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Vertical drainage of compressible soils under the Moroccan high-speed railway line

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Abstract. This research work presents the high-speed railway line (HSRL) case study constructed on soft soils deposits. The performance of the improvement method combining both PVD's (Prefabricated vertical drains) and surcharge preloading was evaluated herein based on numerical simulation approach to predict the induced deformations during the HSRL construction phase. For this aim, the performance of the PVD-assisted preloading was evaluated based on in situ measurement database from a selected well instrumented embankment. From the results, it was observed that the use of the PVD and preloading was found as the most efficient improvement method for improved section. In addition, multiple modelling approaches were used for the studied section to evaluate the usefulness of the published literature on the PVD- surcharge system performance. For that, is was concluded that the well-developed numerical approaches in the literature is an encouraging factor for using the PVD-preloading improvement method in both practice and research.

1 Introduction

The economic expansion and population growth in Morocco demands rapid construction of infrastructure projects such as roads, bridges and railways. Herein a section of the first high speed railway line (HSRL) is studies. The HSRL is located in the western coastal line (Figure 1), linking the northern city of tangers to Casablanca (200 km line) that was inaugurated in 2018. Geologically speaking, the high speed railway line cross over some recent quaternary soft soil deposits localised in the Rharb basin [1]. In this study our main focus is the soft soil behaviour under Sebou right bank embankment (Figure 1) which are generally containing silts, silty clays and clays.

Soft soil deposits have relative low permeability, high compressibility and low shear strength. To avoid the embankment failure and to reduce the time required for consolidation, prefabricated vertical drains (PVD's) and preloading were taken as a ground improvement technique. To evaluate the soft soil behaviour, the finite element method is used as a numerical modelling method to evaluate the subsoil behaviour based on the soft soil creep model (SSCM) in the analysis. The numerical analysis results are validated based on field monitoring data.

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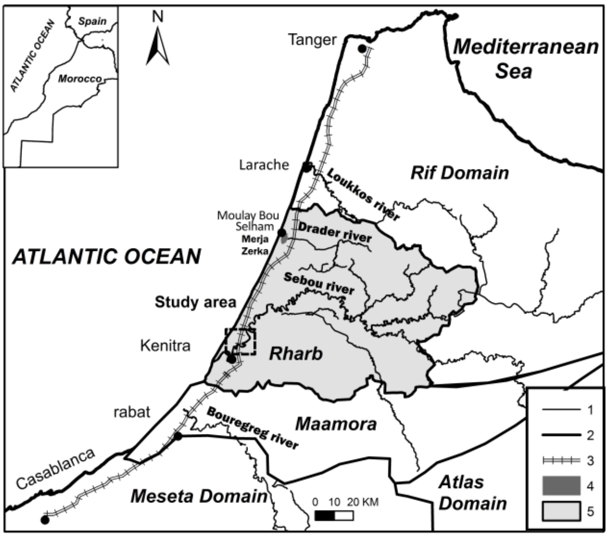


Fig. 1. Location of the high speed railway line and the study area location

1: rivers, 2: boundaries, 3: high speed railway line, 4: water area, 5: Rharb basin.

2 Site description and soil characterization

2.1 Construction procedure and field monitoring

Sebou right bank embankment is a 4m high, 14m width at the crest, with a 38m footing and 2:1 slope gradient. The embankment consists of 0.3m gravely drainage layer underlying weakly graded gravel, underlying a sandy filling material for the upper layers including a 1.5m thick preloading layers. All layers were compacted during the construction attaining a 20 KN/m^3 density. The embankment is constructed on improved subsoil with prefabricated vertical drains? To meet the project requirement. PVD's were installed in a rectangular pattern with 1m spacing, and a depth of 35m. the embankment was monitored by various field instrumentation. Such as settlement cells, interstitial pressure sensors, a 10 m piezometer (Figure 2).

