Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-425

Acceleration of embankment construction on soft soils of Salamanga using wick drains and counterweight fills

Accélération de la construction de remblais sur sols mous de Salamanga à l'aide de drains verticaux et des remblais de contrepoids

H. Dete*, C. Quadros
TÉCNICA – Engenheiros Consultores Ltd., Maputo, Mozambique

**hans.brigido@gmail.com*

ABSTRACT: The construction of embankments on soft soils is an inevitable solution in the case of roads crossing thick clayey alluvial deposits. In such cases, consolidation acceleration techniques can be adopted, in order to prevent excessive settlements to occur as a result of the stress increase induced by the embankment or causing it to fail due to insufficient shear strength of the foundation. This paper evaluates technical solutions for accelerating the construction of embankments on soft soils using wick drains and counterweight fills. This solution was implemented on the construction of a 9.6 m high embankment between the years 2016 and 2017, along the Maputo River floodplain, in Salamanga District. The construction was preceded by an extensive geotechnical investigation, including in situ and laboratory tests, which identified the existence of a 39 m thick deposit of soils that were not only highly compressible and of low permeability, but also had a low shear strength, reason why counterweight fills were adopted to prevent failure of the embankment during the staged construction. Because of the uncertainties involved in the characterization of soft soils, related to the sedimentation process, and spatial variation of their properties, and in predicting their behavior when loaded, an instrumentation and monitoring plan of the construction was implemented, whose results were used to calibrate the geotechnical model. From the collected data, it was concluded that the designed solution performed satisfactorily and the project assumptions regarding the allowable residual settlements and stability of the embankment were met before laying the pavement.

RÉSUMÉ: La construction de remblais sur sols mous est une solution incontournable dans le cas de routes traversant des alluvions argileuses épais. Dans ces cas, des techniques d'accélération de la consolidation peuvent être adoptées, afin d'éviter que l'augmentation des contraintes induite par le remblai ne produise des tassements excessifs ou ne provoque pas sa rupture en raison d'une résistance au cisaillement insuffisante de la fondation. Cet article évalue des solutions techniques pour accélérer la construction de remblais sur sols mous à l'aide de drains verticaux préfabriqués et des remblais de contrepoids. Cette solution a été mise en œuvre pour la construction d'un remblai de 9,6 m de hauteur entre 2016 et 2017, le long de la plaine inondable du fleuve Maputo, dans la région de Salamanga. La construction a été précédée d'une vaste investigation géotechnique, y compris des essais in situ et en laboratoire, qui a identifié l'existence d'un dépôt de 39 m d'épaisseur de sols qui étaient non seulement hautement compressible et de faible perméabilité, mais avaient également une faible capacité portante, raison pour laquelle des bermes à contrepoids ont été adoptées pour éviter la rupture du remblai lors de sa construction par étapes. En raison des incertitudes liées à la caractérisation des sols mous, à cause de leur nature sédimentaire et à la variation spatiale de leurs propriétés, et à la prédiction de leur comportement en charge, un plan d'instrumentation et de surveillance de la construction a été établi, dont les résultats ont été utilisés pour calibrer le modèle géotechnique, à partir duquel il a été conclu que les hypothèses du projet concernant les tassements résiduels admissibles et la stabilité du remblai étaient respectées avant la construction de la chaussée.

Keywords: Acceleration of embankment construction; soft soils; wick drains; counterweight fills.

1 INTRODUCTION

Among several factors, the design of a highway is constrained by the topography, geology and hydrology of the site.

Indeed, in the cases where a road layout crosses a river valley, it is frequent to build embankments adjacent to the bridge abutments to avoid overtopping of the roadway during extreme floods.

In such cases, the viability of such construction must be very well analysed, for the river valleys are generally composed of saturated alluvial soils, of low bearing capacity and high compressibility, requiring the use of non-conventional construction methods to prevent excessive settlements of the infrastructure during the service phase.

According to Almeida & Marques (2010), the choice of the most adequate method depends on the geotechnical characteristics of the deposit, use of the area, including the neighbourhood, as well as construction deadlines and costs involved.

Therefore, this paper presents the use of wick drains with surcharge loading and counterweight fills (berms) as an alternative method for the construction of embankments on soft soils.

2 TECHNIQUES TO ACCELERATE THE CONSTRUCTION OF EMBANKMENTS ON SOFT SOILS

2.1 Wick drains with surcharge loading

The construction of road embankments on deep soft soil deposits is usually done by preloading the ground through an additional depth of fill, during a period long enough to allow most of the consolidation settlements to occur before laying the pavement.

