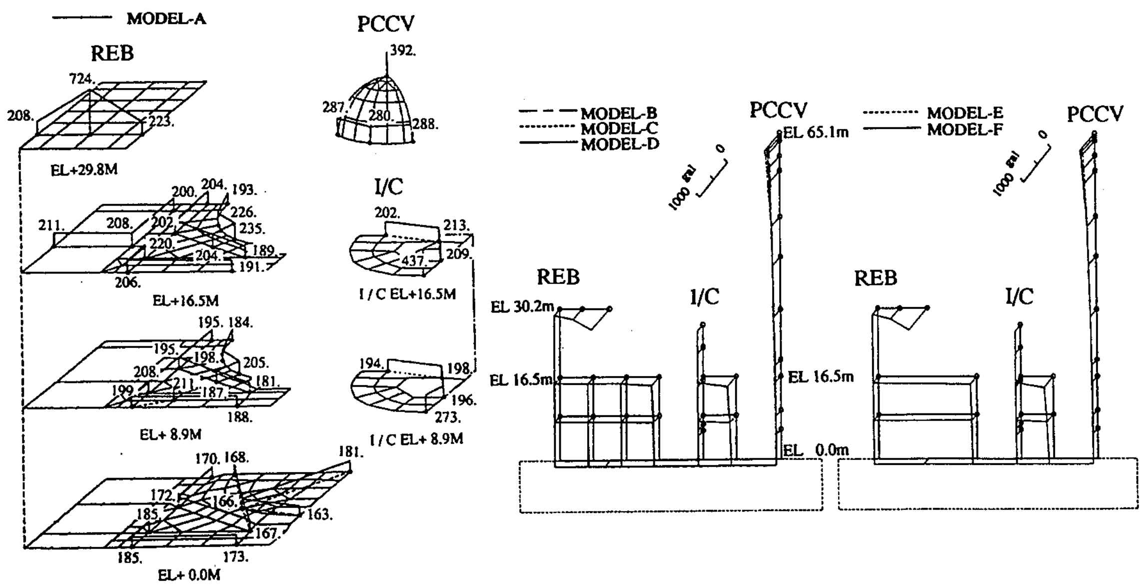
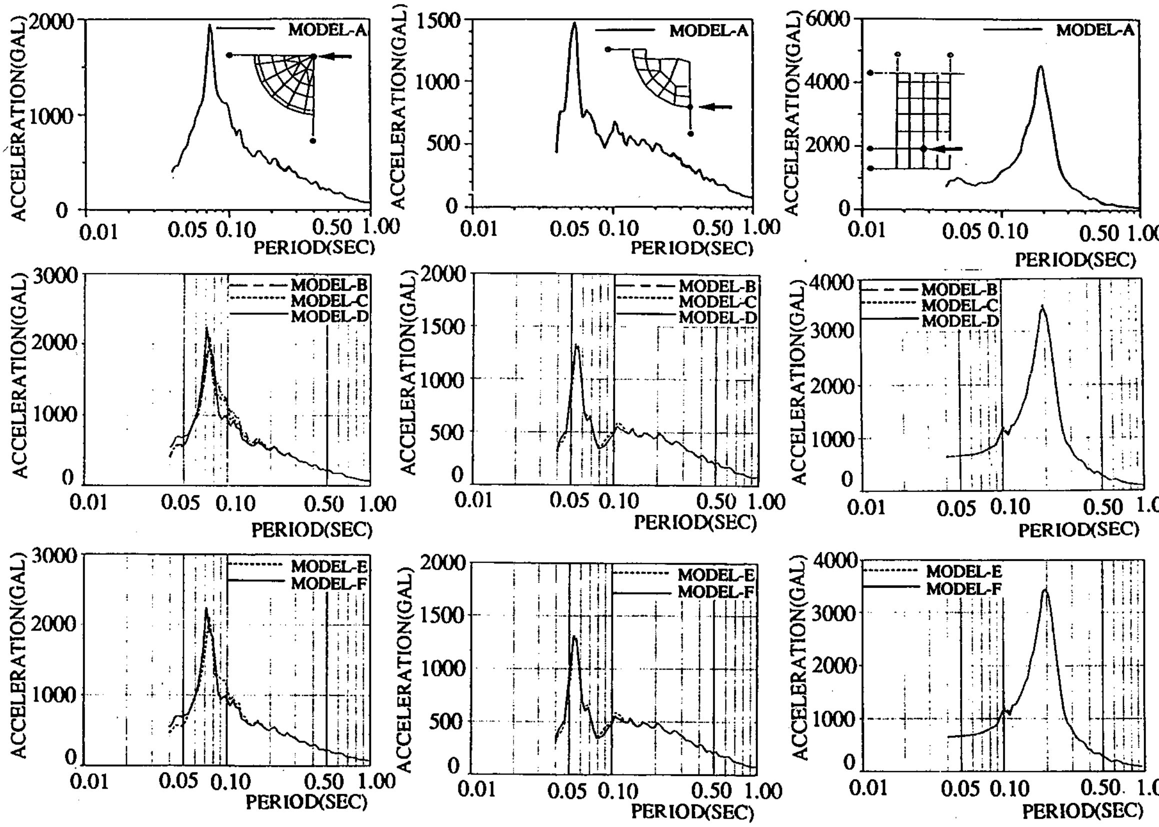


