Foundation of industrial floors on improved soils

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Abstract. The floor slabs are structures placed directly on ground, with large dimensions in X and Y directions generated by storage space requirements. The proposed paper presents a brief analysis of the foundation of industrial floors on improved soils so that to provide an adequate wearing surface with acceptable deformations and rotations, on which operations can be performed efficiently and safely. The choice of the foundation type depends both on the nature of the subgrade, but also on the size of the loads at the level of the floor slab and on the imposed limits in terms of allowable settlements. All these criteria lead to the correct choice of the floor slab foundation system.

1 Introduction

Currently, the logistics warehouses market is in full development in Romania and Eastern Europe. The main elements in these warehouses are the floor slab and the storage systems (e.g., racks) which must take the loads and safely send them to the foundation soil. In general, the floor slabs are structures placed directly on ground, with large dimensions in X and Y directions generated by storage space requirements. The floor slab is constructed so that it must provide an adequate wearing surface with acceptable deformations and rotations, on which operations can be performed efficiently and safely. These large surface floors are expected to be built at the lowest possible costs and perform without issues year after year. The imposed loads and deformations together with foundation ground are the main elements that are designing the floor slab and its founding system. Considering the similarities of the floor slabs embankments to the road embankments, most of the technical guides that are used in the design of floor slabs embankments are also used in roads design. The major difference between industrial floors and roads is given by loads, namely: floors take mostly static loads, while roads are mainly required to take dynamic loads. The choice of the foundation type depends both on the nature of the subgrade, but also on the size of the loads at the level of the floor slab and on the imposed limits in terms of allowable settlements. All these criteria lead to the correct choice of the floor slab foundation system. In situations where the loads are high at the floor slab level and the settlement requirements are restrictive, combined with the placement of the floor slab on a weak ground (with low bearing capacity and/or highly compressibility), the need for soil improvement appears [1].

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2 Foundation of floor slabs

2.1 Slab-on-grade (shallow foundation)

The slabs-on-grade are realized through embankments formed of multiple compacted layers similar to those used in roads engineering. The main purpose of using multiple layers is to obtain a gradual transition of stiffness from the floor slab to the foundation ground (subgrade). The American Concrete Institute, ACI360R-10, divides the embankment into several horizons similar to those of roads as follows:

- **subgrade** which is most often represented by the natural soil to be compacted or by soil improved by the adding binders or by backfill compacted in elementary layers of materials with or without addition of binders
- **subbase** which generally consists of a granular material which, in addition to bringing a large contribution of load-bearing capacity and stiffness, also has the role of breaking capillarity
- **base layer** on which the floor slab is actually made. This layer can be made of a granular material stabilized with cement in order to increase the bearing capacity and stiffness

Analysing the three horizons described above, it is to be noticed that there is a gradual transition of stiffness from the floor slab to the foundation ground (subgrade).

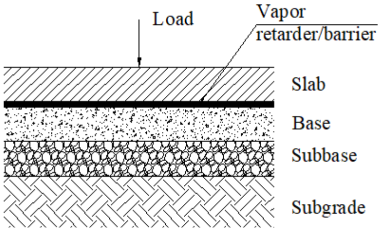


Fig 1. Slab support system terminology [1]

2.2 Slab-on- improved grade (shallow foundation on improved soil)

In situations where the loads are high at the floor slab level and the settlement requirements are restrictive, combined with the placement of the floor slab on a weak ground, the need for soil improvement appears. Basically, in this situation, from the three layers described above, the improvement it will be only for the subgrade layer. This solution is known as soil reinforcement. The soil reinforcement methods are for example with concrete columns, stone columns or with stone columns stabilized with cement. One of the methods which has experienced a fast development in the last years is the so-called „rigid inclusions" method [2].

