Increasing of strength-rigidity parameters of bases of metallic silos

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Abstract. To date, effective codes of Ukraine limit settlement of foundations of metallic silos to 15 cm. To provide normative settlement of foundation with diameter up to 40 m and more is not always possible without additional essential measures for strengthening or changing base soils. Taking into account high levels of loads, soils of bases in natural condition can not carry stress under the base of foundation and require strengthening. Execution of works on change of soils of bases or installation of soil cushions is not always possible taking into account underflooding of territory, building development that exist near at hand, or other complicating factors. Soil cement after Deep Soil Mixing (DSM) technology, Jet Grouting, injection and micropiles were considered for different types of strengthening taking into account application in great volumes. From analysis of the obtained results, it was determined that soil cement after Deep Soil Mixing technology is the most economically justified method. Application of Jet Grouting is justified during strengthening of soil thicknesses locally separated by depth. Injection and micropiles are used appropriately only in conditions of reconstruction under absence of direct access to the base.

1. Introduction

Ensuring of reliability and safety of operation of metallic silos with the goal of decreasing of foundation settlements is topical both for new building and for objects already brought into operation [1–5]. Taking into account requirements of effective land legislation to efficient land management, new building is planned on plots unsuitable for agriculture. Therefore, topical is the need of using development sites characterized by complicated geotechnical conditions. At present a considerable part of metallic silos for storing of grain crops in Ukraine is built in such conditions [6–8]. Now, effective codes of Ukraine limit foundation settlements of metallic silos up to 15 cm. To ensure normative settlement of foundation with diameter up to 40 m and more is not always possible without additional substantial measures for strengthening or replacement of soils [8,9].
2. Aim
Application of “parametric” strengthening of soil for foundations of big dimensions, which makes it possible to optimize stress-deformed state of foundation, its settlement and to increase reliability of operation of foundation and structure as a whole by way of examples of application of soil cement by Deep Soil Mixing technology (DSM), Jet Grouting, injection and micropiles.

3. Tasks
On the basis of analysis of practically realized methods of strengthening of soils of base of metallic silos from the viewpoint of technology of execution of big volumes of work (equipment, materials, method of arrangement), to calculate and compare indicators of their economy, to present generalized indicators for application in engineering methods during selection of rational methods of strengthening of soils of bases characterized by complex geotechnical conditions.

4. Methodology
Building of agro-industrial objects in Ukraine most frequently occurs in complicated geological and hydro-geological conditions. Considering high levels of loading, base soils in natural state are not capable to take up stresses under foundation foot and require strengthening. Territories on collapsible, filled, silted or peat soils most frequently belong to building sites that require strengthening.

Execution of works to replace base soils or to arrange soil cushions is not always possible taking into account high level of ground water, existing development or other complicating factors.

Strengthening parameters are determined from conditions of given settlement of building or structure in particular soil conditions under given level of loading [10].

Plate foundations on natural and artificial bases and plate-pile foundations are most widespread as foundations of granaries of silo type on soft soils. Long-term experience of operation of such silos [11, 12] and numerous examples of observation of built silos performed by the authors of this investigation indicate inevitability of essential risk when using soft soils as foundation base. In the process of designing it is necessary to consider also essential mutual influence of neighboring silos on settlement of their bases. A peculiarity of stressed state of silo bases is in cyclic influence of pressure from periodic loading and unloading of grain into silos, so this requires obligatory precise geodesic observations of such structures. Way out of this situation is increasing of load-carrying capacity of soils by reinforcing of base under structures.

By reinforcement of base is meant improvement of physical-mechanical properties of soil mass by arrangement of more strong and rigid elements that work in common with soil but are not connected structurally with foundation (figure 1). Strengthening of base by reinforcement is based on interaction of soil with inclusions in the form of elements of increased rigidity from stabilized or compacted soil or other materials. The necessary parameters of rigidity and strength of bases are achieved through arrangement of more rigid and strong elements in soil, that have good bond and friction with natural soil. Depth of reinforcement and step of arrangement are calculated and taken depending on necessary strength-rigidity parameters of reinforced soil. The placement of reinforcement elements depends on technology of their fabrication [13, 14].

To reinforce base it is possible to use different kinds of piles – precast-concrete, auger cast, grout-injected and soil cement elements.

