THE IMPORTANCE OF PROPER EVALUATION OF THE GEOLOGICAL CONDITIONS FOR THE DESIGN OF INDUSTRIAL FLOOR SUBBASE

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Abstract

Nowadays many problems concerning industrial floors or floors in shopping centres occurred when local geological characterization is not adequately considered by structural designers, material selection is not evaluated properly and in time for future stability, or consolidation of soft organic subsoil laid in active zone is not taken into account during design evaluation. Similar problems occur when flooding effects on subbase layers cause a new settlement of the upper floor structure. Generally speaking, majority of these symptoms of floor damage have their origin in underestimation of the geotechnical risk. At some locations, the selection of support structure and material type is not adequate due to lack of experience and in order to offer the lowest price as a contractor.

Keywords: organic soft subsoil, unfavourable geological conditions, floor deformation, numerical modelling, consolidation settlement

1 INTRODUCTION

With the example of a damaged industrial production hall floor, which caused a lot of problems and money loss to contractor and supplier of civil works, an alternative floor support layer design for (otherwise) unfavourable geological conditions can be demonstrated. Due to the fact that the problem is still active and not yet fully closed, it cannot be described in detail. The main objective of this article is an explanation of potential risks and presentation of all kind of geotechnical and structural evaluations, which must be done for this type of structures.

A floor plate at standard production hall thickness of 160 mm, with uniform loading of 20 kN/m^2, loading from forklifts with weight of 30 kN on an area 1.3 x 2.6 m, and mobile platforms with weight of 30 kN (1 x 2.4) m was designed. Design criteria for the floor plate subbase layer were established by the values of deformation modulus $E_{def,\,2} > 80$ MPa and ratio criterion $E_{def,2}/E_{def,1} \leq 2.5$ at the level of concreting.

2 GEOTECHNICAL CHARACTERIZATION OF LOCALITY

Appropriate evaluation of geotechnical conditions must lead to an adequate design of the floor subbase structure [1]. There is also demand for an appropriate in-situ testing or laboratory analysis to discover any possible negative impact on the lifetime stability of the structure and stability of the active geological environment below the floor. For example, at this locality a dynamic penetration test was performed as auxiliary testing method. However a static penetration test with measurement of pore pressure (CPTu) might have been more suitable [2]. For prediction of consolidation settlement in time, a testing of deformation parameters – coefficient of consolidation c_V, c_H and permeability parameters – and filtration coefficients k_{fx}, k_{fy} were important.

Not less important are the hydrogeological conditions at the locality, where possible flooding effect and uplift pressure on the floor structure must be evaluated. It is also important to know the ground water level (GWL) oscillation and its impact on the effective stress in subsoil. A high GWL increases risk due to the mentioned influence of uplift on the stability of the subbase layer. Also, a very low GWL causes increasing of effective stress in the active zone and it creates new settlement. Influences on foundation soil stability play an important role due to possible exploitation by special thermal conditions of hall production units [3, 5].

Geotechnical properties of soils at the top of profile were tested in the laboratory and were evaluated by 10 dynamic probes. Dynamic penetration curves clearly show the variable deformation properties at the surface zone of antropogenous and quaternary deposits and they indicate zones of soft and very soft soils, which are not suitable for carrying the load transfer from heavily loaded floor. Values of the deformation modulus range from 0.3 to 3.7 MPa with an average value of 1.0 MPa, which represents very soft and soft soils at the active profile with thickness from 1 to 3 m. Conditions were complicated and unfavourable due to closed ground water level and other mentioned factors.

3 REALIZED DESIGN AND REMEDIATION

3.1 Realized geotechnical works for carrying capacity improvement

Many geotechnical arrangements were proposed to ensure structural stability of floor:

- basal reinforcement of subbase layer with geosynthetics,
- usage of geodrains to improve consolidations, (rejected due to high GWL),
- pile support and basal reinforcement below subbase, (expensive, but suitable solution),
- application of geocell improvement of bearing capacity [4],
- massive stabilization and mixing in place.

The selected contractors focused on solution that is more economical and chose the lime stabilization and partial replacement of organic soft soils below the subbase layer by compacted crushed stone. After the first year of production hall, first cracks occurred on the floor plate. Structural deterioration over time continued and precise geometrical measurement of the floor settlement started, Fig. 1. The continued settlement was progressive and additional cracks appeared.

