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Site characterization for a new refinery in a disposal area for bituminous residue

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ABSTRACT: This paper presents and discusses results of the first 25 weeks of monitoring on trial embankments aimed to obtain parameters for foundation design for an industrial development. The area (60 ha) is covered by a thick (2÷6 m) layer of a material denominated "pitch", constituted by a mix of natural soil and residual bituminous material from past industrial processes. The design involves the construction of an embankment, 3÷4 meters thick, acting as a capping, and avoiding excavations and dewatering in the contaminated soil. For the estimate of parameters for foundation design, it has been deemed unrealistic to use the traditional correlations with the most common in-situ tests. Reliability of laboratory tests to estimate site behavior is also questionable. Hence, a monitoring system of three trail embankments has been built on an area (about 30 m width) that is reasonably representative of the stress increase in the operating conditions.

Development of industrial site utilizing neighboring areas generally represents a cost-effective and practical solution. However, it happens sometimes that areas nearby existing industrial facilities present severe environmental problems, especially in light of the existing Laws and Standards, which have become more stringent meantime. However, if the removal of such materials is not required by current Laws and Rules and it is impracticable or very expensive, the left-in-place solution, providing that environmental, health and safety countermeasures are taken, in compliance with local Laws, becomes attractive and viable. This is the case of the site in question, which has been used, through the decades, as disposal site for bituminous materials, mixed with the natural soil on site in various and uncontrolled percentages and methodologies.

The actual thickness of this layer of "pitch" material is ranging from 2 to 6 m, as an average. Its consistency range from relatively firm material (where the pitch has been mixed with high percentages of existing natural soils, constituted by silty sands and sandy silts), to almost "fluid" state, where very little, if no mixing at all, has been carried out. The pitch material overlies weathered limestone, becoming relatively intact at depth.

The basic project includes a capping of a clean, coarse grained material, 3÷4 m thick. In addition to the function of capping, this solution reduce issues related to future excavation/dewatering for foundation and underground services installation. The basic design problem related to this solution is the assessment of the potential settlement due to the compressibility of "pitch" material. This also defines the need and governs the design of soil improvement methods, and, in some case, requires the use of piles as foundation solutions.

Considering the peculiarity of the behavior of such materials, it has been concluded that the usual correlation between deformability parameters of natural soils and results of in situ tests (such as SPT, CPT or other) would results unreliable for the relevant case. Even more questionable would be the adoption of laboratory testing for the scope, involving some tricky problems related to the "undisturbed" sampling of this material and to the representativeness of the sample behavior with respect to the site conditions. In addition, the required duration of tests, that would unavoidably consider the expected "viscous" behavior of this "pitch", constitutes severe limita-

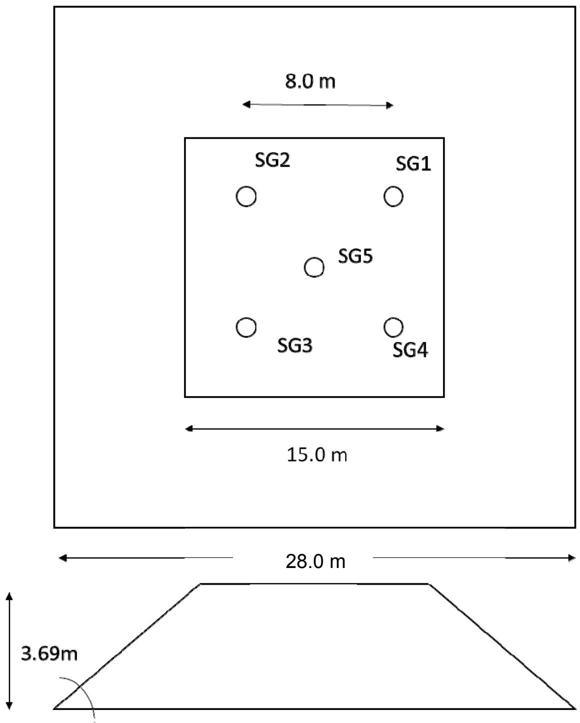

Figure 1. Plan arrangement of the settlement plates and typical cross section.

tions of this approach.
Owing the above, it has been decided to investigate the settlement behavior of this material erecting three trail embankments, having an height of in the range 3.5 to 3.7 m, and a square base of about 27 m. Adopting a slope of about 30°, the top of the embankment resulted in approximately 15*15 m in plan.
Under this conditions, it is reasonable to consider that the stress increase, in the centre of the embankment, is constant through the depth of the pitch material, even considering its maximum thickness of 6 m, such that the settlement of the centre of the embankment are representative of the effect of the construction of design final fill.

