CONTROL OVER DISTRIBUTION OF CONSTRUCTION LOADS ON FOUNDATIONS OF TOWER BUILDINGS

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Abstract

The article describes the tasks and traditional approach to organization of full-scale instrumental observations over vertical deformations of engineering tower structures. Issues related to interpretation and use of the results of repeated geodetic observations during the study of tower structure foundation deformations are considered. The article presents an algorithm for processing of the results of repeated leveling of deformation control benchmarks set along the foundation perimeter, which allows calculating mutual displacement of settlement points due to local deformations of foundations, accompanying gradual settlement of foundation base groups. A possibility of identifying a direction of total foundation inclination is outlined for the purpose of effective management decisions related to adjustment of construction process with regard to redistribution of loads along the perimeter of tower structure foundation with the aim to eliminate its inclination.

Keywords

Tower structures, settlement, deformations of foundations, repeated geodetic observations, foundation inclination, redistribution of loads on foundation, elimination of foundation inclination

Introduction

Modern engineering tower structures, behavior of which depends on strict adherence to design solutions during construction and their stability during maintenance, include reactor buildings and cooling towers of nuclear power plants, blast furnaces, elevators, television towers, and other high-rise structures.

High-rise tower structures are characterized by load concentration reaching tens of thousands of tons and more (Mikhelev et al., 1977, Bolshakov et al., 1980) on foundations of small size (more often, base slabs). Heavy concentrated loads on foundations and their beds cause rapid and considerable settlement of high-rise structures under construction.

A distinctive feature of high-rise tower structures is their sensitivity to relatively inconsistent foundation inclinations due to non-uniform deformations (compaction) of foundation subgrades. Non-uniform deformations of subgrades occur often because of uneven construction loads on the foundation, even upon homogeneous structures and physical and mechanical properties (compressibility).

Subject, tasks and methods

Construction technology for tower structures provides for support of construction works with geodetic surveying to observe possible deformations of erected structures. Suffice to say that every single construction of tower structures is completed with repeated high-precision geodetic surveying revealing presence or absence of foundation settlements, i.e. passive control of foundation settlements and such generated deformations as inclinations is performed.

The practice of geodetic surveying of deformations of tower engineering structures (Bolshakov et al., 1980; Bright et al., 1959; Ganshin et al., 1981; Clough et al., 1979; Mikhelev et al., 1977; Volkov, 2015; Costachel, 1967; Mishra, 2011; Rincon, 2013) points out the necessity to monitor distribution of construction loads, transmitted from a part of the erected tower structure to the foundation and soils, with the help of repeated geodetic observations providing reliable designed condition of structures both during its construction and maintenance.

There is no method of distribution of construction loads during construction of tower engineering

structures using results of repeated high-precision and accurate geodetic observations which include repeated leveling of deformation control benchmarks along the perimeter of foundation slabs of erected high-rise structures. Passive control of settlements of such deformation control benchmarks allows only calculation of inclinations in separate directions connecting two deformation control benchmarks, but does not allow establishment of total inclination of the foundation slab and its azimuth, which, in its turn, eliminates ability to control and modify construction loads, leading to inclinations of erected structures.

To solve these problems, a special technique of processing of the results of repeated leveling of deformation control benchmarks was developed; this technique allows control and distribution of loads across foundations of tower structures under construction with the help of identified total inclinations of foundations, occurring as a result of total gradual settlements, followed by development of an algorithm for their elimination.

