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KW2/1

Dynamic behavior of buried pipelines of VVER 440 and VVER 1000 MW nuclear power plants

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ABSTRACT

The aim of the investigations was to reanalyse typical pipelines of the VVER-440 MW and VVER-100 MW nuclear power plants to demonstrate their dynamic behavior in interaction with the soil and the connected buildings as well as to determine dynamic responses and stresses in characteristic regions of the pipelines during an earthquake using appropriate solution procedures as well as complex finite element mathematical models for comprehension of the structural capabilities of the interacting complex soil-structure systems.

1 INTRODUCTION

According to the relevant-codes and standards, all safety-related structures of a nuclear power plant must be designed to withstand loads induced by earthquakes. This also applies to safety-related buried piping systems. These structures are typically embedded in about 2-6 meters of layered soil, and sometimes protected by concrete slabs resting on the ground surface. It is known that current simplified calculation procedures and assumptions do not satisfy the required accuracy and the state-of-the-art in the seismic analysis of structures. It is however also known that a rigorous solution for the dynamic response of such a structure would require nonlinear capabilities and three-dimensional effects to be considered. Although nonlinear analysis is possible when using specialized computer programs and mathematical models for consideration of the nonlinear behavior of the soil, such an analysis would be prohibitively expensive and would require assessment of the real soil characteristics of the backfill which should be derived by detailed laboratory tests. This again would require investigations which are expensive and of which no definitive result (for backfill material) can be expected. Considering these arguments, alternative studies were performed in which the soil properties were assumed to be nearly linear-elastic. It appears that using this assumption for the soil and representing the soil and the piping system by explicit complex mathematical models results may be obtained which are more realistic and usefull to be effectively used for design purposes.

In order to demonstrate the applicability of the (quasi) linear-elastic analysis, 3D finite element models of two selected pipelines were derived in which the coupled vibrating structure (the pipelines, the soil on the sites as well as the buildings connected by the pipeline) are appropriately represented by finite element models. The calculations were

performed in the frequency domain using a specialized computer program (modified version SASSI [1]). To reduce the size of the mathematical problem to be solved, the building structures were represented by simplified models (single mass models and rigid foundations).The investigations were performed for two typical pipelines (emergency cooling water supply pipeline) of the VVER 440 and the cooling water line of the VVER 1000.
It has been assumed that the soil conditions (layering and capabilities) and the seismic input motion (free-field excitation) correspond to the latest data defined for the sites PAKS and Kozloduy respectively.

2 DESCRIPTION AND MODELING OF BURIED PIPELINES

The emergency cooling water supply pipeline of the VVER 440 MW PAKS is located between the condensing and emergency cooling water building and the turbine house. It is buried in the soil at a depth of about 3 m. The pipeline is made of steel. It has a diameter of 720 mm and a wall thickness of 20 mm. The configuration of the pipeline is shown in Figure 1. The total length is about 250 m. The stiffness of the penetration concept through the building walls has been estimated approximately on the basis of available as-built data.

For this study the complex pipeline-soil system (as shown in figure 3) was analyzed. The soil was assumed to be composed of four horizontal layers (Table 1). The upper soil layer has a shear modulus of about 95 MN/m^2. The seismic excitation was represented by means of artificial acceleration time histories corresponding to the free-field spectra (b_o = 0.25 g and 0.20 g or the horizontal and vertical direction respectively) of the site (Figure 5a). The cooling water line of the VVER 1000 (Figure 2) is located between the VVER 1000 reactor building (Unit 5) and the corresponding sprinkler pool. It is buried in the soil at a depth of 2.,5 m. The pipeline is made in steel. It has a diameter of 1080 mm and a wall thickness 20 mm. The mathematical model of the pipeline is shown in Figure 4. The basis of the investigation and the soil conditions (Table 2) and free-field excitation (b_o = 0.20 g and 0.10 g) for the horizontal and vertical direction respectively (Figure 6) of the site Kozloduy. In both cases, the seismic excitations were represented by means of artificial three acceleration time histories acting simultaneously in both the horizontal and the vertical direction(Fig 5 and 6).