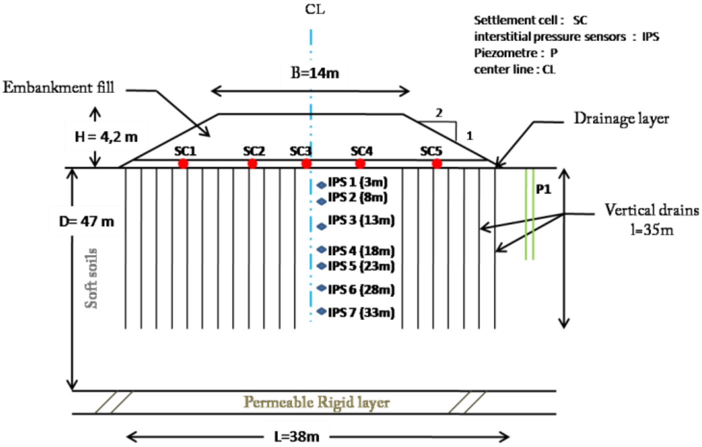


Fig. 2. Location of the high speed railway line and the study area location

2.2 Soil characterization

Sebou subsoil deposits can generally be described as heterogeneous soils [1], with complex distribution mode along the Rharb basin. For this raison, various field data (such as CPT's, SPT, Boreholes) and laboratory tests were performed during the investigation, to comprehend subsoil variation and the geometry along the high speed railway line. Five dominating soil layers were characterised for this section. A 5 m dense clay layer (A), underlined by 5m silty clay layer (B), followed by soft clay (C) with 6m thickness. The deeper layers regroup two major soil type dominance, silty clay (D) and soft silts (E) with 19m and 12m thickness respectively. Soil type variation and properties values fluctuation (Figure 3), necessitate a more detailed soil profile for the numerical analysis summarized in Table 1 and 2.

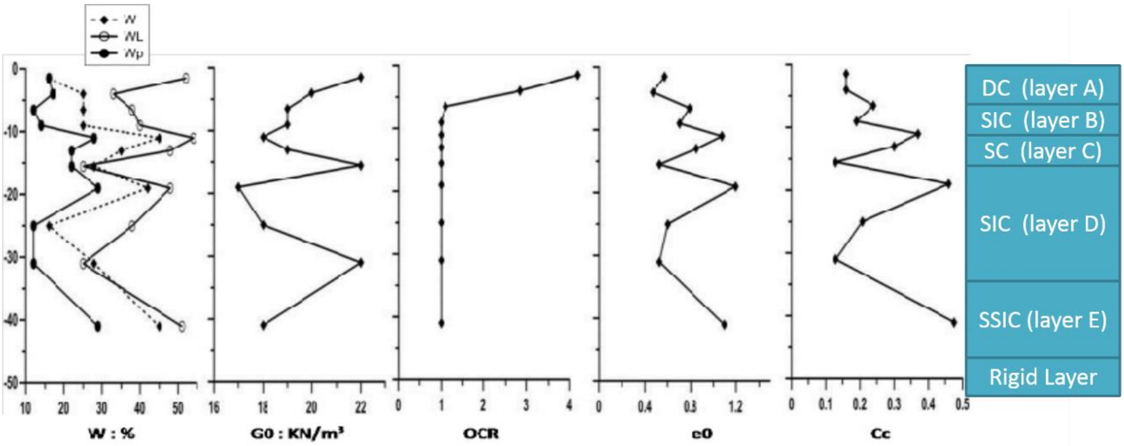


Fig. 3. Soil profile properties

W: water content; LL: liquid limit; PL: plastic limit; γ: unit weight;
e0: initial ratio; Cc: coefficient of compressibility
STC: Stiff Clay; SIC: Silty Clay; SC: Soft Clay; SSIC: Soft Silty Clay

3 Numerical modeling

In the last decade and due to the development of numerical modeling methods to solve challenging geotechnical problems, researcher have advanced their research methods to predict soft soil behaviour while using prefabricated vertical drains [2], when some presented a complete detailed studies based on numerous matching method when using PVD's [3] [4]. Similarly, in the studied area multiple publications have been published in regards of soil behaviour prediction under the Moroccan high speed railway Embankment [5] [6] [7], of which soft soil behaviour was studied during Classe A and Classe C prediction for precise numerical simulation objective in Sebou area [5][7]. In addition to studying artesian pressure effect of soft soil behaviour in Drader area under the HSRL. However, the PVD effect of Soft soils consolidation performance under the High speed railway embankment makes the subject of this publication.