Due to the low permeability of soft soils, the consolidation period might be too long (Terzaghi et al., 1996), thus not complying with the construction deadlines.

In such cases, the preloading is combined with wick drains (Figure 1), which are installed relatively close to each other to reduce the drainage distance up to 1 to 2 meters, therefore accelerating the consolidation (Espinoza et al., 2020).

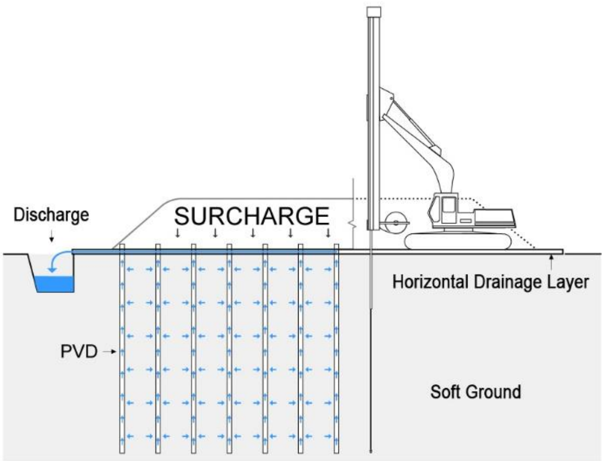

Figure 1. Preloading embankment combined with wick drains. (Source: Prefabricated Vertical Drains, 2017).

2.2 Counterweight fills

Despite the fact that the construction of embankments on soft foundation must account for excessive settlements, it is also necessary to ensure that the embankment height will not cause failure of the foundation due to its low undrained strength.

According to (Jakobson, 1948), if the required embankment height does not comply with the foundation shear strength, counterweight fills (loading berms) can be adopted to decrease the shear stress along the critical failure surface (Figure 2).

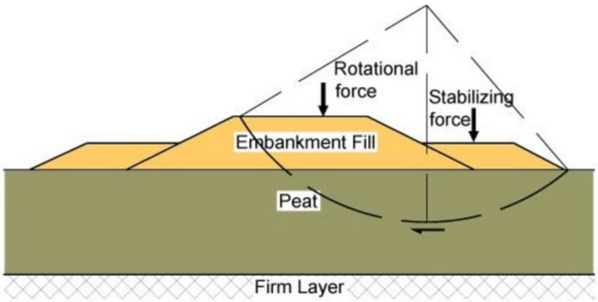

Figure 2. Effect of counterweight embankment on the stability of the embankment. (Muhammad, 2018).

3 CASE STUDY

3.1 Project description

The new Maputo – Ponta do Ouro road crosses an alluvial floodplain within the Salamanga District, near the Maputo River.

Since the ground level was +3.0 m and the design flood level was +8.054 m, it was necessary to build an embankment to enable the safe vehicle circulation during extreme floods.

After an extensive geotechnical survey along the road alignment, it was observed that the foundation mainly comprised fat clay with sand (CH) along 3.6 km up to a maximum of 39 m deep, as illustrated on Table 1A and Table 1B (CRBC, 2018).

Table 1A. Soil profile characterization.

Layer (depth, m)	**Soil**	***c*** **(kPa)**	***ϕ*** **(°)**	***γ*** **(kN/m³)**	***e₀*** **(-)**
1 (0.0 – 3.8)	CH	12	14	14.6	2.298 3.412
2 (3.8 – 9.3)	SC	12	13.4	14.5	3.412 2.487
3 (9.3 – 18.6)	CH	12	14	14.2	2.547 2.607 2.619 2.619

Table 1B. Soil profile characterization (cont.).

Layer (depth, m)	**Soil**	***c*** **(kPa)**	***ϕ*** **(°)**	***γ*** **(kN/m³)**	***e₀*** **(-)**
4 (18.6 – 33.6)	CH	17	22.4	16.1	0.722 2.165 1.852 1.645
5 (33.6 – 39.0)	CH	17.9	17.8	18.3	0.948 0.946 0.949

As per the geotechnical investigation results, the foundation soil has a very low shear strength and is highly compressible (compressibility index between 0.973 and 1.864), requiring special construction methods prior to the final loading.

