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12-13 October 2017 | LNEC Lisbon | Portugal

Improvement Reinforcement and Rehabilitation of Transport Infrastructures

12-13 October 2017
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Edited by

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Improvement, Reinforcement and Rehabilitation of Transport Infrastructures

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EXTENDED ABSTRACTS BOOK

Organized by
Portuguese Commission on Transportation Geotechnics (CPGT)
Portuguese Commission of Geosynthetics (IGS Portugal)
Portuguese Geotechnical Society (SPG)

With the support of

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Preface

The Portuguese Commission on Transportation Geotechnics (CPGT), Portuguese Commission of Geosynthetics (IGS Portugal) and the Portuguese Geotechnical Society (SPG) organized the 1st Seminary on Transportation Geotechnics " Improvement, Reinforcement and Rehabilitation of Transport Infrastructures", that took place in the Laboratório Nacional de Engenharia Civil, Lisbon, in 12-13th October 2017.

Taking into account the planned investments in transport infrastructures and the importance of ensuring the principles of circular economy applied to civil engineering works, this seminar aims to present, with emphasis on innovation, sustainability and work cases, geotechnical solutions for improvement, reinforcement and rehabilitation of transport infrastructure, including roadway, railway, airport and sea-port infrastructures, as well as the structures and infrastructures located in the vicinity of the former.

The Editors,

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THE USE OF COMPACTION GROUTING ON GROUND IMPROVEMENT SOLUTIONS FOR TRANSPORTATION INFRASTRUCTURES

Goran Vukotic
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1. INTRODUCTION

In this presentation will be exposed the most important details of compaction grouting process, its field of application and limitations, quality assurance, etc. Various projects with selected details and advantages that present the use of compaction grouting on ground improvement solution for transportation infrastructure will be presented also. Based on these practical examples the basic framework for the design, execution and monitoring will be outlined.

The compaction grouting process, which was developed in USA during the 1950 is getting more and more acceptance in Europe since 1990. During this long period of application, a lot of experience was gained with this technology and enormous progress was made pushing forward boundaries and limitations for its application. The continuous development has been experienced not only regarding design methods and standards, but also equipment to carry them out in practice.

Originally compaction grouting had been used mainly for the foundation stabilisation and rehabilitation of settlement sensitive existing structures, but in last decades the field of its application has been considerably extended. Nowadays this technique is used for general improvement of soils with insufficient bearing capacity and low relative density, cavity grouting and liquefaction mitigation. In general this technique is used to repair natural or man-made compaction deficiencies in various types of soil formation, loose granular soils above or below the groundwater table, loose non-saturated fine grain soils, collapsible soils and voids in soil or rock.

2. COMPACTON GROUTING PROCESS

When applying the compaction grouting process usually a stiff to plastic grout is injected into the soil under pressure. It expands in the soil as a relatively homogeneous mass and at the same time is forming almost ball-shaped grout bulbs while the soil surrounding the grouted area is displaced and at the same time compacted. Compared to other grouting techniques, the grout material neither penetrates into the pores of the in-situ soil. During the compaction grouting process pressure and grout quantity as well as possible deformations at ground surface, respectively at structures are monitored. Depending on the design requirements, the compaction grouting process will be terminated either when reaching a maximum pressure, a maximum grout volume, when achieving the desired or maximum programmed uplift of the structure or working platform. The execution method of the compaction grouting process is laid down in the European Standard EN 12 715.

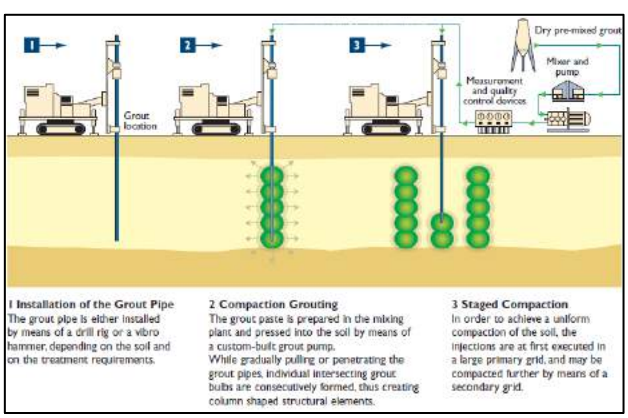

Figure 1. The compaction grouting execution process

3. ACCESS TO THE TRAIN STATION SANTS, BARCELONA

The analysis of several solutions with the object to guaranty bearing capacity, to limit settlements of the railway corridor coverage structure and to avoid possible damage to the existing HST (*High Speed Train*) tunnel, yielded that soil improvement by compaction grouting was the more adequate solution. It is important to emphasize that other very important conditioners were considered as well: soil characteristics, geometry and other particular limitations.

During the presentation the most important design, execution and monitoring details will be developed.

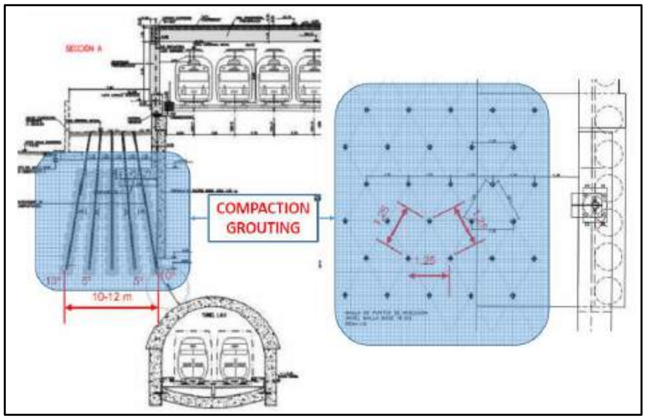

Figure 2 and 3. Adopted solution: Typical section and layout; compaction grout equipment and installation.

4. SOIL IMPROVEMENT OF THE HST EMBANKMENT, SANT CELONI (SPAIN)

In order to limit progressive settlements and guaranty the stability along 100 m of the existing HST embankment T-2 in Sant Celoni (Spain), Keller proposed and executed soil improvement by compaction grouting. The treatment was performed to a depth of 6,0 to 12,0 m, depending on the geotechnical characteristics of the materials that formed the embankment and according to its geometry in the affected areas. The basic or primary grid of the treatment was 2,4 x 2,4 m (see Figure 4 - blue compaction grouting columns). In addition, it was reinforced in the central embankment area by the secondary grid distributed at 2,4 x 2,4 m also (see Figure 4 – green compaction grouting columns).

Due to the limitation and restrictions that presented the project, particular attention had been paid to the formation of the adequate working platform, calibration and control of the execution parameters, monitoring of the possible HST tracks displacements and movements of the embankment in general.

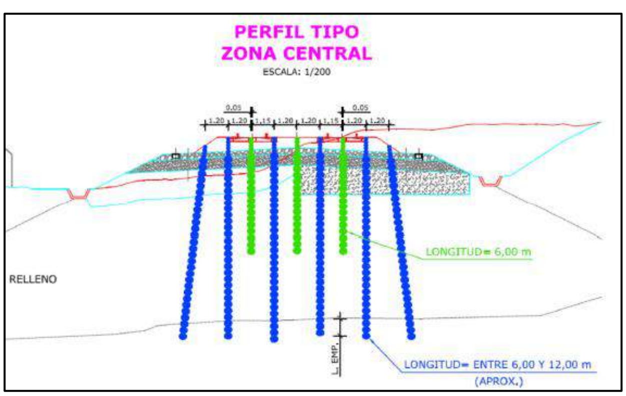

Figure 4 and 5. Adopted solution: Typical section; compaction grout equipment and installation.

EUROPEAN STANDARDISATION FOR SOIL TREATMENT IN EARTHWORKS

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EXTENDED ABSTRACT

In the past, Standardisation for Earthworks has been mainly organized at national level. National experience was adapted to local grounds and climates, thus covering a part only of all existing situations. The idea of creating standards covering the whole field of earthworks at European level was suggested about fifteen years ago and it first met some resistance, each national community being convinced that their own traditions were the best and nothing could be anticipated from international cooperation (Gomes Correia and Magnan, 2012). Fortunately, a CEN Committee (CEN 396 Earthworks) has now been working for eight years. The works aim at sharing national practices and creating a common framework, which keeps easy access to national experience and enables to share possibly better practices (Gomes Correia and Magnan, 2012).

With the creation of this Technical Committee, several European Standards within the framework series of EN 16907 on Earthworks will be published covering:

— Part 1: Principles and general rules;

— Part 2: Classification of materials;

— Part 3: Construction procedures;

— Part 4: Soil treatment with lime and/or hydraulic binders (this document);

— Part 5: Quality control;

— Part 6: Land reclamation with dredged hydraulic fill;

— Part 7: Hydraulic placement of mineral waste.

This presentation is focused only to the soil treatment in layers, produced for earthworks in situ or from a mixing plant, as opposed to the deep treatment, by columns for example. The objective of soil treatment is to enhance the properties of materials with poor geotechnical characteristics for use as a construction material in earth structures or in specific applications like capping layers. The treatment is applied for two main purposes: soil improvement when the short term performance is the objective, or soil stabilisation if medium and long term performance are to be accomplished mainly through a couple of mechanical properties associated with strength and stiffness.

Although the soil treatment technique has been used for a long time, its application at a large scale, for the construction of earth structures, started in the 1960s. Its application in Europe was more oriented for soil improvement while in the USA more oriented for soil stabilisation.

