Development of calculation methods of foundations on the pliable basis in Ukraine

Elaboration de méthodes de calcul des foundations sur la pliable base en Ukraine

P. Krivosheev, Y. Slyusarenko, J. Chervinsky
The State Research Institute of Building Constructions, Kiev, Ukraine

ABSTRACT

Basic principles of calculation method of the structures, taking into account variable rigidity of the ground basement, are introduced. The method of variable coefficients of rigidity of the basis allows taking into account non-linear and non-elastic deformability of ground and any displacement of a contact surface of the basis at calculations.

RÉSUMÉ

Cet article mèns les principes fondamentales de méthode de calcul de constructions, avec consideration de rigidité variable de sol de fondation. La méthode des coefficients variables de rigidité de base perms tenir compte (de) la capacité de deformation non linéaire et mou du sol et tout déplacement de la surface de contact de base en calcul.

Keywords : The deformable basement, contact task, variable rigidity

1 INTRODUCTION

The calculation of structures taking into account deformative properties of bases supposes the proper idealization of variety of mechanical properties of soils present the base. The level of abstraction here depends on requirements, produced to the calculation chart of the system of "structure–base". In general case it is possible to select three basic groups of calculation methods: method of local resilient deformations; method of general resilient deformations; combined methods.

The method of local resilient deformations (Vinkler hypothesis) is based on precondition that deformations of foundation take place only in the place of appendix of force and it is considered that pressure in this point in direct ratio to its moving $p = c \times w$, where p – force in the point of deformation of foundation; c – a coefficient of proportion (coefficient of rigidity of the basis); w – moving of foundation in the point of appendix of force.

The method of general resilient deformations is based on precondition that deformation of the bases take place in any point of resilient half-space with coordinates x and y , on-the-spot which in a point with coordinate's ξ и η single force is attached. The size of deformation of foundation depends on distance between the points of appendix of force and point of resilient half-space $w\left(x, y\right) = k\left(x-\xi, y-\eta\right)$.

However paradoxical it is, but the basic lacks of the methods indicated higher are their fundamental conceptions: ignoring of distributive ability of foundation in the case of Vinkler's bases and excessive distributive ability of resilient half-space. Therefore, quite natural were developments of the combined methods of design grounds in which these failings were smoothed out due to introduction of additional conditions at mathematical problem definition. In this article the method of variable coefficients of rigidity of the bases (MVCR) is examined, founder of which was professor S.N. Klepikov.

2 GENERAL CONCEPTION OF THE MVCR

On a figure 1 the chart of the system of «structure–base" is shown. It consists of two subareas of top level digitization: B – structure and F – foundation.

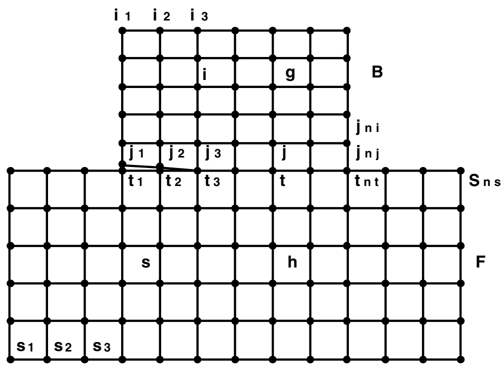

Figure 1. Chart of the system of « structure–base ".

Subareas B and F have a grid of division on elementary subareas of the following level, built on knots I, J, S and T, for which sets I and J, similarly as well as S and T – non-overlapping, and sets I and T have common knots:

$$I \cap J = \varnothing; S \cap T = \varnothing; (I \cup J) \cap (S \cup T) \neq \varnothing, \quad (1)$$

Where $I = \{i_1, i_2,\ldots,i_{ni}\}$ - set of knots of a grid of digitization of structure which do not contact to a surface of basis; $J=\{j_1, j_2,\ldots, j_{nj}\}$ - set of contact knots of a grid of digitization of structure (knots which can come into contact to a surface of basis); $S=\{s_1, s_2,\ldots, s_{ns}\}$ - set of knots of a grid of digitization of basis which do not contact to a surface of structure; $T=\{t_1, t_2,\ldots, t_{nt}\}$ - set of contact knots of a grid of digitization of basis (knots which can come into contact to a surface of structure); *ni, nj, ns,*

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nt - amount of proper knots. *J knots* and *T* further under the text we shall name external, and *I knots* and *S* - internal.

