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LOOKING INTO AN APPROPRIATE METHODOLOGY FOR THE EMBANKMENT DESIGN AND CONSTRUCTION ON SOFT SOILS

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ABSTRACT: The difficulty of simulating real field behavior during design stage causes construction difficulties that could not be foreseen for the embankments on soft clays. Although observational method seems to be the only tool to overcome these problems, the conventional observational methods suffer from the time lags between parameter revision and next stage of construction. New methodologies are needed which provide direct links between measurements and adjustment of parameters. The Oztoprak & Cinicioglu method is a modern version of the observational method for embankments on soft clays. In this paper, the applications and outcomes of this method on the two embankments; Cubzac-les-Ponts and Stanstead Abbotts, were outlined and compared with the findings by the application of two FE softwares; the Sage Crisp and Plaxis. These comparisons should be interpreted as the comparison of real behavior and highly effective prediction tools. The results indicated the incomparable effectiveness of the field measurements based approach but this does not imply that prediction methods should be overlooked, instead their capacities should be enhanced by the information gained through real nature of field behavior.

Keywords: Embankment, soft clay, real field behavior, instrumentation, observational method, prediction methods

INTRODUCTION

The presence of thick deposits of soft clays is the main cause of the problems encountered in relation to the design and construction of embankments. However, the problem is mainly due to the difficulty in simulating the real field behavior at the design stage. Appropriate soil model and parameter selection are the crucial factors that affect the outcome from the finite element prediction methods. It is well known, however, field behavior deviates from the predicted behavior and there is a continual change in the parameters as construction proceeds. Reasons are several, among these strain rate effect may be pronounced as the most typical for soft clays. The research presented in this paper aims to provide a comparison of the outcomes from a field behavior based method (Oztoprak & Cinicioglu method) and two different finite element prediction methods; Sage Crisp v4.0 and Plaxis v8.0.

The method by Oztoprak & Cinicioglu (2005) can be accounted for as a modern version of observational method because it involves a design philosophy which eliminates time lags between measurements and parameter revision. Moreover, the process is not really a parameter revision type, but the method inherits the property that the parameters take their due values as measured deformations and excess pore water pressures were fed into the method without a need for a back calculation process. Since, the method uses field measurements as the direct inputs to the framework of the constitutive behavior, the field behavior can be followed in terms of stress paths as construction proceeds. Therefore, the Oztoprak & Cinicioglu method gives a unique opportunity to compare the real field behavior with what would be found with the prediction methods. This is expected to supply information to enhance the possibilities of the prediction methods. For this purpose the method by Oztoprak & Cinicioglu were applied on two well documented case histories namely; Cubzac-les-Ponts and Stanstead Abbotts (Willow Plantation or Harlow) embankments. The stress paths thus obtained were then compared with the stress paths found by applying Sage Crisp and Plaxis on the same two embankments. Changing state of behavior in different locations in the foundation soils could be accounted for by applying a zonation system. The results gave a clear indication of the difficulties of predicting field behavior and advantages of the field based approach which incorporates design with construction.

BASIC FEATURES OF THE METHODOLOGY

The Oztoprak and Cinicioglu (2005) method follows the soil behaviour in the shear stress (q), mean effective stress (p′) and specific volume (v) space. The values of q and p′ are interrelated by the coefficient of lateral earth pressure (K) at any non-failing stress state:

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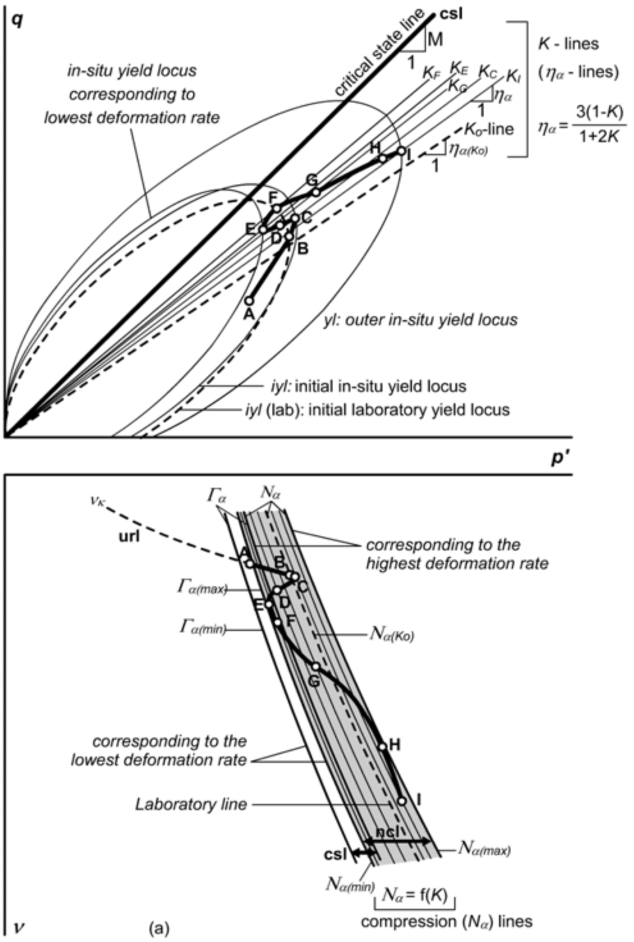

