APPLICATION OF BACK-ANALYSIS FOR STRUCTURAL FOUNDATION IN SOFT SOIL IN SEISMICALLY PRONE AREA

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SUMMARY

This paper presents some experience gathered during the application of the back-analysis approach in founding of a residential-business complex located in seismically prone area.

The previously performed field and laboratory geomechanical tests proved that the geotechnical medium of the location was characterised by a high heterogeneity of soil materials with predominant presence of layers of low strength-deformability characteristics. A high underground water level and layers of fine-grained uniform sands susceptible to dynamic instability under seismic effects were observed. Such an unfavourable geotechnical situation of the given location imposed the need of improving of the natural foundation soil. The most favourable and rational solution that could provide safety and stability of structures was the use of gravel piles and a sub-base.

The analyses were done in three phases. The first phase consisted of two parts: analyses of possible settlement by using the parameters of natural non-improved soil and analyses by using the parameters of improved soil. The fact that the location was of specific geotechnical properties imposed the need to include also the effect of soil-structure interaction in the analyses. To analyse the integral soil-structure system, the substructure method was applied, which represented the second phase. The project anticipated observation of the structure in all the phases of construction and later during the serviceability period. The data from the observations were used to perform a back-analysis, which was the third and final phase of the analyses.

The application of the back-analysis represents a qualitative advance made in determination of the Stress-strains State of soil. In the presented project, the application of the back analysis was of a great benefit because of the results and data that verified not only the methods and the models but also the applied technical solution.

Special attention was focus on the seismic response and site effects of the location. Also seismic soil-structure interaction was taken under consideration.

INTRODUCTION

Presented in this paper are the analyses and the results on the Stress-strain State of soil and soil-structure interaction.

The field and laboratory geomechanical surveys done for the considered structure have shown that the location is characterised by a great heterogeneity of soil materials, with dominant presence of layers of weak strength-deformability characteristics. Improvement of the foundation soil was done by gravel piles and a sub-base layer. The analyses have been performed based on the results obtained from the performed control geomechanical tests on the level of improvement of the natural soil. Apart from the mentioned analyses, the effect of soil-structure

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interaction has also been computed. Within these frames, particular attention has been paid to the distribution of the computed settlement and the stress-strain quantities in the elements of the foundation structure.

IMPROVEMENT OF NATURAL SOIL

The unfavourable geotechnical structure of the considered location has imposed the need of improvement of the natural foundation soil. The most appropriate and rational solution to provide safety and stability of the structures was the solution involving incorporation of gravel piles with a length of 10 and 6 m and a diameter of 25 cm. On the sites of both structures, over an area of 2 x 40 x 18 m, improvement has been done by a total of 614 deep and 676 shallow piles or a total amount of incorporated gravel material of 694 m3. Fig. 1 shows the distribution of the gravel piles in the base of the foundation soil.