3 CHARACTERISTIC RESULTS

In order to demonstrate the dynamic behavior of the emergency cooling water supply pipeline, the dynamic response data (time histories and response spectra) in their characteristic regions (shown in Figures 3 and 4) were calculated. The results obtained for both buildings as well as the pipeline were compared by plotting the results in one single diagram (Figures 7 to 10). Contrary to the expectations it can be observed that the dynamic response of the pipelines in the regions between the buildings does not at all follow the motion and the response of the free-field or the connecting building structures. Only in the vicinity of the buildings ist response is rather similar to the response of the building structures.
However there are still important differences in the spectral displacements in the regions of the pipes (especially close to the buildings) which finally result in internal member forces and stresses in the pipeline system.
The forces (stresses) induced by these differences are shown in Figures 11 to 13 and 14 to 16 respectively. According to the differences in the relative displacements, the largest forces/moments and consequently stresses are expected in areas in which the pipeline is connected to the building penetration structure. However, these results correspond to the boundary assumptions made for these regions of the pipeline on the basis of the available

data for the as-built penetration concepts. For the emergency cooling water pipeline (VVER 440), maximum values of about 26 N/mm^2 for the bending stresses and of about 225 N/mm^2 for the axial stresses were calculated. The maximum values of the stress in the cooling water pipeline (VVER 1000) correspond to 77 N/mm^2 and 37 N/mm^2.
The relatively high axial stresses in the piplines are the result oft the motion of the rather big masses of the buildings pushing the piplines as well as the assumptions of that every pipline possesses on its end a fix point or constructiopnal stop in axial direction.

4 CONCLUSIONS

It is difficult to represent the typical nonlinear (elasto-plastic) soil behavior realistically by means of simplified procedures. The chosen linear-elastic assumptions and modeling concept (state-of-the-art procedures) did, however, allow the dynamic behavior as well as the dynamic response of the buildings as well as the relative motion of the structures and the free-field to be investigated appropriately. Therefore, the motion (displacements) of the pipeline sections connected to the buildings in the axial direction should also be rather realistic.
It may also be assumed that the moments/stresses obtained for the first section (up to the first elbows) of the pipeline (for the assumption related to the stiffnesses of the penetrations) should be quite realistic.
Only stresses in the pipeline section far from the buildings could be (due to the linear-elastic assumption chosen for the soil) less reliable. However, the stresses in these sections are of minor importance because of lower relative displacements along the pipeline in these regions. This can also been seen from an evaluation of the response spectra obtained for the characteristic regions of the pipeline.

5 REFERENCES

[1] SASSI/S „Analysis of Soil Structure Problems
Siemens Software Package based on software developed by Lysmer, J., Tabatabaie-Raissi, M., Tajirian, F., Vahdani, S., and Ostadan, F.
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[2] Arnold, P., Drewes, T., Jakub, M.,
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[4] N.J. Krutzik, W. Schütz
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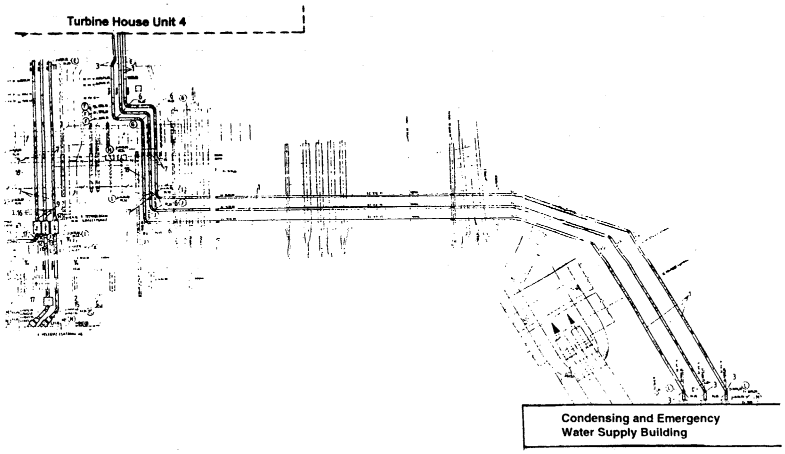