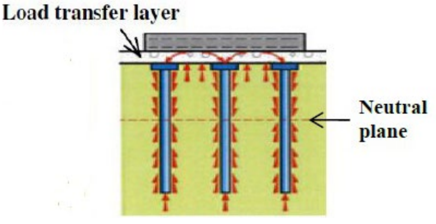
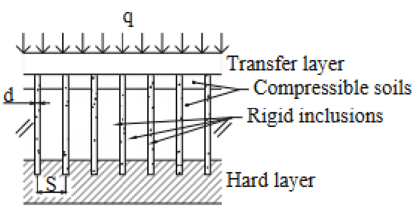


Fig 2. Rigid inclusions system [3]

This technique consists of a soil improvement method using in general non-reinforced concrete columns with a soil displacement method. The rigid inclusions are in general separated from the structure by a granular load transfer layer (embankment). This load transfer layer can be assimilated with the two layers described above (subbase and base layer).

3 Bases of design of improved soil with rigid inclusions

The goal is to install a set of inclusions in soils with low bearing capacity and/or highly compressibility to create a layer of compound soil-inclusions material that has better mechanical properties. The improvement or reinforcement of soils with rigid inclusions is commonly used to ensure bearing capacity and/or reduce settlements. The solution is characterized by the fact that the traditional mechanical link between the pile and the structure (floor slab) does not exist. A distribution layer, also called a Load Transfer Platform (LTP), is usually placed between the inclusions and the structure to be supported, and this is what marks the difference between piles and inclusions. The distribution layer (LTP) spreads the acting loads on the slab towards the underlying soil-inclusions setup. The system described is configured as shown in Figure 3 [2]. In this case, in a first step it will be a settlement of the transfer layer itself, then the settlement of the entire system. In this situation the floor slab can be reinforced with steel fibres which is the most common method for reinforced the concrete floor slabs in the warehouses. This system is suitable for those floor slabs which have to take over a common loads or even high loads but with not restrictive requirements regarding to allowable settlements.



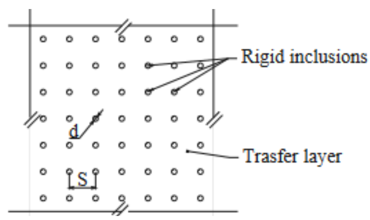
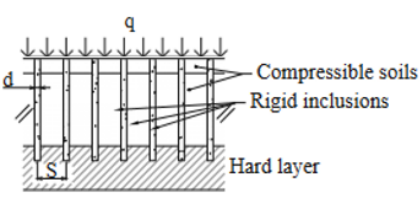


Fig 3. Inclusion under a load uniformly distributed on the surface. Side and top views. Case with LTP [2].

If there are high concentrated vertical loads combined with restrictive allowable settlements can be used to directly transmit the loads to the soil-inclusions setup. In this case, the rigid inclusions are directly in the contact with the concrete floor, and the settlements will be less than the case with LTP presented above (at least with the settlements of the transfer layer) because the concrete inclusions will mobilize immediately to take over the loads. In this situation the floor slab cannot be reinforced with steel fibres because at least in the area of rigid inclusion it appears bending moments and shear forces which cannot be taken with steel fibres. This system is suitable for those floor slabs which have to take over high loads but with restrictive requirements regarding to allowable settlements.



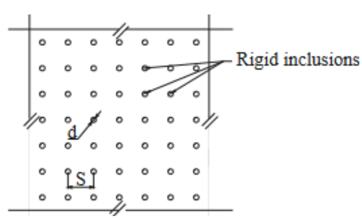


Fig 4. Inclusion under a load uniformly distributed on the surface. Side and top views. Case without LTP [2].

Depending of the thickness of the floor slab, can be adapt the spans between the rigid inclusions and this span can be bigger than the case with LTP. In this case can appear the necessity to reinforce the columns.

