Ovidius University Annals Series: Civil Engineering, Year 21, 2019
DOI: 10.2478/ouacsce-2019-0004

Proper Infrastructure Design at High Vertical Loads, Nearby Waterfront Structures

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***Abstract* – Hence economic growth requires more and more investments in the harbor area, especially nearby waterfront structures, a special attention must be taken into account regarding proper infrastructure design for structures with high vertical loads. At the same time, we have to consider the good behavior of the new design structures and also their impact on the existing nearby waterfront infrastructure. Being adjacent to waterfront structures and due to the limited available space, these structures are typically tall and narrow, and exert average soil pressures on the order of 300KPa. These loads can only be accommodated by ground with an adequate bearing capacity. This publication presents case studies of waterfront projects like grain silos storage facility. Available results for the certification and monitoring of the works are also presented, as well as other considerations based on the author's experience.**

***Keywords* –proper infrastructure design, structures with high vertical loads, waterfront projects**

1. INTRODUCTION

Most of the working areas nearby waterfronts (harbor sites) require a soil improvement activity in order to support high vertical loads coming from proposed structures. Typically, the soil improvement technique is verified by in situ testing to demonstrate that a sufficiently improved soil strength and soil modulus is reached. We could choose to apply for some soil improvement methods like: (i) dynamic compaction, (ii) rigid inclusions and (iii) compaction grouting, as they have been used for the construction of some waterfront structures. Still, the proper solution for soil improvement has to be considered in accordance with the technical limits imposed by the existing nearby structures.

However, managing big structures nearby waterfront line, it also issues a problem regarding the infrastructure interaction between existing (quays) and new ones. Even though we improve the soil, we have to consider the horizontal loads imposed to the existing waterfront structure by the new heavy infrastructures.

Also, considering that the cost for a safety infrastructure has a major impact at the beginning of the investment, a proper solution for the infrastructure design is needed.

Considering the above approach, we will present two case studies as follows:

- Case A : Settlement differences for different types of foundation;
- Case B: An alternative cost effective solution for constructions nearby waterfront structure.

2. CASE A: SETTLEMENT DIFFERENCES FOR DIFFERENT TYPES OF FOUNDATION

This project consists of grain storage facilities (harbor area, nearby waterfront structures) and it was developed by the owner, during a period of 15 years. Figure 1 shows the entire grain storage facility project, involving a total of 9 silos that were built on two phases. At the beginning (in 2006) , a number of three metallic silos (Type I) was built considering a solution of direct foundations, resting on port fill. In 2013 there were constructed four silos on inclusions (Type II, towards the shore), and two silos on big diameter piles embedded in limestone (Type III, next to the quay).

Silo diameter and height were 24 and 22 meters respectively, while the capacity was 6,300 tons per silo. The inclusions were spaced at 2.5m2 from which derives a capacity of 35 tons. This capacity was verified in the field as shown in Figure 2.

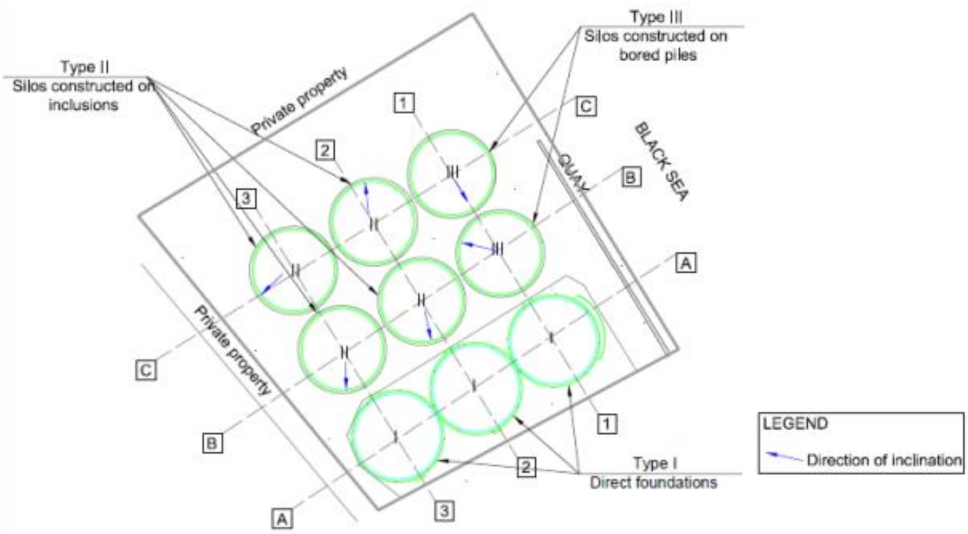

Fig. 1 Silos on direct foundations (I), inclusions (II) and bored piles (III)