One efficient trend in decreasing of cost of pile foundations is the use of soils that lie in the base of buildings and structures. For this purpose vertical reinforcement is arranged, which is carried out with the use of base soils strengthened by cement mortar – soil cement elements (SCE).

Reinforcing of bases by soil cement elements is reasonable in cases of high depth of soft soils and deep arrangement of bearing soil layer. Application of piles in such soil conditions requires
substantial length of piles to rest on bearing layer of soil.

Method of strengthening of soft soil by soil cement elements makes it possible to ensure bearing capacity of foundation and to maintain normative settlements without substantial penetration along the depth of geologic section. The depth of compressible thickness of soil under silo foundations usually does not exceed 15 m. Thus, if the depth of soft soils of building site exceeds the mentioned value, then it is reasonable to use soil strengthening for arrangement of foundation base instead of pile base.

Otherwise there arises the necessity to use augercast or grout-injected piles, or components of precast concrete piles to reach the depth of bedding of bearing soil layer. In such conditions deadlines and cost of building increase substantially.

Figure 1. Strengthening of the base by vertical elements of the silo base in urbanized settlement uts. Dniprov’s’ke of Dnipropetrov’s’k region: 1 – silo foundation, 2 – sand from riddlings of crushing of igneous rocks, 3 – foundation mat, 4 – soil cement elements 505 mm in diameter, 8 m in length, 5 – damper layer from crushed rock size fraction 20-40 mm, 6 – silo axis.

Soil cement bored piles have all advantages of bored piles, but technology of their arrangement completely excludes the necessity for additional provision of stability of bore walls in any
geotechnical building conditions including complicated ones [15,16].

One of the most important characteristics of soil cement from the viewpoint of its structural operation is mechanical strength and its increase with time. Investigations show that strength of soil cement increases with time, and such process can continue for years [17]. Increase in temperature and humidity of environment substantially accelerates the process of solidification of soil cement. When soil cement is in water, more intensive increase in strength is observed. This undoubtedly indicates that being in water-saturated soils is the most favorable for solidification of soil cement [18].

Placement of reinforcement elements depends on technology of their fabrication. Soil cement elements can be obtained by using Deep Soil Mixing technology (DSM), Jet Grouting. Deep Soil Mixing technology is the most widespread in the Ukraine’s territory.

Efficiency of this technology consists in low consumption of materials, machines, and energy. In reinforcing of soils by Deep Soil Mixing technology only 15-20% of cement are used, the other 80-85% fall on soil that is strengthened. Strengthening of soil by Deep Soil Mixing technology is used in different directions – vertical, at an angle, and horizontal depending on drilling rigs that are used. Vertical reinforcement is used most frequently for preparation of bases of buildings and structures [19].

Deep Soil Mixing technology of arrangement of soil cement most frequently is performed with diameters up to 650 mm and depth up to 10 meters. This is connected with the present-day technical possibilities of soil mixing with necessary rate of rotation and the number of passes in the borehole. Also, the limitations of Deep Soil Mixing technology are arrangement of soil cement in the whole borehole from the surface of pit to the bottom of the borehole. Unlike Deep Soil Mixing technology, soil cement elements in Jet Grouting technology have larger diameters, and diameters less than 700 mm are even difficult to arrange. Jet Grouting technology makes it possible to arrange soil cement elements from any depth from the surface (most frequently to arrange horizontal grout curtains). Thus, with the help of Jet Grouting technology it is possible to strengthen interlayers of soft soils that lie deep (up to 100 m). Advantage of soil cement is the possibility to fabricate reinforcement elements in water-saturated soils.

Jet Grouting technology makes it possible to create soil cements elements of various diameters depending on the kind of soil (from 0.7 to 5 m). But presence of different layers of soils when drilling vertical borehole does not make it possible to maintain the same diameter of the pile along the length. And if stones or hard inclusions are encountered, “shade” in the form of unfilled soil arises behind them.

One more disadvantage of Jet Grouting is increased leakage of soil cement in the process of formation of soil cement piles compared to Deep Soil Mixing technology. During leakage, loss of cement mortar takes place, which correspondingly raises the cost of production of soil cement.

5. Results

Indicators of examples of projects on strengthening of bases under metallic silos realized in Ukraine are presented in tables 1-4 and figures 1-7.

Analysis of constructional designs for strengthening of silo bases indicates dominant use, as a means for strengthening of bases, of piles fabricated by Deep Soil Mixing technology for new building (figure 8).

