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Monitoring of performance in four dikes on soft soil

Suivi du comportement dans quatre digues sur sol mou

J.L. Justo, J. Saura, E.M.J. Da Silva, C. Soriano & P. Durand
Department of Continuum Mechanics, University of Seville, Spain

ABSTRACT

The final stretch of the low Guadalquivir Canal includes an irrigation control pond, enclosed by four homogeneous embankments with initial heights over foundation up to 11.2 m, three of them placed on marshland. Preliminary calculations, based upon a conventional site investigation, indicated that the factor of safety at the central part of highest dike was 0.29 and settlement was high. These results have compelled to place topographic marks, settlement plates, piezometers and inclinometers, in and under the embankments, and to take measurement of the instrumentation at short time periods. Up to now, settlement measurements have been taken over 2500 days. The measurements are being interpreted using Plaxis 2D program, and Mohr-Coulomb and soft-soil-creep models. The dikes have been successfully completed and the water has been raised up to a little less than 1 m below the maximum level.

RÉSUMÉ

La section finale du Canal du Bas Guadalquivir inclut un étang de control pour l'irrigation, fermé par quatre remblais homogènes, jusqu'à 11,2 m d'hauteur, dont trois sont placés sur le marais. Des calculs préliminaires ont donnée un coefficient de sécurité de 0.29 dans la partie centrale de la digue plus haute et des tassements importants. Ces résultats ont obligé à placer des points de repère, plaques de tassement, piézomètres et inclinomètres dans et au-dessous des remblais, et à prendre des mesures dans des intervalles courts. Jusqu'à présent des mesures de tassement ont été prises pendant 2500 jours. Le programme Plaxis 2D et des modèles rhéologiques Mohr-Coulomb et soft-soil-creep ont été utilisés pour interpréter les mesures. Les digues ont étés finis, et le niveau d'eau a arrivé jusqu'à 1 m au dessous du niveau maximum.

Keywords : monitoring, performance, inclinometers, piezometers, settlement plates, reinforcement geotextile, band-shaped drains

1 INTRODUCTION

The design of the final stretch of the low Guadalquivir Canal includes an irrigation control pond, with a capacity of 7.9 Hm3, enclosed by four embankments with initial heights over foundation of 11.2, 6.2, 9.0 and 5.0 m. Dikes No. 1, 2 and 3 are placed on marshland. The four dikes (see Fig. 1) are homogeneous and were initially designed with a horizontal downstream drain, upper slopes 3.5H: 1V upstream and 3H: 1V downstream, 2.5 m wide berms at level 6 m, and from that level down with a slope of 6H: 1V at both sides.

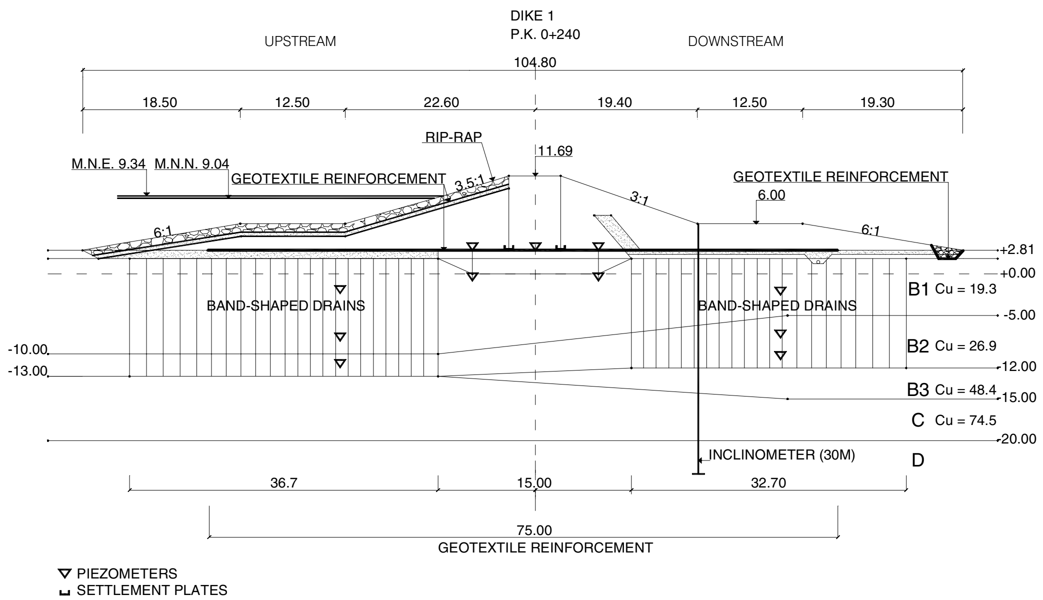

Fig. 1. Final design of dike 1, showing instrumentation, reinforcement geotextile, band-shaped drains and the undrained strength of clay layers.