The part 4 developed by the CEN Committee actually covers both improvement and stabilisation and is presented in PrEN 16907-4:2015 "Earthworks. Part 4. Soil Treatment with Lime and/or Hydraulic Binders". It covers mainly the following items: (1) Constituents and mixtures; (2) Laboratory testing methodology; (3) Performance classification of the mixtures; (4) Execution and control. The materials covered are: soils, weak and intermediate rocks (including chalk), recycled materials, and artificial materials. They can also be mixes of these different types. soils, weak and intermediate rocks (including chalk), recycled materials, artificial materials. They can also be mixes of these different types. The hydraulic binders covered are: cement, granulated blast furnace slag and hydraulic road binder.

The content aims to describe the requirements to the success of a treatment operation, as well as good practices that closely depend on local geological and climatic conditions. Thus, in addition to those requirements, notes of guidelines of good practices are also included in or presented in some of the 14 annexes.

This presentation will be focused more in the performance based tests for stabilised soils, mainly advanced non-destructive seismic test methods for mechanical performance evaluation, in laboratory and in field (Silva et al., 2014;

Santos et al, 2015). It will also highlight international experience using roller integrated continuous compaction control. Finally, recommendations are proposed to assure that the solution of soil treatment will be based in sustainable principles (Gomes Correia et al, 2016).

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EUROPEAN STANDARDIZATION IN THE FIELD OF SPECIAL GEOTECHNICAL WORKS: CURRENT SITUATION AND ITS IMPACT IN PORTUGAL

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EXTENDED ABSTRACT

The presentation shows the current situation of European standardization in the domains bellow referred to and its reflection on the Portuguese normative.

According to the Portuguese legislation in force, the Comissões Técnicas de Normalização (CT) are technical bodies that aim "the drafting of normative documents and the issuance of normative opinions in certain domains and in which volunteers and interested entities on the matters concerned participate, reflecting as far as possible a balanced representation of the socio-economic interests covered by its scope", as per IPQ-RPNP – 030/2014, version 2/ 2014.

The CT 156 – Geotecnia em Engenharia Civil has as its target the "monitoring of all standardization activities of European and international scope, relating to all aspects of Civil Engineering involving Geotechnics, regarding the techniques of execution, testing, exploration and characterization of geotechnical works ", and its Subcommittee 010 (SC 10) is monitoring the similar activities of the European and International Technical Committees (TC), namely:

i) the CEN/TC 288 - Execution of special geotechnical works which scope is the ”Standardization of the execution procedures for special geotechnical works (including the testing and control methods of the procedures) and of the required material properties”;
ii) partially, the CEN/TC 341 - Geotechnical Investigation and Testing dealing with the “Standardization in the field of geotechnical investigation and testing relating to equipment and methods used for drilling, sampling and field and laboratory testing”;

as well as the translation of the different standards into Portuguese language that afterwards will become Portuguese norms (NP EN…).

References

IPQ: http://www1.ipq.pt/PT/Normalizacao/Pages/Normalizacao.aspx

CENTC288:https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:6269&cs=142DFBD862641F5760BAC160BC3EF62BA

CEN TC 341: https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:404517&cs=1F3FE96F5DAF6930D9DDDDE926415BA7F

ISO TC 182: https://www.iso.org/committee/54054.html

NUMERICAL ANALYSIS OF SOME SOLUTIONS FOR CONSTRUCTION OF EMBANKMENTS ON SOFT SOILS

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EXTENDED ABSTRACT

The construction of motorways, railways and airports frequently requires the rapid building of embankments on areas with poor geotechnical characteristics, such as low strength, high compressibility and low permeability. In general, these embankments experience stability problems and large displacements. To minimize these adversities, various improvement techniques are often used, such as: vertical drains, gravel columns, preloading, deep soil mixing columns, etc. In this paper, the behaviour of a road embankment built on the soft soils of the "Baixo Mondego" is analysed, comparing field data with the numerical results obtained considering staged construction with vertical drains and two additional methodologies: gravel columns and deep soil mixing columns. The modelling of those techniques is performed with the finite element code Plaxis based on the constitutive Soft Soil model (soft soil) and Mohr-Coulomb criterion (embankment).

The site under consideration is located in Portugal at km 7.775 on the A14 motorway, the geotechnical profile is shown in Fig. 1. Alluvial sandy-silts and clay-silts were found over limestones. The water table is located 0.5 m below the ground surface. The soil foundation was instrumented by the following equipment: (i) a subvertical inclinometer tube at the foot of the main slope; (ii) three settlement measuring plates (T_1, T_2, and M_1); (iii) and an electric piezometer (P).

The method of staged construction (SC) associated with vertical drains is intended to simulate the field conditions. Thus, in order to accelerate the consolidation (Fig. 1), pre-fabricated vertical drains (PVDs) were installed in a quadrangular pattern with a spacing of 2.2 m. The geotextile strip drains used are 100 mm wide and 3mm thick. The construction sequence for the embankment is subdivided into six sublayers, corresponding to elevations 1.1, 1.85, 3.45, 4.7, 7.55, and 8.1 m, applied at times 0, 80, 240, 290, 385, and 420 days, respectively.

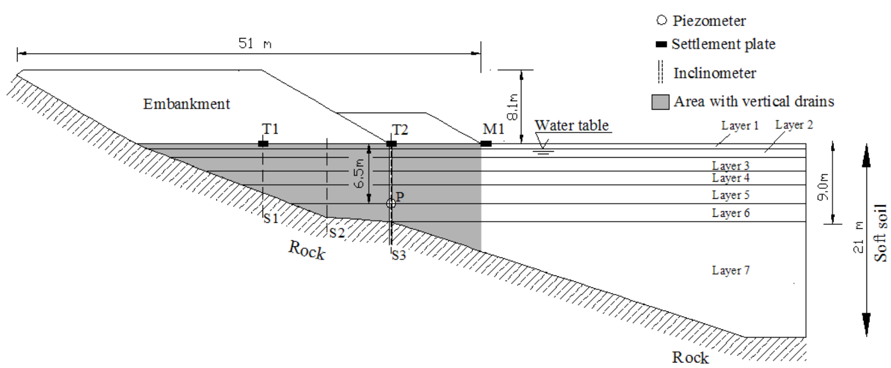

Figure 1. Geotechnical profile of the embankment with the PVDs (Venda Oliveira et al., 2010, 2013).

The solution applied in the field (SC with PVDs) is compared with two additional methodologies, gravel columns (GC) and deep soil mixing columns (DSMC). In both cases, the columns have a diameter of 1.0 m and a distance between columns of 3.0 m, in a square pattern (Fig. 2).

The three cases studied are numerically modelled in the plane-strain analyses. The flow induced by the PVDs is simulated by an equivalent overall coefficient of permeability based on Venda Oliveira et al. (2010). The GCs and DSMs are simulated by walls of an equivalent material, in accordance to Zacarias (2016) and Zacarias et al. (2016).

Figure 3 compares the numerical results obtained from the three numerical cases with field data, in terms of evolution of the settlement on plate T_2 (Fig. 3a) and horizontal displacement under the foot of the main embankment slope (Fig. 3b). It is observed that the numerical results of the SC associated with PVDs reproduce the embankment behaviour, in terms of settlements and horizontal displacements, satisfactorily. The results obtained with the GCs show that the GCs behave like giant drains, since they induce the fast dissipation of the excess pore pressures. Additionally, the GCs, in comparison with the method of SC with PVDs, induce a decrease in the settlement after the consolidation process and a superficial horizontal displacement similar to that obtained with SC, although with lower magnitude at depth. The use of DSMCs promotes a high decrease of the settlement and horizontal displacement in relation to the other two methodologies.

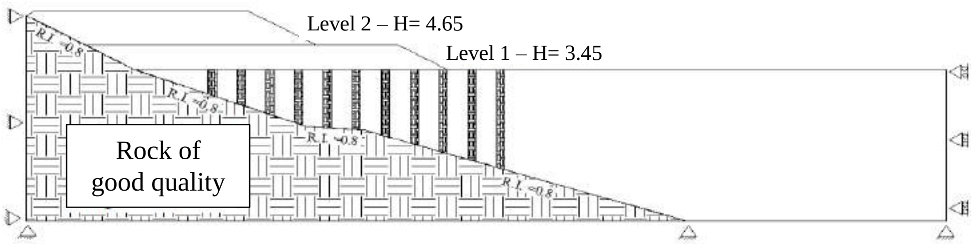

Figure 2. Scheme used to simulate the gravel columns and the deep soil mixing columns (based on Zacarias 2016; Zacarias et al. 2016).

