Advanced numerical model based on the theory of General Lateral Pressure

Model numerique avancée d'aprés in theorie d'Pression Latérale Générale

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ABSTRACT: An advanced numerical model and computation program for retaining structures were developed by the theory of General Lateral Pressure (GLP). Parallelly, during years of 1998, 1999, two medium physical model experiments E1 and E2 with the ideal non-cohesive sand were carried out. The experiments were repeated in 2000 also numerically as experiments N1 and N2.. The paper presented information about the algorithm and program of the numerical model and a possible part of the comparative study of physical experiment E1 and numerical experiment N1.

RÉSUMÉ: Le modèle numérique avancé ainsi que le programme informatique ont été créés d'après la théorie de pression latérale générale (GLP). Au cours des années 1998 et 1999, deux expériences de physique E1 et E2 ont été réalisées avec les modèles de sable de friabilité idéale. Ils ont été réalisées de nouveau en 2000 de manière numérique. Il s'agissait d'expériences N1 et N2. L'intervention porte sur l'information concernant l'algorithme et le programme du modèle numérique avec une possible partie d'étude comparative de l'expérience de physique E1 et de l'expérience numérique N1.

1 INTRODUCTION

The actual conventional theory of earth pressure (in mechanics more widely as "lateral pressure") is based particularly on the works of Ohde, Terzaghi (1936), Caquot-Kerisel, Ehrenberg, Jáky (1944), de Wett, Sowada, Siedek, Myslivec, Pruška (1973), Janbu, Morgenstern, Eisenstein, Gudehus (1980a,b) and developed by others among whom e.g.. in Tokyo 1999 Ariizumi et al., Kort et al., Onishi &Sugawara, Powderham, Siemer et al., Uchiyama should be mentioned in connection with static problems.

Although theoretical knowledge has advanced, a large part of the theory, particularly of static pressure, is still based on the ancient idea (probably of French and Belgium fortification engineers) on the effect of earth pressure. This idea is noted for a single plane or (in a more modern version) curved failure surface and an undeformed active part of the soil mass above the surface. Both the standards and the computation models of earth pressure are elaborated particularly for plane slip surfaces. Probably the most worldwide computation method, i.e. the Dependent Pressures Method (DPM - Zapletal 1981), is based on the simple elastic-plastic relation; however, the conventional theory does not provide a satisfactory calculation method of adequate limit movements (Koudelka 1990, 1999a). The known computation models based on FEM or BEM do not afford entirely satisfactory and reliable results for the practice and very often are controlled by a conventional simple method.

2 OBJECTIONS TO PRESENT THEORY

The present theory contains several discrepancies, which are more or less known or obvious, but have not received due attention either in theory or in practice. The fundamental objections to this theory include the following points:

a) Only a single value of the pressure at rest is considered in the area of zero or very small movements of the retaining structure. The magnitude of the value almost always corresponds with the value of active pressure at rest, although the theoretical existence and the approximate value of the passive pressure at rest have been known for over the past 25 years (Pruška 1973, Koudelka 1990).

b) The idea of a single (mostly plane) shear or slip surface in the mass and the full mobilization of the shear strength on it in an otherwise not deforming (granular) soil mass as the condition of the *general* effect of extreme values of active (minimum) or passive (maximum) pressure affecting the *whole* retaining structure is unrealistic particularly for geometric, but also for other reasons (Koudelka 1998, 1999b, 2000a, Koudelka & Valach. 2000).

c) In the area of current movements of the retaining structure only the values of active or passive pressure (extreme values during the shear strength peak mobilization) are considered. However, it is generally known that during shear tests, after the respective peak displacement has been exceeded, the shear stress drops to the residual value. The residual strength is significantly lower than the peak strength, which is illustrated below in Fig.1. Thus, this assumption is very optimistic and, therefore risky (Koudelka 1999a, 2000b).

There are other objections, but the three mentioned above can be considered as the most important.