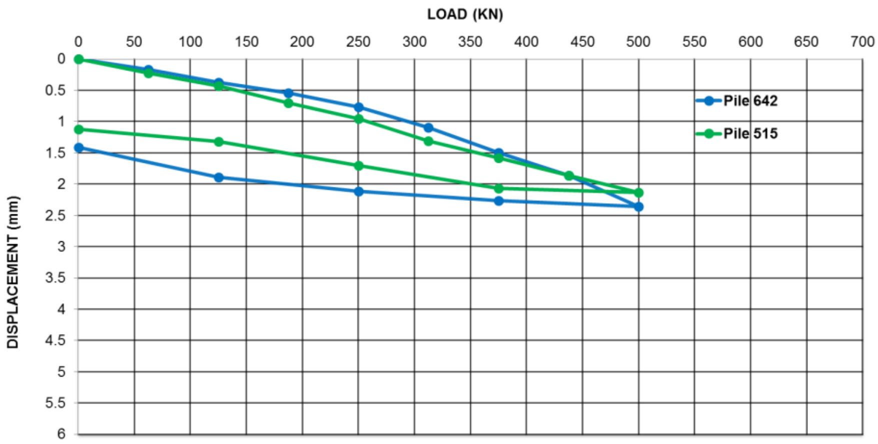

Fig. 2 Static Axial Load tests

Based on the monitoring measurements the following conclusions can be made:

- For type I silos,it was measured a total settlement of about 120mm and based on the evolution of settlement it is concluded that settlement on port fill is long term. Settlement for type II and III silos was between 5,9 and 4,6mm respectively.
- The silos founded on piles and inclusions exhibit similar behavior at maximum load.
- Settlement in this case is typically stabilized after almost 3 cycles of loading unloading.
- While the settlement of several centimeters can be acceptable, due to the non-homogeneity of port fill, indirect foundations or ground improvements are necessary to protect the metallic structure from differential settlement.
- For the project in question, the differential settlement limit of 2/1000 imposed by the supplier of the metallic silos was fulfilled for both types II and III.
- The direction of differential settlement is random.

