# The prognosis of stressed-deformed state of the system 'construction-foundation' considering the construction stiffness changing during erection

# Pronostic de l'état de contrainte-déformation du système 'construction-couche de base' en tenant compte des changements de la rigidité de la construction au cours des travaux

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ABSTRACT: In this report we dwell upon the main ideas of the method which gives an opportunity to modify the technology of building taking into account a building rigidity, soil massif heterogeneous in depth and soil non-linear deformation in the process of loading. Also we present our investigation of the building technology influence upon the stressed-deformed state (SDS) of the base and contact stresses allocation along the bottom of foundation. The ideas of this method are supported by the results of the deformation design of an old building in case of raising a new monolithic house alongside. These design results are compared to full-scale subsidence observation within a year.

RESUME: Ce rapport représente les idées principales de la métode visant à modeler les technologies de construction des ouvrages en tenant compte de leur régidité croissante, de l'hétérogénéité de la profondeur du terrain naturel et de la déformation non-linéaire des sols au chargement. L'auteur a aussi examiné l'influence des technologies de construction des ouvrages sur la formation de l'état de contrainte-déformation de base, de la distribution des contraintes de contact de l'assise de fondation. Ces idées sont illustrées par les résultats des études des déformations d'un ancien immeuble au cours de la construction à côté de lui d'un nouvel édifice en monolithe. Les données de calcul sont comparées au contrôle d'après nature des précipitations au cours de l'année.

## 1.INTRODUCTION

The problem of the stressed-deformed state (SDS) of the foundation and building prognosis appears before the beginning of every big construction. During the erection and exploitation the construction interacts with its foundation continually, i.e. the construction and the foundation make the unified system and influence on each other.

Most of constructions begin with the excavation. It leads to the changes in surrounding soil SDS, and the trench's bottom lifting. This process is not fully taken into consideration in the most of calculating schemes. The designers usually choose the schemes in accordance with finished object characteristics. They use to consider the load applied to the foundation which is instantaneous, and the spatial stiffness of the building is pre-set. Proceeding from these assumptions and using these or those methods of calculation, they obtain design building's sinking (deformations), reactive forces that the foundation is subjected to, and so on.

In fact every construction is being erected gradually, phase by phase, and the same way the spatial stiffness and foundation loading are increasing /2/.

We have studied the influence of increasing construction stiffness to the SDS of the foundation, using the method of finite-elements. The report describes the methods and algorithm of calculation under 'PLAST' program, with realizes the method of finite-elements.

## 2. BASIC TECHNIQUES IN APPLICATIONS METHOD

Flat quadrangular isoparamethric elements form the base of the 'PLAST' program. Soil is presented by the well-known ideal elastoplastic model. For the yielding criterion which indicates the stress point at which the plastic deformation starts we chose Mohr-Coulomb yielding criterion. 'PLAST' program takes into account different stress and deformation qualities of soil in depth of its deposition.

In solving nonlinear equations the finite-element discretisation results in the consistent equations of the following type:

$$[K]\{\delta\} - \{F\} = \{\Psi\}, \qquad (1)$$

where: [K] - system stiffness matrix; $\{\delta\}$ - displacement vector of nodal points; {F} - vector of external forces; $\{\Psi\}$ - residual force vector, for the system in the state of balance $\{\Psi\} = 0$.

