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Reconstruction of foundations in Russia

Bachelor’s Thesis 2015
ABSTRACT

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Reconstruction of the foundation in Russia, about 45 pages
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The purpose of the work was to analyze and to review the field of the foundation reconstruction in Russian Federation. It was necessary to investigate the modern appearance causes of the reconstruction necessities and to determine the strengthening goals of the foundations. And finally, it was required to identify the most popular methods of the reconstruction, to compare them with the most popular Finish ones and to confirm them by the real structural examples.

For these goals, the scientific works of the leading Russian experts in the field of geotechnical engineering were used. A large number of materials of the research papers, theses, textbooks and publications were analyzed. Also, project materials of the real objects from different design companies were used.

All results of the researches can be found in this work. All major reasons of the foundation reconstruction and strengthening in Russia are given below. The most popular methods of strengthening were chosen and the details and conditions of use were presented and compared with Finish situation. The problems of foundation reconstruction on the objects, which are influenced by the dynamic loads, were also examined. The features of such objects and the difficulties, which arise there, were analyzed. All methods are supported by examples of real reconstruction works. In the end, a short reference comparative table of these methods was created.

Keywords: reconstruction of the foundations, reasons of reconstruction, static and dynamic influences, methods of reconstruction, foundation soil, foundation footing.
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1. INTRODUCTION

In the 20th century in Russia (Soviet Union) there was a significant gap in the development of industry, science, construction and many other areas. If we talk about buildings, that were built large structures (cosmodroms Plesetsk and Baikonur, St. Petersburg and Moscow underground, nuclear power-stations, etc.) as well as the most common structures (social buildings, roads, bridges, tunnels, etc) across whole country.

Unfortunately, the development of infrastructure does not always go without leaving a trace. In that time the motto was "We build, build, build!", but for preservation of the existing buildings there were not so much attention. At the same time, the development of underground structures (underground passages, parkings, subway, etc.) has led to changes in soil conditions under existing buildings. And this is just one of the reasons why the issue of foundation reconstruction in Russia is on the leading positions.

Despite the power of the Soviet Union in view of construction quality, in 90s after the collapse of the country, Russia has turned into something that resembled only vaguely the great building power. Crime, theft, negligence led to the fact that the structure, which were built about 20-25 years ago, also in need of renovation. Engineering surveys were conducted poorly, materials supplied with understated properties than which were ordered, money were stolen, and the process of building was controlled badly.

There are many other reasons for the need of reconstruction of foundations. It should be remembered that Russia is so vast, that it is very easy to find all kinds of geological, natural and weather conditions in its territory. In view of the changes, a lot of structures are not meet the requirements, according which they were built during the recent renovations or first arrangement.

Also, the science and building technologies are developed now rapidly. The ideas of reconstruction, maybe, are the same as they were 50 years ago, but
the way of execution of these ideas are changed radically. The number of technology is growing. Some of them are successful, some as yet unknown, but all of them could be applied. In addition, in Russia there are many historic areas and buildings, sites and monuments. Caring for them is also require the most advanced technologies and fast response, especially in places with such weak and unstable soils, as St. Petersburg.

It is because of all these reasons, the issue of the foundation reconstruction in Russia is very relevant today. However, naturally, carrying out such work involves not only the selection of the first available method of strengthening and its performance. This is a big task, which requires:

1. Determination of the strengthening reasons;
2. Accomplishment a thorough research of geotechnical conditions, the condition of the foundation, the superstructure of the building. In general, the full picture of the situation;
3. Determination of all possible acceptable methods of work and careful final choice of technology;
4. Finally, the implementation of a range of works on strengthening and further maintenance of the situation.

About the main reasons of the strengthening and the most popular methods of the foundation reconstruction in Russia is the next text.

2. REASONS OF THE RECONSTRUCTION

As a rule, the need of reinforcement and reconstruction of the foundations and hardening of the foundation soils appears during reconstruction of whole building, including its overhaul and heightening of the additional floors. This questions are also appears when there are relative settlement of the building, equalization of building’s heeling, underground services laying, building of foundation in cramped conditions and in other cases, when there are no normal
conditions to maintenance. The common reasons, which follow the need of reconstruction, in 4 parts can be grouped.

- Reconstruction of the building (include overhaul and heightening of additional floors);
- Breakdown of the foundation’s materials and reduction of its dampproofing behavior;
- Disturbance of stability conditions of the building during maintenance;
- Development of large deformations in the building (Polischuk 2004).

2.1. Reconstruction of the building (include overhaul and heightening of additional floors)

Reconstruction of the building in most cases binds with rising of the foundation and foundation soil. It concern not only dead load, but live load too, because of changing old technical equipment, rising of its amount, installation of heavy bridge crane and so on. As a result, the pressure under foundation’s footing can exceed the design resistance of the soil. So that, it demands to make the foundation’s footing bigger or make the soil stronger if there is no reserve of veering capacity of the foundation soil.

![Deformations of maintained buildings in time of the construction of new buildings near them](image)

Figure 2.1 Deformations of maintained buildings in time of the construction of new buildings near them (a) or contiguity it to new buildings (b). [32]

The problem of the influence of adjacent buildings on the footing of each other should be also taken into account.
In time of reconstruction of the ready-made areas in the city and during rising of the building density, implementation of the new building near legacy one will follows irregular deformation and settlement with appearance of cracks especially next to the area of building connection. Data of Saint-Petersburg State University of Architecture and Civil Engineering says, that there are 128 building, new buildings were made near which in Saint-Petersburg and about 80% are have serious deformations because of it. There is the same situation in Tyumen, Tallinn and other cities. The reasons are follows:

- Changes in mode of deformation of foundation footing;
- Technological influences (vibration during notching, soil freezing, piping and others).

2.2. Breakdown of the foundation’s materials and reduction of its dampproofing

Breakdown of the foundation’s materials and reduction of its dampproofing behavior often happens because of aggressive ground water influence. It appearances because of the solution of salt in the ground, chemical bath leaks from sewer net and other things. Because of the interaction of salt solutions with foundation structures in the voids of the foundation material a lot of pressure due to the crystallization of salt appears. This reduces the strength of the concrete, mortar of brick masonry and gradual destruction of the foundations.

Sometimes some dynamic actions could be a reason of foundation crumbling. These dynamic actions are vibration from transport, work of different mechanisms, pile driving and so on.

The common reason of foundation’s materials breakdown is the problem with waterproofing. Most of all it is popular reason for old building because of the rising of the cultural layer. The result is that the horizontal waterproof sinks under surface of the soil and ground water could go into the structure materials without any problems and destroy the construction in time.
In history, there are many examples of material breakdown because of the groundwater level changes. The most typical example is rot process of wooden piles in place of their connection with grillage after decreasing of the groundwater lever (see figure 2.2). It leads to mutilation of a head part of the pile under loads and to the significant relative settlement of the building. It happened with building of Maly theatre in Moscow and center part of Turku city because of the installation of many engineering services. The settlement was stopped only after reconstruction of foundations with help of armo piles, reinforced concrete piles “Mega” and multisectional steel piles “Gustavsberg” (Tishkov 2014).

![Figure 2.2 The rot process of wooden piles. [45]](image)

Sometimes in reinforced concrete elements the reinforcement is broken down due to the corrosion. The most popular reasons are availability of vagabond currents or aggressive environment influence (soil, acid, alkali solutions) (see figure 2.3). Corrosion leads to reduction of reinforcement sizes. So that, in
foundations take place the development of the cracks and reduction of working area of foundation bed what leads to additional settlement.

Figure 2.3 The corrosion of the reinforcement. [30]

2.3. Disturbance of stability conditions of the building during maintenance

The disturbance of stability conditions of the building during maintenance appears by several reasons. The most common are changes in hydrogeological conditions of the area, water leakage from the utilities (water supply system, sewerage system, heating networks), bad control of surface water and so on. The additional ground moistening leads to degradation of the mechanical properties of the soil and to the attenuation of the ground footing. As a result, excessive foundation settlement, deformation of another parts of the structure and risk of failure. In some cases, the weakening of the base by reducing the strength characteristics of the soil leads to the emergency condition building.
Researches show that in some industrial Russian cities noted intensive groundwater rising. For example, for the period from 1965 to 1977 the groundwater level raised on 10-15 m in Dnepropetrovsk, Zaporozhye, Hersone, Rostov-na-Dony and other cities. The reasons for this are intensive development of the territories, which violates the terms of surface runoff, leakage of communications, tanks, and water flooding through the construction of dams and reservoirs (Konovalov 2000).

In researching for industrial building in Dnepropetrovsk, the groundwater was not found even on the depth of 30 m. The building was designed and built with short (10-12 m) vibroshtamp piles. By the time of delivery of the building in operation was recorded significant settlement with a tendency of increasing in time. It was found that the cause of settlement is a rising groundwater level to a depth of 14 m. Due to the significant deformation of the building, it was not taken over and was in need of perform the expensive works to strengthen the foundations of columns with jacking piles up to 30 m (Konovalov 2000).

There are cases of foundation footing instability under dynamic effects, karstic-piping processes with the formation of sinkholes under the foundations, with intensive decomposition of organic substances in the soil, as well as additional moistening of the soils. The disturbance of foundation stability conditions is observed on the permanently frozen soil, which happens due to the defrosting process of the base after the penetration of the heat flows, and in some other cases.

Excavation development next to the existing foundations leads to loosening of the soil base and to reducing their strength characteristics. To reduce the impact on the foundations, the careful fencing of the existing foundations is required.

Thus, the disturbance of the ground stability leads to the serious damages of the buildings and then, to the need of time-consuming repair work.
2.4. Development of large deformations of the building

Development of large deformations of the building in most cases is explained by mistakes during exploration, projecting, implementation and maintenance of the building.

Not enough amount of researches is the most popular mistake in exploration. It means that not enough boreholes and pits were made and that leads to incorrect and incomplete data about ground footing. There could be some geological element (peat, pulp, another soft soil) on several depth, which have low compression strength or can decompose well, because of which the building will have deformation. Not enough amount of researches leads also to lack of data about karstic deposit or underground vesicle in base, during providing the geotechnical investigations sometimes, there are cases of incorrect determination of the soil properties, mainly strength and deformation. This is due to the violations in the selection, transportation and storage of samples (Polishuk 2004).

In practice of exploration for residential buildings of low and medium-size, the depth of boreholes usually does not exceed 8-10 m. It is considered sufficient to characterize the properties of the soil and make the necessary calculations of the foundation. However, this principle does not work when buildings stand on the peaty areas, which are composed ground plant residues, including layers or lenses of the buried peat.

A year after taking over, the three-story brick building got the increasing in time irregular settlement. The observation of the technical documentation showed that at the base of the building laid a thick layer of moraine refractory plastic loam (see figure 2.4). However, the growth of the building’s settlement continued, so that, it was decided to carry out additional geotechnical observations. After drilling a borehole with 15 m depth (before this, the standard depth does not exceed 8 m), the lens of peat (thickness is 6 m or more), which was widely developed in the plan, was found. The presence of strongly pressed
soil, which was not detected at the stage of research, became the cause of the building deformation.

Figure 2.4 The destruction of the building part (1) due to the band of soft soil (2) availability. [31]

Distorted data of the soil properties can be obtained by the prediction error of groundwater level changes and by the overall assessment of the hydrogeological conditions of the site. There are examples of getting the false information about the strength and deformation characteristics of soil as a result of incorrectly chosen research techniques, as well as due to the lack of attention to the chemical properties of groundwater.

