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ASPECTS OF THE IMPROVEMENT OF FOUNDATION SOILS CONCERNING THE DEPTH VIBROTHRUSTING

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Abstract: *The paper presents the application of the technology of depth vibrothrusting improvement of the foundation ground for two high buildings : a Groundfloor + 10 Floors tower type social – administrative building placed in Timisoara and a Basement + Groundfloor + 9 Floors dwelling block placed in Arad. The first researches and practical aplication of the experimental technology of depth vibrothrusting for low foundation grounds were realized at the former Roads and Foundation Department from the Politehnica University Timisoara. The applied technology, the checking proceeding of the improvement quality and the behavior in exploitation of the two presented buildings are the novelty elements of the researches. The technology of depth vibrothrusting improvement of the foundation grounds is very efficient in the case of the sandy loose grounds and sandy water – saturated grounds. Principially, this technology consists of the introduction of an equipment into the ground through vibration on the width of the weak layer. The equipment consist of a rod and horizontal ribs, disposed in space. Because of the reduction of the friction between the sand fragments (which can go up to 90 %), these are rearranged in a settled stale. The extraction of the equipment is resolved also by vibration, with a speed of 0,5 m/minute. Usually, the vibrotampering equipment is placed in the corners of a grid consisting from equilateral triangles. For the two aforementioned buildings, the foundation ground consists of partially saturated sand which is a natural state falls into yhe category of grounds that can be liquefied under seismical conditions. For the strengthening of the seismical protection of the other buildings, the depth compaction of the foundation ground was done through vibrotampering. The verification of the compaction quality was done by dynamic penetration drilling using the cone dynamic penetrometer. The very good behavior in exploitation of the two constructions underlines the efficiency of this method of strengthening the foundation ground. This method may be applied on special constructions from agricultural domain, e.g. bins, if the ground conditions mandate it.*

Key words**:** *vibrothrusting, vibrostinging, vibrogenerator, liquefying.*

INTRODUCTION

For the improvement of weak foundation grounds through depth vibrothrusting, the vibrostinging method is applied. This method has been generally researched and applied in the practice of foundation works by the Department of Roads and Foundations, from the „Politehnica" University Timisoara.

The vibrostinging method has proven to be very efficient for the improvement of the foundation grounds consisting of mellow and saturated sands with high liquefying potential, under the action of some dynamic stresses, especially of seismic nature.

Under the effect of vertical sustained vibrations, the friction between the sand fragments is heavily reduced. These fragments are arranged in a tamped state, with a corresponding higher stability and a lower liquefying potential.

MATERIAL AND METHODS

The vertical vibrations developed by a vibrogenerator are transmitted in depth through the in-soil introduction of a work equipment (fig.1), consisting of a metallic case, actually a rod with a length of 6...8 m with horizontal bars (1/10 ... 1/6 of the length of the rod) attached.

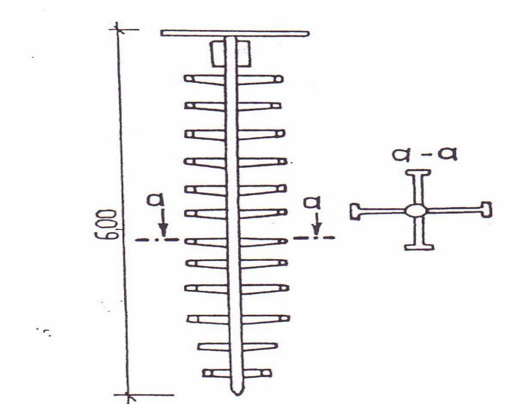

Figure 1: Work equipment

In the case of vibrothrusting of saturated sands through vibrostinging, the vibrations are transmitted in horizontal direction on a distance of up to six times the length of the horizontal bars on the work equipment.

