Possible measures to reduce uneven deformation of floor structures of warehouse complexes

Tatyana Rytova¹ and Sergey Rytov²

¹Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia
²Gersevanov Research Institute of Bases and Underground Structures (NIIOSP) - JSC NITs Stroitelstvo, 109428, 59, building 1, Ryazansky prospekt, Moscow, Russia

E-mail: rytovsa@gmail.com, lab38@niiosp.ru

Abstract.
The article discusses measures to reduce uneven deformation of floor structures of warehouse complexes. The main goal was to identify ways to reduce the unevenness of sediment in the floors of the warehouse. To obtain optimal reinforcement of the floor structure of warehouses, to reduce unevenness of floor sediments, two methods are used: increasing the rigidity of floor structures and (or) increasing the rigidity of the base due to the use of piles or its reinforcement. This article presents the experience of applying the technology for converting the construction properties of soils using crushed stone reinforcing elements (vibro stone columns) when installing floors in warehouses. This technology allowed to reduce the deformation of the base of the floors, to reduce their reinforcement.

1. Introduction
One of the directions in construction is the construction of warehouse complexes. These are mainly warehouses, logistics complexes, hypermarkets with an increased storage area. At these facilities, the floors are subject to increased technical requirements for operational characteristics (for example, wear resistance, low deformability of the base of the floors). These complexes are characterized by high floor loads from stored materials, shelving, floor transport.

In Russia, regulatory documents on the floors of SP 29.13330.2011 [1], state standards for floor testing GOST R 56379-2015 [2], standards of STO NOSTROI 2.6.171-2015 [3] organizations on the quality of monolithic floors are in force. The standards give general requirements for materials and products when installing floors, set out the rules for the manufacture of floors with a cement concrete coating, with a concrete coating with a hardened top layer, with a coating of heat-resistant concrete, with asphalt concrete coating, etc. The issue of increasing the rigidity of the base of floor structures is not sufficiently considered in these documents; there are no requirements for regulatory deformations of the base.

In Western Europe, this problem is also relevant. The regulatory framework of the Russian Federation on technical requirements for the floors of industrial buildings is closest to European standards [4-6].
To obtain optimal reinforcement of the floor structure of warehouses, to reduce unevenness of floor sediments, two methods are used: increasing the rigidity of floor structures and (or) increasing the rigidity of the base.

In the first case, new types of coatings, floor slab technology are being developed. In the works of Voilokov I.A., Gorba A.M. [7-12] presents a two-layer type of coating for industrial floors using a wear layer of steel fiber concrete. The use of steel fiber as a reinforcing factor for the wear layer of industrial floors reduces the labor costs and the cost of installing floors in comparison with traditional methods of coating reinforcement. The use of dispersed reinforcement with steel fiber makes it possible to obtain effective reinforcement with a concentrated load from the racks of shelving in warehouses. This coating has high performance characteristics (high strength characteristics, crack resistance, wear resistance), in comparison with traditional coatings of industrial floors made of concrete and reinforced concrete.

A significant number of works consider the advantages and disadvantages of types of coating for industrial floors, but these works do not contain an analysis of possible uneven floor sediments from high loads during operation and methods to eliminate them.

One way to solve this problem is to reduce the deformation of the base by converting the properties of the soil. One of the methods for transforming soil properties is to reinforce the base with crushed stone reinforcing elements (vibro stone columns). In [13-14], the experience of applying the technology for converting the construction properties of soils using crushed stone reinforcing elements in civil and residential construction is given. This technology is widely used in Europe [15].

This article describes the practical experience of increasing the rigidity of the base of the floors due to the use of injection piles and crushed stone reinforcing elements for trade and storage and logistics complexes in the Moscow region (Russia).

2. Materials and methods

The floor structure is generally calculated as a slab on an elastic soil base. At the same time, technogenic highly compressible bulk soils serve as the base of the floors. As a rule, the deformation characteristics of bulk soils in the process of engineering and geological surveys are not determined.