Among the errors in the design of foundations, there is wrong assessment of specific soil properties and foundation bearing capacity during freezing and thawing of the seasonally frozen ground, possibly increasing level of groundwater, infiltration of salts, acids and other chemical solutions into the soil. Design errors are caused by the underestimation of the composition and nature of the load transfer, acting on the foundation. The additional settlements and unacceptable roll structures may incur under repeated alternating loads (Polishuk 2004).
Errors during construction were the cause of strengthening and reconstruction works a lot of times, especially in construction of buildings and structures in complex engineering-geological conditions. In one of the areas of mass building of Moscow there was 12-storey house built. According to research materials, there was filled-up ground on the surface, with thickness 3.5-4.0 m and the alluvial deposits (loams, peats) were under it. These deposits had low loadbearing capacity and high deformability. Below, at a depth of 10-18 m thick layer of sand was located. The project decision was the installation of pile foundation with 12 m piles. Due to the different depth of the sand layer, ends of piles under part of the building were buried in the sand, and the other part, as a result of poorly studied area, were in the middle layer of loams.

During the process of building erection, the differential settlements started to appear. The researchers showed that the settlement difference to the end of erection could be about 12-13 cm.

The development of large building and structure deformations are caused, sometimes, by incorrectly selected design models and methods of design calculation. There were cases, when the design of the buildings on the highly compression grounds did not include the activities to increase the spatial rigidity of the building. It led to unacceptable cracks in the walls and deformation of the other building structures. The absence of settlement joint at the junction parts in the buildings with different height parts, as well as a significant difference of pressure on the foot of the basements in the same building, caused the development of differential settlement of the foundations.

Mistakes, which are made in constructing of footings and foundations, are the most common in practice of the construction and cause the development of the unacceptable deformations of the buildings and structures. The problems appear in disturbance of the soil structure due to improper organization of the dewatering work on the site and pumping water from the pits, during the development of trenches and other excavations at the sites with weak clay soils. Development of inadmissible deformations of the buildings and structures in the construction process occurs sometimes, due to the freezing and thawing of the
soil under inopportune filling cavities of the foundations or absence of basement frost protection.

In recent years, the number of cases of significant and uneven settlements of the buildings in use is increased significantly because of the pile unsinking up to design levels. The reason for this is mainly a wrong selection of pile-driving equipment.

Settlement of a paper machine factory near Imatra (Finland), as a result of pile unsinking up to design levels, was 150 mm. To correction, the resulting bank a challenging work and high costs were demanded.

In the practice of construction, there are cases when there is no control over the quality of performed work and the bases and foundations are arranged with disturbance of building codes. Typical examples are piling with a deviation from the design position (see figure 2.5), poor compression of bedding course in foundation footing, concrete freezing of the foundation construction, laying of the concrete of the monolithic grillage on contaminated pile heads. The builders often consider that it is unnecessary to protect interior and exterior basement walls from the effects of groundwater by waterproofing or screens. Problems in the construction and maintenance of buildings can occur if you did not perform works on preconstruction compression of weak of water-saturated ground footings (Konovalov 2000).

Figure 2.5 Pile horizontal deviation from the design position. [7]
Typical causes of technology construction disturbance of the foundation could be: long downtime of open pits, mistakes in foundation installation and discrepancy of the foundations to the project sizes, using of reduced concrete grade, unjustified exchange of structures and materials, poor performance of joints and interfaces.

Mistakes which are made during the maintenance of buildings and structures also cause the development of non-uniform deformations. Most often, the deformations of the structures in this case are the result of soaking the soil with water, human waste water and process solutions, which are coming from the faulty engineering services. Most affected by aggressive actions are foundations of industrial buildings of chemical, aluminum and petrochemical industries.

The disturbance of the building normal use occurs when bearing structures are overload by the installation of new additional equipment. Abnormality of equipment action often leads to the redistribution of loads on the foundations and, as a consequence, their destruction.

Problems in building use arise under the disturbance of temperature and humidity indoor condition, under the wrong device of openings in concrete walls and in other cases.

2.5 Violation of building and structure stability on the slopes

During operation of the buildings and structures, which were built on the slopes or near them, there is the risk of loss the stability and strength of the structures due to potential landslides of the ground. This deformation may occur both on the structure because of the effect of the unstable soil masses pressure and on the foundation footing because of loosening of the foundation soil under the building as a result of the landslide mass displacement down on the slope. Such ground motion on an inclined surface can begin for a variety of reasons: the shear forces are bigger than holding ones; the logging of the slope and as a result - reducing the strength characteristics of the soil on its slope; abrasion of
the slope bottom by the sea or river water and as a result - the imbalance of the ground mass; wind erosion of the surface layers; seismic influence, and so on.

Practically, the danger to the buildings and structures is the result of a ground masses influence on it in case of occurrence of the landslide movements on the slopes. When the structure stands in the upper part of the slope, the “creeping out” of the ground from under the building and loosening of the base is happened (Figure 2.2.a). As a result, under foundation footing, the foundation soil becomes heterogeneous and in the building the vertical cracks start to appear as a result of uneven settlement. When the building stands directly on the slope, after the activation of the landslide, there is a displacement of the soil beneath the building - in part together with the construction, in part, by flowing around its basement (Figure 2.2.b). In this case, illegal building deformations can be caused by soil pressure on it, or by the uneven movement of the individual parts of the building. In case, when the building is located at the bottom of the slope, it usually gets the pressure of the ground shifting masses (Figure 2.2.c) (Polishuk 2000).

Figure 2.6 Violation types of the building stability on the slope: a – foundation soil loosening under the foundation structures; b - displacement of the soil beneath the building; c – pressure on the construction of the sliding down ground; 1 - the existing building; 2 - slope surface; 3 - sliding surface of the landslide. [31]
3. SYSTEMATIZATION OF THE DEFORMATION CAUSES

There were 130 buildings inspected. They are located throughout the country. These works were carried out between 1980 and 1998. The task was to identify the causes of the building deformations (sometimes accidental), to evaluate their serviceability and the foundation strengthening, to elaborate the decisions on reconstruction, heightening and others (Polishuk 2000).

The buildings were built at different times, from 1900 to 1995. Classifications of the inspected buildings by the type of foundation, structural scheme type and the presence of basements are presented in the following tables:

Table 3.1 The distribution of the inspected buildings by the foundation type.

<table>
<thead>
<tr>
<th>classification of the surveyed buildings</th>
<th>The proportion of the surveyed buildings, %</th>
<th>Distribution of the surveyed buildings by the foundation type, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Shallow foundations</td>
</tr>
<tr>
<td>Industrial buildings</td>
<td>62</td>
<td>52</td>
</tr>
<tr>
<td>Civil buildings</td>
<td>38</td>
<td>28</td>
</tr>
<tr>
<td>total</td>
<td>100</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 3.2 The distribution of the inspected buildings by the design scheme type.

<table>
<thead>
<tr>
<th>classification of the surveyed buildings</th>
<th>The proportion of the surveyed buildings, %</th>
<th>Distribution of the surveyed buildings by the design scheme type, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Load-bearing walls</td>
</tr>
<tr>
<td>Industrial buildings</td>
<td>62</td>
<td>33</td>
</tr>
<tr>
<td>Civil buildings</td>
<td>38</td>
<td>35</td>
</tr>
<tr>
<td>total</td>
<td>100</td>
<td>68</td>
</tr>
</tbody>
</table>

Table 3.3 The distribution of the inspected buildings by the presence of the basement.
Thus, the most part of the surveyed buildings is classified as industrial (62%) with load-bearing walls, without the basement and with shallow foundations.

The portion of civil buildings from the total number is 38%. Most of them are erected with the load-bearing longitudinal walls with the basement and on the shallow foundations.

From the all inspected buildings (structures) those, which have had the deformations or the destruction of the individual sections and elements, were identified. The portion of such buildings was 63%. The other buildings have had no deformation (destruction) of walls, foundations, and other structures, and the inspection was related to the heightening, redevelopment, replacement of technological equipment, etc. The results of this inspection were analyzed. According to these finding, the most common reasons of the building deformation (destruction) were determinated (see table 3.4) (Polishuk 2000).

There were four main groups of reasons. The first group includes deformations (destructions) of the buildings which were occurred as a result of mistakes in building design stage (including stage of the construction engineering investigation).

The second group is the group of deformations (destructions) of the buildings which were occurred as a result of mistakes in process of erection (maintenance, reconstruction) of the building.
The third group includes the deformations (destructions) caused by the mistakes, which were made during the operation of the buildings.

The fourth group includes deformation (destruction) of the buildings that were occurred as a result of physical depreciation, fire, impoundment of the sites and others. These deformations of the buildings integrated into the group "other reasons".

On the basis of the approach, which was adopted (see table 3.4), It was found that the biggest number of the building deformations (42%) occurred at the stage of building upkeep because there was not proper supervision of the state of building structures and elements (soaking the soil, foundations and other above-ground structures, the heat and humidity changes in the premises, unreasonable overloads of the building individual sections, the effects of the negative temperature on poorly protected elements, etc.) (Polishuk 2000).

Table 3.4 The main causes of the building deformation or destruction.

<table>
<thead>
<tr>
<th>№</th>
<th>Reasons of the building deformations and destructions</th>
<th>The proportion of the determinated reasons, %</th>
<th>Distribution of the reasons for the inspected buildings, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Industrial buildings</td>
</tr>
<tr>
<td>1</td>
<td>Mistakes in building designing (including construction engineering investigation)</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Mistakes in erection (maintenance, reconstruction) of the building</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>Mistakes in upkeep of the building</td>
<td>42</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>Another reasons (physical)</td>
<td>15</td>
<td>8</td>
</tr>
</tbody>
</table>
In analyzing the results of the survey, the reasons of the building deformation, which have occurred only because of the loss of operational qualities of the fundamental part were revealed. These data show that the portion of deformed buildings in which structural deformation occurred due to loss of performance of the foundation is 63-65%. From this fraction 66% are the industrial buildings and 34% - civil buildings.

Thus, analysis shows that the main part of deformation and destruction of the buildings are the result of errors, which were made during the construction stage and operation period of the buildings. Their combined share of the total number is 74%. The remaining causes of deformations of the buildings (26%) are associated with errors that have been committed at the stage of design, construction and engineering research, as well as the physical depreciation of the buildings, natural disasters and others. All this indicates that the questions of the design, construction, reconstruction and operation of the foundation of the industrial and civil buildings are in need of more attention (Polishuk 2000).

4. METHODS OF THE RECONSTRUCTION

The deformations of constructions are happened during the long period of buildings and structures exploitation. The main cause of the foundation destruction is irregular settlement which causes the disturbance of walls, columns and slabs during the buildings implementation on the soft soil.

Selection of technologies for foundation reconstruction depends on the category of the building conditions, as well as the estimated risk category of the reconstruction works. The main factors in technologies choosing are those factors which are associated with the design features of the building, the
condition of the soil under the foundation and the equipping of organizations which are engaged into the work.

Modern calculation methods make it possible to simulate the competitive variants of ground base and foundation strengthening technologies on the basis of geotechnical information. For difficult cases of the reconstruction, it is common to use complex of technological methods. In all cases, the proposed technology should provide a reliable long-term exploitation of the building. The economic, environmental and safety factors should be taken into account.

4.1. Foundation widening

There are the traditional methods of foundation strengthening. They are associated with the increasing of the foundation footing sizes.

