TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

MACIEJ SZCZYGIELSKI*, ŁUKASZ STOPA**

USAGE OF NEW SOIL IMPROVEMENT TECHNIQUES IN ROAD EMBANKMENT CONSTRUCTIONS

WYKORZYSTANIE NOWOCZESNYCH TECHNOLOGII WZMACNIANIA GRUNTU PRZY POSADOWIENIU NASYPU DROGOWEGO

A b s t r a c t

A gravel piles foundation technique as an alternative to the soil replacement method is presented in this paper. The authors describe both technologies and carry on the comparative analysis, regarding the economical and technical aspects of them. The work is based on a real life example from multi-storey car park construction project carried out in Tychy

Keywords: gravel piles, soil improvement

S t r e s z c z e n i e

W artykule omówiono technologię wykonywania pali żwirowych jako alternatywną dla wymiany gruntów metodę wzmocnienia podłoża gruntowego. Przedstawiono charakterystykę opisywanych technologii, a także wykonano analizę porównawczą, uwzględniając techniczne i ekonomiczne aspektu obu rozwiązań. W artykule wykorzystano dokumentację projektową parkingu wielopoziomowego wykonanego w ramach inwestycji przebudowy transportu publicznego w Tychach.

Słowa kluczowe: pale żwirowe, wzmacnianie gruntu

* M.Sc. Maciej Szczygielski, Department of Geomechanics, Civil Engineering and Geotechnics, Faculty of Mining & Geoengineering, AGH University of Science&Technology.

** M.Sc. Łukasz Stopa, Aldesa Construcciones Polska.

1. Introduction

In recent years the construction of bigger and more sophisticated buildings has become a noticeable tendency in civil engineering. Projecting and constructing such objects is possible mainly due to the newer and more advanced building materials, as well as computer aided design systems used by designers and contractors. At the same time urban regeneration causes a lack of suitable terrain and thus poor ground conditions for such complex buildings. The characteristics of today's civil engineering issues described above, determines the progress of new foundation techniques. In view of the foundation for buildings issue, two types of foundation are considered: shallow foundation and deep foundation. First type is used usually used in favorable ground conditions. Spread footing, grillage, raft or inverted arch foundation can be specified as an examples of shallow foundation. The second group of solutions, is usually recommended for soils situated below the projected building where the ground is soft. Due to this, shallow foundations are not suitable for to transferring the loads from the building to the earth in safe way. The safe way of transferring loads to the earth is when the settlement of the ground below the building and does not cause structural damage to the building [1]. Pile or well foundations are performed in these unfavorable ground conditions, and both can be considered as an examples of deep foundations. In relation to dynamically developing foundation techniques on the market, it is possible to distinguish another group of methods where the soft soil strata can be strengthened.

In this paper methods of soil strengthening are listed and two of them are described. The gravel pile foundation technique is also presented as a foundation for a road embankment, based on a real life example from a multi-storey car park construction project carried out in Tychy. The solution is then compared with the soil replacement method. To conduct a comparison of the methods described, a time and economical analysis is performed.

2. Soil strengthening technologies

There are a wide variety of technologies which allow constructors to strengthen the soil structure below planned building. It would be impossible to describe all of the available methods of soil strengthening which have been undertaken by domestic authors in numerous literature in one paper [2–4]. Based on it, methods of soil strengthening can be categorized in fallowing manner:

– **Soil replacement**, where partial and total soil replacement can be specified, dry and wet (dredging) replacement methods are also available depending on the ground water table.
– **Soil strengthening without insertion of admixtures or other materials**, sorted into static and dynamic methods of soil compaction. Static methods are based on the application of preliminary loading of the subjected soil. Due to a consolidation effect induced by loading the parameters of soil improves. It is worth mentioning that classical methods of preliminary loading is very time absorbing. In order to speed up the consolidation vertical drains are used. This procedure speeds up the outflow of water from soils by cutting down the filtration path. Dynamic compaction, explosive compaction or vibroflotation are considered as dynamic soil strengthening methods.

– **Soil strengthening with insertion of admixtures or other materials**, where fallowing methods can be distinguish: surface stabilization methods, ground injections and a strengthened columns created in ground. There are several methods of forming columns in the ground, and at this point the vibro replacement method or the dynamic replacement method should be pointed out. Another popular technique is jet grouting where high pressure jet of fluid is used to break up and loosen the soil, and then to mix it with a self-hardening grout in order to form a stiff , durable column in the ground.

