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Utilization of Expanded Polystyrene for Embankments Founded on Compressible Soils in The Pk8+650 And Pk10+500 Points of The Tangier-Tangier Med Port Highway's Third Section

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Abstract*: This research introduces EPS substitution of embankment soil to the Moroccan context, and the highly compressible soils of the Tangier-Tangier Med port highway's third section. Compressible soils are a major hindrance when it comes to construction of medium to high embankments, proving to be the source of major instability and inefficient exploitation of Morocco's transport networks, especially when taking into consideration the lack of options for stabilizing such structures. this study will focus on computing safety factors related to landslide rupture for several expanded polystyrene substitution heights for two different embankments in each point of the aforementioned highway section, and compare said factors to the classical solution of soil treatment by ballasted columns that is mostly adopted in Morocco for similar soil constraints. Results yielded proved very promising for future uses of the newly introduced approach in the country's problematic soils and promises closer deadlines as well as fewer maintenance and reinforcement efforts.

***Keywords*: ballasted columns, compressible soils, embankment, expanded polystyrene, substitution.**

I. INTRODUCTION

The major drawback of an embankment on compressible soil is the positively correlated growth of its instability with the height of the embankment on one hand, then the depth and compressibility of the layers supporting the structure on the other. Therefore, several soil structures with significant heights (generally exceeding 10 meters) are predisposed to landslides as well as strong deformations.

Classical approaches remedying said drawback in Morocco summarize in intervening on the embankment's supporting soil, opting for the improvement of its characteristics, or in more unfavorable cases, a purging of the surface layer to a depth allowing an admissible safety factor.

As these remain the recommended solutions in the Moroccan context, the purpose of this study is to quantify the gain out of substitute materials in the embankment's mass, particularly in the case of highly compressible soils in northern Morocco (the Rif region). Indeed, replacing the backfill material with expanded polystyrene (EPS) has been present since 1972 and has yielded satisfactory results as regards embankment stability over bad soils as well as longevity [1]. Still unknown, introducing this technique could prove more effective than the ballasted columns approach, where the goal is to improve supporting soils by keeping the permanent load at the origin of instability constant.

II. SITE CONTEXT

This study will focus on section 3 of the highway Tangier and the Tangier Med port, a road crossing the mountainous region of the Rif. Well known to contain huge depths of compressible soils, this area automatically requires improvement to the embankment foundation in order to accommodate them.

The geological context, resulting from the dispersion of sediments expelled by tectonic actions, is defined by the presence of aquifers whose nature alternates between marl and sandstone. Seismic activity is present, with potential tectonic activity given the contact between the African and Eurasian plates. However, no risk of presence or proximity to active faults has been reported.

regarding lithological sections of studied points, we find the following stratigraphy:

- For the PK8 + 650: silts 5 to 6 meters thick, over a 4 to 5 meters thick sandy layer, over a 10 to 15-meter-thick layer of ooze, and a pelitic bedrock and the presence of sandstone banks;

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- For the PK10 + 500: clays 7 to 9 meters thick, over an ooze layer 9 to 10 meters thick, followed by silts between 7 and 8 meters thick, and a pelitic bedrock.

We note from the aforementioned stratigraphy that the foundation is of high compressibility, giving a good idea of the necessary reinforcements for this project. The studied soils' mechanical characteristics appear in tables I and II.

Table- I: soil characteristics at the PK8+650

Soil layer	Long Term			Short Term		
	γ *kN/m³*	*c'* *kPa*	*φ'* *°*	*γ* *kN/m³*	*cu* *kPa*	*φu* *°*
Embankment	20	0	30	-	-	-
Silts	21	4	20	20	80	0
Silts w/ BC	20	0	28	20	112	0
Sands	20	0	22	-	-	-
Sands w/ BC	20	0	27	-	-	-
Ooze	20	1	15	20	60	0
Ooze w/ BC	20	0	24	20	94	0
Sandstone	20	24	14	-	-	-
Pelite	20	6	27	-	-	-

Table- II: soil characteristics at the PK10+500

Soil layer	Long Term			Short Term		
	γ *kN/m³*	*c'* *kPa*	*φ'* *°*	*γ* *kN/m³*	*cu* *kPa*	*φu* *°*
Embankment	20	0	30	-	-	-
Clays	20	0	24	20	114	0
Clays w/ BC	20	0	29.5	20	82	0
Ooze	20	0	15	20	60	0
Ooze w/ BC	20	0	24	20	94	0
Silts	21	4	20	21	80	0
Silts w/ BC	21	0	28	21	112	0
Pelite	20	6	27	-	-	-

III. EXPANDED POLYSTYRENE IN EMBANKMENTS

The use of light materials to replace the soils constituting the embankments is an approach which aims at reducing the permanent load on the supporting soil whose nature is generally restrictive as to great embankment heights.