Figure 4.1 Traditional technologies of pinning: a – new bonded masonry; б, в – through concrete foundation fork; г – through reinforced concrete foundation fork; 1 - wall; 2 – new bonded to old masonry; 3 – old masonry; 4 – metal hitch pin; 5 – concrete foundation cage; 6 – reinforced concrete foundation cage; - 7 - macadam; 8 - concrete cage; 9 – working beam; 10 – distribution beam; 11 – concrete calking. [38]

Foundations can be strengthened by the bilateral or unilateral concrete (see figure 4.1 a, b, d) or reinforced (see figure 4.1 c) concrete foundation cage. The widening through the concrete foundation cage is 20-30 cm on each side, through the reinforced concrete foundation cage is not less than 15 cm. The cages are anchored by the metal rods every 1-1.5 m in order to connection with the foundation (Shvec 1985).
Widening of the foundation footing without pre-pressing of the ground is ineffective. The foundation starts to work only after the additional loading and then additional settlement. This settlement can take a long period of time and over this period the designed widening works only as a dead weight. This is clearly seen on Figure 4.4. Unfortunately, the additional settlement may be
limiting for the old building, which is in need of strengthening. So that, prepressing of the ground with sand or gravel is the best way (Shvec 1985).

Figure 4.4 Scheme of the foundation footing widening (pressure diagram in the plane of the footing): 1 - the existing foundation; 2 - design widening; 3 - reinforcement; 4 - diagram of pressure before widening; 5 - diagram of pressure after widening and additional loading of the foundation. [38]

Basic technique of the foundation widening is as follows. Reinforced foundation is divided into separate divisions (areas) 1.5-2.0 m long. In these areas the ditches are dug up by hands. The width is 1.2-2.0 m to the level of the foot. After that the metal pins are hammered (either immersed into a pre-punched holes with 50 cm staggered step) into the foundation. Then the formwork is installed and the widening is concreted.

One variant of such strengthening is through drilling of the foundation body and arrangement of the binding bolts for assurance the existing foundation and strengthening constructions collaboration. In another variant, monolithic concrete constructions are installed under the footing of the existing foundations too and formed a "tooth".

One of the main tasks at the concrete cage installation is to provide durable bonding of the new concrete to old. This is achieved by selecting the most effective method of cleaning the surface of the foundation under pinning when
not only dirt, soot, oil and other chemicals (especially in the reconstruction of the chemical industry) are removed, but also damaged and poor quality concrete or mortar masonry (see figure 4.5). There may be applied: washing with high pressure water or with a mixture of water and compressed air; chemical flushing (hydrochloric acid); dry or wet sandblasting; surface machining for providing roughness. The roughness of the foundation surface is created by punches or by coal hammers with special nozzles (Tishkov 2014).

![Figure 4.5 Cleaning process of the concrete surface. [46]](image)

All these processing methods are complex and expensive, and, most importantly, performed mostly by hand. Moreover, in areas where there is high enough groundwater horizon, the value of work increases significantly due to the need of pumping the water from the ditches. Pumping should be done in such a way as to avoid the disturbance of the natural addition of the soil under foundation of the reconstructed building and around it. Otherwise, works of strengthening will only aggravate the condition of the building in whole.

The advantage of the method is increasing the bearing capacity of the foundations at the expense of the foundation widening and the protection of the foundation material from further destruction.
4.2 Injections

In world practice there is a large arsenal of various chemical reagents, which are capable to secure foundation soil for a sufficiently long period. The advantages of chemical methods are: a high degree of mechanization of all operations; the possibility of hardening the soil in its natural occurrence to set the parameters of the project; relatively low labor-output ratio; the sharp decline of unskilled manual labor by digging up the ditches; the relatively low cost of raw materials (Dalmatov 2006).

Chemical grouting allows to solve many problems in the reconstruction of fairly complex engineering and geological conditions successfully.

The choice of the chemical agents must be very rigorous because of the high attention to environmental protection. So, for example, the widely recommended acids and alkalis high concentration influence on the surrounding loose soil and underground water harmfully.

It seems reasonable the refusal of many specialists from the use of most of the chemicals, with the exception of silicates, which are traditionally used (one- and two-stage silicatization). Silicatization is based on the use of silicate solutions and their derivatives, which are in combination with a coagulant can form a gel of silicic acid which cements soil particles (Dalmatov 2006).

The idea of one-stage silicatization is that the ground is pumped with preliminary prepared by the composition of the gel-forming base (liquid glass) and hardener. At a low viscosity of the mixture it can be injected even in the lowfiltrate sandy soils (see figure 4.6).
A well-known example of this method are stabilization works of the deformations of Odessa Theater of opera and ballet building, which was built in 1887.

Due to the foundation soil soaking, undamped settlement of the building began to appear. Over time, they became accident. Then the solution of sodium silicate began to inject in foundation soil under pressure through injectors.

The project provided silicatization of the entire thickness of the subsiding soil to the top of the firm unsubsiding red-brown clay under all load-bearing wall foundations of the theater. The ground was mounted through the clogged vertical injectors. The result of the work is that under each wall there were two strip-walls of the stabilized soil under each wall. (Figure 4.8)
Installation drawing of the injectors upon the silicatization is shown in figure 4.7 and figure 4.8.

Figure 4.7 Arrangement of the injectors upon the foundation soil silicatization of the Odessa Opera and Ballet Theater. (On the picture every point is place of injection). [43]

Figure 4.8 Sectional drawings of the footing under theater foundation: 1-wall; 2-injector; 3-loess under silicatization; 4-filled soil; 5-loess; 6-red-brown clay. [19]
In total, there were 2300 injection points. Running measure of all strip-walls is about 22 000m. The amount of injected sodium silicate solution was 5400 m³.

Method of the two-stage silicatization was used in the strengthening of the sand foundation soil under the walls of the Bolshoi Theatre building in Moscow.

This method was also successfully used in the reconstruction of the chemical factory, where there was a leak of phosphoric acid solutions into the ground for a long time. As a result, material of the foundations under the bearing columns of the building was damaged badly and foundation soils began to swell. The project envisaged the arrangement of the walls, which were fixed by silicatization along the perimeter of each foundation. The sodium silicate solution was pumped into the ground in volume of 300-400 liters per 1 m³. The project allowed to neutralize the effects of aggressive phosphoric acid solution on the foundation material, to consolidate soils and prevent further swelling.

The consolidation of the soil using Portland cement is safe in terms of impact on the environment. The hardened Portland cement consists mainly of the calcium silicate, which is practically insoluble in water. Because of it, injection and drilling-mixing ways are promising. These technologies are based on a mixing of the soft soil with water-cement slurry (Dalmatov 2006).

The injections of the cement slurry are useful for soil strengthening when the soil consists of the medium or large size grains or gravelly sands, as well as gravel and pebble soil. The soil after cementation is fossilized. In the coarse soils grouting is often used to create a waterproof screens than to increase the carrying capacity of the ground.

The main disadvantages are high cost of the work, difficulties in checking the uniformity of the injected material distribution in depth, and in the plan (Dalmatov 2006).

It is possible to strengthen the body of the foundation by Injecting the cement mortar or synthetic resins, etc into the body of foundation if the material is in
poor condition (mechanical damages, presence of the sedimentary cracks, exfoliation and cracking of the foundation body as a result of freezing, etc). For the cementation in the foundation body holes for the injectors are drilled. The diameter of the holes should be larger than the diameter of the injector on 2-3 mm. The distance between them along the strip foundation corresponds to 50 - 100 cm. When the foundation is single, not less than two openings on each side are punched. The depth of immersion of the injector into the foundation is 0.4-0.6 m. The injector is introduced into the hole, and through it the liquid cement mortar is injected under pressure. It fills the space from 0.6 to 1.2 m in diameter, located around the injector (see figure 4.10). Usually the number of injection sites depends on the degree of destruction of the foundation masonry (Dalmatov 2006).

Figure 4.9 Chapel-monument "For grenadiers, who fell a victim under the Plevena". a-outward appearance; b-foundation plan; 1-central column; 2-side columns; 3, 4-brick arches; 5-brick vaults. [6]
In 1997 in Eliinski square (Moscow) there were the reconstruction work in the chapel-monument (it was created in 1887) "For grenadiers, who fell a victim under the Plevena" (see figure 4.9). Memorial Chapel is about 14 m height, the basement depth is about 7 m, and the mass of the monument is 130 tons. The foundation soil is small grain sand. Inspection of the chapel-monument foundations showed that it is able to perceive the existing load but require a major overhaul due to the deterioration of his body.

The survey showed the urgent need of strengthening the masonry of the supporting pillars and foundation arches by cementation of its body. All these
works were carried out in time and qualitatively. Chapel-monument continues to operate normally.

Sometimes contractors, and sometimes customers, include in cementation work of the foundation body also cementation of the contact zone "foundation-ground". If the foundation soil is composed of sand, gravel and pebble soil, the injection of the cement mortar into the soil, which is possibly weakened by piping of the sand fractions, can improve the contact between the foundation footing and the soil. But if the ground is composed of natural structure of the clay soil, the contact of soil and foundation is sufficiently thick and there are not any gaps or voids. In this case, the pumped under pressure cement mortar penetrates into the sewers, other underground utilities and other available in the soil cavities. Thus, the valuable building material is wasted (Dalmatov 2006).

4.4 Foundation slab

During the building erection or reconstruction, the additional loads could appear and then the uneven settlement. They occur most often because of the soft soil under foundations, a significant difference in the loads on them, local soaking or freezing. For solving this problem, cast-in-situ foundation slab can be used (see figure 12). Erection the foundation slab under the building reduces the pressure on the ground, so that, it is one of the most effective ways to increase the area of foundations. The erection of the foundation slab is particularly advantageous if there is filled soil under the foundation or if the settlement of the overloaded foundations during the construction or operation grows intensively and tends to increase the maximum allowable (see figure 4.13). The best place for erection of the slab is at a height of 75 ... 80 cm from the base of the existing foundation (Dalmatov 2006).
Before the erection of the foundation slab, crushed stone bed total thickness of 15 ... 20 cm with careful layer-by-layer compactor is carried out.

Fig. 4.13 Increasing of the bearing surface by the cast-in-situ reinforced concrete slab with pressuring the soil: 1-the existing foundation; 2-reinforced concrete slab; 3-a pipe for the injection of the expanding cement; 4–cement mortar between the slab and the ground. [6]

Installation of the slab foundation during the requires careful and rigorous implementation of all phases of envisaged by the project work. Otherwise, the main objective - transfer of high load from the structures to the foundation soil - will not be achieved.
Example of this is fail of the foundation slab installation in clubhouse on Pokrovka street, 13 in Moscow, during its reconstruction. The old brick building was built in XIX century. Several thick exterior brick walls in some areas of the building were embedded into the weak saturated clay soil and worked as foundations additionally. Under their footings wooden logs were stacked. The foundations under interior columns were wooden piles. The level of groundwater in the area of building located above the base of the foundation. However, in 30s of this century due to construction of the subway tunnels and underground utilities near the building, underground water level dropped rapidly, wooden logs and piles were bared and began to rot. It was the reason of big uneven settlement and appearing of the big cracks into the body of the existing foundation. By the time, the deformations became critical. The project of reconstruction included the process of installation of the reinforced concrete foundation slab above the existing concrete floor. Before erection of the new slab, project envisaged cleaning of the existing floor and punching holes in it to install pipes through which would be cement mortar injected. However, this important step in the further work was not carried out completely and accurately, so that, the new foundation slab in almost its purpose has not worked. Deformation of the building continued to grow, and only thanks to massive external and internal walls, it has not lost its serviceability.

Subsequently, the building was reconstructed a second time with a replacing of the walls and interior columns on grout-injected piles and now the deformations are completely stopped.

