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Reevaluation of the Seismic Resistance of the 1000 MW NPP Belene

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1 INTRODUCTION

The NPP Belene in Bulgaria is located on the right bank of the Danube river - 250 km from the Vranchea seismic source in Romania which generates earthquakes occurring at the depth range of 60 - 160 km with M_{max} = 7.0-7.5 and many shallow events. The spectral characteristics contain predominant periods in the range T = 0.3-0.5 second and T = 0.8-2.5 sec. The long distance effect is typical for the Vranchea source. The specific characteristics of the source and their significant modification through the local ground conditions need special investigation and reevaluation of the 1000 MW block of the NPP Belene. The site is also excited by shallow crustal earthquake with M=7.0 located from 60 to 320 km. Small local earthquake near to the site with $M \leq 5.5$ must be taken into consideration. The earthquake resistance of the buildings and equipment should be reevaluated.

2 SEISMIC DESIGN CHARACTERISTICS FOR BELENE SITE

The peak ground acceleration is reevaluated by deterministic and probabilistic methods (1,2). The maximum peak acceleration for SSE is established 0.2 g (intensity - VIII) and for OBE 0.1 g (intensity VII).

Because of the specific characteristics of the Vranchea source the design response spectra are determined from records obtained by the Vranchea 1977 earthquake, 170 km from the epicentre, and Nish, in Yugoslavia, at the distance of 420 km. The deconvolution of the four horizontal components, for base rock, and the convolution for the Belene geological conditions is made applying the SHAKE program. The obtained envelope spectra are different from the US.NRC.RG.1.60 spectra, (Fig. 1), mainly in long period range. The earthquakes in 1986 (M=7.0) and 1990 (M=6.7), from the same source, have similar frequency content.

3 GEOLOGICAL CHARACTERISTICS OF THE SITE

In the reactor area, the clayey and sandy soils with thickness of 12 m where removed and replaced by compacted sandy gravel fill. The reactor is founded on this compacted fill which overlies an 8 m natural gravel deposit and few

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hundred meters marl layers. The reactor building is imbedded by another compacted sandy gravel layer with thickness of 6.5 m.

The thickness of the design geological profile - 209 m is divided in 15 layers, 5.5 - 9.0 m each, in upper part and 14 - 20 m in the deeper part of the profile. The shear modulus, soil damping, mass density Poisson's ratio are in function of the depth. During the analysis the shear modulus is varied with ±25%. The soil shear modulus and damping is in function of shear strain level. The water table location is taken in consideration.

4 DESIGN ACCELERATION

Three component free-field accelerograms are generated from the design envelope response spectra (Fig. 1) by AGA program (3). The response spectra from shallow crustal earthquakes are covered by the design envelop spectra. The free-field accelerograms are deconvoluted for the respective layer according to the mathematical model. In the modification of the accelerograms with depth the Seed and Idriss curves for shear modulus and damping strain relation, G-γ and D-γ, respectively, are used.

5 REACTOR BUILDING CONFIGURATION AND MATHEMATICAL MODEL

The 1000 MW reactor building consists of the following main structural parts: reinforced foundation plate 72x72 m, 2.8 m in thickness. The upper part of the structure 64x64 m is constructed by very rigid reinforced shear walls covered by another reinforced concrete plate with the same thickness (Fig. 6). Three independent structures are founded on this second plate : containment, outer building and internal structure (Fig. 6). The containment is a prestressed reinforced concrete cylinder with an elliptical cup dome up to El. 65.95 m. The outside diameter is 57.4 m and the thickness of the cylindrical wall is 1.2 m. It is prestressed by 96 post tensioned tenders at an angle of 35 degrees from horizontal. The outer building, at El. 45.60 m arounding the containment, is separated by gaps 110 mm side.

The internal structure consists of reinforced concrete walls. Many walls are interconnected by concrete floor slabs at El. 19.34, 25.7, 29,0 and 35.90. The mathematical model for investigation of the described structure with ground layers is formed on the principles of soil-structure interaction (SSI).