Fig.4 Comparison of Maximum Response Accelerations (Vs=1500m/s)

Table 4 Comparison of Maximum Response Values (Vs=1500m/s)

MODEL	Maximum Response Analysis (gal) A	B	C	D	E	F	Maximum Response Displacement (cm) A	B	C	D	E	F
PCCV Top (EL65.1m)	392	403	460	542	461	545	0.073	0.094	0.077	0.078	0.077	0.079
Spring-Line (EL40.5m)	280 ~288	281	263	275	264	275	0.053 ~0.054	0.066	0.054	0.047	0.054	0.047
I/C Edge of Slab (EL16.5m)	437	292	307	327	312	330	0.053	0.105	0.050	0.049	0.050	0.049
Bottom of Wall (EL16.5m)	202 ~213	201	184	185	185	185	0.023 ~0.025	0.032	0.026	0.026	0.026	0.026
REB Center of FHB Roof Slab	724	654	641	656	643	658	0.770	0.662	0.645	0.663	0.647	0.665
Edge of FHB Roof Slab (EL30.2m)	208 ~223	207	189	186	193	190	0.055 ~0.062	0.033	0.032	0.033	0.032	0.034
Edge of Slab (EL16.5m)	193 ~235	277	261	244	236	221	0.033 ~0.040	0.044	0.033	0.035	0.032	0.034
Octagonal Inner Wall (EL16.5m)	189 ~220	204	202	198			0.029 ~0.038	0.032	0.028	0.029		
Outer Wall (EL16.5m)	191	203	190	187	185	182	0.030	0.029	0.025	0.026		
Bottom of the FHB Steel Column (EL16.5m)	200 ~211	198	180	178			0.035 ~0.044	0.026	0.023	0.026	0.024	0.026
Base Mat (EL0.0m) Bottom of PCCV	163 ~168	171					0.026 ~0.027	0.028				
Bottom of Octagonal Inner Wall	167 ~185	175	166 ~ 170	168	166 ~ 170	168	0.026 ~0.032	0.026	0.022 ~ 0.025	0.024	0.022 ~ 0.025	0.024
Bottom of Outer Wall	173	182					0.027	0.025				
Center of Base-mat	181	175					0.019	0.026				



(a)Top of PCCV (EL 65.1m) (b)Edge of I/C Slab (EL16.5m) (c)Center of FHB Roof Slab (EL30.2m)

Fig.5 Comparison of Floor Response Spectra (Vs=1500m/s) h=0.05

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PARAMETRIC STUDY FOR THE SEISMIC RESPONSE OF EMBEDDED FUEL TANKS

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SUMMARY

This paper addresses the finite element analysis of embedded earthquake loaded fuel storage tanks of the nuclear power plant Biblis. The fundamental problem thereby is the developement of practical approximations of the soil-tank interaction which allow a dimensioning on the safe side. With plane models the soil-tank interaction is examined and as a result a set of parameters is found which estimates the loading conditions for the three-dimensional calculations. The analysis of the three-dimensional model with quasi-static loading conditions proves that the stresses meet the allowable values and that an adequate safety margin against stability failure exists.

