Foundation Works for Aktau Port

I. Rasin Duzceer

Kasktas Piling, Drilling Co., Istanbul, Turkey

Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

FOUNDATION WORKS FOR AKTAU PORT

I. Rasin Duzceer
Kasktas Piling, Drilling Co.,
Istanbul, Turkey

ABSTRACT:

The purpose of this paper is to review the design, installation and performance of steel tubular piles and steel sheet piles in the Port of Aktau, Kazakhstan. Due to steady increase in the level of Caspian Sea since 1977, the level of the existing quay was increased. The works consisted of rehabilitation of quay frontage including general raising of the port working areas by about 2 meters. The subsoil consists of 5 m medium dense to dense fine sand underlain by 6 m thick very stiff silty clay. Fractured limestone were encountered at a depth of 14 m. A total 592 vertical and raked piles of 660 mm diameter and 106 piles of 865 mm diameter were installed under the new quay. Two compression and one tension load tests were carried out on 660 mm piles to verify the design criteria and installation procedure. At a distance of 3,50 m from the existing quay wall a new sheet pile wall was formed by driving Larssen type sheet piles.

INTRODUCTION

The Port of Aktau is located on the Eastern Side of the Caspian Sea, in the Republic of Kazakhstan (Figure 1). The port was originally constructed in 1963 to serve the development of the local oil fields, the population of Aktau and its surrounding region, and the development of other local mineral resources and industries. The port was constructed at a time when the water level in the Caspian Sea was low in relation to its long term average sea level. The minimum sea level since the 1930's has been –29.03 absolute (in relation to Baltic Sea Level). However, since 1977 the level of the Caspian Sea has risen steadily until the current level of about –27 a rise of about 2 meters. The rise in the sea level affected the normal operation of the port. Quay heights were below efficient working levels and utilities were flooded.

In 1996 Aktau Port handled 275 000 t of dry cargo, 100 000 t of crude oil. Upon completion of rehabilitation project, it is claimed to increase the port's capability, for dry cargo handling up to 1 550 000 t, and 8 000 000 t crude oil a year. Within the project it was planned to upgrade the equipment, reconstruct the berth for dry cargo and the causeway so that any rise in the sea level would not affect the normal operation of the port. The works consisted of rehabilitation of much of the quay frontage including general raising of the port working areas by about 2 meters. The foundation works were started in November 1997 and completed 1999 in parallel to civil works. Foundation and civil works have been performed in four different phases to allow an uninterrupted services of port facilities.

SUBSOIL CONDITIONS

Geology:

The geological and lithologic section of the territory is composed of Quaternary strata and Tertiary aged carbonate formations. Lithologically, the quarternary strata are composed of sand and clays. Limestone-clay marl is widely spread among the sediments of this complex. They are represented by dark grey, yellowish color. The limestone layer becomes fissured and weathered. It belongs to the category of weak rocks.

Site Investigation and Testing

A total of 12 boreholes were carried out with regular SPT's to a maximum depth of 30 meters below existing quay level. The investigation included determination of the subsurface soil conditions and engineering properties of soil and rock layers.

A general soil profile is given in Figure 2. Yellow to beige color fine to medium sand has been placed over the quay area ranging in depth from 4.70 to 7.0 meters. The sand is medium dense to dense with SPT blow counts in the range of N= 7 – 60. A layer of silty, fissured yellowish-greenish gray color clay is present below sand and extends to bedrock 14.5 – 15.0 m below ground surface. Clay layer attain very stiff consistency with SPT blow counts in the range of N= 12 – 60.

Fig 1. Site Location

Limestone, consisted of cemented carboned shells and shell fragments is encountered below clay layer. The rock quality designation (RQD) values vary between 0 – 74. Uniaxial compressive strength of limestone were determined as q_u= 3.59 – 38.3 MPa. Based on the RQD values limestone may be classified as very poor rock. Based on q_u values this layer may be classified as moderately strong. Geotechnical properties of soil layers and base rock are summarized in Table 1.