Fig. 1 Schematic representation of the method

$$q = \sigma'_v - \sigma'_h = \sigma'_v(1-K) \tag{1}$$

$$p' = (\sigma'_v + 2\sigma'_h)/3 = \sigma'_v(1+2K)/3 \tag{2}$$

Below are the equations to find K values as a function of minor to major principal strain ratios ($\varepsilon_3/\varepsilon_1$) as given by Zhang et al. (1998):

$$R = \begin{cases} R_\varepsilon & (K \le 1, \textit{Active States}) \\ 2 - R_\varepsilon & (K \ge 1, \textit{Passive States}) \end{cases} ; \quad R_\varepsilon = \frac{\Delta\varepsilon_3}{\Delta\varepsilon_1} \tag{3}$$

$$K = \frac{1-\sin\phi'}{1-\sin\phi' \cdot R} \qquad (-1 \le R \le 1) \tag{4}$$

$$K = 1 + \frac{\sin\phi'}{1-\sin\phi'}(R-1) \qquad (1 \le R \le 3) \tag{5}$$

Effective vertical stress, σ'_v was calculated as $\sigma'_v = \sigma'_{vo} + L - u'$ where L is the surcharge load and u′ is excess pore water pressure. To construct the stress path, v values should also be determined. For this purpose $\Delta v/v = \Delta V/V$ correlation was adopted to find specific volumes in relation to the measured changes in the volume, V of a zone. ΔV was calculated by using the measured displacements at the corners of each zone.

Anisotropic elastoplastic soil model was accommodated in the q-p′-v stress-strain space in order to analyse the behaviour in the context of the constitutive theory and to provide direct links between measurements and design parameters. Schematic representation of the method is given in Fig. 1 which demonstrates the stress-strain paths in q-p′ and v-p′ planes. The implications of time dependency and anisotropy can be observed in terms of differing laboratory and in situ yield loci or rotating yield envelopes in Fig. 1. The problem of stress axis rotation which is a result of the geometry of embankment problem can also be dealt with the method.

APPLICATIONS OF THE METHODOLOGY

Selected Real Embankments

The Oztoprak & Cinicioglu method was applied on two different real embankments; the Cubzac-les-Ponts and Stanstead Abbotts. Both are fully instrumented, built on soft soils and field measurements are available in the literature. The main difference is in the drainage possibilities, since vertical band drains were installed in the Stanstead Abbotts case. This difference is crucial to interpret the influence of drainage possibilities on the implications of time dependency. Mainly, three types of analyses were applied for the two cases; the Oztoprak & Cinicioglu, Sage Crisp and Plaxis. Modified Cam Clay (MCC) model with consolidation analysis was selected to conduct the Sage Crisp and Soft Soil Creep (SSC) model with undrained analysis for the Plaxis. Parameters used by the Oztoprak & Cinicioglu method, the Sage Crisp and the Plaxis analyses were displayed in Tables 1 2, 3 and 4. As seen in Tables 1 and 3, entry parameters are almost common in all three of the methods. However, the stress paths found by each of these methods have big discrepancies both in terms of the respective stress states and in view of the progression.

It is thus clear that, what causes the differentiation is the way the parameters are redefined as construction proceeds and soil conditions change. The Oztoprak & Cinicioglu method provides direct links between any deformation state (found by field measurements) and stress state. As a result, parameters take their due values corresponding to any soil state automatically. This is very difficult to achieve with the prediction methods which conduct a learned process that may considerably deviate from field behavior. The observational method (Peck, 1969) was proposed for providing the required remedy to control the parameter revision during construction. Conventional observational methods have proven success to improve the application but they suffer from time lags since revised parameters fed for a succeeding stage are actually the parameters corresponding to a previous stage. Moreover, parameter revision is a cumbersome process and knowing the combined effect it is almost impossible to find any uncoupled effect of each parameter.

A further investigation was carried out in this study to find out the effect of parameter revision. The deviation between the in situ overconsolidation ratio, OCR_{insitu} and laboratory OCR found by 24 hour multistage loading in oedometer (MSL_{24}) tests was one of the causes in the big discrepancy of the resulting stress paths. Differing values of coefficient of permeability, k may be the other important influential factor. Both of the FE analyses were conducted again once with revised 'k' in Tables 1 and 3 and the other time with the revised 'OCR' ($OCR_{in\ situ}$) in Tables 2 and 4 in order to find the uncoupled effects of each of these parameters. $OCR_{in\ situ}$ concept was discussed in Oztoprak and Cinicioglu (2006). The information related to the revision of these two parameters was gained by the application of the Oztoprak and Cinicioglu method on the same two cases. Following are some information about the embankments and the results of the analyses. Cubzac-les-Ponts test embankment B was built with a safety factor of 1.5 on viscoplastic clays in six days (with a height of 2.3 m) and monitored for a long time reaching up to 2000 days. Soil conditions at Cubzac-les-Ponts and the zonation system used for the method were outlined in Fig. 2a. The construction history and selected dates to apply the Oztoprak and Cinicioglu method and FE analysis were given in Fig. 2b.

Stanstead Abbotts embankment was constructed on very soft alluvial deposites with drains in 1988. The embankment was built to 8.05 m. in 274 days. Soil conditions at Stanstead Abbotts and the zonation system were outlined in Fig. 3a. The construction history and selected dates to apply the Oztoprak and Cinicioglu method and FE analysis were given in Fig. 3b. As seen in soil profile and properties beneath the embankment were defined in Table 3. Very soft peat layer of 3.0 meters exists beneath the embankment. The embankment was reported with no evidence of failure.