At the base of the embankment, 5 settlement plates have been installed, as shown in Figure 1, where a cross section of a typical embankment has been reported.

During embankment construction, the density was checked, indicating an average unit weight of about 17.5 kN/m3. The applied stress is therefore of about 65 kPa, that is considered as representative of the stress increase due to the design fill construction.

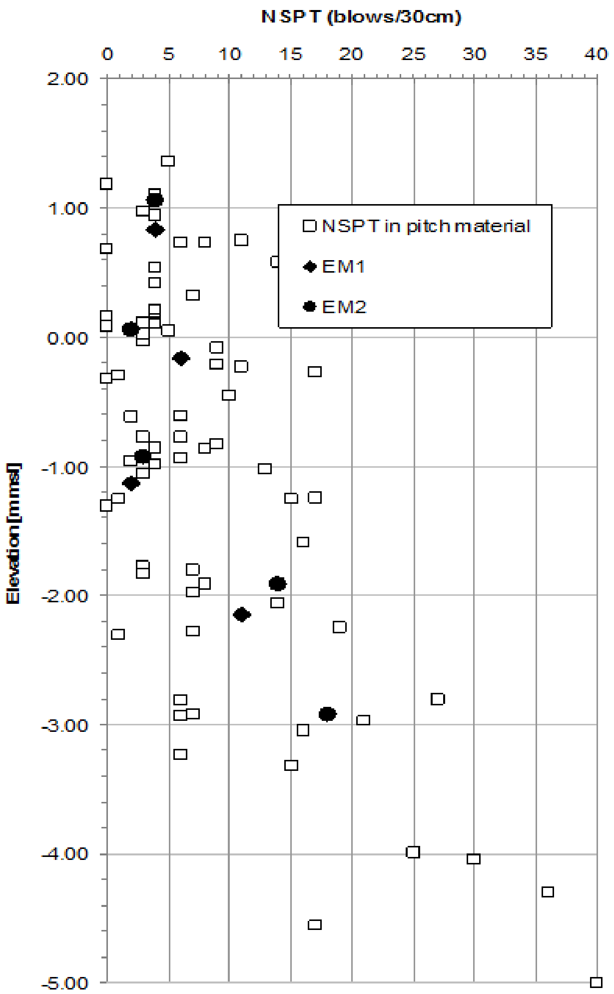

Figure 2. Results of SPT tests in the Pitch area and under EM1 and EM2.

1 RESULTS OF "TRADITIONAL" SITE INVESTIGATIONS

1.1 *SPT tests*

Figure 2 shows the results of the SPT tests carried out in the whole Pitch area, relative to about 27 boreholes, carried out in the pitch material only. Ground level in the area is ranging from 1.5 to 2.5 m msl.

Also reported in the figure are the results of the SPT carried out in the boreholes beneath embankment 1 and 2 (EM1 and EM2). Embankment 3 has been constructed on the area with very small thickness of pitch, and no SPT tests are available.
Maximum thickness of very soft pitch, having SPT of less than 5blows/30 cm, are in the order of 2-4 m.
As can be seen, the general pattern of NSPT indicate a fairly tendency of increasing with depth, therefore suggesting a "soil-like" type of behavior.
As can be seen, the conditions found beneath the EM1 and EM2 can be considered as representative as a reasonably "lower bound" condition of the site, with thicknesses of soft pitch material in the order of 2.5 to 3.5 meters.

The estimate of constrained modulus in soft soils on the basis of SPT can be carried out according to Stroud (1974), even it has been recognized during recent decades that these relationships lead to remarkable approximations (see for example Kulhawy and Mayne, 1990). In addition, these relationships do not allow for a definition of the development of settlements vs. time.

