Foundation solutions for cereal silos in Romania

Solutions de fondation pour les dépôts des céréales appliqués en Roumanie

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ABSTRACT: The development of the grain industry resulted in the construction of numerous silos, located mainly in plain, rural, areas but also in harbours. Geotechnical and groundwater conditions vary and dictate diverse foundation solutions depending on the loads transmitted to the soil and the specific site conditions. Site located in plain areas are characterized by difficult foundation soils including soils sensitive to water (collapsible soils – loess); in these cases are necessary special foundation solution or consolidation of soil. For silos constructed on waterfront, it is necessary to evaluate overall stability when adopting the foundation system – this results in additional verifications. Multiple situations require placing the silos in the immediate vicinity of existing operating quays and imply foundation solutions by wich the new efforts must not affect the bearing capacity and stability of such quays. The paper presents various case studies regarding this type of works, as well as specific computation aspects for the adopted foundation systems.

RÉSUMÉ: Le développement de l'industrie céréalière en Roumanie a conduit à la construction de nombreux silos des céréales placés en général en plaine zones, mais aussi en ports. Les conditions variables géotechnique et hydrogéologique ont imposé des différentes solutions pour les fondations. Les emplacements en champs sont caractérise par des sols difficile (en général collapsibles sols - loess) qui impose de solutions spéciales des fondations de travaux de consolidation. Pour les silos réalisés sur les quais portuaires sont nécessaire des vérifications supplémentaires de la stabilité générale. Quand les silos sont placés dans la proximité d'un quai opérationnel il faut vérifier que la capacité portante et la stabilité du quai ne sont pas affectées par les contraintes induites par les fondations des silos. L'article présente quelques études de cas concernant ces types des travaux et des aspects spécifiques de calcul pour les fondations.

KEYWORDS: silo foundation, rigid inclusions, solid injection, consolidation of soil

MOTS-CLÉS: fondation de silos, inclusions rigides, injection solide, consolidation du sol

1 INTRODUCTION

Construction of grain storage transmitted a substantial value of pressure on the soil foundation, who leads to settlements and inclinations more than admissible value for the safe operation.

By analyzing several grain terminals, founded directly or indirectly, It could establish a correlation between the foundation system and settlements.

2 HORIZONTAL SILOS (WAREHOUSE)

In order to optimize the use of existing quays in Constanta Port are developed new efficient solutions; taking into account the evolution of technology in some port terminals (Figure 1), it is necessary to perform global stability analysis of the waterfront structures under the new loading conditions.

The warehouse is 135m long and has a capacity of 50,000 tons. Due to the limited space on the platform, the width of the warehouse was limited to 29 meters (Figure 1). The load transferred to the platform is approximately 300kN/m2, which increases the horizontal loads on the quay (Figure 2). Under these conditions, the stability of the quay is of great concern and requires further investigation.

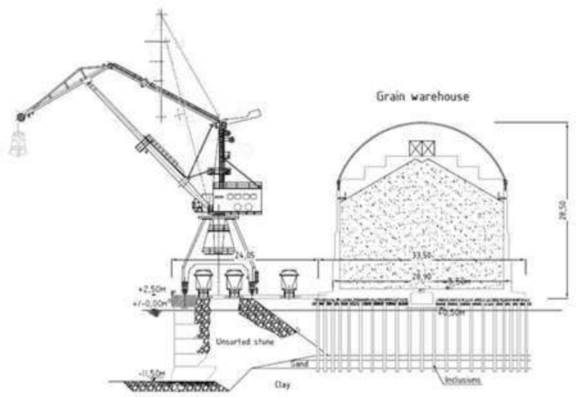

Figure 1. New horizontal silo (warehouse) for grain

In order to evaluate the effects of the new loads on the stability of the quay and to provide an appropriate solution both technically and economically, but also one that could be constructed within a limited construction schedule of 6 months, were conducted numerical modeling and experiments.

Numerical modeling was performed to evaluate the stability of the quay under the new loads. The objective of the analysis was to determine the horizontal forces and evaluate the global stability of the structure. This included the safety factors for sliding and overturning as well as the new pressures applied on the rock and the soil.

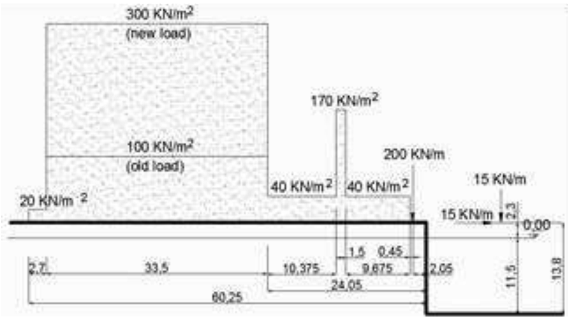

Figure 2. Loads applied on the quay

The results of the analysis indicate that under the new loadings, the stability of the quay is questionable based on an increase in the magnitude of horizontal forces on the order of 25%, from 470kN/m to 590kN/m.