Warehouse complexes are characterized by high pressure values from the support racks of the racks, a large award area. Robotization of warehouse complexes with a laser positioning system requires a significant reduction in uneven floor sediments (inadmissibility of significant non-uniform floor sediments).

Often, when uneven sediments of floor structures occur, it is necessary to suspend the operation of an industrial building to carry out restoration repairs and prevent the creation of emergency situations. Which is very laborious due to the lack of economical and fast repair technologies.

The choice of a constructive solution of the floor is carried out from the operating conditions, the adopted constructive decisions of the floor should ensure the reliability and durability of the floor, the minimum cost of installation and operation. In fig. 1 shows the types of floor structures in the logistics complex.

According to the joint venture [16], when setting the normative load in warehouses, the equivalent uniformly distributed floor load should be taken into account. This type of load is assigned taking into account the specific gravity of the stored material, distributed over the area of the room. According to the joint venture [16], the normative value of a uniformly distributed load should be taken for trading warehouses of at least 5.0 kN / m2 (0.5 tf / m2), for industrial storage facilities for slabs of at least 3.0 kN / m2 (0.3 tf / m2), the standard value of concentrated load not less than 6.0 kN (0.6 tf) for trade warehouses and not less than 3.0 kN (0.3 tf) for industrial storage facilities.

When calculating floor designs, it is necessary to take into account a number of mechanical effects, such as loads concentrated on a limited area: stationary (from equipment, shelving) and temporary (from individual products, supports), indicating: the total and specific load on the floor, shape and size traces of supporting objects, the possible closest approximation of places of application of loads during installation, operation.
The peculiarity of the distribution of technological loads on the floor lies in the layout of equipment and a rack with stored materials (Fig. 2).

According to the joint venture [1], traces of bearing loads must be divided into elementary areas of simple geometric shape (rectangle, square). When supporting racks of racks, the length and width of elementary platforms is taken equal to 0.3–0.5 distances from their center of gravity to the design center (Fig. 3). When placing racks in several rows, the same elementary areas are placed symmetrically with respect to the coordinate axes.

According to the joint venture [1], when applying a hard underlying layer to prevent floor deformation during building upset, it is desirable to provide a cut-off from the columns (Fig. 4). If this cut-off is absent, then part of the load from the power floor structure will be transferred to the column and the foundation under it will be loaded. In fig. Figure 5 shows an uneven draft of the floor base in the trade and warehouse complex of the Moscow Region.

According to the requirements of the joint venture [1], the soil subfloor must perceive the distributed load transmitted through the underlying layer, from the condition of strength and reduction of vertical floor deformations.

The underlying layers are calculated by the method of limiting states on the action of vertical loads from stored materials and technological equipment. I count the floor constructions as unsuitable for normal use due to loss of bearing capacity and as unsuitable for normal use due to the formation and excessive opening of cracks and the appearance of unacceptable deformations.

According to [1], when calculating hard underlying layers in strength, the condition must be met:

$$M_p \leq M_{ult}$$

where $M_p$ – calculated bending moment in the considered section of the underlying layer, $M_{ult}$ – ultimate bending moment in the considered section of the underlying layer.

Estimated bending moment $M_p$ in the underlying layer, located on the foundation soil, when a load is applied to the floor, evenly distributed over the footprint in the form of a rectangle, is determined by the formula:

$$M_p = k \cdot P_p$$

where $P_p$ – the design load acting over the entire area of the track, multiplied by the reliability coefficient for the load, equal to 1.2 under the action of loads from stored materials, $k$ - trace-based coefficient.
Ultimate bending moment $M_{ult}$ taken according to the formula for concrete sections of floors with structural reinforcement:

$$M_{ult} = R_{ult} \frac{h^2}{3.5}$$

(3)

where $h$ – the thickness of the underlying layer. If the base is stiffened, bending moments in the floor structure can be reduced.

**Figure 2.** Placement of racks in a warehouse

**Figure 3.** Layouts in terms of loads and separation of load tracks into elementary areas
In [7], it was shown that the actual distribution of base loads significantly differs from that recommended in regulatory documents.