Using Stroud, and a multiplier coefficient of SPT equal to 5, one could obtain constrained modulus in the order of 1-2 MPa, for the lowest values of SPT (less than 5blows/30cm). This still leave great uncertainty in the estimate of settlement, in addition to give no information regarding the development of settlement during the lifetime of the structure.

1.2 *Flat dilatometer tests*

At three location beside the embankments 1 and 2 (EM1 and EM2), denominated A, B and C, flat dilatometer (DMT) have been carried out through the thickness of the pitch material. Results are reported in Figure 3, in terms of dilatometer modulus Ed as a function of elevation (ground level shall be taken at an elevation of +2 m msl, as an average).

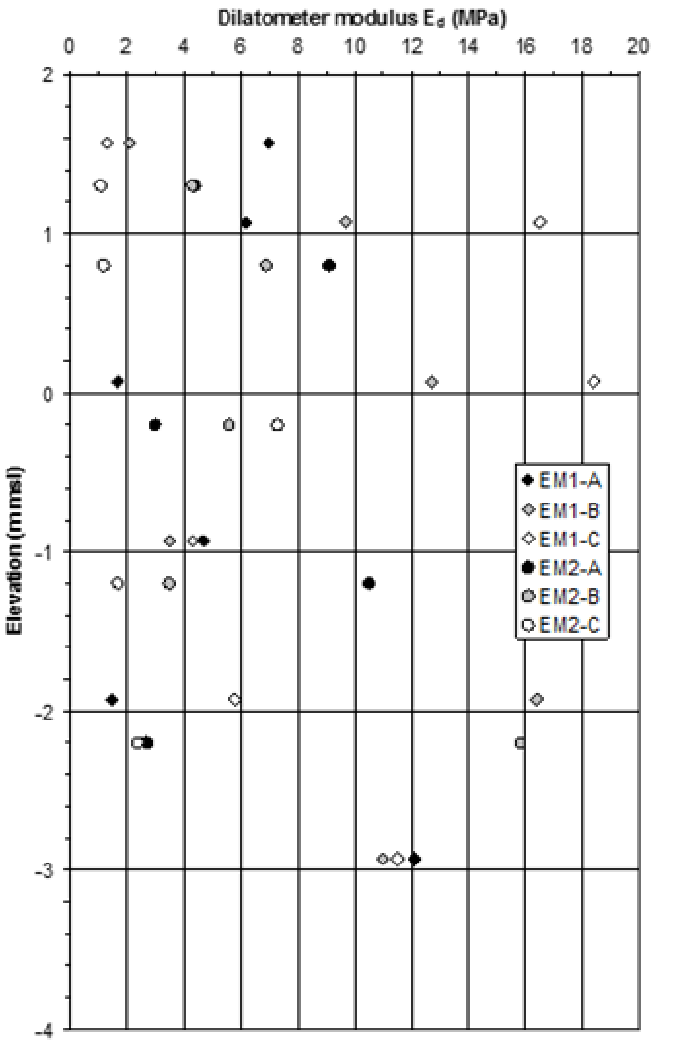

Figure 3. Results of DMT tests under EM1 and EM2.

For the reasons already discussed in the introduction, it is considered that the adoption of the usual correlation between the results of the DMT tests and the deformability parameters to be adopted for design (such as those proposed by Marchetti et al. (2001)) is questionable for the relevant location. It shall however be noted that results indicate that an interpretation using the correlation recommended for clayey soils gives values of constrained modulus M of few MPa, that shall be considered as reasonably representative of the expected values of this peculiar material. However, it shall be kept in mind that the long terms deformability could be of major importance for the settlement estimate at this location, and that DMT interpretation does not consider this contribution.

1.3 *Plate Loading Test*

Under the embankment EM1, a Plate Loading Tests (D=600mm), has been carried out, showing the result presented in Figure 4. Inferred operative Young modulus between 100 and 225 kPa is in the order of 5÷6 MPa. As it will be discussed later, however, this value of the modulus do not incorporate the "long term settlement" (due to evident practical restriction in time for the conduction of in situ tests), and therefore the above values of modulus cannot be taken as a safe estimate of the operative parameters for foundation design.