Fig. 1 **Arrangement of the Cold Water Supply Intake Pipelines VVER-440/213 PAKS, Unit 3/4**

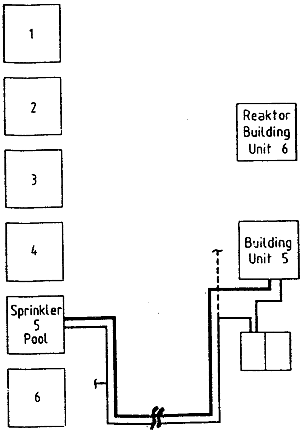


Fig. 2 **Arrangement of the Cooling Water Pipeline**

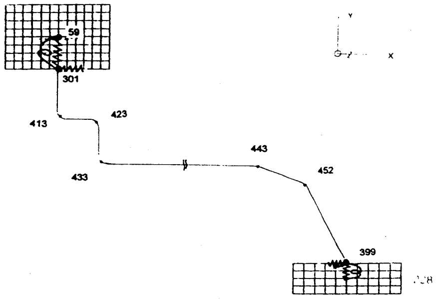


Fig. 3 **Mathematical Model of the Emergency Cooling Water Line**

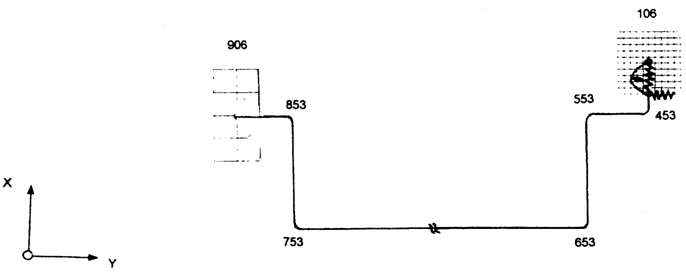


Fig. 4 **Mathematical Model of the Cooling Water Line KOZLODUY**

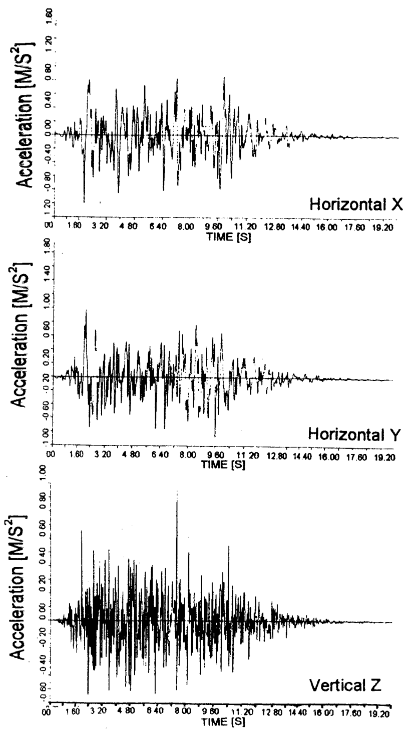


Fig. 5 Artificial Time Histories for the Site PAKS

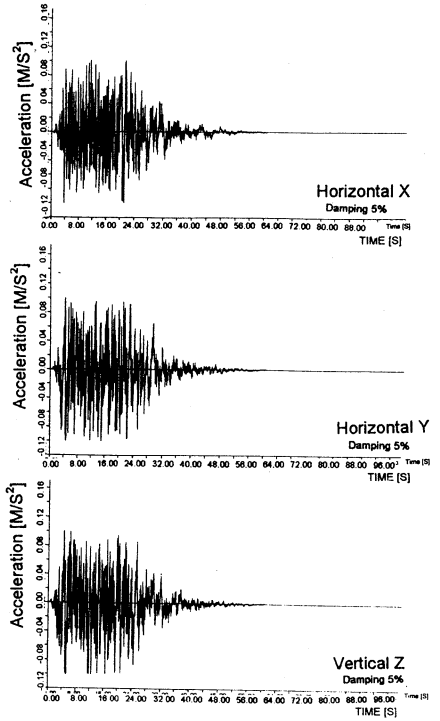


