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THE INFLUENCE OF LONG TERM DYNAMIC AND VIBRATORY LOADS ON BEARING STRUCTURES OF THE AMMONIA REFRIGERATING SYSTEM BUILDING

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For ensuring safe conditions of maintenance of buildings and structures, primary importance is supporting of its due technical state, displaying of its physical depreciation and causes, which determine its technical state. The vibration, among of all types of mechanical effects, is the most dangerous for engineering structures. The destruction of structures comes by vibrational influences under conditions of resonance. This process is very fast and it comes frequently. Accordingly the influence of long term dynamic and vibratory loads on bearing structures of the Ammonia Refrigerating System (ARS) building on pharmaceutical enterprises in Lviv has been investigated. It is developed the option of basements reinforcement by using of drill piles and concrete jacket. Recommendations of taking measures for elimination of factors which led to damage and destruction of constructions have been formulated.

Key words: beam, armature, vibratory and dynamic loads, reinforced concrete structures, basement, levers, engine room.

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ВПЛИВ ТРИВАЛИХ ДИНАМІЧНИХ ТА ВІБРАЦІЙНИХ НАВАНТАЖЕНЬ НА НЕСУЧІ КОНСТРУКЦІЇ БУДІВЛІ АМІАЧНО-ХОЛОДИЛЬНОЇ УСТАНОВКИ

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Для забезпечення безпечних умов експлуатації будівель і споруд першорядного значення набуває підтримання на належному рівні технічного стану будівель і споруд, виявлення ступеня їх фізичного зносу та причин, що зумовлюють їхній технічний стан. Вібрація серед всіх видів механічних впливів для технічних об'єктів найбільш небезпечна. Знакозмінні напруження, спричинені вібрацією, сприяють накопиченню пошкоджень в матеріалах, появі тріщин та руйнуванню. Найчастіше і доволі швидко руйнування об'єкта настає при вібраційних впливах за умов резонансу. Значні пошкодження обстежуваної будівлі виникли внаслідок її неналежних умов експлуатації та виконанням будівельних робіт із влаштування конструкцій під час зведення будівлі. Переважно це стосується фундаментів та стін, які зазнали найбільших руйнувань від постійних динамічних впливів та вібрації. Постійний динамічний вплив вібрації на фундаменти створюють компресори, які розміщені у машинному залі. Ще більшим є

вплив вібрації внаслідок відсутності деформаційного шва між бетонною підлогою машинного залу та фундаментами компресорів, а також відсутність деформаційного шва між бетонною підлогою та стінами будівлі. Фундаменти будівлі також постійно підмиваються відпрацьованими водами та мають неналежну глибину закладання із різною основою опирання їх подошви. У нашій роботі ми вказуємо на основні причини, які привели до руйнувань фундаментів та стін будівлі АХУ і пропонуємо методи вирішення усунення динамічних, вібраційних та інших впливів на конструкції будівель. Відповідно було досліджено вплив тривалих вібраційних та динамічних навантажень на несучі конструкції будівлі аміачно-холодильної установки (АХУ) на фармацевтичному підприємстві у м. Львові. Візуальним та інструментальним обстеженням і контрольними розрахунками встановлено несучу здатність та придатність до експлуатації основних конструктивних елементів споруди. Розроблено варіант підсилення фундаментів за допомогою буронабивних паль та бетонної сорочки. Сформульовано рекомендації для усунення чинників, які призвели до пошкоджень та руйнувань конструкцій будівлі АХУ.

Ключові слова: балка, арматура, вібраційні та динамічні навантаження, залізо-бетонні конструкції, фундамент, тяжі, машинний зал.

