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PILE FOUNDATIONS OF MEGA PROJECTS: NEW RAILWAY STATION AND LRT IN PROBLEMATICAL SOIL GROUND OF ASTANA

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Abstract

The article considers the project a new railway station on problematical soils of Astana, as well as light rail LRT Project.
This article includes a summary of dynamic and static tests of driven and bored piles. Also, it is given the methodology for determining the bearing capacity of piles. As an example of these methods, the results of the dynamic, static and new PDA (Pile Dynamic Analyzer) test of teamwork and piles of soil carried out on the construction site "The new railway station in Astana" and Project light railway LRT (Light Railway Transport) planned to build in time for the World Expo in Astana EXPO-2017.
This paper presented a short description of changes to the concept of Kazakhstan pile foundation design and to use PDA and DLT and SLT pile load tests. By georadar survey was funded the areas which reported a hard rock at a depth of 16 meters and other soil layers.

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Keywords: bearing capacity, pile foundation, LRT, PDA, SLT, DLT;

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1. Introduction

At present time the pile foundations widely are used on problematic soil grounds, such as a problematic soil grounds in North Kazakhstan or Astana city. In this direction in our country the foreign investors used their techniques and technology in mega projects and constructions - New Railway Station, Expo-2017 site, high-rise multifunctional complex “Abu-Dhabi Plaza” and Project “Light Railways Transport” (LRT).

1.1. Project New Railway Station

The new dead-end station "Astana Passenger" has a capacity of 40 trains and 12000 passengers per day. The carriage rolling stock "Astana Passenger" station consist six dead-end tracks, a local VIP platform and three center platforms.

The building of the railway station is a six-story and in the plan dimensions of 630 x116 m. The South (right) part of the building intended for the departure of passengers, the northern (left) part of the building intended for the arrival of the passengers.

At the level +0.100 buildings are covered parking, including office and industrial facilities. Also in the pass space that links with each other parks can find shops, catering areas, the main green area. To communicate with the platform and concourse provided escalators, elevators and stairs. At the level +3.850 are car parks, technical and office facilities. On platforms (level +9.750) is the pavilion with escalators, elevators and stairs. Car access is provided to a center platform for the meeting of the official delegations. On the concourse (a level +19.600) is placed the main distributional room with sitting areas, service centers, offices and administrative offices of railway station. The station complex includes activities for people with limited mobility service (disabled persons). Railway station complex will be equipped with modern visual, acoustic and tactile information.

Today, on the railway station monolithic concrete constructions has been established; more than 150.000 m^3 of concrete has been laid. Around 26.000 tons of metal structures (88%) have been assembled. The glass mounted front system has been made installed for 15% (7200 m^2). Approximately 20% of the roof (11 000 m^2) has been already constructed.

The construction of railroad overpass to the railway station is underway, about 26.7 thousand m^3 (96%) concrete out of the total volume of 27.8 thousand m^3 has been filled, more than 24.0 thousand tons (92%) of metal structures has been installed.

Rails, concrete, metal, fittings, cement are used from domestic production. Mounted roof made by «VEMO» company from Germany, supporting parts under the railroad overpass - «MAGEVA» Switzerland.

For the convenience of passengers a new building will be equipped with energy-efficient elevators and escalators. The underground heat-exchangers will be installed; they will heat the station with the help of thermal springs. This technology will allow the room to warm in winter and cool in summer.

The project includes the construction of six receiving and departure tracks, the seventh path taking into account in the long-term expansion of the railway station.

For this project were used the bored piles of 1500 mm diameter and 8.60 m in length and driving piles 300x300 mm, 12.0 m in length are designed to install in water saturated argillite (clayed soil).

1.2. Project Light Railway Transport (LRT)

The Astana LRT Network approximately is planed of 22 km in length and will realize from two parts: (1) from the Astana Airport to the site known as the Expo 2017 site half way between the airport and Syganaq Street, and (2) from the Expo 2017 site continuing north up to Syganaq, then turning east towards the Abu Dhabi Plaza site on Syganaq Street, one block south of and parallel to Nurzhol Boulevard, the axis along which Astana’s major government buildings and monuments are located. It is planned to be the site of an iconic structure, possibly the highest structure in Central Asia (building of Abu-Dhabi Plaza). From there, it continues along Syganaq Street crossing over the River and continuing along Shamshi Qaldayaqov Street past its intersection with Tauelsizdik Avenue for 3 kilometers eastward. A Length of piles in the Project Area for LRT is 16 meters and more. Types of piles are driving and boring [1].