1. DESCRIPTION OF THE STRUCTURE

The embedded, double-walled steel tanks /4/ are placed in groups at a depth of about 1.5 m below soil surface (Fig. 1). These cylindrical tanks with a length of about 13 m and a diameter of 2.9 m are stiffened with internal ring-shaped T-profiles. The minimum filling condition is 80 % of the tank volume. The tanks are fastened to thick concrete slabs with tension steel sheets to avoid lifting. Fig. 2 shows the specified ground response spectra. Besides seismic loading the tanks are stressed by dead load, filling, soil burden and an internal pressure of 0.6 bar.

2. CONCEPT OF THE ANALYSIS

Seismic influences on underground structures might be approximated by a method using seismic coefficients /1/. There, the earthquake loading is estimated by quasi-static pressures. The method was used to analyze a tunnel under the Tokyo Bay in Japan for example /2/.

For the present case, applicable coefficients are not available. So the soil-structure interaction effects have to be included in the analysis, taking into account the interrelation of loading and support. Under this aspect finite element models are used which consist of the vessel as well as parts of the surrounding ground. Facing the size of the calculation model and the complexity of the influences such as stiffness, boundary conditions, liquid filling and interaction between adjacent tanks, a parametric study has been carried out for a plane model in order to get safe approximations of the influenced quantities for the three-dimensional finite element analysis. The final stresses for the stress report according to DIN 18800 are calculated using a three-dimensional finite element model of the embedded single tank together with quasi-static loading. The complete model (including shaft and dummy masses to estimate pipe forces) is analyzed for simultaneous acceleration in two horizontal and one vertical direction. The safety against buckling of the tank bottoms is insured by a limit analysis of the acceleration in lengthwise direction of the tank /5/. Vessel parts such as the cylindrical wall, and stiffeners are not endangered by stability failure, so that only the stress limits have to be met.

3. PARAMETRIC STUDIES

Object of the parametric studies is the determination of those soil solid measurements which lead to a maximum loading on the tanks. Besides that the sensitivity against changes in the soil solid measurements, the influences of soil parameters, adjacent tanks and different boundary conditions are examined. Because of the length of the cylindrical wall, the effects of a horizontal acceleration can be analyzed using the plane mode shown in Fig. 3. The model of the cross-direction consists of the vessel, the concrete slab, a cork sheet under the vessel and the surrounding soil. The density of the vessel wall is increased from ρ to ρ^* at the vessel sides to take into account the filling. The base of the model has fixed supports in all directions, the sides remain unsupported (on the safe side).

The loading of the tanks is determined with the Response Spectrum Method (spectrum see Fig. 2). For a safe estimate, the curve for the resulting excitation of the field spectrum (upper curve) is used for the calculation. The superimposition of the parts of the modes is done according to the SRSS-Rule. The dead load and the earthquake load are combined corresponding to the above described.

First, at fixed height of the soil solid below the slab (H = 1000 mm, see Fig. 3) it was determined, which width of the soil solid leads to a maximum loading on the tank. The stiffness of the soil was assumed as a lower boundary of back-fill material (EB = 30 N/mm^2, ν = 0.33). The first three mode shapes and frequencies of a soil soild with a width ranging from B = R + 1000 mm to R + 2450 mm are shown in Fig. 4. Fig. 5 displays the extreme fiber stresses due to dead load, filling and earthquake.

As a result of examinations with various height and width of soil solids, it could be found /3/ that the mentioned combination leads to a maximum loading on the tanks and that the sensitivity of the system is slight compared to the modifications. As expected the loading was less than described above, when the soil solid had horizontal supports at the sides, the filling was neglected or the stiffness of the soil was increased. Fig. 6 shows the model of two adjacent tanks. The stress extremas calculated with this model (62.4 N/mm^2) lay below the values of Fig. 5.

The seismic loading is caused basically by the oscillation in the first mode shape. Therefore those stresses are determined which result of the approximation of the seismic excitation by a quasi-static horizontal acceleration. The superimposition of the absolute values of the load cases filling, dead load (vertical 1.0 g) and horizontal acceleration (0.5 g) is shown in Fig. 7. The maximum stress is 63.8 N/mm^2 and lays above the value of the reference solution in Fig. 5. So the most unfavourable parameters and boundary conditions are determined. Furthermore it could be shown that the seismic load can be replaced by a quasi-static horizontal load in the present case.