Introduction. The necessity of inspection of buildings and constructions is carried out with the aim to get objective data about actual technical condition of building constructions considering its changes over time. There is a change in properties of materials and constructions. As a result the risk of integrity is increased in the process of exploitation under the influence of aggressive environmental factors and technological processes (such as long term dynamic and vibratory loads), which lead to considerable material costs related to the restoration of operational properties of the structures of the building. Untimely established and eliminated defects of elements of building constructions often grow into serious damage. It is very important to estimate correctly the condition of structures and equipments of buildings in time, predict the possibility of developing defects and take measures for its stabilization and elimination. Vibration is the most dangerous form of the mechanical impacts on the technical buildings. Alternating stresses caused by vibration contribute to the accumulation of damage in the materials, the appearance of cracks and destruction. Destruction of the building occurs more often and rather quickly because of the influence of vibrations under resonance conditions. To ensure safe operating conditions of buildings and structures, it is important to support buildings and constructions at the proper state of technical conditions, to find out the degree of physical wearing and the reasons that determine these technical conditions. It is also important the development of measures to ensure the normal performance of the constructions.

Significant damages of the surveyed building were caused by improper using of constructions while building. It concerns basements and walls that were damaged by long term dynamic influences and vibrations. The previous inspections didn't solve the issue of reduction of the vibratory influence on bearing structures. In this work we point to the main causes which led to destruction of basements and walls of the building of ARS and propose solution methods of elimination of the dynamic, vibratory and other influences on the constructions of the building.

To get more information we stop on constructive and planning schemes of the ARS building. The building of Ammonia Refrigerating System is situated on the territory of pharmaceutical enterprises in Lviv (Ukraine). The building was projected in 1982 and was built in 1984. The purpose of the building is pharmaceutical production. The category of firefighting building is "B". The class of explosive danger is "B-16". The major repairs have not been carried out for all the time of exploitation except repairing of soft roof and walls reinforcement by using armature levers.

ARS is one-storey brick building of axis "1"..."1/1" and "2"..."3", two-storey building of axis "1/1" and "2", without cellar, rectangular in plan, 6.5 x 22.15 m. in size (Fig. 1 and Fig. 2).