**4.5 Pressed piles**

If the bearing capacity of such slabs is not sufficient, it is possible to leave the holes in them and arrange pressed multisectional piles (see figure 4.14). It is arranged due to the close conditions of the building process. Pressed piles are also used for exclude dangerous dynamic influence on the old buildings and soft soil.
In Finland, Sweden and Hungary in 60s the piles by pressing were popular. They have been widely used to strengthening of the grounds and foundations in Helsinki, Stockholm and Budapest. In some cases, the pile is supplied directly by the foundation. These piles can be round and square section, the mass of the element is up to 100 kg.

These piles provide not only unload of the weak soil layers located in the upper area of the base, but also the transfer of loads from the building to more strong deep soils (length of pile is up to 25-30 m). Such piles are made of precast concrete elements 80-100 cm in length. The sequence of arrangement such pile is as follows (see figure 4.16). Bottom first element with point (in soft ground without it) is plunged by jack. The reinforced concrete distributive beam works as a support. The advance of the prefabricated elements is produced until the bottom one reaches the hard soil that will provide the necessary load-bearing capacity of the whole system. The head element is set at last, the cross sectional area of which is much greater than the cross sectional area of the pile. After plunging to the design level of the pile under load, it is blocked by special strut. Struts are positioned between the distributive beam and the pile head and the resulting hole is filled with concrete (Kuzevanov & Shulyat’ev 1994).
The main advantages of technology are follows:

- The possibility of determining the bearing capacity of pile and prediction of the foundation deformation;
- Compaction of the soil during the plunge of piles;
- The absence of dynamic effects on the ground.
There is no doubt that the jacking guarantees the high precision of plunging. It allows significantly reduce energy costs and prevent the dynamic effects, dangerous vibration, noise and air pollution, which are foregone with using of the diesel-compressor.

However, this technology has very serious imperfections. The main is very low productivity.

Other disadvantages of this method are: the high cost of the work; limitations of work in certain categories of soil; uncertainty about the value of force, which will be transmitted to the pile. Furthermore, during subsequent operation, the additional piles settlement due to plastic working of the soil may be occurred. This can lead to the formation of gaps between the piles and the foundation, which means no load transfer from the foundation to the piles.

4.6 In-situ piles

The high deformability of the foundation soil and availability of the groundwater make the process of widening the existing foundation or its additional deepening more difficult. In this case, the loads from the building are transmitted on more solid layers of the soil by transferring the existing foundation on piles.

First variant is using the casting pipe and rebar cage. The casting pipe is immersed into the foundation soil, then the ground is removed from the inner cavity of it and then it is filled by concrete. Then, the concrete reinforcing bars are introduced. The piles used in this way are called bored cast-in-place pile. By way of concrete consolidation piles are:

- concreted with compaction (Straus piles) (for cases of foundation soils without groundwater only);
- combi piles with the concrete consolidation by the compressed air;
  These piles are used in every hydrogeological conditions.
For Straus piles the height of each loaded into the pipe portion of the concrete should be at least 0.8-1 m for possibility of the special concrete consolidation without the formation of a concrete plug. In the process of concrete consolidation the casing pipe rises slowly up and then completely removed from the soil. The lateral surface of the pile becomes corrugated, and it increases the adhesion between the pile and the ground. The trunk of the pile is reinforced only at the top. The length of Straus piles in process of the foundation strengthening is 6-12 m. The bearing capacity of the friction pile is 200-400 kN, of the column pile - 800-1000 kN and more (Konovalov 2000).

For arrangement of the combi piles the airlock device is installed to the upper part of the casing pipe. This device is connected to the air line network. Then the underground water is extracted from the bore under the pressure about 0.4 MPa, generated by the device, and the concrete is compacted.

For strengthening of the strip foundations the bored cast-in-place piles are arranged in parallel rows on both sides of the foundation that makes them outriggers. The distance between piles in a transverse direction is determined by the width of the foundation, as well as the ease of the drilling equipment arrangement (see figure 4.17). Single foundation can be strengthened by two and, if necessary, by four symmetrically arranged piles (Konovalov 2000).
The works on transferring the foundation on the piles in going according to the following algorithm:

The concrete or steel edge beams are placed on the both sides of the foundation footing in specially punched longitudinal groove and then are carefully concreted; then the bores are drilled and the casting pipes are installed in them; then the pile crowns are reinforced and each row is jointed in one-piece grillage or the metal wall beam are installed. These beams are needed for jacking the piles into the ground and to add them into work.

The foundation strengthening of the hotel "Metropol" in Moscow was performed on the bored cast-in-place piles. The building was erected in the first half of the XIX century. It had three floors and wooden pile foundations. After 60 years of operation it was reconstructed, and two floors were added. At the same time the foundation was changed from the wooden piles to the shallow foundation on natural ground with a depth of 5 m lying and wooden piles were, respectively, cut on the same depth. But because of not very good calculations, uneven settlement of the building as well as big number of cracks were appeared. The situation became worse due to the building of the metro tunnels near the hotel, that leaded to removal of fine particles of soil from the foundation ground. So, the decision of the transplant the walls of the building on the bored cast-in-place
piles with the grillage from the steel beams was accepted. There were made 1700 piles 11-14 m long. The result was the stabilization of the sediment.

![Implementation of the cantilever beams on the bored cast-in-place piles.](image)

Figure 4.18 Implementation of the cantilever beams on the bored cast-in-place piles. [3]

An another example of the industrial enterprise reconstruction with bored cast-in-place piles could be the foundations of the paper machine on factory, owned by company Enso Gutzeit in Imatra (Finland), which were recovered by "Pohyavahvistus" company. At the base of the machine, about 200 meters long, difficult bedding soil with a layer of strongly compressible silty clay was appeared. The surface of the rock lay at a depth of about 50 m. Foundations were made from driven piles. After beginning of using this machine, the undamped deformations of the footing were marked. A few years later, the difference in settlement in longitudinal direction was 150 mm, and a cross-up to 70 mm. Subsequent researches showed that in places of the biggest settlement the ends of the piles stood in the layer of soft strongly compressible soil and sank gradually into it under loads.
The project of reconstruction included, without stopping operation of the paper machine, to transfer the machine bed on the reinforced concrete beams with consoles, which were supported by the bored cast-in-place piles 25 m maximum length and after that to produce its alignment (see figure 4.19). Piles near the bed are working on the indentation, and the second, more distant - for pulling out, so that, it is tied by steel anchors in rock. After transferring, the alignment in cross direction was made with help of the jacks. Longitudinal alignment did not carry out because it does not disturb to the operation of the machine. Totally, 120 bored cast-in-place piles were arranged. The works took 2 years and cost for the Enso Gutzeit company about 20 million Finn marks.

The second variant of the existing foundation transferring on piles is method of high-pressure injection of the hardening solution in the ground. This method is known as "jet technology" or “jet grouting”.

The jet technology allows to implement very effective variant of foundations strengthening: to increase the width of the footing and, at the same time, to increase the foundation depth. This is achieved through the arrangement of the cement-ground material array under the foundation. From all currently available
injection technologies, only the jet technology allows to create a relatively homogeneous array of stabilized soil nowadays (Bogov 2007).

It is possible to improve the conditions of load transferring on the foundation soil through the creation of the rows of continuous, inclined to each other, walls of the stabilized soil under foundation footings. Such constructive scheme allows to limit the deformations of the soil arrays, which are located between the created inclined walls. Every wall consists of individual cement-ground piers, which is performed according the "X" shape (see figure 4.20 a) and, during the performance of work, are almost unified with the footing of strengthened foundation. The strengthening is realized so, that the arranged cement-ground elements are remained in the load-bearing layer of sandy soil and do not cut it. Thus, they improve conditions for the load transfer from the basement to the upper dense layers of the soil.

An example of this method is reconstruction of the building, located in St. Petersburg, Karpovka embankment. Reconstruction of the building is related to the changing in its functionality, the increasing of the number of stories and increasing of the live load. The building was erected in 1905 with longitudinal load-bearing walls. The strip foundation depth is 2.1 m, and the width is 1.5 m. The geotechnical conditions are typical for the central part of St. Petersburg. Foundation soils contain concertal saturated sands. Sands bed thickness below the foundations footing was 2-3 m. Sub- and late-glacial deposit of sandy clays, which are lying under them, had low deformation characteristics and could contribute to the development of significant additional settlement upon the load increases without special activities of strengthening.
In the context of building reconstruction, the heightening with a significant increasing of the loads (in some places twice the current) was planned. The complicated factor for the reconstruction was the availability of areas with expanded sands in foundation soil. It was suggested to perform the strengthening of the foundation soil by the jet technology. The project of strengthening consisted of two main stages. The first stage contained the cementation of the existing rubble masonry foundations and ground from the contact zone "foundation – foundation soil" by plasticized cement mortar. The
second stage – arrangement of the cement-ground inclined piers with 0.6 m in diameter in staggered order. These piers were produced in a layer of sandy soil. The location of the piers was appointed so as to avoid technological settlement and caving. The angle of the pier slope and their step were appointed in such way as to create a solid array of the cement-ground material under the existing foundation footings (see figure 4.20 c) and to improve the conditions for the transfer of loads to the foundation soil. Totally, more than 500 piers were erected to implement the project.

Figure 4.21 General view of the pile wall made by jet grouting technology. [14]

The performance of all project requirements and functional control of work quality allowed to obtain the ground stabilization with specified dimensions and necessary characteristics. After works, the settlement did not exceed 3 mm (Ulickiy & Shashkin 2010).
Technological sequence of works by this method is as follows (see figure 4.22): borehole cavity is drilled (1); an injector dipped into the borehole cavity with special orifice – nozzle (2); the injected mortar is conveyed under high pressure (100 MPa); the injector is withdrawn with rotation; the pier with the desired diameter or wall of the piers is formed (Ulickiy & Shashkin 2010).

An important factor in strengthening the foundation or the array of ground by the jet technology is possibility of maintaining of the high pressures (80-100 MPa). This imposes certain requirements on the used equipment, a supply line and so on (Ulickiy & Shashkin 2010).
The main advantages of jet technology:

- The ability to carry out the works in any adverse grounds and cramped conditions;
• Ecological purity of all technological operations.

However, jet technology has a number of drawbacks, the main ones are:

• The risk of local deformations in the process of soil array temporary erosion under the foundation before the full hardening of the mortar;
• The high cost and material consumption due to the large volumes of the soil consolidation;
• Increased danger upon the work with high pressure.

4.7 Grout-injected piles

In the last 20 years in the practice of strengthening, the grout-injected piles are increasingly used, both vertical and inclined. With the help of the grout-injected piles the strengthening of the foundations can be carried out without developing the ditches and without disturbing the natural structure of the foundation soil. This is possible because the device, which is used for the pile arrangement, does not create dynamic effects. Strengthening this way is most appropriate to carry out if the foundation soil of the reconstructed buildings has low bearing capacity. In this case, some or all of the load is transmitted from the foundation to a more deep-seated layers of the ground by the strong piles (Ulitskiy & Shashkin 2010).

The main advantages of the grout-injected piles:

1. They completely eliminate the manual earthworks. Wells drilling is conducted directly through the foundation, without impact on the communications passing around buildings and in basement.
2. Using small-sized equipment. The work can be carried out from the basement height of 2.0-2.5 m. If necessary, work can be carried out from the first floor of the building.
3. It does not change the appearance of the structure. That is important upon the working on the monuments of architecture.
4. Works can be carried out on the existing facilities without stopping the production process.
5. The cost of the manual labor at all technological operations is minimum; method is economical, with low material consumption.
6. There is ecological advantage compare with chemical injections. It is very important in view of hard ecological control.