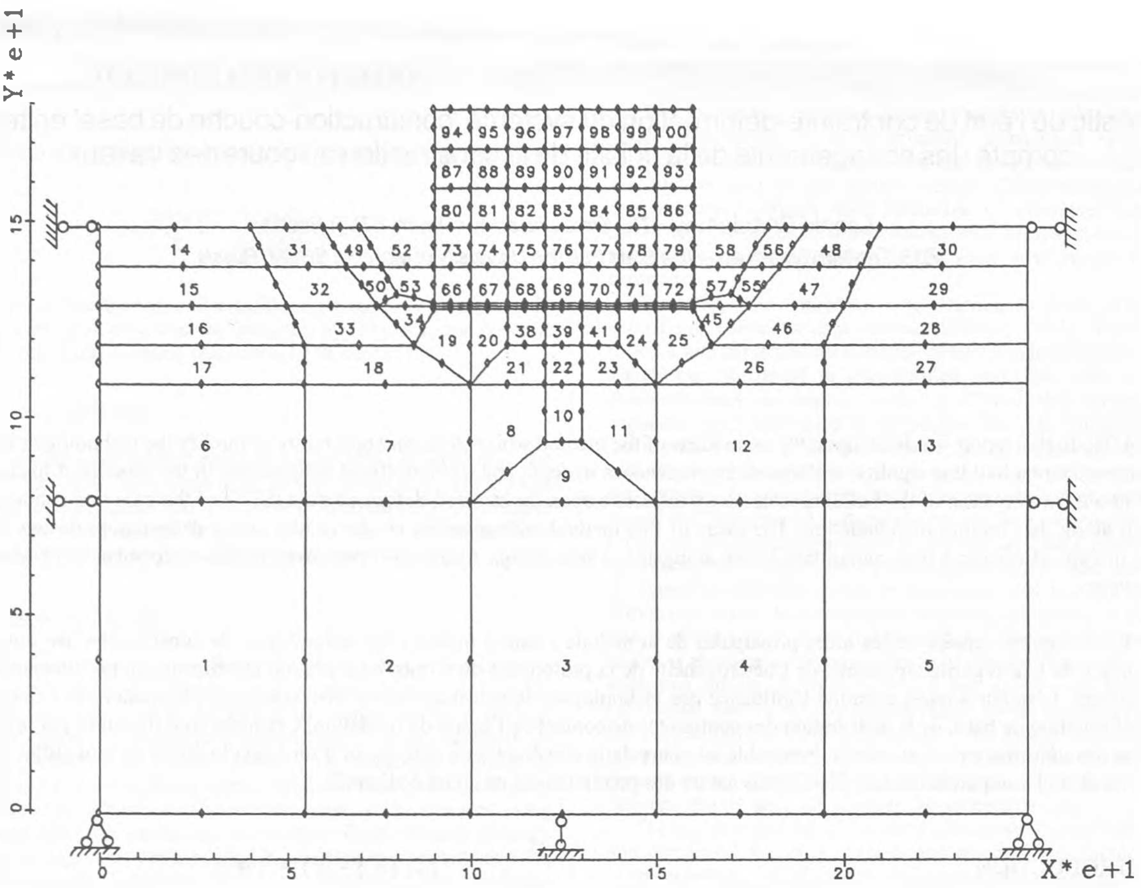
We are used to solving the equations of this type (1) with the help of the method of initial stiffness. The system stiffness matrix is calculated at the beginning and doesn't change. But we applied another method - the tangential stiffness method, and the stiffness of all element was recalculated for the first iteration of every increased loading.

We worked out a new method of design to model the changing structure of the zone. At each stage of loading we changed the vector of external forces and the stiffness matrix. In accordance with this some elements were included in or discharged out of the structure /1/. Therefore the equation (1) ran as follows:

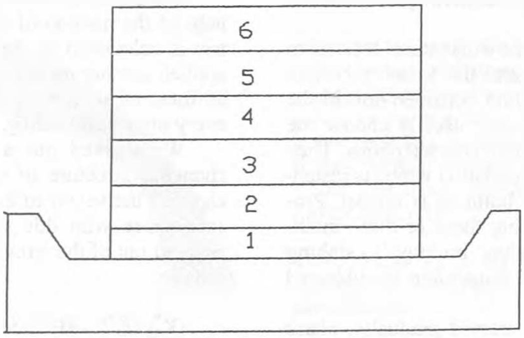
$$[K_T^n]\{\delta^n\} - \{F^n\} = \{\Psi^n\}, \qquad (2)$$

where $[K_T^n]$ - the tangential stiffness matrix for n-stage of loading, n - the number of a loading stage.