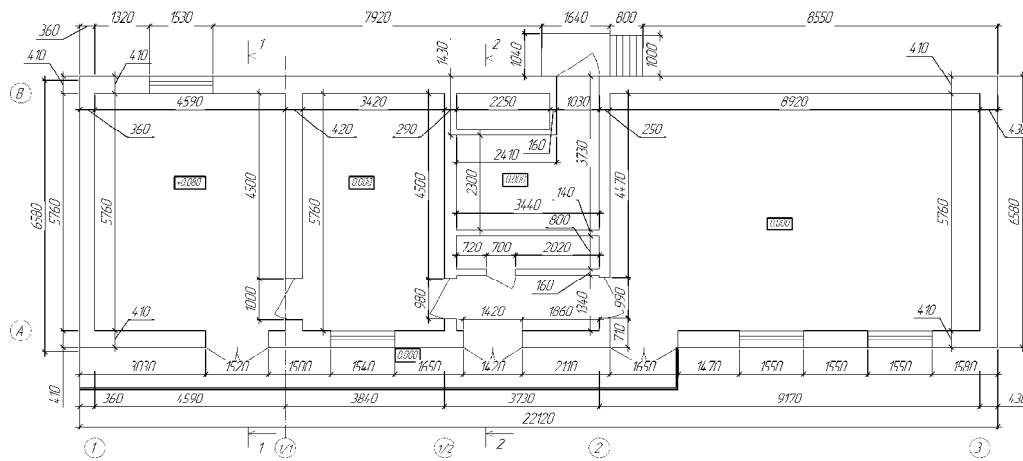


Fig. 1. Plan of the ARS building

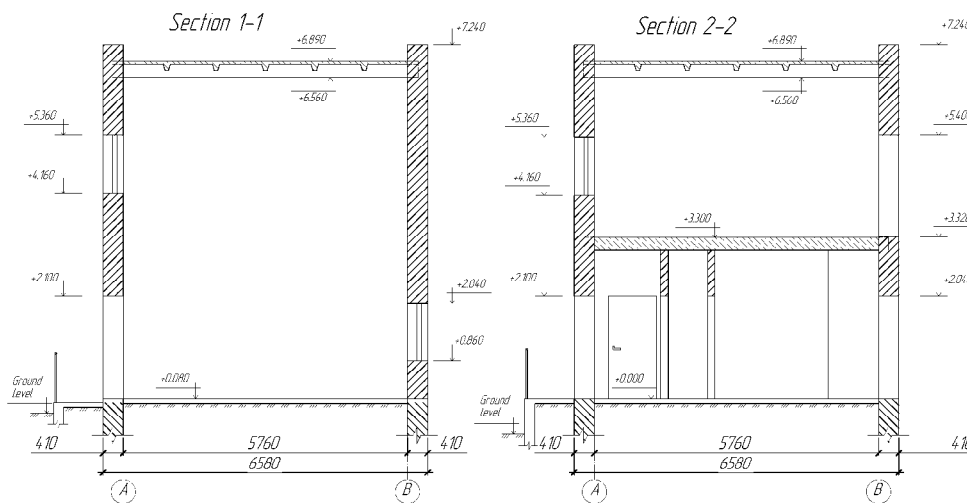


Fig. 2. Sections 1-1, 2-2

The height of one-storey ARS brick building to the lower part of bearing structures of coating is 6.3 m, the height of every floor of two-storey building of axis “1/1” and “2” is 3.3 m. The building of Ammonia Refrigerating System is the separate technological construction that is not connected with the other constructions of the factory. The structural scheme of the brick part of building consists of longitudinal bearing walls (axis “A” and “B”) and transverse self-supporting walls (axis “1”, “1/1”, “2”, “3”). The beams for the pendant crane with load carrying capacity of 2 t. are mounted in the engine room of axis “2”...“3”. The basements under the brick walls are strips, made of prefabricated concrete blocks. Engineering geological researches were made to carry out the necessary strengthening of the building and measurements of the basements were determined in the open pits. The second floor prefabricated reinforced concrete slabs with the round cavities on the mark of 3.300 of ARS brick building are 6000 mm in length and 220 mm in height. The prefabricated reinforced concrete ribbed slabs serve as coating of the building of axis “1”...“3” that are 6000 mm in length and 220 mm in height. Such reinforced concrete coating provides the stiffness of the building along and across. The brick walls are 380 and 250 mm in size and are made from lime and cement. The exterior walls of axis “1”...“3” are made from the red clay bricks and the facing layers by thickness of 120 mm are made from silicate bricks. All coverings are also made from bricks by thickness of 120 mm. The brick building has double slope roof with the inner drain through one drain funnel.

Analysis of the recent investigations and publications. Having studied the recent investigations and publications dedicated to the subject of this article we note that all authors pay attention to three basic concepts that refer to the influence of dynamic and vibratory loads on structures of the building [1, 2]. In the first place

are sources of vibrations and fluctuations from the foundations of equipments. Building and sanitary-engineering equipments could be the sources of vibration in housing and public buildings. It also could be industrial installations and transport facilities which create hard dynamic loadings and which cause spreading of vibration in the soil and building constructions. Such types of vibration could also be the reason of sound inside the buildings (underground of a shallow foundation, heavy trucks, trains, trams etc). The foundations of machines with dynamic loadings are the sources of waves, spreading in soil. The authors note their harmful effect on constructions of buildings and structures, housing and public buildings with close location.

Fluctuations from the foundations of equipments could cause unequal settling of the basements and extra tension of buildings with close location, which would be the reason of formation of cracks and future destruction. Such kinds of vibrations could have an influence on the work of some kinds of machines and measuring equipments. The waves spreading in soil from low-frequency foundations of machines (with frequency 400 min^{-1} and less) and fluctuations with frequencies close to the own fluctuations of buildings have the most influence on the fluctuations of structures of the nearest buildings. The fluctuations from machines with medium (more than 400 min^{-1}) and high (more than 1500 min^{-1}) frequencies as a rule are less dangerous for the nearest buildings [3]. The reason is the absence of conditions for the formation of resonance fluctuations of the buildings. Using [4], we can determine the level of fluctuations spreading in soil from foundations of machines according to the formula:

$$A_{v,h} = A_{0,v,h} \cdot \left\{ \frac{1}{\delta \cdot [1 + (\delta - 1)^2]} + \frac{\delta^2 - 1}{(\delta^2 + 1) \cdot \sqrt{3} \cdot \delta} \right\}, \quad (1)$$

$A_{v,h}$ – the amplitude of vertical (horizontal) fluctuations of the soil on the surface in the point at the distance r from the axis of the foundation – the source of waves in the soil; $A_{0,v,h}$ – the amplitude of free or forced vertical (horizontal) fluctuations of the foundation – the source at the level of the sole of the foundation; $\delta = \frac{r}{r_0}$ (r_0 – radius of the sole of the foundation – the source, m, equals $\sqrt{\frac{A}{\pi}}$, where A – the area of the sole of the foundation – the source, m^2).