4 Analysis of soil improvement with R.I. use a design software

It will be analysed a ground floor slab which have to take over a common load of 5 tones/sqm with 30-40 mm allowable settlements located in an area with a weak soil from the compressibility point of view. The soil (subgrade) will be improved with rigid inclusions (R.I.). It will take into account the both cases namely with LTP and without. The lithology in the site is as follows:

Table 1. Soil lithology in the site and soil parameters

Layer	Depth m	E_{eod} kPa	ɣ kN/m^3	φ' °	c' kPa
Top soil	2.00	4000	17	10	10
Alluvial clay	4.80	6000	18	18	11
Clay base altered	5.80	14000	19	23	23
Base coat - clay	25.00	25000	19	23	30

The length of the columns is 6 m, diameter 40 cm and a grid 2.25x2.25 m. The grid, the diameter and the length of the rigid inclusions stay the same in the both cases. In the case with LTP the thickness of the transfer layer is 75 cm.

4.1 Case with LTP

In this case, the load is applied to the soil and to the column through an LTP, over a large uniform grid of columns which is assumed to be infinite [4].

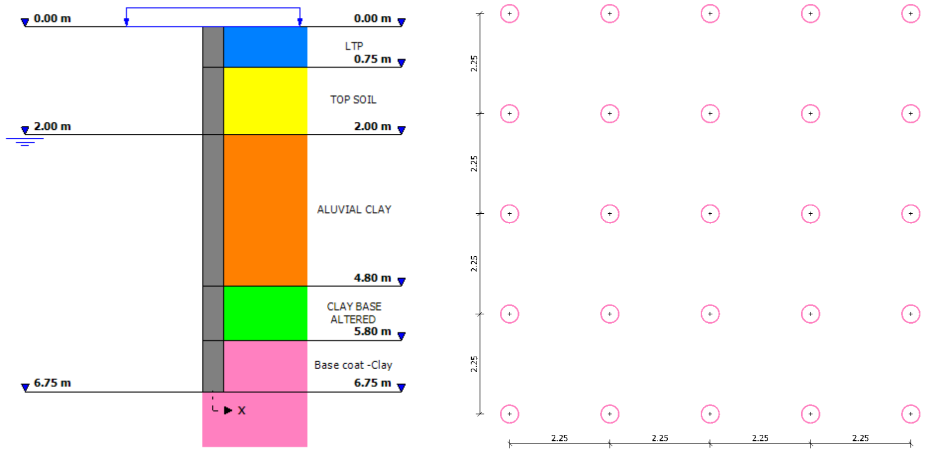


Fig 5. Design model [4]

Table 2. Soil parameters for the load transfer platform - LTP

Layer	Depth m	E_{eod} kPa	ɣ kN/m^3	φ' °	c' kPa
LTP	0.75	30000	19	30	0

This system can be analysed looking at a unit cell out of one column and the corresponding soil and preservation of the complete load in this unit cell system. New layers (for example the LTP) not replacing a previously existing layer can be considered as an additional load, which is applied progressively over the thickness of the new layers. The settlement of the soil is calculated using the constrained modulus E_{oed} and the stress in each sub-layer as a result of first the load applied on the soil on top and second its changes due to the load transfer to and from the column. For rigid slabs, an equal settlement of column and soil at the upper limit of the system is considered as a boundary condition. This system corresponds to the analytical calculation method for unit cells called "common spacing" in [3]. This unit cell model is appropriate for large loading areas, for which the assumption that no load propagation occurs over the length of the column can be made (sum of load in the column and in the soil remains the same at each depth level). Possible settlement group effects for columns close to each other are represented automatically in the unit cell approach for the layers with columns. The calculation gives a settlement over depth for column and soil, a distribution of positive and negative skin friction (only positive if no LTP) that means the mobilisation compared to the limit values and a distribution over depth of the load and stress in column and in soil (with overburden stress and without) [4]. In the below figure is shown the settlement obtain through calculation in the case with LTP.