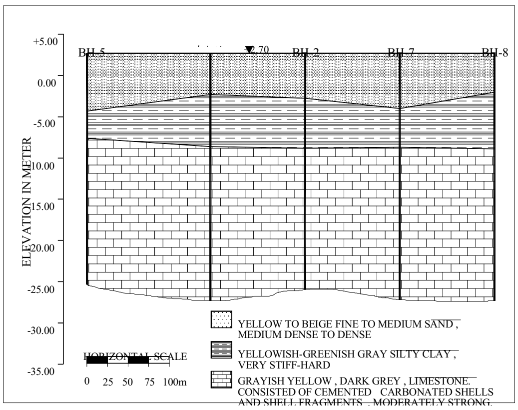

Fig 2. Generalized Soil Profile

Seismicity

As far as the seismic characteristics of the North-Eastern part of the Caspian Sea and the adjoining territories located to the North of Turkmeno-Precaucus abyssal fault, the region is relatively stable. Based on the data recorded by regional seismic stations of the former USSR and historic data there is no information about seismic activities of this area.

Table 1. Summary of Soil Properties

	Soil Classific (USC)	Unit Weight γ_n (kN/m^3)	Water Content w_n (%)	Uncon. Compress Strength q_u (Mpa)	SPT Blow Count (N_{ave})	RQD (%)
SAND	SP-GP	19	--	--	25	--
CLAY	CH	18	29-65	0.3	20	--
LIMESTONE		22	1.3-1.9	24	--	15

DESCRIPTION OF THE PROJECT

The works consisted of rehabilitation of quay frontage including general raising of the port working areas by about 2 meters. The total usable quay length of approximately 600 meters was provided upon completion of additional works. A total 592 vertical and raked piles of 660 mm diameter and 106 piles of 865 mm diameter with a rake of ¼ were installed under the quay wall. The details of the installed piles are given in Table 2. At a distance of 3.50 meter from the existing quay wall a new sheet pile wall was formed by driving Larssen type sheet piles. Sheet piles were penetrated 6 m to the ground. Typical section of the quay is given in Figure 3.

PILE DESIGN

Material

New quay piles were designed to carry the specified service loads with a minimum factor of safety of 2. Grade 43A (f_y= 275 MPa) spirally welded steel tubes complying with BS 4360 were used. The piles were designed for a service life of 50 years. Pile characteristics are summarized in Table 2.

Table 2. Pile Characteristics

Pile Dia. (mm)	Wall Thickness (mm)	Rake	Ave. Length (m)	Safe Working Load (kN)	
				Compres.	Tension
660.4	12.5	1/3	14.50	1700	750
863.6	12.5	¼	14.30	2300	0
660.4	12.5	1/8	14.35	1800	0
660.4	12.5	Vertical	14.40	1700	0

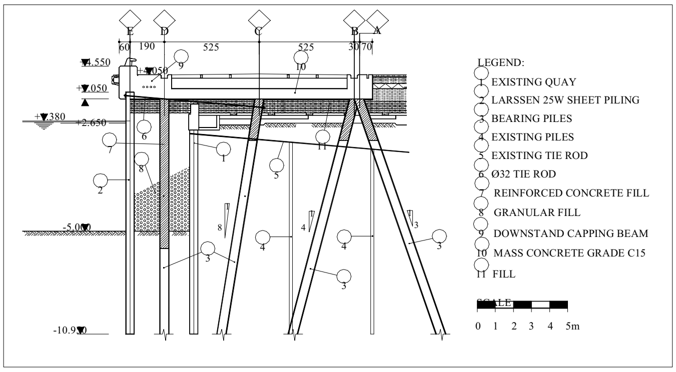

Fig 3. Typical Section of the Quay

<u>Bearing Capacity</u>

The ultimate load of open ended steel tubular piles were calculated using FHWA (Federal Highway), COE (Corps of Engineers), Lambda and API (American Petroleum Institute) methods. Pile capacities are summarized in Table 3.

Table 3. Pile Capacities

Pile Dia. (mm)	ULTIMATE LOAD (kN)					Safe Working Load (kN)
	FHWA	COE	LAMBDA	API	AVERAGE	
660.4	4113	3831	3277	3344	3642	1820
863.6	6501	5001	4175	4260	4985	2942

<u>Structural Capacity</u>

Piles were designed by the working stress method. Allowable working stresses for steel H and pipe piles specified in some representative codes and standards are summarized in Table 4.

For steels with a yield stress of 275 MPa, values of the nominal factor ranging from 2.0 to 3.0 are indicated by the allowable stress varies from 85 MPa to 140 MPa.

