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Foundation of a Coal/Coke Stockyard on Soft Soil with Geotextile Encased Columns and Horizontal Reinforcement

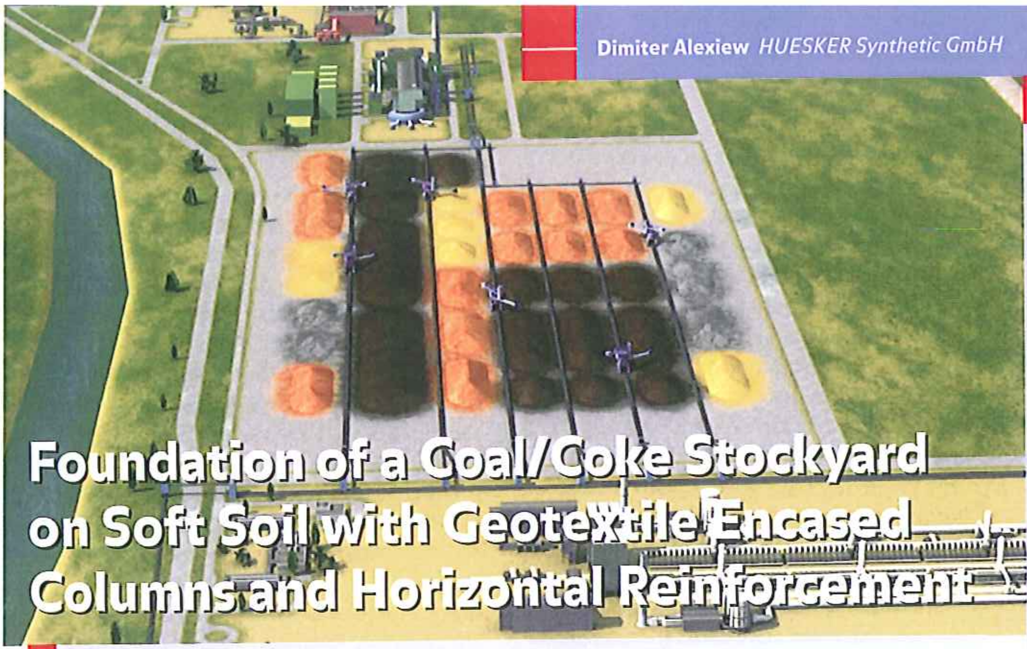

Figure 1 TKCSA steel plant: partial overview, in front the stockyard with stockpile beds and runways with stacker/reclaimers.

Summary

ThyssenKrupp Steel (TKCSA: ThyssenKrupp Siderúrgica do Atlântico) is building a steel plant in the lowlands at the Brazilian seashore near Sepetiba – an overview is given in Glockner et al (2008) – inclusive of a 380.000 m² stockyard for raw materials. The area consists of soft soils of very low bearing capacity and a thickness of up to 20 m; the ground water level is just below the surface. Beside the stockpiles of ca. 13 m height, the stockyards also include runways (RW) for the so called stacker/reclaimers (S/R) similar to the heavy excavators in open mining *(figure 1)*. The focal point of this publication is the foundation solution for the coal/coke stockpiles and the RWs under these extremely problematic conditions.

Geotechnical conditions

Most critical is the very soft 'upper clay' in the first ca. 8 to 10 m *(figure 2)* being saturated, of high plasticity, low consistency and normally consolidated with the following main parameters: oedometric modulus $E_{s,E}$ [MN/m²] = 0,1 + 0,06 • t with t = depth [m], say only ≈ 0,2 - 0,5 MN/m², c_v = 2-4 · 10^{-8} m/s, and an undrained shear strength of only c_u = 5-15 kN/m².

After heavy rains the terrain is under water. Because under such conditions construction activities were practically not possible, at the beginning a sand platform with a thickness of ca. 1,5 to 2 m was dredged on the entire area.