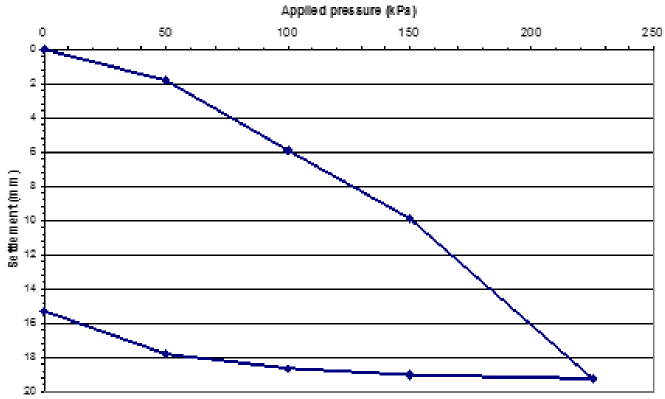

Figure 4. Results of PLT D=600mm under EM1.

As can be seen, the settlement recovery upon unloading is very small, indicating that a remarkable yielding of the pitch material took place.
Similar results have been found at other locations, showing different values of Young modulus, but all showed a very small recovery upon unloading.

2 EMBANKMENT SETTLEMENTS

Figure 5. Picture of trial embankment

Figure 5 shows a picture of one of the embankments at the end construction.
Figures 6 and 7 show the settlements of the various plates installed beneath EM-1 and EM-2. Settlement monitoring started immediately after the end of the construction of the embankment. Therefore, the "immediate" settlement has not been measured.
In relation to the observed pattern of the settlement vs time, the following is noted:

- Embankments 1 and 2 are located in similar soil conditions, i.e. with pitch material with low consistency (i.e. NSPT≤ 5 blows/feet) in the order of 2.5÷3.5 m thickness. Reasonably, they also show similar results, being the maximum settlement in the order of 65 to 70 mm.