The three dimensional mathematical model for structure and soil based on finite element method is very complex. This is the reason the structures to be modelled as beam model (Fig. 2) and the interaction with the soil to be investigated by two methods:
- indirect method (Fig. 2) with equivalent linear representation of the soil
- direct method (Fig. 3) with representation of the soil as a layered system with radiation of the energy, rigid foundation and determination of the impedance functions.

For the direct method the floor response spectra is investigated by SASSI computer program (4)

In Figs 4 and 5 are compared the floor response spectra determined by the direct, indirect method and original design spectra. It is evident that the indirect method is more conservative and give higher values than the direct method. The calculated response spectra, in most of the cases, are smaller than the original design spectra (Fig. 6). They exceed the original design spectra, in high frequencies, in some elevations only (Fig. 6). The reactor building is under construction and the increased responses can be reduced by design supports for the respective equipment. Some of the tension stresses and meridional bending moment of the containment are given in Fig. 5).

6 EXPERIMENTAL INVESTIGATIONS OF 1000 MW BLOCK

The 1000 MW block - Kozlodoy NPP was shaken for investigation of the dynamic characteristics and deformations due to the building and ground effects. The horizontal and vertical displacements are measured at basement and roof level (Fig. 8). Translational, rotational displacements of the foundation and shear deformations of the structures are presented Fig. 8).

From total displacements 80% are due to soil deformation and only 20% are from deformations into the structure. The first natural period is 0.4 sec.

7 CONCLUSIONS

Using mathematical models and analytical methods for investigation of SSI, taking into consideration energy dissipation in the ground and increasing the damping in the system, reduction of the floor response spectra is obtained. The equivalent linear method for representation of SSI gives more conservative results on floor response spectra and stresses in the structure. The experimental data demonstrate that for a very rigid reactor building up to 80% of the total displacements are due to the soil deformations. The verification of the mathematical models and analytical results by experimental studies is necessary.

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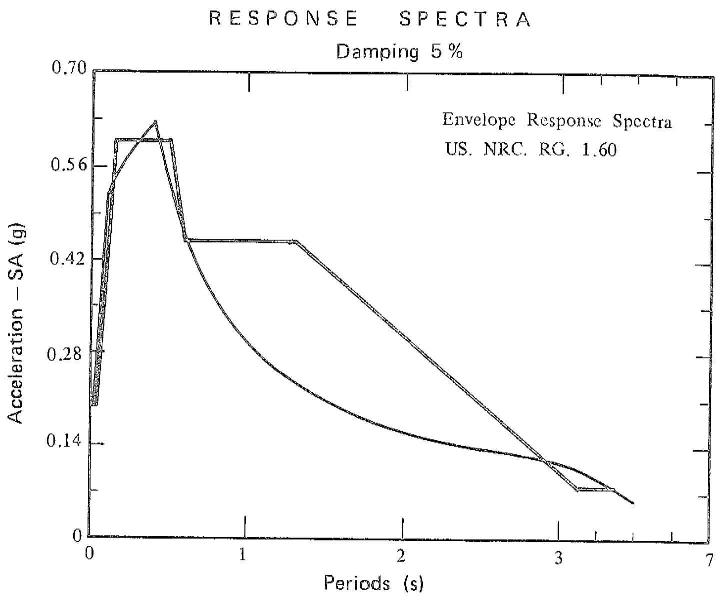
RESPONSE SPECTRA
Damping 5 %
Envelope Response Spectra
US. NRC. RG. 1.60
Acceleration – SA (g)
0.70
0.56
0.42
0.28
0.14
0
0
1
2
3
7
Periods (s)

Fig. 1.