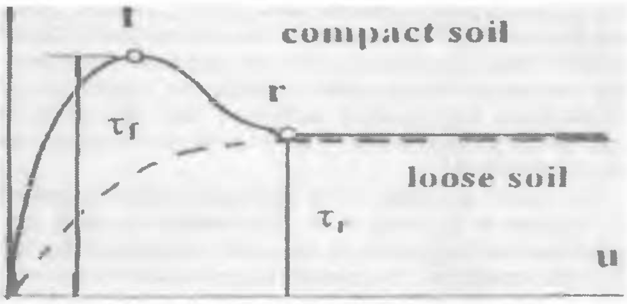

Figure 1. Relation of shear strength on displacement for compact soil (solid) and loose soil (dashed).

3 THEORY OF GENERAL LATERAL PRESSURE

The research of both physical and numerical models was carried out in the past few years. Its purpose was to formulate and, if possible, verify a more advanced concept of the lateral (earth) pressure theory which would eliminate the objections to the conventional theory. The developed more general and more advanced theory can be called the "General Lateral Pressure"(GLP - Koudelka 2000b) theory and is defined by the *different* comprehensive non-linear constitutive relations of acting lateral pressure on movements of adequate structure contact points, i.e. the lateral pressure against ***each contact point*** of structure acts respecting its according movement (see below in Fig.2).

The level of GLP theory of 2000 and an advanced numerical model (presented by the below noted FORESTR computation program of the second generation) are shown by some results of the comparative study of the physical model experiment E1 and the analogous numerical experiment N1

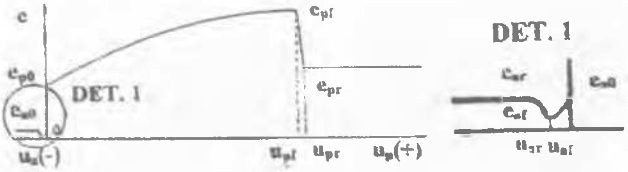

Figure 2. General theoretical dependence of lateral pressure against a general point of structure on the point movement.

4 NUMERICAL MODEL

The numerical model N! applied the second generation FORESTR program in Version 2.8. No other numerical model for analysis of retaining structures according to the General Lateral Pressure theory was known, as a result of which no comparison with other numerical model could be made. Therefore, it was impossible to apply any known methodological or theoretical procedures to model development. The first deliberations on the new algorithm were based on the practice of the DPM; however, it had become obvious soon that it was necessary to devise an entirely independent algorithm. The first foundations of development of such algorithm were laid by the firm Petris,Ltd. as early before 1990. The algorithm and the numerical model were developed under the name of FORESTR. The methodological procedures can be divided into theoretical ones, concerning the algorithm proper, and the programming ones. Both of them are described in the permitted scope.

4.1 *Algorithm*

So far the model development has undergone two phases. The first about 16 versions of the first generation model sought, verified and developed the optimum static patterns, the most general and the most reliable formulas for the computation of lateral pressure values, the iteration procedures and their convergence and particularly the appropriate algorithm for computation of displacements corresponding satisfactory with the individual limit lateral pressure values. This program generation did not use FEM or BEM.

The second generation of the algorithm has been elaborated in 9 versions so far, based on the FEM program and using optimized and verified procedures and partial programs of the first algorithm generation. For reasons of applicability to domestic practice the computation of extreme lateral pressure values (active and passive pressures) corresponds with the respective Czech standard ČSN 73 0037 the values of which approach those specified by EUROCODE 7-1 (Geotechnical design – Part 1 – General rules). Because of theoretical discrepancies the algorithm does not respect the table of standard limit movements considered for the mobilization of peak shear strength. By the end of the first half of 2000 all substantial parts of the algorithm corresponding with the present-day concept of GLP theory were elaborated.

4.2 *Program*

The program is broken up into individual modules which are developed separately. The principal modules are :

- generation of retaining structure,
- generation of finite element mesh of the soil mass,
- computation of earth pressures and displacements,
- programs for the computation of the retaining structure and the soil mass stress state,
- graphic presentation of results.

