Method of Conservation for Design Position of Buildings and Structures Operated in Complex Engineering & Geological Conditions Using Spring-Jack Modules

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Abstract. Construction standards are providing a number of measures to reduce deformations in the foundation bases and their influence on structures. These measures do not exclude a change in the spatial position of the structures, especially when it comes to significant uneven deformations. In connection with this, it is urgent to develop a method that allows supporting structures of buildings and structures in the design position with uneven local deformations of the ground base but with significant deformation occurrences accompanied by the tilts of the entire building and allowing to correct the geometric object position. The investigations carried out at this stage made it possible to develop a model range of spring-jack modules, produce experimental samples of spring-jack modules, obtain a picture of the work quality of the proposed technology.

1. Introduction
During construction and operation of construction sites in complex engineering and geological conditions and in the territories under cultivation, the foundations of buildings and structures are exposed to natural and man-made impacts, as a result deformations in the structures occur which lead to a decrease in the stability and reliability of structures and can lead to development of emergency situations [1].

Modern construction standards [2] are providing a number of measures to reduce deformations in the foundation bases and their influence on structures. These measures do not exclude a change in the spatial position of the structures, especially when it comes to significant uneven deformations. In connection with this, it is urgent to develop a method that allows supporting structures of buildings and structures in the design position with uneven local deformations of the ground base but with significant deformation occurrences accompanied by the tilts of the entire building allowing to correct the geometric position of the object [3-5].

Developments and studies in this direction were carried out by LLC NPF Interfiotech together with scientific workers from the Department of Civil and Political Sciences from the Faculty of Civil and Political Sciences of the Platov South-Russian State Polytechnic University (NPI).
2. Concept of preservation for design position of buildings

In order to solve the task at the first stage, the concept of a system for preserving the design position of buildings and structures operated in complex engineering and geological conditions was developed. The system is based on a symbiosis of technological equipment for lifting and buildings levelling with plate jacks [6], microprocessor controllers, monitoring system and spring-jack modules [7].

The technical capabilities of the system for preserving the design position of buildings and structures provide operation in three modes:

- the monitoring mode - control of the technical condition and geometric position of the building and its structures;
- the mode of local deformations correction;
- the mode of lifting and aligning the object.

The working units of the system, namely, spring-jack modules, are placed under the bearing walls between the foundation and the ground part. In the case of local deformations in the foundations of foundation bases, the springs block receives the load from the building's structures, transfers it to the foundation and, by means of expanding, compensates for the movement of the foundation part. The loss of the compression force of the springs as a result of their stretching is compensated automatically by means of a hydraulic jack when the limiting strain of the spring unit is reached which is controlled by the displacement sensors.

If there are significant uneven deformations of the basement foundations accompanied by tilts that are fixed by the monitoring system, the presence of jacks makes it possible to implement lifting and levelling [6] and prevent over-standard values of deformations of the building base structures.

Automation and operational efficiency of the system is provided by its functional configuration represented in Figure 1:

- the hydraulic drive control unit intended for giving opening and closing commands to the hydraulic distributors responsible for supplying the working fluid to the corresponding spring-jack modules. It manages the amount of working pressure at pressure stations and also turns them on or off;
- the monitoring unit designed to collect information from motion, pressure and other types of sensors. It operates on the basis of controllers that convert an analog signal from the sensors of various types into digital. It provides the control of system operation safety [8];
- the unit of communication with a remote PC designed to receive and transmit data from the monitoring unit and commands to the hydraulic control unit from a remote PC via GSM network;
- the remote PC designed to control and analyse the geometric parameters of the object, the state of the hydraulic drive and the formation of commands for its control. It is the workplace for the system operator.

Due to the fact that one of the main functions of the method for conservation of the design position of buildings and structures is lifting and levelling, designing and preparing the base structures of the building while maintaining the design position are identical to the design of the adjusted foundations [9-12].

The monitoring unit is formed on the basis of the survey results on the technical condition of the building [13], regulatory requirements for the parameters of building structures and the building as a whole (crack openings, tilts, vertical deformations, horizontal displacements, etc.). The number and types of sensors are assigned based on this data. In order to control the processes in the ground base, the monitoring system can be equipped with the humidity sensors having piezometers and dynamometers [14,15].

At the modern level of microprocessor and computer technologies development, the solution of tasks to provide automation of monitoring, control and management of the system is not difficult. These functions are mostly implemented in their "upbuilding" software package [16].
Figure 1. Functional configuration of the system for preserving the design position of buildings and structures.

3. Applying the spring-jack module
The spring-jack module consists of a displacement compensator in the form of a spring block, a hydraulic flat jack [17] for restoring forces on the spring unit and a displacement sensor to monitor the deformations of the module (Figure 2).

Figure 2. Spring-jack module: 1 - the spring block; 2 - flat jack; 3 - displacement sensor.
The main condition for the operation of spring-jack modules combined into a single system for preserving the design position of buildings and structures is observance of the equilibrium condition when \( N_k = N_n \), where \( N_k \) is the force from the building's structures; \( N_n \) - force on the spring unit.

Thus, the main task in the calculation of spring-jack modules is the selection of optimal springs and the choice of hydraulic jack, and the following conditions should be met:

- the maximum compression forces of the springs of the spring-jack module \( F_{nb} \) should be selected according to the condition \( F_{nb} = 1.5 N_k \);
- the carrying capacity of a flat hydraulic jack should be selected according to the condition \( N_d > 1.2 F_{nb} \), where \( N_d \) is the lifting capacity of the jack.