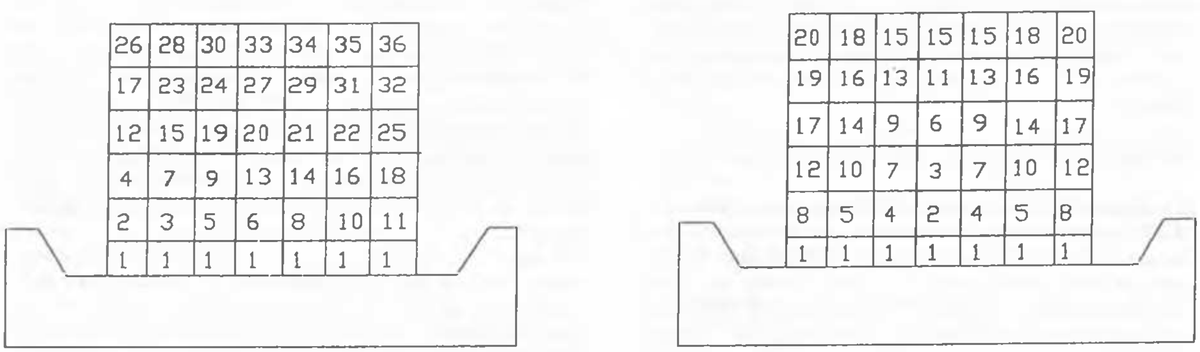
In the process of the zone generating we took into consideration all structural elements (p.1). On the first stage we applied the natural weight of the massif. Consequently all modifications of the elements above the massif were equal to zero and augmented nothing to the vector of external forces $\{F^n\}$. The deformation modulus for the elements above the massif was approximated to zero. On the next stage we modelled massif excavation. Firstly we subtracted massif excavation elements' augmentation out of the vector of external forces and then we came over to the solving of the equations system (2). Next we modelled the erection of the building. The augmentations of the 'included' elements were added to the vector of external forces $\{F^n\}$, and a new deformation modulus of the included elements was applied to the stiffness matrix which was recalculated for a loading stage and since then we started solving the equations system (2).



Picture 1: Design diagram to model geometry changes of the zone.



p.2a - A building erection scheme in lifts.



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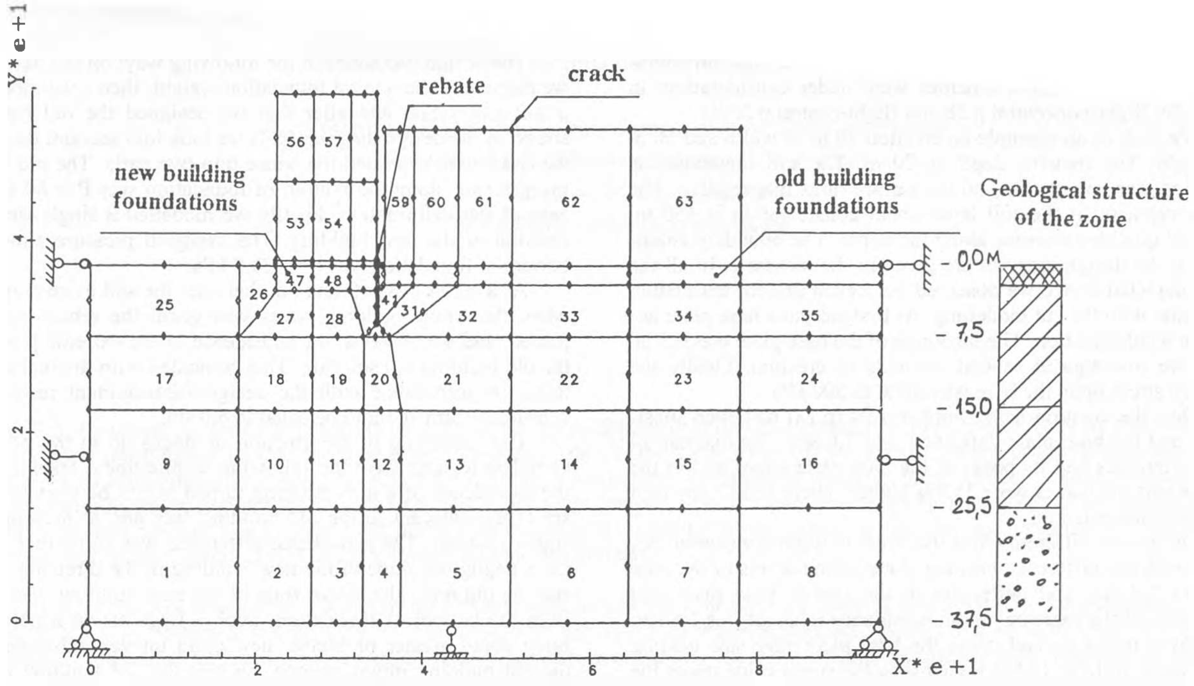
|---|---|---|---|---|---|---|
| 26 | 28 | 30 | 33 | 34 | 35 | 36 |
| 17 | 23 | 24 | 27 | 29 | 31 | 32 |
| 12 | 15 | 19 | 20 | 21 | 22 | 25 |
| 4 | 7 | 9 | 13 | 14 | 16 | 18 |
| 2 | 3 | 5 | 6 | 8 | 10 | 11 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 |