Another method used to strengthen the soil is a method where *geosynthetics are* designed. Finally soil parameters can also be improved by the implementation of *foundation piles,* in this group precast concrete impacted piles are popular and widely applied as a suitable technique.

In this work the authors precisely describe two soil strengthening methods: soil replacement by dredging and forming gravel columns in soft soils with the vibro replacement technique. Both technologies are analyzed in time and economical aspects, in a following part of this document.

2.1. Soil replacement by dredging

Soil replacement is a procedure where soft soils are partially or totally excavated, and the empty space is filled with a new soil material with the proper mechanical parameters. It allows for the creation of a foundation bed made of hard soil which can bear the load of the structure. Soil replacement can be carried out when the ground water surface is below the depth of excavation. If the ground water surface is above the planned depth of excavation, replacement can by performed by the dredge method.

The dredge is a method where excavation is made without pumping water out from the trench. After excavation is performed, trench is filled with soil by a bulldozers. In the end, the new stratum of strong soil is compacted.

2.2. Gravel columns

Gravel columns are formed in a ground by the vibro replacement technique which is a modification of the vibroflotation method. It is a popular technology with a wide spectrum of equipment and vehicles, used for creating columns. Because of that, the range of offered depth and diameter of columns is extensive. Furthermore, the ground condition in which columns can be implemented are very diversified.

Columns are performed by a specialized vibratory probes installed on a dedicated vehicle. According to the expected length of columns, an excavator or piling machine can be used as a dedicated vehicle. (when an excavator is used maximal depth is 7 meters and when vibrator is installed on piling machine, maximal depth is 20 meters).

The technology used for forming gravel columns can be divided into several characteristic stages. The first stage being a vibratory probe filled with gravel material is driven into the ground. Vibrator depth can be additionally aided by pressure from the specialized vehicle.

In the second stage the vibrator is pulled out while the aggregate is released from the tip of vibrator and fills the empty space. It is a stage when a gravel column is formed in the ground. Afterwards the vibrator repenetrates the soil, which results in pushing the gravel into the surrounding soil, and increasing the diameter and degree of compaction of column. This reciprocating movement of vibrator continuities along the depth of the shaped column. The final effect is an elastic column with a high shear strength. In addition during the process of forming columns, the soil near them is compacted which increases its mechanical parameters.

3. Application of gravel columns in foundations of road embankment using the example of a fire road around a multilevel car park in Tychy

3.1. Description of the investment and geotechnical conditions

The Fire road embankment foundation, which is described and analyzed in this article, is a part of "Redevelopment of Public Transport in Tychy – A Multilevel Car Park investment. Investment which is located beside the crossroad of the streets Adama Asnyka and Generała Andersa in Tychy. The Fire road is situated at the northern part of building, in the direct proximity of Potok Tyski river. On the grounds of geotechnical documentation made at the design stage, the existence of organic soil and a plastic silt strata was established in this area. These unfavorable ground conditions disqualify carrying out direct foundation of fire road embankment. Ground conditions were also confirmed in complementary tests carried out during the execution of the investment.

3.2. Presentation of analyzed design solutions

3.2.1. Preliminary design solution

Design documentation indicated the need for a complete exchanging of the ground by dredging, as a solution for a weak ground under road embankment. During the design verification stage carried out by the general contractor, it was shown that because of the complex ground conditions, high level of ground water surface and location of the road, it would be impossible to execute foundations according to design documentation without many additional works.

The inflow of ground water and surface water coming directly from the canal of Potok Tyski river was predicted in the case of excavation under the level of the water surface in the canal. Consequently the ground under the bottom of the canal could slide into the open excavation. To protect against this situation, the construction of an additional hermetical wall to a depth of 6 meters under the bottom of the excavation, would have to be prepared.

The next element not included in the design documentation, but necessary because of the terrain condition was a drainage system which would allow inflow from Potok Tyski river to be pumed out in the case of heavy rain. Further protection against flooding of investment where other works were in progress, would be to build a depression wells system with pumps and pressure pipes.

The difficulties described above convinced the General Contractor to look for alternative methods which would allow the road embankment to be built on the weak ground.