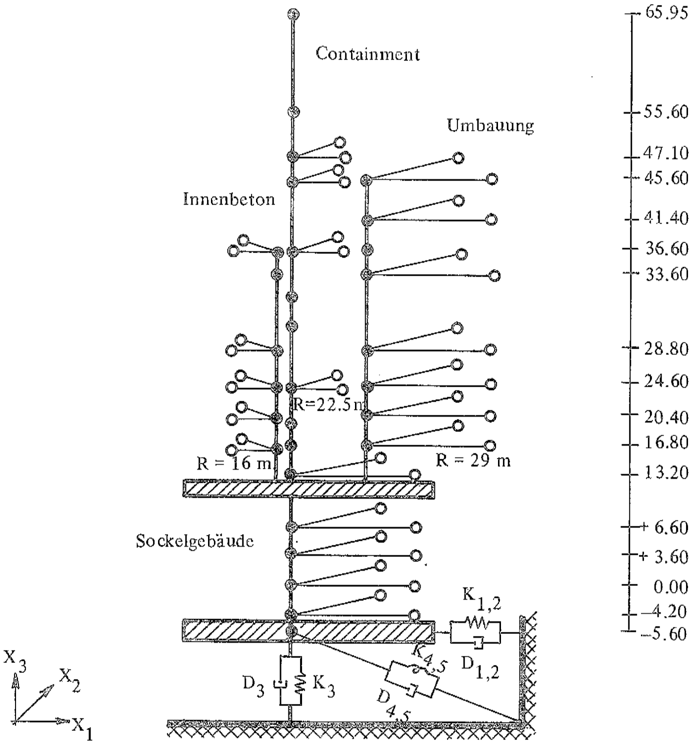
Containment
Umbauung
Innenbeton
R=22.5m
R = 16 m
R = 29 m
Sockelgebäude
$K_{1,2}$
$D_{1,2}$
$K_{4,5}$
$D_{4,5}$
D_3
K_3
X_3
X_2
X_1
65.95
55.60
47.10
45.60
41.40
36.60
33.60
28.80
24.60
20.40
16.80
13.20
+ 6.60
+ 3.60
0.00
–4.20
–5.60

Fig. 2.

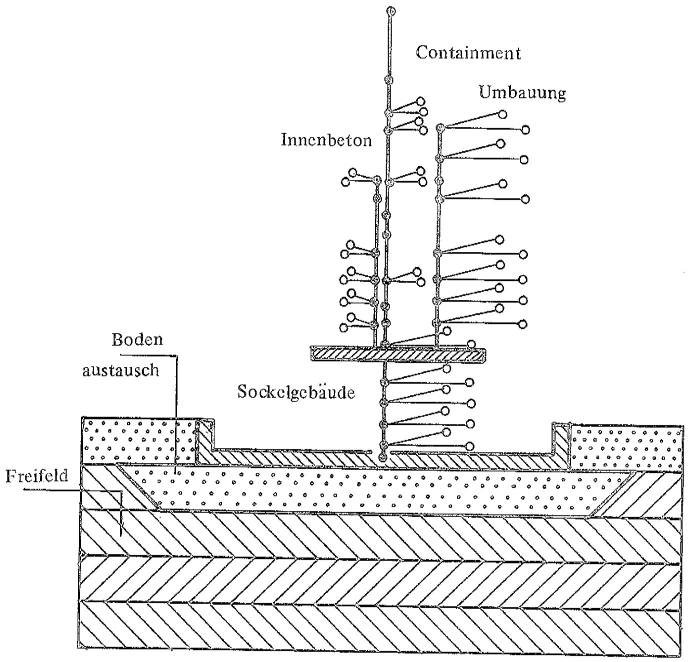

Fig. 3.

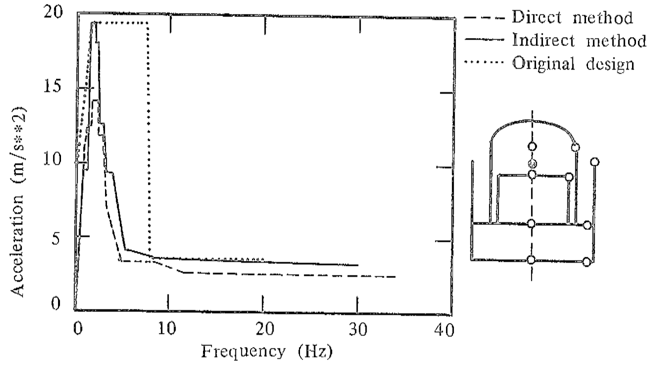

Fig. 4.

