The Results of Dynamic (Pile Driving Analysis) and Traditional Static Piling Tests in Capital of Kazakhstan

Askar Zhussupbekov¹, Rauan Lukpanov², Abdulla Omarov³

Department of Civil Engineering, Eurasian National University, Astana, Kazakhstan

E-mails: ¹astana-geostroi@mail.ru (corresponding author); ²rauan_82@mail.ru; ³omarov_01@bk.ru

Abstract. Traditionally, pile load tests in Kazakhstan are carried out using static and dynamic load test methods. Static pile load test is the most reliable method to obtain the load-settlement relation of piles. Most of the static pile load tests are performed using reaction systems. Furthermore, cost and time for the static pile load test are relatively high compared to the dynamic pile load testing. Therefore, the number of pile load tests in construction site is limited to 2 or 5 piles in usual of constructed piles in Kazakhstan.

This paper includes the short summary about dynamic and static tests by driven piles (cross-section 30×30 cm and length of 12 m). The methodologies of definition bearing capacity of the pile by aforementioned methods were also given. As an example for those methods, paper describes the results of the dynamic, traditional static and the new PDA (Pile Dynamic Analyzer) tests of cooperative work of soils and piles performed in the construction site of the New Railway Station in Astana. According to the results of tests were determined the possible depth of penetration and bearing capacity of piles, as well as recommendations on the device of working. The construction is part of the preparations for EXPO 2017. It will be 11 times bigger than the existing railway station. The height of the six-floor complex will be 49.5 metres, the width 116 metres and the length 630 metres.

Keywords: foundation pile, static and dynamic vertical load tests, load-displacement curve, PDA test.

Conference topic: Design experiences and theoretical solutions.

Introduction

The existing railway station provides services to more than 7,000 passengers per day and the capacity of the New Railway Station in Astana will be up from 12,000 to 35,000 passengers per day (see Fig. 1). The main railway gates of the capital will provide bandwidth for all its adjacent directions.

The construction is going to be finished before the international exhibition EXPO-2017 to be held in Astana in summer. The railway station will be built using green technologies, for example, it will have energy-saving lifts and escalators, heat exchangers as well as solar batteries and geothermal power generators, which is very relevant given the fact that the theme of the upcoming EXPO-2017 in Astana is Future Energy. This technology will heat the complex in winter and cool it during summer.

The building presented by reinforced concrete structures. Totally building area is 84000 m².

A metal-covered railway platform with a length of 2,550 meters is being constructed because the trains will arrive directly into the building. So far, 87 poles and 17,300 tons or 69 percent of the total metal spans have been installed, are also see in Figure 2.

Field tests carried out in accordance with requirements GOST 5686-94, 1994 and definitions of bearing capacity of the piles in accordance with requirements of SNIP RK 5.01-03-2002, 2002 and ASTM D4945-12, 2012.

Fig. 1. Railway station a) Cross section of station
b) Master plan of station

Soil profile, results of soil tests and CPT

Figure 3 shows the results of the oedometer tests, axial stress σ_a versus axial strain ϵ_a . The one-dimensional deformation modulus, $E_c = \Delta\sigma_a / \Delta\epsilon_a$, was estimated from the stress range from 0.1 to 0.3 MPa.

The results of CPTs, the cone tip resistance (q_c), and the sleeve friction (f_s) are also indicated in the Figure 4.

Fig. 2. Railway station and railway platforms

Fig. 3. Results of oedometer tests

Carrying capacity and length of piles needed to be clarified for field testing piles. All experiments were performed with CPT surface. Soil test at each point of penetration came to an ends when the limit forces on the probe in accordance with GOST 19912-2001 (2001). The bearing capacity of the pile cross-section 30×30 cm on the results of CPT (see Table 1).

The bearing capacity of piles is given without regard to the safety factor for the ground, which is equal to 1.25.

Plate Load Test

Plate Load Test is a field test for determining the ultimate bearing capacity of soil and the likely settlement under a given load.

Table 1. Results of cone penetration test (CPT)

Number CPT	Number of wells	The bearing capacity of piles F_d (kN) at a depth H (m)
		12
15	309-14	868

Fig. 4. Results of CPT 1

The Plate Load Test basically consists of loading a steel plate placed at the foundation level and recording the settlements corresponding to each load increment.

The test load is gradually increased till the plate starts to sink at a rapid rate. The total value of load on the plate in such a stage divided by the area of the steel plate gives the value of the ultimate bearing capacity of soil.

The ultimate bearing capacity of soil is divided by suitable factor of safety to arrive at the value of safe bearing capacity of soil.

Field tests carried out in accordance with requirement GOST 20276-99, 1999.

Totally two tests (one test in Plate Load Test 1 (further PLT-1 and second test in Plate Load Test 2 (further PLT-2) a depth of 12 m) had been made. Diameter of the plate $D = 276.4$ mm and area $A = 600$ mm².

The load intensity and settlement observation of the plate load test are plotted. The figure shown below shows a set of typical load settlement curves.

Figure 5 shows the result the pressure-settlement diagrams of PLT tests of PLT-1 and PLT-2.

Modulus deformation of soils in PLT-1 – 20 MPa and PLT-2 – 22 MPa, at a depth of 12 m.

Fig. 5. Load – settlement diagram from PLT results

Methodologies of the piled field tests

Dynamic Load Test (DLT)

Dynamic Load Test (further DLT) 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 redriving of the piles after their “rest”. The rest time depend on soil condition of site: for clayey soil 6–10 days, for sandy and gravel soils up to 3 days (Zhussupbekov *et al.* 2015).