In the case of expanded polystyrene, its appreciable resistance and its ultralight weight make it an excellent option for said substitution.

The process is based on the use of EPS material in order to replace a certain height of the upper, lower or all of the fill, thus benefiting from a mass reduction reaching in our study almost 20 times that of the embankment soil itself. This reduction can be greatly improved upon with the use of ultralight EPS materials.

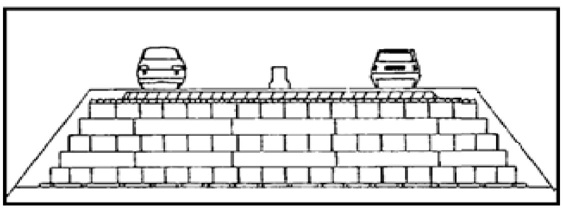

Fig. 1.Example of a EPS embankment

This material's lightness makes it a better candidate for substitution than other that can be described as such, and serve well in other techniques aimed at improving the structure's serviceability [2].

In addition to its low density, expanded polystyrene's good resistance to physical and chemical degradation (in the presence of adequate protective devices), as well as remarkable mechanical behavior to cyclic loads, common application mode in road and rail infrastructures.

We can therefore identify the different areas of use of EPS in earth structures:

- In cases limiting of the embankment's mass becomes imperative;
- In cases where the embankment's supporting soil's stability are prejudiced by the compressible nature and quality of the latter.

The use of this material would also considerably reduce embankments' footprints by allowing near-vertical slopes for side surfaces.

A near-zero Poisson's ratio eliminates the transmission of vertical loads by lateral ground pushes, making it an excellent substitute in case of high-elevation embankments.

Implementation of this material is straightforward: the EPS is supplied in blocks of variable dimensions and various qualities in accordance with the NF EN 14933 standard. These blocks are mounted in layers so that the edges do not overlap, and the blocks located in the same level follow a layout plan provided in the companies' execution documents in order to bind to the layers immediately above and below.

A granular layer must be placed at the base of the EPS foundation and properly drained. This consists of 0/6 sand in the case of a freestanding block. A change to a coarser material is necessary in the presence of a slope.

Installation is also accompanied by adequate comfort in the form of gravel lateral back-ups, the dimensional characteristics of which are present in the NF EN 14933 standard. A minimum thickness of said back-up is recommended in order to avoid infiltrates and physical damage to the blocks.

In the context of embankments supporting cyclic and/or rolling loads, at least two layers of EPS must be provided [3], since different alternating orientations will favor both the blocks' sliding resistance and the homogeneous behavior of the mass of polystyrene.

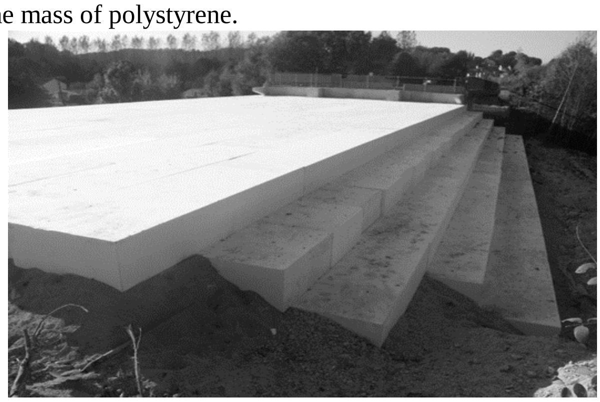

Fig. 2.Example or type KNAUF TP 120 EPS blocks in an embankment

Expanded polystyrene's vulnerability to rolling loads' direct physical aggression (in case of embankments supporting traffic) requires the addition of a reinforced concrete slab between 10 and 15 centimeters thick. [2] present this alternative as a solution to several possible problems relating to the EPS' nature, in addition to allowing a better supporting platform for traffic, reducing the need for a thick pavement structure.