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The dikes were founded at a depth of 1 m and the cut-off at 3m. Preliminary stability calculations, based upon a conventional site investigation, indicated that the short term factor of safety at the central part of dike 1 was 0.29 and settlement would be high. Due to this, it was decided to carry out an improved site investigation based upon piezocone, vane, and Marchetti dilatometer tests, and excellent piston samples. With better parameters, the factor of safety of dike 1, assuming cracking of the embankment, was still below 1. As a result of this study, it was decided to take the following steps to improve and reinforce the foundation and the dike (Fig. 1):

- A reinforcement geotextile with a stiffness of 8,333 kN and a strength of 1000 kN/m was placed at the base of the embankment in dike No. 1.

-Introduce band-shaped drains (Fig. 1 to 3) spaced from 1.5x1.5 m to 2x2 m, and upper sand blankets at dikes 1 and 3.

-Change the horizontal downstream drain to a chimney drain at dikes 1 and 3, and extend the berm to 12.5 m.

2 MONITORING AND SOIL MODELS

Settlement plates, piezometers and inclinometers (shown in the plans of Figures 2 and 3) were installed in Dikes 1 and 2.

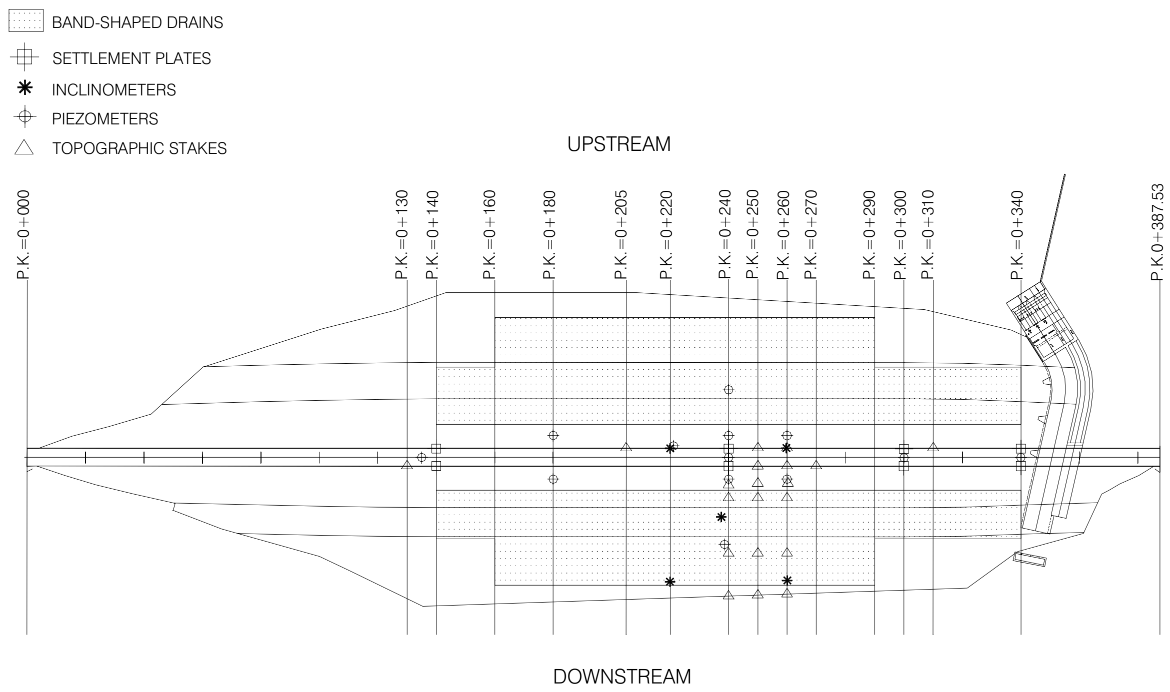

Figure 2. Plan showing the instrumentation in Dike No. 1.

