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STATIC FOUNDATION ANALYSIS STUDY FOR NUCLEAR POWER PLANT

Main aim of the study was evaluation of the possibility to realize construction of nuclear power plant from the foundation point of view for selected locality of the wider character and for existing geological and geotechnical conditions. Paper describes feasibility study for the first step, during which only static loading was evaluated. Geological and geotechnical conditions are therefore briefly specified. For 2 typical representatives of nuclear blocs of the third generation produced worldwide (one for lower capacity around 1200 MW and second one for roughly 1800 MW) subsoil improvement was proposed in different alternatives. These alternatives were consequently verified with the help of analytical and numerical methods.

Keywords: soil-structure interaction; nuclear power plants; subsoil improvement; analytical and numerical methods; feasibility study.

1. Basic characteristics of the entry conditions

The main attention was focused in the first step on the following 2 basic areas:

- Detailed evaluation of all existing data leading to the closer specification of the geological conditions of sub-soil (specification of the geological model) and to the closer specification of the all geotechnical properties of the individual sub-soil layers (specification of the geotechnical model);

- Evaluation of all obtained information which are most important from the foundation engineering point of view for proposed structures as well for SSI – Soil Structure Interaction. Namely plan, volume and weight characteristics, situation of the centre of gravity, supplemented by values of acceptable deformation – total and differential settlements.

1.1. Evaluation of geological and geotechnical conditions for selected locality

Geological model specifies 3 basic subsoil layers as the result of most simple interpretation of all data obtained for the selected locality and it's surrounding:

– Top layer with thickness of about 15 m is composed from the fine grained soils, marked as loess or loess loam, in lowest part as alluvial clays;

Middle layer with thickness of about 13 to 20 m is composed from more permeable, coarser materials as gravel, sandy-gravel, sand. Ground water table was observed there;

– Bottom layer, pre- quaternary is on the top also coarser – gravel, sandy-gravel, sand; however gradually finer up to of clay character. Maximum depth in which tertiary clays were recorded was 44 m below surface.

The basic output is the statement that for selected area the section with a length of 200 m can be found where the surface and basic subsoil layers are practically parallel and horizontal. Therefore the selected area can be judged as appropriate from the foundation engineering point of view as the potential risk connected with differential settlement is very low.

Geotechnical model (Fig. 1) was specified from the set of realized field and laboratory tests, including geophysical tests. From evaluation it was possible to define for basic layers (and even for more detailed specification of subsoil) characteristic values of geotechnical properties (shear strength, modulus of deformation ...) needed for calculation model – first of all for numerical modelling.

Fig. 1. Geotechnical model of the locality

From the other geotechnical investigation outputs are important the following ones:

- top loess layer is more compressible however it is not sensitive to the structural collapse;
- layer of sands is not sensitive to the liquefaction during seismic loading;
- ground water level is relatively stable with minimal observed fluctuation and is not aggressive.

1.2. Evaluation of information from the suppliers of NPP from the view of foundation engineering and SSI

The evaluation comes out from the questionnaire dispatched to all potential suppliers of NPP. The extend of information in individual responses was different however at least this forwarded data allowed to specify values about ground plans, depth of foundation, in some cases values about centre of gravity, contact pressure in the foundation bottom or values of acceptable total and differential settlements.

The representatives of so called lower energy output NPP (1200 MW) and higher energy output (1800 MW) – were selected for the subsequent SSI analysis of the building of nuclear reactor with subsoil as the data for them were more complex.

In all cases roughly the foundation slab is in the depth of about 10 m. Checked possibilities allowed for different slab area – circle or rectangular and for the loading – different contact pressure in footing bottom. Also acceptable total settlements were very close, about 300 mm with acceptable differential settlement (inclination) 0.001.

2. Analysis of the subsoil behaviour (bearing capacity, settlement) without improvement

Bearing capacity and foundation settlement without any improvement was calculated with the help of classical methods of soil mechanics for the recommended depths of foundation.

Obtained results approved that bearing capacity is very safe, mostly due to large size of foundation slab; factor of safety is around 10. On the other side the total settlement is higher than generally accepted, roughly about 0.55 m. The theory of structural strength (which is in agreement with

Czech and Slovak standards) was applied for the settlement calculation giving generally lower values of settlement than settlement calculation based on the theory of elastic half space [1]. Therefore it was necessary to propose subsoil improvement.

3. Proposed subsoil improvement

Proposals for the subsoil improvement are based on the preference of shallow foundation and the following options were examined (Fig. 2):

- subsoil improvement with the help of sandy-gravel cushion, where part of the less appropriate soil (loess) is substituted by sandy-gravel;
- subsoil improvement with the help of piles, which are embedded into gravel layer and are in upper part interconnected by reinforced concrete slab.

