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Quay Operational Capacity Extension in Cernavoda Port Area by Consolidating the Old Structure

Extention de la capacite d'operation portuaire dans le Port de Cernavoda par consolidation de la structure ancienne

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ABSTRACT: A port operator for loading/unloading timber products in Cernavoda Port on the Danube decided to increase his operational capacity by purchasing a new high productivity prototype hydraulic crane able to work under very low water levels of the Danube. The old sloped quay structure with a previous stage elevated operating platform experienced troubles in operating for the usual Danube convoys for low waters levels of the Danube. Furthermore, in the central area of the mooring front, instability phenomena (port platform settlements, crest reinforced concrete beams displacements and other geometry changes) were registered. By means of the design scope of work the port operator called for a design and build port infrastructure project in order to support the new crane platform runway system foundations, but also to solve the local and general stability quay issues and return to safe operating conditions.

RÉSUMÉ: Un operateur portuaire des produits de bois industriel dans la zone portuaire de Cernavoda sur le Danube a decidé d'augmenter sa capacité d'operation en achetant un nouveau prototype de grue à haute productivité pouvant également fonctionner pour les niveaux basses du Danube. Le vieux quai, ayant une platforme portuaire a niveau surélevé dans une étape précédente, avait du mal à derouler des operations portuaires pour les convois habituels aux niveaux bas du Danube. De plus, dans la zone centrale du front d'amarrage, des phénomènes d'instabilité (tassement de la plate-forme, déplacement des poutres de couronnement, autres déviations de la géométrie du quai) ont été enregistrés. Par son thème de conception, l'opérateur a appelé à la conception et à la réalisation d'une infrastructure portuaire pour sécuriser les fondations des voies de roulement de la nouvelle grue portuaire, mais également à résoudre les problèmes locaux et généraux de résistance et de stabilité du quai afin de lui permettre de revenir aux conditions de fonctionnement sûres.

Keywords: sloped quay, crane runway, Danube low water levels;

1 INTRODUCTION

Cernavoda Port is located on the right bank of the Danube km D 298-299, right away downstream the Danube - Black Sea Channel (figure 1), being developed both on the river bank and in a port basin. Through the scope of work a stevedoring company operating in Cernavoda Port aimed at upgrading the crane runway to allow operations (loading / unloading timber products) for 2000 tons river barges with a new hydraulic harbor crane with a working range of 40m, 5 tons lifting capacity and a total weight of 76 tons.

Figure 1. Cernavoda Port location on the Danube

The crane will run on a railroad track (type CF rail 49, H = 150mm) with a length of 65.00m and a narrow track width of 5.00m.

The new crane runway must generate a logging storage space for the timber products, with lengths between 2.6m and 5.5m and weights between 0.3 tons and 1.5 tons with the purpose of inventorying and stocking with the crane grab or front loader (reach stacker or forklifts) and stack in the nearby storage area. Occasionally logging will be done with tire equipment (equivalent to 25 kN/m²) on the concrete platform up to the warehouse.

The modernization appeared to be necessary as a consequence of the replacement of the existing tower crane directly founded with the new harbor crane. In the Cernavoda Port location Danube annual water level variation between high water levels and low water levels is around 6.50m.

Under operating conditions (shiploads throughout the year - both at high but most of all for Danube low water levels), it was necessary to move the crane runway closer to the water. The quay's crest level (reinforced concrete beam) was set at + 8.45m local Cernavoda and the minimum level of the Danube for which operation was requested was proposed to be -1.00m local Cernavoda (figure 2). The quay stability verification as a result of crane runway relocation was done in accordance with the eurocodes and Romanian norms (Eurocode 7/SR EN 1997-1, Eurocode 8/SR EN 1998, NP 124/2010, NP 123/2010, P100/2013, SR EN 19921-1, SR EN 1536) .

