Ground Improvement By Dynamic Replacement Columns On The Basis Of The Segment Of Siekierkowska Highway In Warsaw.

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Abstract: The paper presents research and observations carried out during performing ground improvement in the segment of Siekierkowska Highway located in Warsaw. The authors describe a technology of column formation, acceptance criteria, and calculations compared with the measurements of embankment settlements. The acceptance tests executed during the work were aimed to check the quality of the formed columns. They also pointed at bottom rebound at the foundation and a distinct pore overpressure migration caused by the pounder energy. After some time, the repeated dynamic sounding in the columns resulted in an improvement of the column and consequently a dissipation of pore overpressure caused by the compaction.

1 INTRODUCTION

An essential and urgent work when building the Siekierkowska Highway in Warsaw was a realization of the segment from Bora-Komorowskiego Street to the intersection of Ostrobramska, Płowiecka, and Marsa Streets. On account of ground conditions (organic ground) and the deadline, which is the end of 2005, it has been decided to apply a Dynamic Replacement method by making dynamic replacement columns. It concerned a segment where the thickness of weak ground exceeded 3-4m. There, where the occurrence of organic soil was shallow, it has been decided to apply soil replacement by so called: gredging. Executing the dynamic reinforcement mainly aimed at accelerating organic ground consolidation. The organic ground was loaded with a road embankment in order to meet the bearing capacity and settlement conditions as fast as possible, taking into consideration operational load of embankment and road. The reinforcement was executed by Freyssinet Polska company under geotechnical supervision of the Building Research Institute.

2. WATER-GROUND CONDITIONS

The planned site is located on the overflow area of the Vistula river. On the whole new-built segment, there occurred river deposit such as: organic clay (silty clay) and mud. The mud (organic ground, stratum II) occurred approximately 1m under the organic clay stratum or partially directly under the surface of the site. In the primary report, their condition was defined as soft – I_C=0.60, with a natural humidity of approximately 70%. In stratum III (silty clay) medium ones, I_C=0.25-0.49 – yielding state. The maximum depth of organic ground deposition was approximately 4 meters beneath the surface of the site. Beneath the organic ground stratum there occurs moderately compacted medium and coarse sand - (I_C=0.50-0.65). The first water table occurred periodically on the surface (on mud and organic clay stratum). The second water table is forming under the organic ground stratum, in sand on the depth of approximately 4-6 m beneath the surface of the site and has a tense character (Fig. 1).

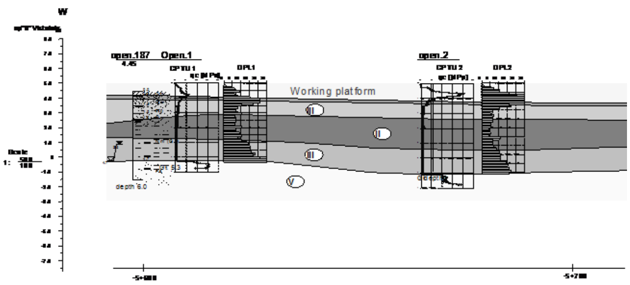

Fig. 1. Fragment of a soil profile through the Siekierkowska Highway segment planned to reinforce by Dynamic Replacement columns. Nm – mud, Ps – M Sa, Gp – siCl, Gb – Humus.

3. DYNAMIC REPLACEMENT COLUMNS EXECUTION

On account of a short lead time, it has been decided that a part of road embankments will be founded on the ground improved by Dynamic Replacement method. The Dynamic Replacement method is a consistent expansion of the Dynamic Consolidation method applied by Louis Menard. By using the same equipment and a similar technology, it is possible to improve the soil which did not improve by applying the Dynamic Consolidation method.

For ages, the Dynamic Replacement method is successfully applied in organic ground, mud and peat, which are the ground similar to the ones that deposit on the area of the building highway.

The Dynamic Replacement method consists in making grain material large diameter pillars in the cohesive soil (figure 2).

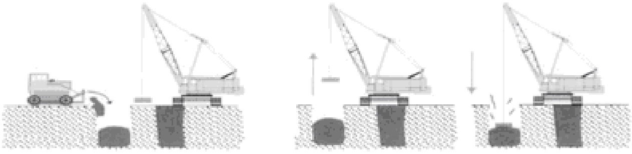

Fig. 2. Flowchart for the sequential stages of the Dynamic Replacement columns execution

It has been decided that in this case, the pillars will be formed by sticking in specially selected aggregate with a 12 tons pounder dropped at the height of 20meters. In order to lift and drop the pounder, a crawler crane with bearing capacity of 70 tons, equipped with a free-falling mechanism has been used (Fig. 3).

