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Confrontation at underground wall construction development

Confrontation à la construction d'une paroi souterraine

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SYNOPSIS: At the present times - a universal effort manifests itself - to optimize every structure and to obtain a solution, which is not only technically perfect, but also most profitable economically. This effort leads to the creation of continually more perfect solutions by means of three methods. The main contribution of this paper is the solution of a new way of the modelling method. The possibility of model measurement connection with mathematical calculations was studied with the aim to attain the most economical methods. An example of such complex modellings is given by the construction development of the Prague subway under the protection of underground walls (UW).

1 ANALYSIS OF MATHEMATICAL MODELLING

Few calculation systems exist, which would apply plastic deformation by cooperation of the UW with the rock massif. Essentially it were Brinch Hansen, Windels and Weissenbach who published works treating the loading mechanism. By means of the Brinch Hansen method, it is not possible to calculate foundation pits of greater depth, because it limits itself on individual supported faces. Windels - in his method does not presuppose any distribution of rock and soil pressure. Under the presupposition, that parts of the pit behave plastically, there occur large redistribution of earth pressure. Weissenbach takes these states into consideration only approximately. Brinch Hansen is the only one, who occupies himself with earth pressure redistribution in connection with plastic linkages. For the calculation - kinematic methods are to be considered. Brinch Hansen considers the face sections between individual plastic connections as rigid. In the bracing region appear - with this procedure - the largest loads. Windels presupposes a classical distribution of pressure and earth resistance without redistribution. The moments of fields and supports are supposed to be equal for the individual fields. The contemporary calculation procedures are founded on methods, which - even with considerable difficulties - give a true picture of the state and behaviour of rocks only approximately. The consequence of this is that UW use to be oversized, because it is not possible to risk a breakdown not only from the point of view of economic loss, but above all from the point of view of users safety. For this reason there is in the whole world the endeavour of all scientific specialists to take part in the development of more accurate methods for the solution of UW. The application of these methods requires to use a highly efficient calculation technique. Therefore it is necessary to study accurately the mechanism of foundation pit wall loa-

ding. Further it is necessary to determine earth and rock pressures in the area of wall plastic deformation and what pressure distribution has to be presupposed for the loading mechanism. It is necessary to occupy oneself with the questions - what kind of strut forces are decisive at the loading mechanism and extent of the influence of the lateral forces on the plastic deformations of the foundation pit wall. For the execution of numerical calculations and the value determination of the shearing and normal forces, principal stress, displacements and optimum fixing depth of the casing structures (bracing and anchoring) it is possible to content oneself with the solution of distribution methods and of the finite elements method. The essence of the finite elements method consists in the dividing of the continuum solution into discrete elements for which the conditions of behaviour under the influence of loading are determined. By arranging the mutual linkages of these elements for the entire continuum - a system in a set of equations is obtained. Their primary unknowns are - according to the model type chosen - (compatible, balanced, hybrid and mixed) either the fields of connection stress modes displacement or a mixed field of displacements and stresses. The objective evaluation of the UW cooperation with the rock has a considerable significance for the determination of the real deformations in the UW surroundings. The UW cooperation with the rock has - of course - also influence on the dimensioning of structural elements. The solution of this problem is taken within the framework of the PODIS subsystem complexly into the total area solution inclusive the mutual influencing of the rock effects on the UW and the other way round. The contact problem is expressed here by the physical properties of the isoparametric contact elements, inserted on the border. An analogous procedure is applied also in the modelling of tec-