3.1 Construction procedure and field monitoring

Prefabricated vertical drains are usually modelled under 2d plane strain condition. Hence, the actual field condition under the embankment need to be converted from axisymmetric 3d condition to a 2d plane strain condition. Taking smear zone (which is the disturbed soils around the drain affected by the mandrel insertion during installation) effect into account in the matching procedure, requires a good assumption of d_s/d_w ratio (with d_s and d_w are the smear zone and mandrel diameters respectively), and k_h/k_s ratio (kh and k_s are horizontal permeability of natural and disturbed soils respectively). For that, the d_s/d_w ratio was taken equal to 5 as suggested by [8], and k_h/k_s equal to 20 according to [9]. Many matching methods can be found in the literatures [11], however only three methods are used herein.

a) Method 1: Indraartna and Redana (1997) [8] developed a matching method by converting the multi drains in 3d to parallel wells in 2d. the method is based on adjustment of two different permeability coefficients. The first one is assigned to the intact zone and the other for the discturbed zone? The relationship between k_{hp} and k'_{hp} presented in equation 1:

$$\frac{k'_{hp}}{\mathrm{khp}} = \frac{\beta}{\left[ln\left(\frac{n}{s}\right)+\left(\frac{k_h}{k'_h}\right)\ln(s)-0.75-\alpha\right]} \tag{1}$$

With $\beta = \frac{2}{3}\frac{(s-1)}{(n-1)n^2}[3n(n-s-1)+(s^2+s+1)]$, $\alpha = \frac{2}{3}\frac{(n-s)^3}{(n-1)n^2}$

Where β and α are geometric parameters, with $n = R/r_w$, $s = r_s/r_w$. r_w and r_s are the radius of the drain and the radius of the smear zone.

b) Method 2: Hird et al (1992) [10] developed a simple approach by estimating the vertical hydraulic conductivity in plane strain condition (k_{pl}), by excluding smear zone effect and well resistance as shown in equation 2:

$$\frac{k_{pl}}{k_{ax}} = \frac{\frac{2}{3}\frac{(n-1)^2}{n^2}}{[\ln(n)-0.75]} \tag{2}$$

With $n=d_e/d_w$

Where k_{pl} is the hydraulic conductivity in plane strain condition, k_{ax} is the hydraulic conductivity in axisymetrique condition, d_e is the effective diameter of a drain influence. d_w is the equivalent drain diameter suggested by Hansbo [11].

c) Method 3: Chai et al (2001) [12] introduced a parameter called the equivalent hydraulic conductivity (k_{ve}) for the PVD improved zone without including the drain elements in the FE model. The k_{ve} is expressed in equation 3:

$$K_{ve} = \left(1+\frac{2.5L^2K_h}{\mu.D_e^2.k_v}\right).k_v \tag{3}$$

Where l is the drainage length, D_e is the diameter of unit cell and μ is a parameters based on the discharge capacity and smear zone permeability and the equivalent diameter.

3.2 Input parameters

The embankment materials were modelled with Mohr-coulomb model assuming the material parameters values presented in table 1 and 2 summarizes the soil parameter and state variables for the SCC model proposed by Neher [13].

Table 1. Embankment parameters values

Material	$E'(MPa)$	γ'	$\emptyset'$	φ'	c'(kPa)	γ (KN/m^3)
Fill	40	0.2	35	0	0.1	20
granular	100	0.2	40	0	0.1	20

Where $E^{'}$ is the young modulus, $\varphi^{'}$ is the dilatancy angle, $c^{'}$ is the effective cohesion and γ is the unit weight of the embankment materials.