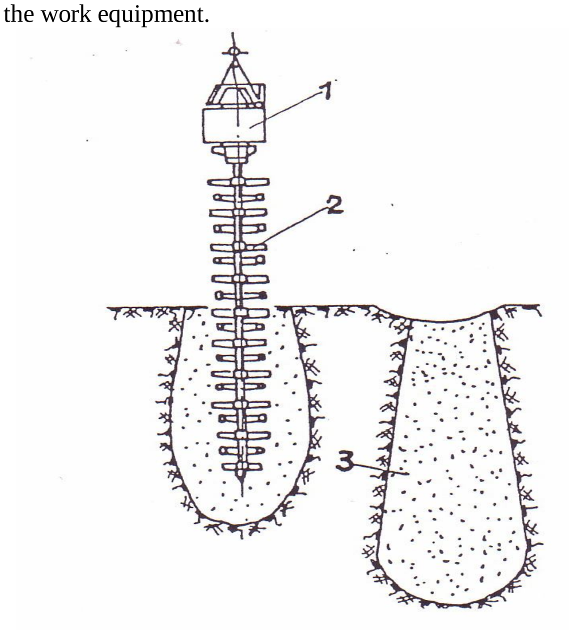

Figure 2: Execution technology
1 – vibrogenerator; 2- work equipment; 3 – vibrothrusted area

The execution of the depth vibrothrusting of foundation grounds through the vibrostinging method contains the following technological phases (fig. 2):

- the in-soil introduction of the working equipment with a speed of approximately 1 m/min., until the improvement depth (foreseen in the project) is reached

- the maintaining of the work equipment at the attained depth level and its continuous vibration for another 2...3 minutes

- the extraction of the work equipment through vibration at a speed of maximum 0,5 m/min. Thus, the result is the vibrotamped area (3), with a funnel-shaped subsidence – its depth is bigger, the better the vibrotamping was.

The formed subsidences in the axes of the vibrotamped areas are filled with soil and are compacted through a surface compaction process.

The points in which the vibrostingings are executed are placed in the corners of an equilateral triangle grid. Their edge is determined based on the initial and final porosity of the sail.

The improvement of foundation grounds through vibrostinging was applied by the Department of Roads and Foundations for the execution of a large number of constructions. Their behavior in time was very good; two significant objectives are presented in the following rows.

RESULTS AND DISCUSSIONS

Administrative tower building (P+10E) from Timisoara

On the site of the aforementioned building (fig. 3), the stratification of the soil is comprised of the following layers:

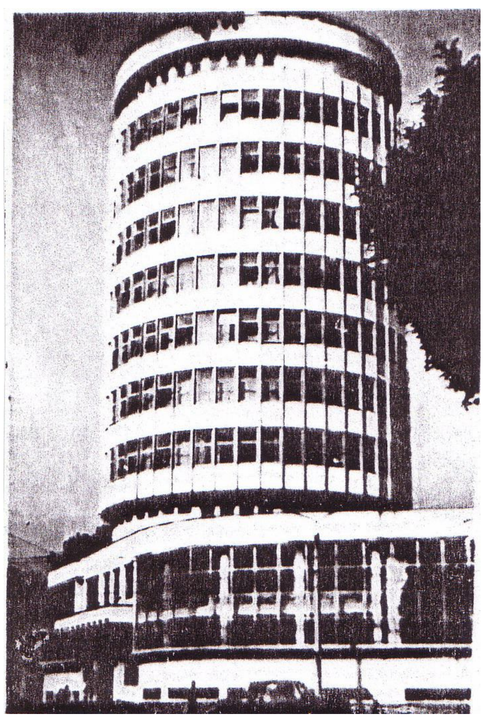

Figure 3: Tower building (G + 10 F)

- inhomogeneous filling with a width of up to 1,40 m;
- fine and middle sand, extended to a depth of about 8 m;
- middle sand from 11 m downward.

The underground on-site water was intercepted at a depth of 3.50 m. The vibrotamped state of the fine and middle sand layer was relatively weak, especially in the upper part of the layer. Thus, the engineer has foreseen the foundation on a general grating, in a depth of 4,80 m.

The execution of the grating foundation at the foreseen depth (1.30 m under the subterranean water) required dewatering works, as well as the bracing of the digging walls with sheet-piles. Taking this fact into consideration as well as the high liquefying potential of the foundation ground (mainly consisting of weakly tamped and saturated sand), the solution of improving the foundation ground through vibrothrusting with the method of vibrostinging was applied. This solution has permitted the reduction of the foundation depth from 4,80 m to 3,10 m – a level situated above the subterranean water.