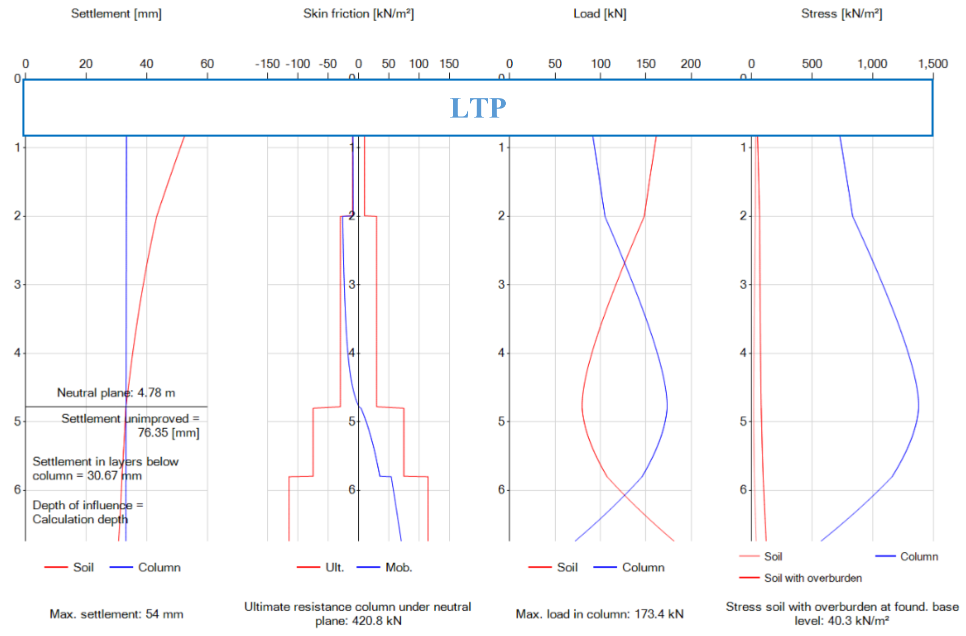


Fig 6. Results – case with LTP [4]

In the above picture it is indicated also neutral plan, which is located at 4.78 m depth, that means till 4.78 m depth on the inclusion appears negative skin friction.

The slab bending moments can be calculated after the plate load theory for a circular plate fixed at the edge under constant partial area load. The partial area loads applied on the plate are the load applied on top of the slab, the soil reaction directly under the slab from the LTM (Load transfer method) calculation, and the reaction of the column considering a diffusion of the column reaction in the load transfer platform (see Figure 7). The column reaction is calculated for the given diffusion slope with the load conservation theory (total load applied on top equals total soil reaction and total column reaction with dispersion) [4].

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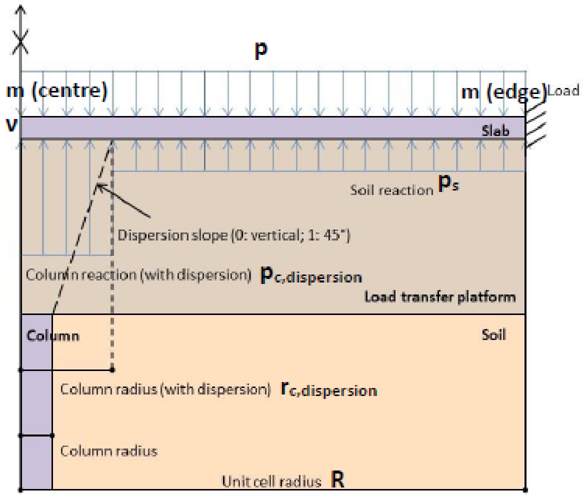

Fig 7. System for calculation of slab bending moments after plate load theory [4]

4.2 Case without LTP

In this case, the rigid inclusions are directly in the contact with the concrete floor, and that means that the loads are applied directly to the columns and the settlements will be less than the case with LTP. The earthworks under the floor slab in these situations consists only of the subbase layer of granular material that plays the role of a working platform. This layer is laid directly on the ground (subgrade). After the execution of rigid inclusions, the subbase layer provides a temporary support layer for the floor slab during its execution until the concrete become hard enough. In the below figure is shown the settlement obtain through calculation in the case without LTP.

