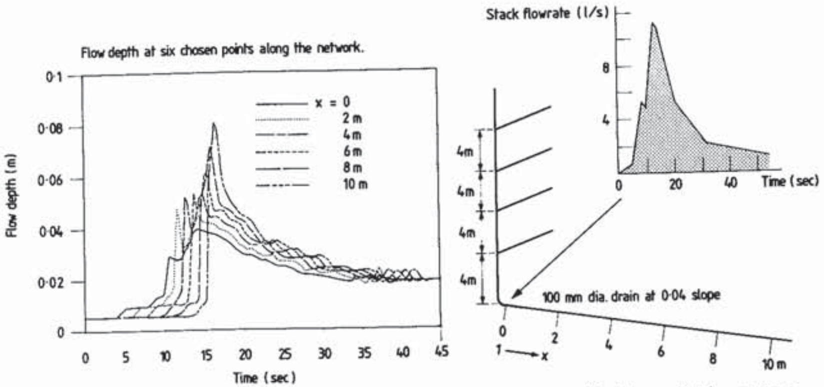

Figure 4 Application of the computer model to the prediction of the surge capacity of a building collection drain serving a 4 storey vertical stack.

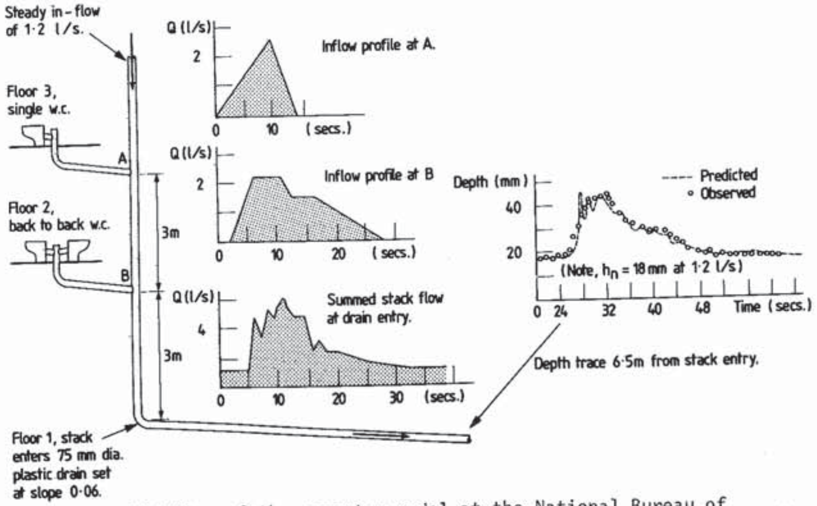

Figure 5 Validation of the computer model at the National Bureau of Standards, Centre for Building Technology, plumbing tower facility.

Computer Aided Design of Time Depending Structure-Soil Interaction

Ludvik Trauner

University of Maribor
Faculty of Technical Sciences
62000 Maribor, Yugoslavia

KEYWORDS

Geomechanics, Structure-Soil Interaction, Non-linear, Time Dependant, Deformation Analysis.

ABSTRACT

The paper presents graphical interpretation of non-linear time dependant interaction between elastic structure and high flexible non-homogeneous (layered) soil. The use of program has been shown on space reinforced concrete frame structure on a layered halfspace.

Time dependant displacements were evaluated successively by computer as to load path and the consolidation process in soil of viscous unequal thickness clay layers on a rock basis. The program uses deterministic analysis on a theoretical Kelvin´s rheological model. An incremental iterative method is used: skeleton structure is presented by linear finite elements but the soil is described using analytical function defining non-linear and time dependant relations. Rheological soil characteristics were determined with slow, drained triaxial tests and monotonouosly increasing (decreasing) load.

A graphic simulation of structural displacements during the construction and after it has been built up enables better, faster, more economical design and higher safety in everyday engineering practice.