In addition, the safety factors for both sliding and overturning are unsatisfactory. Furthermore, the maximum pressures on both the rock and the soil were 400kPa, which also provided for inadequate factor of safety in terms bearing capacity.

To ensure stability of the quay, were considered the few solutions and was selected the warehouse foundation of rigid inclusions. (Figure 3).

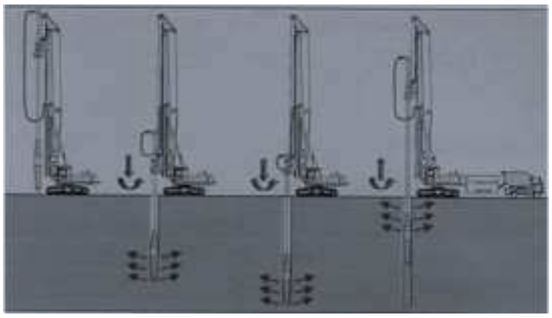

Figure 3. Execution of rigid inclusions.

3 CELLS SILO ON THE QUAY PLATFORM

The soil supporting the warehouse is improved with the construction of rigid inclusions, disposed at a grid (Figure 4) with sides having dimensions 1.35 to 1.85 m. The rigid inclusions have a diameter of 0.40m and a depth of 12 m with minimum penetration of 0.50m into the stiff clay layer (Figure 5). They are made of concrete C20/25.

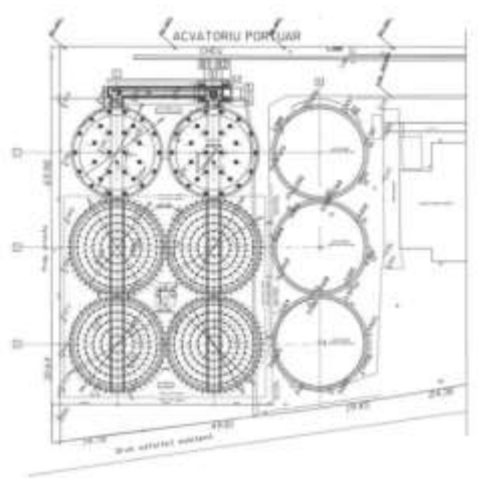

Figure 4. Silo in the working port of Constanta – plan

This technology involves transfer the load to the rigid inclusions and soil and to 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 and concreting through it from the bottom up (Figure 3).

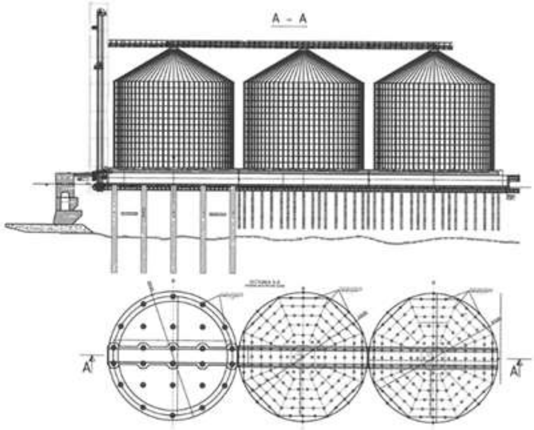

Figure 5. Section through working port.

Advantages of this technique include:

- There are almost no excavation spoils
- Small consumption of concrete
- Improved bearing capacities

Figure 4 shows a project involving a total of 9 silos that were built on two phases. In 2006 the first three silos (Type I) were built on direct foundations resting on port fill. In 2013 were constructed four silos on inclusions (Type II, towards the shore) and two silos on big diameter piles that were embedded in limestone (Type III, next to the quay). Diameter and height were 24 meters; capacity was 6,300 tons per silo. The inclusions and piles were spaced at 1,60 and 5,0 m from which derives a capacity.

4 SILOS ON BERTH 45-40 IN CONSTANTZA PORT

This terminal of 240.000 t have 32 cells with 23,70 m diameter. Foundation was achieved on 3,0 m layer of crushed stone. (figure 6) on the 12,0 m of port filling.

Compared with piles, the cost is reduced, but increase the cost of maintenance.

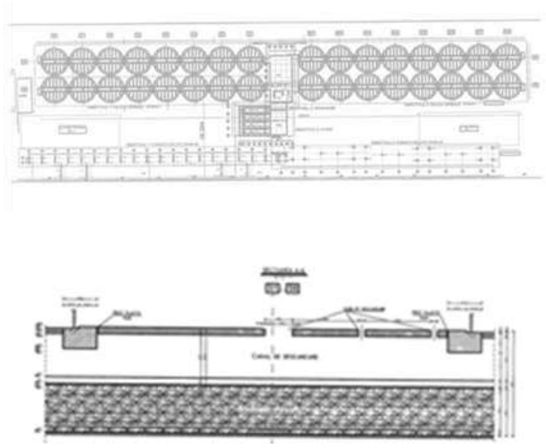

Figure 6. Silo on berth 45-40 in Constantza Port – plan view and section

Each cell was loaded gradually in 4 steps to consume for the beginning the settlement. The initial settlement was 220 mm.