Fig. 6 Artificial Time Histories for the Site KOZLODUY

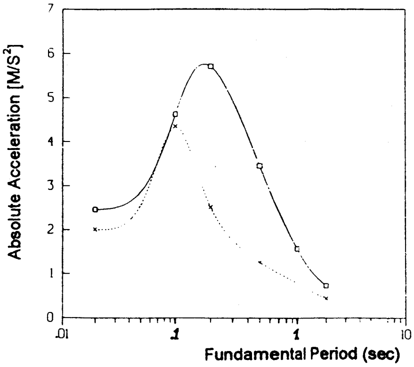


Fig. 5a Target Response Spectra (5% Damping) for Site PAKS

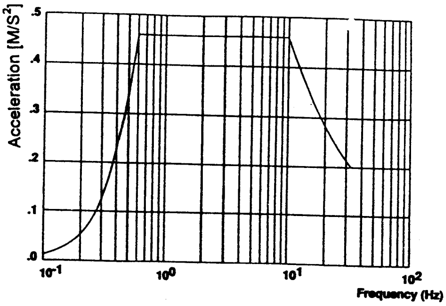


Fig. 6a Free-Field Spectrum (5% Damping) for the Site KOZLODUY

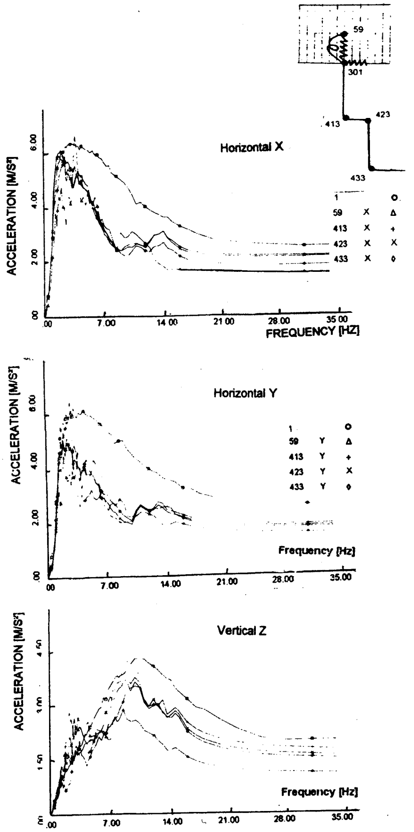


Fig. 7 **Buried Cooling Water Pipeline PAKS Unit ¾ Comparison of Dynamic Response in Characteristic Regions**

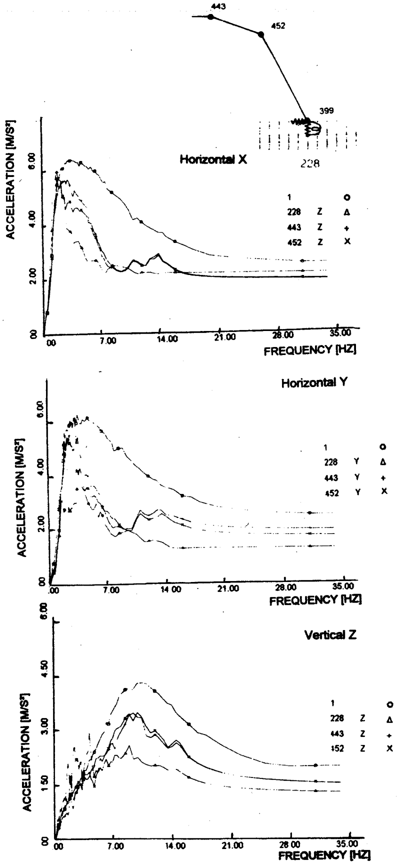


Fig. 8 **Buried Cooling Water Pipeline PAKS Unit ¾ Comparison of Dynamic Response**