p.2b - A building flight-noncentral erection scheme.

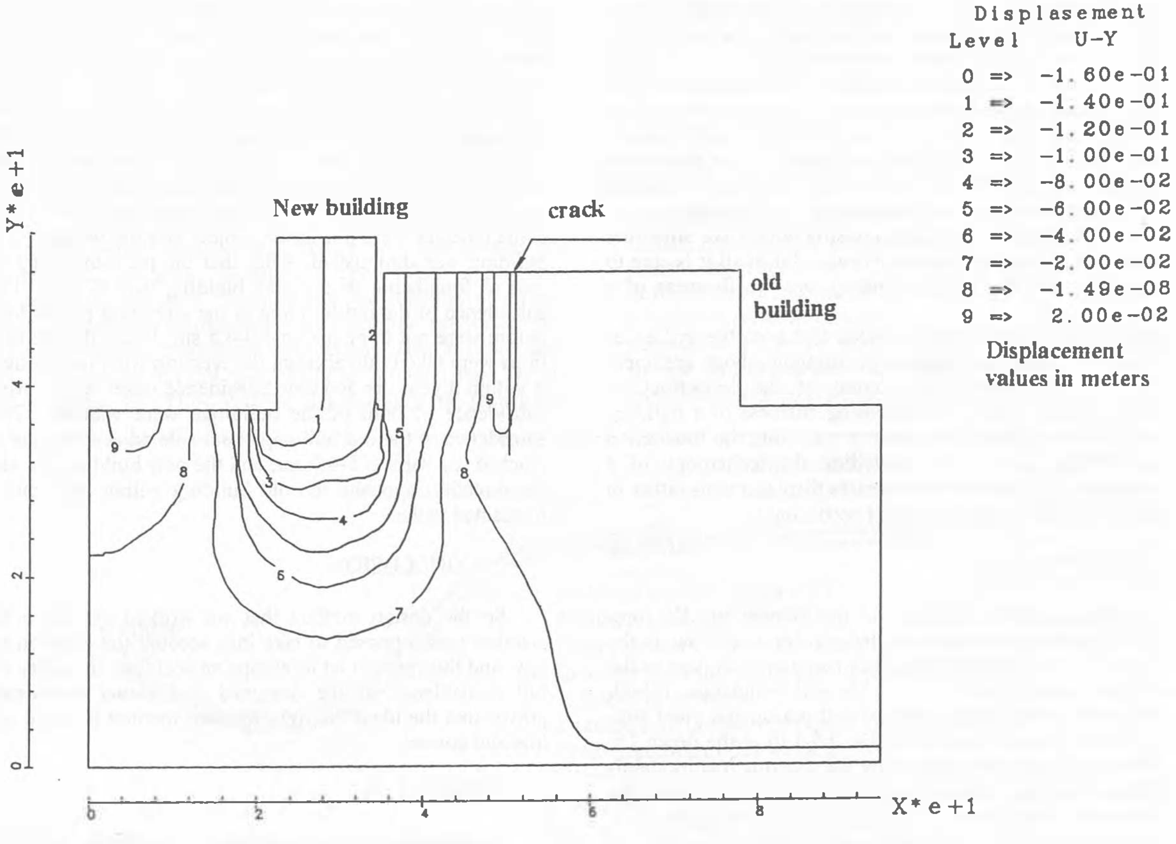
| | | | | | | |
|---|---|---|---|---|---|---|
| 20 | 18 | 15 | 15 | 15 | 18 | 20 |
| 19 | 16 | 13 | 11 | 13 | 16 | 19 |
| 17 | 14 | 9 | 6 | 9 | 14 | 17 |
| 12 | 10 | 7 | 3 | 7 | 10 | 12 |
| 8 | 5 | 4 | 2 | 4 | 5 | 8 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 |