5 USING SOLID INJECTIONS

In area between cells, the pressure is about double than in the middle (figure 7). The cells settlement was up to 211 mm, and inclination up to 1:130, more than admissible value.

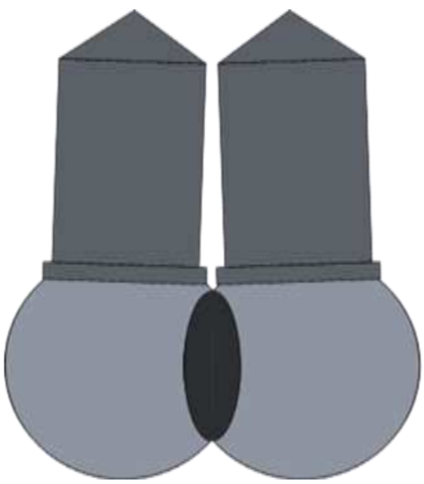

Figure 7. The pressure between cells

Based on data from another site can be made another qualitative comparison. Figure 8 shows a site with 10 cereal storage silos with direct foundations on loess 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.

For the soil consolidation was used the solid injection (figure 9) The medium diameter was 35 cm and length 8,0 m. The consummation of mortar was 100 liter/m. To obtain the same settlement the soil must be improved differential.

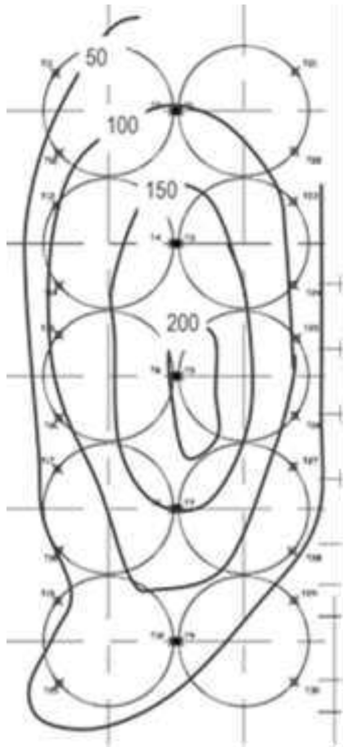

Figure 8. Maximum settlement for silos with direct foundations on loess.

After consolidation the special monitoring system show the settlement in time evolution. After 6 months was observed that settlement is stabilized for the pressure up to 250 kPa.

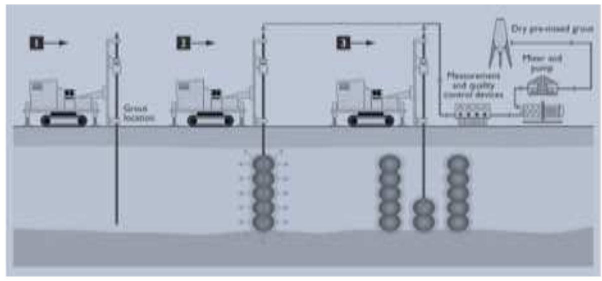

Figure 9. Solid injection technology

6 SETTLEMENT VERSUS TYPE OF FOUNDATION

Based on monitoring measurements the following conclusions can be made:

• For type I silos, 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 3 cycles of loading unloading.

• While settlement of several centimeters can be acceptable, due to the non-homogeneity of port fill, indirect foundations or ground improvement are necessary to protect structure from differential settlement.

• The differential settlement limit of 2/1000 imposed by the supplier

The composite block then transfers the loads to stiffer foundation ground. For average load and settlement requirements this method is cheaper compared to piling solutions due to the following:

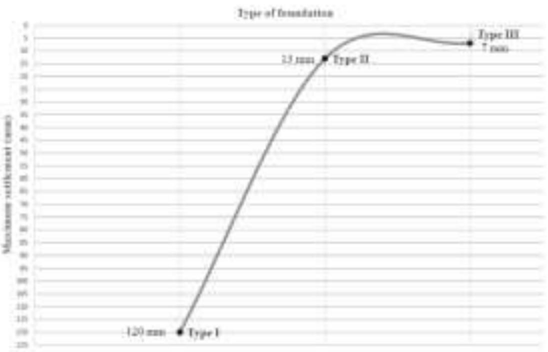

Figure 10. Maximum settlement versus type of foundation.

The evolution of settlements shows a clear pattern of maximum settlement evolving between the silos which is not observed for the project with piles and inclusions.

7 CONCLUSIONS

After the technical and economic analysis, were applied different solutions for silos foundations used concrete piles, rigid inclusions or thick layer of rockfill.

Soil consolidation by solid injections, vertical and inclined, it is a new technology that has advantages which finally is reflected in the cost.

The main advantage is possibility to optimization solution based on real site conditions by varying the length, injection pressure, the arrangement etc, is obtained controlled lifting of the foundation soil and recover horizontality of construction. The equipment have small sizes, so that can be treated the areas where access is reduced.

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