The calculation of the spring parameters is carried out in accordance with the requirements of GOST R 50753-95 "Springs, Coil Cylindrical Compression and Tension of Special Steels and Alloys. General Technical Conditions" [18].

Based on the parameters of the flat hydraulic jacks DGP-200, DGP-100 [19], a series of spring-jack modules has been developed.

In order to assess the performance of the system, the site of the building, supported by a group of spring-jack modules, should be analyzed. A simplified model of such a system can be represented as a rigid beam loaded with a uniformly distributed load and supported by springs mounted on a deformable base (Figure 3).

**Figure 3.** Model of the system "building-spring modules-foundation": a) the initial position of the system; b) position of the system during local deformations.

In the initial position of the system the spring blocks are pressured by the force from the loading of the ground part of the building. When local deformations of the ground base appear, the spring blocks expand after the base while supporting the ground structures of the building. The reactions on stretched springs are reduced while the load from the ground part of the building is distributed and the forces on adjacent modules located on the area without deformations increase.

### 4. Experimental studies

At the next stage the experimental studies of the system for preserving the geometric position of buildings and structures with spring-jack modules on a large-scale model were carried out. During the experiments the work of a group of 4 spring-jack modules was analyzed.
As a test installation a beam system with axial dimensions of 4 m x 4 m was used hinged on four separate columnar foundations with plan size dimensions of 1.4 m x 1.4 m. The beam crate is composed of two major and three minor beams of I-beams No. 35K2 according to GOST 26020-83 (Figure 4).

![Figure 4. General view of the test installation.](image)

As working units of the system, four prototypes of spring-jack modules with a working force of 70 kN were installed on the anchor part of columnar foundations.

The control of efforts on the spring-jack modules was carried out with the help of force sensors, the movement and deformation control was implemented with the help of 8 inductive displacement sensors united in a single system with automatic interrogation. In addition, with the help of level and time-type sensors, deformations of the entire experimental setup were evaluated.

In order to simulate uneven deformations of the ground base and the process of lifting and levelling, hydraulic jacks of the DGP-100 type were used according to TU 4833-001-27194434-2007, included into the spring-jack module and integrated into a single hydraulic system. The hydraulic system also includes hydraulic valves, high pressure hoses, distributors, pumping station and control system.

In order to create the load 20 wall foundation blocks of the FBS 4 type with dimensions of 2.4 m x 0.4 m x 0.6 m (h), with the weight of 1.2 t, i.e., a total vertical load on the beam stand was 240kN.

In order to establish the dependence of the compression amount of the spring on the load, the calibration of an experimental spring-jack module was carried out at the department of Underground and Civil Engineering of Platov South-Russian State Polytechnic University (NPI) on the IP-2000 press to the effort of 66.25 kN.

The hydraulic system of the experimental installation (Fig. 5) includes the hydraulic plant, switching devices P1 and P2, hydraulic valves KN1-KN4, flat hydraulic jacks 1, piping system, displacement sensors 3, hydraulic and electrical switching devices, cable management system, power sensors 2 (DS-1 (1) - DS-1 (4)), manometers MH1-MH6. For the convenience of work, the hydraulic circuit is divided into two flow streams.

The hydraulic system of the experiment is shown in the initial non-operating position. The system operates in two modes: the setup mode and the operating mode. In the tuning mode the hydraulic components of the hydraulic station and the external hydraulic system are tested and checked while the working fluid does not enter the jacks. The hydraulic system operates as follows.

After the pumping station is switched on, the working fluid (oil) enters the KH1-KH4 hydraulic valves normally closed and drained into the tank. The pressure is changed on the operator's panel (not
shown on picture) and voltage is applied to the KH1-KN4 hydraulic valve which opens, and the working fluid is fed into the jacks.

![Diagram of the hydraulic system of the experiment.](image)

**Figure 5.** Diagram of the hydraulic system of the experiment.

In order to study the operation of the system for conserving buildings and structures using spring-jack modules, several variants of uneven deformations can be implemented in the experimental setup. Based on the parameters of the experimental setup, the following variants of modelling the non-uniform deformations are implemented:

- Modelling the draft of a single foundation;
- Modelling the draft of two foundations located diagonally.

Recent experiments have shown the qualitative work of spring-jack modules in the range of displacements up to 2 cm, the following is established:

- The force on the spring in the module with the specified movement is reduced according to the calibration data;
- The loads on the stationary supports increase in proportion to the reduction in force on the spring in the module with the specified movement;
- There is no movement of the beam stand, i.e. constructions that rely on spring-jack modules do not move.

Further studies are required to identify the main boundary conditions for the applicability of this technology, develop a methodology for calculating buildings and structures that rely on spring-jack modules.

5. Conclusion

The way to preserve the design position of buildings and structures operated in complex engineering and geological conditions with the help of spring-jack modules allows to solve a set of problems ensuring operational reliability and trouble-free operation of the construction sites:
- to preliminary identify uneven deformations of the soil foundation;
- to support the ground structures of the building in the design position when local deformations occur;
- to eliminate the effects of uneven deformations in the soil base;
- most of the tasks are solved in an automated mode and in conditions of remote access.

The investigations carried out at this stage made it possible to develop a model range of spring-jack modules, produce experimental samples of spring-jack modules, obtain a picture of the work quality of the proposed technology.

The developed technology is included into the list of critical technologies of the Russian Federation approved by the President of the Russian Federation on May 21, 2006, Pr-842 and refers to the critical technology "Technologies for Reducing the Risk and Reducing the Consequences of Natural and Man-made Disasters" [20].

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