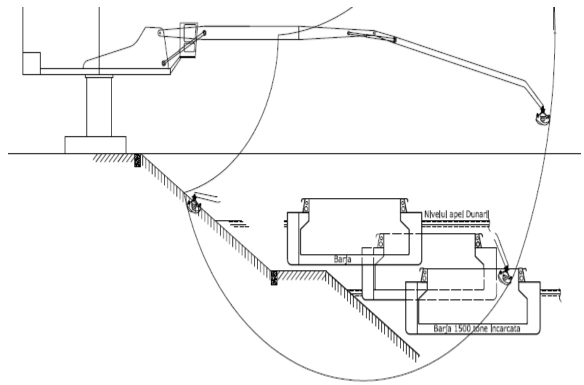

Figure 2. New crane operating outline for different Danube water levels

2 DESIGN CRITERIA

The adopted solution design has taken into account the following fundamental criteria:

- Crane safety and stability operation;
- Keeping and improving existing quay stability;
- Easily port operating;

3 GEOTECHNICAL REPORT

The geotechnical report was conducted by Romanian company Agisfor and included a 25ml depth bore-hole performed by a Beretta T44 installation equiped with a Shelby type sampler and also included SPT tests. Soil layers at Cernavoda site can be described as follows: Soil complex 1, a superior cohesive group of layers with a total thickness of 5.30m, between the depths of 0.70-6.00m, consisting of a four-layer sequence in which soft gray-yellowish silty clay with limestone fragments, brownish silty clay and yellowish-gray silty sandy clay with concretions of limestone predominate.

Soil complex 2, noncohesive inferior with a total thickness of 17.00m, between the depths 6.00-23.00m, consisting of a four-layer succession: fine sand, yellow silty–sand, brown silty clay, with limestone concretions, medium gray sand. Geotechnical characteristics determined by laboratory and field tests are presented in Table 1:

Table 1. Geotechnical report features

Soil complex	γ (kN/m^3)	E (kPa)	φ' (^{0})	c' (kPa)
Soil complex 1				
1.1 layer	21.00	12000	20	30
1.2 layer	18.00	5000	10	5
1.3 layer	20.00	15000	15	35
1.4 layer	20.00	15000	20	30
Soil complex 2				
2.1 layer	20.00	15000	33	-
2.2 layer	20.00	17000	34	-
2.3 layer	20.00	20000	36	-
2.4 layer	20.00	20000	37	-

Geotechnical studies confirmed a very soft yellow clay presence (depths between 2.00m and 4.50m) with very low consistency which required a secondary consolidation with crushed stone filled drilled piles.

4 PROPOSED STRUCTURE. LOAD TESTS.

Quay crest level in our location is +8.45m local Cernavoda, which corresponds to level Nmax 5% + a safety clerance g=1.00m. New crane runway was founded on large diameter piles and the reinforced concrete platform plate was fixed in-between the beams grid (figure 3). Reinforced concrete beams grid have deep foundations, two rows of 900 mm diameter drilled piles, 22.00 m in length, with spaccing of 5.00 m in-between the two rows. For each of the two parallel rows the piles were located every 3.00m interax distance. Each of the two longitudinal reinforced concrete beams composing the new crane runway had a cross section of B=1.30m and H=1.20m. New crane runway stiffness was reached with reinforced concrete cross-beams with the section 45 cm x 80 cm, located at points of intersection with piles. In order to be able to accommodate a surcharge of 25 kN/mp, a reinforced concrete plate was proposed in-between the two longitudinal runway beams with B=4.20m and a variable H=27-35cm. The concrete slab was embedded in the transverse and longitudinal beams. As mentioned before the very soft yellow clay presence (depths between 2.00m and 4.50m) with very low consistency (ø'=10º si c'= 5kPa) required limited soil replacement and a secondary consolidation with crushed stone filled 900mm diameter drilled piles.

In order to check the piles bearing capacity, two static load tests have been performed, one for each of the two piles rows. Each test included loading of a group of 3 piles, central pile was compressed and the two marginals were tested on pulling out forces (figure 4).

Excavated soil from the bored piles confirmed poor mechanical characteristics as indicated in the geotechnical report, and it was decided to replace the soft soil with crushed stone, 25-63mm in order to improve the general stability of the foundation ground.

Crushed stone piles (two rows) were arranged behind the water row of concrete piles. The distance between the piles axes was proposed at 1.10m, resulting in a distance of 20cm between their tangents. Lenght of these piles was 8.0m, embeded about 2.0m into bearing layer.

Figure 3 shows the existing sloped quay structure (ESQS) and new proposed structures RCBNP (reinforced concrete beams network founded on piles) and RSS-CS (replacement of soft soil-crushed stone).