Additional difficulties

The calculated local and global stability of the stockpiles and the runways was completely insufficient, and the settlements and displacements were far beyond the acceptable limits as well. Additional specific significant difficulties resulted e.g. from the changing shape, geometry and positions of the stockpiles, the fast loading-unloading process under operation (0 to >100 kN/m² surcharge), the moving and rotating 750 tons S/Rs and the strictly limited allowed dispalcements of any type of their sensitive RWs *(figure 3)*.

An optimized solution had to consider not only technical aspects, but also costs, the very limited time for execution of ca. two years for a 380.000 m² area, the different requirements for different zones, logistic aspects and the availability of different techniques in Brasil.

Foundation of coal/coal stockpile beds

Local and global stability had to be adequate, settlements and settlement differences had to be reduced and especially the horizontal displacements ('spreading') from the stockpiles outwards to the RWs had to be minimized to acceptable values. The 'spreading' is of critical importance. It endangers not only the stability but also the proper operation of the S/Rs being of key importance for the entire steel plant. Ultimate (ULS) and serviceability limit state (SLS) calculations were performed for different shapes and positions of the stockpiles and the S/Rs during stockyard operation for the two main axes: N-S and W-E *(figure 3)*. Analytical and numerical analyses were performed and the results compared. In all cases and directions the analyses resulted in the necessity of horizontal geosynthetic reinforcements in both directions: N-S & W-E. The required short- and long-term tensile stiffness of the reinforcements and

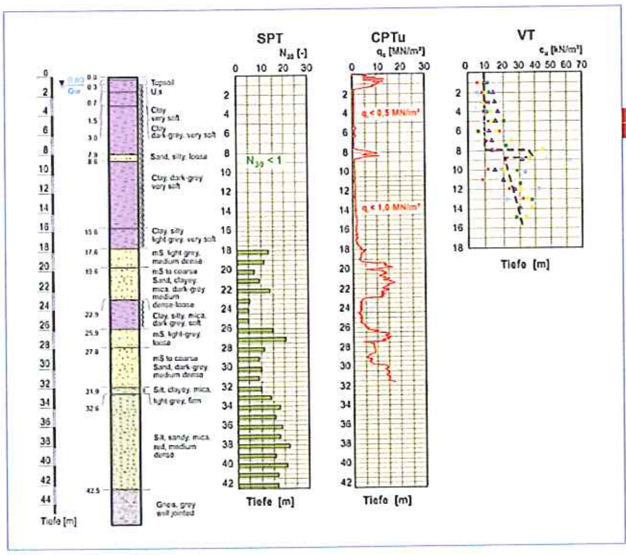

Figure 2 Typical geo-technical conditions.

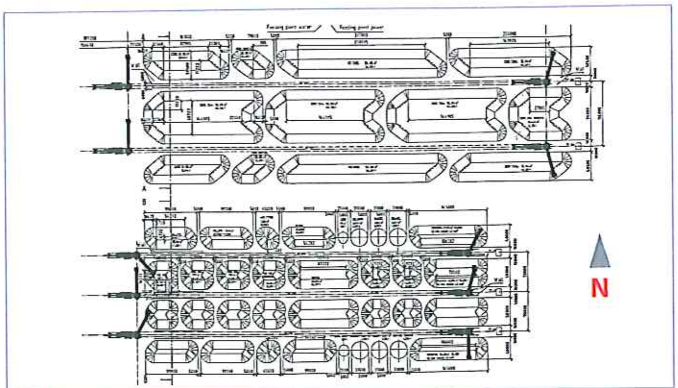

Figure 3 Stockyard; up (North) coal/coke, down (South) ore/additives, runways for the stacker/ reclaimers running West-East.