Results and discussions

The essence of the proposed method is as follows. Non-uniform deformations of the structure foundations generate their inclinations which are characterized by indicators well-known in the engineering and geodetic practice, such as inclinations in the direction of longitudinal i_x and transverse i_y axes of the structure (Bolshakov et al, 1980; Kosterin, 1990; A. Filiatrault et al., 2013; Paz, 2012). In order to adjust the construction flowsheet, the proposed method allows for establishment of the maximum increasing amount of inclination of the structural foundation i_{max} and its direction (azimuth). To this end, deformation control benchmarks are marked along the perimeter of the foundation of the erected tower structure (Figure 1), which after a period of time T are repeatedly leveled (leveling of Class I and II, 1982; Zharnikov et al., 1990). The first and subsequent cycles of repeated geodetic observations include laying of leveling lines from the reference benchmark to each deformation control benchmark $j = \overline{1,m}$. According to the results of the first cycle of leveling, exceedances between deformation control benchmarks and their levels $H_1, H_2, …, H_m$ are determined.

By taking deformation control benchmarks $1, 2, …, m$ by turn as the origin of coordinates, the levels of remaining deformation control benchmarks are calculated on the basis of exceedances in two compared cycles. Comparing the levels of deformation control benchmarks received during two cycles, we receive the first row of discrepancies $δ_{kj}$. Similarly, taking the $2^{nd}, 3^{rd}, …, m\text{-}th$ deformation control benchmark as the origin of coordinates, we get m rows of discrepancies $δ_{kj}$ ($k = \overline{1,m}$ and $j = \overline{1,m}$ are the numbers of deformation control benchmarks, respectively, for which discrepancies between levels

and values taken as the coordinates origin are calculated).

Thus, these rows of discrepancies are tabulated (Table 1), revealing a quadratic symmetric matrix A_m with diagonal elements $δ_{kj}=0$ symmetrically equal in absolute magnitude but opposite in sign to non-diagonal elements $δ_{kj}= −δ_{jk}$.

$δ_{av,j}$ value is the value of average displacement of jth deformation control benchmark in relation to all deformation control benchmarks, occurred during a period of time T between two cycles of repeated leveling.

Estimation of destabilization or invariance of the level of deformation control benchmarks during a period of time T is carried out on the basis of analysis of values $S_{av} = \dfrac{\left[δ_{kj} \right]}{m-1}$. Benchmarks falling within the inequality $\left| S_{av} \right| \le t_β μ \sqrt{π S_{av.j}}$ (where μ is the mean square error of the unit weight, $π S_{av.j}$ is a reverse weight of value $S_{av.j}$, $t_β$ is a coefficient of conversion from mean square errors to limit errors) refer to deformation control benchmarks that have preserved their high-rise level (Volkov et al, 2015; Mikhelev et al., 1977). Otherwise, the deformation control benchmark belongs to the category of unstable values, i.e. benchmarks with considerable settlement.

Differences of significant average displacements $δ_{j+1} −δ_j$, $δ_{j+2}−δ_j$, …, $δ_{j+m} −δ_j$ reveal reciprocal (local) displacement of deformation control benchmarks j and $j + 1$, j and $j + 2$, ..., j and $j + m$ during a period of time T.
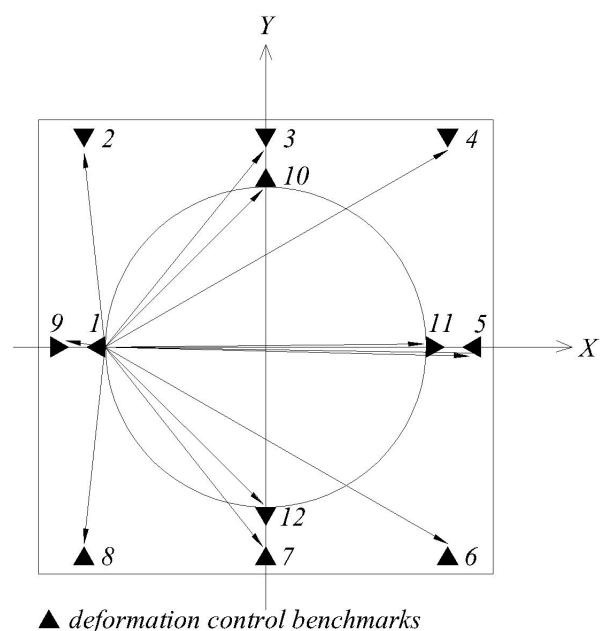

