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# DETERMINATION OF SEISMIC FLOOR DESIGN SPECTRA FOR THE MUEHLEBERG NUCLEAR POWER PLANT, SWITZERLAND

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## SUMMARY

The 20 year old Muehleberg nuclear power plant (NPP) required an up-to-date evaluation of floor design spectra at various damping levels taking into consideration dynamic soil-structure interaction (SSI). Certain aspects of the investigation are discussed here.

## INTRODUCTION

The Muehleberg nuclear power plant, which is owned by the Bernische Kraftwerke AG, has been in service since 1972. Since the original planning and construction phases the seismic safety requirements of NPP's were update in 1981 by the Swiss regulatory authority (HSK). At the same time the owner started work on the installations for the SUSAN project within the reactor complex, thus necessitating a re-evaluation of the design basis for the verification and possible retrofitting of some important components.

The firm NOK was subsequently commissioned to carry out the seismic investigations, the aim of which was to obtain the response (or so-called floor) spectra for given damping values under horizontal and vertical motion at selected points of the structure for SSE and OBE design levels. The effects of dynamic interaction between the structure and the ground were also taken into account.

## DESCRIPTION OF SITE AND STRUCTURE

The reactor building is situated close to the river Aare in canton Berne. It is about 60 m high and 44.6 m diameter and embedded 14.5 m deep. The thickness of the outer cylindrical shell is 0.6 m. The total mass is 68,000 t. The upper 6 m of soil consist of loose to medium dense fill material, which is underlain by 4 m of dense river gravel and bedrock, whose weathered zone was not explicity removed. A plan view of the plant is shown in Fig. 1.

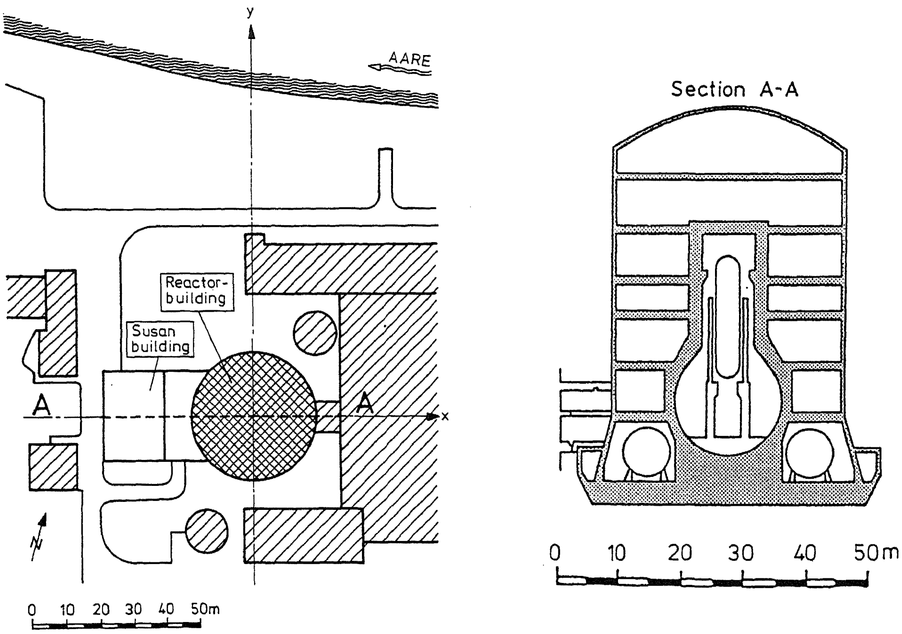



Fig. 1 Plan of reactor building of the NPP Muehleberg with the planned SUSAN building.

## METHOD OF ANALYSIS

Frequency domain analysis with a probabilistic definition of the seismic input was chosen (Program PLUSH). An added advantage of this method is the exact consideration of radiation damping. A probabilistic input definition allows:

- The regulatory stipulated design spectra could be adopted without having to generate artificial time histories.
- Considerable reductions in computer time
- Avoidance of artificially conservative random effects in certain frequency ranges sometimes associated with time history input, especially at low damping values.
- Simplification and cost saving in smoothing the definitive response spectra

With the available 2-D computer program the 3-D geometry of the actual system was approximately simulated by taking 2 vertical sections normal to each other. These planes correspond to the principal axes with respect to bending behaviour. There were altogether per damping value 4 computational runs under horizontal and vertical excitation for each of the load cases SSE and OBE. The final spectra for each damping value were obtained by constructing envelopes to the individual spectra obtained for the X-Z and Y-Z planes.