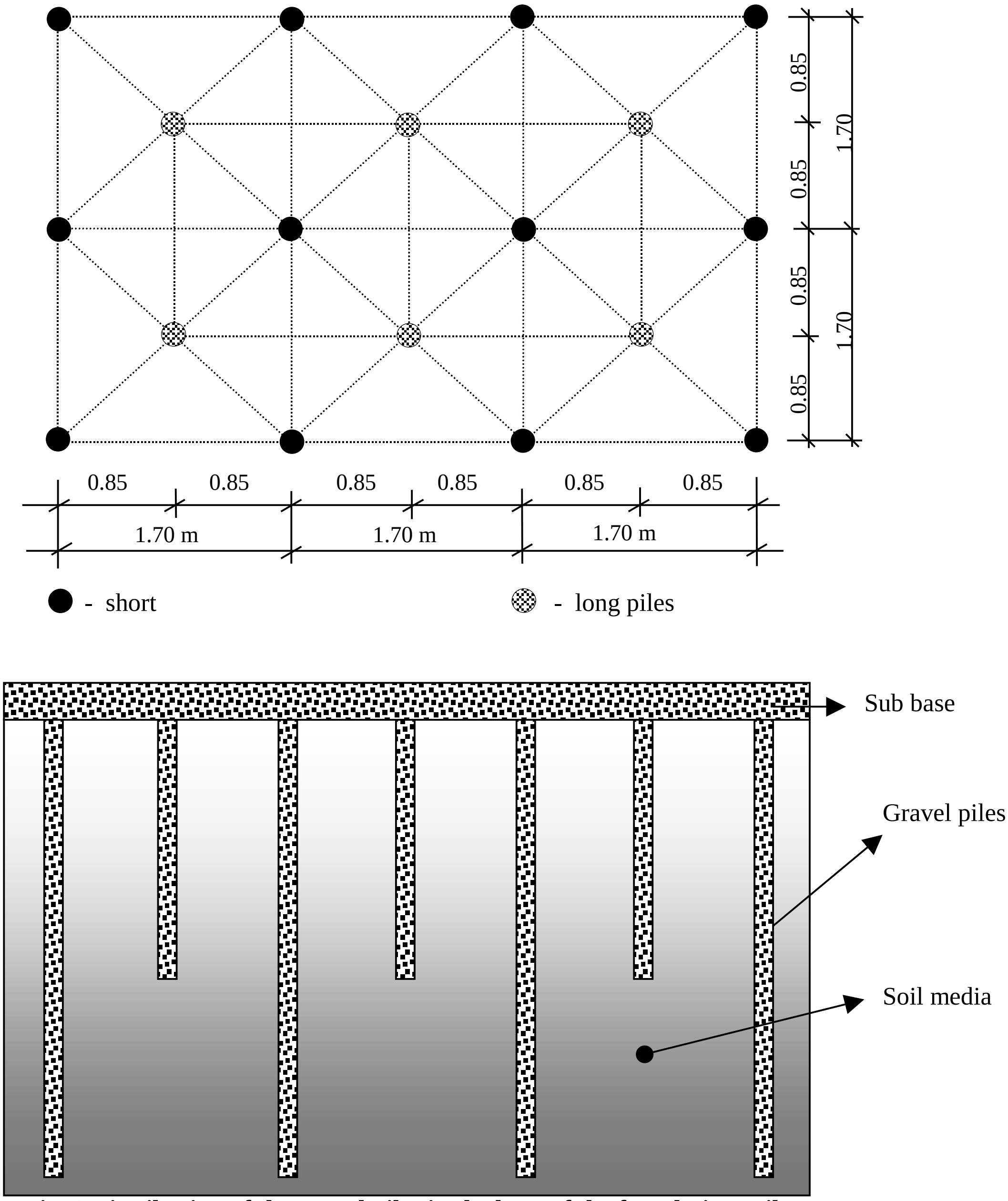

Fig. 1 Distribution of the gravel piles in the base of the foundation soil

The objective of such a combined solution along with the finishing sub-base is to form a geotechnical skeleton through which the following effects shall be achieved:

- improvement of the general characteristics of the foundation soil through the increase of the total volume mass;
- transfer of part of the load of the structure along depth;
- decrease and uniforming of settlements up to acceptable limits that shall not affect adversely the stability and the functioning of the structures;
- drainage of the soil and acceleration of the consolidation process;
- providing of stability of potentially unstable soil layers under seismic excitations that are expected at the site due to the high seismicity of the Ohrid area.

Figs. 2 and 3 show photos taken during the construction of the gravel piles on: "Kej 1" site - Ohrid.

Fig.2 View of construction site

Fig.3 Construction of a gravel pile

To evaluate the compactness of the soil and the level of improvement prior and after the construction of the gravel piles, field tests were continuously done by static and dynamic penetration up to a depth of 6 - 11 m. Presented shall be only a general view of the level of improvement through comparison of the dynamic specific resistance prior and after soil improvement. Fig. 4 displays the average values of the specific dynamic resistance.