the soil solid (E = 30 N/mm^2) a soft and massless supporting layer (BS = 1.5 m, EBS = 2.25 N/mm^2) is provided, which has constraint displacements normal to the outer surface. The other boundary conditions are those used in the plane model. The inner tank wall (cylinder and bottom) has a thickness of 9 mm according to DIN 6608 /4/. The outer wall (t = 4-5 mm) is neglected in the analysis. The corner stiffeners (pipe 100x100x5 mm) of the control shaft are modeled using beam elements. To approximate pipe forces, four translatory single masses of 75 kg each are placed at the shaft walls. The shaft is assumed to be directly connected to the inner tank wall. All steel parts are modelled with 4-node shell elements. For the soil solid, the concrete slab and the cork sheets 8-node solid elements are used.

The calculated results, due to equivalent loads (0.5 g) acting simultaneous in the three directions, superimposed with the load case dead load and dead load + internal pressure are shown in Table 1. The highest loads result from the excitation in cross direction. This is additional verification of the chosen procedure.

Table 1: Equivalent Stresses in N/mm^2

	g + earthquake		g + Pi + earthquake	
	TOP	BOT	TOP	BOT
cylinder	93.2	65.3	90.0	60.2
stiffeners	136.7	138.6	131.7	132.9
bottoms	134.1	134.3	127.9	125.8
shaft	34.4	30.6	34.3	30.2

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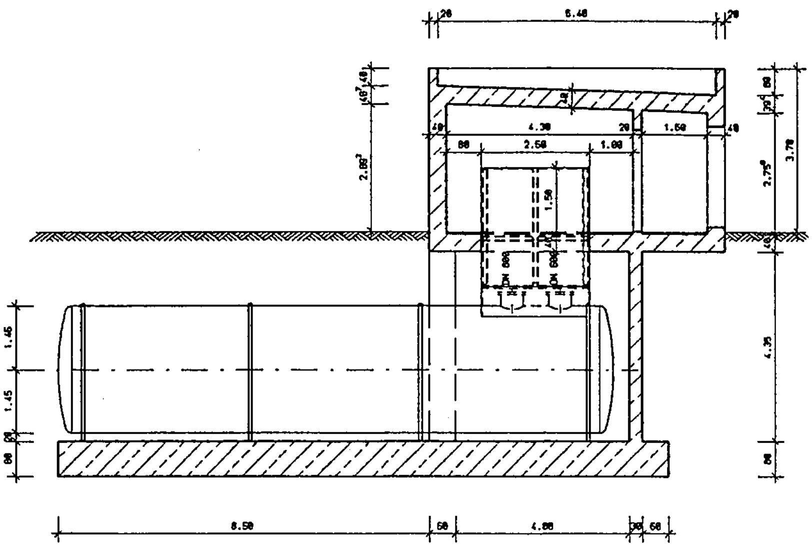