At proper sequence of numbering of internal and external knots in procedure of a method of finite elements, considering the subareas, constructed on *I knots J*, *S* and *T* as finite elements, for a construction the following equation of balance is possible to write down

$$\begin{bmatrix} [K_{ii}][K_{ij}] \\ [K_{ji}][K_{jj}] \end{bmatrix} \begin{Bmatrix} \{V_i\} \\ \{V_j\} \end{Bmatrix} = \begin{Bmatrix} \{F_i\} \\ \{F_j\} \end{Bmatrix} \quad (2)$$

Where *[K]* - submatrixes of the coefficients of rigidity on proper knots; $\{V_i\}$, $\{V_j\}$ - vectors of displacements of internal and external knots; $\{F_i\}$, $\{F_j\}$- vectors of the loadings resulted in internal and external knots. After proper transformations this equation can be written down in the following kind

$$([K_{jj}]-[K_{ji}]\,[K_{ii}]^{-1}\,[K_{ij}])\,\{V_j\}=\{F_j\}-[K_{ji}]\,[K_{ii}]^{-1}\,\{F_i\} \quad (3)$$

Similarly, for the basis it is received

$$([K_{tt}]-[K_{ts}]\,[K_{ss}]^{-1}\,[K_{st}])\,\{V_t\}=\{F_t\}-[K_{ts}]\,[K_{ss}]^{-1}\,\{F_s\} \quad (4)$$

The equation of balance on contact knots for system " structure-basis" looks like

$$([K_{jj}]-[K_{ji}]\,[K_{ii}]^{-1}\,[K_{ij}])\,\{V_j\}+[K_{ji}]\,[K_{ii}]^{-1}\,\{F_i\}-\{F_j\}=$$

$$=\{F_t\}-([K_{tt}]-[K_{ts}]\,[K_{ss}]^{-1}\,[K_{st}])\,\{V_t\}-[K_{ts}]\,[K_{ss}]^{-1}\,\{F_s\} \quad (5)$$

Let's stop more in detail on the circuit of interaction of contact knots of structure and basis. During complex loading of this system two statuses of job of contact knots are possible: 1 status - when proper contact knots of a structure and the basis have made contact; 2 – no contact. Each contact knot is mathematical model of an elementary platform of a contact surface to which all of its properties are appropriated, therefore, speaking about interaction of contact knots, it is necessary to examine interaction of these platforms with their properties. On a figure 2 the circuit of modeling of interaction of elementary contact platforms by contact knots is shown.

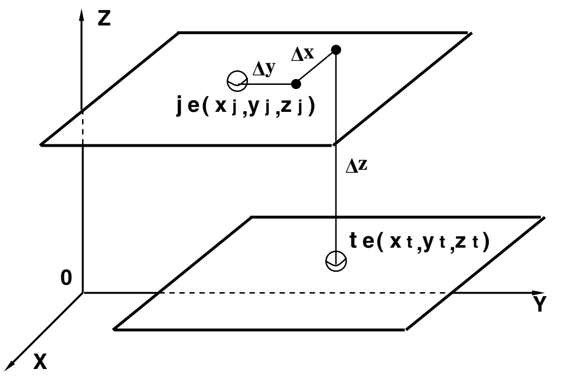

Figure 2. The circuit of replacement of platforms by contact knots

Basic concept of the MVCR is approximation of continuous quantity, characteristics of rigidity of basis, set of the piecewise continuous functions, determined on finite number of sub areas - contact knots of the basis.

On a figure 3 the schedule of deformation of the ground basis at punch tests for detrusion at sign-variable static detrusion loading is shown. On a figure 4 schedules of ground tests by piles at action of pressing and pulling out loadings are shown .

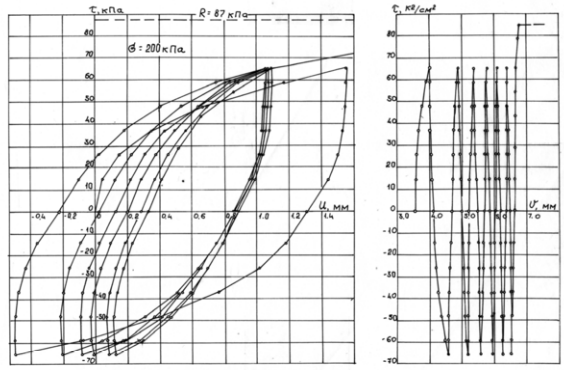

Figure 3. Schedules of deformation of the ground basis at punch tests for shear. 1 - horizontal displacements.
2 - vertical displacements.

