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Geotechnical protection techniques for buildings adjacent to site territories

Méthods géotechnique protection des térritories urbains

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ABSTRACT

Maintenance and protection measures for buildings adjacent to near-site territories are divided into several groups. To major groups we can refer the mining measures, like establishing a coal pillar, filling in the mined-out space with rough, harmonic undermining together with mutual strain absorbing by simultaneous beds mining; the construction measures like compartitioning of the buildings into bays, changing the stability of buildings' foundations and bearing structures and adjustment of tilted carcass height. This paper presents measures aimed to diminish the exposure to structure's base. Generally, such measures are taken at the foundation-basement part of the building or at the foundation-soil contact line.

RÉSUMÉ

Les mesures de maintenance et de protection des immeubles adjacents aux sites d'extraction se répartissent en plusieurs types, dont les principaux sont: mesures miniéres – maintien de blocs de charbon non-cassés, remplissage des galeries d'extraction avec compensation mutuelle harmonieuse des déformations entre les différentes couches d'extraction exploitées simultanement; mesures de construction – décomposition du bâtiment en segments, modification de la stabilité des fondations et des structures porteuses du bâtiment, et ajustement de la position inclineé en hauteur. Sont étudiées en particulier les mesures visant à diminuer de manière significative l'impact sur la base.

1 INTRODUCTION

Through the coal-bed mining the rocks are filling the mined-out space. Over the mined-out space the deformation area is made in the form of bowl-shaped cavity on the day surface, which is called displacement trough. Many years of studies allowed determining the strain process mechanism and how its parameters depend on mining and geological conditions of underworking. The parameters are as follows: trough size, settlement and horizontal displacement values, and surface distortion. These parameters change the physical and mechanical properties of soil at the contact line with foundations and cause the differential settlement, tilting of buildings and structural deformations, which may reach their limit states and use up their durability completely.

Mechanical diagrams of carcass deformation depict the relation between its structural system and resistance of structural elements (foundation, walls, floors) to internal forces. Under the same parameters of surface shearing on the site the carcass having ultimate stiffness may be non-uniformly strained both in vertical or horizontal directions. (Figures 1, 2, 3).

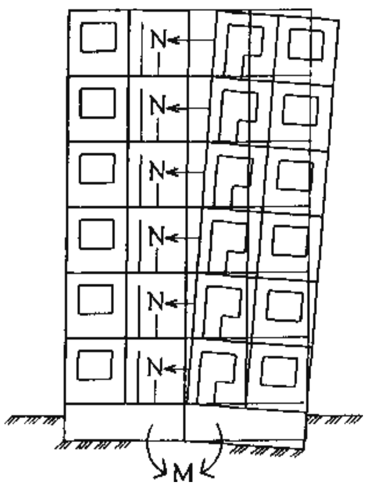

Figure 1. Building deformation behavior under tension strain of floor plates caused by foundation distortion.

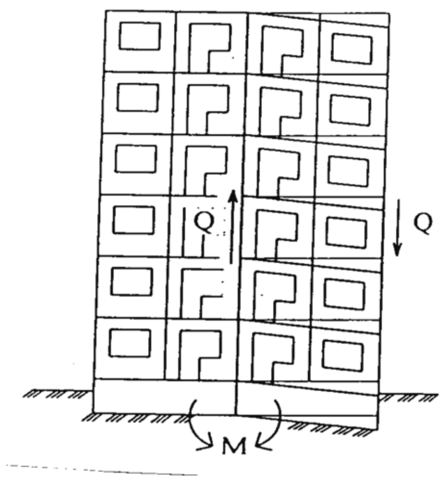

Figure 2. Building deformation behavior under wall panels tilting caused by foundation distortion.

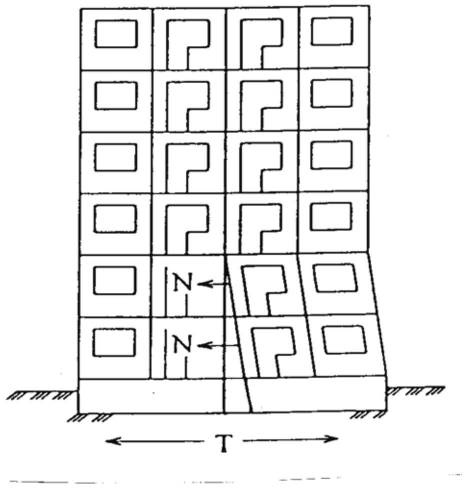

Figure 3. Building deformation behavior in lower storeys caused by elongation of foundation.