3.2.2. Alternative design solution

As an alternative solution which would provide the required load capacity for the base of the road embankment, would be to strengthen the ground using gravel columns. Considering the ground conditions, this technology seemed to be the optimal solution. The design project consisted preliminary of lowering the terrain and preparing a working platform necessary for the execution of gravel columns, which would be inserted into the ground to the depth approximately 0.5 meters under bottom level of the stratum of soft grounds. The level of the working platform was established, to avoid ground water problems and to prepare a guard bank against water from Potok Tyski river. Platform was executed from the embankment material and thanks to the proper organization of works, anticipating moving the piling machine over previously executed gravel columns, the platform was not damaged. Thanks to that it could be included as a part of the construction of the future embankment. Gravel columns of approximately 1 meter in diameter were carried out at spacings of 2,1 × 1,7 meter [6].

3.3. Time simulation of analysed solutions

In order to carry out a comparison analysis between the solution presented, time simulation in Microsoft Project Software was performed. The time simulations considered all necessary activities in both ground improvement methods. Labor consumption according to KNR (Catalogues Imputations of Matters) were considered as a standard model, which was also used during the economic study. This approach to the problem establishes reference elements for both cases.

Time simulation for ground replacement by dredging was carried out taking works included in design documentation and additional works, necessary for finalizing the task into consideration. Actions were sorted into four groups: The execution of a hermetical wall with a working platform for machines, sets of depression wells, excavation with transport and utilization of the material and filling the trench by dredging with transport of embankment material. The time line for this task is presented at the Fig. 1.

The analogical analysis was prepared for alternative solution in the form of ground improvement using gravel columns. In this case the following groups of tasks were specified: preparing working platform for piling machines with preliminary lowering the level of the terrain to the designed level, execution of canals to make surface drainage possible, forming gravel columns and making an embankment from the level of gravel columns to designed level. Fig. 2 presents the time line for described solution.

Based on the prepared models, the time necessary to complete all tasks connected with replacing the ground by dredging is 57 labor days, and for improvement the ground by gravel columns is 43 labor days. In both cases 12 hours labor day was considered.