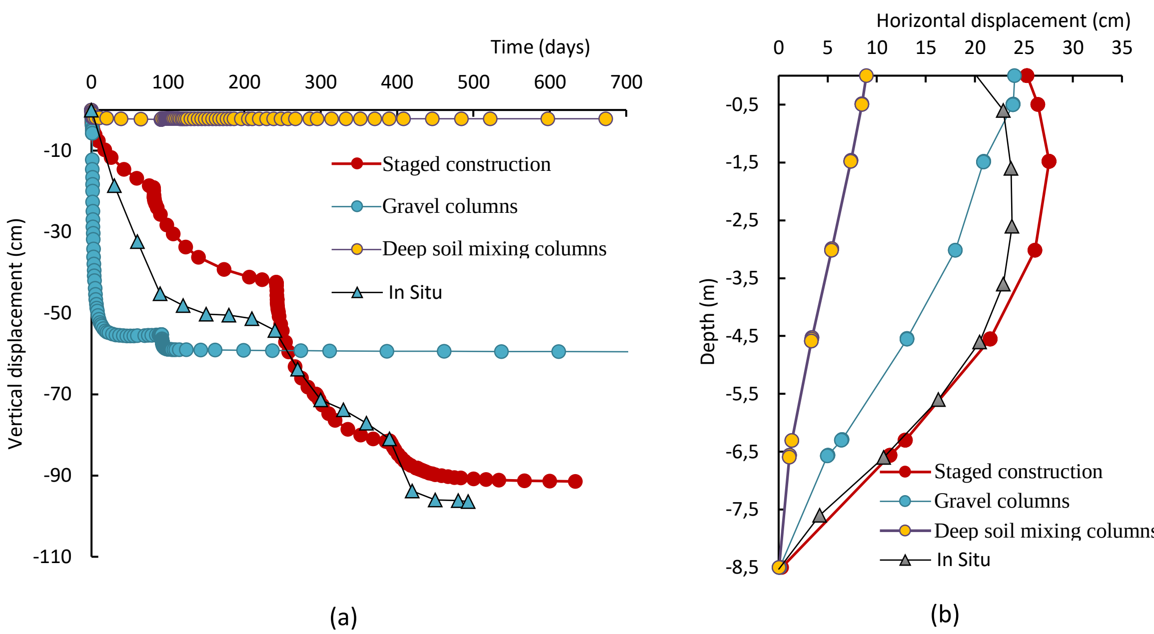

Figure 3. Numerical results obtained from the three methods (based on Zacarias 2016; Zacarias et al. 2016). a) Time evolution of the settlements on plate T_2. b) Evolution of the horizontal displacements (inclinometer).

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STABILIZATION OF SOILS WITH ALKALI ACTIVATED CEMENT

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EXTENDED ABSTRACT

The scope of the present work is within the treatment solutions, namely through alkaline activation, for improving the mechanical properties of soils to be used in low cost roads. In general, these roads are built without bituminous surface layers and quite frequently it is necessary to stabilize or improve the in-situ soils, either with other selected soils/aggregates or with binders, building a stronger pavement on top to support heavier vehicles or higher traffic flows. This will help spread vehicle loads without causing deformation. Traditionally, these binders are cement and/or lime, which bind the soil particles together through chemical reactions. However, cement production has severe environmental impacts, using vast amounts of fossil fuels and being responsible for the emission of more than 5% of all the carbon dioxide worldwide (Provis & Deventer, 2014). Hence, the use of increasing amounts of waste as a material source for the construction industry represents a highly significant contribution for the reduction in cement consumption.

The objectives and motivations for the work presented herein were to study a new solution of soil treatment without using cement or lime, based on alkali activation of fly-ashes from coal. Alkaline activation is a reaction between alumina-silicate materials and alkali or alkali earth substances, namely alkaline ions like sodium or potassium, or alkaline earth ions like calcium. It can be described as a polycondensation process, in which the silica and alumina units interconnect and share the oxygen ions. Materials formed using reactions between silica and alumina and alkali cations like sodium or potassium are very similar, at a molecular level, with natural rocks, sharing their stiffness, durability and strength (Davidovits, 1991). For soil improvement applications, the alkaline activation of fly ash creates a geopolymeric gel to bind the soil particles as it was successfully applied to replace traditional Portland cement concrete (Bernal, et al., 2011).

To follow the proposed goals, the study was developed in the Central Laboratory of MOTA-ENGIL (leader of the project), in the Laboratory of Geotechnics of Faculty of Engineering of University of Porto (FEUP, co-promotor of the project) and in the Laboratory of Geotechnics of Polytechnic Institute of Guarda (IPG, co-promotor of the project), as well as in the Microscopy unit of University of Trás-os-Montes e Alto Douro (UTAD) and in the Universidad Militar de Nueva Granada (UMNG, Colombia). The studied soil was collected in the south of Bogotá (Colombia) in one of the main geological spots used in constructions in the city, where MOTA-ENGIL has strategic interests of internationalization. The activities developed during the project can be summarized as follows:

a) Selection of Colombian soils
b) Laboratory identification of the soil before treatment at its compaction properties (Mota-Engil Central Laboratory)
c) Mechanical and chemical laboratory characterization of the soil (FEUP and IPG laboratories)
d) Micro-structural and mechanical characterization of mixtures and its evolution with time (FEUP, IPG, UTAD)
e) Evaluation of the influence of curing conditions in the mechanical and hydraulic behaviour of mixtures, using the phyto-climatic chamber of Polytechnic Institute of Guarda
f) Construction of large scale specimens in MOTA-ENGIL calibration chamber (4x2x2 m^3), to be tested by traditional in-situ tests used in the industrial work (dynamic penetrometers, impact deflectometers, plate load tests, gamma-densimeters)
g) Construction of large specimens to evaluate the fatigue resistance in the prototype developed in Universidad Militar de Nueva Granada (Colombia)

The obtained results at controlled temperatures (25ºC) confirmed the expectations of a mechanical improvement, revealing an increase of strength and stiffness when compared with the properties of the soil in its natural state, although with smaller gains at short term that those commonly observed with cement treatment (Rios et al., 2017). However, the strength at short term of alkali activated mixtures is still significant with reference values of 1 MPa after 5 days of curing. At long term, the experiment revealed that the strength and stiffness increase of alkali activated

mixtures follows a potential law and last longer than the observed in cement treatments, usually stable after 28 days of curing.

On the other hand, the experiments performed in the phyto-climatic chamber (IPG) and in the large scale specimens (MOTA-ENGIL chamber and UMNG prototype) revealed that curing conditions can have a significant influence on the final results. In fact, it was observed a loss of strength and stiffness when the curing temperatures were lower (15 to 12ºC, at the phyto-climatic chamber), showing some influence in the geopolimearization reactions. This loss was observed both in compressive and diametral tests and in seismic wave propagation velocities. Moreover, concerning the humidity conditions both laboratory tests and large scale experiments showed a reduction of mechanical properties after emersion in water or when the application was performed with rainfall (Cruz et al., 2017).

Finally, the chemical analysis performed on the leachate produced during the laboratorial experiments confirmed that the cementation was not strong enough to prevent particles from the ashes and the alkali activator to be carried by the water, which needs to be adequately controlled.

The main conclusions arising from this study can be summarized as follows:

a) The addition of ashes to the natural soil reduces the global mechanical properties. Alkali activators create a cementation structure that generates a significant improvement of mechanical behaviour, which is higher than the observed in the natural soil and in the soil+ash mixture. There is some discrepancy between laboratory and in-situ test results.

b) The passage of water through the mixture generates an important strength decrease, as it was observed in phyto-climatic chamber and in large specimens. Moreover, the water that crossed the mixture, revealed the significant presence of chemical elements that come out from ashes and activators, which may be responsible for the mechanical loss observed after inundation of the sample. These two problems related with the water influence have to be solved for the adequate application of this methodology.

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REINFORCEMENT AND STABILIZATION OF SLOPES AS REHABILITATION MEASURE OF SEVERAL REGIONAL ROADS ON MADEIRA ISLAND

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EXTENDED ABSTRACT

Tecnovia started its activity in the Autonomous Region of Madeira in 1978, having built several transportation infrastructures in the archipelago, such as highways, tunnels and viaducts.

The present presentation is based on the vast experience acquired by Tecnovia Madeira, in works to reinforce roadway safety on Madeira Island, through the reinforcement and stabilization of slopes.

The geomorphological characteristics of Madeira Island demands that many of its roads have to be built on slopes, in some cases in profile of excavation and in others in profile excavation and embankment.

Over the years, the slopes have evolved into situations that endanger the safety of people and property, not only because of the possibility for overhanging slopes to collapse or slide, but also because of the instability of the slope base on the track.

The presentation will focus on two case studies on regional roads, namely the intervention work on the embankment ER 222 on the site of Rateira, in Ponta do Sol municipality, and the work on the stabilization of a road platform on a section of ER 107, in Curral das Freiras.

The slope at Ponta do Sol consists of formations belonging to the Post-Miocene Volcanic Complex β^2, formed by alternations of compact and hard basaltic lava flows, but almost always very fractured, with levels of pyroclastic, more soft and friable pyroclastic materials, in certain highly eroded areas. In general terms, the natural process of evolution of these slopes is marked by the degradation and erosion of the softer and friable layers leaving the basaltic levels unsupported at the base and at risk of collapse.

During the project design stage, several blocks of different sizes were observed, which presented a high risk of fall off from the surface of the slope, in the short / medium term, reaching the ER 222 used frequently by people and vehicles. It was also observed the existence of small caves and more depressed zones in the breccia levels and at one end of the slope, it was also verified that a negative profile slope already exists, with a development of 20m and 3m of maximum height of the console.

The solutions defined for this slope were the excavation and dismounting by levels, together with a systematic treatment with projected concrete and nailing and installation of dynamic barriers.

In Curral das Freiras, the intervention was due to the landslide of a section of the platform of the road, which is located in an embankment, executed over a thick and relatively consolidated slope deposit that is crossed by a water line approximately halfway of this section. The volcanic deposit in this region consists essentially of formations belonging to the Mio-Pliocenic β^1 volcanic complex, which comprises a chaotic heap of coarse pyroclastic materials, with more or less angular blocks, volcanic bombs and slag. In this zone, the volcanic deposit is covered by a thick heterogeneous slope, formed by angular and sub angular blocks and basaltic rocks of various dimensions fragments, surrounded by a thin matrix of essentially argillosteoste, relatively consolidated but breakable when exposed to atmospheric agents.