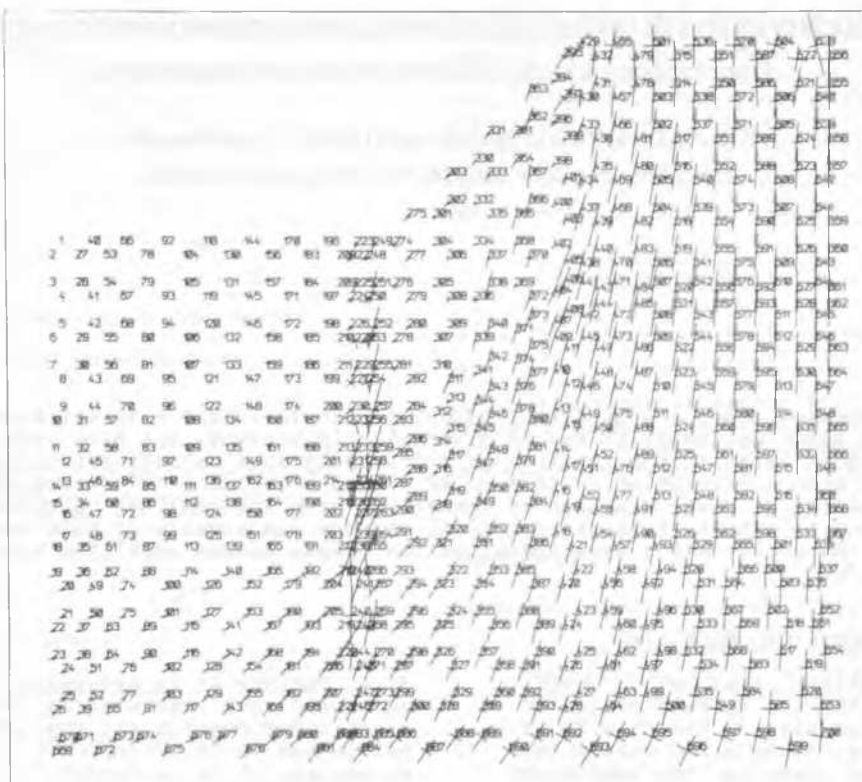


Figure 1. Subsystem PODIS Geo-Brno-12

tonic faults. The UW is introduced into the calculation model either by - conveniently chosen finite elements or by the rigidity matrix of the corresponding type, which has in the contact points - degrees of freedom corresponding to the finite elements, care must be taken that the axial rigidity EF and bending rigidity EJ of the UW are maintained in the mathematical model. The contemporary version of the PODIS subsystem uses for the solution of obligatory and spatial tasks a hygrometric model with elements in the form of linear triangles and generally curvilinear quadrangles with linear, quadratic and cubic representation. The form functions for these element types take into consideration two unknown quantities in the nodal points - the displacements in the directions on the global - axes - x - and - y - and secure the continuity of the first derivations according to the displacements; for instance, the designated region Geo-Brno-12 has been triangulated with a total number of 700 elements and 380 nodal points. Evaluation of the gained results of input values are the stress and vector components of nodal point network displacement in the plane of the coordinate system. In an elastic isotropic medium - the deformations are in linear relation with the stress, but if the medium behaves also plastically, it is necessary to take into consideration

also nonlinear relations. Kondner formulated for cohesive and cohesionless soils a hyperbolic relation of stress - deformation. Kondner's soil model was adjusted for the method of finite elements - as first - by Duncan and Chang, who derived from the dependence an expression for the tangential modulus of elasticity and used this dependence together with Mohr's criterion of limit plastic equilibrium for the formation of a more general mathematical soil model. The writers verified the convenience of this model and used it for the solution of the concrete model Geo-Brno (figure 1.).

The distribution theories are used with success in the solution of many problems of structure theory (distribution theory and general method of grillage structure analysis - Henry and Jaeger). The general problem formulation at the evaluation of foundation pit wall sheeting structures is founded on the method of elastic and plastic calculation. If - for instance the wall is tensioned by anchors, tensioning by minimum force may be presupposed, which will be larger than the force, evoked by plastic pressure (for instance - the station Sokolovská - subway Prague). In order to limit the deformations in the neighbourhood of the pits, it will be desirable to maintain the rock pressure on the wall in the limits of given possibilities, i. e. superposition of elastic and plastic



Figure 2. Physical Model Geo-Brno-78

sizes of the resulting stress (station of Cosmonauts - Prague subway). In the region of the fixed wall it behaves as a layer obeying the Winkler law (method of Winkler subgrade application by elastic springs for ideally elastic plastic matter). The rock is simulated by n - springs. The spring constants N_i are derived from the bedding coefficients K_i . It is presupposed, that the spring coefficients differ linearly, N being equal to the coefficients of the first spring, loaded on unit length which give rise to unit deflections. The distribution method has the advantage, that more accurate and more truthfull results of the internal wall forces are gained. The solution procedure is not difficult. The stated calculation was elaborated by the writer on the automatic computer (program under the title Geo-Brno-DM) in the calculation centre STÚ Prague, Rationalization and experimental laboratory.