The first versions of the program were programmed in Turbo-Pascal. However, due to the fast development of programming languages and of the algorithm further versions were redesigned. The latest versions apply modern programming means (object programming, modern programming languages C++ and Fortran 90). The fully 32 bit program makes use of the WINDOWS 95/98/NT operating systems. The trial program versions are partly provided with user facilities. It is assumed that the demonstration and the future commercial versions will be provided with the environment compatible with MS Office 97.

5 COMPARISON OF NUMERICAL AND PHYSICAL EXPERIMENTS

The research comprised two complete comparative studies of both experiments (Nos. 1 and 2). We present here a few results of study comparing the E! and N! experiments, permitted by the limited scope of the paper (For further results see Koudelka 2001).

5.1 *Physical model experiment*

Two medium-term (nearly 6 and 4 month) practically the same experiments E1 and E2 with the very non-cohesive flowing sand (see I-net http://www.itam.cas.cz/~koudelka and Koudelka 1999, 2000) showed the very different behaviour of the tested granular mass according to the three different types of the retaining structure movement (rotation about the toe and the top, translative motion). The size of samples was 1.0*1.5 m, height 1.2 m, height of the retaining wall 1.0 m. These physical experiments revealed also the physical base of objections to the present earth pressure theory. Experiment E1 wsa repeated as experiment E2 and the little expected results of E1 were confirmed. The paper presents a part of comparison analysis of the first experiment on active structure rotation about the toe.

The basic properties of the E1 mass follow below and are valid for the numerical experiment too :

- unit weight	γ = 14,88 kN/m^3
- water content	w = 0,04 %
- compaction	loose
Shear strength :	
- angle of top shearing resistance	ϕ_f'= 48,7°
- top cohesion	c_f'= 0 kPa
- angle of residual shearing resistance	ϕ_r'= 37,7°
- residual cohesion	c_r'= 0 kPa

5.2 *Numerical model experiment N1*

Physical experiments were modelled numerically in accordance with the present-day level of the GLP theory. The numerical experiment N1 observed the same history of retaining wall movements in all phases incl. Stepping to achieve the maximum similarity of the physical and numerical models. The numerical modelling omitted only the re-consolidation periods, but their results were included also into numerical models. This concept required 559 computations of reatining wall positions for the numerical modelling of the physical experiment E1; each of these computations presented the data on 5 tensors and the value at the toe of the retaining structure. The computation database of the numerical model N1, consequently, consisted of 3354 data sets, and 6720 data sets for both experiments (N1 and N2), i.e.

1120 data sets more than the database of physical models without intermediate observations in re-consolidation periods. An example of the computed constitutive relation in the location of a tensor is shown in Fig. 3.

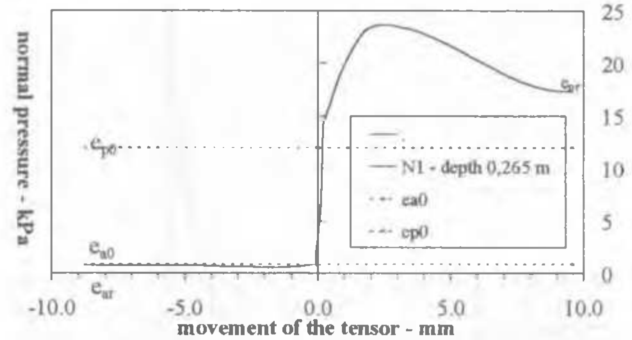

Figure 3. Numerical model N1 relation between the normal component of lateral pressure and the structure rare face point in the depth of 0.265 m, resp. in the location of the tensor no.2.

5.3 *Small passive and full active rotation about the toe*

For the purpose of comparative analysis the compressive normal *stresses* applied to the tensors were computed on the basis of measured compressive *forces* of individual tensors. The history of the computed stresses in places of all tensors during experiment N1 is presented in Fig. 4. The measured compressive *stresses* in places of the individual tensors no.2 and 4 are shown in the diagrams in Figs. 5 by the lines marked E1. Therefore, their values do not agree with the measured values of compressive *forces* shown in the diagrams of the previously published results of E1 experiment. The lines characterizing the results of numerical model are marked N1. The maximal movements of the top were considered of +0,2 mm (passive side) and –8,75 mm (active side) like the experiment E1 had been carried out.