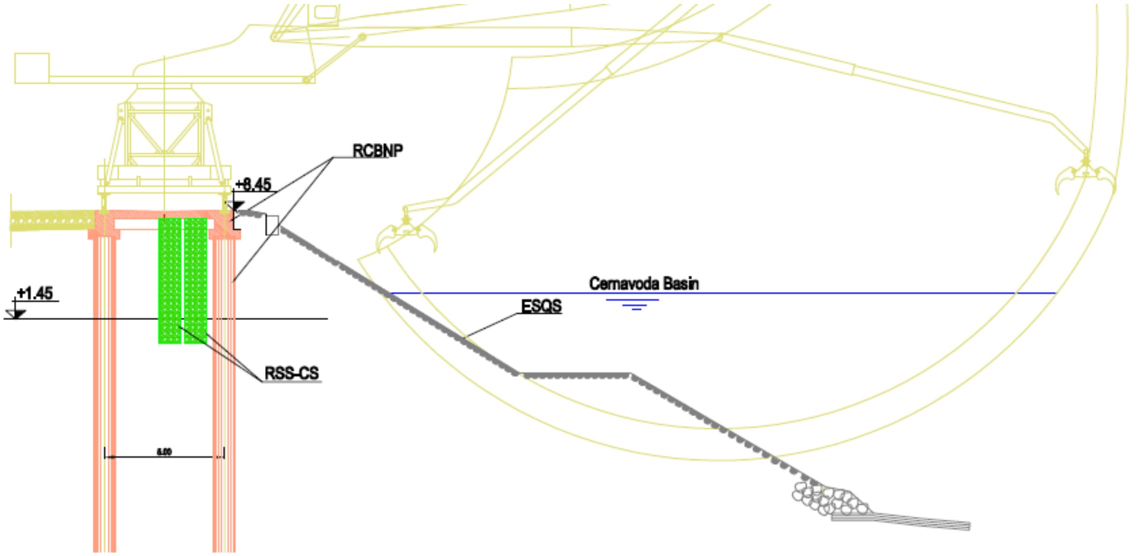

Figure 3. Existing quay structure (ESQS) and new proposed structures (RCBNP) and (RSS-CS).

During execution, static pile load tests were carried out (Bauer, 2014) to confirm the preliminary bearing capacity in the project (axial stress, compression and tension) according to NP 045-2000 (figure 4);

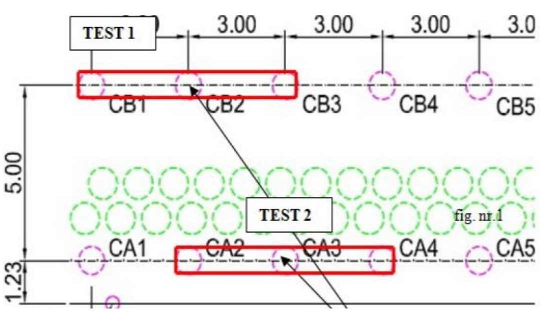

Figure 4. Axial load tests 1and 2 locations.

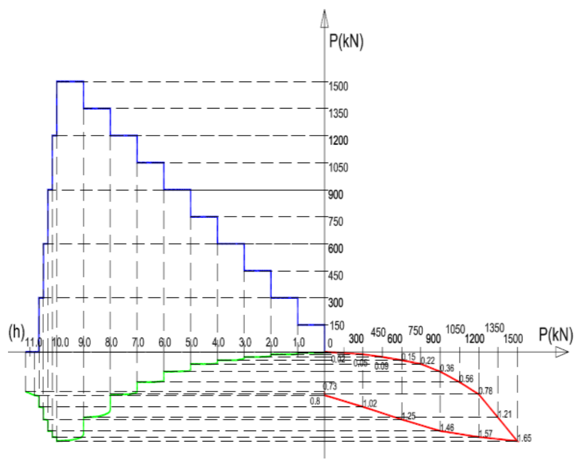

Figure 5. Loading steps,settlement diagram

Maximal vertical force applied was 1500 kN, tested with loading steps according to diagram presented in figure 5 resulting in a shore / water pile a 1.65mm / 1.69mm settlement and a residual settlement after unloading of 0.73mm / 0.49mm.

All piles integrity have been tested with clasical equipment to check lenght and for PIT performance according SR-ASTM D5882 - 2005.