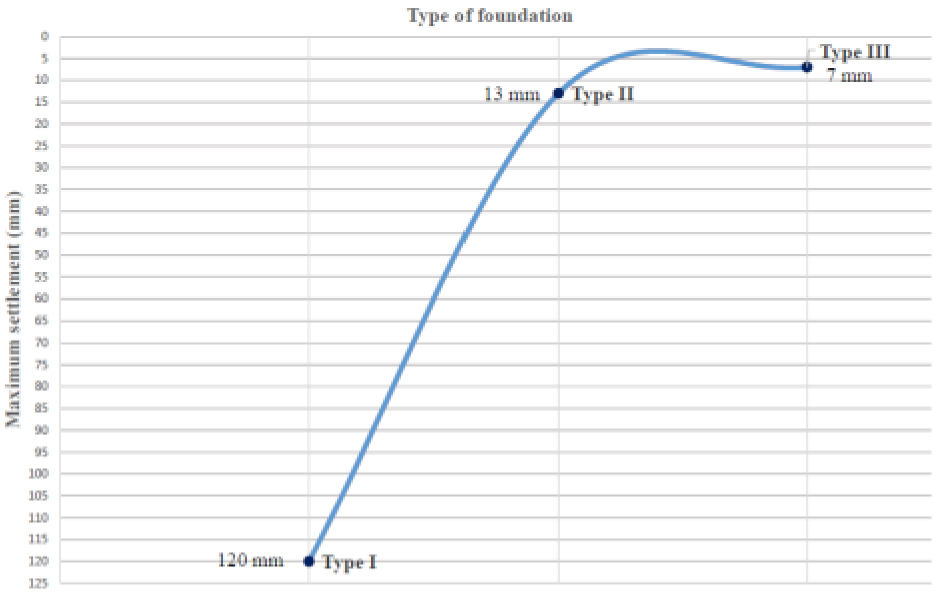

Fig. 3 Maximum settlement versus type of foundation

Based on the data from another project, there can be made some additional qualitative comparisons. Figure 4 shows a site with 10 cereal storage silos constructed on direct foundations on loess deposits and the measured maximum settlements. In the first few years, big cracks and displacements in the concrete slab around the silos developed; settlement was not stabilized 5 years after construction and the investor had to resort to compaction grouting. The evolution of settlements shows a pattern of maximum settlement evolving between the silos which is not observed for the project with inclusions, as a foundation system.

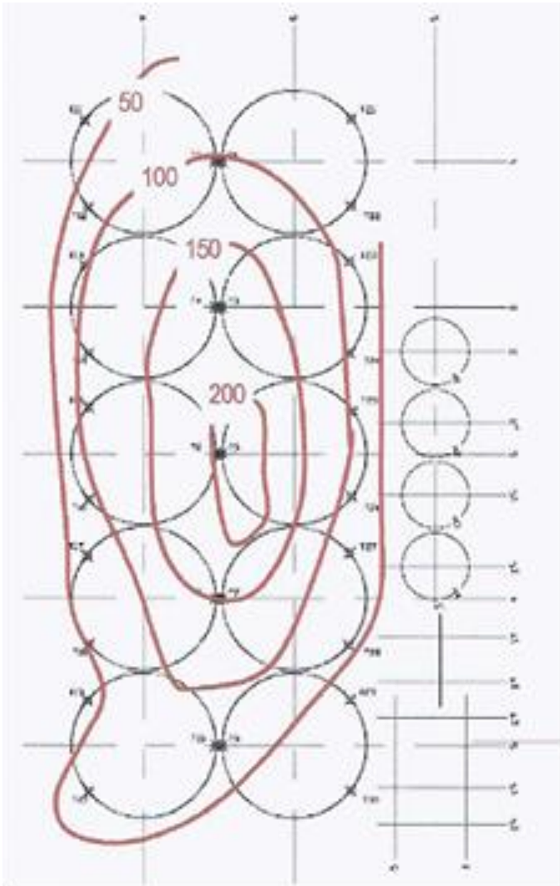

Fig. 4 Maximum settlement for silos with direct foundations on loess

3. CASE B: AN ALTERNATIVE COST EFFECTIVE SOLUTION FOR CONSTRUCTIONS NEARBY WATERFRONT STRUCTURE

The solution consists of using concrete rigid inclusions as a solution of soil improvement in order to undertake the loads coming from a new proposed warehouse as grain storage facility (see Figure 5 for site location), nearby the waterfront structures. The technique has been used in the last years also in the port environment for the foundation of metallic silos for storing grains.

The warehouse is 135m long and has a capacity of 50,000 tons. Due to the limited space on the port platform, the width of the warehouse was limited to 29 meters (Fig. 6).