p.2c - A building flight-central erection scheme.

Picture 2: Building erection diagrams. 1,2,...n - steps of a building loading with its actual weight.



Picture 3: Design diagram to model a new building erection next to the old one.



Picture 4: Displacements lines.

## 3. EXAMPLES OF CALCULATION

All the problems were solved under flat deformation conditions. Different erecting schemes were under consideration: in lifts p.2a, flight-noncentral p.2b and flight-central p.2c /1/.

We took as an example an erection 70 m in width and 50 m in height. The trench's depth is 20 m. The soil foundation is stratified: hard plastic clay on the surface turns into argillite. The whole capacity of the soil layer under consideration is 150 m. The soil qualities increase along the depth. The boundary conditions of the design diagram are given in the picture 1. In all the cases depicted above we observed the trench bottom excavation alongside with the cut modelling. At first we put a base plate under the whole erection. The thickness of the base plate was 0,5 m. Then we investigated several methods of erection. Finally the erection stress upon the base was equal to 500 kPa.

Thus the erection being built in lifts (p.2a) had even subsidence and the base plate deflection was 1,0 sm. The diagram of contact stresses had its peaks at the base plate edges and in the middle part the values were 35,8% higher. There wasn't any area of plastic deformation.

But it is all different when the stress is flight-noncentral. So, the subsidence difference between the extreme points of the base plate is 0,9 sm, and deflection in the central base plate part (midvalue of the extreme points subsidence relatively) is 1,8 sm. The stress in the ground under the base plate edge (the loading was started with) is 12,5% higher than the stress value under the opposite edge and 38,8% - with the regard to its middle part. The area of plastic deformation emerged under the base plate edge (the loading had been started with) at the 32 step /1/.

In case of the flight-central loading (p.2b) the SDS of the base acquires a symmetry type. The deflection of the central part of the base plate is 4,8 sm. The extreme values of the contact stresses in the ground from those in the middle part in 1%. We didn't observe any area of plastic deformation /1/.

The comparison of different schemes of erection proves that it is mostly irrational to erect a building in accordance with the flight-noncentral scheme. But this scheme is the most common one. One of the best ways to erect a building is the scheme of flight-central loading. In this case the exertions are allocated gradually along the bottom of foundation, and the diagrams of stresses in the reinforced concrete constructions have smoother outlines and with less quantity stress leaps. All in all it is sure to influence upon the longlasting standing and the firmness of a building.