5 IMPROVING STABILITY

Consequently, a new crane runway foundations system was designed for the port equipment using a grid of reinforced concrete beams (longitudinal and transversal stiffening) on drilled reinforced concrete piles foundations. Main design loading data were the harbor equipment features (maximum working radius of 40m, total weight 76 tons, rail type 49, length 65.00m and carriage crane system width of

500cm), related with various operation scenarios.

Distance in-between the piles for each of the two rows of 3.0m has been calculated with Ito-Matsui method based on the plastic deformation theory, in order to avoid soil slip in-between adjacent piles for most high-risk stability scenarios.

Calculation scenarios have been based on most high-risk port operation scenarios, during port structure designed life. Table 2 and 3 presents maximal values for axial (N), shear (T) and bending moment (M) for beams grid and piles, for static and seismic loads.

Table 2. Nmax, Tmax, Mmax values for RCBNP structure elements-static

STATIC Element	Nmax (kN)	Tmax (kN)	Mmax (kNm)
Long Beam	-	760	765
Trans Beam	64	200	365
Pile water row	1520	143	326
Pile shore row	1520	131	215

Table 3. Nmax, Tmax, Mmax values for RCBNP structure elements-seismic

SEISMIC Element	Nmax (kN)	Tmax (kN)	Mmax (kNm)
Long Beam	-	570	470
Trans Beam	160	320	700
Pile water row	1200	260	600
Pile shore row	1200	438	741

For table 2 values scenarios, maximal values have been obtained for a combination of gravitational loads, earth and water pressure crane wheels loads and platform surcharges. Safety factors have been considered according SR EN 1997-1:2006 and SR EN 1997-1/NB:2007. For table 2 seimic loads have been calculated considering P100-2013 with the location features (ag=0.20g, IMR=225 years, Tc=1.0s).

Reinforcement of all structural elements of the cross sections meets all the safety and stability requirements provided by national and european requirements, allowing port safe operations. Capable bending moments are for a water row pile 900kNm and 1110kNm for a shore row pile. Capable bending moments are for a longitudinal beam 770kNm and for a trans beam 750kNm. Bearing capacity for a pile has been estimated to 1600kN.

New port crane loads have been offered by the producer and the most severe considered scenario was crane loading arm rotated 45^0, wind behind.

According to the Romanian similar experience for a slope, in order to be stable, the minimum factor of safety required is F_S=1.50, the study considering the safety factors methodology. The analysis using Geo 5 software indicated that on the initial state, the sloped quay *(ESQS)* was unstable (Fs=0.99 figure 6). By adding the designed structure (*RCBNP)* a stable situation was obtained (Fs=2.44 figure 7).

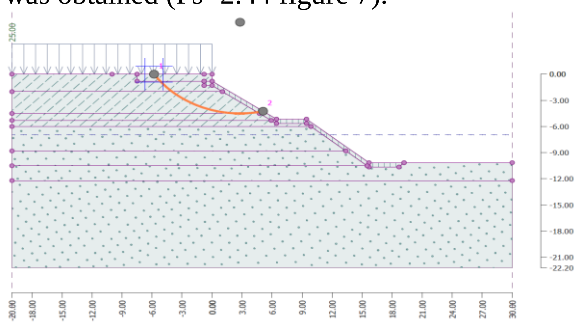

Figure 6. Unstable sloped quay (ESQS)

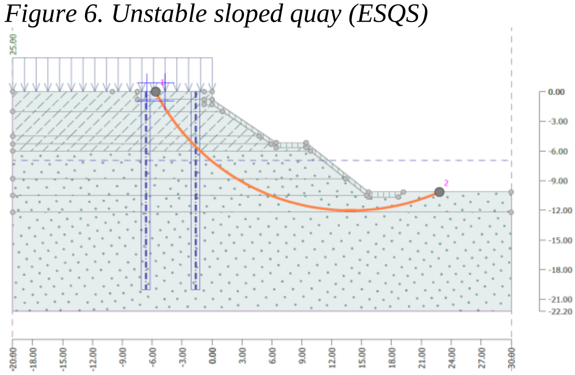

Figure 7. Stable sloped quay (ESQS) + (RCBNP)

However some cvasi-instable sliding surfaces (close to Fs=1.37-1.44) may occur in front of the structure where only crushed stone piles have a limited stability role (figure 8). Those situations may occur with high risk when Danube water levels are rapidly decreasing to very low waters levels and so monitoring/supervising equipment have been installed in front of the sloped quay.