CONCEPTION INFORMATISÉE DE L´INTERACTION CONSTRUCTION-SOL DÉPENDANT DU TEMPS

Ludvik Trauner

L´Université de Maribor
Faculté des Sciences Techniques
62000 Maribor, Yugoslavie

MOTS-CLÉS

Géoméchanique, Interaction construction-sol, Non-linéaire, Analyse des déformations, Dépendant du temps.

SOMMAIRE

L´article présente l´interprétation graphique de l´interaction non-linéaire dépendant du temps entre une construction élastique et un sol non-homogène (avec des couches) de haute flexibilité. L´applicabilité du programme est démontrée sur une construction 3-dimensionelle à squelette en béton armé fondée sur des couches demi espace. Les déplacements dépendant du temps ont été successivement évalués a l´aide de l´ordinateur; il s´agit du chemin de la charge et du procès de la consolidation dans le sol consistant des couches d´argile visqueuse d´épaisseur inégale reposant sur une base rocheuse. Le programme utilise l´analyse déterministe suivant le modèle théorique et rhéologique de Kelvin. Une méthode incrémentale et itérative est employée: la construction à squelette est presentée au moyen des éléments finis linéaires, mais le sol est décrit par la fonction analytique qui définit les rélations non-linéaires et dépendantes du temps. Les caractéristiques rhéologiques du sol ont été determinées par des épreuves 3-axiales sur des échantillons chargés d´une manière monotone croissante et décroissante. Ces expériments sont lents et drainés.
La conception informatisée des déplacements de la construction pendant la construction et après celle-là nous permet de mieux projeter et en même temps de projeter d´une manière plus rapide, plus sûre, et plus économique. Tout cela est très important en pratique quotidienne des ingénieurs.

INTRODUCTION

We are dealing with several practical cases of structure-soil interaction where a dependence between structure and soil can be given with uneven loading on the structure and with non-linear rheological soil characteristics. A numerical solution is given by levelling layered soil and structural foundation displacements[3]:

$$d\rho_r = A_r \, dQ_r - I \, dU_{or} = S_r \, (dP_r - dQ_r) \tag{1}$$

where A_r represents a soil flexibility matrix, I is a unit matrix, S_r is a structure flexibility matrix and dQ_r dU_{or}, $d\rho_r$, dP_r represents vectors of increments of unknown foundation contact pressure, translation and rotation of foundation contact surface, foundation relative displacements, and structure loads respectively.
A stress-strain relationship is in general non-linear but in addition a viscous flow has to be taken into account at unchanged stress state. Previous studies[3-5] determined rheological dependencies for coherent soils on the basis of slow, drained triaxial test with monotonuously increasing load.

A non-linear and time dependant relationship for soils in the range of secondary consolidation branches is given by analytical expressions in a form of elastic-viscoplastic model. This solution enables sufficiently exact analytical determination of stress-strain state for practical engineering problems, i.e. where primary hidrodynamic effects can be neglected.

The paper presents calculation and graphic interpretation of the non-linear time dependant interaction between elastic structure (skeleton) and highly flexibile layered soils. The incremental concept has been taken into account with monotonously changing load and experimentally determined rheological relations for soils in the form of a non-linear Kelvin´s model[2] and well-know Hook´s model for structure.

Rheological relationships for soils

On the basis of slow, drained and monotonously loaded and unloaded triaxial tests, one can determine volumetric dilatation $\varepsilon_v^{(e)}$, axial strain ε_1 and their corresponding elastic components $\varepsilon_v^{(e)}$, $\varepsilon_1^{(e)}$. Strains ε_v, ε_1, $\varepsilon_v^{(e)}$ and $\varepsilon_1^{(e)}$ can be divided into spheric, distortional and viscous components, which are expressed analyticaly[4] by stress invariants:

$$p = \sigma'_{ii}/3,\quad q = \{(3/2)S'_{ij}S'_{ij}\}^{1/2},\quad S_{ij} = \sigma'_{ij} - \delta_{ij}\sigma_{kk} \qquad (2),(3),(4)$$

where σ'_{ij} means effective stress tensor and δ_{ij} is Kronecker symbol. Subtracting corresponding elastic $(\varepsilon^{(e)})$ and viscous $(\varepsilon^{(v)})$ components from ε_v an ε_1, one can get plastic strains: $\varepsilon_v^{(p)}$ and $\varepsilon_1^{(p)}$.