<u>Driveability</u>

Piles are subjected to stresses during installation that could be considerably higher than those resulting from service loads acting on the pile.

Davisson suggests that the maximum steel stress level of about 83 MPa for average driving conditions is reasonable. Dismuke contends that current experience with the steel pile stress level of 0.50 f_y is considered to be sufficient for inclusion as an allowable stress (Fuller, 1979).

Section 7.4.6.3. of BS 8004 (1986) states that "When the design safety factor on driving resistance is 2 the maximum working stress should normally be limited to 30% of the yield stress. However, when piles are driven through fairly soft soils to refusal on a sound rock stratum at a known level, then the maximum working stress can be increased to approximately 50% of yield stress".
In this project maximum steel stress level of about f_a= 83 MPa (30% of the yield stress) for average driving conditions was considered reasonable and appropriate.

Two different load cases are considered in the structural design of piles:

- Driving stress check for the uncorroded pile section.
- Working stress check under service loads when the pile is at the end of its design life and suffered maximum design corrosion.

<u>Durability</u>

Deterioration of pile material for a design life of 50 years leads to reduction in pile cross section. Corrosion of steel piles driven into undisturbed soils is negligible irrespective of soil type and characteristics. The corrosion rates of piles which are driven in soil either above or below water table vary within the range of 0.015 to 0.03 mm / side / year [BS 8004 1986, Pilling Handbook 1997, Tech. Stand, 1991].

For the purposes of calculations a maximum corrosion rate of 0.015 mm / side / year was used. For a design life of 50 years, protection of the piles against corrosion were accomplished by increasing wall thickness by 1.5 mm (0,015 mm / side / year x 2 x 50 years).

PILE INSTALLATION

The project at the Port of Aktau involved driving open ended steel pipe piles. Grade 43A spirally welded steel tubes complying with BS 4360 and BS 3601 were supplied to site in 12 m lengths. Piles were driven with a Delmag D-36 single acting diesel hammer mounted to Link Belt LS 118 crawler crane. Pile driving was continued until either driving resistance criteria or the desired tip elevation was obtained. The pile tips were protected from buckling by a stiffening ring. Internal rings were used for piles subject to tension where support to the pile is provided by skin friction. Installation of raked piles is shown in Figure 4.

SHEET PILE INSTALLATION

Larssen type (section modulus: 2540 cm^3/m) sheet piles were supplied to site in 14 m standard lengths. Steel grade was S 355 GP complying with the requirements of EN 10248 (minimum yield strength, f_y= 355 MPa).

The top of the sheet piles was painted over the top 2 m on the seaward face and top 1 m on the landward face for corrosion protection. For this purpose, Icosit SW 500 solvent free epoxy-resin was applied with a dry film thickness of 500 microns.

Fig 4. Installation of Raked Piles

Steel sheet piles were temporarily tied back to steel piles until the heads of sheet piles were permenantly fixed by crown concrete deck. 32 mm diameter tie rods were installed at 1.20 m horizontal spacing.

Larssen type sheet piles were driven by ICE 416 vibrohammer mounted to Link Belt LS118 crane. Prior to driving of sheet piles, 4 m wide strip along the quay, the bottom of the sea was checked by ecosounder to avoid any obstacles which might fall from ships or berth. A steel guide frame was used to install the sheet piles in their correct position.

STATIC PILE LOADING TESTS

A total of three pile load tests were carried out on selected working piles. Two compression and one tension tests were carried out 1.50 times the design load to verify the design assumptions. The loading tests set-up consisted of steel beam which transferred the applied load to two reaction piles. The reaction piles were spaced 2.50 m from the test pile.

The tests were carried out in the following manner:

- The load was applied in increments of 50 kN every 5 minutes.
- When the applied load has reached the working load, the load was maintained for 24 hours.
- Further loads were applied in 50 kN increments until the applied load is 1 ½ times the working load. This load was maintained for 12 hours, measurements being taken hourly.
- When movement has ceased, the load was removed in 50 kN stages and measurements taken at each stage until all loading has been removed.

Load vs. displacement curves of tests piles are shown in Figure 5. The results of pile load tests are summarized in Table 5. The allowable residual displacement of the tested piles was 5 mm. According to test results, all tested piles were deemed satisfactory.