Analysis of parametrical indicators for different objects of building is presented in table 4. One can see essential dependence of consumption of strengthening material on geological conditions and inessential – on loads and dimensions of foundation (figure 9, figure 10).

To substantiate economically appropriateness of application is possible after comparing variants of arrangement of base by strengthening of soil or by use of piles taking into account indicator of cost.
Table 1. Parameters of foundations of silos and artificial bases.

| Object number | Object name                                                                 | Silo diameter (m) | Depth of laying (m) | Constructional design of foundation | Silo height H (m) |
|---------------|------------------------------------------------------------------------------|-------------------|---------------------|-------------------------------------|-------------------|
| 1             | Sumy region, Krolevetsky distr., t. Krolevets’ (figure 2, 3)               | 27.5              | 1.2                 | Reinforced concrete,                 | 29.7              |
|               |                                                                              |                   |                     | with under-silo storey               |                   |
| 2             | Sumy region, Krolevetsky distr.                                            | 22.5              | 1.6                 | Reinforced concrete,                 | 24.0              |
|               |                                                                              |                   |                     | with underground gallery             |                   |
| 3             | Chernigiv region, Bakhmatsky distr.                                        | 27.5              | 2.5                 | Reinforced concrete,                 | 29.7              |
|               |                                                                              |                   |                     | with underground gallery             |                   |
| 4             | Chernigiv region, Borznyans’ky distr., v. Velyka Doch (figure 4, 5)       | 24.0              | 2.6                 | Reinforced concrete,                 | 24.0              |
|               | Dnipropetrovs’k region, Verkhn’odniprovs’ky distr., uts. Dniprovs’ke,    |                   |                     | with underground gallery             |                   |
|               | Kyivs’ka str., 1 (figure 1)                                                 |                   |                     |                                     |                   |
| 5             | Kharkiv region, Novovodolaz’ky distr., v. Palatky                           | 9.2               | 1.5                 | Reinforced concrete,                 | 19.25             |
|               |                                                                              |                   |                     | with underground gallery             |                   |
| 6             | Kharkiv region, Krasnograd’s’ky distr., v. Dobren’ka                       | 22.5              | 1.6                 | Reinforced concrete,                 | 24.0              |
|               |                                                                              |                   |                     | with underground gallery             |                   |
| 7             | Krasnohors’ky distr., v. Doksy                                               | 27.5              | 2.4                 | Reinforced concrete,                 | 17.5              |
|               |                                                                              |                   |                     | with underground gallery             |                   |
| 8a            | t. Zaporizhzhya                                                             | 27.5              | 1.6                 | Reinforced concrete,                 | 29.7              |
|               |                                                                              |                   |                     | with underground gallery             |                   |
| 9a            | t. Zaporizhzhya, Zaporizhchien OEP                                         | 22.0              | 1.6                 | Reinforced concrete,                 | 30.7              |
|               |                                                                              |                   |                     | with underground gallery             |                   |
| 10            | Sumy region, t. Shostka (figure 6)                                          | 27.5              | 2.4                 | Reinforced concrete,                 | 29.7              |
|               |                                                                              |                   |                     | with underground gallery             |                   |
| 11            | Lugansk region, t. Svatove                                                | 32.0              | 2.6                 | Reinforced concrete,                 | 37.4              |
|               | Kharkiv region,                                                             |                   |                     | plate grillage                       |                   |
| 12            | Valkiv’ky distr., uts. Kov’yag (figure 7)                                  | 22.5              | 1.1                 | Reinforced concrete,                 | 24.0              |
|               |                                                                              |                   |                     | plate grillage                       |                   |

* Objects already built, where strengthening of the base was necessary in connection with above-normative settlements.
Figure 2. Water lowering before performing works on exploitation of pit and reinforcing silo base in t. Krolevets’ of Sumy region.

Figure 3. Arrangement of silo foundations on the base of strengthened soil in t. Krolevets’, Sumy region.

Figure 4. Strengthening of silo base by vertical soil cement elements in v. Velyka Doch, Chernigiv region.

Figure 5. Arrangement of damper layer over reinforced base of silo by vertical soil cement elements in v. Velyka Doch, Chernigiv region.

Figure 6. Arrangement of crushed rock cushion on sand soils under silo foundation in t. Shostka of Sumy region.