In general the strain tensor consists of 36 constants, determined experimentally. Due to the elimination of some constants[3] the solution can rapidly deduce[1] to Sekiguchi (1977), Shibata (1963) or Roscoe (1963) models.

The stress and displacement increments calculation

If a contact pressure dQ_r is continuous and smooth and applied on polygonally shaped foundation contact surface S_k (k being a number of discrete surface) to a non-homogeneous soil halfspace with known stress and time depandant spheric (K_r) and distortion (G_r) deformational modul at each point i then stress and displacement can be determined at these points using the following equations[4]:

$$(d\sigma_{mn})_r = \iint_{S_k} f_\sigma(x,y,z,dQ_r,K_r^{(ep)},\ G_r^{(ep)})\,dS \qquad (5)$$

$$(du_m)_r = (du_m^{(ep)})_r + (du_m^{(v)})_r \qquad (6)$$

$$(du_m^{(ep)})_r = \int_m\iint_{S_k} f_u(x,y,z,dQ_r,K_r^{(ep)},\ G_r^{(ep)})\,dm\,dS \qquad (7)$$

$$(du_m^{(v)})_r = \int_m f_{u*}(x,y,z,p_{r-1},q_{r-1},\dot{p}_r,\dot{q}_r,\ K_r^{(v)},\ G_r^{(v)})\,dm\,dt \qquad (8)$$

where $\dot{p}_r = dp_r/dt_r$ and $\dot{q}_r = dq_r/dt_r$ are velocities of stress invariants p_r and q_r at a relative time t_r^*.

An iterative calculation on incremental basis

At r-th incremental step using known load (dP_r) and time (dt_r) increments we can evaluate load P_r at relative time t_r^*. If we suppose that load velocity $\dot{P}_r$ equals stress velocity $\dot{\sigma}_r$ at all joints i of a halfspace we get the following:

$$\dot{P}_r = dP_r/dt_r = \dot{Q}_r = \dot{p}_r = \dot{q}_r \qquad (9)$$

The calculation is performed in two successive iteration loops[4]: in the first loop we solve elastic and plastic relations between structure and soil while in the second a viscous (i.e. time dependant) relation of soil consolidation is evaluated.
The iteration loop is repeated using equations (1), where matrix A_r and incremental vector of foundation relative displacement $d\rho_r$ are changing, until the following conditions are satisfied:

$$dQ_r = dQ_{r,\theta} = dQ_{r,\theta-1} + \delta Q_r \qquad (10)$$

where $\theta = 1,2,3,\ \ldots,\ n$ represents iteration cyclus and δQ_r takes desirable small value.
After the iteration the following values are known: dQ_r, K_r and G_r (or A_r). Substituting these values into Eq. (5) or (8), using Eq. (9) we get at first the stress increments $(d\sigma_r)$, displacements (du_r) and finally we find stress-displacement state using:

$$\sigma_r = \sigma_{r-1} + d\sigma_r,\quad u_r = u_{r-1} + du_r,\quad Q_r = Q_{r-1} + dQ_r \qquad (11),(12),(13)$$

NUMERICAL EXAMPLE

The computer program was written by M. Jeler on the basis of the above equations. The test was performed on the example shown in Fig. 1, Fig. 2, Table I. and Table II. Triaxial Tests of constituents were performed in the laboratory (See Ref. 3 and 4).

The space frame structure of reinforced concrete with rectangular shaped foundation is founded 1m under the ground level. The load P_r is continuous at the upper level of the structure and time increasing to the final value within 18.5 monts. (The program allows also any non-continuous load as applied in practice).

Fig. 3 shows few sensitive results of the numerical analysis: foundation settlements and frame displacements.