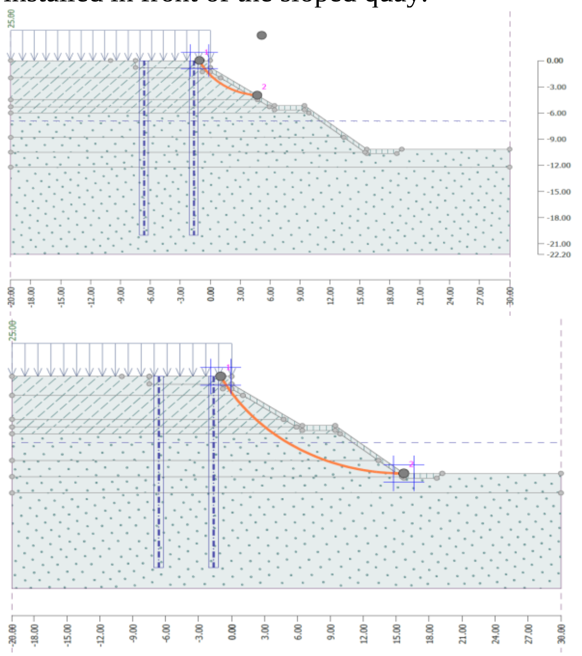

Figure 8. Fs=1.37-1.44 sliding surfaces may occur in front of the structure

6 CONCLUSIONS

With a crest previously raised with few meters by filling with dredged sediment material with very poor mechanical characteristics, the sloped quay experienced instabilities. Designing and building a reinforced concrete grid of longitudinal and transversal beams on bored reinforced concrete piles d = 900mm with 22.00ml lenght which represents the infrastructure of the new crane runway for the new port crane accomplish also the consolidation function for the Danube sloped quay. It was also necessary to replace part of the upper sloped quay material by driving piles of crushed stone, d=900mm and lenght l = 8.00m, which generated additional stability. Actually, works have been finalized and the new quay structure is safely operational with the new crane (figure 9).

Figur 9. New crane operating safely to the sloped quay in Cernavoda Port area.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

Agisfor, 2014, Studiu geotehnic pentru amplasamentul situat la cheul de descarcare nave fluviale Lessoplast Cernavoda/ Geotechnical report for the site located on Lessoplast Cernavoda Quay;

Bauer, 2014, Fundatie cale de rulare macara cheu Lessoplast Cernavoda, Raport de incercare la incarcari statice, piloti CB2 si CA3/Foundation for quay crane runway Lessoplast Cernavoda, Static load tests report for CB 2 and CA3 piles;

Geotechnical software suite Geo 5. User's Guide; 2010.

Ilieș N., Farcaș V., Coț R., Moldovan I., 2015; The control of natural disaster caused by slopes sliding by means of stepped buildings Procedia Technology, Vol. 22, 391-398, Elsevier;

Ito T., Matsui T., 1975, Methods to estimate lateral force acting on stabilizing piles. Soils Found 18(4):43–59;

Lessoplast, 2014, Modernizare cale de rulare macara portuara Cernavoda / Modernization of port crane runway Cernavoda;

Marinescu, C., Slopes and embankments stability protection (in Romanian), Editura Tehnica, Bucuresti, 1988;

Morgenstern, N.R. & Price, V.E., 1965, The analysis of the stability of general slip surfaces. Géotechnique, 15(1): 79–93;

NP 045-2000, Romanian Norm for on site and foundations piles;

NP 124-2010: Romanian Design Norm for geotechnical design of retaining structures;

NP 123:2010, Romanian Geotechnical Design Norm for piles foundations;

P100 : 2013 – Seismic Design Code;

SR ASTM D 5882:2005, Standardized method for determining piles integrity through low distortion tests;

SREN 1998-1:2004 Eurocode 8: Structures Design for earthquake loads - Part 1: General rules, seismic actions and rules for buildings;

SREN 1997-1:2006, Eurocode 7: Geotechnical design – Part 1: General rules;

SREN 1997-1 / NB:2007, Eurocode 7: Geotechnical design – Part 1: General rules. National Annex;

SREN 1992-1-1:2004/NB:2008/A91:2009 Eurocode 2: Design of concrete structures;

SREN 1536: 2004 Special geotechnical Works. Drilled piles;