After the general digging down to -3,10 m, a 50 cm ballast layer was disposed, up to -2,60 m. At this level, the work equipment was vibrostuck in the soil for the in-depth compaction of the foundation ground. The real depth of the vibrostucking was about 5,00 m. In plane, these were disposed in the nodes of a equilateral triangle grid with the edge of 1,50 m.

In order to prevent the upset tendency of the sandy soil, because of the depth vibrothrusting, 2 rows of ballast columns were realized, on the circular contour of the site.

The checking of the compaction quality, done by depth vibrothrusting, was conducted through the cone dynamic penetration method, using the light dynamic penetrometer.

The dynamic penetration diagrams in Fig. 4, corresponding to the natural soil (1) and improved through depth vibrothrusting (2), undoubtedly underlines the much higher penetration resistance of the improved soil. This also means a substantial raise of the tamping degree and thus better stress and deformation properties.

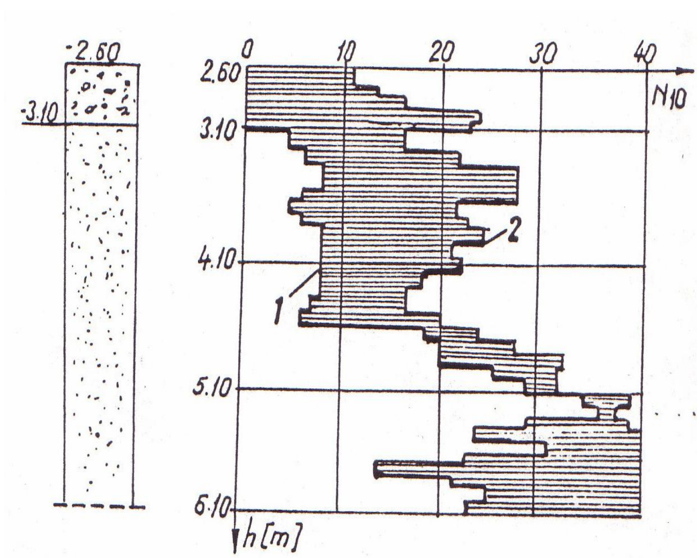

Fig. 4 Dynamic penetration diagrams
1 – natural ground penetration; 2 – improve ground penetration

After the finalization and checking of the in depth compaction quality of the foundation grounds, the 50 cm ballast layer (used as a geological load against the surface upset), was removed. Subsequently, the execution of the grating foundation was conducted under dry conditions.

The construction has been in exploitation for the past 30 years, all the while behaving very well from the point of view of the collaboration with the foundation ground.

Dwelling block with S+P+8E in Arad

The on-site conducted geotechnical investigations have underlined the presence of a package of middle sands, even gross, saturated sands (beginning from 3,00 m down to 8,50 – 9,00 m) in the soil stratification.

Figure 5: Dwelling block with B+G+8F

Under the aspect of the granularity, the sand package in the soil stratification is characterized by the following main elements:

- granular fractions: gravel: 12...15%, coarse sand: 27...40%; middle sand: 38...50%; fine sand: 5...12%
- porosity: 44...46%
- average diameter: $d_{50\%}$ = 0,42...0,50 mm;
- effective diameter: $d_{10\%}$ = 0,22...0,27 mm
- nonuniformity grade: U_n = 2,5...3,0.

From the analysis of the dynamic cone penetration conducted on-site and based on the existing correlations in the technical literature, between the value of the tamping grade I_D and the number of hits for the in ground protrusion of the penetrometer in a depth of 10 cm, N_{10}, the following facts have surfaced:

- the existence of a relative uniformity of the soil stratification, both horizontally and vertically;
- the tamped state of the sand package, between the depths of 3,00 m and 6,00 m, is to the lower limit of the middle tamping domain (I_D = 0,40...0,50);

- the tamped state of the sands, between the depths of 6,00 and 8,00 m, fits the domain of middle tamping (I_D = 0,50...0,55)

- under the depth of 8,00...8,50 m, the sands in the soil stratification fit the domain of high tamping (I_D = 0,70...0,85).