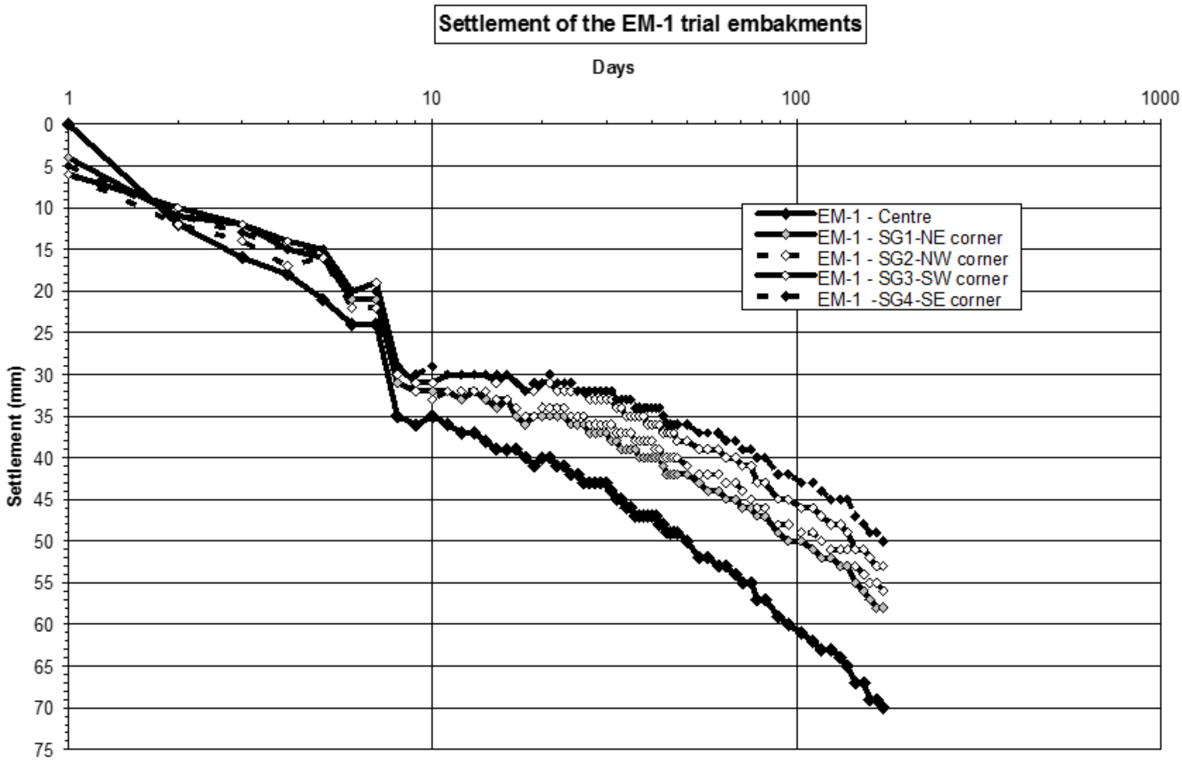

Figure 6. Settlement records of EM-1.

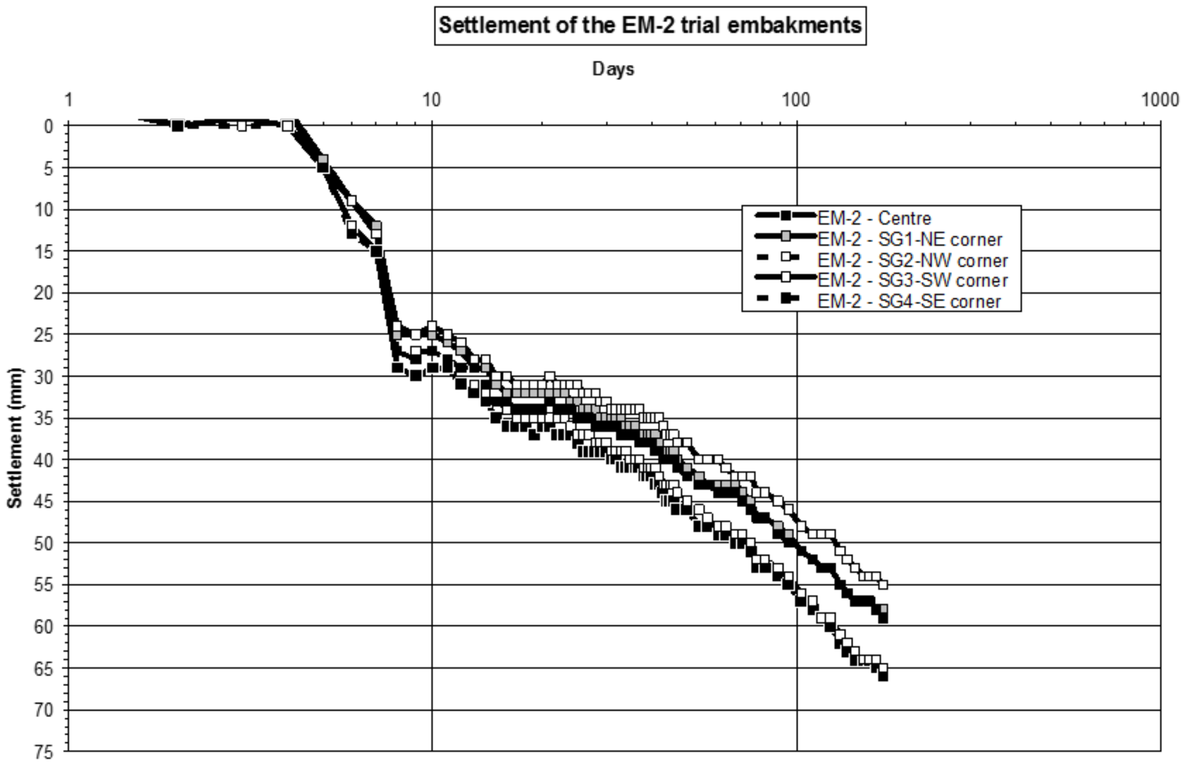

Figure 7. Settlement records of EM-2.