2. Geology and site characterization

The Middle–Late Paleozoic pattern of Kazakhstan is dominated by strongly curved magmatic arcs, which unconformably overlie older structures. The external belt comprises volcano-sedimentary Silurian rocks and a thick Lower–Middle Devonian terrestrial volcanic pile. The Late Devonian–Early Carboniferous volcanics overlie the Silurian and Early Devonian flysch series. The composition of the volcanic series strongly varies from basalt to andesite, dacite and then to rhyolite. Since the Silurien and until the Late Early Permian, the volcanics are calcalkalin affinity and considered to be related a shrinkage of ocean basin that was located in the present day interior of the arcs. Several deformation events affected these belts, but the volcanic are not so strongly deformed.

According to performed boreholes, rock units are encountered at varying depths between 9.0 m and 13.0 m depths. Above the rock units sandy/gravelly/silty clay, silty/gravelly/clayey sand and sandy gravel units are encountered. Sandy/gravelly/silty clay units are brown, moist, coarse-fine grained sandy, fine to coarse grained, angular gravelly, low-high plasticity, stiff to hard. Gravelly/clayey sand units are brown, moist, fine to coarse grained, angular gravelly, clayey, medium to coarse grained loose to dense. Sandy gravel units are brown, wet-moist, coarse grained sandy, fine grained, angular, and dense. According to seismic risk distribution map, peak ground acceleration a_{max} should be taken a value between 0 m/s^2- 0.2 m/s^2 which is equal to 0.02g therefore could be ignored in structural design.

A Figure 1 are introduced a map of the potentially affected area, which presented by the area geology and a locations of required pile lengths of LRT's construction (from the Abu Dhabi Plaza to New Railway Station).

At the construction a new railways station all experiments were performed with CPT (cone penetration test). Soil testing at each point of penetration came to the end to the limit forces in accordance with GOST 19912-2001 [2].

The bearing capacity of driving piles 30x30 cm on the CPT results are recommended at the depth of 3.0 m bearing capacity 184-754 kN; at the depth of 4.0 m bearing capacity 291-789 kN; at the depth of 5.0 m bearing capacity 321-814 kN; at the depth of 6.0 m bearing capacity 445-972 kN; at the depth of 7.0 m bearing capacity 568-802 kN; at the depth of 8.0 m bearing capacity 574 kN; at the depth of 9.0 m bearing capacity 565 kN; at the depth of 10.0 m bearing capacity 712 kN; at the depth of 11.0 m bearing capacity 840 kN; at the depth of 12.0 m bearing capacity 868 kN. The bearing capacity of piles is given without the safety factor, which is equal to 1.25.

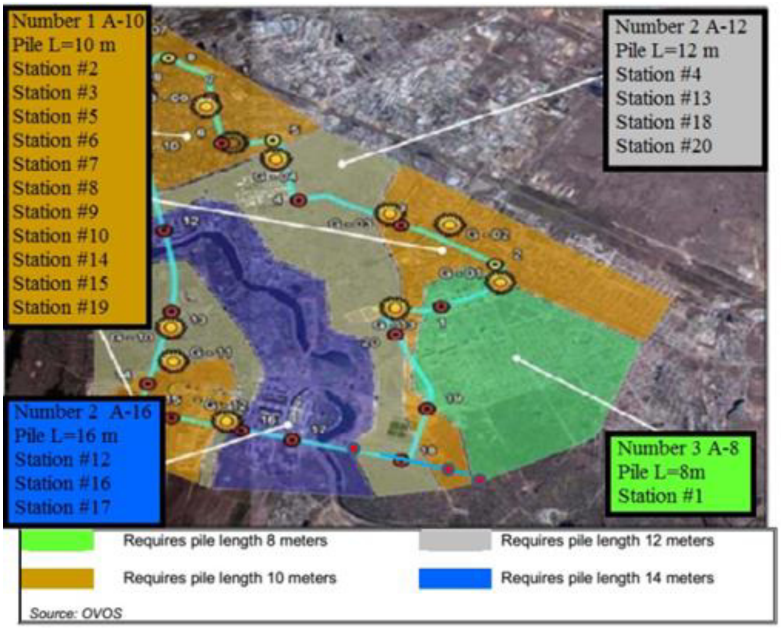

Fig. 1. A Plan of required pile depth on ground conditions for Project of LRT.