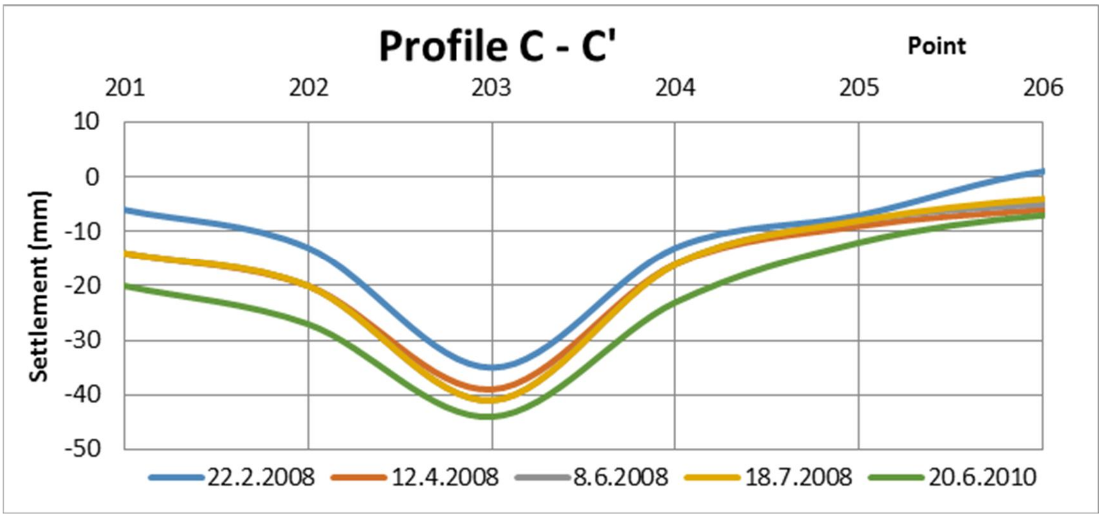

Figure 1. Example of measured floor settlement in profile C - C’

3.2 Causes of floor cracking and destructions

Ground improvement design by lime stabilization had a positive effect on the short time deformation resistance, the measured deformation modulus during construction time matched the design criteria and the crushed stone layer depth was capable to transfer load to the soft subsoil.

At this point designers missed an important calculation of serviceability limit state in the evaluation process, which is the settlement due to weak zone consolidation of the saturated clays and ground water level oscillation and its negative effect on the stress and lime stabilization layer [1, 4].

A simple 2D model was created to confirm the measured consolidation settlement and to predict future deformation with use of the FEM software Plaxis, Fig. 2.

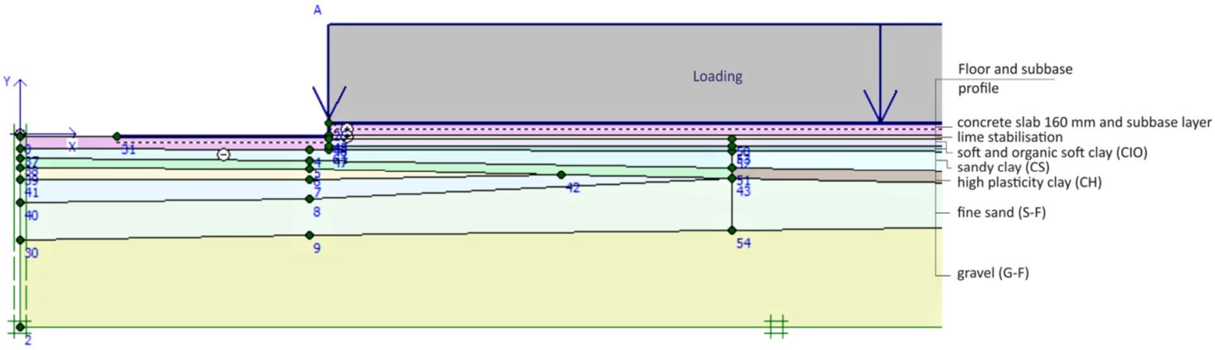

Figure 2. Model of the floor slab with subbase and loading

4 NUMERICAL MODELLING AND PREDICTIONS OF DEFORMATIONS

For adequate evaluation of the actual state of deformations and for prediction of another consolidation settlement, it was important to use an advanced material model and the Soft soil model (SS) [6] represented weak layers below the loaded floor structure. Calculation was arranged in six stages, including consolidation time after completion of the structure and time of loading and operation. It was supposed that loading from vehicles or work platform had the status of live loading, therefore any influence of them on the consolidation calculation was not considered. The penultimate step of consolidation was the calculated settlement at the time of realized geodetic measurement of floor deformation, which was 2.5 year after the floor completion. Calculated values of vertical deformations range from 27 to 51 mm, and they are in good agreement with the measured data of floor deformation. The final calculation was done for a period of 7.5 years, Fig. 3.