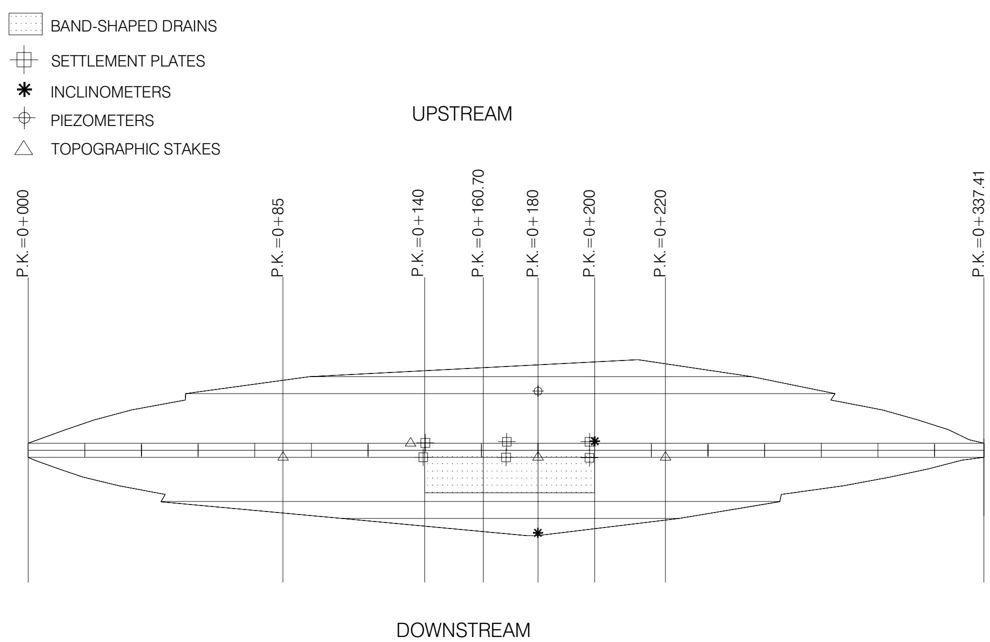

Fig. 3. Plan showing the instrumentation in Dike No. 3.

Figure 1 shows the layout of the instrumentation through section 0+240 (dike 1). The measurements are being interpreted using Plaxis 2D program and Mohr-Coulomb, soft soil and soft soil creep models (Plaxis, 2008). The Mohr-Coulomb model is a non-associated, perfect-plasticity model, with a plastic potential function defined by the dilatancy angle ψ. The soft soil models are similar to cam clay, without or with creep. The geotextile increased the safety factor, using an undrained Mohr-Coulomb Plaxis analysis, up to 1.5, but with a soft-soil model, the equilibrium was not reached under the water load. The low safety factors compelled to take measurements of the instrumentation, at short time periods. Up to now, settlement measurements have been taken during 2500 days.

3 SOIL PROFILE

The following soil types appear from top to bottom:

A. Top soil

B'. High liquid limit, organic clay and silt, slightly overconsolidated.

B. High liquid limit, soft to medium, blue organic clay and silt.

C. High liquid limit, stiff, yellow clay.

D. Very stiff to hard, green, clayey marl.

Figure 1 shows a geotechnical profile through section 0+240 (dike 1). The average layers' properties for dike 3 are collected in Table 1.

Table 1. Main calculation parameters in dike 3

Soil layer	γ kN/m^3	k_h m/day	k_v m/day	k_h* m/day	C_c	C_s	C_α	c_u kPa	c' kPa	Φ'	Φ'	*OCR*	ν'	E'* kPa	Ψ
B'	16.7	5.7E-05	1.3E-5	1.1E-5	0.474	0.149	0.0025	39.7	11	18	18	4.8	0.30	6750	0
B1	16.1	1.3E-04	3.0E-5	2.3E-5	0.550	0.118	0.0049	21.1	12	23	23	1.0	0.35	3587	0
B2	16.6	10.0E-05	3.1E-5	1.9E-5	0.573	0.166	0.0026	36.5	25	12	12	2.0	0.30	6205	0
C1	17.8	4.7E-05	4.7E-5		0.315	0.067	0.0045	75.0	41	18	18	2.6	0.25	12750	0
C2	17.8	4.7E-05	4.7E-5		0.315	0.067	0.0045	112.5	45	20	20	2.6	0.25	19125	0
Embankment	18.0	9.0E-06	9.0E-6					47.6	48	20			0.35	28000	0
Sand	17.6	2.0E+01	2.0E+1					1	1	45			0.35	20000	5

E'* = modulus of linear deformation for soft soil and soft soil creep models k_h* = horizontal coefficient of permeability in zone occupied by drains

To translate the three-dimensional layout of the band-shaped drains to the two-dimensional model, the distance between drains has been maintained and the coefficient of permeability has been changed according to Cheung et al. (1991) in the volume occupied by the drains.