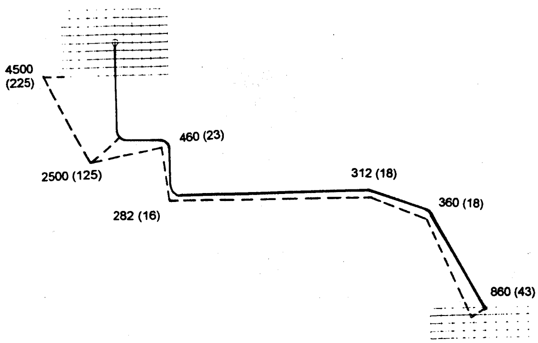
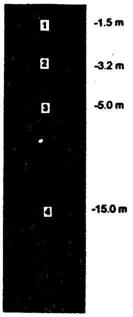


Fig. 11 **Buried Cooling Water Pipeline PAKS Unit 3/4 Distribution of Normal Forces (kN) and Associated Stresses ()***



Layer 1: G_o = 95 MN/m²
D = 7%
ν = 0.30
ρ = 1.90 t/m³

Layer 2: G_o = 114.5 MN/m²
D = 7%
ν = 0.30
ρ = 2.0 t/m³

Layer 3: G_o = 136 MN/m²
D = 7%
ν = 0.48
ρ = 2.10 t/m³

Layer 4: G_o = 160 MN/m²
D = 7%
ν = 0.48
ρ = 2.1 t/m³

Tab. 1 **Reactor Building PAKS Units 1-4 Soil Profiles below Foundation Level**

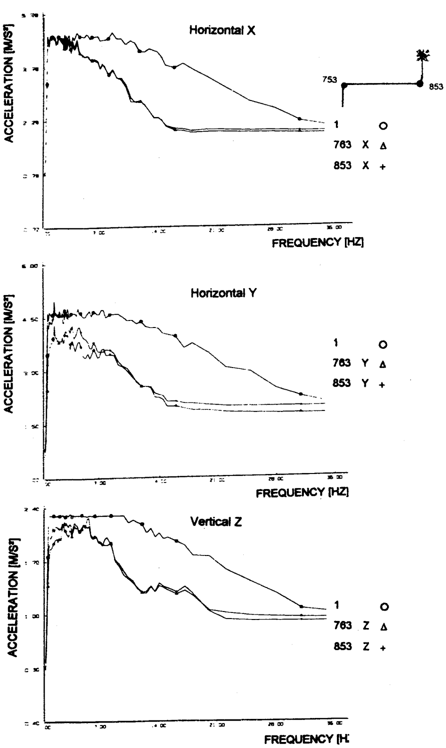


Fig. 9 **Buried Cooling Water Pipeline KOZLODUY Unit 5**
Comparison of Dynamic Response in Characteristic Regions

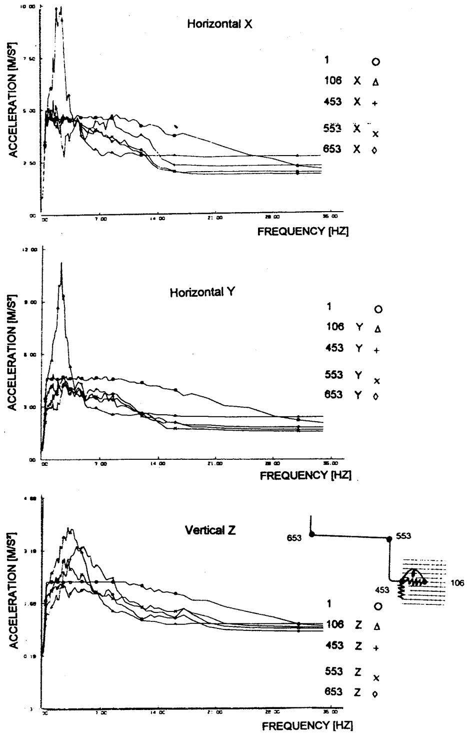


Fig. 10 **Buried Cooling Water Pipeline KOZLODUY Unit 5**
Comparison of Dynamic Response in Characteristic Regions