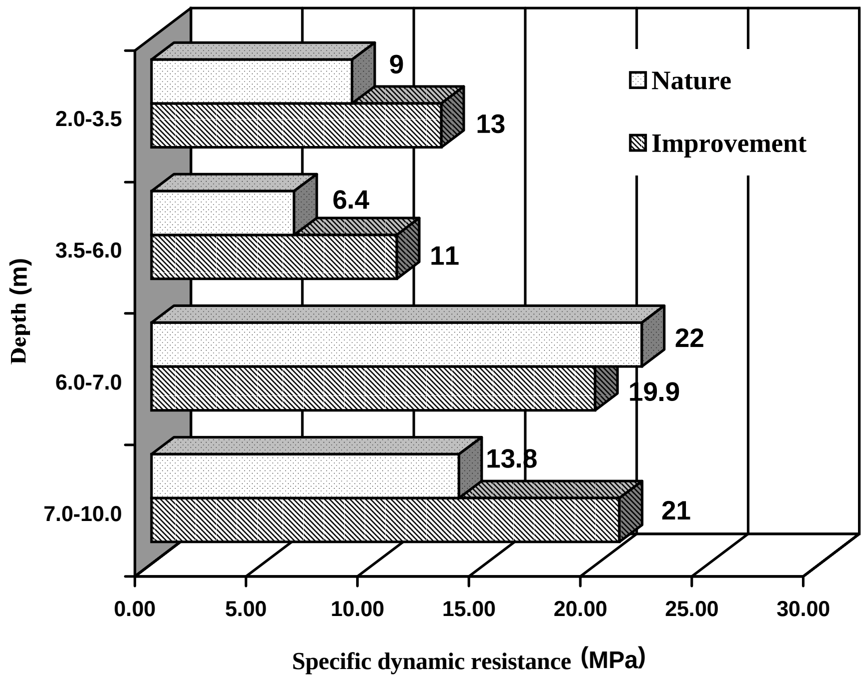

Fig.4 Diagram of average values of specific dynamic resistance

ANALYSIS OF SOIL-FOUNDATION-SUPERSTRUCTURE SYSTEM

Static Analyses

To define the Stress-strain State of soil layers under the load of the planned structures, analyses that basically treat the geotechnical media as elastic half-space have been done.

The analyses of stresses and strains have been performed according to the designed solution of the super structure and the foundation structure for the computed distribution of loads. The analyses show the spatial distribution of stress-strains in the soil media under gravity loads.

The fact that a location of specific geotechnical properties is in question imposed the need of analysing the effect of soil-structure interaction. Since it is a compressible and deformable geotechnical medium, the super structure with its stiffness undoubtedly affects and redistributes the stresses and strains in the foundation soil. This effect is, first of all, in the direction of reduction of relative settlements and averaging of the maximum computed settlements. Such a phenomenon is certainly accompanied also by variation of the stress state in the elements of the structure that absorb the relative settlement through additional stresses.

To analyse the integral soil-structure system, the method referred to as the "substructure method" has been used. With this method, the problem is analysed in separate independent steps.

The first step represents, in fact, analysis of the Stress-strain State of soil under the effect of the loads. In the second step, soil parameters in the form of equivalent springs are defined to simulate the effect of soil in the total integral system. The equivalent springs have been defined based on the results from the previous step. In the third, i.e., the last step, the structure represented by a spatial 3-D model has been analysed. In this model, the soil medium is represented by a set of equivalent elastic elements defined in the previous (the second) step. The applied procedure of analysis of soil-structure interaction is presented in Fig. 5.

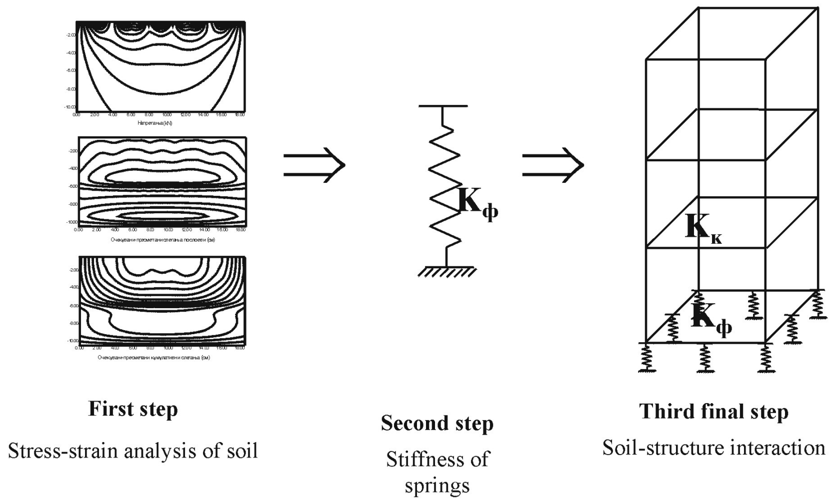

Fig. 5. Method of static analysis of soil-structure interaction

The analyses of soil-structure interaction were necessary to be performed in order to get a more realistic insight into the Stress-strain State of the contact surface. In this way, the rank of relative expected settlements, which are of primer importance for the functioning of the structure, could be defined more precisely.