The solution defined in the project went through a change on the track layout on the direction of the slope, in order to sanitize the slope deposits and insert it into the rocky substrate. For this purpose the excavation of the slope was carried out with projected concrete and nails, as well as a curtain of piles anchored and regularization and channelling of the existing water line.

The presentation will focus on the solutions adopted and present the construction processes for the works execution, the main difficulties and final results.

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HIGHWAY EMBANKMENT STABILIZATION WITH AN ANCHORED PILE WALL

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EXTENDED ABSTRACT

Within the conservation of the highway network managed by Brisa Concessão Rodoviária, SA, it were carried out the construction works for the "Stabilization of the embankment slope at Km 128+650 (North/South direction) in the Section Fátima/Leiria of A1-Auto-Estrada do Norte".

The construction works foreseen for the stability of the said embankment were the following: i) construction of a stabilizing rockfill embankment at the foot of the lower slope; (ii) execution of a confinement landfill (in crushed aggregate of extensive granulometry) that allowed the creation of a working platform; (iii) execution of a pile wall (26 units with ø0.8m), with an anchored beam at its top (28 units with L = 32 m); iv) rehabilitation of the highway pavement in the section where cracks and settlements occurred due to the vertical and sub-horizontal movements of the embankment; v) installation of instrumentation of the embankment and of the executed structures, in order to control its behaviour during and after the stabilization works; vi) general interventions for the rehabilitation of the surface drainage system and the highway fences.

Figure 1 shows an overview of the reinforcement and stabilization works of the highway embankment slope.

Figure 1. General view of the reinforcement and stabilization works.

This communication aims to briefly present the design background, the geological-geotechnical model, the causes of instability and the project solutions, as well as the work carried out during the construction phase.

The highway embankment has an asymmetric profile, being located on a hillside, and it is founded on deposits. This embankment already had a history of instability associated with the existence of low resistance formations and the permanent presence of groundwater level at its base.

Briefly, it is considered that the following factors were the source of the failure:

- The embankment foundation consists of colluvial materials, consisting of clayey soils and levels of sand, which will not have been subject to indentations, taking into account the relatively small inclination of the slope;
- Soon after the construction, settlements began to appear due to the collapse effects, boosted by the weathering of the marl blocks then applied, which are also visible at the face of the slopes;
- Installation of a circular failure surface on the embankment, with the occurrence of movements of the body of the embankment by its foundation and the appearance of traction cracks at the level of the highway platform.

Any of these previous phenomena are naturally enhanced by the presence of water in the body and foundation of the embankment, which may migrate to the landfill by percolation through the contact of the foundation with the natural soil or by infiltration from the surface. In any case, these phenomena are always enhanced following rainy periods, especially when these are long and intense.

Considering the risk / safety analysis performed for the embankment, it can be considered that the risk of failure, existing before the reinforcement works, was low, although lower than the recommended safety factor values of 1.5, for the referred highway embankment, which is a strategic infrastructure.

Therefore, given the extension in time of the deformations in the embankment, in addition to the low safety factor registered, it was considered advisable to promote reinforcement works in the slope enabling the increase of the infrastructure safety.

Within the scope of the Final Design and based on the geotechnical survey, laboratory tests, surface recognition and evaluation of the existing situation, it was chosen and developed a solution based on the execution of a reinforced concrete pile wall associated with an anchored beam at the top of the piles, as well as a confinement landfill (in crushed aggregate of extensive granulometry) on the upper slope and a stabilizing rockfill embankment at the foot of the lower slope. This solution aims to rehabilitate and guarantee, not only the stability of the embankment slope under study, but mainly the safety of the highway platform through the control of its settlements.

The execution of this solution anticipated distinct stability scenarios during the construction phase. The current scenario, with the determined geotechnical parameters, does not guarantee the safety of either the slope or the highway platform. Wherefore after the beginning of the construction of the confinement landfill and the reinforced concrete pile wall, associated with an anchored beam, it is achieved a considerable improvement of the safety factor, thus ensuring overall safety factors greater than 1.5 (static) and 1.1 (dynamic) on the highway platform.

On the other hand, landfills are also associated with excavation and other deforestation and stripping works, consisting on the total rehabilitation of the embankment through the substitution of materials with better characteristics and the removal of the unstable surface mass.

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DESIGN GUIDELINE FOR BASAL REINFORCED PILED EMBANKMENTS, BASED ON EXPERIMENTS, FIELD STUDIES AND NUMERICAL ANALYSIS.

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Three field studies, a series of nineteen scaled 3D experiments and 3D FEM analysis were conducted on basal reinforced piled embankments. Based on this, the new Concentric Arches was developed, which is a design model for the basal geosynthetic reinforcement (GR) of a piled embankment.

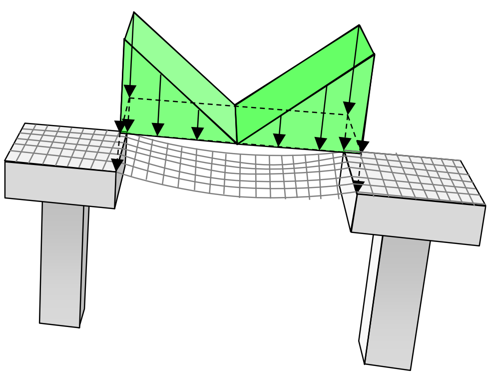

Figure 1: Load is attracted to the GR strips and the net load distribution on GR strips followed from the experiments and is confirmed by numerical calculations by for example Han, Bhandari, Wang, 2012, Girout, Blanc, Thorel, Dias, 2014 and Van der Peet and Van Eekelen 2014.

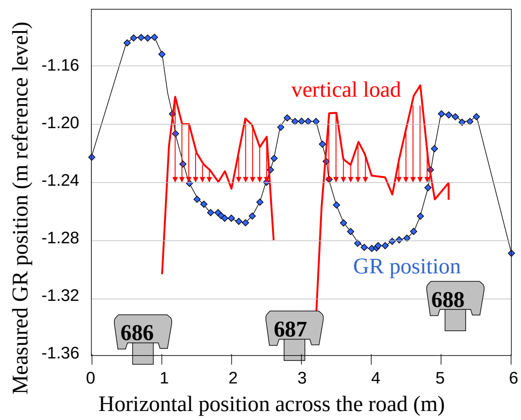

Figure 2: The inverse-triangular net load distribution was confirmed in the field with measurements in settlement tubes attached to the GR. The second derivative of the tube position gave the load distribution.

The observed load distribution is concentrated on the GR strips between adjacent pile caps and inverse triangular and can be explained by the GR deflection, or vertical deformation. The areas with the least deflection attract most load. Therefore, the piles attract most load. Secondly, the GR area close to the pile caps deflects least, because the deflection is limited by the unmoving pile cap. This location therefore attracts more load than the GR areas further away from the pile cap. So, the highest pressures are found alongside the pile cap, with the lowest pressures on the GR strip being found at the central point between the pile caps.

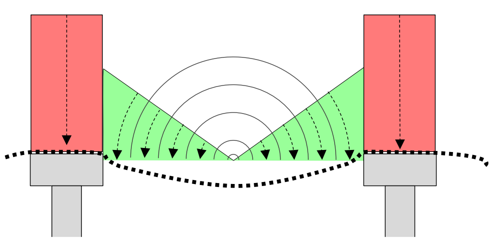

Figure 3: Explanation of the observed load distribution: the more vertical deformation, the less load it attracts. This behaviour can be described with these concentric arches. The larger the arch, the more load it transports.

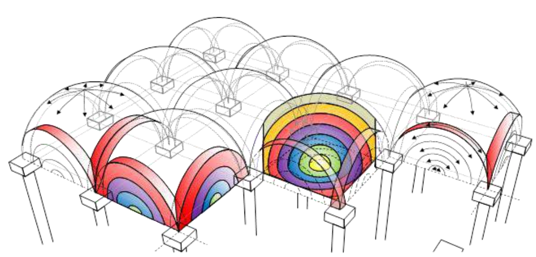

Figure 4: 3D version of the Concentric Arches model of van Eekelen et al, (2013, 2015) and van Eekelen (2015). The load is transported along the 3D hemispheres, outwards, towards the piles and the GR strips. Above the GR strips, the load is forced to follow the 2D strips, towards the piles and subsurface.

The new Concentric Arches model gives a good match with measurements and numerical calculations and was therefore adopted in the new design guideline CUR226:2016 (van Eekelen and Brugman, 2016). A model factor and partial safety factors were included. The values of these factors were determined with a probabilistic study to meet the reliability requirements of the Eurocode (van Duijnen et al, 2015).

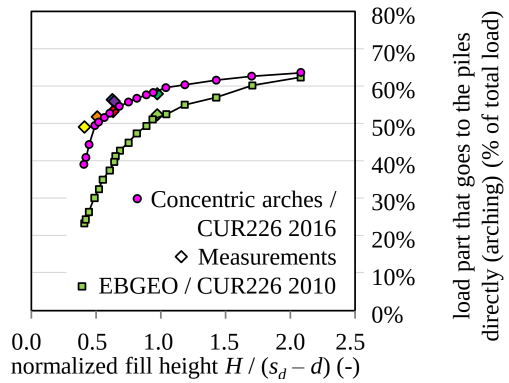

Figure 5: Comparison results scaled 3D experiments with design methods.