Ground characterization was performed by the geophysical methods (Geoelectrical, Induced Polarization, Electromagnetic Induction, Georadar).

The Figures 2 and 3 show the typical soil profile by georadar survey in railway construction site.

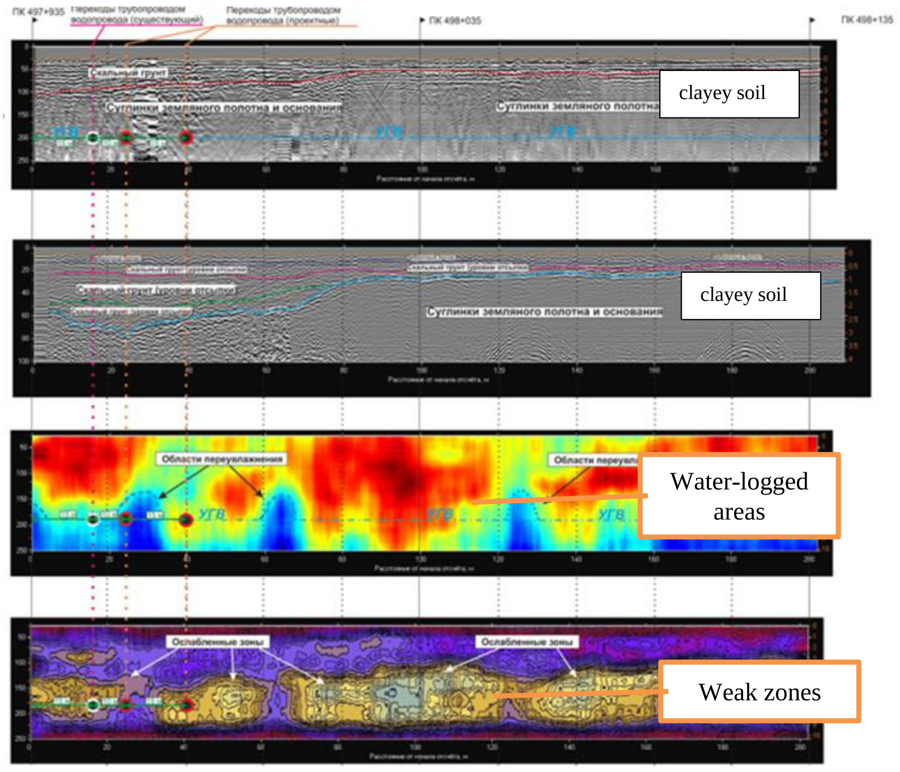

Fig. 2. Results of georadar by 2D.

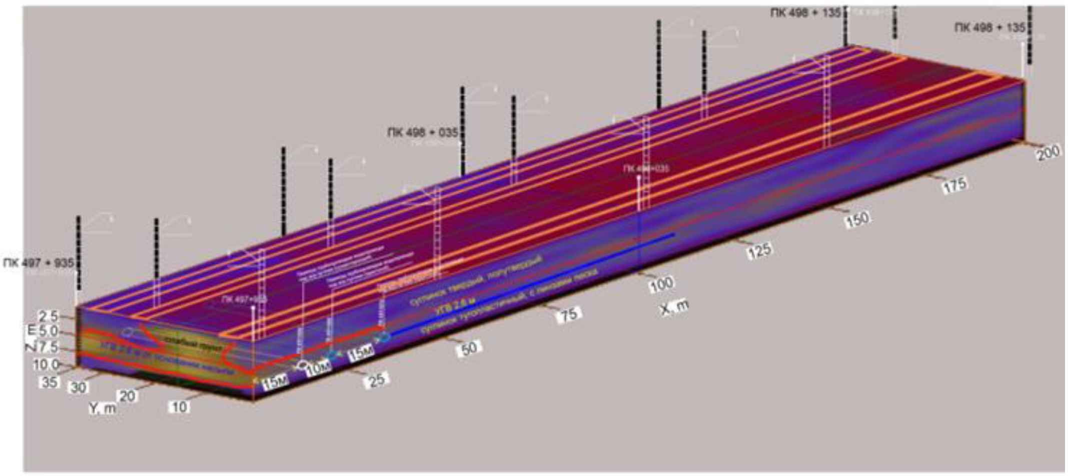

Fig. 3. Results of georadar by 3D.