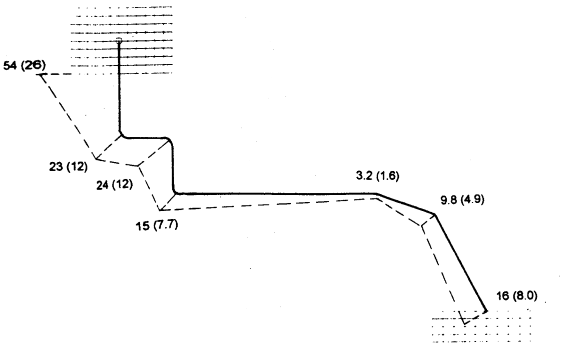
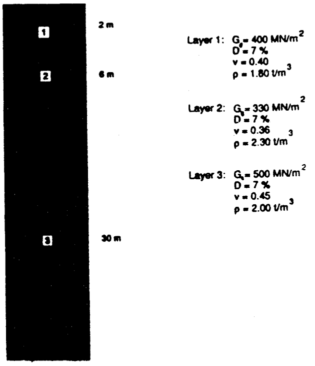


Fig. 12 **Buried Cooling Water Pipeline PAKS Unit 3/4**
Distribution of Moments (kNm) and Associated Stresses ()*
Acting in Plane X-Y



Tab. 2 **Reactor Building KOZLODUY Unit 5**
Soil Profiles below Foundation Level

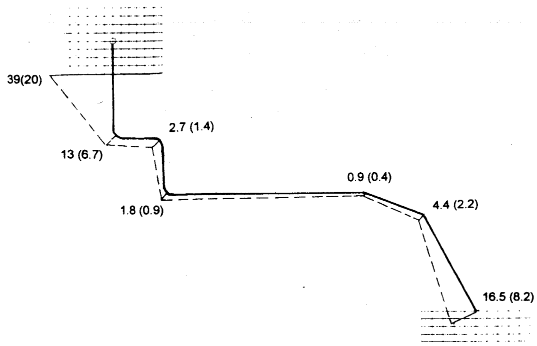


Fig. 13 Buried Cooling Water Pipeline PAKS Unit 3/4 Distribution of Moments (kNm) and Associated Stresses ()* Acting in Plane X - Z or Y - Z

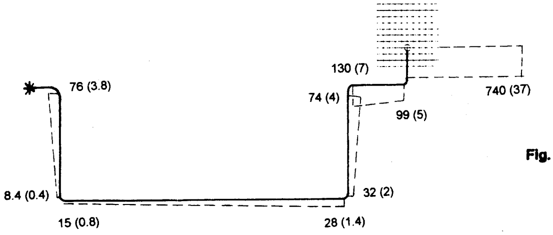


Fig. 14 Buried Cooling Water Pipeline KOZLODUY Unit 5 Distribution of Normal Forces (kN) and Associated Stresses ()*

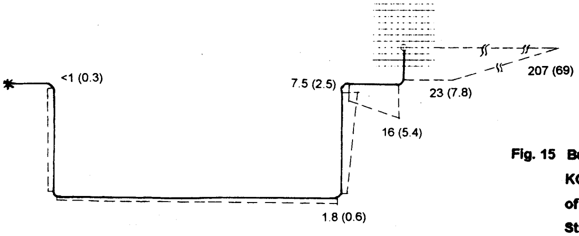


Fig. 15 Buried Cooling Water Pipeline KOZLODUY Unit 5 Distribution of Moments (kNm) and Associated Stresses ()* Acting in Plane X-Y

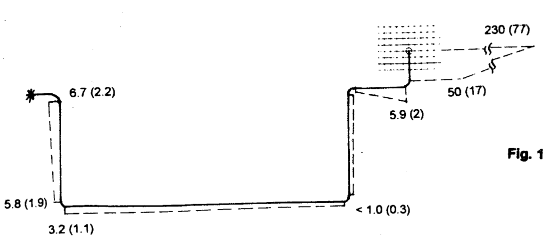


Fig. 16 Buried Cooling Water Pipeline KOZLODUY Unit 5 Distribution of Moments (kNm) and Associated Stresses ()* Acting in Plane Y-Z