In this context, the engineering design adopted a solution based on the consolidation process, which consisted of installing wick drains (prefabricated vertical drains). Additionally, counterweight fills (loading berms) were adopted to increase the factor of safety against the slope failure, during the staged construction.

A general scheme of the adopted engineering solution is presented on Figure 3.

For this study, a road section with 379 m of length was considered. On this section, the design height of the embankment was 6.7 m, the top width was 11.5 m and 1:1.5 slopes. The counterweight fills were 3 m high and 15 m of width on both sides of the main embankment.

The wick drains were installed up to 30 m deep, under a triangular pattern.

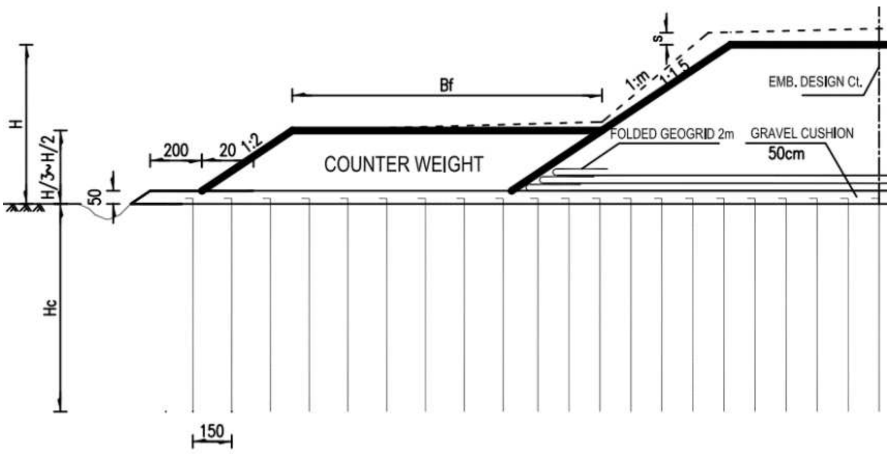

Figure 3. General scheme of the adopted engineering solution (all the dimensions are in centimetres).

3.2 Settlement prediction and design criteria

Settlements were predicted using the horizontal consolidation coefficient (c_h) determined by the Asaoka's observational method, as per the settlements measured until 5.3 m height of the embankment (Figure 4). Further calculations indicated that the consolidation settlements with respect to the design embankment is 2.6 m.

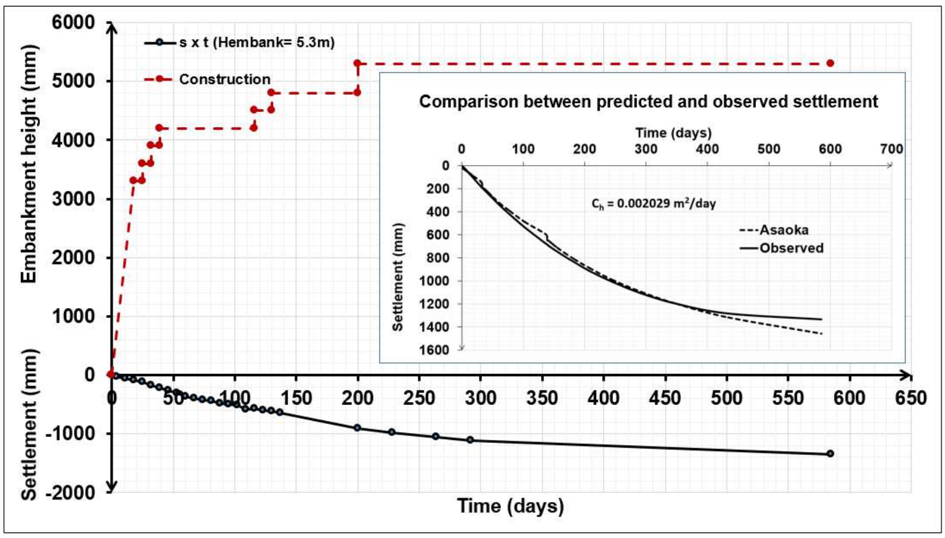

Figure 4. Observed and predicted settlement of the embankment during construction.