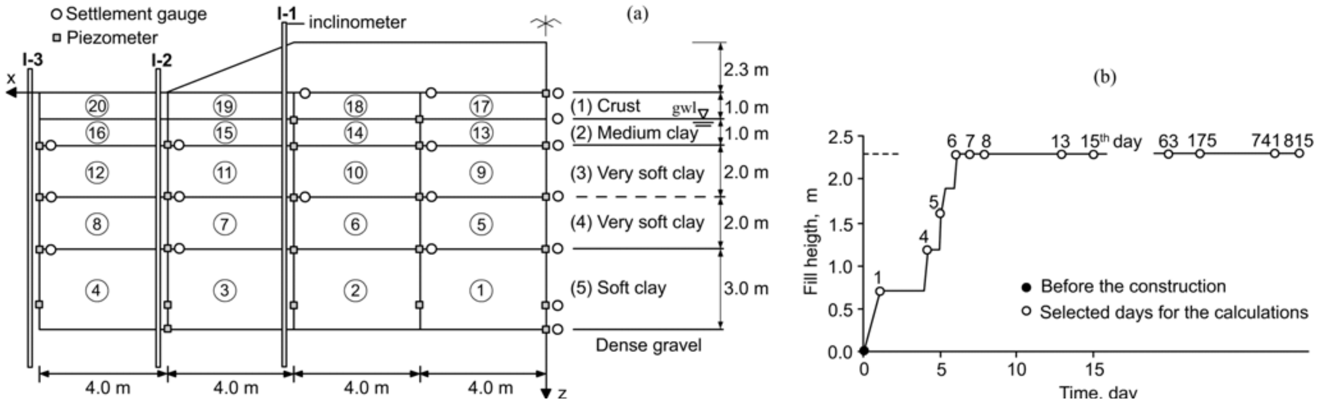

Fig. 2 Cubzac-les-Ponts embankment (a) Zonation system according to the soils and instrumentation, (b) Construction history

Table 1 Soil parameters used by the Oztoprak & Cinicioglu method and FE analysis for Cubzac-les-Ponts embankment

		Wood, 1990			*Magnan et al., 1983*		*this study (revised)*		*Wood, 1990*					*transformed from Wood, 1990*			
Soil	Depth *m*	γ *kN/m³*	e_o	OCR (++)	k_x *m/sec*	k_x *m/sec*	k_x *m/sec*	k_y *m/sec*	κ	λ	e_{cs}	*M*	*G* *kN/m³*	λ^*	κ^*	μ^* (+)	ϕ' *°*
(1)	0.0-1.0	17.0	1.0	8.82	4.6E-10	4.6E-10	4.5E-08	4.5E-08	0.017	0.120	1.37	1.29	930	0.060	0.0085	0.0003	32
(2)	1.0-2.0	15.0	2.6	2.99	1.4E-09	1.4E-09	6.0E-08	3.0E-09	0.022	0.530	4.19	1.16	1670	0.147	0.0061	0.0022	29
(3)	2.0-4.0	14.0	3.2	1.46	2.6E-09	2.6E-09	3.0E-09	1.5E-09	0.085	0.750	5.22	1.03	400	0.179	0.0202	0.0080	26
(4)	4.0-6.0	15.0	2.25	1.22	1.5E-09	1.5E-09	1.5E-09	1.0E-09	0.048	0.530	3.74	1.03	670	0.163	0.0148	0.0067	26
(5)	6.0-9.0	15.0	2.3	1.20	1.5E-09	1.5E-09	1.5E-09	1.0E-09	0.043	0.520	3.91	1.03	1050	0.158	0.0130	0.0063	26

(+) Creep parameter μ* selected for this study ; (++) Interpolated from Magnan et al. (1983)

Table 2 OCR values used by the Oztoprak & Cinicioglu method and FE analysis for Cubzac-les-Ponts embankment ($OCR_{in\ situ}$ values are revised values for the FE analyses) (Oztoprak and Cinicioglu, 2006)

Zone No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
OCR	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.5	1.5	1.5	1.5	3.0	3.0	3.0	3.0	8.8	8.8	8.8	8.8
$OCR_{in\ situ}$	*1.2*	*1.2*	*1.1*	*1.0*	*1.3*	*1.3*	*1.1*	*1.0*	*1.3*	*1.3*	*1.1*	*1.0*	*1.5*	*1.5*	*1.3*	*1.0*	*3.4*	*3.4*	*2.6*	*1.1*

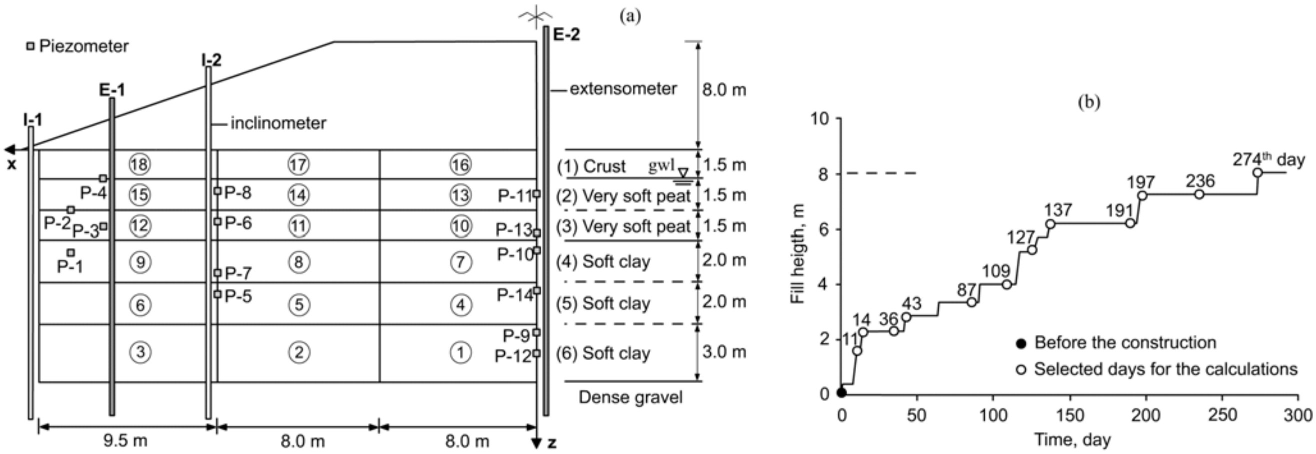

Fig. 3 Stanstead Abbotts embankment (a) Zonation system according to the soil properties and instrumentation, (b) Construction history