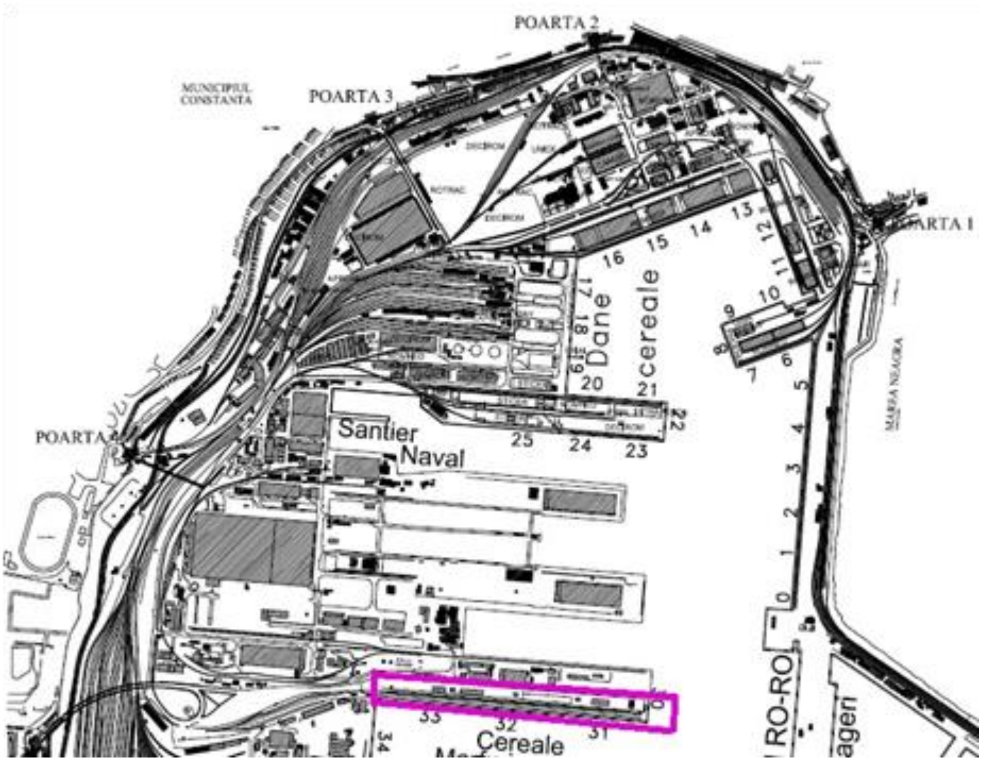

Fig. 5 Grain storage concrete warehouse - Constanta Harbor

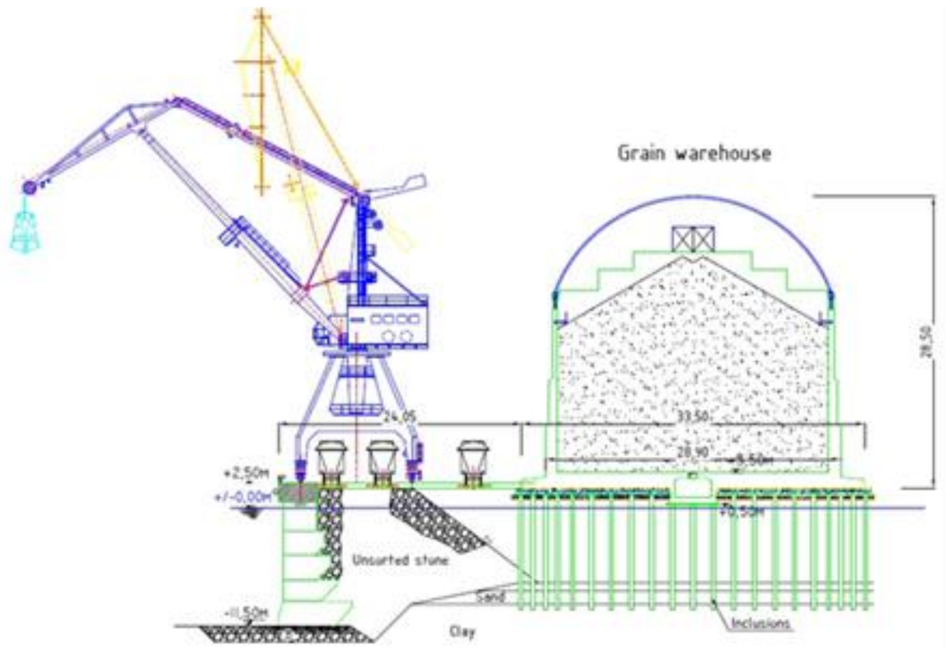

Fig. 6 Warehouse location nearby quay

3.1 Existing waterfront structure

The existing quay consists of concrete blocks of 1,000kN each. The blocks are placed on top of each other, resulting in 5.5 m wide stacks; a concrete cap beam connects them together in groups of five. The quay is 14-m high of which 11.5 m located below sea level. It is founded on a 1.5 m thick layer of rock fill, constructed on top of a stiff clay with bearing capacity of 400 kN/m2. In order to reduce the load induced by the filling on the quay was designed a prism of coarse stone. On the quay are cranes which run on two rails: one on the cap beam and one at a distance of 10.90m. The rails are founded on reinforced concrete sleepers. Also, under the crane portal are two railways lines and two more outside. From the outside ones, one was decommissioned as it was in the footprint of the new warehouse. The overall width of the port platform is 60 meters. The load transferred to the platform is approximately 300kN/m2, which increases the horizontal loads on the quay. Under these conditions, the stability of the quay is of great concern and requires further investigation. (Fig. 7).