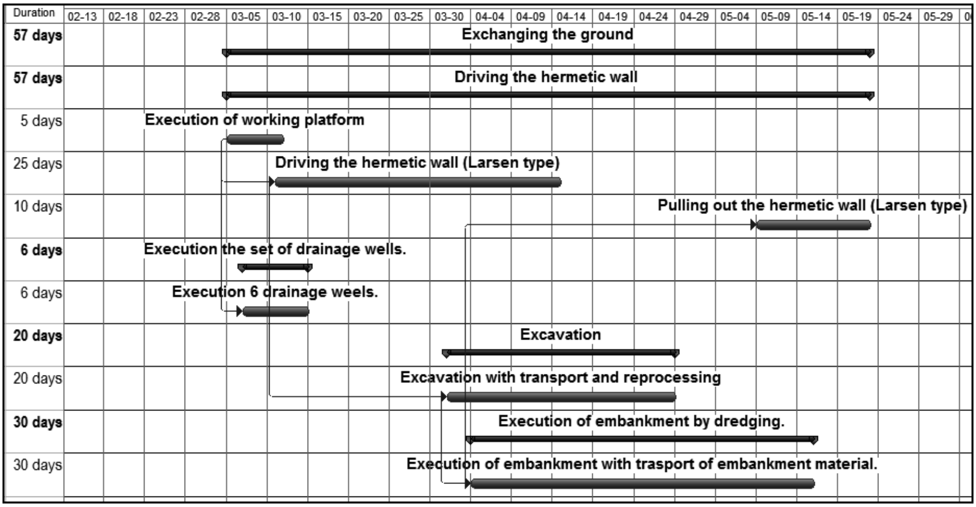

Fig. 1. Time line for exchanging the ground by dredging

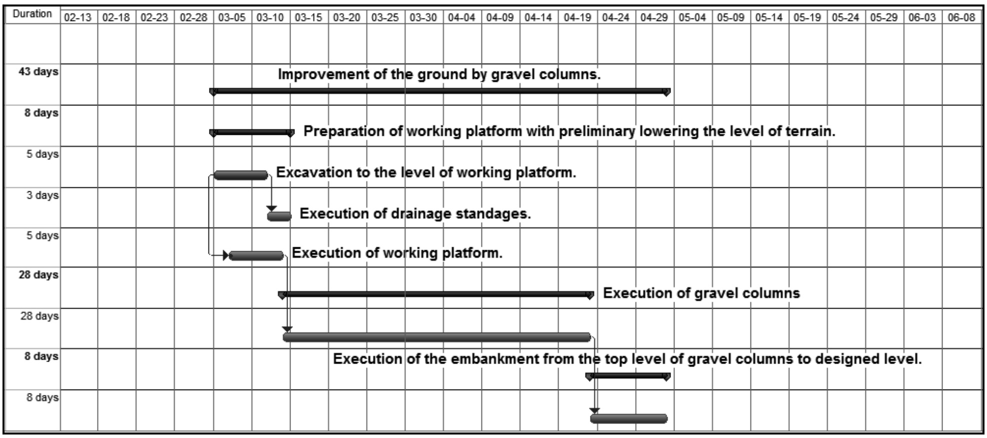

Fig. 2. Time line for improvement the ground by gravel columns

3.4. Cost analysis of described solutions.

For a comparison of economic aspects of the methods used to improve the ground under road the embankment, a cost estimation was carried out for both solutions. To show the level of the cost differences "Sekocenbud" bulletin for 4th quarter of 2013 was considered as a base for the cost estimation of works, including machine and material consumption. In both solutions a mid level of labor costs, renting the machines and buying the materials was considered. Calculation indexes of overheads were also considered as mid level for indirect costs and profit. This assumptions allows for a reliable comparison of solutions and demonstrate the percentage difference of costs. General cost estimations are shown in Table 1.

Table 1

General positions of cost estimation for analyzed solutions

Description	Value [PLN]
Ground replacement	
1. Driving the hermetic wall (Larsen type)	458537,09
2. Execution the set of drainage wells.	38066,40
3. Excavation with transport and utilization of soil material.	327724,90
4. Execution of road embankment.	1097475,44
Total value	**1921803,83**
Improvement of the ground by execution gravel columns.	
1. Preparation the working platform with preliminary lowering the level of terrain.	131489,99
2. Forming gravel columns.	193052,31
3. Building road embankment to designed level.	272164,98
Total value	**596707,29**

3.5. Conclusions

Considering the results of analysis presented in this article, the advantages of suggested alternative solution are easy to observe. Regarding the time consumption aspects and value of required work, soil strengthening by forming gravel columns is a more preferable technique. It is also worth noting that time analysis was carried out on the basis of premeasurements, which in the case of large volume ground works can be inaccurate, considering this fact using gravel columns is a safer solution regarding promptness.

Further analysis of results show the necessity of executing additional works in soil replacement method improves the cost of the project about 135% in comparison to the cost of dredging without extra works. Due to the works mentioned, operation completion time is almost double.

Another observation from result analysis is that even when additional works were not necessary, ground replacement method would still work out to be a more expensive solution.

4. Conclusions

Wide spectrum of available technologies for placing building on soft soils allows for the designing and execution of objects in almost any terrain conditions. Based on the investment project described in this article, it can be observed, that designers willingly choose traditional, checked solutions, however, when compared with new methods available on the market, these are proving not to be economically viable. Confirmation of this can be seen is the results of the time and cost analysis performed in this article.

References

[1] Pisarczyk S., Grabowski Z., Obrycki M., *Fundamentowanie*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2005.

[2] Dojcz P., Łęcki P., *Problematyka oraz sposoby stabilizacji i wzmacniania gruntów budowlanych*, ITB, 2008.

[3] Pająk M., *Podstawowe zagadnienia fundamentowania budowli*, Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków 2006.

[4] Pisarczyk S., *Geoinżynieria, Metody modyfikacji podłoża gruntowego*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2005.

[5] ViaCon Polska Sp. z o.o., „Projekt wykonawczy. Wzmocnienie podłoża nasypu dróg wokół parkingu wielopoziomowgo dla węzła przesiadkowego Tychy Głowne," ViaCon, Tychy 2013.

[6] Przedsiębiorstwo Wiertniczo-Geologiczne Tychy, „Dokumentacja geologiczno-inżynierska dla terenu przeznaczonego pod budowę parkingu wielopoziomowgo dla węzła przesiadkowego Tychy Główne w rejonie ulic Andersa i Asnyka w Tychach," PWG, Tychy 2012.