DISCUSSION

Numerical calculations using finite element methods for space problems tend to be too expensive considering non linear and time dependant constitutive laws (owing to wide, high compressibility and non homogeneous soil halfspace).

The paper presents joint solution of structure-soil interaction given by a numerical method for structure and analytical functions (based on experiments) for soil,which in practice design is sufficiently exact and economical.The given solution is straightforwardly applicable for the determination of foundation settlements and stress-deformation state of structure.

ACKNOWLENGEMENT

The author wishes to thank Mr. S. Škrabl, Mr. D. Rebolj and Mr. M. Jeler (University of Maribor) for elaborating the numerical example. The study was financially supported by the Research Council of Slovenia (Raziskovalna skupnost Slovenije).

REFERENCES

1. H. Sekiguchi, "Rheological Characteristics of Clays", Proc. 9 th Int. Conf. Soil Mech. Found. Eng., (Japanese Soc. Soil Mech. Found. Eng., Tokyo, 1977), Vol. 1, 59., pp.289-292.
2. M. Saje, I. Kovačič and L. Šuklje, "Joint Solution of Diffusion and Equilibrium Equations for Non-Linear Viscous Soils", Acta Geotechnica 81-85 (81), pp. 321-337, (1982).
3. L. Trauner, "Uporabnost teorije elastičnosti pri projektiranju temeljev (The Use of Theory of Elasticity in Foundation Design, PhD)",Doktorska Disertacija, (E. Kardelje University in Ljubljana, 1982), p. 115.
4. L. Trauner, "The Flexibility Matrices for Non-Linear Viscous Soils", Proc. 16 th Jugoslav Cong.Theoret. Appl. Mech. (Nat. Soc. Mech., Bečiči,1984), Vol. 307, pp. 401 - 408 .
5. L. Trauner, "Sovisnost med objektom in tlemi (Structure-Soil interaction)", Report on Research work, (Research Council of Slovenia, Ljubljana, 1982/83/84/85) C2-0138/797, p. 67/49/ 33/44.

Table I. Time dependant loading data for skeleton structure

Relative time		Increments of time		load		Total load	
t^*_r	(days)	dt_r	(days)	dP_r	(kN)	P_r	(kN)
t^*_o	1	dt_1	36	dP_1	200	P_o	0
t^*_1	36	dt_2	102	dP_2	200	P_1	200
t^*_2	138	dt_3	204	dP_3	200	P_2	400
t^*_3	342	dt_4	213	dP_4	200	P_3	600
t^*_4	555					P_4	800

Table II. Basic physical soil characteristics.

Clay[a]	Characteristics Symbol[b]									
	w (%)	w_L (%)	w_p (%)	γ_s	γ (kN/m^3)	e (%)	S_r (%)	k (cm/s)	c' kPa	ϕ' (^{o})
CI	29	39	21	27	20	80	96	$3x10^{-9}$	36	18
CH	60	60	35	17	18	100	100	$2x10^{-9}$	0	21

[a] AC classification.

[b] ISSMFE classification.