The main weaknesses of this method:

1. Insufficient knowledge about work of these piles in soft ground.
2. Low bearing capacity due to the small diameter that means the minor lateral and tip surface area.
3. It is complicated to secure qualitatively the head of the pile in case of old foundation, which subsequently works as a grillage. The lack of the appropriate calculation.
4. It is impossible to implement the pile from heavy concrete (small diameter wells can be filled only by the cement mortar).

The arrangement of the piles begins from drilling the well diameter of 80-250 mm. Vertical or inclined holes are made by the vertical boring machine. Removal of cutting is going through the holes with help of pressed air or the well is washed with fresh drilled solution for 3-5 minutes (Ulitskiy & Shashkin 2010).
After completing the drilling to the essential depth, the boring machine is taken out. Then, in well with clay mortar the reinforcing cage is lowered section by section (see figure 4.26). The length of the reinforcing cage is limited by the height of the room in which the work is going on, and usually does not exceed 3 m. The sections are connected with each other by welding. The column piles are reinforced on the entire length. The friction pile can be without reinforcement at the bottom (Ulitskiy & Shashkin 2010).

After setting the reinforcing cage or parallel with it the injection tube is lowered into the well. This injection tube is 25-50 mm in diameter and consists of the units 1000-2500 mm length. Through this tube, the well is filled with cement-sand mortar, which is pumped (Ulitskiy & Shashkin 2010).

Figure 4.26 Technological scheme of the grout-injected piles production with washing the wells by bentonite solution: I — cutter drilling of the wells; II—reinforcing cage installation; III—the injection tube installation and filling the well with a solution; IV—bridge installation and pressing the well; V—pressing the well starting from the wellhead: 1—boring bar; 2—reinforcing cage; 3— injection tube; 4—the strengthened foundation; 5—wellhead tray; 6—bridge with gland; 7—finished pile. [24]
Pressing is an important step in the formation of the grout-injected pile body, which is arranged in the soft ground under the protection of the mud solution. From the value of pressure and pressing time the subsequent crimping frictional resistance on the side surface of the pile is depended on. So that, it influences on the value of pile load-bearing capacity. The partial cementation of the soil on the pile-ground contact is happened. In soft ground at the pressure of 0.2-0.4 MPa the soil around the pile takes place, the pile cross-section increases and the available spaces are filled with a solution.

The example is strengthening works on the ancient building in Arkhangelsk. The ground was peaty soil and the grout-injected piles were discovered in the foundation. Their actual diameter was 290 - 300 mm diameter, but the initial drilling diameter was 151 mm. Thus, the bearing capacity of piles in weak peaty soils can be formed using the mode of pressing and the sand-cement or just cement mortar mix design.

Sometimes, some technological methods are used to improve collaboration of the system "foundation - pile - soil foundation". For example, the strengthening of the column footing of the Roman Catholic Church of St. Catherine in St.
Petersburg (Nevsky prospect, 32). After the injection of foundation masonry, the injection of the contact layer between foundation and foundation soil was repeated. That contributed to more efficient operation of short inclined piles of the strengthening (see figure 4.28). In the sixties of the XX century, the underground passage under Nevsky prospect was built. It led to the underground water horizon lowering. So that, wooden ground beams of the church began to rot. The process of rotting caused the uneven settlement of the building. Maximum absolute settlement of the central dome during 4 years of observations reached 8.2 cm.

Figure 4.28 Strengthening the foundation soils and the foundations of the Roman Catholic Church of St. Catherine in St. Petersburg (Nevsky prospect, 32-34): 1-rubble foundations; 2–grout-injected (tapered) piles; 3-wooden foundation beams; 4-concrete layer on the contact “foundation – soil”. [43]

The variant of the grout-injected short piles set in the form of a fan was chosen (see figure 4.28). Because of the “reinforcing” of the relatively strong layer of
sandy soils by the concrete reinforcing rods (thin grout-injected piles), the conditions of the load transfer were improved and sand layer has reduced down the pressure on the weak underlying layers of sandy loam to the safe values.

The grout-injected piles have been successfully used for reconstruction of Moscow Art Theater and the State Tretyakov Gallery, in the stabilization of emergency deformations of an apartment house in Pskov, for the Riga Electrical Engineering factory, for the club on the Pokrovka street in Moscow, etc.

In Rome, Cathedral of St. Andrey was strengthened, in Venice - leaning tower of the St. Martino Church on the island with the same name. Companies «Fondedile», «Bauer», «Keller», «Miver», «Fundex» and others, successfully use this method.

However, sometimes, the using of the grout-injected piles can lead to a crash. In St. Petersburg, in the building of beer production of the Stepan Razin factory the foundations were under reconstruction. Footing size is 4.5 x 4.5 m. Building stands on the powerful layer of the weak saturated soil. The project provided the strengthening of each foundation by three grout-injected piles with a diameter of 150 mm and a length of 13.2 m. But after strengthening, the settlement started to grow faster. In all likelihood, the additional weight of these three piles promoted to the growing, and piles did not work because of the weak soil.

Generally, when there is large thickness of the weak soil (for example, in St. Petersburg its capacity reaches 25-30 m) the effectiveness and efficiency of thin long grout-injected piles may be debatable.

A lot of numerical studies and experience of foundation reconstruction showed that using of the grout-injected piles should consider the following circumstances:

1. The angle of the piles inclination has little effect on the value of the settlement of the reinforced structure, but the increasing the piles
inclination increases greatly the internal forces in the piles. So that, there is no need to increase it. This fact simplifies maintenance work on piles arrangement.

2. Piles must be secured in the foundation footing carefully. So that, the old foundation, which consists of individual fence stone with the old solution, should be strengthened by injections of cement mortar. The foundation actually turns into a grillage and its strength must correspond to this purpose. If the strength of foundation is insufficient or the pile incorporation into the body of the foundation is realized less than on the deep of 5 its diameter, it is necessary to create an additional structure on "foundation-soil" contact, so-called "contact layer".

3. Upon the using of the reinforcement cage, the equal strength joints should be designed and implemented. Actually, durable pipes, metal profiles and special glass could be in role of the reinforcing agent. In any case, in conditions of the weak soils, the reinforcement should be made depending on the actual bending moments in different sections.

4. Technology of the grout-injected piles arrangement, which provides the required design strength parameters in the soft soils, is difficult and requires the use of special equipment complex. In order to develop such complex, it is necessary to analyze the main advantages and disadvantages of the grout-injected pile technology (Ulitskiy & Shashkin 2010).

4.8 Complex cases

In each case, there are multidisciplinary geotechnical tasks which require exhaustive information about soils and parts of structure, changes in their properties during its continuous utilization in the process of new foundations or underground structures implementation next to these soils. Questions about foundation soil and foundation strengthening must be solved comprehensively, perhaps, using several ways to strengthen at once. Examples of complex methods of the foundation reconstruction and foundation soil strengthening are the following objects.
4.8.1 Shopping center in Ufa

Strengthening of the foundations, which was carried out for the shopping centre under construction. This is multi-storey multi-span building with two underground floors (parking). Overall dimensions of the building are 69.15 × 239.48 m (see figure 4.29).

Figure 4.29 General view of the building. [16]

Foundations are made with piles and cast-in-place grillage under the columns and with piles and strip cast-in-place grillage under the walls.

Piles are driven with square section. According to the geological survey, piles go through the layers of filled soil, soft and hard-plastic loams and are sunken from 1 to 3 m in solid and semi-solid clay. Due to the heterogeneity of the footing both in plan and depth, the length of the piles varies from 4 to 17 m (Gotman & Devletyarov 2014).

Work on the construction site of the shopping complex was started in 2007. In 2008, the erection of the building was stopped.
In 2012, a new architectural concept was made and the decision to continue the construction was approved. At this point, all the foundations and 3 floors of the building were made.

Due to the new architectural concept and the new space-planning decisions the new working documentation was developed. This documentation provided the strengthening of the foundations under columns because of the load increasing compared to the original project in 1.2-2 times (Gotman & Devletyarov 2014).

Strengthening the foundations was performed in 3 ways, which were determined by the difference between the design load on the foundation, in accordance with the new space-planning decisions:

- Raising of the new design load up to 300 kN - the strengthening of the foundation soil under the grillages by the pressure cementation through underivable injectors;
- Raising of the new design load from 300 to 500 kN – the grillage widening and the strengthening of the foundation soil under the grillages by the pressure cementation through underivable injectors;
- Raising of the new design load up above 500 kN – arrangement of the additional grout-injected piles and loads transferring on them through the new grillage, which is concreted directly under the existing one.

Grout-injected piles diameter is 425 mm, and its length is 13 or 12 m. The feature of this solution is that the additional foundation on grout-injected piles starts to work only after bearing capacity exceeding of the existing foundation and its piles (see figure 4.30). In this case, the work scheme of the implemented foundation is not changed, so the reinforced concrete existing grillages do not require amplification (Gotman & Devletyarov 2014).
4.8.2 Business center in Moscow

Unfinished construction of the business center was located at the address: Moscow, Ryazan prospect-20. Overall building dimensions are 128×96 m.

The main load-bearing structures of the building are made from cast-in-place reinforced concrete. The columns arrangement is made according to the mesh 8,0 × 8,0 m. The foundation is made from reinforced concrete foundation slab thickness from 500 to 1000 mm. In April 2014 the underground floor of the building and part of the ground floor were erected (Makovetskii & Zuev 2014).

The geological structure of the site: filled soil with power 2.8-3.5 m; sands of small and medium size grains, its opening capacity is 15,2-18,3 m. Groundwater level is in a layer of sand on 7.7-7.8 m under the surface.

Due to the change of the building purpose building and its heightening, the complex of the loads on the foundation was increased. The existing foundation slabs did not provide the design character of the stresses distribution on the foundation soil and normative value of the difference between the settlements. It was decided to strengthen the existing foundation by piles, which are performed by the jet grouting technology. The total number of piles - 1070 pcs. The load on one pile is from 200 to 220 tons. Design pile length - 10 m, the calculated diameter of the pile - 600 mm (Makovetskii & Zuev 2014).
In order to absorb the axial pressed load, the piles were reinforced by the central core – it was a tube with 159 mm in diameter. The bottom section of the tube was plugged. After immersion of the core, it was filled by cement-sand mortar. The space between the core and the foundation slab was minted by the fine aggregate concrete (Makovetskii & Zuev 2014).

After curing, the pile head was pressurized by the cement - sand mortar for collaborative work of the pile and the existing foundation (see figure 4.31).

The piles were arranged through the technological holes diameter of 240 mm in the existing foundation slab. Drilling was carried out by the diamond boring bits. The total volume of drilling - 898 m piles length (see figure 4.32).
4.8.3 The building of the Admiralty in St. Petersburg

The project of the additional foundation floor arrangement in the basement of the Admiralty building and the strengthening of its foundations. Design work was carried out in 2014.
At first, injection strengthening of the foundations, foundation soil and contact layer "soil-foundation" was carried out.

Then the ground up to the design level was dug up. The new interior floor level became deeper on 2.8 m and the exterior on 2 m. The groundwater level was located at the depth of 1.5 m below the old level of the first floor. For its containment the enclosing sheeting was installed.

The pressing of the gravel layer (100mm) was implemented and the layer of the lean concrete (50mm) was underpoured. After that, the capillarity protection...
waterproofing in the footings of the walls was performed as well as felling of the foundation masonry part and cutting of the grooves.

Figure 4.36 Stage №3. [33]

Then the installation of reinforced concrete foundation slab 200 mm thickness was performed. This slab was arranged on 150 mm deep into the body of the existing foundation. The reinforced concrete cast-in-place foundation cages (pressure-exerting prisms) to strengthen the existing foundations were arranged. The preparation of the external surfaces of the foundation was also implemented.