Fig. 3. A view of the crawler crane. In the upper right corner there is a cubic pounder (one side – approximately 1.2m, weight- 12 tons). Beside, the moment of impact at the height of 20m.

The beginning of the compacting process was performed on the surface of the formed working platform, which made up of non-condensed layer derived from non-cohesive ground (with thickness of approximately 1m). It also enabled the heavy equipment to move on the platform.

A single column execution was preceded by few series of blows. The first series of blows was executed on the surface of the working platform which resulted in creating a crater with the depth of approximately 2m. In most cases the crater's diameter in its upper part amounted to approximately 2.5m, while nearby its bottom it amounted to approx. 1.5m. Next, a batch of aggregate was poured into the crater interior and some blows were executed until the column's bottom displaced. Successive stages such as: pouring the aggregate into the excavation and performing the blows, were repeated until a distinct reduction of the pounder penetration in comparison with the previous stages. In many cases, the end of column forming was signalized by a dead sound combined with a sudden decrease of pounder penetration value, which meant that any further displacement of the column is impossible.

The completion of the column forming amounted to a total crater filling and concentration of the upper part of the column by a series of blows. The densification of the column at the final stage was completing when the ground started to heave visibly. An average ground heave in the column surroundings amounted to approximately 15cm (Fig. 4.)

It has been noticed that when performing further blows it is possible to drive other rations of aggregate into the core of the column. It involved a massive heave (even higher than 50cm) around the pillar which betoken a significant diameter increase of the column in its upper part.

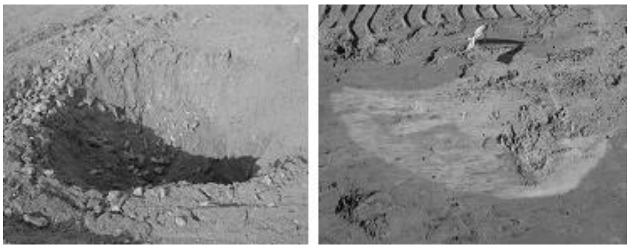

Fig .4. A view of the crater (approximately 2m in diameter). Beside, there is a column formed after truncation, which is clearly visible on the working platform background.

The columns were made on a square grid with a displacement of every second row. The site was divided into two parts: In the first one, loaded with embankment at the height of over 4.5m a column grid measuring 5 x 5m was applied, and 5.5 x 5.5m in the second one.

The material used for forming the columns was an aggregate prepared on the building site. There have been used some demolition materials such as crushed concrete debris in the ratio of 1 to 3 with the medium sand.

The final stage was aimed at densification of the working platform and the surface of the ground with an approximate volume of 2m. It took place as a result of surface pounding, a so-called "Ironing Phase". The process involved a usage of a flat-shaped pounder and a square base. Single blows were performed on a two times more dense grid so that 50% of the reinforced area could adjoin to the pounder base. After the procedure, the surface stratum of the ground (approximately 50cm) or the surface of the working platform was still slightly loose. Performing the classic concentration by heavy vibrating rolls was essential. There have been applied 4 one-track roll passages, taking an optimum humidity (spraying) into consideration.

4. CALCULATIONS AND SETTLEMENT MEASUREMENTS

Before performing the reinforcement, in order to accelerate the work, some calculations aiming at justifying the choice of the method described above and its efficiency have been made. On the one hand a consolidation of cohesive organic ground had to be accelerated, but on the other the bearing capacity of the ground had to be improved in order to continue the work connected with making the surface of the road directly after creating the embankment and without a risk of damaging the road. The ground settlement value after applying the embankment load had to be given. It was also necessary to determine a minimum value of the parameters for the planned columns.

Following parameters connected with applying the embankment load were fixed:

- embankment foot- 45m;
- maximum vertical stress in the embankment place with 5.7m of volume for a station pole 5+600 amounted to P~118 kPa;

The ground parameters deriving from the documentation and own ground research made by: DPL, CPTU and DMT soundings:

- organic ground – (uniform stratum – fen soil and mud) - E_o =1.2 MPa;
- medium sand - E_o = 50 MPa;
- dynamic replacement column - E_o = 40 MPa (setting a condition of a value correlated with I_D = 0.5)

The following parameters of the dynamic replacement columns have been set:

- spacing (s) – 5m;
- diameter of columns (D) – 2.0m;
- (average) depth of columns – 4.0m;
- column intersection surface – A_{col} = 3.14 m^2
- reinforced field surface - A_{gr} = 25 m^2
- ground exchange degree of the improved soil:

$$\tau = \frac{A_{col}}{A_{gr}} = 0{,}12$$

4.1. Settlement Calculations:

Ground and column composite deformation module:

$$E_{av} = E_{gr} \times (1 - \tau) + E_{col} \times \tau \approx 6MPa$$

Total settlement of 4-meters non-improved ground stratum:

$$s = 0.423m$$

Total settlement of the ground and column composite:

$$s = 0.113m$$

The calculations proved a fourfold increase (in comparison with the non-improved ground) in the settlement caused by a road embankment after performing the improvement. All of this has been confirmed by the settlement measurements of the whole embankment construction carried out on the founded benchmarks.