Calculation of the amplitude of fluctuations spreading in soil from foundation – the source according to formula (1) is done not only in cases, when it is necessary to estimate the influence of fluctuations of foundations of machines with dynamic loads on the other objects, but also in cases, when it is necessary to estimate the amplitude of fluctuations of neighboring foundations of machines equal to kinematic impact at their collective installation in the workshop. The formula (1) is based on the generalization of available experimental data, according to which amplitudes of spreading fluctuations, when $\delta \leq 3$ are proportional to $\frac{1}{\delta}$, but when $\delta \geq 3$ are proportional $\frac{1}{\sqrt{3} \cdot \delta}$.

The main means of protection against vibration of various types are using of vibroinsulators (elastic elements which have a low rigidity). Spring or rubber vibroinsulators are used to reduce vibration, which is transferred to the bearing structure. Spring vibroinsulators are recommended for the aggregates with the speed of rotation less than 1800 rpm (revolutions per minute); rubber vibroinsulators are recommended for the aggregates with the speed of rotation more than 1800 rpm. Steel vibroinsulators which are durable and reliable at work are used for vibroinsulation at low frequencies.

Machines with dynamic loadings (fans, pumps, compressors etc.) are recommended to be firmly mounted on the heavy concrete slab or metal frame based on vibroinsulators [5]. Using the heavy slab reduce the amplitude of fluctuations of aggregate installed on the vibroinsulators. In addition the slab provides the firmly centering axle and reduces the location of the center of gravity of the installation. The weight of the slab is supposed not to be less than the mass of the machine, which is isolated. The foundations of machines with dynamic loadings should be separated with the seam from the adjacent basements of the building, construction and equipment to reduce the transmission of vibrations. The

distance between the lateral faces of the foundations of machines and the adjacent basements of buildings should not be less than 100 mm. It is very important for the periodic action of low-frequency machines and shock loads machines to arrange a gap between foundations of machines and basements of the buildings. The following steps could be applied for reducing the amplitude of fluctuations of low-frequency foundations of machines: to increase the firmness of the base of the foundation by increasing its sole in the direction of the horizontal loading, arranging of a pile foundation (at vertical loads), chemical consolidation of soil, arranging of foundation bearer with a firm soil; to equip a common foundation under several machines; to connect the foundation of the machine with the concrete workpiece [6–8].

The recent researches and publications confirm the fact that the basic requirements for the designing of foundations, the bases of which are located in the zone of distribution of sources of vibration, are to determine the safe distance to the source of vibrations on the basis of calculations of bearing capacity and deformation of the bases, considering the frequencies and amplitudes of fluctuations of the source of foundation. The safe distance to the object is determined under conditions that the maximum amplitude of fluctuations of the foundations in combination with the base should not exceed maximum permissible values of sanitary norms and requirements of legal norms [9]. Calculations of foundations with the bearing capacity of bases in the zone of influence of sources of vibration should be done taking into account the voluminous forces of inertia. Settling of foundations with the action of static and dynamic loads should be determined by using the dynamic characteristics of the soil, having got according to the results of the test vibration dies or according to the data of experimental tests of foundations by using vibromachines.

Summarizing, we would like to pay attention that the most effective way of designing the foundations, located in the zone of action of sources of vibration, is to anticipate the measures of reducing the parameters of dynamic influences in the source – changing the technological process, transferring the source of fluctuations, vibroinsulation (spring, rubber, combined insulators etc), placing screens in the form of walls or trenches on the way of distributing fluctuations from the source, changing the mass of foundation or firmness of the base, balancing machines, changing the working frequency of machines and mechanisms [10].