Carcasses (frames) having infinite stiffness may suffer displacement without deformation of their components, however building serviceability parameters may fail to conform to building code in this case.

2 CHANGING THE FOUNDATION STABILITY

If foundation bed consists of loess subsiding soils or macroporous weak soils, soil subsidence caused by adjacent man-made ground movement may be compensated by controlled settlements with use of deep dosed watering.

In 1971-1972 full-scale test of an experimental 9-storey large-panel house of 1-480 AP series was carried out under conditions of non-uniform collapsible soil settlements, which was caused by controlled watering. The test revealed that large-panel buildings have stiffness and bearing capacity high enough to withstand non-uniform deformations up to 400 mm per 25 m in length under maximum settlement of 600 mm. There were no significant deformation in structures and inter-structure joints within the bays of 25 m. Results of the full-scale test facilitated the development of cities with buildings, which are protected by special measures, namely: ground bed to partially balance the subsidence, compartitioning into bays, installation of shear connectors in wall-panel joints, waterproof measures.

3 JACKING SYSTEMS

The jacking system is placed in basement wall pockets. It is hydraulic-driven with the help of subsystem comprising distributing pipes, pumping plant, valve control sensors, displacement sensors and control panel. Natural bed bearing pressure is controlled by pressure capsules, embedded in foundation body on the bed side. Relative vertical displacements of foundation and adjacent bed are measured with the help of levelling survey while the area is underworked. Soil toughness is determined with admissible accuracy by foundation settlements and plate-bearing tests.

As an alternative, jacks also may are arranged along the length of foundation between posts made from concrete planks installed together with PTFE inserts. While the part of the building is jacked up, unloaded planks are pulled out of the posts and the building is subsequently jacked down up to complete vertical aligning of foundation axis.

New jack design in form of torus-shapes shells, which are cut along internal diameter and joined with coupled bottoms, that takes up most of vertical loads caused by pressure of working fluid when building superstructure is jacked. Automated jacking control system is also developed. Jacking equipment application requires some changes to building foundation design (Figure 4).

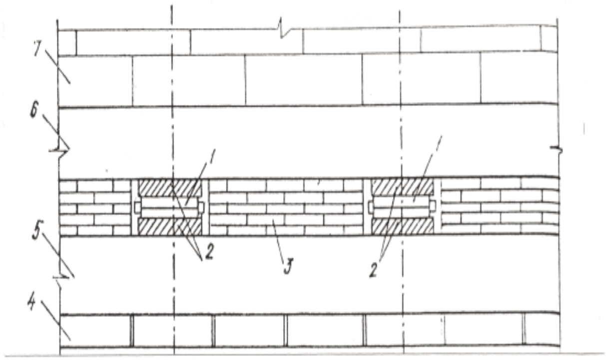

Figure 4. Foundation fit for jacking system application:
1-flat hydraulic jack; 2-distribution pads; 3-brickwork; 4-cushions; 5, 6 –lower and upper distribution belts; 7–basement walls.

Lower distribution layer is mounted over the cushions. The belt is designed to take up horizontal surface deformation and concentrated jack loads. Several brickwork layers are laid between upper and lower distribution belts. In-between brickwork layers the pockets are made at a certain distance for installing hydraulic jacks. The pockets are bricked in (with lean mortar). If the building is exposed to inadmissible displacements due to undermining, then the pockets shall be demolished when the building is de-tilted. The distribution pads are installed above and under the hydraulic jacks and may be built up as jack is travelling. The building is de-tilted as follows. After the automated hydraulic system is switched on, the building together with upper distribution belt and basement walls is jacked off the foundation. The building's position is fixed by the locking servo-mechanism consisting of self-locking wedge sets. Upon switching off the locking servo-mechanism the pressure relief in hydraulic jacks cause the building's moving down to the sliced foundation surface. The above technique allows other schemes of application. The jacking system feature is its absolute reliability. It may be applied for de-tilting of any building under conditions of undertime. Moreover, – and it is very important for densely built-up areas, – this technique does not require additional working area to the area of building.

Disadvantages of hydraulic jacking are as follows: significant materials consumption as for building foundation since it is subjected to heavy concentrated loads from jacks.

To apply the jacking system it is essentially required to have the upper and lower stiffening belts in the foundation, which are redistributing the concentrated loads from jacks onto the foundation bed and superstructure, thus providing better structural behavior.