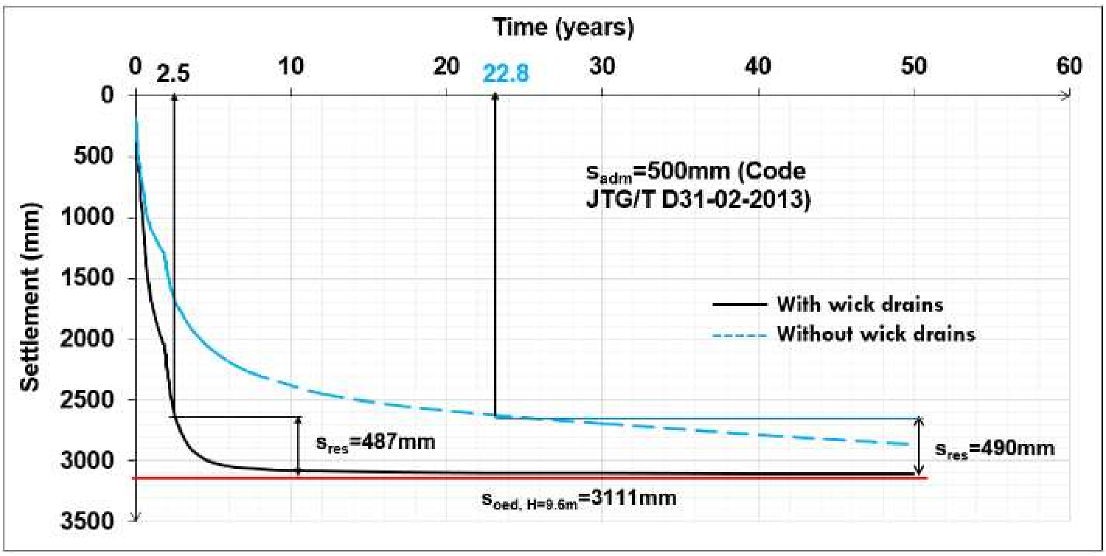

Figure 5. Settlement vs. time curve of the foundation with and without wick drains.

In order to comply with the design height of the embankment and thus, of the road elevation, an additional surcharge fill of 2.9 m was prescribed for the construction stage. Therefore, the total height of the fill was 9.6 m, which would cause a total consolidation settlement of 3.1m (Figure 5).

The construction took 26 months and, according to JTG/T D-31-02-2013, the residual settlement should not exceed 500 mm on the transition section between the embankment and the box culverts (piled foundation with almost no settlement).

Moreover, it was expected that the consolidation process would end 4 years after the construction, reason why maintenance measures such as refilling the pavement on critical sections were prescribed in order to provide good driving conditions.

4 CONCLUSIONS

This paper presented the engineering solution adopted to accelerate the construction of the road embankment accross the Maputo River floodplain, in Salamanga District.

From the study, it is concluded that the installation of wick drains led to a significant acceleration of the consolidation process, keeping the residual settlements within the pavement allowable settlement. In fact, the settlement-time curve presented on Figure 5 shows that without this technique, that process would last for almost 22 years, what is clearly unfeasible.

Finally, it is important to note that the success of the described solution relies not only on the extensive geotechnical investigation, but also on the evaluation of the settlement measurements acquired during the construction monitoring.

5 REFERENCES

Almeida, M. de S. S., & Marques, M. E. S. (2010). *Aterros sobre Solos Moles - projecto e desempenho*. Oficina de Textos.

CRBC. (2018). *Republic of Mozambique South Maputo Link Roads Project AS-built drawing* (Vol. 1).

Espinoza, D., Li, C., De Melo, L., & Gupta, R. (2020). Application of Hybrid Drained-Undrained Model for Analyzing the Stability of Reinforced Soil Structures Over Soft Foundations with Prefabricated Vertical Drains. *ISSMGE International Journal of Geoengineering Case Histories*, *5*(3), 138–151. https://doi.org/10.4417/IJGCH-05-03-01.

Jakobson, B. (1948). The design of embankments on soft clays. *Geotechnique*, *1*(2), 80–90. https://doi.org/10.1680/geot.1948.1.2.80.

JTG/T D-31-02-2013. (2013). *Technical Guidelines for Design and Construction of Embankment on Soft Ground*. China Communications Press.

Muhammad, N. (2018). *The effect of temperature and kaolin mixture on plasticity characteristics and shear strength behaviour of natural soil* (Issue July). Malaysia Pahang.

Prefabricated Vertical Drains. (2017). https://greencosmos.com.sg/prefabricated-vertical-drains-pvd/prefabricated-vertical-drains.

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). *Soil Mechanics in Engineering Practice* (3rd ed.). Wiley-Interscience.