Aim of the work. We highlight the main aspects that are the aim of this work:

- 1) to observe the characteristics of bearing structures of ARS the building of pharmaceutical enterprises and to investigate the influence of long term dynamic and vibratory loads, using non-destructive and destructive methods of test;
- 2) to do visual and instrumental survey of damaging of the building, to do a comprehensive analysis of its technical condition, to identify the main factors that were the reasons of damaging;
- 3) to note the high devastating effect of vibration on bearing and fencing structures of the ARS building, which is the most dangerous form of mechanical influences on technical objects;
- 4) to make conclusions and practical recommendations for suitability and further exploitation of the ARS building, having done visual and instrumental survey of the building structures, taking into consideration the negative influence of dynamic and vibratory loads.

Presentation of the main material. The investigation of the building structures and damaging of ARS under the influence of long term dynamic and vibratory loads. The basements and walls suffered the most of the damage of the low-quality constructions, bad exploitation and long term dynamic and vibratory influences. All of these factors led to an emergency. Let's dwell in detail on the survey of basements and walls and point to the main damages and reasons of formation [10–13]. We also focus on the previous investigations and reinforcement of bearing structures from the influence of vibration loads, which didn't give the desirable results (photo 1).

Compressors located in the engine room (axis “2”...“3”, “1”...“1/1” “A”...“B”, photo 2) create a permanent dynamic impact and vibration on the basements.

The absence of deformation seam between concrete floor of the engine room and foundations of compressors create even more influence of the vibration. The deformation seam is also absent between concrete floor and the walls of the building. In 2008 the walls were reinforced with the help of a system of gravity. The armature Ø 28 class A240 was installed in three levels of wall height by the contour of the building [6–8].

Although that reinforcement created the effect of tapes and reduced the significant development of cracks in brick walls (photo 3, 4), the destruction of the foundations of the ARS building wasn't stopped because of the influence of the vibration from compressors. Besides, the foundations are constantly washed out by the waste water and have too little depth of laying with different base of supporting of their soles.



Photo 1. The main facade of the building ARS of axis "1" ... "3"

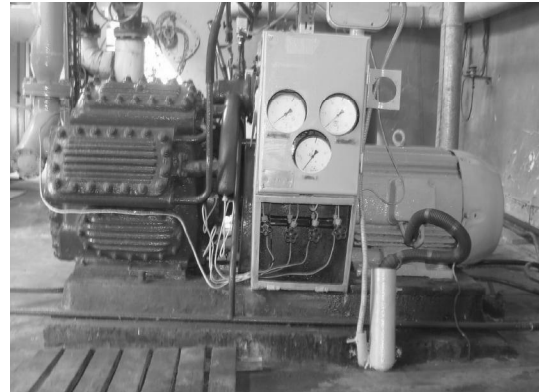


Photo 2. Equipment (compressors) that create vibration and dynamic loads on the building



Photo 3. The state of the foundation of wall blocks by axis "B" between axes "1/1" ... "3". Moving units by horizontal and vertical seams and by contact of walls and blocks



Photo 4. The state of the foundation wall blocks by axis "A" between axes "2" ... "3". Deviation from vertical, moving units by seams

Moreover, several areas of small depth of foundation laying from the soil surface were identified by the results of shurfing. Uneven settling of foundations was as a result. Strong influence of vibration and further destruction of the tape foundations are due to the fact that the sole of the foundations under the vibration equipment is at the level or higher than the surface paving of axis "B" and are based on technogenous and settling soils. Because of this, there is a slope of the foundations of equipment to axis "B". The fact of further destruction is based on sliding by horizontal and vertical seams of concrete blocks and by the contact of walls and blocks. The violation of the verticality of the socle wall and cracks in vertical seams were also found (photo 3, 4).

A lot of cracks of the walls of the building are seen because of the vibration of compressors and absence of the strain seams between concrete floor of the engine room and the walls (photo 5, 6, 7, 8, Fig. 3, 4). Let's emphasize that the greatest number of cracks of the walls all over the height of the building are along axis "B". This is especially due to the axis "2" ... "3" and "1" ... "1/1" where the compressors are situated and the waste water is drained. Besides a lot of slopping and vertical cracks of the inner wall along axis "2" are seen. It is related to vibration and defective drainage system of rainwater from the roof through the drain pipe inside the building. The slope of the cracks of the outside wall along axis "A" and at the crossing of axis "1" ... "A" means the settling of the corner of the building. The defective sewer pipes could be the reason of such situation. The destruction of brickwork made of two rows of lining above the

concrete blocks also affects the creating of wall cracks. The lining is made of solid red brick, destroyed at some places. For today the brand of brick does not correspond to the design.