The lateral earth coefficient is calculated based on the equation $k_0 = (1 - sin\varphi')OCR^{sin\varphi'}$, where φ' is the effective friction angle, the permeability k_h, k_v in addition to λ^*, k^*, μ^* (see equations 4, 5 and 6) values were drawn from incremental oedometer tests as presented in Table 2.

$$\lambda^* = \frac{C_c}{(1+e_0)\, ln10} \quad (4); \qquad K^* = \frac{2C_s}{(1+e_0)\, ln10} \ (5)\ ; \qquad \mu^* = \frac{C_\alpha}{(1+e_0)\, ln10} \ (6)$$

Table 2. Soil permeability

Table 3. Soil constant values

Layer	***Depth***	k^*	λ^*	μ^*	c'(kPa)	φ'	k_h (m/day)	k_v (m/day)
L1	0-3	0.02	0.052	0.01	18	16	9.0E-5	1.7E-4
L2	3-5	0.02	0.05	0.018	20	13	3.4E-4	2.2E-4
L3	5-8	0.03	0.09	0.015	35	15	4.0E-5	2.0E-5
L4	8-10	0.02	0.05	0.024	35	15	5,0E-8	2,5E-8
L5	10-12	0.06	0.08	0.018	33	19	1.4E-4	0.7E-4
L6	12-15	0.04	0.07	0.018	31	20	1.6E-4	0.8E-4
L7	15-16	0.01	0.04	0.018	10	30	2.4E-4	1.2E-4
L8	16-23	0.04	0.09	0.012	30	14	1.3E-4	6,5E-5
L9	23-27	0.02	0.06	0.018	12	31	4.0E-8	2,0E-8
L10	27-35	0.01	0.04	0.018	12	30	2.4E-4	1,2E-4
L11	35-47	0.05	0.09	0.017	30	20	1.0E-4	0.5E-4

3.3 Results

Based on the modeling results from the three methods while using the soft soil creep constitutive model (SSCM) shown in Figure 4, it was clear that all methods give acceptable results especially in short term prediction. The consolidation rate in long term underestimates the settlement especially Method 1 and 2. This may be due to certain simplification as indicated previously.

The results for Method 2 and32 is not mesh dependent the results are the same for every mesh density option. Method 1 however, is highly dependent on mesh density and the result is based entirely on the hardware power used for the finite element modeling analysis.

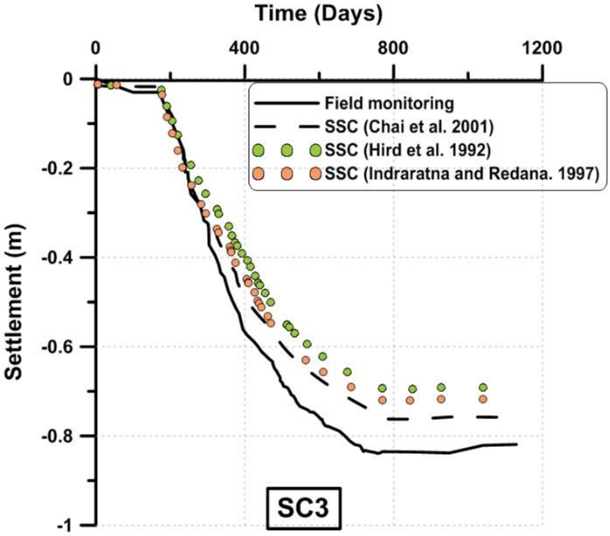
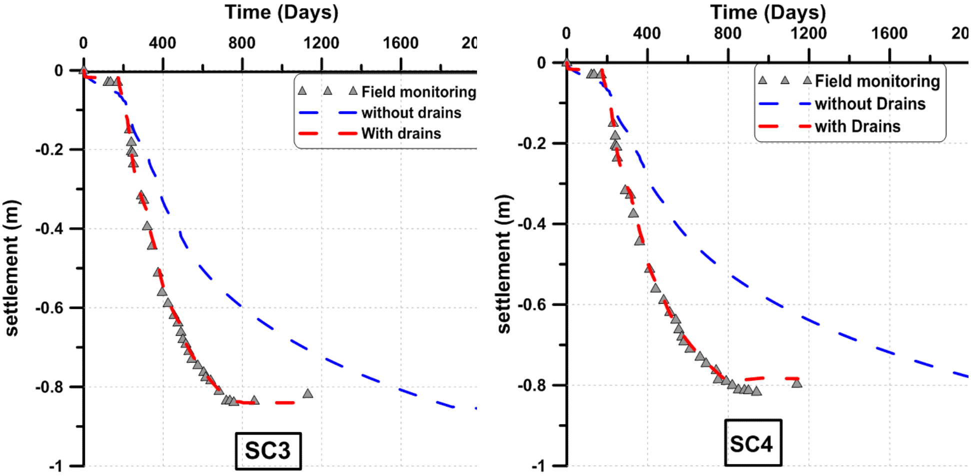