The results of numerical models could be processed, like those physical model, in relation to the movements of the decisive points of the wall with the maximum movement values or in relation to the relative movements of the wall, which is the same in this particular case. In previous publications, however, it was shown that that procedure did not correspond with the actual behaviour of the soil mass too well. For this reason and for better application to theoretical considerations the diagrams are based on the movements of the individual tensors (absolute values of the movements).

6 CONCLUSIONS

6.1 *Pressure at rest*

a) The magnitude of pressures measured in E1 or E2 experiments during the movements on the passive (positive) side did not exceed the values of passive pressure at rest even at the rotation of the top of the wall of some 0.2 mm (E1) or during the translative motion of some 0.5 mm.
b) The agreement of the numerical model N1 with the physical model E1 appears very good, if we consider the lower sensitivity of Nos. 3 and 5 tensors (depth 0.465 m and 0.885 m). The gradients of the lines are practically corresponding.

6.2 *Rotation about the toe*

It is obvious that the respective lines proceed almost parallelly and with the above mentioned reservation the differences in values are not great, either (see Fig.5). The differences could be ascertained at closer inspection in the values of displacements of extreme active pressure (peak pressure) which took place in physical experiments near the area at rest. Taking into account the initial deviations of No.1 tensor in E1, Nos. 4 and 5 in N1 and the sensitivity of individual tensors the agreement of numerical models with reference to both history and values can be assessed as very good.

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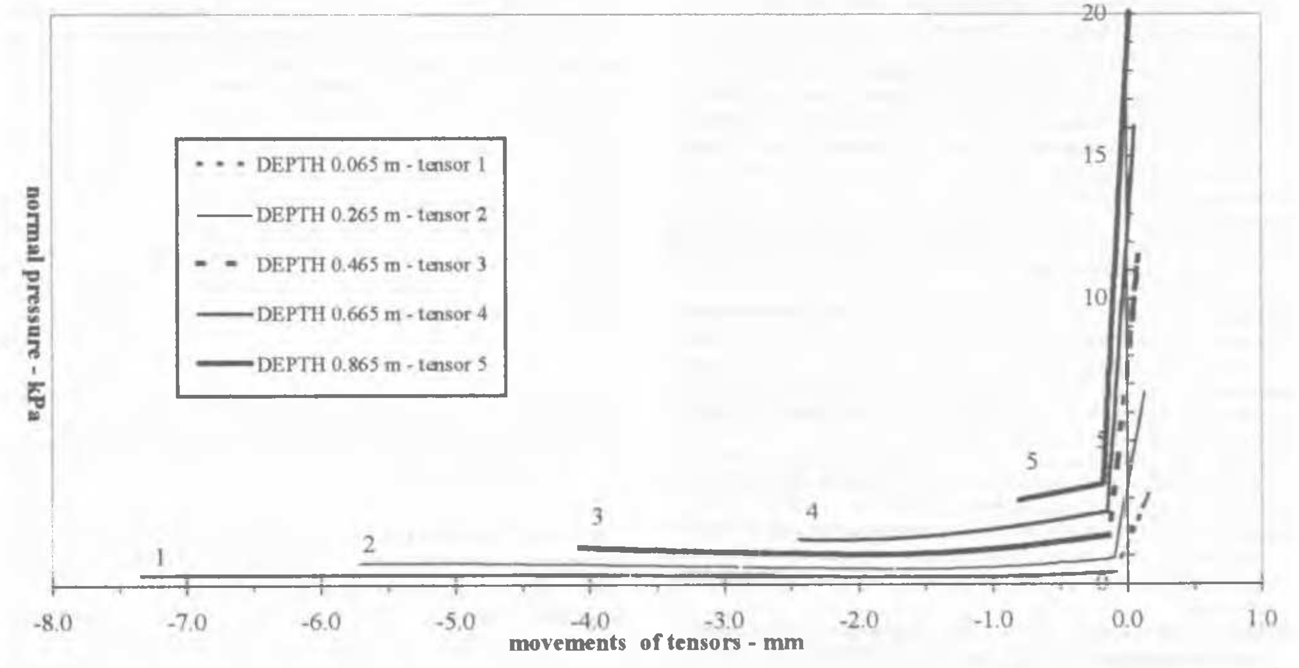