Since a purely probabilistic input had not previously been applied for the definitive calculation of a Swiss nuclear power plant, the consulting engineers to the licencing authority required, in addition, a conventional deterministic analysis (in which program FLUSH was used), and the results were compare at 5 selected points of the structural system. An overview of the computational procedure is shown in Fig. 2.

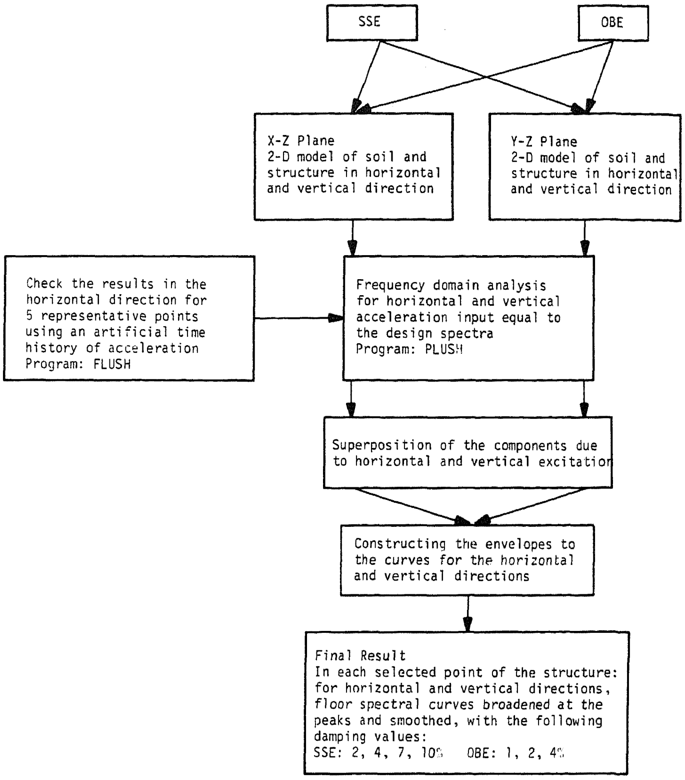



Fig. 2 Method employed to determine floor spectra in reactor building

For a full description of the theories underlying the programs FLUSH and PLUSH for 2-D finite element modelling of dynamic soil-structure interaction the reader should consult the references supplied at the close of the paper [1], [2]. Here it is simply mentioned that the dynamic analysis is based on the complex response method, and that vertical transmitting boundaries close to the structure may be incorporated in a model. 3-D radiation damping effects in the ground are crudely simulated by means of viscous dampers. The program PLUSH facilitates direct introduction of free field design spectra. These are then converted to power spectra by the program using empirical correlation techniques. The latter form the basis of the probabilistic analysis.

## COMPUTATIONAL MODEL

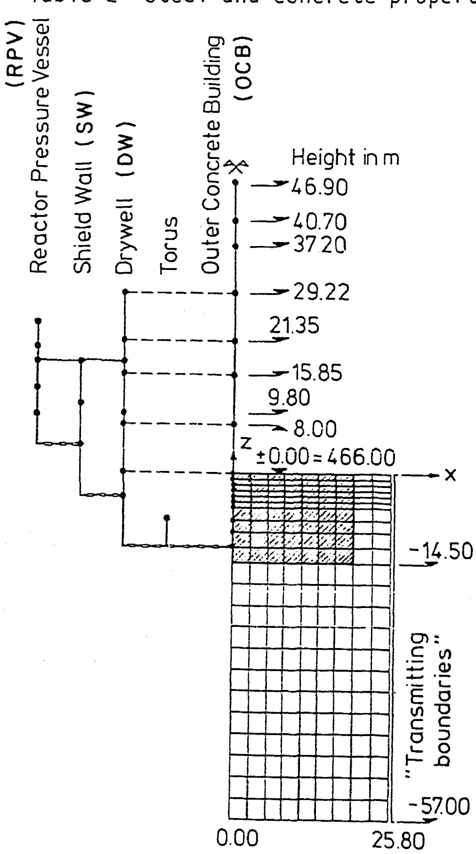
The ground and structure form an integral finite element model. The ground was modelled by 22 layers with the rigid base assumed at a depth of 57 m; the 8 layers in the fill material were assigned a very low shear modules. The material properties (shear modulus and damping) at small ($10^{-4}$%) shear strains were obtained by in situ seismic tests carried out by a local geotechnical firm. The strain-dependent parameter variations were estimated. The values adopted for the complete range of strain are summarized in Table 1. The material properties assumed for the structure are given in Table 2. The structure is modelled mainly with beam elements and concentrated masses. The FE model of the structure and ground is shown in Fig. 3