Dynamic Analyses

The dynamic analysis of soil-structure interaction has been done in order to define the effects of dynamic interaction upon the response of the integral soil-structure system. In the seismic analysis of the interaction, the structure is represented by beam elements with masses concentrated at the level of the floor structure. It is a linear element with three degrees of freedom at each node, two translations and one rotation. The foundation structure is also modelled by beam elements. The analytical model of the structure and the foundation is presented in Fig.6.

Based on previous geomechanical surveys and geophysical measurements, the representative values of the characteristics of the present soil materials have been defined for the considered location. Within the frames of seismic analysis of the interaction, two models of the soil profile have been applied: natural foundation soil and improved soil.

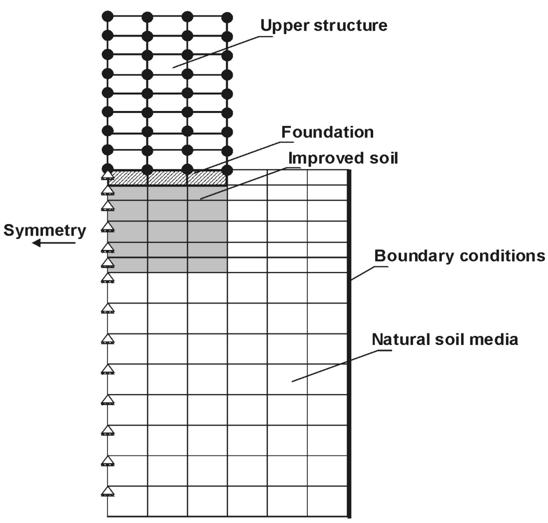

Fig. 6. Analytical model for dynamic analysis of soil-structure interaction

The effects of soil characteristics upon maximum horizontal accelerations at the foundation and the tip of the structure have been summarised in table 1.

Table 1

	Natural soil conditions	Improved soil
Bedrock (input)	0.30 g	0.30 g
Free field	0.47 g	0.51 g
Base of the structure	0.54 g	0.67 g
Tip of the structure	0.44 g	0.48 g

The computed maximum accelerations at free field amount to 0.47 g for natural and 0.51 g for improved soil conditions at free field - effect of local soil conditions. Noticeable at the base of the structure is an additional increase in maximum accelerations of 15% in the model with natural soil conditions and somewhat greater increase of 25% in the model of improved soil characteristics. No greater changes have been observed at the tip of the structure.

The maximum values of horizontal displacements of the integral system obtained by analysis of the interaction are given in Fig.7. The results obtained for the relative horizontal displacements at the foundation level and the tip of the structure point evidently to the effect of soil improvement. The improvement of the soil conditions below the foundation structure up to the depth of 15 m enable to achieve a decrease of total horizontal displacements of 7% at the base and 15% at the tip of the structure. Apart from this, a drop in the relative horizontal displacements from 2.33 to 1.66 cm or 30% is also noticeable at the tip of the structure in respect to those at the foundation base.