Table 3 Soil parameters used by the Oztoprak & Cinicioglu method and FE analysis for Stanstead Abbotts embankment

		Hird et al.,1995			*Hird et al.,1995*		*this study (revised)*		*Hird, 1993*					*Transformed from Hird, 1993*			
Soil	Depth m	γ kN/m^3	e_o	OCR	k_x m/sec	k_x m/sec	k_x m/sec	k_y m/sec	κ	λ	e_{cs}	M	υ	λ^*	κ^*	μ^* (+)	ϕ' °
(1)	0.0-1.5	16.0	0.80	7.58	2.5E-05	2.5E-05	1.0E-05	1.0E-05	0.035	0.190	1.8	1.16	0.22	0.060	0.009	0.001	29
(2)	1.5-3.0	11.4	7.30	2.20	2.5E-05	2.5E-05	1.0E-04	1.0E-04	0.450	2.290	15.5	1.38	0.14	0.147	0.006	0.003	34
(3)	3.0-4.5	11.4	8.20	1.31	2.5E-05	2.5E-05	1.0E-04	1.0E-04	0.470	2.390	15.5	1.38	0.14	0.179	0.020	0.007	34
(4)	4.5-6.5	16.2	1.50	1.09	2.5E-10	2.5E-10	1.0E-08	1.0E-08	0.045	0.220	2.2	1.12	0.30	0.163	0.015	0.007	28
(5)	6.5-8.5	16.2	1.45	1.02	2.5E-10	2.5E-10	1.0E-08	1.0E-08	0.039	0.205	2.2	1.12	0.30	0.158	0.013	0.006	28
(6)	8.5-11.5	16.2	1.40	1.02	2.5E-10	2.5E-10	1.0E-08	1.0E-08	0.035	0.190	2.2	1.12	0.30	0.060	0.009	0.001	28

(+) Creep parameter μ* selected for this study

Table 4 OCR values used by the Oztoprak & Cinicioglu method and FE analysis for Stanstead Abbotts embankment

Zone No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
OCR	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.3	1.3	1.3	2.2	2.2	2.2	7.6	7.6	7.6
$OCR_{in\ situ}$	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.1*	*1.1*	*1.1*	*1.3*	*1.3*	*1.1*	*1.5*	*1.5*	*1.3*	*4.5*	*4.5*	*3.4*

Stress-Strain Behavior and Stress Paths

In Cubzac-les-Ponts case, viscoplastic behavior is evident as observed in the erratic shapes of the effective vertical stress-vertical deformation relations and q-p′ stress paths found by Oztoprak & Cinicioglu method given in Figs. 4 and 5. Comparisons of field and laboratory vertical stress - vertical strain relations and stress paths with those from FE analyses are provided in the same figures. As seen in Figs. 4 and 5, stress paths found by FE analyses could not indicate the viscoplastic action. In the same sense, FE methods have difficulty changing type of behavior in different zones or differing drainage conditions at the early stages. In accordance with this, FE analyses gave the occurrence of lower safety factors in Cubzac-les-Ponts case.

In Stanstead Abbotts case Oztoprak & Cinicioglu method indicated that frictional behavior was more prevalent and viscoplastic action was less evident. Stress paths lie along the K_o axis. Therefore, there is not much change in the values of safety factor. Corresponding values of safety factors from FE analysis were higher. Comparisons of field and laboratory vertical stress – vertical strain relations with those from FE analyses at the foundation soil of Stanstead Abbotts embankment were given in Fig. 6. The corresponding stress paths on the q-p' plane were shown in Fig. 7. For both cases, when ‘OCR_{insitu}’ (revised ‘OCR’) was fed into the FE analyses, the stress paths shifted to the positions corresponding to field and effective stresses took more representative values. In the same way, with revised ‘k’ values the results were improved.