The analysis of the design revealed that both the soil excavation and the erection technology brought about sufficient changes into the whole SDS picture of the 'construction-foundation' system. Thus, the increasing stiffness of a building may diminish displacement asymmetry and bring the foundation stress asymmetry to its end. Modelling the technology of a building erection we can allocate stresses displacements either in the foundation or in the erection itself accordingly.

## 4. RESULTS

This design method was used for the foundation SDS forecast for both the building being erected and for an old one in the city of Perm. A new solid building has being erected next to the old one dated back to the 19th c. In the soil foundation of both buildings there are soft soils (loam of soft plastic and yield consistence with the consistency index I = 0,5-1,0) at the depth 15-20 m. After the foundation excavation the sheeting lost its stability. Horizontal rebate displacement into the trench (within the edge foundation level) was 10-15 sm. Due to the rebate displacement the building's subsidence got uneven, irregular. A vertical crack 3-4 sm wide at the top emerged in the middle part of the building; and the building's subsidence were 6 sm at the trench side and 0,5 sm at the crack. All that causes a threat for the old building: it might be ruined in the process of erecting of a new building next to the old one. We made some forecasts of the old and new building's deformations, when the new one was erected already. For this we investigated the geology of the zone up to 37,5 m in depth (p.3); and it was taken into account.

Under the old building up to 7,5 m deep we used the deformation modulus E = 5,4 MPa for the natural foundation got stiff after a whole century.

The design was made in the following way: on the first stage we calculated the natural foundation weight, then - we modelled a soil excavation and after that we designed the old building stress. In the design diagram (p.3) we took into account the vertical crack which divided the house into two parts. The old building pressure along the bottom of foundation was P = 60 kPa in case of flat deformation. Finally we modelled a single-storeyed erection of the new building. The designed pressure along the bottom of foundation was P = 120,0 kPa.

As a result it was found out that after the soil excavation and when the whole building stress was given the rebate got displaced; and we observed the subsidence of the extreme points of the old building 6,0 sm long. This coincided with the real conditions. In accordance with the design measurement results the subsidence turned out to be equal to 6,0 sm.

The modelling of the erection in stages up to the point of complete loading gave the following displacement results. Thus the subsidence of a new building turned out to be uneven: 11,7 sm at the adjacent to the old building side and at the opposite side - 15,4 sm. The subsidence difference was equal to 3,7 sm, i.e. a negligible slope of the new building in the direction opposite the old one. The active zone of the new building was 18 m from the bottom of foundation. Such a large active zone might bring about greater problems: new extra uneven subsidence of the old building might emerge. So that the old building points which are near the new one are sure to set subsidence of 7,5 sm. Judging by the picture 4 we guess that it is only the 'torn out' part of the old building that is sure to get set. The subsidence fade away and there is none behind the crack.

All in all the design proved that with the pressure P = 120 kPa along the bottom of the foundation produced by the new building its average subsidence would be equal to 13,5 sm; the slope in the direction opposite the old building would be i=3,08*10-3. The old building would get extra uneven subsidence from 7,5 sm at the flank wall up to 0,0 sm at the crack. Those extra subsidence might lead to the ruin of the load-bearing walls of the old building. We offered to diminish the weight of the new building and reinforce the load-bearing walls and the whole old building. In accordance with our recommendations some changes were put in the project and the weight of the new building was diminished. After that the pressure along the bottom of foundation of the new building was 97 kPa. The extra subsidence of the old building at the adjoining points forecasted before were not to be above 3,0-4,5 sm. When the recommendations were taken into account the erection went on. At the end of it within a year the geodesic subsidence observations were held, subsidence of both of the buildings were watched. The extra subsidence of the old building flank side adjacent to the old one reached the value 3,5-4,0 sm, and the new building got sloped in the direction opposite the old building within the limits of the forecasted value.

## 5. CONCLUSION

So the design method that we worked out for a building erection was supposed to take into account the erection technology; and this method let us escape an accident. In reality we got a full coincidence of the designed and actual subsidence that proves that the ideas the SDS forecast method is based upon are true and correct.

## REFERENCES

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