Over 30 years we successfully applied different jacking systems, which enable us to subject various structures to tests.

During the period from 1974 to 1990 NIISK has been performed a comprehensive experimental analysis of buildings adjacent to man-made ground movement in Donbass region. For every full-scale test we tried out newly developed testing procedures and innovative measurement procedures to define the strain-stress state of buildings.

During the period from 1977 to 1979 in West Donbass region the two bays of 5-storey large-panel building series 111-121 were subjected to tests. Bay length was 30.8 m. To test the first bay, we developed the technique allowing to regulate the differential settlements, which was caused by sand wash-out, through the gate floor over the reserve hollow under the building spot. The building was exposed to 12-step deformation due to settlements with deflecting radius 12 to 2.1 km and offset height 80 mm. Pressure capsules (dynamometers) installed under foundation base were used to obtain actual bearing pressure profile at every stage of testing. Superstructure external wall panels with openings were equipped with strain-meters to measure the tilt distortion. Almost all wall panel joints were equipped with strain-meters in order to measure the joint opening and relative panel displacement. Strain gauges were installed in inter-panel connections to measure their stress level. Such an approach enabled us to collect numerous data as regards actual service of the whole building and its structures. The similar instrumentation was applied at the second bay superstructure. The building was tested with the jacking-up technique. Observed parameters of carcass deformation were within the following values: vertical joints opening up to 12 mm; relative panel displacement up to 7 mm; panel tilt – $4{\cdot}10^{-3}$; crack opening up to 4 mm.

During the period from 1985 to 1986 in Lugansk (Donbass region) the two bays of 5-storey large-panel building series 121-013/1,2 were tested. Superstructure was made from three-layer panels. The space-frame foundation was in the substructure of the first bay; typical basement panels were used for substructure of the second bay. Length of the bay II was 30.8 m; length of the bay I was 15.4 m. The bay I was subjected to the ledged displacements, the bay II passed the bending test with altering the buckling radius of foundation bed from 10 to 3 km. The stress-strain state of structures and parts was registered at all test stages for the both bays. Structure deformations were within rated limits. Based on the data collected we may specify the field of application as regards the building of above series.

In 1987 in Makeyevka (Donbass region) 9-storey large-panel building series 96 was tested. Superstructure was made from composite panels with rigid connections, the foundation-basement part was made from basement panels. Length of the building bay was 25.2 m. The building was subjected to settlements with radius of bend curvature from 5 to 2 km. The testing method was raft jacking down. During the whole test the following results were recorded: vertical joint openings caused by carcass buckling up to 7.6 mm, relative displacement up to 4.15 mm, panel tilting up to $6{\cdot}10^{-3}$, crack opening in wall panels up to 1.1 mm. Based on the data collected we may specify the field of application as regards the building of series 96.

In 1990-1991 the 9-storey residential building series 121-043/1,2 with multi-layer panels in superstructure was tested in Stakhanov near the city of Lugansk (Donbass region). The substructure was built as space-frame foundation. Length of the building bay was 22.4 m. The bay was subjected to the ledged displacements up to 100 mm at 3.2 and 4.6 mm from the end. The test method was jacking up. The stress-strain state of the building, its structures and parts was recorded at all stages: vertical joint openings up to 1.7 mm, relative panel displacement up to 2.7 mm, panel tiling up to $4.6{\cdot}10^{-3}$, crack opening up to 3.5 mm.

The full-scale test for in-service building is conducted in two stages:

- experimental bench study of fragments sampled from in-service building that includes the modeling of force and deformation stresses combinations with reaching critical load.
- in-situ test, analysis of panels and joints stress-strain behavior allowing for the bench-test results.

This approach enabled us to assess the safety margin more reliably for structural elements and parts, and to restrict the field of application for buildings to be built in regions with heavy ground conditions.

4 THERMOPLASTIC LINERS

Liners inserted between foundation belt and basement walls are equipped with electric heaters in order to regulate the aggregative state of structure material and reach the corresponding settlements. Prefabricated asphalt concrete units are used as thermoplastic liners. They are produced of special road-oil sand in vibrocompacting molds. In addition to vertical displacement compensation the belt of thermoplastic liners may also serve to relieve the horizontal contact stresses between foundation and bed, Figure 5.