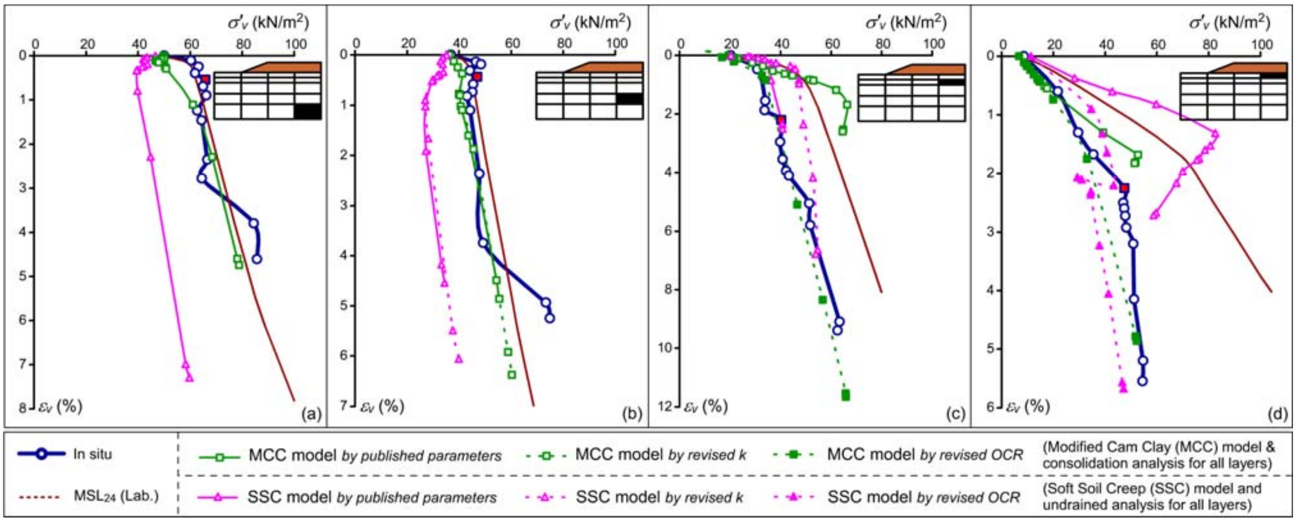

Fig. 4 Comparison of field and laboratory vertical stress – vertical strain relations with those from FE analyses at the foundation soil of Cubzac-les-Ponts Embankment

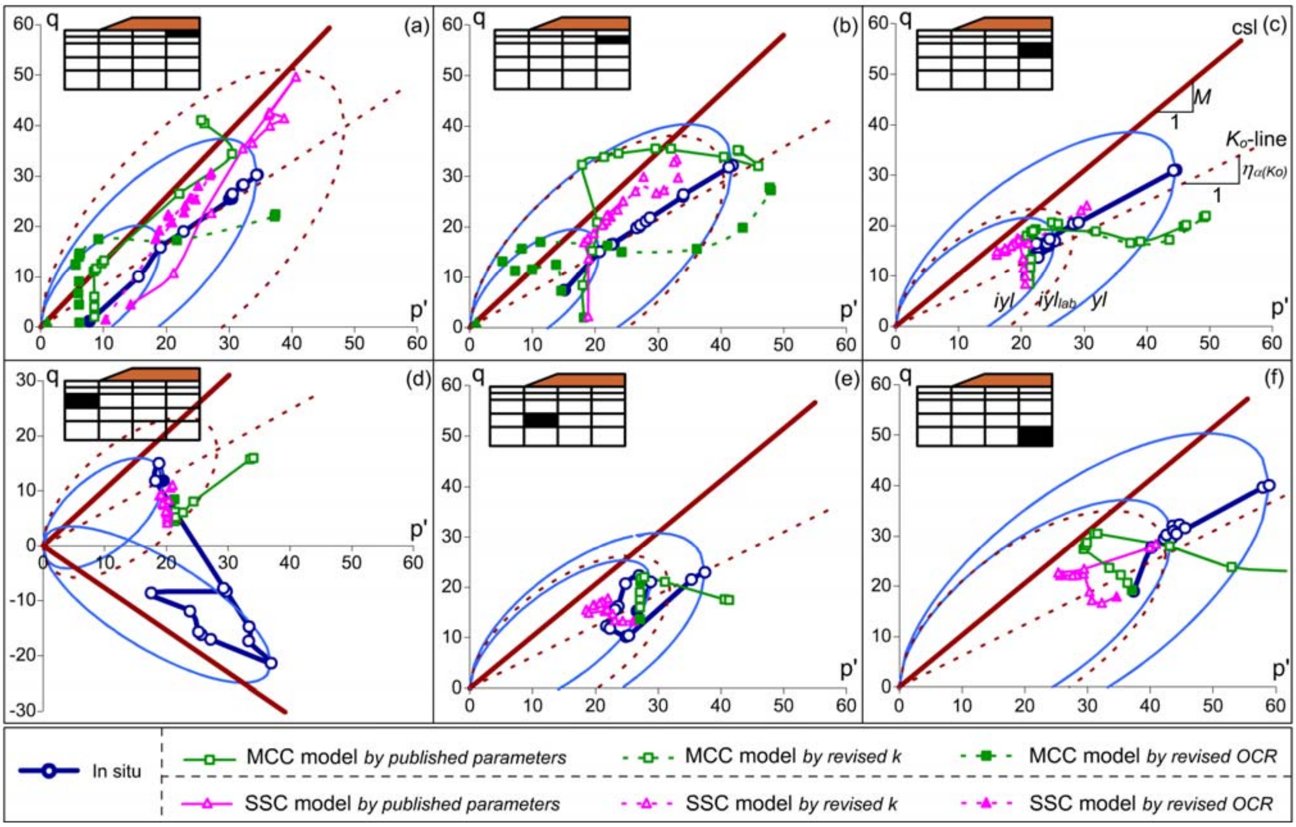

Fig. 5 Achieved stress paths by the Oztoprak & Cinicioglu method and calculated ones with FE analysis on the *q-p'* plane for various zones in the foundation soils of Cubzac-les-Ponts test embankment B (iyl, iyl_{lab}, yl, csl, and K_o-line are located by the Oztoprak & Cinicioglu method; iyl: initial in situ yield locus, iyl_{lab}: initial yield locus obtained from MSL_{24} test, yl: outer in situ yield locus)