Depending on the site's hydrological conditions, a network of drains may be necessary.

Several special precautions should be taken into account when using expanded polystyrene as embankment fill:

- Archimedes' push in case of embankments of which base can be overtaken by the water table;
- The amount of oxygen in the EPS in the event of fire or presence of ignition factors;
- The lateral effects of the wind which can cause the structure to overturn…

Prolonged exposure to ultraviolet rays (as much as several months) can induce slight degradation of the EPS blocks' surfaces, adding adequate protection against UV lights to the necessary precautions [4].

The durability of structures made of expanded polystyrene is very satisfactory: for example, several sites made of EPS material offer satisfactory performance with no pathological defects nor performance reduction during their exploitation, ranging in the case of the embankment on the compressible soils of the "Pont des Quatre Canaux" site for up to 35 years [5].

Also, and according to Norwegian experience (country using expanded polystyrene for the first time in embankments), the material exhibits good aging behavior and an improvement in its mechanical characteristics over time and compression load application, unlike the more commonly used granular materials [6].

Such durability can only be guaranteed within compliance with the material's constructive requirements, as well as correct protective measures against any possible physical or chemical aggressive factors.

Also, and in order to maintain the structure's minimum level of service, regular monitoring must be planned by the project manager. This monitoring consists of sampling possible deformations, visualizing damage on the blocks, abnormal mechanical behavior of the embankment, etc.

IV. METHODOLOGY

Since solutions commonly adopted in Morocco mainly target the supporting soil in order to improve its quality, it is necessary to show the increase in security factors that can be provided by EPS substitution. This will be achieved through direct comparison between landslide safety factors in this case study's embankments.

The chosen sites both present soils with high compressibility, with a considerably greater layer depth in the second case, in addition to a saturated clayey layer on top.

Water table levels are very close to the surface in both cases, which increases the risk of foundation instability.

At each point, two different embankment heights will be considered: heights of 15 and 10 meters for the PK8+650, and 13.5 and 10 meters for the PK10+500.

First, we will determine the effect of substituting embankment materials with expanded polystyrene on the structure's mass, thus giving an assessment of mass reduction rates in terms of substitution height.

Secondly, we will quantify the substitution's improvement of safety in these embankments by comparing obtained safety factors to those obtained by treating supporting layers using ballasted columns. Factors will be obtained using the Bishop model and the GEOSTUDIO SLOPE/W computing software.

Given the soil's compressibility, any sliding safety check must be done in both short and long terms.

Several substitution heights are possible, even entirely substituting the embankment by a structure fully made of EPS blocks. However, in our case, we will limit the study to assessing substitution results of three different levels: the first 3, 6 and 9 meters at the high-end of the embankment.

It should be noted that several variants of expanded polystyrene present mass reductions much greater than that which we chose (in our case, density is almost 95% of the soil's), but this one will be taken as being more prejudicial than the others from a masse's point of view. It is indeed possible to lower density below 1% of that of the embankment for certain types of EPS [3], all without affecting its ability to withstand traffic loads. Studies of EPS material's behavior showed that mechanical characteristics improve with increasing density, and that said material behaves well against fixed and cyclical loads regardless of chosen density [7].

Choosing expanded polystyrene over other materials such as extruded polystyrene or polyurethane is based on its favorable price compared to other options [2].

A gravel back-up will also be considered in our model: it will be integrated as permanent load, the contact interface of which will be riser-shaped to reduce slipping risks and facilitate access. Aforementioned back-up has a 17.7 density.

V. RESULTS

Mass reduction is one of the main reasons for EPS material use in embankment fills: having an appreciable mechanical resistance at greatly reduced mass, its inclusion in the body of the embankment becomes a necessity in case of unsuitable foundation soils.

This reduction was evaluated for the embankment of the 15-meter-high PK8+650 embankment, being the most massive. Results are shown in Table III.

Table- III: soil characteristics at the PK8+650

Fill height (m)	3	6	9
Weight reduction (%)	10.5	23.4	39.0

We note that aforementioned reduction can reach almost half the mass in case of high embankments, suggesting similar (or even greater) reductions in embankments of lower height.