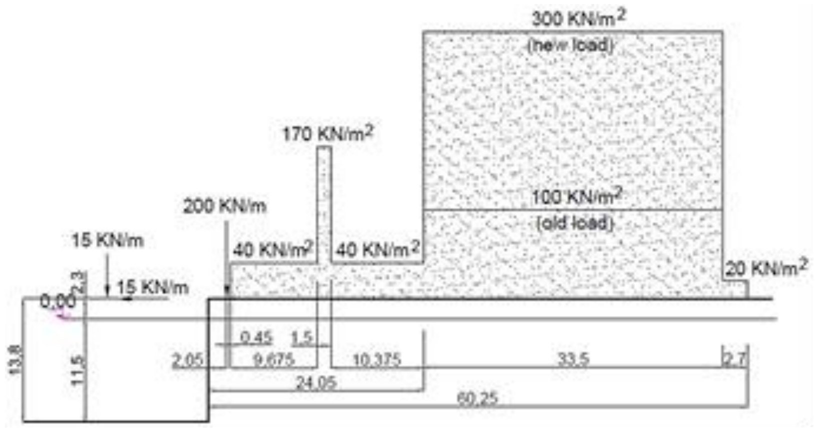

Fig. 7 Loads applied on the quay

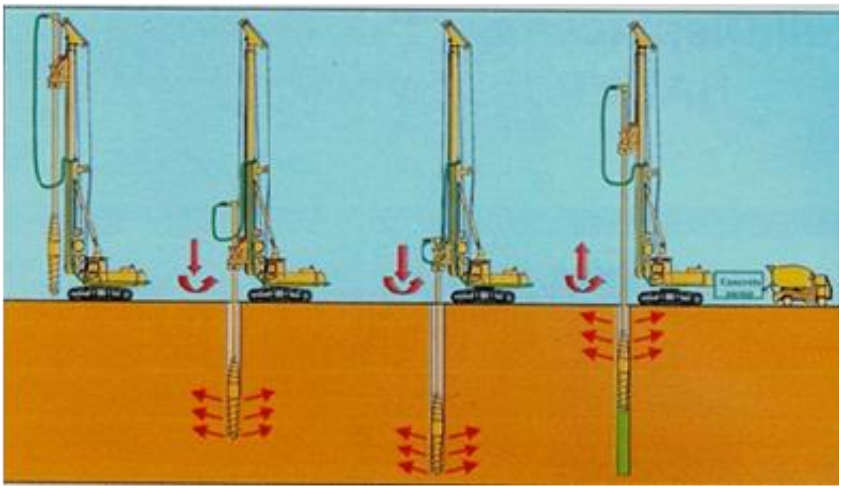

Fig. 8 Execution of rigid inclusions

3.2. Solutions considered ensuring stability of the quay

To ensure stability of the quay, were considered the following solutions:

- Strengthening the structural capacity of the quay.
- Constructing the warehouse on big diameter piles to reduce the load on the quay.
- Improving the ground under the warehouse and transferring the loads in depth.

Analysis indicated that the first two solutions carried a substantially higher cost premium compared to the third one. In addition, the first solution required decommissioning the quay for a period of three months. Consequently, was selected the third solution, which is described in more detail below.

3.3. Solution with rigid inclusions

Considered one of the major advancements in the ground improvement industry, inclusions appeared in several European countries in the early 1990's. They have been used on well-known projects such as the Rion Antirion Bridge in the Corinthian gulf, and been the topic of research projects such as the Euro 2.7 million A.S.I.RI. Research program (France 2007-2011).

This technology involves the construction of a load transfer platform and rigid inclusions to (i) transfer the load to the rigid inclusions and soil and (ii) reinforce the soil. The composite block transfers the loads to stiffer foundation ground. The inclusions are constructed by drilling with a special full displacement tool or by vibrating a closed ended steel pipe and concreting through the tool/pipe from the bottom up (Fig. 6). Generally, the inclusions span over the thickness of the soft layers on a firm layer and can reach 25-30 meters with a powerful drilling rig.