Fig. 1 Embedded Fuel Tank

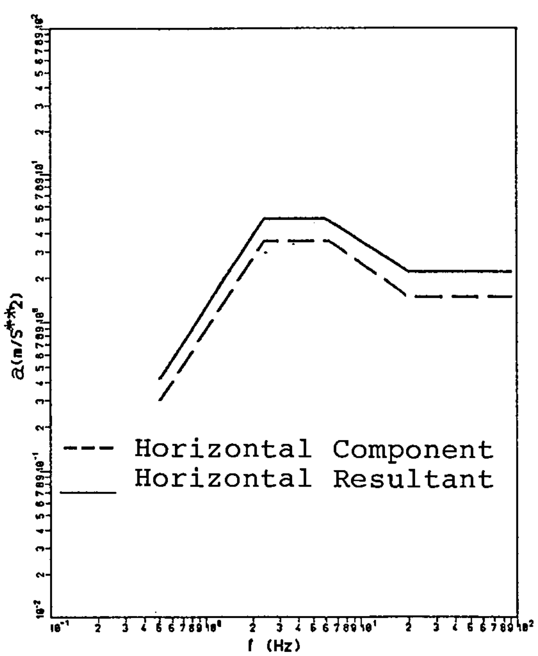


Fig. 2 Ground Response Spectra

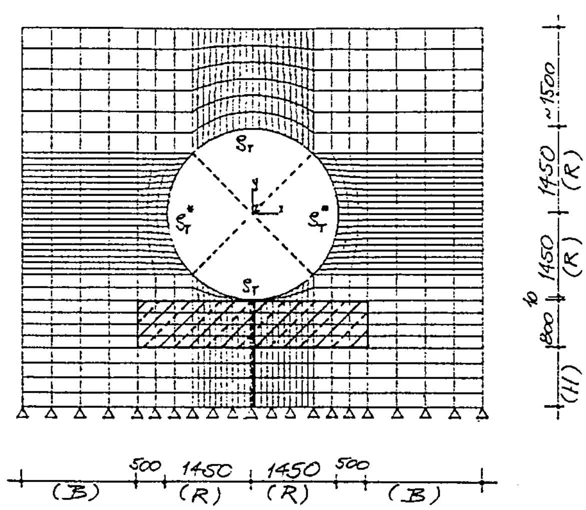


Fig. 3 Plane Model

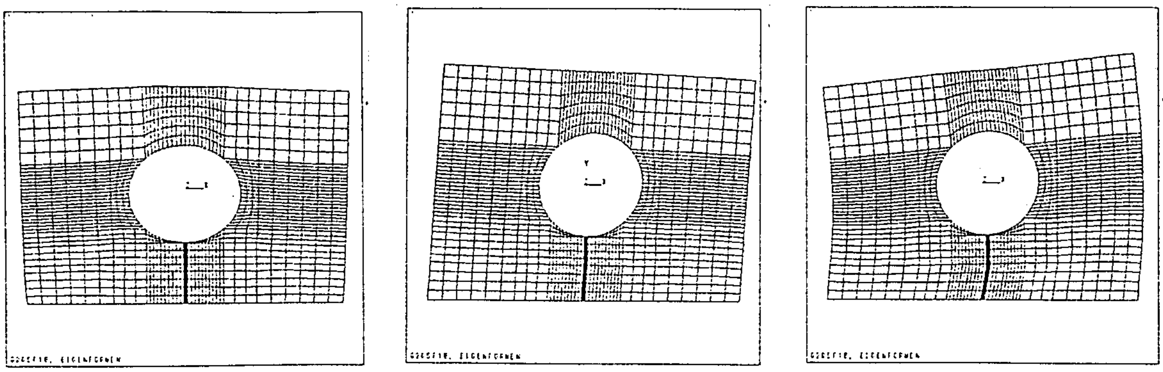


Fig. 4 The First Three Mode Shapes of the Plane Model
(f1 = 2.4 Hz, f2 = 5.4 Hz, f3 = 6.0 Hz)

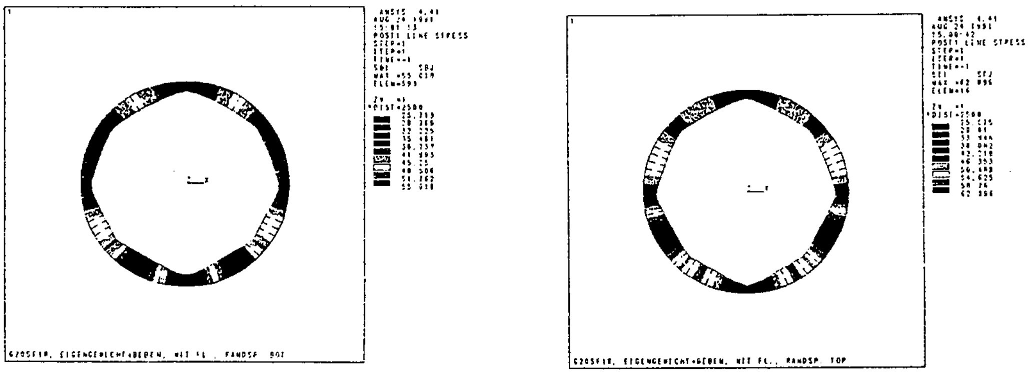


Fig. 5 Extreme Fiber Stresses of the Plane Model
Stress Maximum 62.9 N/mm**2 (Top)