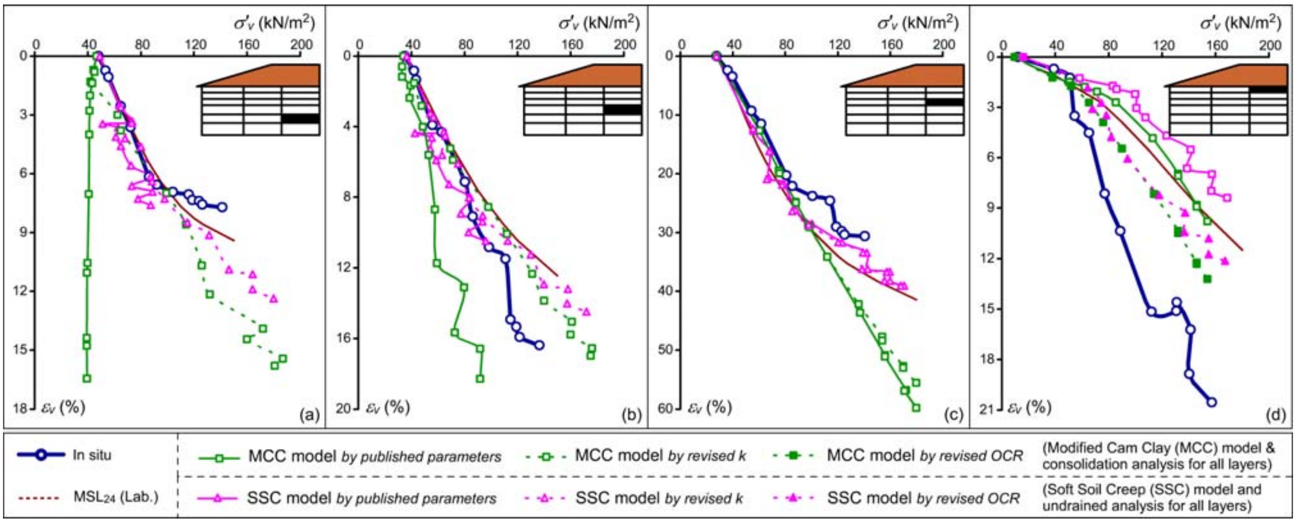

Fig. 6 Comparison of in situ and laboratory vertical stress – vertical strain relations with those FE analyses at the foundation soil of Stanstead Abbotts embankment

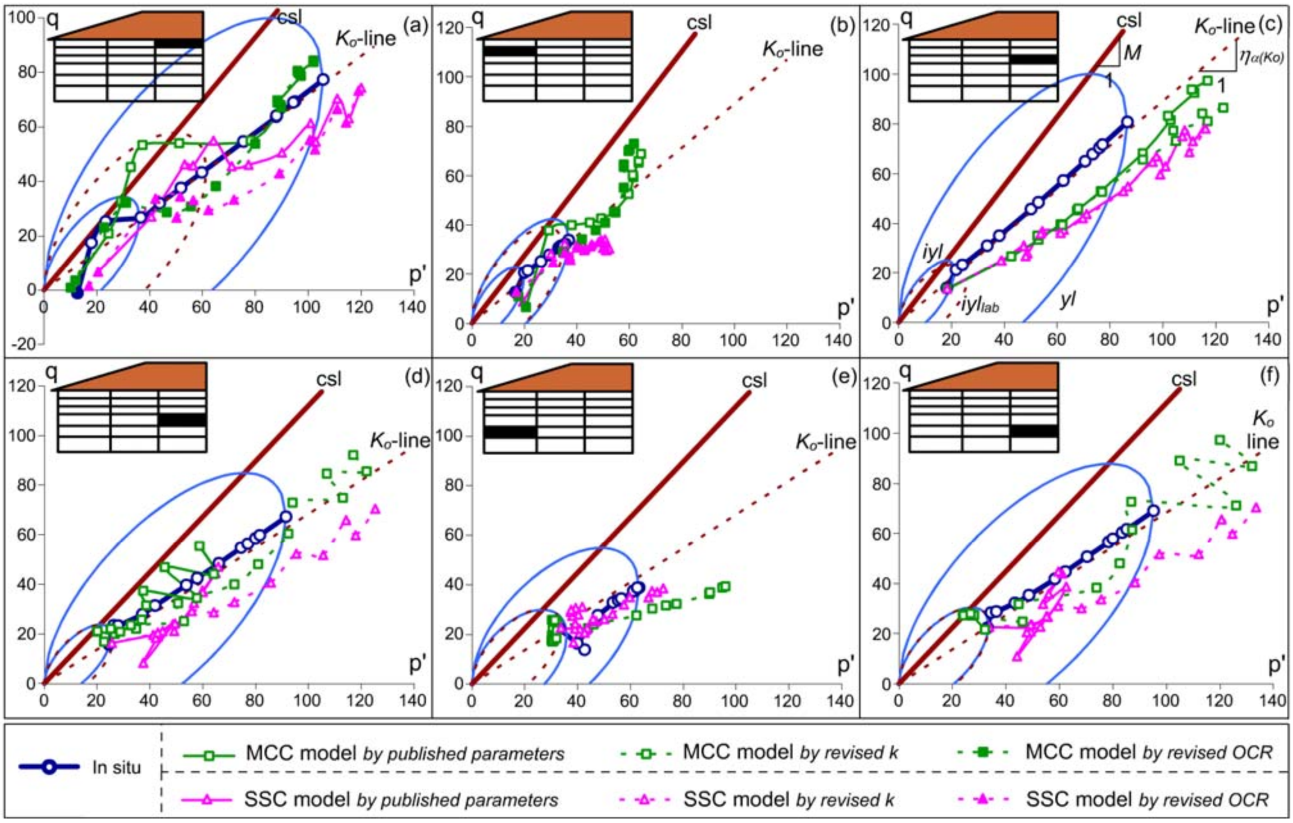

Fig. 7 Achieved stress paths by the Oztoprak & Cinicioglu method and calculated ones with FE analysis on the *q-p'* plane for various zones in the foundation soils of Stanstead Abbotts embankment (iyl, iyl_{lab}, yl, csl, and K_o-line are located by the Oztoprak & Cinicioglu method; iyl: initial in situ yield locus, iyl_{lab}: initial yield locus obtained from MSL_{24} test, yl: outer in situ yield locus)

Safety and Performance Evaluation

To evaluate the safety of zones $FS = M/n_\alpha$ equation can be used at any state on the yield surface. M value is chosen as M_c or M_e depending on the type of action of stresses; either compression or extension, n_α is the current stress ratio. Figs. 8 and 9 presents the FS values of zones for various days at Cubzac-les-Ponts and Stanstead embankments respectively. In the Figs. 8 and 9, shaded zones represent the lowest safety factors for the related row or column.