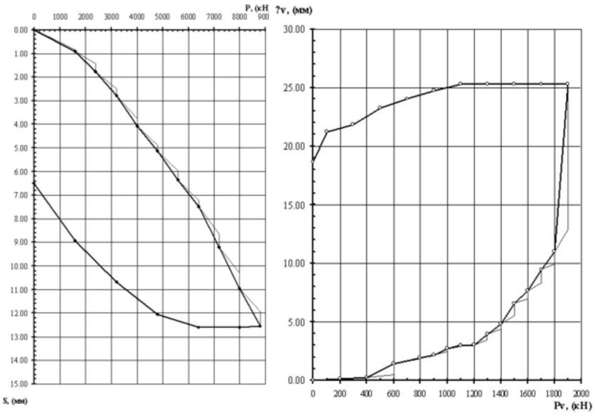

Figure 4. Schedules of ground tests by piles. 1 - pressing loadings. 2 - pulling out loadings.

Considering a punch as an elementary contact platform of structure, we abstract up to the contact knot of structure, in which vertical and horizontal loadings operate. Considering a surface of a ground on contact of a sole of a punch as an elementary contact platform of the basis, we abstract up to the contact knot of basis which possesses determined rigidity properties. It is possible to consider schedules shown on a picture 3 as function of dependence of displacements *{V}* the contact knot of the basis from loadings working in the contact knot *{F}*: *{V} = [K] {F}*. Here *[K]* - a matrix of rigidity of the contact knot of the basis.

Let's consider a head of a pile as the abstract contact knot of structure in which the pressing or pulling out loadings operate, put to a head of a pile. Considering the part of a pile which is taking place in a ground as an elementary contact platform of basis we abstract up to the contact knot of basis. It is possible to consider schedules that are shown on a picture 4 as function of dependence of displacements of the contact knot of the basis from loadings working in the contact knot *{V} = [K] {F}*.

At the description of stickiness properties of basis in the MVCR it is possible to allocate three basic hierarchical levels:

1. Stickiness properties of the basis are divided by the form of its deformations: coefficients of rigidity of basis at compression - K_{cm}; coefficients of rigidity of basis at shear - K_{dt}.
2. Each kind of coefficients of rigidity depends on geometrical features of a contact surface, in particular on coordinates of contact knots on a contact surface, a geological structure of basis, mutual initial position of contact surfaces of a design and basis;
3. The coefficient of rigidity in the contact knot, generally, is quantity of a variable, according to the nonlinear job of a

ground of the basis and depends on properties of a ground is taken into account in calculation. Deformation properties of basis in the contact knot are described by complex characteristics - functions "displacement - effort" which for the non-linear and non-elastic basis in a general view can be written down:

– At compression:

$w = f_1\left(p\right)$; $w = \psi_1\left(p\right)$ – active deformations of compression;

$w = f_2\left(p\right)$; $w = \psi_2\left(p\right)$ – passive deformations of compression;

$w = f_3\left(p\right)$; $w = \psi_3\left(p\right)$ – active deformations of a stretching;

$w = f_4\left(p\right)$; $w = \psi_4\left(p\right)$ – passive deformations of a stretching

where w – displacement of the contact knot on a normal to a contact surface; p – effort in the contact knot in this direction; $\psi = f^{-1}$ – inverse functions.

– At detrusion:

$u = g_1\left(t\right)$; $t = \zeta_1\left(u\right)$ – active deformations at detrusion in a positive direction of displacement;

$u = g_2\left(t\right)$; $t = \zeta_2\left(u\right)$ – passive deformations at detrusion in a positive direction of displacement;

$u = g_3\left(t\right)$; $t = \zeta_3\left(u\right)$ – active deformations at detrusion in a negative direction of displacement;

$u = g_4\left(t\right)$; $t = \zeta_4\left(u\right)$ – passive deformations at detrusion in a negative direction of displacement;

where u – displacement of the contact knot on a tangent to a contact surface in a direction of an examined coordinate axis; t – effort in the contact knot in this direction; $\zeta = g^{-1}$ – inverse functions.