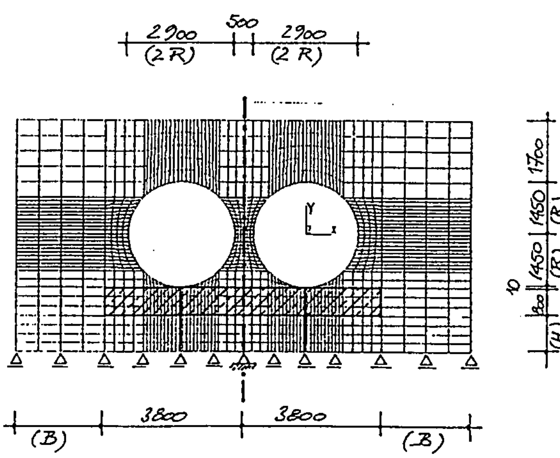


Fig. 6 Plane Model of two
Adjacent Tanks

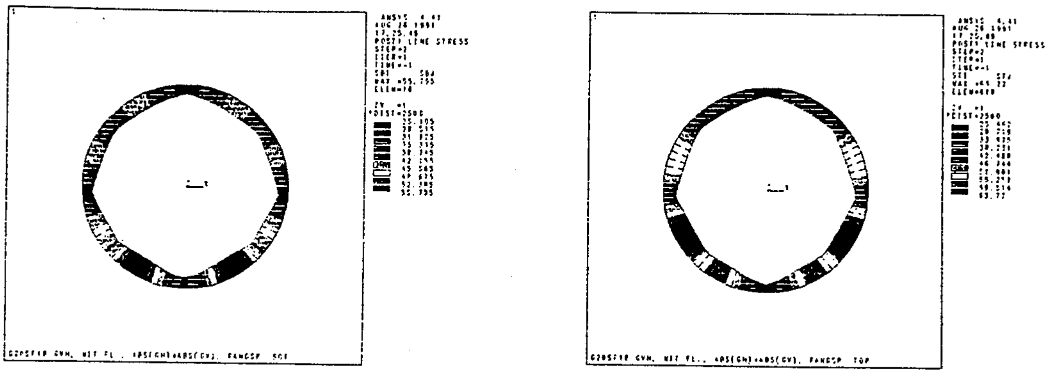
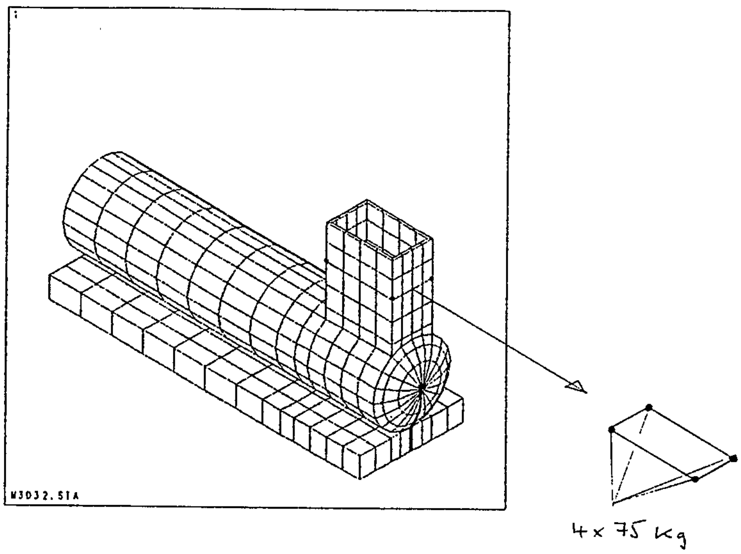


Fig. 5 Extreme Fiber Stresses of the Plane Model Due to Quasi-Static Loading
Stress Maximum 63.8 N/mm**2



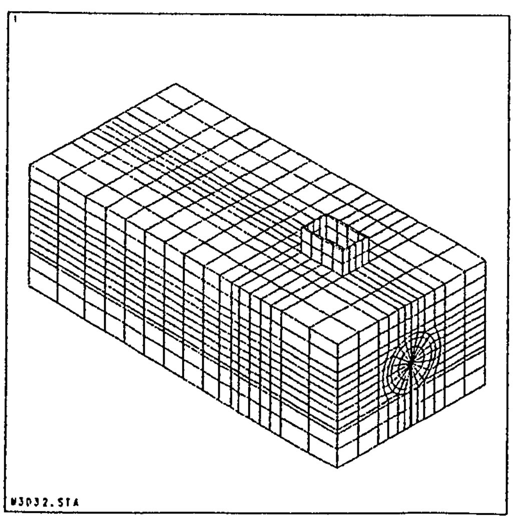


Fig. 8 Three-Dimensional-Model