Figure 4.37 Stage №4. [33]
Then, the surface waterproofing and protective layer on the surface of the rubble foundations and performed reinforced concrete structures was performed, and the blind area as well as the yard coverage was restored.

Figure 4.38 Stage №5. [33]

Finally, the cast-in-place reinforced concrete slabs of the first floor 200 mm thickness and its finish layer were implemented.

Figure 4.39 Final stage [33]
5. COMPARISON OF RUSSIAN AND EUROPEAN METHODS OF FOUNDATION RECONSTRUCTION

The idea of comparing the methods of foundation reconstruction in Russia and in Europe may seem a little strange. The deal is, that the reconstruction method itself is chosen, based on the following key features and options:

- Cost of work
- State of the around territory (presence of other buildings next to the reconstructed, their condition and status)
- The speed of work
- Possible limitations on the architectural and visual aspects (for example, the need for renovation without affecting the appearance of the building)
- Geotechnical conditions

That is, for the different methods and technologies differences in these characteristics are required. However, the first 4 conditions may be different or absolutely identical in all parts of the world, and soil conditions in Europe and in Russia are so vast and varied because of the magnitude of the regions that the latter option of comparison is also not indicative. In other words, we can say, that because of the size and diversity of these regions, there are no significant differences or peculiarities in the conditions for reconstruction between them. By this, it was decided to compare the smaller regions that are more interesting in this study, Finland and St. Petersburg.

First of all it must be mentioned, that the difference is manifested not only in technology renovation, but in terms of initial construction. We are talking about ground conditions, the density of the surrounding development, the necessary characteristics of the foundation, which depend on the size, number of floors of the building and its materials. All these factors affect on the type of foundation on stage of building erection.
In Finland, the high-rise buildings are not too popular. Most tall buildings do not exceed 90 m, and the foundation reconstruction concerns most often the old low-rise buildings or cottage-type buildings. In St. Petersburg the situation is a little different: the construction of high-rise is developed stronger. Tallest buildings reach a height of 120-140 meters, and the average height is about 70-80 m. In the central part of the city, where are situated most of the houses in need of renovation, the building has 6-7 floors in height. It means, that for buildings in St. Petersburg, the foundations have to be a bit more massive and have to take heavier loads.

In addition to this we must not forget about the ground conditions. Perhaps, it is the most serious factor of all. Moreover, the difference in this option between Finland and St. Petersburg is the most significant. 54% of bedrock in Finland - is a different rocks of granite. It is located not too deep, allowing to implement the quite strong foundations on a natural basis. As a strengthening, the methods of metal screw piles or micro piles, where they may be used (in the rock they can not be used), are very popular as well as the creation of reinforced concrete cages for cottage-type buildings (chapter 4.1).

Examples of micropiles technologies.

MESI system micropiles (see figure 5.1) are made of steel pipes, which have special injection nozzles in points of load transmission. This method makes it possible to obtain an element of pile foundation with high-strength materials and high load-bearing capacity of the ground, which is the result of several injections into the base of a pile. Because the injection is performed multiple times, the ground around the injection tube is subjected to a further compaction, which improves the working conditions of the micro piles.
Drilling micro piles (see figure 5.2) consists of a central disposed element in the form of pipe with an external thread, and the injection mace of the cement mixture. Pressures on the compression and tension transmitted through the mace from the load-bearing element (steel pipe) to the ground footing. Drilling micro piles are performed by small plants, require small diameter of boreholes and do not give large amounts of debris. Oscillations and vibrations are also small in size. A steel pipe in this manner is the drill pipe, the injection pipe and reinforcement bar simultaneously.
Drill pipes are produced with a diameter from 30 to 150 mm. This makes it possible to generate the optimum length and diameter of the micro piles.
Examples of metal screw piles technologies.

Screw-type foundation «BAU» (1) is forged conical body (2) to which a steel helix (3) in special configuration is welded (see figure 5.3). The design of the screw foundation requires different variants of building materials connection (4). According to the technology, the screw piles are screwed like screws into the ground by hand or by means of small-scale mechanization.

Figure 5.3 Screw pile type BAU: 1-the body of the pile; 2- conical body; 3-steel helix; 4-variants of connection. [36]
According to another technology (see figure 5.4), to facilitate the screwing the pile, the portion of the blade, in a range of 2/3 - 3/4 turns, should be placed on the tip. This design feature of the screw pile is significant because it allows you to refuse heavy axial additional loads. For piles of this design only minimum additional load for installation is required (in almost all cases, the load of pile and screwing mechanism is enough).

In St. Petersburg the situation is reversed. Weak unstable ground does not allow to build in St. Petersburg residential high-rise buildings on the shallow foundations. Most often it is friction piles, because a good rock ground is situated on a 80 meters deep. The implementation of the piles of such length is
very time-consuming and expensive. Nowadays such piles are erected only for one structure, for the skyscraper under construction Lahta-center (see figure 5.5 and 5.6). On the other hand, the buildings, which are in need of foundation renovation, are building in the downtown, the historical building, and, most of all, the foundations are shallow foundations, standing on the wooden logs. So, basically, the reconstructed foundations are similar to each other, but the used methods of reconstruction are different. The most popular ways in St-Petersburg are grout-injected piles or injections into the soil the cement-sand mortar or silicates. And multistage piles under pressure are also widely used. The detailed description of these technologies are described in chapters 4.7; 4.2 and 4.5 correspondingly.

Figure 5.5 The project of Lahta-center. [21]
There is another big difference, which proves the using of these methods in Finland and Saint-Petersburg. We are talking about surrounding area. The challenge of foundation reconstruction in the heart of St. Petersburg in addition to the floating soils is that fact, that the buildings are situated close to each other. The density of building development is very high. It turns out that strengthening works should provide as small impact of the surrounding buildings as possible. Because of it, the technologies of piles under pressure or injections into the ground look so effective. It does not influence any dynamic effects on the surrounding foundations. The additional advantage of the such technologies is that the works are carried out directly at the territory of the reconstructed building without using the surrounding area.
At the same time, in Finland this situation can be found only in the central areas of the largest cities like Helsinki and Turku. For the rest, creating a metal screw or micro piles with shallow undercutting with console support the building on a foundation is very suitable for Finland.

6. SELECTION OF METHODS OF FOUNDATION RECONSTRUCTION

The selection of the methods of foundation strengthening depends on the following main groups of factors:

- geotechnical and hydrogeological conditions;
- the condition of the existing foundation and its design;
- characteristics of the strengthening process;
- capabilities and requirements of the building;

Geotechnical and hydrogeological conditions include soil characteristics, which occur under foundation footing, and the groundwater level as well as its aggressivity.

To assess the condition of the existing foundation, it is necessary to work in accordance with the following factors:

- Works should begin with a thorough analysis of the geotechnical materials, observations of foundation deformations, establishing of the reasons of the deformations with comparing the calculated and actual values of the settlements and heels.
- On the basis of the existing design and survey materials analysis the project of the additional geotechnical and hydrogeological surveys of the building and foundation conditions at the time of reconstruction should be drawn up. Their goal - to determine how the already made structures correspond to the project, to assess the condition of structures,
foundations and foundation soil, to determine their strength properties, bearing capacity and the possibility of increasing the load, to predict the additional settlements, which are associated with an increasing of the loads.

- In the course of the survey it is necessary to determine the compatibility of the actual operating conditions with the project ones. This compatibility includes the comparison of design and technological values of loads, water balance, project and actual chemical analysis of process water, its leakage and so on. This information is necessary for determination the degree of the technology impact on the environment, including, the impact on the foundation soil, underground building structure and foundations (Recommendations for strengthening…1992).

In assessing of the need of the foundation strengthening, it is necessary to carry out the calculation of the existing foundation on the expected loads after reconstruction with the actual values of strength and deformation characteristics of foundation materials and foundation soils.

The characteristics of the foundation strengthening methods are follows:

- The possibility of carrying out the process under load;
- The possibility of carrying out the process without changing the dimensions of the foundation;
- The possibility of making the construction parts of the strengthening on the factory);
- The simplicity of the implementation;
- The rapidity of the implementation;
- The ability of the quick transfer of the live load after strengthening;
- The ability to work in cramped conditions;
- The level of the mechanization;
- The presence or absence of any changes in appearance of the structure after reconstruction;
- The ability of utilization of the building in the process of reconstruction.
The possibilities and requirements of the existing buildings are follows:

- The possibility of removing the live load from the foundation before its reconstruction;
- The ability to reduce the size of the room due to the strengthening of the foundations;
- The restrictions, which are imposed by the location of the underground structures and communications;
- The possibility of stopping the process of building utilization during the period of the works.

Table in appendix №1 can help with the choice of the method of the foundation reconstruction. It takes into account the most common characteristics of the utilization methods.

If there are several acceptable methods of strengthening in given conditions, for the final selection of the optimal variant the value engineering should be conducted.

7. DYNAMIC INFLUENCE

7.1 Features of the dynamic effects on structures and foundation soil

Dynamic effects on the structures and foundation soils can be caused by various reasons: the technology of construction work (soil compaction by ramming, vibrators, sinking of the pile and rabbet, and so on); technological or operational conditions (unbalanced mass movement of the fixed equipment and machinery; movement of the ground and underground transport, and so on); local natural or geotechnical processes, including the impacts of human activities (wind, wave impacts, karst holes, collapses; pumping of the large amounts of water or injection of the masses of water in deep wells under high pressure, the creation of the large reservoirs in mining and seismic regions,
powerful explosions and so on); modern tectonic movements, which are occurred in the upper part of the earth's crust and appeared on its surface (earthquakes).

These effects become apparent in the form of dynamic loads, fast time-varying in magnitude, direction, and sometimes on the location. The consequences of the dynamic loads are the wave oscillations, which are appeared in the construction and foundation soil. With all this going on, the structure may be the source of vibrations (e.g. machinery foundations with dynamic loads) or may take the vibrations transmitted from other sources. The overall picture of wave propagation can be extremely difficult (see figure 7.1) (Uhov & Semenov 1994).

Figure 7.1 Dynamic effects of the vibration sources on the construction: 1-transport tunnel; 2-ground transportation; 3-sinking of pile; 4-building; 5-plant with dynamic load; 6-bedding soil. [42]

There are vibration loads, under which the forces, causing them, vary according to the harmonic law (for example, the rotation of machine parts with unbalanced masses); shock (pulse) load, which are characterized by single and multiple short pulses (explosions, forging hammers, pile-driving, etc.); seismic loads caused by earthquakes. In operation of some machines there is a combination of vibration and shock loads.
Impact of the dynamic influences on the soil properties change depends on the intensity of the loads frequency and their duration, the type of soil, its state density and moisture content.

In construction practice there are cases where continuous machinery or equipment operation with dynamic loads caused significant settlements which are situated at some distance of the structures and leaded to their destruction and even accidents. There are also cases of the additional settlement appearance of the old buildings on soft ground, because of the dynamic impact of the urban transport with the growing intensity of its movements. These processes are related to the additional compaction by vibration of loose non-cohesive soils.

Long-term vibration and shock can lead to a shear strength decrease of the sandy and clay soils, especially in water-saturated condition. This causes a reduction of the loadbearing capacity of the foundation soil under dynamic loading in comparison with its value under a static load (Uhov & Semenov 1994).