3 PRACTICAL REALIZATION OF THE MVCR

Functional dependence {V}=[K]{F} has obvious nonlinear character, therefore calculation of the system «structure–base" is possible only iteration methods. At a calculation on a difficult ladening, dividing of history of ladening is produced into the row of simple ladenings. At first a calculation is executed on the first load. Then taking into account the got results a calculation is executed on an additional next ladening et cetera. A linear-resilient contact task decides on every step of ladening. Determination of loadings from building on pin of knot of foundation is executed some numeral method. The most compatible numeral method with MVCR is a method of finite elements (MFE) because it is here possible at the calculation of building to take into account rigidity of foundation by the direct adding up of matrices of inflexibilities of the proper contact knots of building and foundation.

The account of non-linear and non-elastic properties of deformation of foundation in a contact knot at a difficult ladening requires permission non-linearity of two kinds: the first is conditioned physical non-linearity of deformation of foundation subloading; conditioned the second by the difficult trajectory of ladening of foundation. Therefore at the design of work of contact knot at the action of squeezing efforts a two-tier chart is accepted:

1. Into a simple ladening procedure of method of variable parameters is used, when in the process of iteration adjustment of secant coefficients of rigidity of foundation is produced at compression.
2. For permission of the second kind non-linearity the method of retuning of charts, describing deformation properties of contact knot at compression is used, in accordance with attained in history of ladening of level of wringing out of foundation. The algorithm of this procedure in a general view is shown on pictures 5 and 6.

Use in MVCR contact knots for modelling process of interaction of a construction and the basis allows to solve tasks of influence on a construction of non-uniform displacements of the basis. Lowering of a surface of the basis is set by change of coordinate of a trace of the contact knot and proper recustomizing of the circuit describing deformation properties of basis. This status is shown on a figure 5. At a rising of the basis the coordinate of a trace of the basis also changes and proper recustomizing of the circuit of deformation in the contact knot of the basis is made. The mark of initial position of the contact knot of a construction is below a mark of a trace, occurs crumbling the bases by the construction. Influence of the basis on structure thus is characterized by $K_{cm\ (i-1)}(w_b - \Delta_{b(i)} - w_{c\pi})$. The circuit of interaction of contact knots at a raising of the basis is shown on a figure 6.

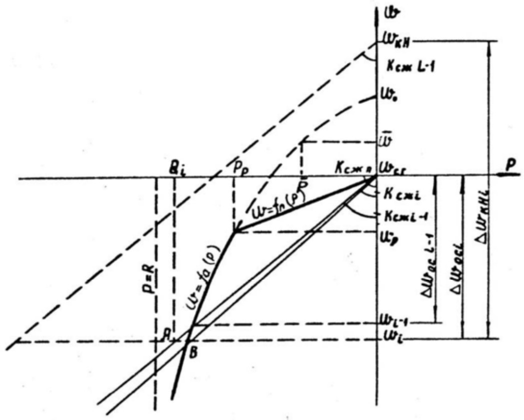

Figure 5. Chart of determination of secant coefficients of rigidity of foundation at compression at lowering of foundation

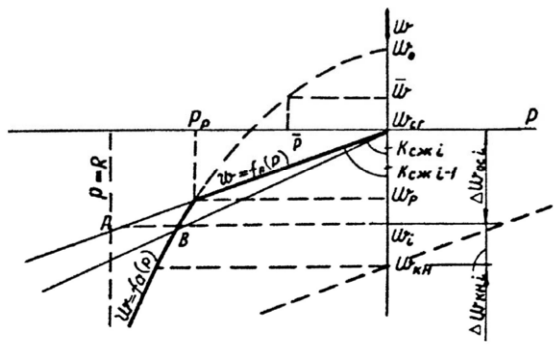

Figure 6. Chart of determination of secant coefficients of rigidity of foundation at compression at rising of foundation

From above-stated it is visible, that at modeling interaction of contact knots during complex ladening procedure of recustomizing of the circuit of deformation properties of the contact knot of the basis has the large value. Such recustomizing is made for two reasons:

1. At transition to the following level of ladening in case at the previous level of ladening *(i-1)* has taken place additional squeezing of the bases, that is if in the contact knot of the basis there were active deformations. In this case change of coordinate of a point of unloading and coordinates of a point of a trace of a construction on the basis is made.
2. At the set deformation influence on structure on the part of basis. In this case parallel carry of the circuit describing basis is carried out, concerning an axis of efforts (an axis p) on size of a rising or lowering of basis, or, that is equivalent, the coordinate of initial position of the contact knot of a construction changes.