4 NEW CACULATIONS

New calculations have been carried out in several sections of dike No. 3 (Fig. 4).

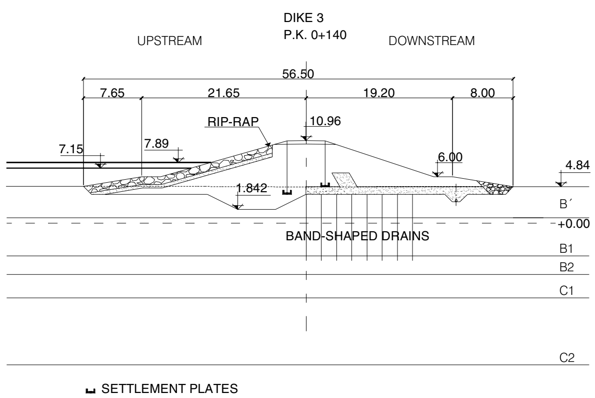

Fig. 4. Final design of dike 1, showing instrumentation and band-shaped drains.

The consolidation phases considered in the calculations are shown in Table 2. Drained conditions were assumed for the embankment.

With respect to the foundation, the following rheological models have been used in the simulations:

SS = Soft soil, similar to Cam clay (see Plaxis, 2008).

SSC = Soft soil creep. Like Cam clay with creep (see Plaxis, 2008).

In soft soil and soft soil creep calculations, the standard value ν_{ur}=0.15 was used.

MCI = Mohr-Coulomb (see Plaxis, 2008) using undrained parameters. The undrained strength was obtained directly from the vane tests.

MCR = Mohr-Coulomb (see Plaxis, 2008) using undrained parameters. The undrained strength obtained from the vane tests was reduced for plasticity index.

Table 2. Consolidation phases considered in the calculations

Phase	Time days
Excavation	9
Cut-off and drains construction	9
Dike construction up to level 4.81	33.5
Dike construction up to level 8.79	181
End of construction	184.5
Consolidation up to filling of reservoir	28
Water raised up to level 4.81	53
Water raised up to level 7.15	134
Consolidation with water at level 7.10	818
Reservoir at average level 7.89	1044

With the Mohr-Coulomb rheogical model, the modulus of linear deformation was obtained from the equation:

$E' = 170\ c_u$

Figure 5 shows the increase of the embankment height during construction and the evolution of water level during filling of the reservoir. It compares measured and calculated settlements in the upstream settlement plate at section 0+140. The best agreement during construction corresponds to model MCR and with reservoir filling to model SS. The soil exhibits more creep than predicted by the models.

Figure 6 compares calculated and measured pore pressures in the piezometers of dike 3. There is an acceptable agreement. The calculated excess pore pressure values indicate that there was important pore pressure dissipation.