3. Methodologies of the Pile Field Tests

3.1. Static load test (top down) bored pile

Layout and design considerations of the bored piles of 1500 mm diameter and about 8.60 m deep piles are designed to install in an argillite. Bottom level of the bored pile excavation is 344.24 m and depth of the excavation is 8.94 m. Pile load test was performed for 1500 mm diameter bored pile [3].

Static tests were conducted in accordance with the requirements of GOST 5686-94 “Soils. Methods of the field tests by piles” [4].

Static Load for bored pile was applied by two hydraulic jacks each having capacity of 500 ton which bears on anchor stand. Reaction strain was received by four anchoring bored piles (see Figure 4).

Fig. 4. Static Load Test of bored piles in construction site New Railway Station, Astana.

Pile was tested by static and step-by-step increased load, that every step was 560 kN and enhanced to 5600 kN. The maximum load applied on the pile was equal to 5600 kN and the corresponding settlement of the pile top was 3.15 mm (see Figure 5).

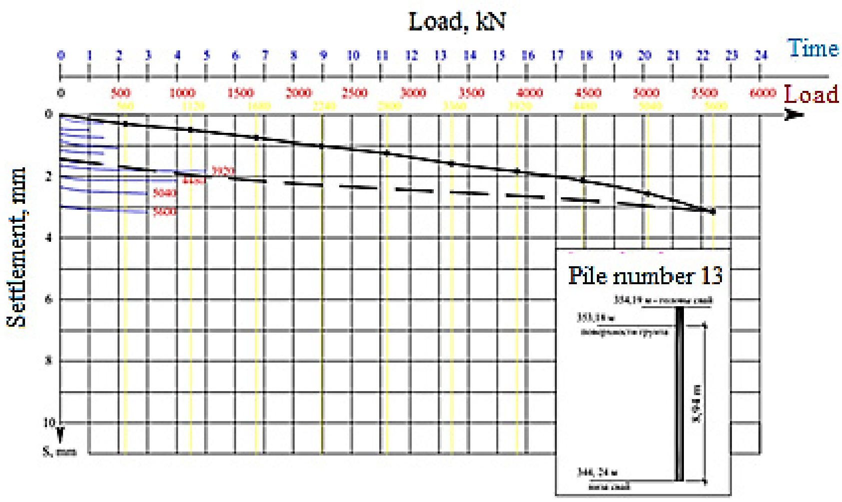

Fig. 5. Comparisons of SLT load-settlement diagrams.

3.2. Dynamic load test by using of driving hammer

Dynamic Load Test is a fast bearing capacity analysis field test and gives more or less reliable value of pile bearing capacity. For definition of the bearing capacities of piles, it is required to use average refusal which are obtained during red riving of the piles after their «rest» [4].

All the reinforced concrete piles having a width b=0.3 m, area cross-section A=0.09 m^2, length L=12 m, weight=2730 kg, modulus of elasticity E_p = 27500 MPa, and density ρ_p = 2500 kg/m^3.

In Kazakhstan, DLT is carried out by using different types of pile driving machines and hammers. Before starting the test, pile surface alone the whole length had been painted through each one meter by marks; last one meter is painted through each 0.1 m [5, 6].

For our project pile driving was performed by using the driving machine “Junttan PM-25” with hydraulic hammer HHK-7A. The weight of the hummer is 7000 kg and the headband weight is 990 kg.

Allowable bearing capacity of the piles with an allowance for safety factor (FS = 1.4) equals to 540 kN [7, 8].

3.3. Dynamic Load Testing of Pile Dynamic Analyzer

Dynamic load testing using Pile Driving Analyser (PDA) equipment is a high-strain non-destructive load test method which can be performed during or after pile installation using conventional pile driving equipment.

Dynamic tests were conducted in accordance with the requirements of ASTM D4945-12. 2012. “Standard Test Method for High-Strain Dynamic Testing of Deep Foundations” [9].