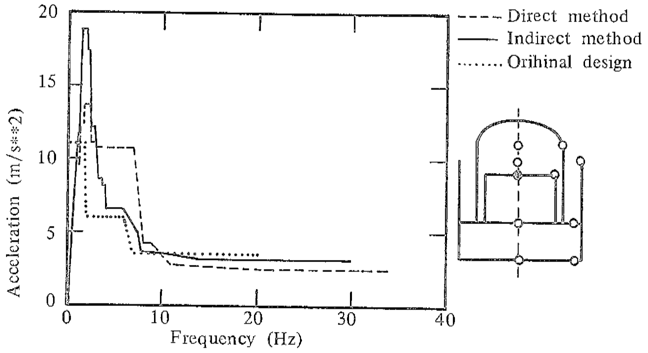

Fig. 5.

Maximum Zero Period Floor Response Spectrum Values

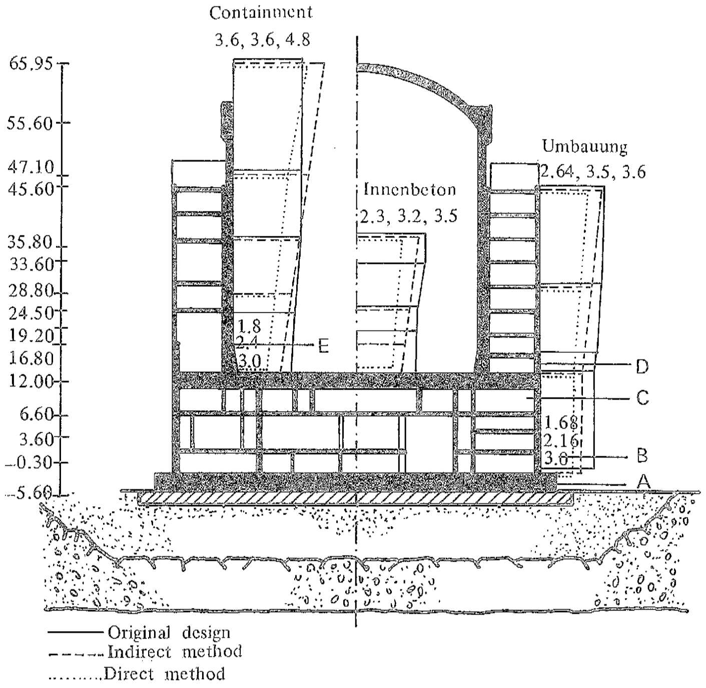

Fig. 6.

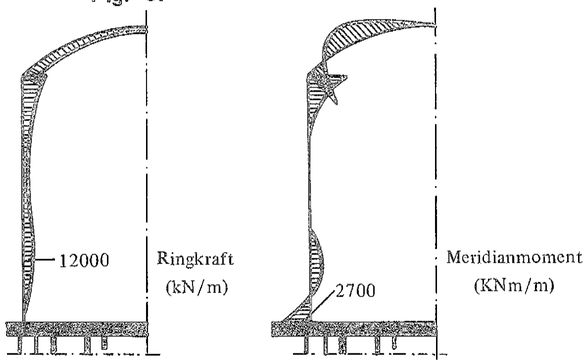

Fig. 7.

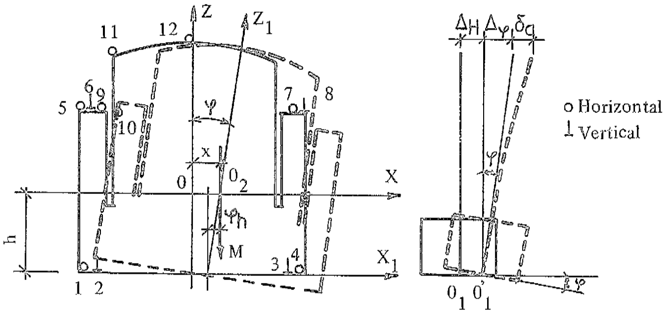

Fig. 8.