Advantages of this technique include:

- Due to displacement there are almost no excavation spoils.
- High rates of production
- No need for steel reinforcement
- Small consumption of concrete.
- Improved bearing capacities.

The load transfer from the warehouse to the inclusions was achieved by a layer of crushed rock reinforced with geogrids, which is typically called load transfer platform (LTP). Under the LPT were designed rigid inclusions disposed at a triangular distribution with 1 inclusion per 2.1 to 3.5m2. The inclusions have a diameter of 0.40m and a depth of 12m with minimum penetration of 0.50m into the stiff clay layer. They inclusions are made of C20/25 concrete (Fig. 9).

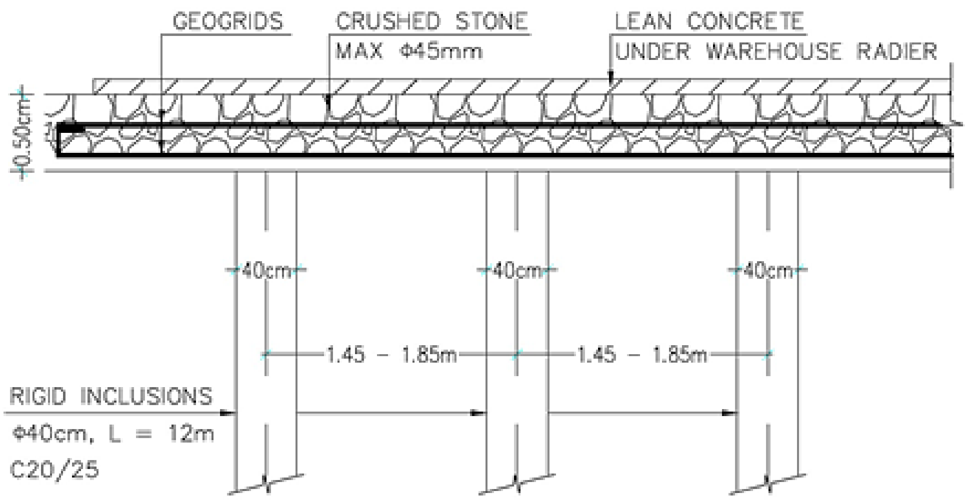

Fig. 9 LTP and inclusions

In terms of quality control were performed various registrations and tests including continuous logging, Sonic Integrity Tests (S.I.T.) and also static axial load tests. As shown in Fig.10 these tests were performed to a maximum load of 45 tons and was obtained a maximum settlement of 3.0mm.

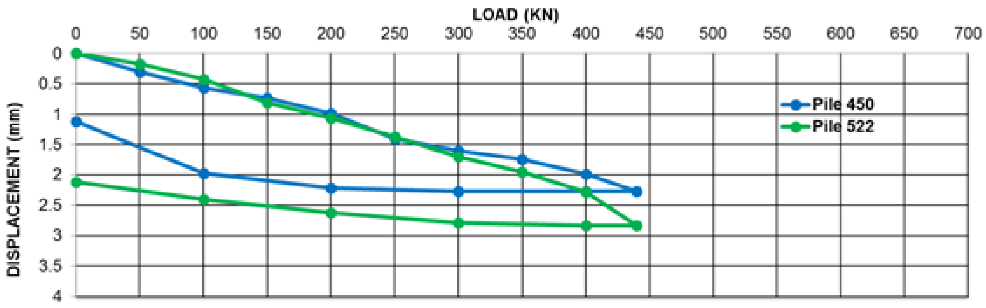

Fig. 10 Results from static axial load tests

4. CONCLUSIONS

This publication presented case histories of proper foundations design to some waterfront projects. Based on experience, for each new design facility nearby the waterfront structures it has to be considered the proper infrastructure design in order to limit the settlement and additional new horizontal loads to existing quays. Different types of analysis including global stability analysis of the waterfront structures has to be performed before considering the proper foundation solution for the new proposed structure.

Also, based on requirements by waterfront facilities owners for cost effective and sustainable solutions, it is expected growing demand for new, efficient alternative technologies and solutions.

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