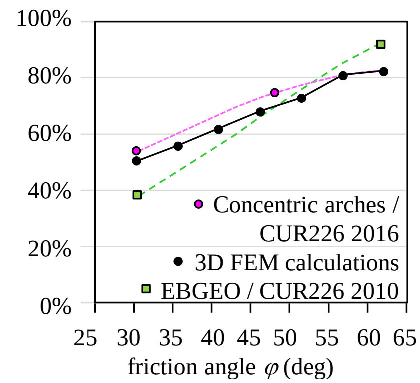

Figure 6: Comparison 3D FEM calculations with design guidelines (van der Peet and van Eekelen, 2014).

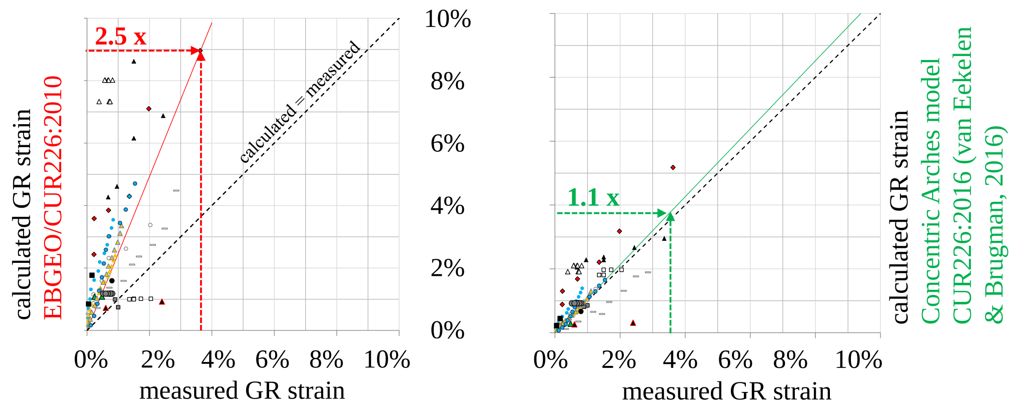

Figure 7: GR strains, measured in a large number of field tests and series of experiments from the literature, listed in van Eekelen (2015) and van Eekelen et al., 2015, compared with results of analytical calculations, including a trend line through all data. Left: the 2010 calculation method is the method adopted in EBGEO:2010 and CUR226:2016. Right: Concentric Arches model as adopted in CUR226:2016 (van Eekelen and Brugman, 2016).

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THE IMPORTANCE OF THE INITIAL PHASE OF STUDIES AND DESIGNS IN A PORT INFRASTRUCTURE PROJECT

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EXTENDED ABSTRACT

The launch of the construction of a major development is usually a major engineering challenge, requiring definition of location, general arrangement, design and construction solutions that meet operational, environmental and safety requirements, optimize cost and construction period, operation and maintenance over its lifetime.

In general, it is in the initial phase, concerning location, design and basic engineering studies, that there is an opportunity to conceive the best solutions and achieve greater savings or, on the other hand, to avoid future damages and losses. By selecting the location and general arrangement of the facilities and the basic engineering solutions of the infrastructures to be built, the fundamental and determinant bases of the investment, operation and maintenance costs over the life of the enterprise are practically laid down.

While in the early stages of studies and designs, the investments are still relatively small, they increase significantly in the phases of construction and acquisition of equipment, when it is difficult or impossible to overcome any deficiencies in location, conception and design, while controlling costs and deadlines. If the works and equipment are well-designed in the initial phase, the costs of subsequent phases will have comparatively less influence on the final overall cost of the enterprise.

The above considerations apply to all types of engineering undertakings. In the specific case of port infrastructures, the issue is particularly important since, in addition to being major investments, they are generally located in areas where local conditions are complex and harsh, and require specialized investigations, studies and designs, which, of course, require experience and time. They are often located in estuaries of rivers where geotechnical conditions are very unfavourable for the installation of heavy structures and the creation of large areas, subjected to high loads and tight demands of deformability, as required in modern port facilities. The structural design of the works is then particularly important due to the need to use special structures and appropriate soil treatment techniques.

Port infrastructures should be designed and sized to be sufficiently efficient and safe, with normal maintenance costs, over a predefined lifetime. According to the EN1990 standard, and depending on the importance of these infrastructures, this useful life should be fixed between 50 and 100 years.

In this communication, with the aim of highlighting the importance of the initial phase of the preliminary study and basic engineering, the construction and rehabilitation of the walls of the inner docks of the port of Leixões is given as an example. The north wall of Dock 2, 300 m long, finished in 1966, was out of service due to anomalies in 1976 and rehabilitated in 1998. The construction of the east quay wall and the 110 m section of the southern quay wall of Dock 4 was suspended in 1976 due to serious anomalies and the docks were rehabilitated in 1999. In addition to the considerable costs of these rehabilitation works, the operation of these docks was impeded for about 20 years.

This situation was a consequence of a policy frequent at the time of contracting public works using design-and-build contracts without the prior preparation of engineering studies and designs supported by sufficient information on the local geotechnical conditions, which were subsequently revealed to be extremely unfavourable.

Eurocode 7 classifies geotechnical infrastructures into three groups according to complexity, experience, information on geotechnical conditions and the risk of damage. The current Portuguese legislation on public works designs (Ordinance 701-H/2008 of July 29) classifies port works in four categories (I to IV) according to the degree of difficulty and complexity of the design. In view of the complexity of the local conditions, the design of the infrastructures of the inner docks of the port of Leixões would undoubtedly currently be given the highest classification under both regulations.

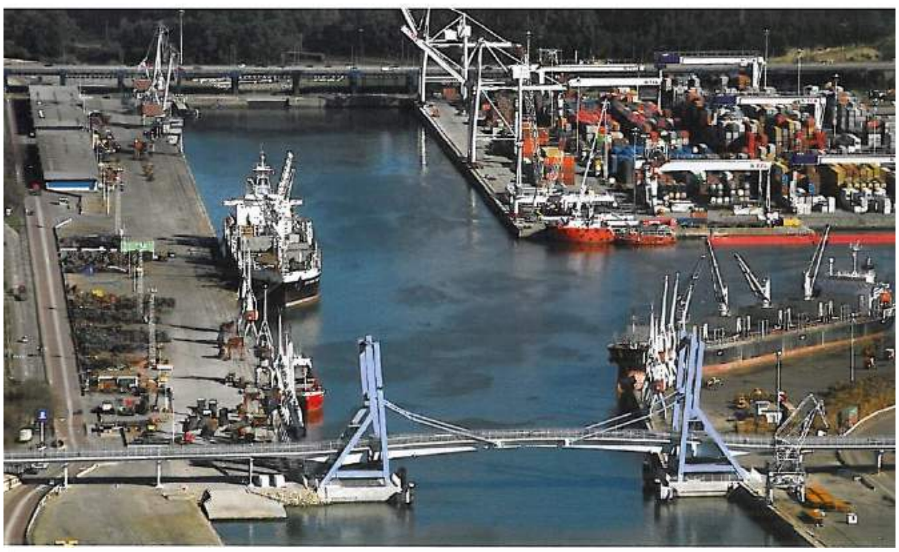
The Portuguese Code of Public Contracts (CCP) of 2008 (Article 43) establishes that the specifications for public works shall form part of the invitation to tender and the detailed design of the solution of the work and that, if the work is complex, this design must be checked by a independent professional entity.

Based on the current Portuguese legislation, it is therefore not possible to contract important public works as the interior docks of the port of Leixões were 40/50 years ago. Regrettably, responsible entities still tend to seek to reduce the initial investment in engineering studies, surveys and designs by employing these services at abnormally low prices and / or with unrealistic deadlines.

As pointed out by the author in the communication presented at a previous international congress (1), the initial investments in these studies, surveys and designs for the two large shipyards of Setúbal and Bahrain were only about 2.9% and 3.4% of overall investments, relatively small.

The cost of these services in the initial phase of the rehabilitation works of the interior docks of the port of Leixões, was also very small compared to the total value of these works, but they took a few months.

It is therefore the main objective of this Communication to emphasize the importance of the initial phase of studies and basic engineering for successful development of better technical solutions with overall economic and time benefits, resulting from a comparatively small additional initial investment, although it obviously requires some time. Neglecting these studies can cause risks and difficulties in later stages, or even jeopardize the viability of a project, and also contribute to the devaluation of the engineering services, diminishing skills of national engineering companies.



Inner docks of the Port of Leixões

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EXAMPLES OF REHABILITATION OF TRANSPORT INFRASTRUCTURES WITH WOVEN AND NON-WOVEN GEOTEXTILES

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EXTENDED ABSTRACT

The rehabilitation of transport infrastructures is the main field of investments and activities of the present and will be even more so in the future in many countries, as in Portugal and Spain, where in the last 20 years all kinds of infrastructures have been developed.

Geosynthetics over the last 20 years have evolved greatly, largely due to increased demand and consumption (See the Table 1 and 2) because of their versatility, excellent cost-benefit ratio and positive ecological effect. Countless geotechnical problems are solved today with the help of geosynthetics of all types optimizing the budgets of any construction project and safeguarding the environment directly and indirectly.

Many researches and experiences have resulted in a better understanding of the behavior of geosynthetics, both in the short and long term, creating design methodologies for many applications and establishing appropriate use regulations and recommendations whose use has been generalized internationally and are still alive, that is to say, in constant evolution and refinement, since the justification of the geosynthetic by dimensioning is often quite complex.