In industrial and warehouse facilities, floor structures are erected after the frame is completely installed. As a rule, the base of the floors is bulk, highly compressible soils, which can cause uneven long-term deformations, which significantly complicates the operation of the complex and complicates the work to eliminate the resulting deformations. Below is an example of the correction of floor deformations of a shopping and warehouse complex.

The retail and warehouse complex in the Moscow Region is a one-story building with dimensions of ≈ 100x40 m in plan. A pile foundation is designed for the building frame. The floor slab is designed from monolithic concrete B25 W4 F75, the slab thickness is 250 mm. The floor plate is made on top of a compacted base, consisting of: compacted gravel of a grade not lower than M600 according to GOST 8267-97 with a rivet, base thickness - 150 mm, compacted sand of medium size, with a compaction factor of at least 0.96.

After the complex was erected, cracks with an opening width of up to 2 mm (Fig. 6) and widespread subsidence were fixed in the reinforced concrete floor slab. When examining the facades of the building, the following defects were recorded: ubiquitous drawdown (up to 10 cm) of the blind area along the perimeter of the building, localized areas of destruction of the blind area, destruction of individual facade plates. The following defects were recorded in the interior of the building: subsidence (up to 3 cm) of floors in local areas, cracks in the joints of floor tiles, opening widths of up to 1 mm. The reason for the appearance of fixed defects is the uneven precipitation of the soil of the base of the floors of the building.
A decision was made to strengthen the floor of the building with its support on brown injection piles with a diameter of 180 mm and a length of 7 m along a 2.4-2.6 m grid and the use of interior height-adjustable partitions.

3. Results

To reduce the cost of installing the base under the floors of the logistics complex, NIIOSP specialists considered the option of converting the properties of the base soil by installing crushed stone reinforcing elements. According to the statement of work, the calculated floor load is 80 kN/m² (8.0 tf/m²), the permissible draft is 50 mm.

This technology is widely used in Europe [15]. The technological scheme of the device is shown in Fig. 7.

To confirm the results of preliminary calculations, NIIOSP conducted field stamp tests of the transformed base with a 3.0 × 3.0 m stamp in four test plots in accordance with GOST 20276-2012 for a pitch of reinforcing elements of 2.5x2.5 m and 1.5x1.5 m. A general view of the test bench is shown in Fig. 8-9. The tests performed showed that the deformation modulus of the transformed base soil increased to 30%. The increase in the rigidity of the base reduced bending moments in the floor structure, reduced the required reinforcement. Reinforcing crushed stone elements play the role of drains, therefore, the time for consolidation of the base soil has been reduced.

Figure 6. Uneven floor settlement of the shopping and warehouse complex
Figure 7. Schematic diagram of the construction of crushed stone reinforcing elements (vibro stone columns): a - well construction by immersion of ramming equipment with a lost tip; b - crushed stone feed into the well with phased extraction of ramming equipment; c - compaction of the sole of crushed stone reinforcing elements by ramming crushed stone; g - layer-by-layer compaction of crushed stone

Figure 8. Test bench layout
4. Conclusions
Based on the foregoing, the following conclusions can be drawn:

1. When designing the floors of warehouse complexes, it is necessary to take into account the specifics of the distribution of technological loads on the floors from racks with stored materials, from technological equipment.

2. The actual distribution of loads on the soil of the base is significantly different from that recommended in regulatory documents.

3. The requirement for deformations of the base of the floors has not been worked out in detail, which is especially important when robotizing warehouse complexes with a laser positioning system.

4. Correction of uneven base sediments during operation is a rather time-consuming and costly undertaking.

5. One of the ways to reduce uneven sediments of the base of the floors is the use of piles or the transformation of soil properties with reinforcing crushed stone elements (vibro stone columns).

6. To determine the characteristics of the converted soil reinforced with crushed stone elements, it is necessary to use field methods (stamp tests according to GOST 20276-2012).

7. This technology of soil transformation with crushed stone reinforcing elements reduces bending moments in the floor structure, reduces the required reinforcement, and reduces the time for consolidation of the soil base.

8. Vibro stone columns can be used for road construction.

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