Fig. 4. Settlement prediction based on three matching methods and the in situ measurements

4 Prefabricated vertical drains performance

As presented in Figure 5, multiple analysis is made to present the PVD's performance under Sebou right bank embankment in multiple points (under the embankment centreline SC3, under the embankment crest SC4 and under the slope SC5). When back-analysing the Numerical model with drains included, a second analysis is performed to study PVD's effect on consolidation in short and long term.



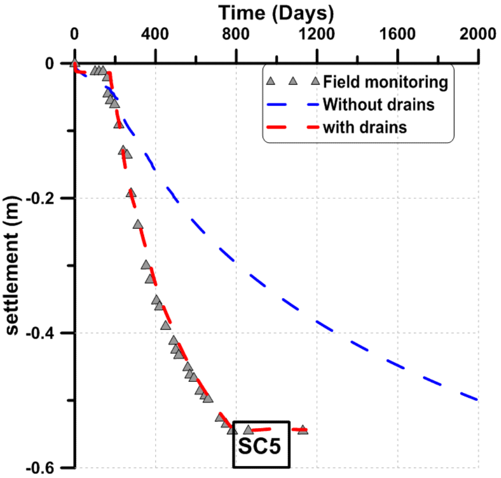


Fig. 5. Settlement prediction with and without PVD's

The results show in short term (when the embankment high was not yet elevated enough) the settlement were the same. However, in long term the consolidation rate was much slower without using the drains. To be exact, the PVD's reduced the consolidation process for as much as 60%, meaning that the PVD's recused the consolidation time of about 3 years.

Excess pore pressures were also dissipated for as much as 30% in short term and 50% in long term as presented in Figure 6, resulting to a safer embankment construction process with high factors of safety when using PVD's.

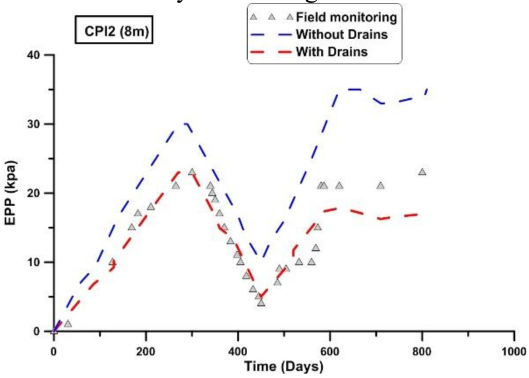


Fig. 6. Excess pore pressure prediction with and without PVD's

5 Conclusion

In this study, soft soil behaviour is presented during the Moroccan high speed railway line construction in Sebou right bank embankment. Some of the results are shown below/

- The use of the prefabricated vertical drains was necessary in Sebou area.
- The combination between the PVD's and the surcharge method resulted in reducing the consolidation process for 60%.
- The use of the vertical drains lowered the Excess pore pressure produced during the preloading period.

- Using a simple matching method such as chai et al (2001) can produce some accurate results.

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