All the reinforced concrete piles having a width $b = 0.3$ m, area cross-section $A = 0.09$ m², length $L = 12$ m, weight – 2730 kg, modulus of elasticity $E_p = 27500$ MPa, and density $\rho_p = 2500$ kg/m³.

In Kazakhstan, DLT is carried out by using different types of pile driving machines and hammers. Before starting the test, pile surface along the whole length had been painted through each 1 meter by marks; last one meter is painted through each 0.1 meters.

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

During the pile driving process the number of blows of the each 1 meter of pile penetration into the soil ground and of the last one meter in each 0.1 meter were counted. The falling heights of blowing part of the hammer were recorded at the same time. Pile driving was continuing till the design refusals – 0.5 cm (cm/blow).

The highest average refusal received during the re-driving of piles after their “rest”. These values of refusals had been used for determination of bearing capacity of piles. According to SNIP RK 5.01-03-2002, 2002, the rest time for the piles immersed into clayey soils should be 6 days.

Re-driving of test piles was carried out sequentially by three and five hammer blows. The strain gauges with the length of 10 cm were attached on top of the piles before starting re-driving. Strain gauges had been fixed on 60 cm from the pile head.

It is common practice to use the following driving equation to estimate the driving resistance (ultimate pile capacity), F_u , in Kazakhstan (GOST 20276 2009):

$$F_u = \frac{\eta AM}{2} \left[\sqrt{1 + \frac{4Ed(m_1 + \varepsilon^2(m_2 + m_3))}{\eta AS(m_1 + m_2 + m_3)}} - 1 \right], \quad (1)$$

where: η – coefficient dependent on the concrete strength of the piles 1500 kPa; A – cross sectional area of pile; M – coefficient (1.0 for hammer impact); Ed – potential energy of hammer – WH-hammer weight; H – fall height of hammer; $h = 0.7$, S-set per blow; ε -coefficient of restitution; m_1 – total mass of hammer device; m_2 – total mass of pile and pile cap, and m_3 – mass placed between pile head and pile cap.

Allowable bearing capacity of the piles with an allowance for safety factor ($FS = 1.4$) equal to 540 kN.

Pile Dynamic Analyzer (PDA)

Today, in process of adaption into Kazakhstan practice is an alternative load test method which precluded disadvantages of both SLT and DLT -Pile Driving Analysis (further PDA) (see Fig. 6) – allow performing up to 10 piles per day and much cost effective than SLT.

Fig. 6. Photo and schema of dynamic load testing

Figure 7 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 analysis results that include plots of measured pile head data obtained under the hammer blows from the end of driving and associated simulated pile head and toe static load-movement relationships are presented in the Figure 10.

Allowable bearing capacity of the piles with an allowance for safety factor ($FS = 1.4$) equal to 714 kN.

Fig. 7. Load-settlement diagrams for the determination of bearing capacity of the piles in PDA

Results of Static Load Tests (SLT)

Static Load Test (further SLT) one of the more reliable field tests in analyzing pile bearing capacity. SLT should be carried out for driving piles after the “rest”.

SLTs carried out for two piles on the construction site (see Fig. 8). The measured relationships between the pile head load, L , and the head displacement, S , of the test piles are shown in Figure 9.

It is seen from Figure 9 that the load-displacement curves of piles No. 3 and No. 24 are almost identical, having an ultimate shaft capacity of 920 kN (No. 3) and 825kN (No. 24).

Table 2. Different tests

No	Name of methods	Safety Factor	The value of the bearing capacity of piles, Qd (kN)	Conditional criteria of comparison, %
1	Pile Driving Analysis	1.4	714.3	100
2	Dynamic Load Test	1.4	540	75.6
3	Static Load Test 1 (pile No. 3)	1.2	767	107.4
4	Static Load Test 2 (pile No. 24)	1.2	687.5	96.2
5	CPT (No. 15)	1.25	694.4	97.2

Standard – SNIP RK 5.01-03-2002 – ultimate value of settlement of the tested pile is determined as and depending on category of construction is equal to 16 or 24 mm. The last argument shows conditional character of SLT method.

Fig. 8. Photo of static load testing in construction site New Railway station

According to Kazakhstan Standard 1% of constructed piles on construction site must be tested by SLT, but at least 2 SLTs in a site must be done.

In Kazakhstan, a safety factor of SLT is 1.2. Therefore, the design value of the allowable piles capacity, Q_d , was estimated to be $Q_d = 920/1.2 = 767$ kN (pile No. 3) and $825/1.2 = 687.5$ kN (pile No. 24).

According to SLT result, the load-settlement diagrams were drawing (see Fig. 9) and compared with PDA results (see Fig. 10).

Fig. 9. Load-settlement diagram from SLT results

Fig. 10. Comparisons of SLT and PDA load-settlement diagrams

Table 2 presents a comparative analysis of the bearing capacity of piles, obtained by different methods in this research (Zhussupbekov, Omarov 2016).

Conclusions

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

According to the results of DLT of driven piles (30×30 cm and length of 12 m) the bearing capacity of the piles amounted to be 540 kN. The bearing capacity of driven piles according to the results of SLT1 and SLT2 amounted to be 767kN and 687.5 kN.

According to the results of PDA bearing capacity of the piles are equal to 714.3 kN. PDA and DLT are more economical issues than SLT. PDA dynamic test shown more coincide with SLT result than traditional DLT test.

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