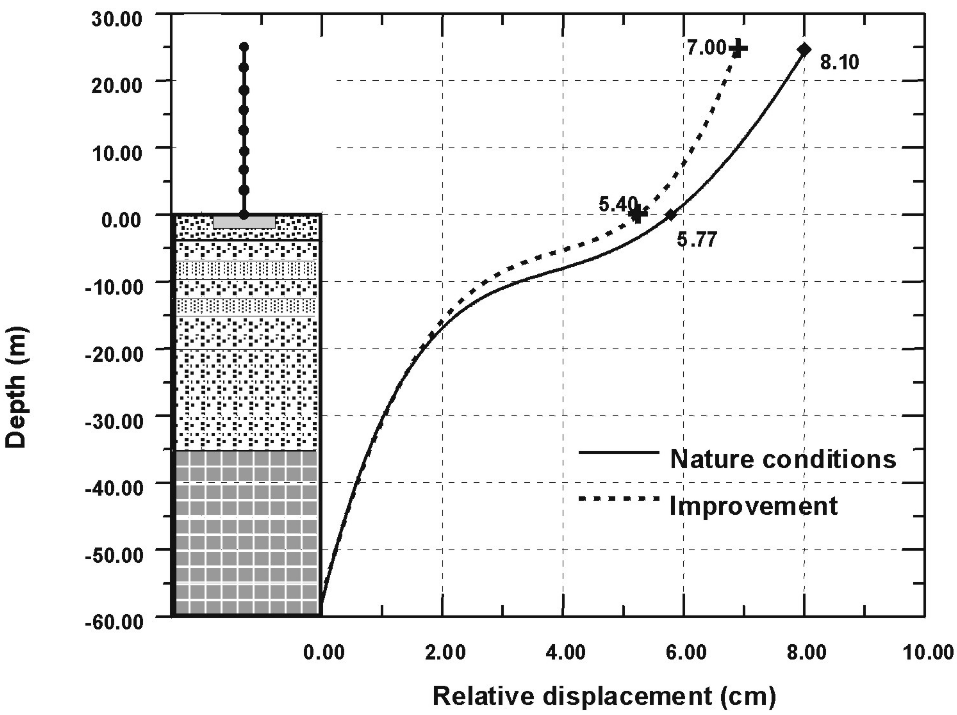

Fig. 7 Results obtained from dynamic soil-structure analysis for the both models

OBSERVATION OF STRUCTURE

Within the frame of this project special efforts were made to observe settlements of soil media and deformation of structure. For that purpose 12 markers were fixed on the exterior columns on the level of first slab, fig.8.

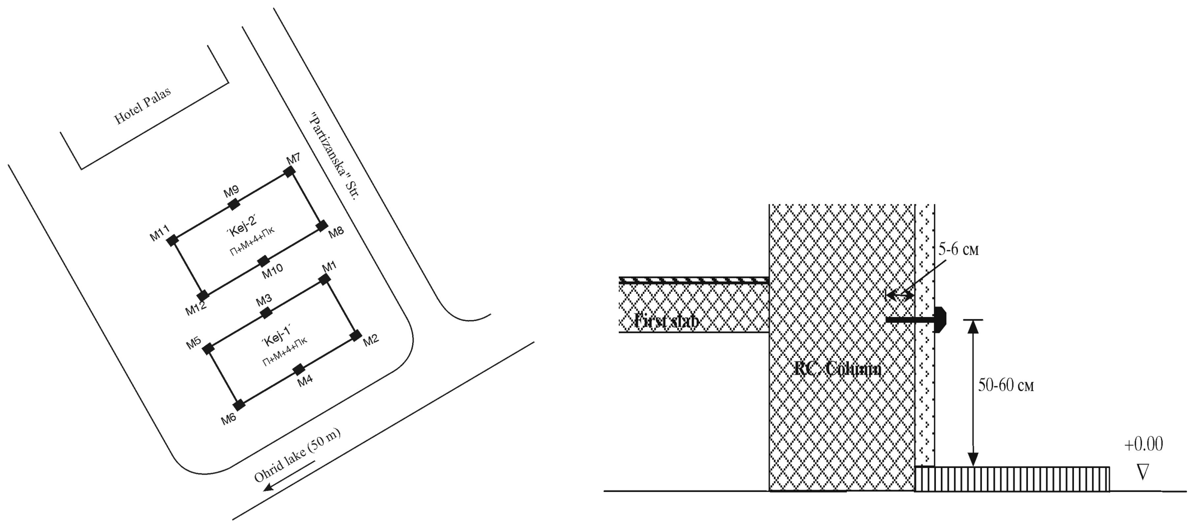

Fig. 8 Scheme of fixing markers in the exterior RC columns

Observation of settlements were planned to be according to this scheme:

- "'0" measurement, after fixing the marker in the column
- measurement during the construction of structure
- measurement after the finishing the structure
- measurement during the exploitation period of the buildings

The collected data from these measurements will be of great importance for verifying the analytical approaches and applied technical solution for improvement of poor soil conditions.

CONCLUSION

The performed field, laboratory and analytical investigations do emphasise the complexity and the importance of foundation of structures in weak soil conditions. The analyses have been carried out in a number of phases. The results obtained from the first analyse done represent a basis for verification or revision of the proposed solution and input for the next step in the analysis. In this way, the analyses are iterated until an optimal solution is obtained. The applied methodology is very suitable also because of the fact that, at each step of the analyses, one has an insight into the data and the results obtained.

The computations have shown that the proposed solution for improvement of the foundation soil enabled decrease of settlement for 60-70% with a reduced time of consolidation. The analyses enabled obtaining of a big fund of data to be used for optimisation of the foundation structure.

Observation of settlements and deformation of structure is of great importance and this is the only valid way for verifying the applied approaches and methods.

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