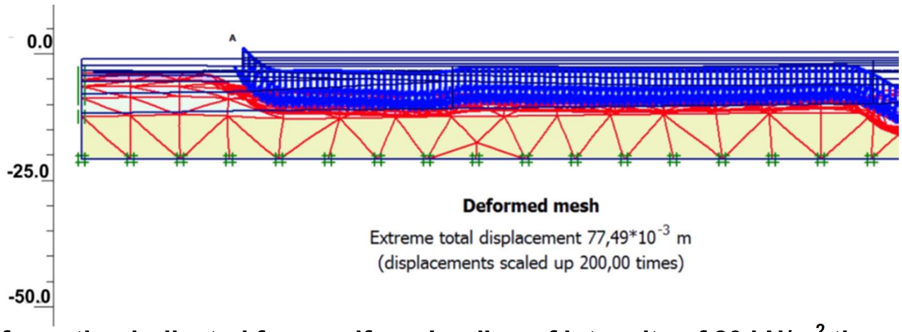

Figure 3. Deformation indicated from uniform loading of intensity of 20 kN/m^2 through the time of 7.5 years creates consolidation deformations of the values from 30 to 77 mm

Total incremental deformation from the year 2013 to 2015 is +2.3 mm; at the places of better support, the incremental deformations are lower. Another consolidation calculation stage after 5 years (2018) indicated an incremental deformation of +1.83 mm. At the time of 10 years after completion, the deformation through the consolidation of soft soils can be +3.86 mm.

Numerical model of the floor structure with subbase layers, as it was constructed in 2006, confirmed deformations, which were smaller at that time. The highest deformations took place within a period of 2 years, (tendency is not progressive) – roughly 0.5 mm/year. It would be optimistic to exclude other factors. This means changes in loading and oscillation of GWL in soil profile.

Therefore, the influence of GWL elevation was modelled with simple ground water change as a construction stage in the numerical model. Firstly, the deformations due to the GWL decrease in soil profile was calculated. This GWL change increased effective stress in soft soil and created space for another deformation in time without extra load. This influence caused + 11 mm of incremental settlement. With another stage of rising GWL after 6 months, (+1 m) to previous design level causing deformations at the level of small spring behaviour -8 mm. When the GWL dropped about 1 m, the resulting deformation within the next 6 months was 80 mm (+ 6 mm incremental).

The influence that is the most significant, is the loading change. A simple calculation with a raised loading to the intensity of 40 kN/m^2 caused an increase of deformation from 20 to 50 mm.

5 CONCLUSIONS

Calculated settlements are relatively similar to geodetic measurements during the period of observations; the received values were 20 to 30 mm, max. 81 mm, but these deformations are inadequately large and they exceed the limit states. Numerical analysis confirmed typical settlement over a period of 7.5 years of the floor operation, the value of new future settlement from consolidation is 0.5 mm/year, but there are other factors, which can cause deformation in the values from 10 to 30 mm/year. The reason for possible new deformations is the oscillation of ground water in profile, which has a significant influence on the settlement [7].

A simple numerical model with changing ground water level confirmed the relatively high influence on the stability of the weak zone under the subbase layer [8]. Possibly higher deformation can also be predicted from a deterioration of the lime stabilization layer and acting new load.

Therefore, it was recommended to design a complex remediation work of the floor structure in the hall. Proposed remediation work due to described geological conditions and realized subbase structure are the following:

- removal of the existing floor and of portion of the subbase layers to realize pile support (driven piles, bored piles, stone column with injection) with basal reinforcement of the subbase layer by geogrids,
- realization of jet grouting columns from the existing floor as a pile support system, followed by reparation of the floor slab and cracking zones,
- removal of floor slab, massive stabilization of the soft soil, and rebuilding of the subbase layer and concrete slab.

Final decision must take into account time factor of remediation, economy of work, and prices of the used new materials.

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