Fig. 2. Subsoil improvement options: 1 – loesses; 2 – alluvial clays; 3 – gravels

Both options have preferred sub-options, when sandy-gravel cushion is reinforced by geosynthetic layers. Similarly the piles are also reinforced around outer perimeter by geotextiles or geogrids with very high initial tensile strength [2]. The proposal comes from positive evaluation of the sensitivity of reinforced earth structures during seismic loading when very high initial tensile strength is increasing stiffness for short time seismic loading.

In both cases 0.5 m thick very well compacted gravel layer is proposed between the zone of improvement and foundation slab as this layer

has positive impact on the interaction of reactor building with subsoil for seismic loading.

The thickness of the reinforced cushion is between 4.5 to 6.0 m for different NPP. So it means that still about 2.0 to 3.0 m of fine soil remained there which is able to protect ground water in lower gravels from potential contamination from the surface. This fact can play very positive role during EIA process of evaluation.

The length of the piles is about 10 m and is embedded into gravel layer on the high of about 3 m.

Subsoil improvement has very positive impact on the limit state of serviceability for both cases of subsoil improvement. Maximum value of foundation slab settlement is now about 160 mm what is now acceptable value. Thus the overall safety is significantly increased by proposed subsoil improvement.

4. Numerical solution

Software PLAXIS was used. This software is based on FEM and belongs for geotechnical problems between the most often used. For static loading a planar (2D) solution was applied for geometrical model with width 2×200 m and depth 100 m. 2D solution is for given problem and given phase of feasibility study very correct and merely conceivable. 3D solution will be applied in future as is more sensitive to the arrangement of individual parts of NPP and to the specification of the technology of construction (with respect to the different depth of foundation and different contact pressure). The subdivision of ground respected different layers in subsoil together with ground water table. Finite element spacing was adapted to the boundary conditions with detailed spacing around places of concentration of stresses. With the help of parametric study it was approved that the constitutive model “Hardening soil small strain model” is closest to the analytical solution using principle of structural strength. This specified model can define different stiffness of soil; for virgin loading, for repeated loading or for the phase of unloading [3].

Numerical parametrical study – large study observed the SSI for both basic cases of NPP, for different subsoil improvement. Selected obtained results are presented, namely with respect to:

- Vertical deformation (Fig. 3) for subsoil improved by sandy-gravel cushion;
- Vertical effective stresses (Fig. 4) for subsoil improved by piles;
- Relative shear strength (Fig. 5);
- Distribution of vertical (contact) pressure in footing bottom (Fig. 6), which is very important from the interaction point of view.

The obtained results are in very good agreement with theoretical assumptions and can be summarized as follows:

- Just before the top of tertiary clays the deformation values are close to zero;
- Total settlement is roughly 160 mm for sandy-gravel cushion even for the cushion thickness of 4 m; the result is in agreement with the analytical solution;
- Lower total settlement of about 60 mm was calculated for the subsoil improved by piles;
- The contact pressure in the footing base is relatively constant with excesses at the end of slab;
- Small plastic zones are confined and there are no marks of further propagation.

Fig. 3. Vertical deformation for sandy-gravel cushion subsoil improvement

Fig. 4. Vertical effective stresses for piled subsoil improvement

Fig. 5. Relative shear strength for piled subsoil improvement

Fig. 6. Distribution of contact pressure in footing bottom for sandy-gravel cushion subsoil improvement

Conclusion

Within the frame of the feasibility study the foundation analysis of the safety-related important structures were applied with the agreements of the MAAE conditions [4].

This analysis approved that for the given geological and geotechnical conditions (and later one also for recommended seismic conditions) the improvement of the subsoil is needed to fulfil all demands defined by basic limit states, namely the limit state of serviceability which is connected with foundation settlement.

Therefore the subsoil improvements, with the help of gravel cushion or with the help of piles, were proposed together with supplemented improvement with geosynthetic reinforcement. For this improvement the analytical methods for the control of individual limit states and numerical methods of the soil structure interaction were performed both for static and dynamic loading.

Parametric study of the soil structure interaction for seismic loading approved also the significance of the individual input data as the different

buildings of reactors, different subsoil improvement and finally the different character of the seismic loading.

However in all cases for the improved subsoil no reasons, from the view of limit states defined for geotechnical structures, were found, eliminating the structure realization, or even significantly limiting structure realization.

The performed analyses approved a safe foundation of the main buildings of the potential nuclear island in proposed locality not only for static loading but later on also for expected seismic loading. This analysis is allowing starting with another more specific phase of nuclear island evaluation and realization.

For this new phase of the evaluation from the view of foundation engineering and SSI the attention should be focused on the following steps:

- Need to realize another more specific geotechnical investigation according to the demands of the IAEA [4];
- Need to define the technology of foundation for the main objects of the nuclear and conventional islands from the potential supplier (or suppliers) of NPP;
- To realize 3D numerical analysis of the SSI for proposed technology of foundation.

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