Figure 7. Strengthening of base by built-up reinforced concrete piles under foundation of silo with underground gallery in uts. Kov’yagy of Kharkiv region.
Table 2. Geotechnical conditions, mechanical and deformation characteristics of bases.

| Object number | Object name | Average pressure under foundation foot $p$ (MPa) | Average modulus of deformation $E$ (MPa) | Average settlement $S$ (cm) | Type of geological conditions |
|---------------|-------------|-----------------------------------------------|----------------------------------------|-----------------------------|-------------------------------|
| 1             | Sumy region, Krolevets'ky distr., t. Krolovets’ | 0.24                                         | 14.3                                   | 11.8                        | Soft soils in the higher zone and buried vegetable soil layer at depth 15 m |
| 2             | Sumy region, Krolevets’ky distr.                 | 0.22                                         | 12                                     | 27                          | Soft interlayer of soil |
| 3             | Chernigiv region, Bakhmats’ky distr.            | 0.23                                         | 14                                     | 14                          | Soft soils in the higher zone and buried vegetable soil layer at depth 5 m |
| 4             | Chernigiv region, Borznyans’ky distr., v. Velyka Doch | 0.22                                         | 12                                     | 13                          | Soft soils in the higher zone and buried vegetable soil layer at depth 16 m |
| 5             | Dnipropetrovs’ky region, Verkhni’odniprovs’ky distr., uts. Dniprivs’ke, Kyivs’ka str. 1 Kharkiv region, | 0.15                                         | 14                                     | 9.7                         | High thickness of soft soils |
| 6             | Novovodolaz’ky distr., v. Palatky Kharkiv region, | 0.22                                         | 12                                     | 22                          | High thickness of soft soils |
| 7             | Krasnograts’ky distr., v. Dobren’ka Kharkiv region, | 0.18                                         | 15                                     | 9.1                         | High thickness of soft soils with laying of sands at depth 6 m |
| 8             | t. Zaporizhzhya                                  | 0.22                                         | 14                                     | 12                          | High thickness of soft collapsible soils with laying of sands at depth 18 m |
| 9             | t. Zaporizhzhya, Zaporizhien OEP                | 0.22                                         | 16                                     | 4                           | High thickness of soft collapsible soils with laying of sands at depth 24 m |
| 10            | Sumy region, t. Shostka                          | 0.23                                         | 23                                     | 8                           | Sand soils with soft loose sands in the higher zone |
| 11            | Lugans’k region, t. Svatove                      | 0.16                                         | 28                                     | 6                           | High thickness of soft soils with sand laying at depth 8 m |
| 12            | Kharkiv region, Valkivs’ky distr., uts. Kov’yugy | 0.22                                         | 18                                     | 5                           | High thickness of soft soils with laying of semi-hard clay at depth 12 m |
Table 3. Constructional design for strengthening of base and parametrical indicators.