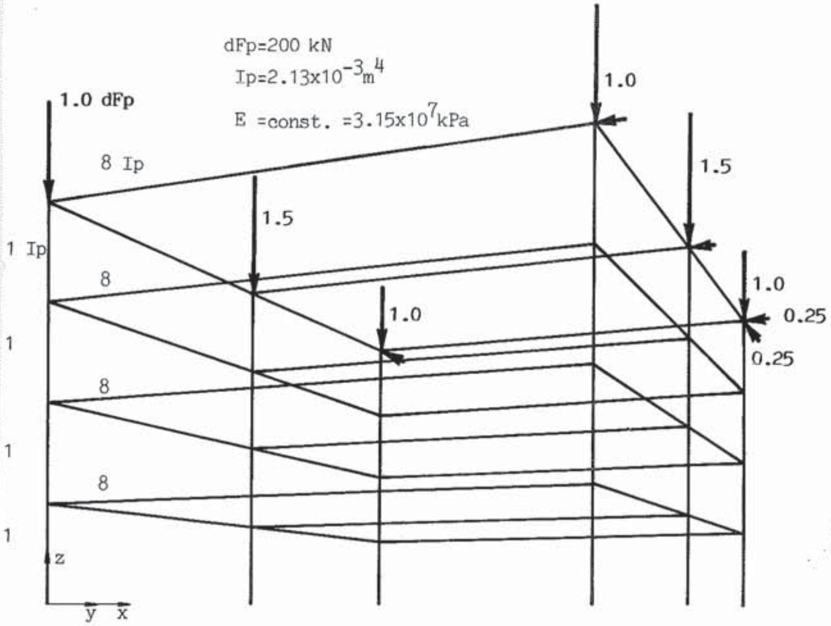

Fig. 1 Geometrical (See Fig. 2), physical and loading data for skeleton structure.

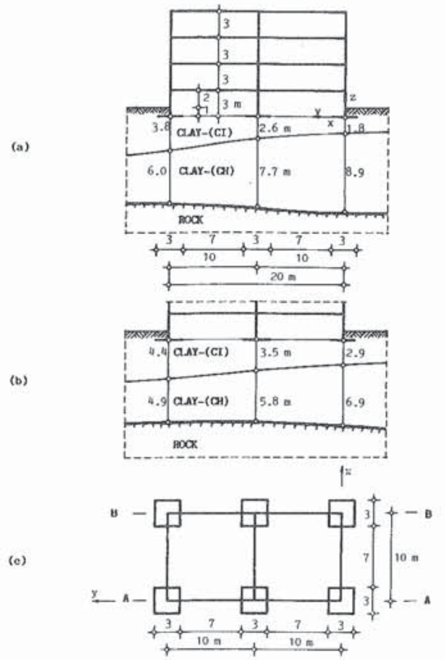

Fig. 2 Stratigraphical data and basic physical characteristics of non-homogenous soil halfspace (See Table II.).

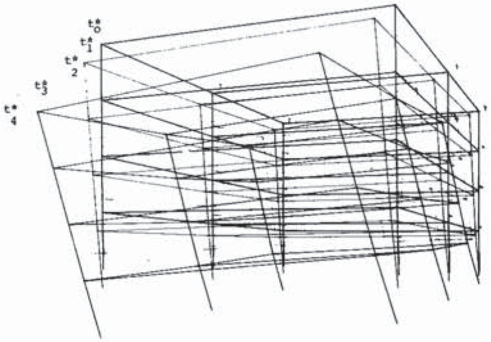

Fig. 3 Time (t^*_r) and load (P_r) dependant (See Table I.) displacements and settlements (increased 15 times) of skeleton structure.

User experience of MICROPAS, SERI-RES and DEROB - similarities, problems and comparisons

I.S. van der Werff and M.R. Donn

Energy Research Group
School of Architecture
Victoria University of Wellington
Private Bag, Wellington
New Zealand

KEYWORDS

MICROPAS, SERI-RES, DEROB, Passive solar, Residential Buildings, Computer Simulation.

ABSTRACT

As of late 1983 the Energy Research Group has been a participant in Task VIII of the International Energy Agency's (IEA) Solar Heating and Cooling Program. The objective of Task VIII is to accelerate the development and use of Passive and Hybrid Solar Low Energy Buildings. With this objective in mind, the authors have been both evaluating, and performing parametric studies with, thermal simulation computer models. The major part of this work has involved the two computer programs MICROPAS and SERI-RES, although some work has been carried out on DEROB V1.0 - IUA. While working with these programs, we have paid particular attention to the completeness of the documentation, and the ease of understanding of the input requirements. Similarities and differences between these programs are documented, and the thermal performance of buildings as predicted by these programs are compared. From the point of view of a New Zealand user, MICROPAS is inadequate, predominantly due to the fact that it can only use imperial units. The input requirements of DEROB are relatively complicated, due to the graphics facilities available. SERI-RES appeared to be the most user-friendly program of the three.