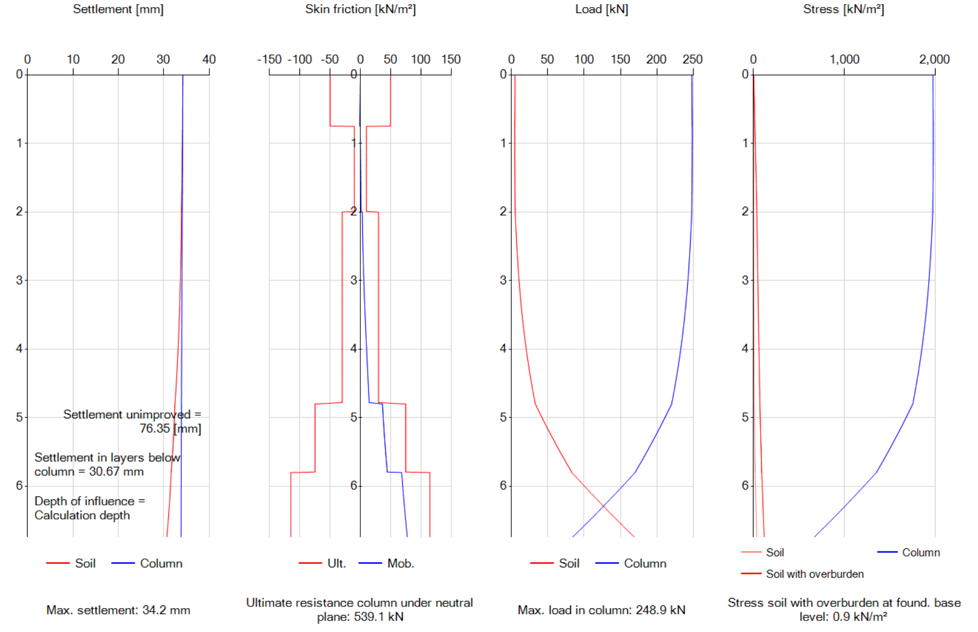

Fig 8. Results – case without LTP [4]

As we can see in the above picture, the settlement is less than the case with LTP with approximately 20 mm (54 mm with LTP towards 34.20 mm without LTP). Also, there is not anymore negative skin friction on the inclusion. It is noticed also the difference of the axial force in the column, in this case the axial force is bigger than the case with LTP. The settlement obtained in the case without LTP it is in the allowable range imposed.

5 Risks and challenges during execution of soil improvement with R.I.

During the rigid inclusions installation, it is very important to monitoring the adjacent inclusions were already executed especially if the spacing between the columns is less than 4 diameters. If spacing is 4 to 5 diameters, generally little to no influence. If the spacing is less than 4 diameters the following signs of adjacent influence can appear:

- horizontal ground displacement which may lead to lateral loads (cracking) or material rise (necking);
- vertical ground displacement which may lead to tension loads (cracking/breaking);
- increased pore pressure which may lead to reduce shear strength (necking);

Taking into account that in the most of the cases the inclusions are without reinforcement because of using LTP, usually a challenge is not to crack the heads of the inclusions during the LTP execution.

6 Conclusions

The floor slabs are structures placed directly on ground, with large dimensions in X and Y directions generated by storage space requirements.
If the floor slab is located in an area with a weak soil from the compressibility point of view, the need for soil improvement appears under the industrial floor so that to provide an adequate wearing surface with acceptable deformations and rotations, on which operations can be performed efficiently and safely.
The imposed loads and deformations together with foundation ground are the main elements that are designing the floor slab and its founding system.
The system with rigid inclusions and load transfer platform (LTP) is suitable for those floor slabs which have to take over a common loads or even high loads but with not restrictive requirements regarding to allowable settlements. In this situation the floor slab can be reinforced with steel fibres which is the most common method for reinforced the concrete floor slabs in the warehouses.
The system with rigid inclusions without load transfer platform (LTP) is suitable for those floor slabs which have to take over common loads or even high loads but with restrictive requirements regarding to allowable settlements. In this situation the floor slab cannot be reinforced with steel fibres but with steel nets. Depending of the thickness of the floor slab, can be adapt the spans between the rigid inclusions and this span can be bigger than the case with LTP.
Analysing the results obtained through calculation, it is noticed that the case without LTP it is the in range of imposed settlements.

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