| Material | Density t/m3 | Young's Modulus kN/m2 | Poisson's ratio v | Damping % SSE | OBE |
|---|---|---|---|---|---|
| Concrete | 2.50 | $3.5 \times 10^7$ | 0.17 | 7 | 4 |
| Steel | 7.85 | $2.1 \times 10^8$ | 0.30 | 4 | 2 |
| Steel: pressure vessel | 7.85 | $1.9 \times 10^8$ | 0.265 | 4 | 2 |
| Water | 1.0 | - | - | - | - |

Table 1 Strain-dependent material properties of the fill and rock layers.

| Material Type | Strain % / G/G max or D % | $10^{-4}$ | $10^{-3.5}$ | $10^{-3}$ | $10^{-2.5}$ | $10^{-2}$ | $10^{1.5}$ | $10^{-1}$ | $10^{-0.5}$ | $10^0$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Soil | G/G max. | 1.0 | 0.96 | 0.94 | 0.81 | 0.715 | 0.44 | 0.325 | 0.105 | 0.05 |
| | D % | 1.0 | 2.0 | 2.6 | 4.7 | 6.0 | 11.2 | 14.7 | 24.8 | 27.3 |
| Rock | G/G max. | 1.0 | 0.98 | 0.96 | 0.89 | 0.845 | 0.605 | 0.595 | 0.39 | 0.3 |
| | D % | 1.0 | 1.6 | 1.8 | 2.7 | 3.0 | 4.3 | 5.4 | 9.3 | 12.0 |

Table 2 Steel and concrete properties assumed for the reactor structure.



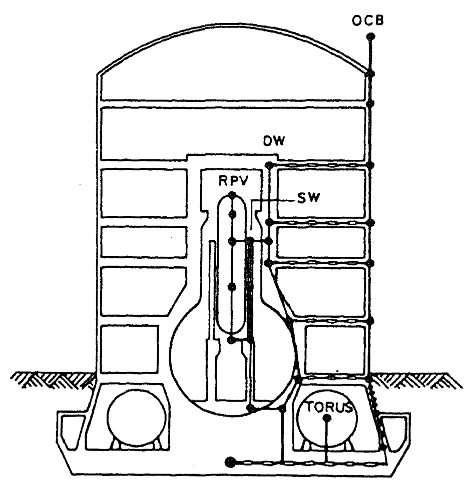




Fig. 3 Integral finite Element model for the structure and the ground

The design spectrum is influenced by the local geology. That chosen here was the standard HSK 5% damping spectrum for rock sites scaled to the maximum input accelerations. The latter depend on the site specific seismic risk estimated from the seismic risk maps for Switzerland [3]. The estimated return periods of 10,000 years (SSE) and 100 years (OBE) correspond to horizontal accelerations of 15% g and 6% g respectively. The vertical accelerations are assumed to be 2/3 the horizontal ones. When the response spectra are converted to power spectra in the program PLUSH, the actual peak acceleration values may be slightly increased (approx. 7%) for low damping values, (2%), if matching is carried out at 5% damping.

The spectra were input at the base of the SUSAN building at a depth of 12.0 m, i.e. 2.5 m above the base of the reactor foundation. Free field and SSI calculations employing artificially generated time histories using the HSK spectrum as target spectrum were also carried out using program FLUSH for comparison purposes.