Figure 4. The history of the computed stresses in places of all tensors during experiment N1 (phase 0 – pressure at rest, phase 1 – rotation about the toe). Positive (passive) movements are towards into the mass, negative (active) ones towards out of the mass.

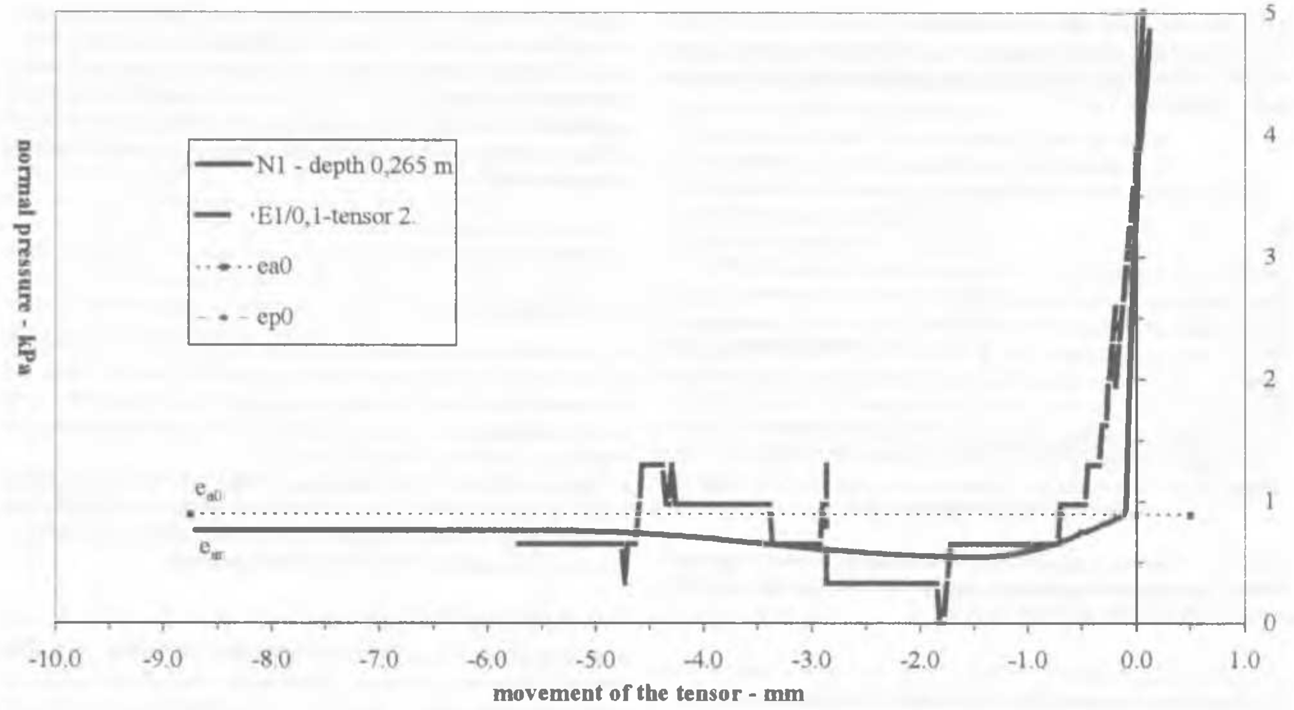

Figure 5. Measured (E1) and numerical (N1) relations between the retaining wall movement in the depth of 0.265 m and the normal component of lateral pressure. Relation is according to tensor No.2.

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