On a figure 7 results of calculation at which modeling natural experiment on research of job of the block of a nine-floor building at passage under it of subsidence of the basis is executed are shown. The basis was modeled by the contact knots working under the non-elastic circuit. As the settlement parameters, contact knots of the basis describing to rigidity, the following sizes are accepted: coordinates of a "characteristic" point of a curve of active deformation of the basis - $w_{ch}=0,020$ м, $p_{ch}=2005$ kN; bearing ability of basis at compression $N=7000$ kN; factor of rigidity of basis at passive deformation $K=22320$ kN/m; size of subsidence of the basis under structure $\Delta h=0,132$ m.

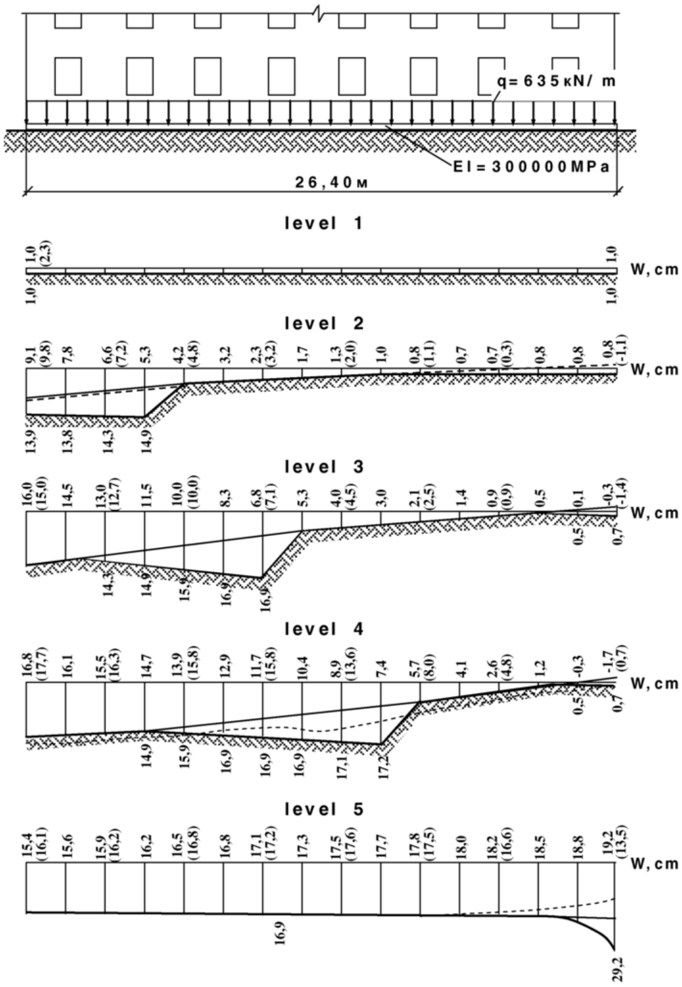

Figure 7. Modeling of natural experiment on under-working of a large-panel building

Experiment was modeled as complex laddering in 17 steps. On a first step loading from a building is set, on the subsequent steps were set subsidence of basis. In figure 7 values of displacements of a building and position of a surface of basis are shown. Results of modeling are shown by continuous line, results of experiment - dashed line (values of displacements are specified in brackets).

The research has been carried out on numerical model showed that at the set sizes of loadings iterative process is steady and quickly converges. Increase of accuracy of the decision on the order (it is no viscous on factors of rigidity of the basis is reduced from 0,1 % up to 0,01 %) increases total of iterations almost by 30 %. Increase of rigidity of structure slows down convergence of iterative process. The increase in rigidity of basis accelerates convergence of iterative process. Change of rigidity of structure, as well as basis, on length appreciably influences a process of deformation of system " structure-basis" at complex loading.

4 CONCLUSIONS

Application of a method of variable factors of rigidity of basis allows to carry out calculations of the systems " structure-basis" at which it is possible to take into account:

- Features of deformation of bases, at presence in them soils, possessing special properties;
- Subsidence and a raising of a surface of the basis at under-working territories, ground slumping from under the bases, karst failures;
- Sign-variable horizontal deformations at passage of a shear surface on under-working territories;
- Rheological properties of the soil of basis.

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