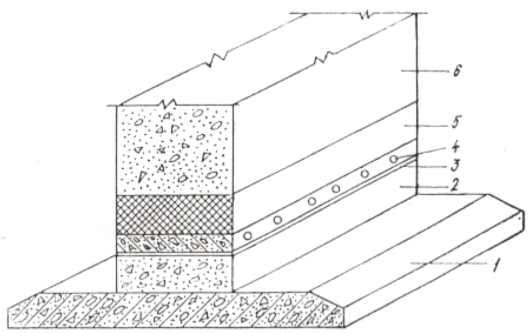

Figure 5. Strip foundation with thermoplastic elements.
1 – cushion; 2 – pedestal block; 3 – thermal insulation; 4 – heating element; 5 – thermoplastic element; 6 – basement wall.

A number of functional strip foundations and post footings with thermoplastic elements was developed for areas adjacent to man-made ground movement. They feature higher performance characteristics, more reliable in service, and fit for controlling over building settlements. Upon full-scale in-situ tests these foundations are proposed and applied as standards design and in housing on the territories having any surface deformations over the worked-out space.

5 DRILLING OF THE GROUND LAYER

Horizontal drilling of the ground under foundation by using varied-diameter augers and varying the distances between the holes as well as the multiple-tier hole arrangement allows changing the foundation stability (Figure 6).

Figure 6. Changing of the foundation stability by drilling horizontal holes.

The service load stress from the structure acting on the non-uniformly drilled ground results in non-uniform settlement with calculated parameters, which countervail the settlement arisen at the near-site territories. Further gradual watering of the ground around holes makes for relieving the structures from the displacement stress along the foundation base, similar to the thermoplastic liners.

The 14-storey large-panel building, series APPS K 134, located in Donetsk with curtain wall panels underwent testing in 1993. The building foundation was solid slab. The module's length was 25.5 m. The structural scheme involves cross-walls. External walls were made from curtain wall panels.

The deformation effect is achieved through non-uniform settling of one and two flanks of the building. This process finishes with de-tilting.

The tests revealed the vertical panel joints opening up to 4.2 mm, displacement of panels up to 2.19 mm, tilt up to $3.1 \cdot 10^{-3}$ and crack opening in the walls up to 0.35 mm.

Findings on structures and assemblies behavior were collected at every stage of test and enabled us to specify the field of application for buildings series APPS K-134.

6 BUILDINGS AND STRUCTURES RELIABILITY

Building-foundation' is a dynamic system. The foundation subjected to stresses at the near-site territories tends to change its geometry and physical properties.

The building carcass or framing is exposed to physical wear that tends to be intensive, especially if loads and different effects, including deformation stress, are combined. Initial absence of failures, which may be counted as reliability if in-place tests are successful, does not ensure long service life for buildings. There are two ways to define reliability. First one gives a structural assessment based on the failure rate and defines a probability when limit movements and deformations are not exceeded within the given period. This assessment method is classified as an inverse problem. It should be mentioned as regards above method that insufficient study of working hypothesis or structural concepts may *firstly* lead to mass damages; *secondly* requires 10-15 years for statistics of failures; *thirdly* requires a long-term forecast for a coal-bed mining. The second way is to specify the required structure durability based on field and fragmentary test results, certification of structures and improvement of structure systems by necessarily including the geotechnical protection methods described therein.

Above reliability factors, which must not be underscored by dividing to major or minor, deserve the further study.

7 CONCLUSIONS

25-year experience in applying geotechnical protection methods enables us to make the following conclusions.

Box system buildings on subsoil, which suffered deformations, including their strong foundations made from cast-in-place and precast constructions and absolutely rigid floor plates (in their plane), which are made by welding panels through embedded parts, with bays up to 50 meters in length, in a whole differed slightly from the initial deformation-free structures. Displacement and strain values were second order infinitesimal and brittle failure of bearing structures were not revealed. In-place tests were performed prior to the large-scale construction work under complicated engineering & mining and geological conditions. The tests results served the grounds to assess the efficiency of structural concepts and base preparation methods, their conformity to standards and regulations in respect of limit states. Test results helped to give a visual prove of limiting state criteria. Professor S.N. Klepikov suggested a flexible criterion by dividing the bearing structures and building envelope deformations into allowable and limiting strains according to the construction system of building and its purpose. For example, allowable width of crack openings in the walls were taken: for hospitals – 2 mm, for factories – 5 mm, for residential and office buildings – 7 mm, service structures – 15 mm. The limiting values for the panel tilt and turning angle of connections were determined on the basis of test results and are well-correlated with base deformations. The classification of these criteria allows putting in order the requirements to the buildings reliability for their period of service or period in-between repairs.

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