## COMPARISON OF METHODS

The investigation showed that for the probabilistic design method (PLUSH) and the established deterministic method (FLUSH) good agreement between the results is obtained, as illustrated in Fig. 4. The curves obtained using PLUSH tend to lie below those for the FLUSH calculations due to peaks introduced in the actual spectra with respect to the target spectra with generating artificial time histories. Here in the comparison the difference is greater due to the base acceleration for the PLUSH calculations being reduced to 0.14 g to account for slightly increased accelerations by the program while converting response to power spectra. For the definitive calculations, however, the value of 0.15 g was used to satisfy regulatory requirements.

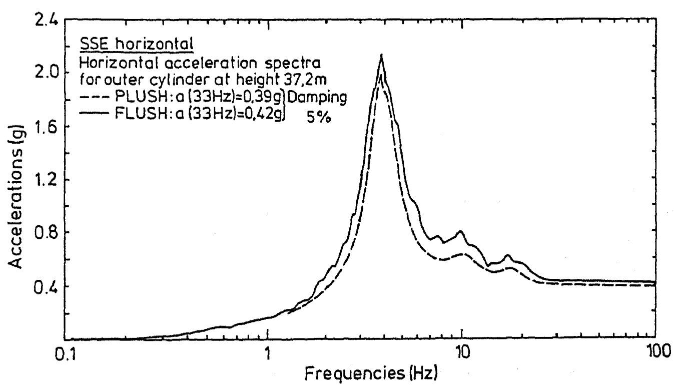



Fig. 4 Comparison of results for the PLUSH and FLUSH calculations

## CALCULATED FLOOR SPECTRA

The floor spectra at selected points were obtained by taking the envelope to the curves obtained from the separate calculations. For vertical response firstly superposition was carried out in the XZ and YZ sections using the RMS method. The spectral curves were also broadened by ± 20% at the resonance positions. This value exceeds that often used [4], as it accounts for no variation of soil properties being made. Finally, the curves were smoothed and the coordinates of selected points of the curve are defined in a table allowing greater flexibility in later use. A typical result under SSE is shown in Fig. 5 for the outer cylinder of the reactor structure.

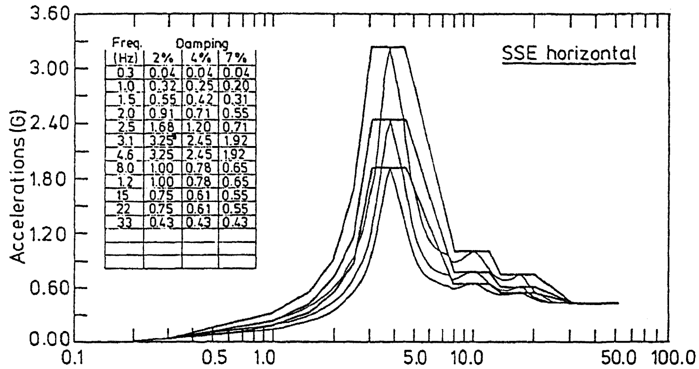



Fig. 5 Floor spectra for point on the outer cylinder at height 37.2 m

## CONCLUSIONS

This was the first time the program PLUSH was used in Swiss practice for the determination of floor spectra in a nuclear power plant, and so accompanying calculations with the better established program FLUSH were required. This allowed the two programs, which differ only in the treatment of the input loading, i.e. probabilistic or deterministic, to be compared. The advantages of the probabilistic method, which were mentioned in the paper could thus be observed first hand in a practical case.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. Lysmer, J., Udaka, T., Tsai, C.-F. and Seed, H.B.; "FLUSH - A Computer Program for Approximate 3-D Analysis of Soil-Structure Interaction Problems", Earthquake Engineering Research Center, Report. No. EERC 75-30, University of California, Berkeley, November 1975

2. Romo-Organista, M.P., Lysmer, J. and Seed, H.B.; "PLUSH - A Computer Program for Probabilistic Finite Element Analysis of Soil-Structure Interaction", Earthquake Engineering Research Center, Report. No. EERC 77-01, University of California, Berkeley, June 1979

3. Swiss Regulatory Authority (HSK); "Earthquake Design Spectra for Swiss NPP", Basler & Hofmann, SB 1244, Rev. 2, April 1984

4. U.S. Nuclear Regulatory Commission; "Development of Floor Response Spectra for Seismic Design of Floor Supported Equipment or Components", Regulatory Guide 1.122, February 1978