The development of the width of the opening of the cracks in the brick walls has been a bit stopped a bit by the arrangement of the system of the levers (from smooth armature class A240 Ø28), which were installed in three levels of wall height. Those reinforcement levers created the effect of clips and reduced further cracks development. However they did not do the main task – to provide the necessary bearing capacity of the foundations and to stop vibration and exploitation damages (as a result, the whole building begins to deviate from the vertical).

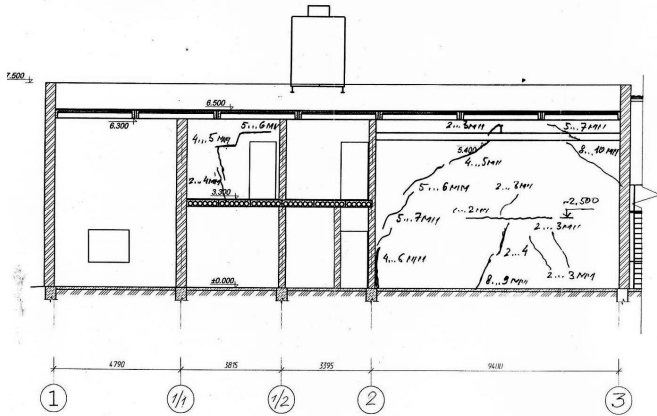


Fig. 3 The scheme of location of cracks along the axis "B"

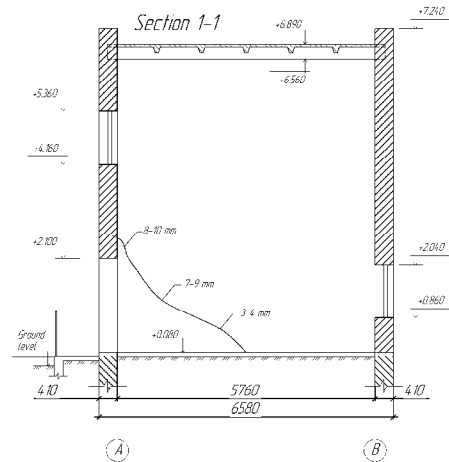


Fig. 4. The scheme of location of cracks along the axis "1"



Photo 5. Vertical crack of the wall along axis "3" between axis "A"... "B"



Photo 6. Vertical crack of the wall at the crossing of axis "3"... "B"



Photo 7. Vertical crack of the wall on the first floor along axis "2" between axis "A"... "B"



Photo 8. Vertical crack of the wall on the second floor at the crossing of axis "A"... "1/1"

The deviation of the Ammonia Refrigerating System building is determined on the basis of measurements of digital tachometer Trimble M3 5"DR (the serial number No. 131612). The average deviation is 20–35 mm.

So for further exploitation of this building, we need to take steps on reducing of vibrations on bearing structures (in particular the walls), arranging the deformation seams, installing the vibration isolators, doing the necessary foundations reinforcements, excluding the impacts of atmospheric and technological water on the foundation by [14–20]. Detailed offers for further exploitation of this building are in part "Summary".

Conclusions. By the results of visual and instrumental inspection of ARS building we can sum up the main reasons of walls and basements destruction:

1) too small depth of foundation laying from the soil surface (normative depth of freezing of soil is not provided for this region of building along axis "A" and "B" and "2"... "6");

- 2) different foundations under the sole of the basements (different types of soils with different physical and mechanical characteristics);
- 3) foundations are constantly washed out by the waste water and broken sewerage;
- 4) compressors located in the engine room of ARS create a permanent dynamic impact and vibration on the basements;
- 5) the absence of deformation seam in the building with compressors between concrete floor and walls from blocks;
- 6) the sole of the foundations under the vibration equipment (compressors) is at the level or higher than the surface of paving axis "B" and are based on technogenous and settling soil. Because of this, there is a slope of the foundations of equipment to axis "B".