Figure 5 presents the monitoring results of PDA test showing pile dynamic compression and tension stresses, static pile capacity and blow counts versus pile penetration depth. CAPWAP is an iterative curve-fitting technique where the pile response determined in a wave equation model is matched to the measured response of the actual pile for a single hammer blow. The pile model consists of a series of continuous segments and the total resistance of the embedded portion of the pile is represented by a series of springs (static resistance) and dashpots (dynamic resistance). Static resistance is formulated from an idealized elastoplastic soil model, where the quake parameter defines the displacement at which the soil changes from elastic to plastic behaviour. The dynamic resistance is formulated using a viscous damping model that is a function of a damping parameter and the velocity [5, 6, 7].

Load-settlement diagrams of dynamic load testing of Pile Driving Analysis shown in Figure 6. Allowable bearing capacity of the piles with an allowance for safety factor (FS = 1.4) equal to 714 kN.

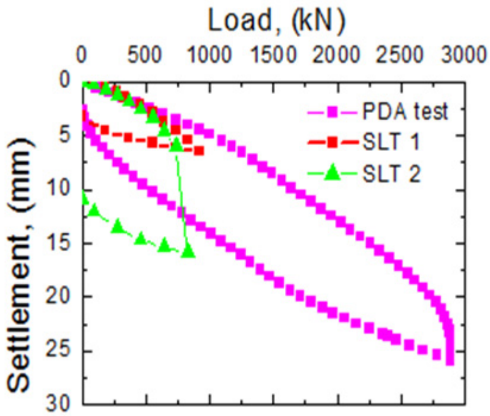

Fig. 6. Results of load-settlement diagrams of Static and Dynamic Load Test (Method PDA).

3.4. Static Load Test in Railway Station Astana (driving piles)

Static tests were conducted in accordance with the requirements of GOST 5686-94 “Soils. Methods of the field tests by piles” [4].

Loading of the tested pile is made uniformly, without shocks, loading steps which value is set by the test program, but is accepted no more than 1/10 the greatest load, given in the program. When burying the lower ends of full-scale piles in coarse elastic rock, gravel and packed sands, and also clay soil of a solid consistence it is allowed to accept the first three steps of loading equal 1/5 greatest loadings.

At each step of loading of a production pile take readings on all instruments for measurement of deformations in the following sequence: zero reading - before loading of a pile, the first counting - right after application of loading, then sequentially four counting with an interval of 30 min and further in each hour before the conditional stabilizing of deformation (relocation attenuation).

For criterion of the conditional stabilizing of deformation in case of test take the speed of settling of a pile at this step of loading which isn't exceeding 0.1 mm:

-in the last 60 min observations if under the lower end of a pile sandy soil or clay soil from solid to low-plastic consistence;

-in the last 2 hours of observations if under the lower end of a pile clay soil from high-plastic to free-flowing consistence.

Load test of production pile should be brought to the value at which the total settlement of the pile is not less than 40 mm. When the penetration of the lower ends of the in-situ piles in coarse elastic rock, packed sand and clay soils which have a solid consistency, the load should be increased to the values provided by the test program, but not less than half the value of the bearing capacity of piles determined by calculation, or calculated resistance of the pile in the material.

During the control testing of piles during construction the maximum load should not exceed the design resistance of the pile in the material.

Unloading piles of produce after reaching the maximum load steps equal to double the value of speed of loading, with each stage of exposure of at least 15 min.

After the complete unloading (to the zero) of watching the resilient moving of pile it is necessary to conduct during 30 minutes at sandy soils bedding under the lower end of pile, and 60 minutes at clay soils, with the removal of counting out through each 15 min.

A safety factor of SLT is 1.2 regarding of Kazakhstan Standard. Therefore the design value of the allowable piles capacity, Q_d, was estimated to be Q_d = 920/1.2 = 767 kN (SLT 1) and 825/1.2 = 687.5 kN (SLT 2).

According to SLT result the load-settlement diagrams were drawing and compared with PDA results (Figure 5).

Conclusions

Existing pile foundation standards practiced in Kazakhstan are out-of-date and are in urgent need for modernization. This paper presented short descriptions of coming changes to the concept of Kazakhstan pile foundation design.

PDA and DLT are more economical issues than SLT. PDA dynamic test shown more confirm to SLT result than traditional DLT test.

Four geological compartments are indicated. Within the green, grey and brown areas the absence of hard rock has been assumed and it is assumed that a layer of gravel at a depth of 12.8 meters will be thick enough to provide sufficient bearing capacity for the LRT piles.

Areas shown in blue are reported to provide hard rock at a depth of 16 meters that will be sufficient to support the piles.

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