Figure 1. Layout of deformation control benchmarks (through example of a foundation slab of a reactor building of a nuclear power plant)

Table 1
Values of average displacement of deformation control benchmarks

j k	Number of an original deformation control benchmark					
	1	2	3	4	…	m
1	0	δ_{12}	δ_{13}	δ_{14}	…	δ_{1m}
2	δ_{21}	0	δ_{23}	δ_{24}	…	δ_{2m}
3	δ_{31}	δ_{32}	0	δ_{34}	…	δ_{3m}
4	δ_{41}	δ_{42}	δ_{43}	0	…	δ_{4m}
…	…	…	…	…	…	…
m	δ_{m1}	δ_{m2}	δ_{m3}	δ_{m4}	…	0
$[\delta_{kj}]$	$[\delta_{k1}]$	$[\delta_{k2}]$	$[\delta_{k3}]$	$[\delta_{k4}]$	…	$[\delta_{km}]$
$\dfrac{[\delta_{kj}]}{m-1}$	$\dfrac{[\delta_{k1}]}{m-1}$	$\dfrac{[\delta_{k2}]}{m-1}$	$\dfrac{[\delta_{k3}]}{m-1}$	$\dfrac{[\delta_{k4}]}{m-1}$	…	$\dfrac{[\delta_{km}]}{m-1}$

Taking one of the main axes of the tower structure (foundation), passing through one of the invariable deformation control benchmarks (reference), as an "original" point, we determine direction azimuth A, passing through the reference and other benchmarks (according to our example (Fig. 1) — $A_{1\text{-}2}$, $A_{1\text{-}3}$, $A_{1\text{-}4}$, …, $A_{1\text{-}12}$). Separate inclinations $i_{1\text{-}2}$, $i_{1\text{-}3}$, $i_{1\text{-}4}$, …, $i_{1\text{-}12}$ are defined according to selected directions 1-2, 1-3, 1-4, ..., 1-12:

$$i_{1-2} = \frac{\delta_1 - \delta_2}{T \cdot S_{1-2}}\rho'', \ \ i_{1-3} = \frac{\delta_1 - \delta_3}{T \cdot S_{1-3}}\rho'', \ ...,$$

$$i_{1-12} = \frac{\delta_1 - \delta_{12}}{T \cdot S_{1-12}}\rho'', \tag{1}$$

where S is the distance between the "original" and j^{th} deformation control benchmarks, $\rho'' = 206265''$.

Inclinations of the foundation (in our case, of the foundation slab) along the selected directions are represented with equations forming the following system:

$$i_{1-2} = i_x \cos A_{1-2} - i_y \sin A_{1-2}$$
$$\text{……………}\tag{2}$$
$$i_{1-12} = i_x \cos A_{1-12} - i_y \sin A_{1-12},$$

where i_x and i_y are separate inclinations along the selected directions, defined according to the system of equations (2) with the least-square method.

The value of the total inclination in a linear measure is calculated with the following formula (Volkov, Severgin, 1989):

$$I = \sqrt{i_x^2 + i_y^2}. \tag{3}$$

The azimuth (grid azimuth) specifying the direction of the total inclination is calculated according to the formula (Volkov, Severgin, 1989):

$$\text{arctg } A_{tot} = \frac{i_y}{i_x}. \tag{4}$$

The further loading of the slab along the line with azimuth $A_{tot} \pm 180°$ leads to decrease of inclination with regard to the foundation and the whole tower construction as a consequence.

Conclusions

The proposed method makes it possible to draw load diagrams for foundations of tower structures (reactor buildings of nuclear power plants, elevators, blast furnaces, etc.) according to repeated geodetic observations, taking into account uneven deformations of foundation soils during construction.

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