| Object number | Object name | Type of artificial base | Volume of material (m$^3$) | Silo capacity (ths. m$^3$) | Specific consumption (m$^3$/ths. m$^3$) |
|---------------|-------------|-------------------------|---------------------------|--------------------------|----------------------------------------|
| 1             | Sumy region, Krovelets'ky distr., t. Krovelets' | Soil cement elements 500 mm in diameter, 4 m in length (SCE-0.5-4.0), step of SCE in both directions 1150x1150 mm | 512.8 | 12.5 | 41 |
| 2             | Sumy region, Krovelets'ky distr. | Jet Grouting of soft layer of soil at depth 3.5 m | 379.94 | 6.25 | 60.8 |
| 3             | Chernigiv region, Bakhmats'ky distr. | Soil cement elements 505 mm in diameter, 8.0 m in length, (SCE-0.505-8.0), step of SCE in both directions 1200x1200 mm | 856 | 12.5 | 68.5 |
| 4             | Chernigiv region, Borznyans'ky distr., v. Veluka Doch | Soil cement elements 650 mm in diameter, 3.5 m in length, (SCE-0.65-3.5), step of SCE in both directions 1500x1500 mm | 295.68 | 7.5 | 39.4 |
| 5             | Chernigiv region, Verhv'odniprovs'ky region, Dnipropetrovs'ky | Soil cement elements 505 mm in diameter, 8.0 m in length, (SCE-0.505-8.0), step of SCE in both directions 1200x1200 mm | 83.2 | 0.9 | 92.4 |
| 6             | Kharkiv region, Novovodolaz'ky distr., v. Palatky | Injection down to depth 4.5 m is required | - | - | - |
| 7             | Kharkiv region, Krasnograd's'ky distr., v. Dobren'ka | Soil cement elements 500 mm in diameter, 5 m in length, (SCE-0.5-5.0), step of SCE in both directions 1400x1400 mm | 410 | 7.5 | 54.7 |
| 8             | t. Zaporizhzhya | Soil cement elements 650 mm in diameter, 5.0-15.0 m in length, (SCE-0.650-5.0...15), step of SCE in both directions 1200x1200 mm | 1730.4 | 12.5 | 138.4 |
| 9             | t. Zaporizhzhya, Zaporizhien OEP | Soil cement elements 505 mm in diameter, 10.0 m in length, (SCE-0.505-10), step of SCE in both directions 1000x1000 mm | 850 | 7.5 | 113.3 |
| 10            | Sumy region, t. Shostka | Crushed rock cushion | - | - | - |
| 11            | Lugansk region, t. Svatove | Piles C 10.0-40-11, 277 in number. | 443.2 | 25 | 17.7 |
| 12            | Kharkiv region, Valkivs'ky distr., uts. Kov'yagy | Piles C 14.0-35-9, 107 in number. | 183.505 | 6.25 | 29.4 |
### Table 4. Reduced parametric indicators.

| Object number | Object name                                                                 | Depth of reinforcement/strengthening of base (m) | \( k_a \) (m²/th. m³) | Indirect step of SCE (m) | \( k_{lb} \) (m/th. m³) | \( k_{lc} \) (m/th. m³ × MPa) |
|---------------|-------------------------------------------------------------------------------|-----------------------------------------------|----------------------|------------------------|--------------------------|--------------------------------|
| 1             | Sumy region, Krovelets'ky distr., t. Krovelets'                             | 4                                             | 10.26                | 1.15                   | 8.92                     | 37.16                          |
| 2             | Sumy region, Krovelets'ky distr.                                             | 3.5                                           | 17.37                | 2.0                    | 8.68                     | 39.47                          |
| 3             | Chernigiv region, Bakhmats'ky distr.                                        | 8                                             | 8.56                 | 1.2                    | 7.13                     | 31.01                          |
| 4             | Chernigiv region, Borzynyans'ky distr., v. Velyka Doch Dnipropetrov's'ky region, | 3.5                                           | 11.26                | 1.5                    | 7.51                     | 34.13                          |
| 5             | Verkhn'odniprovs'ky distr., uts. Dniprov's'ke, Kyiv's'ka str. 1              | 8                                             | 11.56                | 1.2                    | 9.63                     | 64.20                          |
| 7             | Kharkiv region, Krasnoyars'ky distr., v. Dobrena'ka                         | 5                                             | 10.93                | 1.4                    | 7.81                     | 43.39                          |
| 8             | t. Zaporizhzhya                                                             | 13                                            | 10.65                | 1.2                    | 8.87                     | 40.34                          |
| 9             | t. Zaporizhzhya, Zaporizhzhya, Zaporizhzhya, OEP                            | 10                                            | 11.33                | 1.0                    | 11.33                    | 51.52                          |
| 11            | Lugans'k region, t. Svatove                                                | 10                                            | 1.77                 | 1.7                    | 1.04                     | 6.5                            |
| 12            | Kharkiv region, Valkiv's'ky distr., uts. Kov'yagy                            | 14                                            | 2.1                  | 1.93                   | 1.09                     | 4.95                           |

\( a \) Specific consumption of material of strengthening per unit length of reinforcement element.

\( b \) Specific consumption of material of strengthening per unit length of reinforcement element and indirect step of elements.

\( c \) Ratio of specific consumption of strengthening material to loading on unit length of reinforcement element and indirect step of elements.

Reduced indicators of specific consumption of strengthening material per unit length of element show likeness of specific consumptions in arrangement of piles. Reduced indicator \( k_l \) gives possibility to predict material consumption for reinforcement of soil having results of geological explorations.