2 PROBLEM SOLUTION ON PHYSICAL MODELS

On the basis of the homothety theory and dimensional analysis - a model 1 : 10 (figure 2.) of the foundation pit - UW of Prague subway station - was built in the laboratory of physical modelling on the Chair of geotechnique of the TU Brno. The UW model has been made of perspex. For this model, the choice of a convenient equivalent material was very important. Equivalent materials are made of slag and portland cements, silica sand, lime hydrate, mixed in various proportions. The model was built in a stand 150x190x200 cm.

The model wall had the dimensions 100x190x10 cm. In order to get a true picture of the stresses and deformations course. The model was provided with 110 measuring points. On the basis of physical modelling results, the size and the point of action of earth pressure resultants were determined. At angular rotation of the wall fixation - an uprise of earth pressure became apparent in those regions, where displacements against the soil occur. Further - a stress reduction showed itself in those regions, where movement away from the earth takes place. In conclusion of the experiment on the physical model, the number of bracing places, the wall rigidity and the rate of fixing were evaluated.

For the analysis of rock structures - it is necessary to evaluate the threedimensional stress states.

3 MEASUREMENTS IN SITU

Many research workers occupied themselves with the application of the mathematical method on UW solutions. The most recent methods are based on the results of measurements in-situ. The stress analysis of UW requires to take specially into consideration and to verify how and in what value - in dependence of the UW type - the coefficients of loading and uniformity - and the conditions of action are to be introduced into the stress analysis. In order to verify how the large rock pressure really acts on the UW, how its size and distribution vary with progressive foundation pit deepening and its expansion of crown st-



Figure 3. Measurements In-Situ - Geo-Brno-D

ructures or anchoring and how the strength varies in the structure, seven experiments of section measurements were carried out on the construction of Prague subway structure (figure 3.). The UW structures, measured on seven places, have different spatial arrangements. Fifteen lamellas were chosen for the measurements in-situ. Further - for the determination of rock deformation and of stress on the (lamella) contact in the rock - a pit was excavated and an UW was built. In it, the strength and deformation properties of the individual rock types were determined by geotechnical tests. For the anchor force measuring (43 anchors) measuring instruments of Geo-Brno-24 -D were installed. By measuring on the UW - the deformations and stresses in the concrete and reinforcement were determined. The axial face measurements in the station crown head at the assembly of prestressed concrete prefabricated elements - were made by means of string dynamometers, installed in the joint between the lamellas and faces of the beam. The deflection and angular rotation of the wall were measured geodetically. The stresses on the contact between the wall concrete and the rock were measured by means of pressure measuring bags (Geo-Brno-V). For the determination of the most probable quantity values of the whole measuring set for determination of the measuring precision degree, determination of accurate data for the theory of mathematical statistics of random error normal distribution curve - the program Geo-Brno-H was used. The acquisition of 27 000 measured points on UW in the course of 16 years (1970-1985) showed, that it is possible to evaluate from the measured values - both the size of the acting rock uplift and the real state of stressing in the wall.

4 CONCLUSION

The condition - to measure the rock properties under the existing state of stressing and under such force action, as will be evoked in the rock massif by the structure - fulfill only the tests, realized in natural condi-

tions. The measuring of the load bearing structure cooperation with the surrounding rock confirms the rightness of chosen procedure of mathematical modelling (distribution method and the finite elements method). Practically perfect agreement with the reality is gained by combining the physical model method with mathematical modelling. By comparing the calculation model with the experiment (physical model) it was proved, that in the region of wall plastic deformation - the forces in the foundation pit bracing are rising very intensively; here the plastic deformation of the wall influences in a large extent the growing earth pressure redistribution.

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