their design strength are in all cases quite high (see below). To provide sufficient tensile stiffness in an efficient way geosynthetics made from high-modulus low-creep polyvinylalcohol (PVA) were found to be optimal (Alexiew et al, 2000). Generally the optimized solution is as follows: woven PVA geotextile '**Robutec**®' unrolled transverse to the W-E axes of the stockpile beds *(figure 3)* and continuing under the RWs, followed by a 15 cm thick compacted intermediate sand layer and PVA geogrids '**Fortrac**® M' laid the parallel to the W-E axes. The short-term strengths are ranging from 500 kN/m to 1600 kN/m. Additional factors were considered for the final optimized solution: customized production of the reinforcements to save costs, an optimum between differentiation and unification, long rolls to avoid overlaps in the main bearing direction, sufficient bond coefficients of reinforcement etc. Below the stockpiles strip drains are foreseen to accelerate consolidation. Precise installation drawings were made to ensure the high quality of construction and to save the cost of excess materials for the client by producing project-specific roll lengths. All geosynthetic rolls were given labels in the factory showing project- and location-specific descriptions.

Runways for the stacker/ reclaimers (S/R_s)

The runways are wide railway tracks loaded by the moving and rotating S/Rs of 750 tonnes *(figure 1 & 4)*. All deformations (settlements, differential settlements, tilting and lateral displacements) are strictly limited. Analytical stability and bearing capacity calculations with parallel FEM analyses were carried out in a similar manner to those for the stockpile beds. The main problem herein was to ensure the low deformability after a short construction time even without any temporary overload, combined with moving loads (S/R) under operation. The optimum solution found for the runways are sand-filled geotextile-encased columns (GEC) creating a stable and stiff enough, but in the same time ductile and self-regulating system [Alexiew et al 2005, Raithel et al 2005]. All calculations were carried out based on the Raithel's method [Raithel 1999 & 2005] and the draft EBGEO recommendations [EBGEO Draft 2007]. The diameter of GEC is 0,78 m, the length is ca. 10 to 12 m, the axial grid spacing mainly 2,0 x 2,0 m. They pass through the very soft Upper Clay (figure 2) and found in the better sandy intermediate layer. As geotextile encasements the products Ringtrac® 100/250 and 100/275 are used [Alexiew et al 2005]. A discussion point was the long-term behavior of the GECs under the heavy S/Rs moving over them, with a great difference between dead and live load (rather stochastic, large amplitude pulsating load). These thoughts were dismissed among other reasons because of the study of Di Prisco et al 2006, which found that GECs stiffened after loading-unloading cycles. Figure 4 shows a partial cross section of the actual solution for both the coal/coke stockpile beds and runways.

Final remarks

Since February the first S/R and a part of the coal/coke stockpile beds are under operation. First preliminary survey and measurements confirm among others the low deformability of the runways and the low 'spreading' of the stockpiles and generally the suitability and effectiveness of the concepts, design, optimized solutions and materials described.

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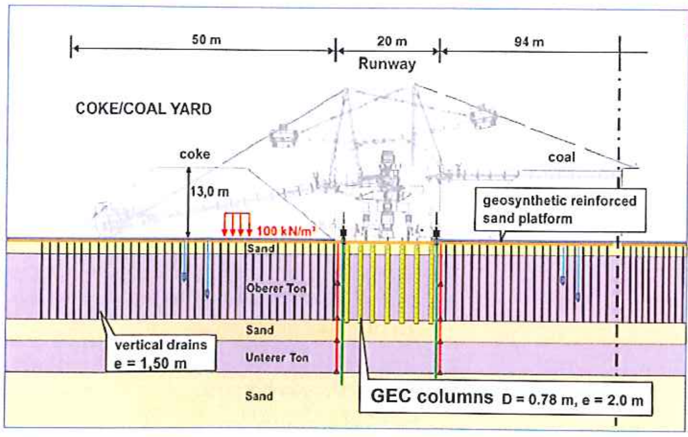

Figure 4 Typical solution for the coal/ coke stockpiles and runways.

Figure 6 Recently installed sand-filled geotextile-encased column (GEC) using Ringtrac® 100/250.

Figure 5 Placed reinforcement: longitudinal (W-E) PVA Fortrac® 800 M geogrid, transverse (N-S) PVA Robutec® 1600 woven with an intermediate sand layer.