Table 1. Demand for geosynthetics (millions m²)[1]

Region	**2007**	**2012**	**2017**
North America	923	965	1300
Western Europe	668	615	725
Asia/Pacific	723	1200	2330
Central and South America	124	160	220
Eastern Europe	248	305	405
Africa/Middle East	115	155	220
Total	2801	3400	5200

Table 2. Estimate worldwide sales of geosynthetics[1]

Type	**Amount (millions m²)**	**Price (USD/m²)**	**Sales (millions USD)**
Geotextiles	1400	0.75	1050
Geogrids	250	2.50	625
Geonets	75	2.00	150
Geomembranes	300	6.00	1800
Geosynthetic clay liners	100	6.50	650
Geofoams	5	75.00	375
Geocomposites	100	4.00	400
Total	2230		5050

The diversity of geosynthetics, in terms of typology, functions and applications, make many professionals in the construction industry have a limited and confused vision, many times, when deciding to use them in their projects and works. This article aims to contribute to broaden and clarify the vision of today's professional who knows that geotextiles separate and filter and know that geogrids reinforce, but have no experience, knowledge or a suitable advice for the use in their projects and rehabilitation works but also aimed at tomorrow's professional that is still being formed today.

There is no doubt that the influence of geosynthetics producers determines what type of geosynthetics are applied locally. Thus, for example, the rehabilitation of railways in the UK mainly use reinforcement geogrids; in Germany and Austria, reinforcement geogrids and geocomposites combining separation, filtration and reinforcement functions are applied; in France, it is carried out with new generation nonwoven geotextiles and with multifunction geocomposites; in the USA, woven geotextile and geogrids are mostly used and in countries, such as Portugal and Spain, where there is no local production, conventional nonwoven geotextiles have been used, but increasingly, new generation nonwoven geotextiles, woven geotextiles, geogrids and multifunction geocomposites are being successfully implemented.

Various applications of woven geotextiles and new-generation non-woven geotextiles in rail rehabilitation works are presented, with different international examples, since they are the least known, but as effective or more effective than geogrids and geocomposites. Separation, filtration and reinforcement and their combinations are the functions of geosynthetics applied in these cases.

As conclusions, it is necessary to emphasize two main ones:

- Multifunction geocomposites, geogrids, woven and non-woven geotextiles are the four types of geosynthetics to be considered in the rehabilitation of transport infrastructures, as evidenced by the experiences in the countries where the main geosynthetics producers are located, which are also the most veterans and the most qualified geotechnically speaking.

- The separation function during the service life of the rehabilitation is the primary function in any case and especially under the ballast layer so that the rehabilitation is technically durable and efficient and, therefore, the investment is profitable.

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NEW PROFILE SUD IN THE BARCELONA HARBOUR. A COMPLETE AND FLEXIBLE SOLUTION WITH GEOSYNTHETICS

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EXTENDED ABSTRACT

Among the works proposed in the construction project "New Profile Sud Phase I", was the commissioning of the new container terminal at Muelle Prat (TERCAT), further subdivided into two areas of action:

- South Link: preload of land for construction of a roundabout located at an altitude sharing 12 m.
- Port Road Round: Run the final road section.

Figure 1. Comparison between the Project scheme and a general view of the work

Given the uniqueness of the area, soils with low bearing capacity and high expected settlements due to a depth of soft soil more than 60 m, the alternatives raised and road links were conditioned by previous treatments of the field.

Giving access to TERCAT without interfering with the works of the later stages required to design a perimeter road to the preload which could be in service during the construction of the first stage of the South Link. For it was necessary to upright the slope of the preload, which was achieved with the help of a wall reinforced with geogrids Fortrac ® of 82 ° slope in the face.

During a future phase, the construction of a concrete wall that will be built at the foot of the reinforcement wall in the area of preload parallel to the river Llobregat, transmit to ground a charge of approximately 200 kPa. Under these conditions, a treatment with Geosynthetics Encased Columns, GEC´s with Ringtrac ® of the soft soil were carried out.

The implementation of the perimeter wall of reinforced earth Fortrac ® geogrids, as well as allowing to upright the spilling of the preload to make them compatible with the following phases of the project, it also allows the absorption of the deformations associated with the consolidation of the underlying ground. This containment system, yet flexible, is faster and cheaper than a traditional concrete wall.

With the choice of GEC´s with Ringtrac ® were achieved the following improvements:

• Reduced clogging of gravel and ensure the draining effect during the consolidation of field induced by the construction of the embankment.

• Increase the shear strength of the ground during the excavation at the foot of the embankment.

• Avoid excessive deformation of the lower portion of the column during the phases of improved ground under embankment preload.

Encapsulated columns were length up to 30 m and 80 cm of diameter placed in triangular mesh of 2.4 x 2.4 m per side along the zone of the concrete foundation.

A high strength woven geotextile Stabilenka ® was installed in the foundation of both, the concrete wall and the reinforced wall with geogrid Fortrac ®. This geosynthetic facilitates the distribution of loads on the columns of gravel and to increase the shear strength of the foundation soil geogrid wall while building the shoe of the future concrete wall. This geosynthetic reinforces and increases the safety factor of the section. In addition, it also separates the material provided in the existing soft ground.

Another flexible reinforcement was used in this job:

• The asphalt was reinforced with geocomposite HaTelit ® on the joints between old and new service roads. HaTelit ® fulfills two important functions in the firm; it increases the tensile strength and it ensures the stress distribution in a larger area, reducing punctual efforts but also overheading risks.

• As recommendations related to the improvement of the soil in the future south link connection (around the wall reinforced with geogrids), it was also decided to include in the project a biaxial geogrid of high modulus PVA Fortrac ® M to reduce and homogenize the settlements that would develop during the consolidation period preload.

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GREAT HEIGHT EMBANKMENT REINFORCED WITH GEOGRIDS, IN THE ALFENA LOGISTIC PLATFORM (VALONGO)

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EXTENDED ABSTRACT

For the construction of the New Jerónimo Martins Logistic Plataforma in Alfena it was necessary to build a great embankment with two Reinforced Soil Slopes (RSS) with high height and two different inclinations (52 and 65 degrees).

The maximum height of the slope with 52º for the Inferior Platform was 34m, while the maximum height of the slope with 65º for the Superior Platform was 25m.

The initial solution foresaw the construction using only continuous sheets of Geogrid wrapped in the facing. The reinforcement of the embankment is obtained with the use of a Geogrid giving turn to the embankment layer that involved each level of Geogrid.

This facing is susceptible to ultraviolet light degradation, vandalism and damage due to fire.
Portugal is a dry country in the summer and very sensitive to occurrences of fires. The solution with exclusive resource Geogrids is adapted at countries with a lot of humidity where in the summer the vegetation doesn't get dry and therefore the facing doesn't take the risk of being destroyed by the fire.

Therefore it was studied a solution that also uses Geogrids for reinforcement, but with a facing in hot dip galvanized steel mesh bent up to the defined angle to form the Wall face that avoids any destruction risk in case of fire.

The product used, called Terra Link©, consists in a welded mesh panel produced with the defined angle of the slope. Geogrids Fortrac put on the ground underneath of the panel (L) and another geogrid with a small mesh is put behind and very closed to the facing with the function to hold the vegetble soil put behind the facing. The function of the vegetable soil with seeds is of facilitating the growth of the vegetation.

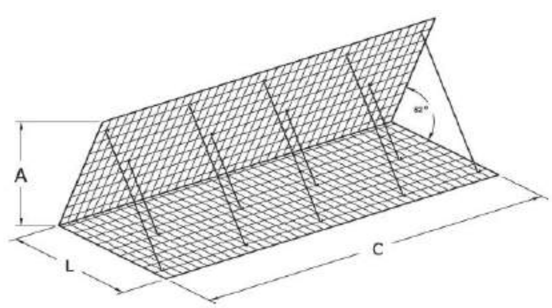

Fig. 1. Terra Link© System

The first Terra Link© Reinforced Soil Slope (RSS) of the Inferior Platform was interrupted by a Mechanically Stabilized Earth Wall. (MSEW) with Gabions facing reinforced with Geogrids Fortrac, because of the limitations due to the property limit and because of the motorway A41 proximity.

Fig. 2. Terra Link© Inferior Platform with Gabions facing system connection

Fig. 3. Terra Link© Superior Platform

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GROUND IMPROVEMENTS FOR LAND RECLAMATION IN TOKYO/HANEDA AIRPORT EXPANSION PROJECT

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EXTENDED ABSTRACT

Outline of the Project

In order to cope with the recent and expected future increase in air transportation and future operations, the construction of fourth runway was planned in 2001 and commenced in 2006. The runway was constructed on a man-made island to the south of the existing airfield, and its construction was completed in 2010 as schedule. The layout of the new island and the current airfield is shown in Fig. 1. The runway is located between the mouth of Tama River and the main sea route to Tokyo Port. The runway was constructed mostly on the reclaimed land, but a part of the runway is constructed on the steel-jacket-platform structure at the west part not to give adverse influence to the water flow of Tama River. As the east part of the reclaimed land was anticipated to obstruct a part of the main sea route, the main sea route had to move to the east, which required additional dredging work of 183 million m^3. The dredged soil was stabilized with cement for reclamation of the island.

Figure 1. Sky view of construction site and existing airfield on March 15th, 2009 (by courtesy of the Tokyo/Haneda International Airport Construction Office).