7.2 Features of the survey of foundations and foundation soils under dynamic loads

Inspection of the machinery foundations under dynamic loads and their foundation soils is implemented according to a special program in case of reconstruction or strengthening of the foundations. In some cases, strengthening of the machinery foundations is realized to reduce the overall level of vibrations to ensure the normal technological process and the requirements of sanitary code. The auscultation of the machinery foundations under dynamic loads includes not only standard whole list of the envisagation activities for the foundation of the bearing structures but also the additional research. This research usually include: measuring of the vibration amplitude of the foundation and its individual parts, as well as the identification of the fundamental frequencies of the natural vibrations and forms of the forced oscillations of the foundation; the study of the oscillation propagation from the
foundation of the structure, as well as the actual state of the foundation, terms of placement of the machine on the foundation and its attachment to it; the definition of the actual elastic and damping characteristics of the soil; identification of the additional dynamic settlement appearance possibility.

In strengthening and reconstruction of the machinery foundations the dynamic forces, which are transmitted to the foundation, are taken, according to the technical data of the machines. In case of absence of such data, the dynamic loads are determined by calculation, according to the SP 26.13330.2012 and the type of machine. However, the calculation of the reconstructed or strengthened machinery basement should be based on the actual dynamic loads, which are perceived by the foundation. Its determination is usually made, as a rule, by special measurements with special organizations.

Experimental determination of the foundation soil dynamic characteristics of the reconstructed or strengthened machinery foundations is produced in according with the results of tests of these foundations on the free (for machines with pulse-load) or constrained (for machines with periodic loads) fluctuations.

During the changing of production technology, in the workshop the new machines with new dynamic load or new foundations for these machines could be installed. In this case, the dynamic properties of the foundation soil should be determined directly at the level of foundation footing by use of special experimental foundation (punches) of various designs.

Inadmissible foundation settlement under the influence of the machines dynamic loading is observed rarely. However, the identification of the appearance possibility of such settlements of the reconstructed or strengthened machinery foundations in some cases is necessary. Sometimes dynamic settlements may cause inadmissible deformations, and even the destruction of the loadbearing and envelope constructions of the workshops, in which there are the foundations of the machines, as well as lead to a deterioration of the technological equipment, because these settlements are characterized by unevenness.
7.3 The increase in mass and stiffness of foundations in their strengthening

The main reason for the machinery foundation with dynamic loads reconstruction is their increased vibration. Methods of reconstruction are mainly structural, and include: an increase in the mass of the foundation or its individual parts; an increase of the rigidity of the foundation, its individual elements, and foundation soil; an increase in the overall stiffness of the system “machine – foundation” due to a more reliable fastening of the machine to the foundation.

It should be noted that the increase in weight of the foundation affects the decrease in the amplitude of its oscillations significantly only when the additional weight is 50-80% of the principal. Particularly ineffective increase in only the mass of the foundation (without increasing in the area of the its footing) for the low-frequency machines, because the increase in the weight of the foundation lead only to the decrease in its own frequency oscillation and approaching the frequency of forced oscillations, that can cause a risk of the resonance. More effective for low-frequency machinery foundations is to increase the stiffness of the foundation footing by increasing the foundation footing area with a simultaneous increase in its mass. In this case, the natural frequency of the basement rises and moves away from the operating frequency of the oscillations of the machine. For the high-frequency machinery foundations, increasing the weight of the foundation without changing the area of its footing may be appropriate to reduce the level of the foundation vibration and to terminate the deformation caused by excessive vibrations (Shvec 1985).

The most effective way to restore the integrity of the destroyed machinery foundations, as well as to increase the rigidity of the foundation base by increasing the foundation footing area with a simultaneous increase in its mass is installation of the rigid cages, which will cover the whole foundation, or several parts of it. This provides not only an increase in cross-section of the foundation and load transfer to the new part of it, but the connection between deformed foundation parts together.
Sometimes the integrity of the foundation can be recovered by the reliable filling of cracks by injecting of the mortar or artificial resin (see figure 7.2). This action can be performed alone or in combination with the concrete cages installation.

Figure 7.2 The cement injections into the cracks in foundation body. [17]

In strengthening and reconstruction of the foundations for machines with dynamic loads another effective way to reduce vibrations and to terminate the deformation caused by excessive vibrations of such foundations is to increase the stiffness of the foundation soil by reclamation (drainage) or solidification of the soil. It is especially advantageous for the low-frequency machines, when the natural frequency of the foundation on the hardened ground is higher than the operating frequency of the machine (piston compressor, log frame, smoke exhaust and so on). In this case, the strengthening of the foundation soil leads to increasing in the natural frequency of the foundation and to reducing the amplitude of the oscillations (Shvec 1985).

The positions of the fixed soil zones under the foundation and their sizes depend on the rate and mode shapes of the foundation. When there are vertical vibrations, the strengthening of the foundation soil is recommended to perform
under the entire foundation footing, in all directions and exceeding the limits of its plan for 0.5-1 m. When there are rotational oscillations, it is enough to strengthening the foundation soil along the perimeter of the foundation footing by strips with a minimum width of 2 m. In both cases, the grouting must be carried out to a depth of 1.5-2 m from the footing of the foundation.

An effective way to increase the rigidity of the machinery foundation footing is the transplantation of the foundation on the driven or bored cast-in-place piles. This method helps to reduce both vertical and horizontal rotational vibrations of the “machine – foundation” system. Furthermore, for foundations, which take the dynamic loads, except prismatic or standard piles it is possible to use the conventional driving piles with one or more enlarged pile bases (see figures 7.3, 7.4). For foundations, which are under the influence of the horizontal dynamic loads, it is recommended to use piles with the broadening of the pile at the top of the body; for bases loaded by the vertical dynamic load - the pile with the broadening of the tip (Alekseev & Shvec 2001).

![Figure 7.3 Bored cast-in-place piles with widening in the bottom part. 1-casing pipe; 2-mechanism of widening; 3-concrete; 4-concreting pipe; 5-soft soil; 6-hard soil. [47]](image-url)
When there are horizontal dynamic effects and the standard vertical piles are not enough for getting the allowable vibration amplitude of the reconstructed foundations, the inclined piles could be as an additional measure to reduce vibrations of the foundation. These piles are located on the perimeter of the pile foundation in the direction of the horizontal dynamic force action.

An example of this is the case of strengthening the massive monolithic foundation of the ball grinder on one of the dressing works in the Urals. According to the project, the foundation soil was the sandy clay with solid consistence. However, during the process of works, under several parts of the foundation, the considerable excess of the ground was allowed (at the level of 1.5-2 m below the footing of the foundation). This production work defect was eliminated by the layer of fine sand with multilayer consolidation.

A few years after the start of the grinder operation, the large fluctuations in its basement were appeared. The amplitudes of these fluctuations exceeded the permissible values significantly. These oscillations prevented the normal operation of the grinder, caused the unacceptable vibration in the bearing and envelope structures of the factory building and improved the overall vibration environment of the industrial area, and it started to influence on the staff badly.

Figure 7.4 Bored cast-in-place piles with widening in the top part. 1-pile widening; 2-foundation panel; 3-plinth panel; 4-grillage; 5-foundation beams; 6-panels; 7-embedded element. [15]
A survey of the grinder foundation showed that under one of its ends the settlement had occurred. At the same time it was found that there had been a rise of the groundwater level, which at the time of the survey was at the level of the foundation footing. This fact and the vibration in the foundation were the reasons of the fine sand compression and, accordingly, the reasons of the settlement.

Strengthening the foundation was carried out by the arrangement of the concrete cage according to the perimeter, which rested on bored cast-in-place piles with a diameter of 500 mm and a length of 3 meters. The piles transmitted the load from the foundation to the undisturbed ground. The oscillation amplitudes of the strengthened foundation and vibrations of the building structures reduced to allowable limits of normative documents.

In case of the significant deformations of the foundations with large and complex configuration, such as the foundations of crushing equipment or basement type foundation under the powerful machines with rotating parts, it is not enough to use for restore the integrity only the concrete cage. It is required to carry out packaged approach.

For example there is the case of strengthening the reinforced concrete basement-type foundation for the centrifuge. Basically, in the technology workshop of the factory in the Urals there were three centrifuges. All these three foundation took the significant vibrations during the work of the centrifuges. The amplitudes of the horizontal oscillations at the top edge of each foundation exceeded the limit on 0.4 mm. The work of one of the centrifuges had even stopped due to the destruction of concrete support under the base bearing. In the foundation under another centrifuge there were cracks at the junction of the column with the top plate.
Dynamic calculation of the foundation under the centrifuge showed that the dynamic load, which is transferred from the machine to the foundation, was determined incorrectly during the process of projecting. So that, the foundation mass is not sufficient to extinguish the vibrations, which appear during operation of the centrifuge and cause the deformations of the foundation. To prevent the further development of the deformations, strengthening the foundations according to the diagram on Figure 6.5 was performed. Along the perimeter of the bottom plate the reinforced concrete cage was arranged. It allowed to increase a little the stiffness of the foundation base as a result of widening its footing. The increasing in mass of the foundation and restore the integrity of the destroyed items were carried out by the concrete casting of the vertical structures of the foundation (walls and columns), as well as the arrangement of the concrete cage around the perimeter of the reinforced concrete supports on its full height underneath the base bearing. The maximum amplitude of the top edge strengthened foundation was 0.114 mm (the allowable amplitude is 0.15 mm); the foundation deformations during the observation period was not found.

Sometimes it is necessary to strengthen the foundations of machines with nominally balanced rotating parts. The increased vibration and destruction of these foundations are usually caused by either a lack of rigidity in fastening of the machine to the foundation or by the low rigidity of certain structural elements of the foundation.
In the operation of centrifugal smoke exhausts in gas recirculation to a turbine unit with capacity of 800,000 KW the increased vibrations in the bearing of the smoke exhaust and bearing of their engines appeared. As a result, there was a breakdown of bearings. In addition, in the body of smoke exhausts foundations vertical cracks appeared. The cracks had a width of 0.3-2 mm opening and they extended from the top edge of the foundation to the surface and were located at zone of fixing machines to the foundation (see Figure 7.6 a). The reinforced concrete massive foundations of smoke exhausts are designed as a single monolithic unit with the necessary ledges and hollows.

![Figure 7.6 Scheme of strengthen the foundation of the smoke exhaust: a-the location of the cracks in the structure of the upper basement; b-the oscillation form of the top edge of the foundation (amplitude, mcm); c-scheme of the foundation, which was strengthened by the reinforced belt-cage; l-the anchor bolts; 2-cracks; 3-circuit of the foundation (dotted line) before strengthening; 4-cage (the shaded portion); 5-reinforcing cage of the strengthening; 6-reinforcement of the foundation; 7-reinforcing trussing. [1]

The measurement results and the resulting waveform (see figure 7.6 b) of the surveyed foundations for the smoke exhausts showed that the upper part of the foundation is not a single array, and is divided into individual conglomerates through cracks. The amplitudes of the horizontal oscillations of the top edge of the foundation reached 0.07 mm and the frame and bearing smoke exhausts - 0.25 mm, that indicates the absence of a rigid connection between the machine and the foundation. The reasons for this is to reduce the stiffness of the anchor bolt in the body of the foundation due to the presence of the cracks and the integrity of its top structure and loosening anchor bolts due to the accumulation of the plastic deformations in the bolts under the combined action of dynamic loads and high temperatures that occur due to insufficient insulation machines.
The latter also contributed to the emergence of additional thermal strains at the top of the foundation.