- Settlement vs time curves for EM1 and 2 show two different slopes: in the first part, immediately after the end of construction (about 10 days), settlement rate is relatively fast and irregular. In both cases, the settlement of the centre is equal to about the half of what measured up to now. It can be assumed that these settlements shall be interpreted as being mainly dominated by the "consolidation" component, it the sense of a re-arrangement of the structure of the material due to the induced change in effective stress.
- About 10 days after, the settlement curves show a more regular pattern. It is supposed that this second part is mainly governed by the viscous compressibility of the pitch material.
- The records show a tendency of an acceleration of the settlement rate with log of time, for all points. This is consistent with found by Soleimanbeigi et al. (2014), A.,Soleimanbeigi and Tuncer (2015), and by Viyanant et al (2007), during the execution of oedometer tests on bituminous material mixed with sand or fly ashes, and on recycled asphalt shingle.
- Also, data suggest that the slope of the curve is lower for corner points, where the stress increase is also small. This is also consistent with the aforementioned laboratory findings, that indicate that the value of $C\alpha\varepsilon$ (where $C\alpha\varepsilon = \Delta\varepsilon/\Delta\log t$) is dependent on effective stress level.
- As expected, the settlement at the center is greater than the ones at the corners. This is certainly true for EM1, while for EM2 the NW corner settled almost identically to the center. This is possibly due to a particularly unfavorable soil condition at that location.

Based on the above, it can be assumed that the "viscous" component of the settlement is the remarkable part of the settlement. Actually, not being recorded the "immediate" settlement upon construction, it is not possible to establish the actual percentage with respect to "consolidation" process. However, the absolute value of these settlements, after 200 days from the end of construction, is equal to 35 mm at the centre for both embankments, showing possible increasing in settlement rate in the *s-log t* plot.

Even if these findings are consistent with literature data, it shall be considered the peculiarity and variability of the soil condition at the relevant site, and the differences with the typically carefully controlled conditions of the laboratory. Therefore, this tendency shall be confirmed by additional monitoring data relative to longer period of observation.

For what design considerations are concerned, it shall be considered that, in the engineering practice, a limit of 25 mm is usually taken as an allowable limit for the "post-construction" settlement (i.e. the settlement that the structure experiences during its lifetime).

It can be observed that the settlement occurred in the first 200 days after the end of the construction of the embankments already exceed this limit. If this tendency will be confirmed by additional data, this involves considerable design consequences, and in particular:
- the most loaded structures will require the support of foundation piles;
- some smaller and ancillary structures, or other structures that typically accept higher settlements (e.g. steel tanks), could be founded on improved ground (for example, installing stone columns);
- the estimate of the long-term settlement of the platform can determine the need or not for soil improvement under areas of remarkable extension, such as those occupied by roads, paved areas and storage areas. For these areas, it will be then decided whether to accept the estimated settlement, possibly providing occasional interventions aimed at the preservation of the functionality of the area, or if a soil improvement is required, with a dramatic increase in foundation costs.

It is finally observed that under no circumstances this observed behavior would have been reasonably predicted by the usual method methods of investigations.

3 CONCLUSION

The monitoring of the settlements of two embankments, 3.7 m, built on top of a layer of material constituted by a mix of soils (sands and silts), and bituminous wastes, 5 to 6 meters thickness, overlying stiff limestone, indicate a remarkable component of a "viscous" settlements.

After 200 days from the end of construction, the total measured settlements is in the order of 65-70 mm, half of which is reasonably attributed, on the basis of the pattern of the log t vs settlement plot, to a "viscous" component. Settlement rate in the s vs. log t plot shows some sign of increasing with time, supporting literature findings coming from laboratory tests.

Practical implication of such amount of settlement, and the pattern of settlement in time, are dramatic in the definition of the foundation works, and soil improvement, in the light of the use of this area for industrial facilities development.

The area of the embankments has also been investigated with SPT tests, PLT's and DMT tests. Values of deformability parameters obtainable from these tests, using the available correlation in the literature, where not able to predict the actual behaviour of the embankment, with particular reference to the amount of settlements in the long-term conditions.

Therefore, in the relevant case, only the monitoring of these settlements, for a remarkable period of time, can give reliable and useful indications regarding foundation design.

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