In Fig 8, the zonation system and the safety factors obtained for the 8th day which corresponds to one day after the completion of the construction stage are shown. As can be observed, they arbitrarily fall onto a slip line that could be used for a slope stability analysis. It is known that the Cubzac-les-Ponts embankment B was built with a safety factor of 1.50 using the know-how gained by the previous test embankment (embankment A) built at this site. The controlling value of the safety factor 1.50 found for the “Zone 7” is an indication of the effectiveness of the proposed method. It may be argued that in Fig. 12, the soil columns C-1, C-2, and C-4 and the soil rows S-3 and S-4 are of more concern in terms of the stability.

For the short term stability of Stanstead embankment, clay layer beneath the peat layer has lowest FS, however, for the long term, peat and clay layers show the same stability level. At day 274, it is noticeable that FS values of all zones approach to each other. This stability pattern reveals the drained behavior of embankment.

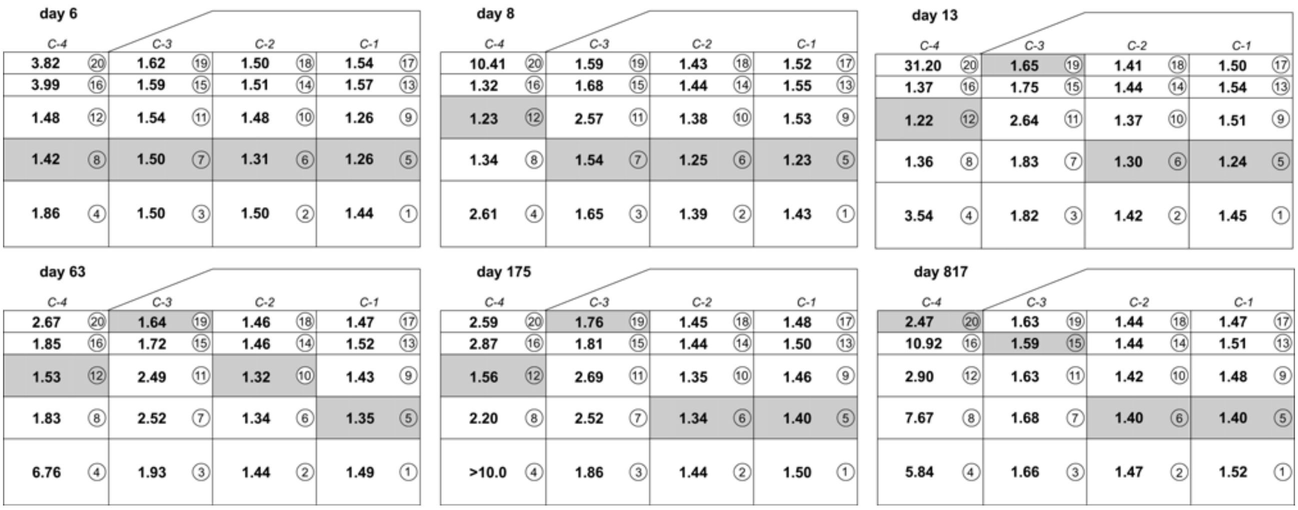

Fig. 8 Safety factors of the soil zones of Cubzac-les-Ponts test embankment B obtained with the Oztoprak & Cinicioglu method at different days (shaded zones have the minimum safety factors of the corresponding soil column)