Ground condition

The ground condition and the major soil properties at the site were extensively surveyed at 16 points (Watabe *et al*., 2007). The ground can be roughly divided into five layers. The most upper layer is stratified at -20 to around -35 m which has high plasticity index ranging 60 to 100 and high water content ranging 100 to 150 %. The undrained shear strength and the pre-consolidation pressure are increased linearly with the depth, which indicates the clay is lightly over-consolidated condition of OCR =1.3. The second upper layer is a clay layer with a local sand layer underneath, which is stratified at -35 to -60 m. Its plasticity index and water content are lower than the first layer. The third layer is stratified clay and sandy layers ranging at -60 to -75 m, whose SPT N-value ranging 10 to 50. The fourth and fifth layers are stiff sandy layer whose SPT N-values are higher than 50. The upper two layers should be improved to increase the stability of superstructures and to reduce the residual settlement of the island, where the sand compaction pile method (Kitazume, 2005), the deep mixing method (Kitazume and Terashi, 2013) and the sand drain method were employed.

Deep mixing method

Almost all part of the sea revetment was constructed with embankment on the SCP improved ground. However, caisson type quays were constructed at the corner of the island for uploading heavy construction machines and pavement materials (CW revetment) and for the approach light structure (CN revetment), as shown in Fig. 1. The block type DM improved ground was constructed to the depth of -45 m, as shown in Fig. 2 for the CW revetment. Based on the laboratory mixing tests, Portland blast-furnace slag cement B type of 110 to 165 kg/m^3 was mixed with the soil to obtain the average field unconfined compressive strength, q_{uf}, of 3,375 kN/m^2 at 28 days curing. The total of about 620,000 m^3 soils was stabilized by four DM vessels within five months, as shown in Fig. 3.

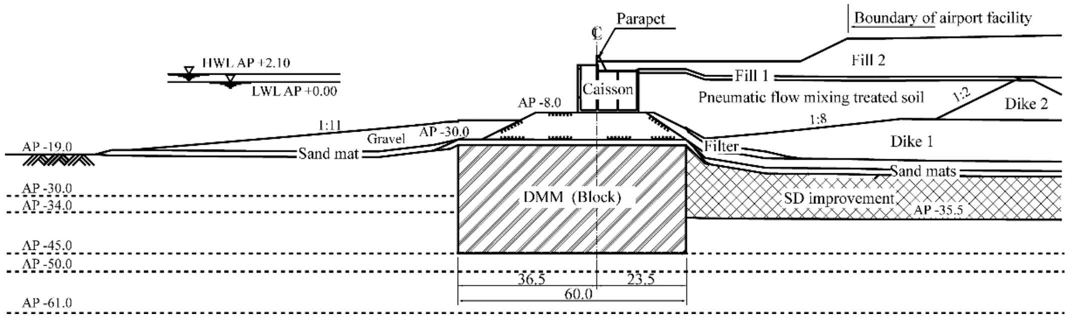

Figure 2. Cross section of DMM improvement at CW revetment.

Figure 3. DM vessels in operation (by courtesy of the Tokyo/Haneda International Airport Construction Office).

At 28 days after the construction, the stabilized soils were sampled to measure the unconfined compressive strength for preliminary quality assurance. The measured data revealed that the mean q_{uf} was 4,094 kN/m^2, 20 % higher than the design, and the coefficient of variation was 28.3 %, lower than the design, 35 %. According to that, the amount of cement was decreased to 80 to 160 kg/m^3 (3 to 27 %). After the construction, the core samplings were carried out on several stabilized soil columns for unconfined compression test for quality assurance. The q_{uf} values after the modification of mixing condition clearly showed that the mean strength of the stabilized soils was 4,066 kN/m^2, assuring the design criteria (Watanabe *et al*., 2008).

Concluding Remarks

The new runway of Tokyo/Haneda International Airport was constructed on the man-made island to the south of the existing airfield. In the construction, several ground improvement techniques, sand drain method, sand compaction pile method and deep mixing method, were employed to improve the ground. This paper briefly introduces the application of the ground improvement techniques at the site.

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STABILISATION OF UNBOUND AGGREGTE BY GEOGRIDS FOR TRANSPORT INFRASTRUCTURE APPLICATIONS

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EXTENDED ABSTRACT

Stabilisation / stiffening is a mechanism leading to reduction of particle movement achieved through confinement. It results in reduction of deformation within non-cohesive materials under load. Stabilisation as function of geosyntethic was recently newly formally defined by ISO TC221. The function has been called for quite a long time as the reinforcement of subbase, base or ballast according to the application. Only recent observations both from laboratories and field prove that it is not the strength which is the factor controlling this function but that certain stiffening of granular material by interlocking is the most importantant one. Because this function is different than soil reinforcement hereafter geosythetic features and performance related parameters are different than for reinforcement. Mechanical properties of mechanically stabilised layers using geogrids are still not defined enough. There is a number of researchers and Engineers who are actively involved in various research and applications with use of geosynthetics for stabilization.

The mechanism of aggregate stabilisation under dynamic load from train is achieved thanks to grain interlocking within non–deformable apperture of the stiff geogrid (see Figure 1).

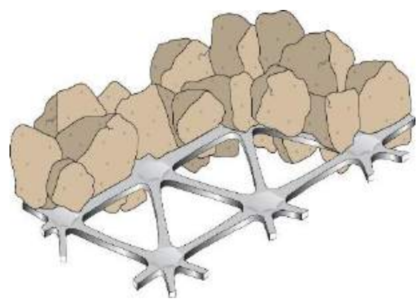

Figure 1. Interlocking mechanism shows grains beeing locked in apperture of monolithic geogrid

The grain penetration through appertures may occur also with flexible geogrids (eg. woven) but then there is no horizontal support against micro displacement resulting in weaker performance. This differentiation in performance is know for nearly quarter of century eg. from early US Corps of Enginners (Webster 1993). The differencies in initial stiffness for difrent geosynthetic are shown on Figure 2 where it's clearly visible that Modulus E for low displacement are dependent on product characteristics

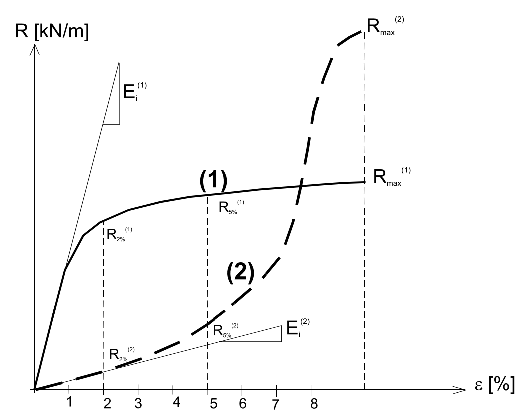

Figure 2. Characteristic for stiff geogrid (1) vs. flexible geogrid (2) showing difference in modulus at low deformation

As affect of interlocking, stiff geogrid provides confinement to aggregate not only in plane but also within some distance. Three zones could be described here (Figure 3):

- Full confinement zone (h3) at geogrid level up to distance of several grain size. Within this zone grain displacement is practically not possible due to interlocking.
- Transition zone (h2) where confinement is reduced from full (at bottom of the zone) to zero (at top of the zone). Grain ability to move is increasing within distance from geogrid. This reduction is non-linear and is dependent on individual features of both geogrid and aggregate.
- No confinement zone (h1) where only internal friction is acting against displacement of grains. To stabilize grains within this zone next layer of stiff geogrid is required.

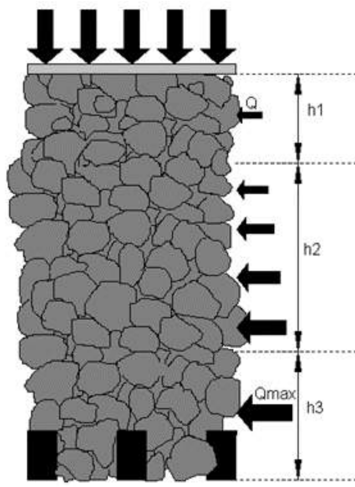

Figure 3. Three zones over geogrid representing different confinement effect to aggregate

Such considerations are bringing us into discussion on mechanism of stabilisation. In contrast to reinforcement, stabilisation is considered at very low displacement level, far below elongations measured at product rapture and described as tensile strength. As consequence stabilisaton mechanism is key function for most of transport infrastructure applications like railways, paved and unpaved roads, container terminal and other trafficked areas.

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OPPORTUNITIES AND CHALLENGES IN THE USE OF GEOSYTHETICS IN ROAD AND RAIL INFRASTRUCTURES

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EXTENDED ABSTRACT

In the last decades the construction cycle in Portugal which corresponded to the implementation of the National Road Plan, was an opportunity for the systematic introduction of geosynthetics in linear construction works, namely in the field of earthworks and drainage. In these domains, the realization by road authorities of specifications governing their use has allowed and promoted the use of geosynthetics as standard building solutions. Similarly geosynthetics have been in the construction of tunnels and underground structures, and have been successfully applied in the reinforcement of landfills, foundations and support structures.

The creation of the IP, Infraestruturas de Portugal, resulting from the merger of the entities responsible for the management of the national road and rail networks, as well as the important set of investments underway for the consolidation of railway interoperability, under the “Ferrovia 2020” program, bring a new cycle of challenges, also technical, fostering new approaches in the application of geosynthetics.

This communication intends to present the experience in the application of geosynthetics in the constructed road and railway infrastructures, built and in service, to discuss critical aspects, as well as to identify opportunities of applicability.

APPLICATION OF GEOGRIDS IN RAIL RENOVATION WORKS - CASE STUDY

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1. Introduction

The application of geogrids in railways' renewal projects are getting more commonly used and can represent an excellent bearing capacity reinforcement solution for the support platform.