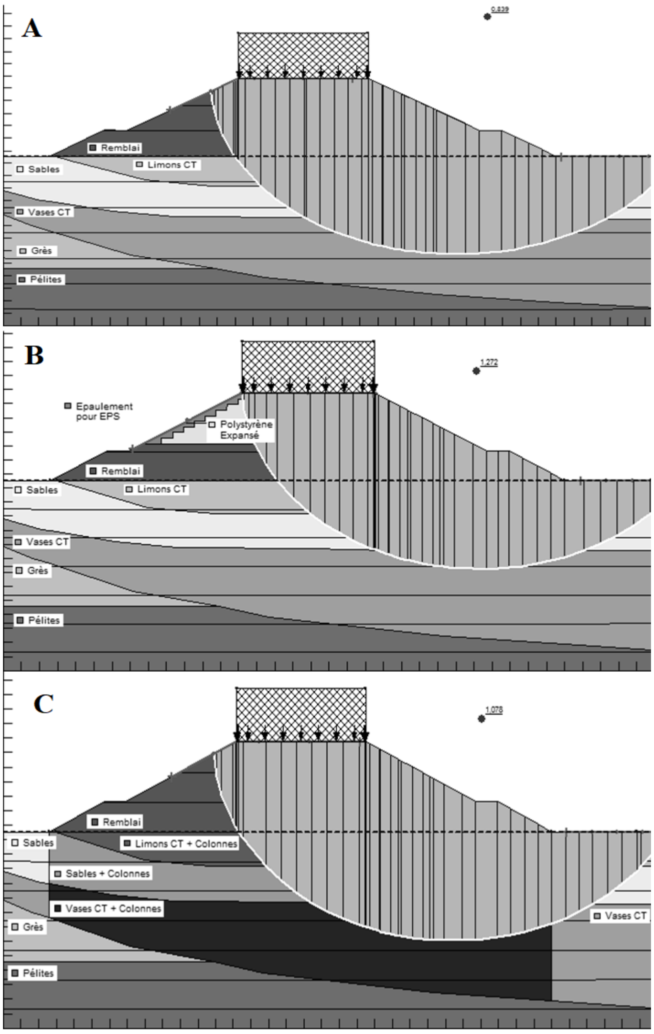

Fig. 3.Slide safety factor and associated slip surface of the 15-meter-high PK8+650 embankment at short term ; A: at its initial state, B: following a 9-meter EPS substitution, and C: following a ballasted column foundation treatment.

Results obtained for the evaluation of sliding stability factors were carried out using the SLOPE/W tool. Some of the studied cases with their respective estimated slip surfaces are exemplified in Fig. 3.

A comparative grouping of sliding safety factors by the Bishop method is shown in Fig. 4. For 10-meter-high embankments, use of EPS will be limited to only 6 meters: indeed, it would be better to consider the replacement of the entire structure in EPS material for higher substitutions.

We see that soil treatment by ballasted columns improves safety factors, justifying its choice for layers above the pelitic bedrock; but also see that the substitution in EPS, a considerably less laborious, more economical and faster process, allows numbers close to those obtained by soil treatment at low substitution heights.

Increasing EPS height in studied embankments directly increases the slide safety factor. We deduce that load reduction on the foundation yields better results than treating it, especially that the depth of the compressible layers in both cases is substantial.

The position of the embankment's substituted part also plays a role, but substitution of the upper part will be this study's alternative [8].