Daily destruction of the walls of the building is formed because of the vibration of compressors and the absence of the strain seams between concrete floor and the foundations (big vertical and sloping cracks are formed). The building has also deviation from vertical within 20–35 mm.

We suggest the following steps for bringing out the building from a state of emergency:

1. to avoid more than normal dynamic and vibratory loads or reduce as much as possible their influences;
2. to do impossible to wash out the foundations by the waste water and broken sewerage (it is necessary to repair the sewerage); to repair cracks in the floor to avoid getting technical water under the foundations;
3. to arrange a new construction of the floor in the building with compressors, to provide the deformation seams between concrete floor and the foundations of vibration machines and the walls of the building;
4. to do paving along axis "B" in a right way, to make a rainwater drainage from the basement by the perimeter of the building to avoid soaking;
5. to make new beacons on the cracks width of opening more than 5 mm, to observe the width of their opening;
6. to do reinforcement using drill piles $\varnothing 200$ mm with supporting them in the soil 4 or 5 (Fig. 5) for ensuring the identical settling of the foundations. For creating the hard drive building to make the concrete jacket for impossibility of further destruction of foundations from vibration influences (Fig. 5).

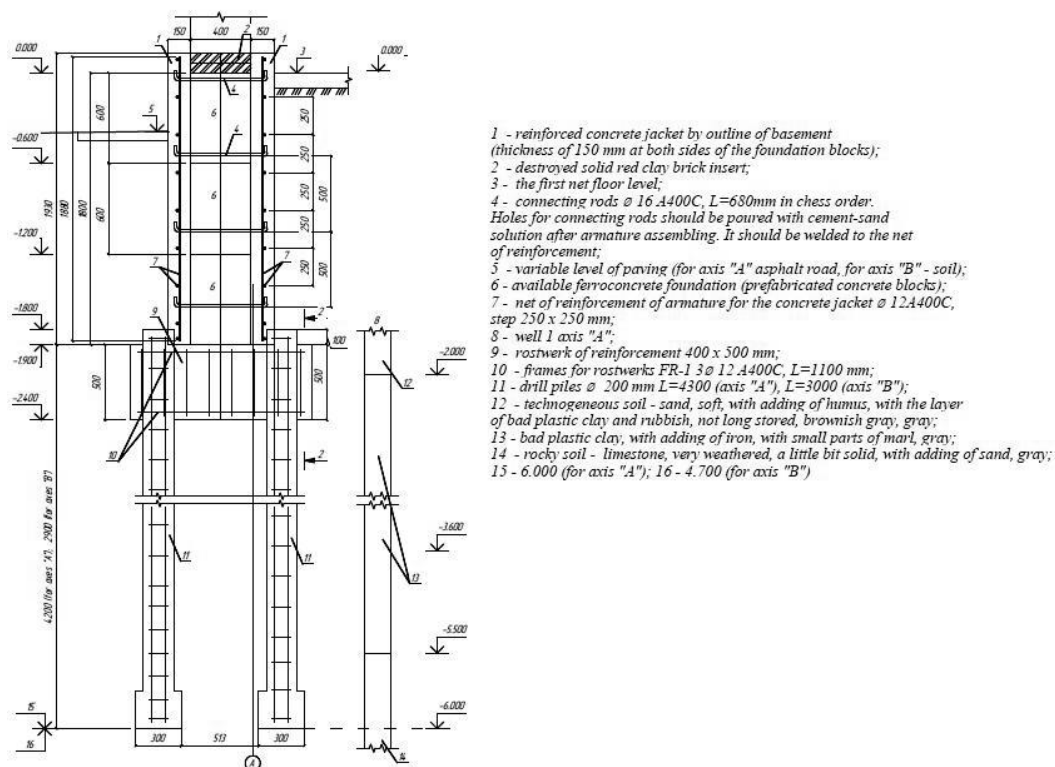


Fig. 5. The principle solution of basement reinforcement by using drill piles and concrete jacket

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