In conformity to the provisions in P125-84 (Technical guide regarding the study of liquefiable noncohesive soils), through its granularity and tamped state, down to the depth of 8,00 and 8,50 m, the sand package in the soil stratification fits the category of liquefiable soils.

For the quantification of the liquefying potential of the sands in the soil stratification, the fact that Arad fits the seismic area with the highest value of the engineering acceleration a_g = 0,16 g and a corner period of T_C = 1 sec. was also taken into consideration.

Taking into consideration the liquefying potential of the foundation ground, it was necessary to choose a foundation solution through which it could be reduced.

In the first variant, the engineer had chosen a direct founding solution, on a grating foundation in depth of 3,00 m, set on a ballast pillow (width 1,50 m), through which the width of the sand package should have been reduced.

Because of the fact that the level of subterranean water was at about 3,00 m in depth, the ballast pillow was entirely submerged. Under these circumstances, for the realization of a corresponding quality pillow it was necessary to execute dewatering works with the help of acicular filers, which would have escalated the cost of the investment.

Consequently, also in this case, the depth vibrothrusting solution (through vibrostinging) was applied.

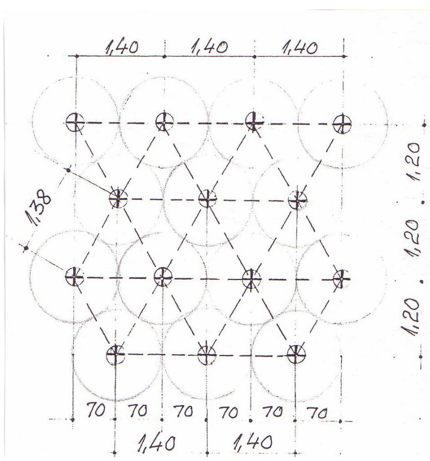

Figure 6: Disposal of the vibrostinging

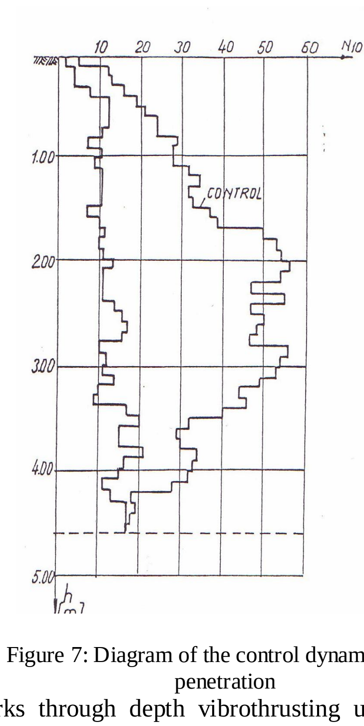

Figure 7: Diagram of the control dynamic penetration

Before executing the improvement works through depth vibrothrusting using the vibrostinging method, research in an experimental polygon on site was conducted. Through this research, the distance between the vibrostings was determined and the efficiency of this method was tested, under the conditions of the on-site soil.

The checking of the quality of the improvement through dynamic cone penetration drilling have fully confirmed the good results attained in the experimental polygon. This fact is underlined by the penetration control diagram in Fig. 7, where it can be observed that the number of hits N_{10} has significantly risen to 30...50 hits. For this number of hits, in conformity to the provisions in C159-89 (Technical instructions for the dynamic cone penetration method), the following values are to be obtained:

- weight in dry state: δ_D = 15,0...16,0 KN/m^3;
- porosity: n = 43,5...39,5%;
- pore index: e = 0,77...0,65;
- tamping degree: I_D = 0,65...0,75
- inner friction angle: Φ = 30...35^o
- linear deformation module: E = 14500...23000 kPa

The dwelling block for which the foundation ground was improved by depth vibrothrusting has been in exploitation for the past 14 years, all the while having a very good behavior.

CONCLUSIONS

The good exploitation behavior of the two relatively tall buildings, founded on potentially liquefiable soils which were improved through depth vibrothrusting, confirm the efficiency of this method which can be applied to a number of other high buildings (bunker, water castles), placed on similar foundation grounds.

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