On the settlement curves diagram (figure3), there have been presented averaging measurements of the actual embankment settlement and computational settlement curves taking into consideration improved and non-improved ground. The measurements presented concern only a 6-week period (with regard to the deadline of the article submission), however it is already visible that the embankment construction exceeded more than a half of the computational settlement and stabilizes distinctly.

Performing the trial load by a circular plate proved that the average modules obtained for the columns and for the ground between them are higher than it was estimated in the calculation.

5. COLUMN TESTING

Performing some soundings of a single column enables to check whether the geometry and concentration of the column fulfills the project requirements or not. The diameter and length of the column fluctuates. At times, a part of the columns is shorter than it was calculated, and sometimes it is significantly longer than the diameter previously set up.

The first task before making the columns was to determine the conditions on the segment expected to reinforce dynamically. In order to do so, three soundings in three different places have been led: static CPTU sounding, dilatometric (DMT) sounding, dynamic penetration tests by a light dynamic probe, and a mechanical (DPL).

Next, the area of experimental plot measuring 90 m x 25 m was allocated and only then it was possible to make the columns. The amount of blows and the aggregate used for making the columns were noted down. After making a group of columns, a column surrounded by already prepared columns was tested. The testing consisted of soundings executed by a light dynamic probe, a mechanical one used inside the columns, at the edge (approximately 1m from inside) and between the columns.

The results from the inside of the columns suggest that the average concentration for the researched columns amounted to $I_{D\,av}$ ~ 0.65 on average. The average concentration at the edge of the columns is slighter and amounted to $I_{D\,av}$ ~ 0.55. By the analysis of the column sounding diagrams it has been noticed that the amount of the probe blows at the bottom of the column (last 0.5m) decreased significantly as a result of the process of column concentration and ground resistance beneath.

The results of the column research proved that the columns "stopped" at the floor of stratum III (organic clay) and in spite of changing the column forming methods it was not possible to obtain columns at the length unambiguously suggesting that they leaned against the bottom sand. The organic clay stratum proved to be so "strong" that it did not undergo any damage while compacting by the energy of the blows amounting to 240 t*m. Its bearing capacity was higher than the energy applicable in the given conditions - apartment buildings nearby. CPTU and DMT research suggest that in spite of low modules in the stratum III (~9 MPa), its bearing capacity was sufficient in order to become a support for the columns.

medium module of the
reinforced mud/peat stratum

By the analysis of the sounding diagrams (figure 5) it is possible to see the difference in the values obtained from the organic ground and in the column itself (diagram 1). Diagram 2 presents the column's geometry – distribution of values within the column as well as out of it. In relation to the "background" value, an improvement of the ground between the columns in first 2m up the surface is visible. However, it is also easy to notice a decrease in the blows' value inside the column within its bottom, even below the "background" value.

Next two diagrams (figure 6) present a phenomenon observed during performing the dynamic replacement. If the acceptance of the column took place directly after its execution (i.e. within 3 days), every time at the bottom of the column regardless of location (different levels of separated strata), a sudden decrease in the amount of blows has been noted e.g. from 20-30 to 5-10 N_{10}. Even the volume of the strata indicating a decrease in the amount of the blows was permanent – approximately 0.4-0.6m. Then, the values of the probe blows "returned" to their typical values of the "background" values in a given depth.

Taking into consideration the same sounded columns after approx. 3 weeks time, no low values were observed nearby the column's bottom. Furthermore, a significant improvement in the obtained results were noticed. The explanation is that there appeared pore overpressure in the ground, which weakened the column at the bottom where the biggest energy connected with striking and re-striking the column out of the bearing layer converges.

The observed "bottom weakening effect" derives from the pore pressure diffusion. There exist two facts that prove the thesis. At first, the trials of increasing the amount of blows and the amount of the aggregate to form the columns resulted in ground upheaval. The second fact is about improving the values obtained at the bottom of the column after some time.

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