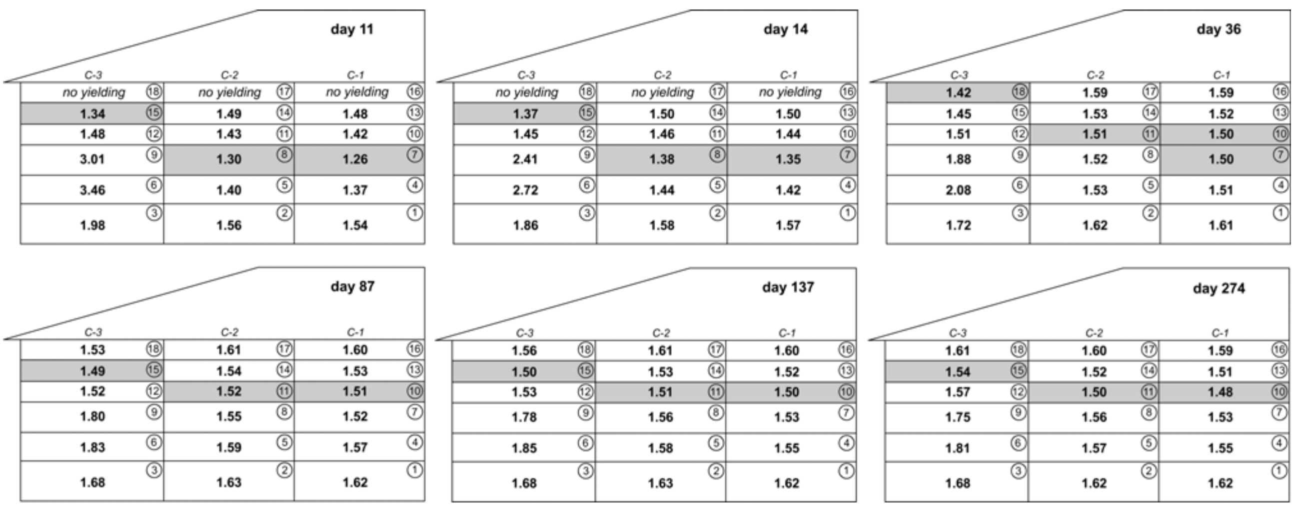

Fig. 9 Safety factors of the soil zones of Stanstead Abbotts Embankment obtained with the Oztoprak & Cinicioglu method at different days (shaded zones have the minimum safety factors of the corresponding soil column)

Taking care of economics and reliability, 5 or 6 zones may suffice to control safety and performance requirements. The zones which are associated with the greatest risk of failure can be conceived according to the prevailing conditions in the field.

CONCLUSIONS

Embankment design and construction are associated with ambiguities and difficulties in the cases where thick deposits of soft clays are present. Regarding the need for an appropriate methodology the Oztoprak & Cinicioglu method was referred in this paper.

The modern version of the observational method, proposed by Oztoprak and Cinicioglu (2005), were applied on two cases. The results indicated that the method has the capacity of following and interpreting in situ soil behavior on the real-time basis at every zone in the foundation soils.

Strain rate effect, structure, anisotropy and stress axis rotation could be taken into account with the method. The effect of viscoplasticity could be observed in the stress paths obtained for Cubzac-les-Ponts where drainage ways are long and highly structured clays exist whereas frictional behavior dominated in case of Stanstead Abbotts where drainage ways were shortened by the inclusions of vertical drains. The effect of anisotropy was interpreted in terms of coefficient of lateral earth pressure, K values.

The differences in strain rates between laboratory and field conditions cause changed preconsolidation pressures and consolidation processes (Kabbaj et al, 1988; Cinicioglu and Oztoprak, 2003). This behavior caused remarkable differences in the field OCRs compared to laboratory values and this was most evident in highly overconsolidated clays such as upper crust layers in both embankments (Oztoprak, 2002; Oztoprak and Cinicioglu, 2003a, 2003b). Any method that could not take care of this action would cause the stress paths to shift and fail to interpret the field build up of excess pore water pressures and deformations. Naturally, this was one of the reasons why stress paths found with FE analyses applied with published data were quite different. Knowing that FE analyses are parameter sensitive, several attempts were made for parameter revision.

In situ OCR values and revised k values were applied separately to find the uncoupled effect of each parameter revision. The result indicated that the stress paths were improved to be more representative of field behavior. However, this investigation has also proven that parameter revision is a cumbersome task and simultaneous revision of all the effective parameters is almost impossible without knowing what would happen in the field. After event revisions may not be representative of the forthcoming event.

REFERENCES

Cinicioglu S.F., and Oztoprak S. (2003). Interpretation of viscoplastic behaviour of clays in the construction of field stress paths. Proc. of International Workshop on Geotechnics of Soft Soils-Theory and Practice, Noordwijkerhout, The Netherlands: 511-516.

Hird C.C. (1993). Numerical Modelling of the Willow Plantation Embankment (Stanstead Abbotts). Research Report No: DCSE/93/G/1, University of Sheffield, UK.

Hird C.C., Pyrah D., Russell D., and Cinicioglu F. (1995). Modelling the effect of vertical drains in two-dimensional finite element analyses of embankments on soft ground. Can. Geotech. J. 32: 795-807.

Kabbaj M., Tavenas F., and Leroueil S. (1988). In situ and laboratory stress strain relationships. Géotechnique. 38(1): 83-100.

Magnan J., Mieussens C. & Queyroi D. (1983). Etude d'un remblai sur sols compressibles: Le remblai B du site expérimental de Cubzac-les-Ponts. Rapport de recherche LPC No: 127, Laboratoire Central Des Ponts et Chaussees.

Oztoprak S., and Cinicioglu S.F. (2003a). Towards an on-time method of interpretation of field instrumentation data. Proc. of 13th European Conf. on Soil Mech. and Geotech. Eng., Prague, Chechz Republic: 783-790.

Oztoprak S., and Cinicioglu S.F. (2003b). Stress-strain behaviour of soft soils under embankment loading. Proc. of Int. Conference on New Developments in Soil Mechanics and Geotechnical Engineering, Turkish Republic of Northern Cyprus: 67-74.

Oztoprak S., and Cinicioglu S.F. (2005). Soil behaviour through field instrumentation. Canadian Geotechnical Journal. 42: 475-490.

Oztoprak S., and Cinicioglu S.F. (2006). In situ yielding and field stress paths of clayey soils under embankment loading. 13th Danube - European Conference on Geotechnical Engineering, 29-31 May 2006, Ljubljana, Slovenia: 481-486.

Oztoprak S. (2002). Stress-strain behaviour of soils under loading - Theoretical development and modelling. Ph.D. Thesis, Istanbul University, Istanbul, Turkey *(In Turkish).*

Peck R.B. (1969). Advantages and limitations of the observational method in applied soil mechanics. Géotechnique. 19(2): 171-187.

Wood D.M. (1990). Soil behaviour and critical state soil mechanics. Cambridge Univ. Press.

Zhang J., Shamoto Y. and Tokimatsu K. (1998). Evaluation of earth pressure under any lateral deformation. Soils and Foundations. 38(1): 15-33.