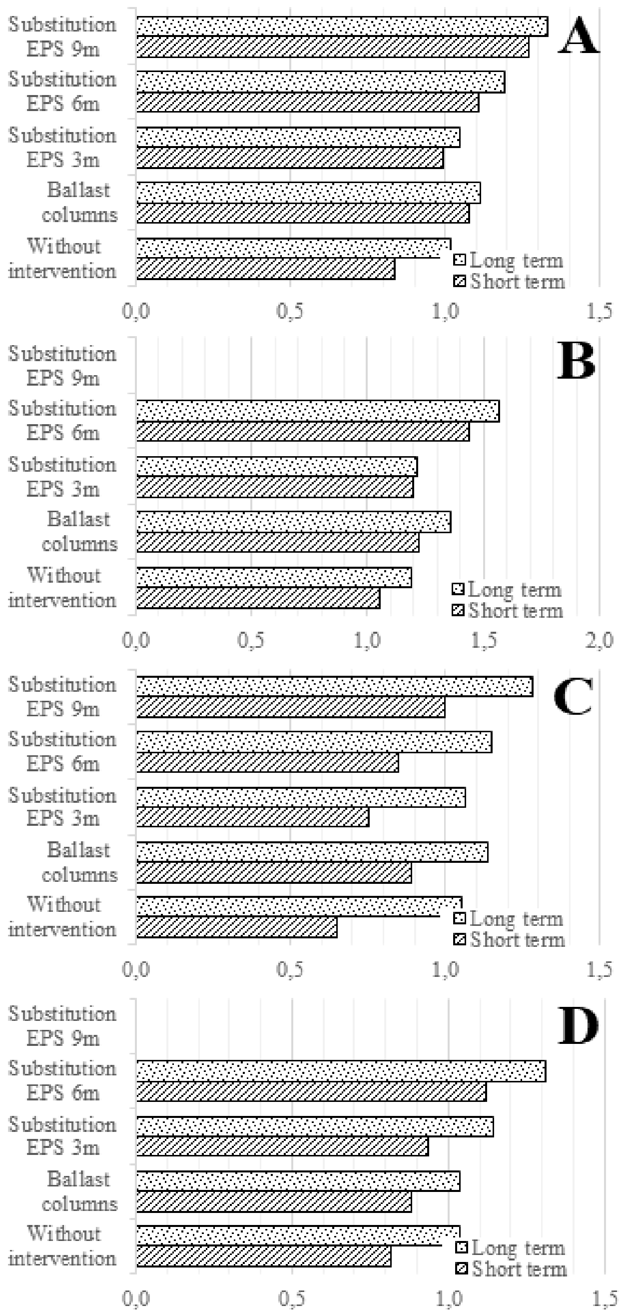

Fig. 4.Slide safety factors FS using the Bishop model in compute for the study cases. A: the 15-meter-high PK8+650 embankment, B: the 10-meter-high PK8+650 embankment, C: the 13.5-meter-high PK10+500 embankment, D: the 10-meter-high PK10+500 embankment.

In order to better compare studied solutions and to highlight the advantage of using EPS materials instead of ballasted columns, Fig. 5 illustrates improvement of computed safety factors of studied embankments when compared to the same structure undergoing no replacement nor supporting soil treatment.

An improvement of more than 50% can be obtained by applying a 9-meter-high substitution in the higher embankments on both foundations, but doesn't exceed 40% in the smaller structure.