The status of foundations required immediate strengthening, which was carried out as follows. Topside, which was weakened by notches and cracks, was strengthened on the entire height by concrete belt-cage thickness of 0.5 m (see figure 7.6 c). That provided the necessary rigidity of the foundation according to the calculation, as well as the reliable connection between the machine and the foundation due to increased stiffness of the top of the basement in zones of anchor bolts fixing. The existing cracks were cemented by the solution of the expanding cement, and in the place of the rock bolt installation were filled by the epoxy resin. At the same time, it was recommended to enhance thermal insulation.

7.4 Regulation of oscillation parameters in the reconstruction of machinery foundations

In some cases, it is expedient to carry out the reconstruction of the foundation with special measures for the vibration reducing of the machinery foundations or for reducing the vibrations of the constructions. These measures are aimed to changing the parameters of its oscillations. In addition with the need to reduce the amplitude of the oscillations, the need to make the bigger difference between the natural frequency of the foundation and the operating frequency of the machine oscillations or the vibration frequency of the constructions is appeared also very often.

The most popular method for this purpose is joining to the foundation the concrete or reinforced concrete slab, which is located on the top layer of the soil. This attached plate can be very tough, and its connection with the foundation could be rigid, fixed by a hinge, movable by a hinge and resilient.

Accomplished studies have shown that the attachment of the slabs with weight of 5-10% by weight of the foundation can reduce its vibrations significantly. This method is greatly more useful for reducing the horizontal and rotational
vibrations, then the vertical ones. If you want to suppress the vertical oscillations of the foundation, it is more expedient to place the slabs on both sides of the foundation. In this case, the influence of these slabs is more intensive than in the one-sided arrangement, but the area is the same (Alekseev & Shvec 2001).

During the projecting of the foundation strengthen it is necessary to take into account that the harder foundation soil underneath the foundation and the slab, more stiffness of the connection between them than the greater effect of the slab connection to the foundation. Despite the high efficiency of the rigid joint, the practical implementation of it is very difficult. In addition, a rigid connection could be used only in hard soils, where the difference between the settlement of the foundation and slab is not sufficient. Therefore, the recommended variant is swing joint. The resilient connections should be used only in cases when using the swing joint is not possible (Shvec 1985).

Figure 7.7 Structural schemes of nodes junction between slabs and foundations: 1-foundation; 2-slab; 3-connection bars; 4-captive assembly; 5-bar; 6-embedded parts; 7-intermediate; 8-concrete filling. [36]
The structural schemes of nodes junction between slabs and foundations are shown in Figure 7.7. Rigid connection (see figure 7.7 a) may be performed by welding the connection bars of the plate and the foundation with followed
captive assembly. For better adhesion the inner surface of the concrete slabs should be produced rough. Swivel (see figure 7.7 b) and movable by hinge (see figure 7.7 c) connections are made by embedded parts. The metal sheets interconnected by a rod of high strength steel, are welded to these embedded parts. For protection against corrosion, these compounds should be asphalted.

Let’s look at one of the typical cases of additional plates. In the main building of the power station in the Urals the cracks in exterior walls and corners of the building, as well as in the internal partitions were appeared as a result of excessive vibrations of the building structures. The results of test measures were: the presence of the vibrating background in whole building, the resonance condition of the individual building structures or its parts, as well as significant fluctuations of massive foundations under the hammer mills. The amplitude of oscillation of the horizontal top edge of foundations hammer mills reached the value of 0.75 mm (in the perpendicular direction to the rotation of the drum), exceeding the permitted value in more than 6 times.

Analysis of the fluctuation records showed that vibration of the bearing and envelope structures of the main building have the same frequency as the frequency of forced oscillations of the hammer mills foundations (12.5 Hz), the natural frequency of the foundation is 123 Hz. Thus, foundations of the hammer mills operated in an area close to the resonance, and for reducing the fluctuations, they should be changed and came out from this zone.

For the natural frequency of foundation changing, the additional slabs, laying on the ground surface, were attached to the foundation by the swing joint. Scheme of this process is shown in Figure 7.8. The area of the slab was 12 m² and its thickness is 0.5 m. The slabs were attached to the foundation on the both sides. They were installed parallel to the axis of the hammer mill. As a result, the natural frequency of the system increased to 16 Hz and amplitude of the foundation vibrations has decreased in 10 times. This reduced vibration of the all structures of the buildings.
Another effective way to control the low-frequency oscillations of the bases of machines, which works in below resonance mode, is to combine massive deep foundations by the elastic foundation slab, which lies on the elastic base. This method raises the basic hardness on the structure system on 30-40% on average and because of the increasing the distance between the values of the resonances, the intensity of the foundation vibrations is reduced significantly.

Combining of the foundation groups by the thin slab not requires the significant material cost. For the role of this thin slab it is possible to use the concrete floor of the industrial zone, but only in that case, when there will not stay the vibration-sensitive equipment or not be the permanent occurrence of the staff. So that, the only requirement for this method is to ensure proper contact between the slab and foundations. Of course, this method demands to carry out such things like reinforcement connections between foundations and slab, using of the concrete with the expanding portland cement because the resulting cracks in the joint minimize the expected effect. For the basement-type foundations it is possible to use as the connection slab the floor slabs, which rests on the foundation. (Alekseev & Shvec 2001).

An example could be the case of the integration of two massive foundations for smoke exhausts gas recirculation unit with capacity of 800.000 KWh. The foundations were integrated by the concrete slab floor, located directly on the soil surface and having a thickness of 200 mm. The distance between the foundations was equal to three times width of the foundation.
The overall level of vibrations of the combined system decreased about 2 times. The amplitude of the vibrations of the foundation with broken (backup) machine decreased by 1.3 times and amounted only 15% of the amplitude of the foundation oscillation with operating machine, vibration of which after conversion fell by more than in 4 times. The oscillation frequency of the machinery foundation during operation, combined with the floor plate, has increased from 22 to 32 Hz and the resonance oscillation amplitude decreased from 170 to 88 microns. It should be noted that after the implementation of the combination between the foundations and the vibration slab, the vibrations of this slab increased by 5-6 times, but damped quickly. However, it excludes permanent residence of the staff on it, as well as the accommodation of the vibration-sensitive equipment next the source of vibrations.

The source of the elevated vibration of buildings on the factories are often became the elastic waves from the foundations for the machine with shock loads.

The options of the massive foundation vibrations during operation or replacing the machine, which is installed on the foundation, can also be adjusted by changing the height and density of the soil backfill. For these purposes, along the perimeter of the external surface of the foundation for the whole its height the envelope structures of any kind are arranged with the gaps. The gaps from the top are covered by plates. If there is the need to change the oscillation amplitudes of the foundation, or the ratio of the frequency of its own and forced oscillations, the gap between the envelope structure and the lateral surface of the basement is filled with tightly packed soil.

Initially the gap is filled with soil to a height, value of which is equal to 40% of that size of the foundation footing size, which is parallel to the direction of the horizontal vibrations. Then, the gap is filled with thick layers of 0.1-0.2 m to achieve the desired maximum oscillation amplitudes. These parameters are set according to the fluctuations of the direct measurement of vibration level in the basement. In general, the height of the side filling in the gap should be equal to the value of the sunken part of the foundation.
For the gap filling it is possible to use and non-cohesive soil and cohesive soil. In the latter case it is necessary to provide constructive measures for excluding the soaking of the filling soil to prevent the formation of the cracks between the foundation and the foundation soil. Using the side soil filling to regulate the parameters of the massive foundation oscillations under the machines with dynamic loadings allows to achieve the optimum mode of operation.

**CONCLUSION**

This thesis work includes many aspects related to the process of foundation reconstruction and strengthening. Many of them have been investigated, but not all have been explored in due form, as originally had been planned.

First of all, in this work there are presented a huge variety of reasons of the foundation reconstruction and strengthening. It is the human factor, firstly. In another words, his mistakes, carelessness, laziness, negligence, randomness, or imperfection of the method. Also, it is the human impact on the world through the construction of such facilities, which affect greatly on the soil conditions. Sometimes the need of reconstruction arises directly from the nature or, in other words, because of the natural effects on the structure. On the other hand, this can be predicted and thus it is also human oversight or inability.

So, it turns out that all the reasons could be solved. It is necessary to train more competent and responsible professionals who will implement own duty with all responsibility. It is necessary to control strictly the construction process of the structure, in order to avoid possible errors or design flaws which can manifest themselves in the future. We have to implement the facilities with a smaller impact on the environment by large researches and development of new technologies. Finally, it is necessary to invent materials, which will be more resistant to the natural conditions to reduce the rate of destructions and damages in the structures from natural influences. Surely it would be in general, more economical than implementing hard and painstaking work on the survey of
the building, variant designing ways to strengthen themselves, and then the construction work.

A further aspect – ingenuously the methods and technologies that are used in the process of foundation reconstruction. Of course, if we speak about the methods generally, their number has not changed much over time. This work presents many different ways to strengthen and almost all are used both in Russia and in Europe. This is due to the fact that for every method it is easy to find a suitable building with the right loads and working conditions and suitable climatic and soil conditions.

Another thing is that the technologies are changing. Some of them are becoming more popular (as grout-injected piles in St. Petersburg) and displace older ones, but some still remain largely unknown. There are appeared more options for combining different methods (for example simultaneous use of grout-injected piles, cementation of the ground and foundation slab) and sometimes even impossible to say exactly what technology was used in this case.

Unfortunately, in Russia, there are no systematic databases of the technology using, and the results to which they led. Of course, such database should be established by all organizations working in the country. It would be very useful and would help to analyze the advantages and disadvantages of all the methods, to sort out the useless methods, to open any innovation and to draw attention to those areas which cannot be solved yet. It is difficult to assess across the whole country, but if to say about the North West region of Russia and St. Petersburg in particular, the most popular methods there are: injections into the body of the basement and into the ground under the foundation footing, multistage piles under pressure and, of course, grout-injected piles. This is due to two factors: 1. An unstable, soft ground and varying of the groundwater level. 2. Compact historical development in the downtown area of the city, which leads to a lot of restrictions on the dynamic effects, settlements and so on. As a result, it is necessary to choose those methods that can be used without great affecting of the surrounding areas. These factors were compared with the terms of the foundation reconstruction on the territory of Finland. The local situation
was analyzed and the most popular methods for the reconstruction on the territory of this country were identified. The difference of the used methods in Finland and Saint-Petersburg was installed and explained as well.

Another aspect is the problem of reconstruction method choice, because there are a lot of ways of strengthen and almost everyone has their advantages and disadvantages. Brief comparative table was made. It is based mainly on the characteristics of the strengthening ways. Comparison of prices turned out quite uninformative, because the methods are very different from each other and each of them may be performed in different ways. Moreover, in various working conditions every single method can also vary greatly in price. In general, the money issue should be solved directly on the basis of the particular characteristics of an object.

Dynamic effects on the foundations have been studied by me not so deep as the other sections of the work. Basically, the study took place in Soviet books, the most recent of which were published in the late 80s. Actually, I think, that the literature for such a serious and relevant area of construction in Russia is sorely lacking. This is true for not only dynamic effects, but also for the most modern methods of strengthening too. But, nevertheless, this issue has been studied. Many reconstruction methods of simple residential buildings and structures are used in this matter too, but there are some special details related to vibration, which are described in the work.

Despite the large number of difficulties in this work, all the sections, which were planned, are presented in one form or another. Many cases of reconstruction and strengthening of foundations in various regions of Russia are considered. The conversation turns on the ordinary civil buildings and, as well, on the largest factories and complex objects of architectural monuments in a good hard of floating and weak soils. Many questions in the field of reconstruction of foundations were raised and the problem areas were found. These problems should be solved in the future.
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The possibility to use method in follow geotechnical and hydrogeological conditions

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