Table 5. Pile Load Test Results

Pile Dia. (mm)	Test Load (kN)	Loading	RAKE	Pile Length (m)	DISPLACEMENT (mm)		
					Working Load	Test Load	Residual
660,4	2700	Compress.	1/8	14	4.10	7.27	1.45
660,4	2700	Compress.	1/8	15	4.71	9.50	3.17
660,4	1125	Tension	1/3	14	3.65	5.01	1.94

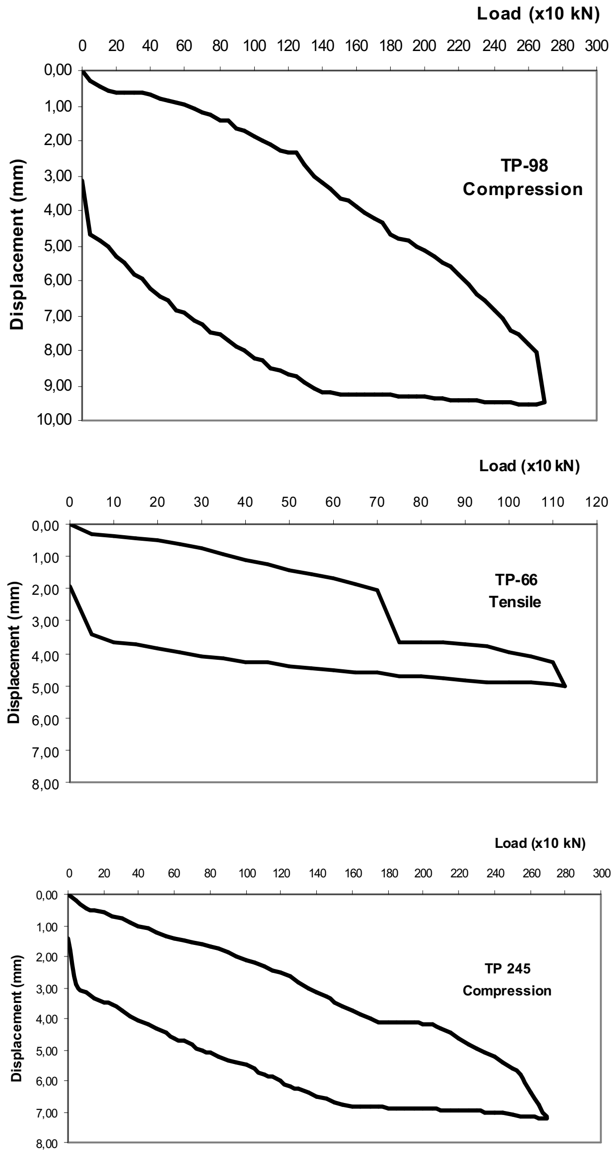

Fig. 5 Load vs. Displacement Curves of Test Piles

CONCLUSIONS

The design, installation and performance of steel tubular piles and steel sheet piles have been described. The following conclusions can be drawn from the results of this case study.

- 10,000 m of pile and 13,850 m of sheet pile installation was completed within a period of 18 months with close cooperation among the general contractor, designer and foundation contractor.
- Pile capacities were calculated by three different static method and verified by performing load tests.
- Allowable stress and rate of corrosion of steel piles prescribed in different codes and standards cover very wide range. The designer have the option of designing at low stress and high corrosion rate with reduced risk. Consequently, pile foundations are often overdesigned. Depending on job site conditions and quality control, the designer have the opportunity to take the advantage of higher design stresses and optimum corrosion rates.
- The results of the loading tests have revealed the satisfactory performance of driven steel tubular piles to support the quay facilities at Aktau Port.

REFERENCES:

BS 8004, 1986. *British Standard Code of Practice for Foundations.* British Standards Institution.

Fuller, F.M., 1979. *"State-of-the-Art Pile Design Practice – Current and Proposed as Reflected in Building Codes." Behaviour of Deep Foundations.* ASTM STP 670, Raymond Lungren, Ed., American Society for Testing and Materials. 84-104.

Piling Handbook 1997, British Steel plc. Image Colourprint Ltd. East Yorkshire.

Technical Standards for Port and Harbour Facilities in Japan 1991. The Overseas Coastal Area Development Institute of Japan.