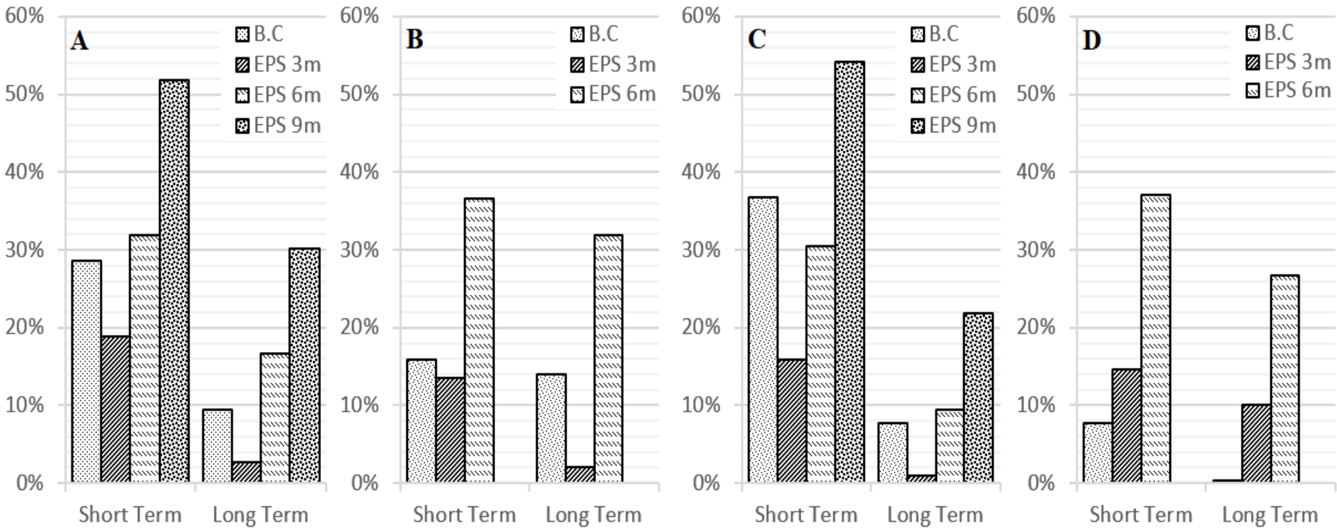

Fig. 5.Improvement percentages of safety factors of both EPS substitution and Ballasted columns (B.C) compared to the embankments' initial state. A: the 15-meter-high PK8+650 embankment, B: the 10-meter-high PK8+650 embankment, C: the 13.5-meter-high PK10+500 embankment, D: the 10-meter-high PK10+500 embankment

VI. DISCUSSION

In the silty support area, a 6-meter-substitution proves enough to exceed the level of performance offered by ballasted columns treatment for the higher embankment, and nearly doubles said performance for the lower one.

As for the clayey support area, and even after superficial drainage, soil treatment with ballasted columns remains much more efficient than substitutions below 6 meters. Ballasted columns do not provide similar performances in the lower embankment, again pinpointing the embankment's mass as being the most unfavorable parameter in this case.

The use of expanded polystyrene is a method still absent in Morocco, leaving conventional solutions (although often difficult to establish and always expensive) dominating soil structures' stabilization. However, in this study, it can be seen that the embankment itself plays the most unfavorable role, and that improving the foundations by use of ballasted column treatment is exceeded in terms of performance by lightening the structure, hence reducing the permanent load on the supporting soil.

With efficiency equal to or greater than that of ballasted columns, replacement with expanded polystyrene is a method which has not only shown its effectiveness in our study, but in several experiments outside Moroccan territory as well, all being with excellent durability and without pathological defects.

From a financial standpoint, it is difficult to compare between these two variants as it relates separately to each case. However, the implementation of EPS blocks is not only less laborious, but also reduces required soil volume (and as mentioned above, a lesser footprint) compared to a conventional embankment, meaning the deadlines will benefit from said choice for the end result, the commissioning of which must always be done as quickly as possible.

If we take into account the additional time required for the implementation and commission of the ballasted columns treatment phase, we can expect substantial deadline advancements, reaching several months before usual commission dates.

VII. CONCLUSION AND RECOMMENNDATIONS

This study was able to demonstrate the effectiveness of the EPS substitution method and its additional advantages, which would help to further increase the structure's slide safety factors: in fact, reduction in the embankment's width by replacing the higher part would also lead to a substantial reduction in its footprint and mass. This would also reduce the risk of differential deformations, which can be duplicated onto the fill's surface, damaging not only the latter, but also any road or rail structure above it.

Several other applications highlight the fact that EPS material can also be considered for widening works in case of stable embankments but presenting displacement reactivation risks under the structure itself (the A8 motorway widening case in the Siagne valley in Mandelieu, 1987) [6].

I addition to the mechanical advantage that this study shows, temporal and financial advantages make this method a viable solution which may prove beneficial in the Moroccan context, especially when considering the embankments' large mass in certain cases, coupled with the dominance of soils of poor behavior and characteristics along the main and the newly designed routes, requiring major interventions in the form of soil treatment which may be less effective and more time-consuming than the proposed solution.

However, it is recommended that the use of such material be accompanied by a suitable quality control: BEINBRECH and HILLMANN [8] detailed the properties subject to controls when it comes to EPS blocks used for road embankments, such as their physical state and geometrical dimensions, density and water absorption controls, as well as mechanical characteristics and evolution throughout the structure's serviceability period.

Adding to the recommendations, the introduction of this approach at the Moroccan level will also require the establishment of a control schedule including routine material properties checkup. Some of these checkups will have to be carried out directly by the supplier of said material in order to assess its durability and confirm its operating longevity.

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