Choice of step of arrangement of soil cement elements influences the value of minimal thickness of damper layer. Usually thickness of damper layer is from 400 mm to 700 mm. Increase of thickness of damper layer caused by increase of step of reinforcement elements causes increase of cost and time of building. Reduced indicator \( k_{ls} \) allows predicting material consumption for strengthening of soil taking into account indirect step of elements.
Figure 8. Comparison of different kinds of strengthening of silo bases.

Figure 9. Reduced indicators of consumption of material on length of elements: ■ – Depth of reinforcement, (m); □ – specific consumption of material of strengthening per unit length of strengthening element, $k_1$ (m$^2$/ths m$^3$).
Figure 10. Reduced parametric indicators of consumption of material taking into account step of elements and load on base: – Step of soil cement elements, (m); – specific consumption of material of strengthening per unit length of reinforcement element and indirect step of elements, k_{ls} (m/th. m$^3$); – ratio of specific consumption of strengthening material to load on unit length of reinforcement element and indirect step of elements, k_{lsp} (m/(th. m$^3$ MPa)).

Reduced coefficient k_{lsp} determines ratio of specific consumption of material used to strengthen base to load on unit length of element taking into account indirect step of elements. The coefficient can be used in designing silos of decreased height or silos of core enterprises for grain crops that are smaller in specific consumption than standard (wheat). Noteworthy is universality of Deep Soil Mixing technology of arrangement of SCE to strengthen bases. Thus, by changing distance between soil cement elements and their dimensions it is possible to make strengthening of soils in any geotechnical conditions (table 2). Experience in soil strengthening proved its competitiveness for filled, collapsible, soft soils and also for sand soils under various levels of ground water. The following may be thought of as general advantages of Deep Soil Mixing technology of fabrication of soil cement elements: low level of vibration and noise during their arrangement, possibility of fabrication and efficient operation in water-saturated, collapsible soils and in limited working space, easy changing of pile diameter by way of increasing diameter of cutting tools, high mobility of set of necessary machines and mechanisms to make piles, which will satisfy tough schedules of present-day building. Also, there is no necessity for regular supplying of fillers for mixture [20]. To increase strength of soil cement it is reasonable to perform operation of vibration compaction by way of vibration of soil cement mixture in borehole. In the process of vibration there takes place elimination of air bubbles, which in its turn causes increase in compactness of SCE. If necessary it is possible also to make reinforcement of soil cement piles. Cost of arrangement of 1 m$^3$ of soil cement by Deep Soil Mixing technology is smaller by a factor of 3-4 than by method of Jet Grouting.

6. Conclusions
From the presented indicators for different objects of building it can be seen that consumption of material for strengthening essentially depends on geological conditions, and on loads and...
dimensions of foundation – not essentially. To substantiate economically appropriateness of application is possible after comparing variants of arrangement of base by strengthening of soil or by application of piles taking into account indicator of cost. Thus, it can be noted that consumption of soil cement is 1.5–4.5 times greater than consumption of piles, but cost of material of piles and works on their arrangement is 10 times greater than soil cement.

The main advantage of arrangement of foundations on bases from strengthened soil is the possibility of realization in conditions of high thickness of soft soils and placement of support horizon for piles at essential depth, for example deeper than 15 m. In conditions of essential depths there arises necessity to use augercast or grout-injected piles, or components of built-up piles. Deadlines of building and cost in such conditions increase essentially.

Also the advantage of use of soil cement is the possibility to use it in saturated soils without additional measures, as distinct from augercast piles.

Quickness is also an essential advantage of soil cement. Compared to driven and augercast piles quickness of arrangement of soil cement by Deep Soil Mixing method is 3–5 times higher and 2–3 times higher when arranging piles by method of driving or jacking. Jet Grouting is justified in strengthening of thicknesses of soils locally separated along depth, but, compared to Deep Soil Mixing technology (DSM), is more consuming by materials, energy, and cost. Application of Jet Grouting is widespread in arrangement of soil cement elements of large diameters for enclosing sheeting, arrangement of waterproof layer, grout curtains, and soil cement piles with essential load capacity.

Such types of strengthening of bases as injection and micropiles are justified more frequently in conditions of reconstruction in the absence of immediate access to the base. Their application is determined by necessity to perform works in reconstruction or overhaul in conditions of tight development and limited access to foundations. It is justified to use them on the basis of injections to stabilize existing foundations of silos with symptoms of loss of bearing capacity or above-normative deformations of settlement.

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