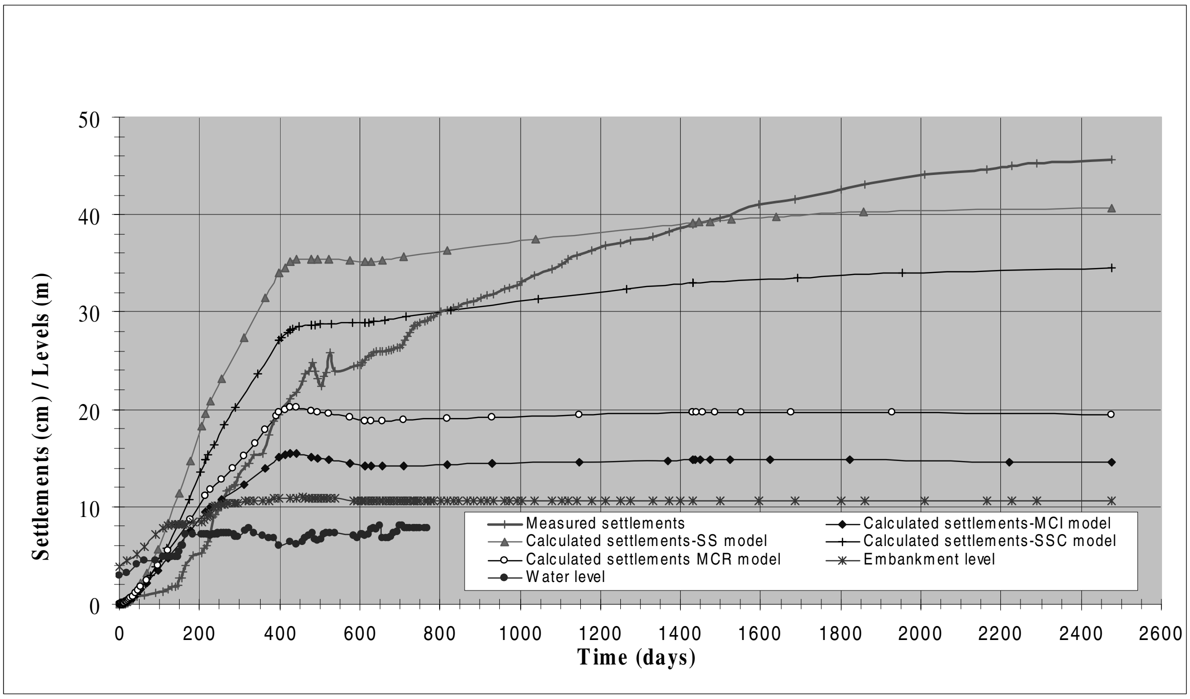

Fig. 5. Comparison between measured and calculated settlements. Dike 3. Upstream settlement plate. Section 0+140

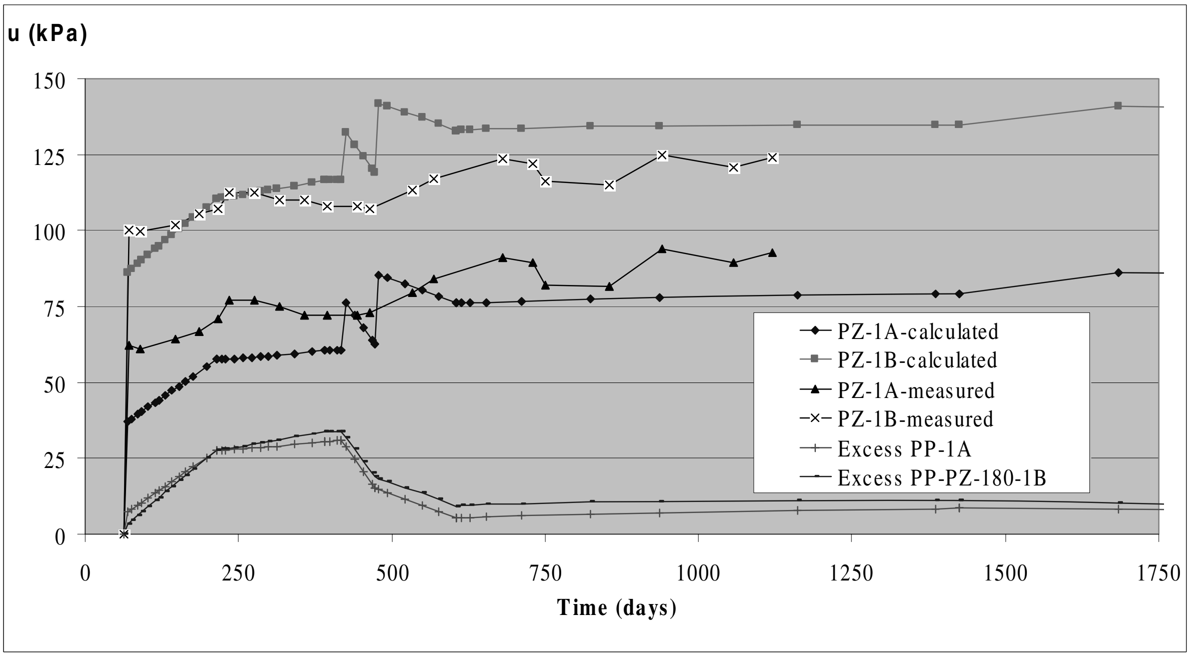

Fig. 6. Comparison between measured and calculated pore pressures. Calculated excess pore pressures. Dike 3. Section 0+180. Piezometers 1A (at level -0.19) and 1B (at level -5.19). Soft soil creep model.

5 CONCLUSIONS

Soft soil and soft soil creep models reproduce better the settlements than Mohr-Coulomb models. There is an acceptable agreement between measured and calculated pore pressures.

Monitoring has allowed a successfull control of construction and filling of the reservoir.

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