This presentation aims to describe the constructive process for superstructure renewal works, regarding the implementation of geogrids under the ballast, and the impact on the necessary methods and means to rebuild it.

This presentation won´t analyse the solution itself on a technical basis, focusing only on the interaction between the geogrids solution and the process and execution methods for the track renewal.

2. Project briefing

The "Northern Line" is the main Portuguese railway line, connecting the two major Portuguese cities -Lisbon and Porto.

Being part of the main railway corridor, it presents a huge demand of traffic and a large diversity and typology of trains, like cargo trains, suburban and long course trains,

Any kind of works on the infrastructure that could limit, in any way, the railway operation would have significant economic impact. In order to minimize this economic impact, all the technical solutions must minimize the impact in the railway operation.

Any intervention in the infrastructure that limits railway operation has significant economic impacts. So, all constructive solutions are obliged to minimize the impact on railway operation.

The "Renovação Integral de Via entre Alfarelos e Pampilhosa" basically consists on track superstructure renewal, between Alfarelos and Pampilhosa with sleepers, rails and ballast replacement. The main objective of this intervention is to improve the general condition of the railway operation, increasing reliability, safety conditions and comfort indices and reducing maintenance costs by starting a new life cycle of the infrastructure.

3. Methodology – Scope of the main works of the project

1) Track replacement;
2) Ballast cleaning;
3) Aluminothermic rail welding;
4) Levelling, alignment and rail tamping ;
5) Preventive rail grinding

Constraints to the constructive process

The condition of minimizing the impact on the commercial offer of the Rail Operators is undoubtedly the most restrictive condition in the entire process and must be in consideration in order to choose the construction methods and the equipment to be used:

- The track renewal works (RIV) must be executed during night periods
- Less than 7hrs work per night, between railway stations and less than 5hrs in railway stations;
- Works executed in temporary single railway line operation (VUT);
- One VUT at the time in all the project extension;

These limitations, as well as the confinement of the railway corridor, don't allow an economically viable intervention on the platform in order to increase the bearing capacity For that reason, it will be implemented a solution incorporating geogrids and geofabrics on critical zones of the platform, to decrease the risk of future instability that could limit or endanger track performance.

It is supposed that the geogrids act as ballast stabilizer and that the geofabrics functions to separate the layers (sub-ballast and ballast) and to filter the small particles that can contaminate the ballast

Track Renewal, Geogrid and Geofabric Application

Track Renewal

The track renewal process consists of replacing the constituent elements of the track, rail, sleepers and fastenings. This operation is carried out with a track renewal system that lifts and lays track panels with 18m length.
After this operation, the track will be operated at a 30km/h speed restriction.

Ballast Bed Cleaning

The ballast shall have the following functions in the track superstructure:

- Homogeneous load transmission;
- Resistance to lateral, longitudinal and vertical actions;
- Absorption of vibrations by dynamic actions maintaining the elastic capacity;
- Enable track maintenance operations, such as levelling and alignment;
- Permeability, to drain water and small particles properly;
- Avoid vegetation growth.

The characteristics of the ballast can be affected by the abrasion of its particles, caused by the dynamic actions of the rail traffic, the operations of mechanical tamping and the contamination of small particles by the lower layers.

Installation of the Geogrid and Geofabric

The geogrid and the geofabric are placed above the platform during the ballast bed cleaning. At this stage, all the ballast is removed and the track platform is accessible to place the geotextile and geogrid, above the platform and under the new ballast bed.
This operation, carried out during the ballast cleaning process, has no impact on the performance of the renovation works.

4. Conclusion

Railway renewal works are generally complex by the means used, the logistics of the materials and mainly by the constraints of the rail operations.

These factors limit the renewal procedures options, methods and equipment to be used on the track renewal.

The application of geogrid and geotextile in the construction process, common in track renewal works, does not affect the constructive methods or performance of these activities.

For those reasons, this type of materials may be a viable solution for reinforcing the track platform.

However, it should be noted that the application of this type of material on the platform and under the ballast bed, constrain the type of machines and the method of ballast cleaning in the future renewals. It won´t be possible to do the work with heavy cleaning ballast machines.

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SOIL TREATMENT WITH LIME IN RAILWAY PLATFORMS – A CASE STUDY

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EXTENDED ABSTRACT

This paper analysis the implementation of an alternative solution of a railway platform, which consisted in substituting the crushed aggregate sub grade (capping) layer specified in the design project by the in-situ treatment of the existing soil layers with lime. In particular, it was applied for a total length of 42 km on the Renewal Project of the Bombel and Vidigal to Évora - Alentejo, Vendas Novas and Évora railway tracks, whose consortium was made up of Somague, Neopul and Tomás de Oliveira companies.

The methodology consisted in a design solution focused on the execution of a subgrade layer in crushed aggregate, with 0.20 m thick, throughout all the extension, except in areas with low trafficability, where it was performed a rock material layer 0/200, with 0.5 m of thickness, and a subgrade layer of equal thickness. In both cases, the solution aimed to provide proper foundation conditions for the railway platform, regarding the bearing capacity of the railway substructure, with a deformability modulus (EV2) on recharge equal or greater than 80 MPa, measured at the top of the subgrade layer.

Firstly, it is analysed the constraints of all the project, such as the high moisture content of the foundation soils, the adverse weather conditions in which a significant part of the work was carried out, and the relevant operational problems, namely the location and licensing of approved dumpsites for spoil materials or storage the aggregate material as well as the access to the working sites, due to its small number of interceptions with the railway line. Secondly, the contracted consortium decided to present an alternative solution that would minimize its negative impacts, namely the difficulty of stabilizing the track foundation, which would make it very difficult or even preclude the execution of the subgrade (capping) layer, the long transport distance to/and in the work sites both of the soils and the aggregates to be transported and also the operating costs.

The alternative solution proposed consisted in the replacement of the granular layer by the in-situ treatment of the soil foundation with lime, in a thickness determined according to the intrinsic characteristics of the foundation soil and its moisture content.

The drafting of the alternative proposal had a decisive contribution of the French experience in the use of lime in road works (LCPC / SETRA, 2000) and railway works (Thomas et al., 2005) as well as the recent Portuguese experience in railway works, namely in the 2.1 Section of the North Raiway (Montes et al., 2005), which was implemented by Odebrecht - Bento Pedroso Construções, SA, Somague Engenharia, SA, and MSF Engineering, SA. The recommendations and assumptions were the ones described in the UIC File 719R (UIC, 2008), the GTR technical guide (LCPC / SETRA, 1992), the GTS technical guide (LCPC / SETRA, 2000) and the implementation project (Ferbritas, 2009).

The characterization of the platform soils was carried out under the alternative proposal which confirmed the characterization done during the project implementation, highlighting a clear predominance of Class B5 soils, according to the French standard classification NF P 11-300 (AFNOR, 1992). These soils have low to moderate values of plasticity index, ranging from NP to 21%, and CBR values between 13 and 36%, with a predominance of values below 20%.

The methodology used in the formulation of the soils treatment with lime was based on the French experience presented in the technical guide GTS (LCPC / SETRA, 2000) and was focused on soil samples collected on site, seeking the most relevant classes, according to its representativeness and to cover a large spectrum of characteristics. Classes B5 and A1 were included.

The results pointed to several lime contents according with the moisture content of the soils and their intrinsic characteristics. They highlighted a clear efficacy in the improvement of soil characteristics, both related with water sensitivity and its mechanical behaviour.

Based on the data of the study and the adopted recommendations, the chosen solution, in general, pointed to the in-situ soil treatment of the existing soil layer in a thickness of 0,35 m, adding percentages of lime according to the nature and water content of the soil at the time of excavation. The overall lime percentage was 2% if the hydrous state was classified as normal, increasing that value as a function of the W / lime content determined in the laboratory study through IPI / Lime content ratio.

The validation of the results of the study were submitted to a rigorous control quality of all works carried out, including the characterization of the platform's soils, before and after the treatment, and the examination of the platform deformability modules through plate loading tests and the continuous bearing capacity equipment (MCSC) – Portancemètre.

Considering all the data collected on site, the solution adopted was acceptable, with an effective outcomes regarding the reduction of water sensitivity of soils and increasing the behaviour of the platform performance level, in terms of bearing capacity.

Finally, the results of this alternative solution showed clearly its applicability, since it had operational and economic advantages as well as is an environmental friendly solution.

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EMBANKMENT STABILIZATION ON AN OPERATING RAILWAY INFRASTRUCTURE

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EXTENDED ABSTRACT

The present communication describes an embankment stabilization in the Portuguese South rail Line, between the pk 252+940 and pk 253+010, at Santa Clara, in Odemira city. In this section the railway is located on a hillside, and it was constructed on a mix cross section of excavation and embankment, with Mira River at the slope base.

During the year of 2010, there were extreme precipitation events, higher than the average value of the reference period 1971-2000, being considered the rainiest year of the decade. In September of that year, on the railway embankment with 15 m height, cracks were detected on the cess side and, as a first level of immediate measures, those cracks were filled with cement grout and waterproof plastic liner was placed, in order to minimize water infiltrations.

In March 2011, precipitation values were again higher than the reference values, increasing the effects that could compromise the slope stability of the railway embankment. As a result, in April 2011, new cracks appeared and extended under the ballast layer with a cess side settlement, suggesting the formation of a failure surface below the outer rail, as well as the reopening of the existing cracks. At the same time, the occurrence of erosion was detected at the embankment base, being this phenomenon related with the rise of Mira river water level. These anomalies affected the railway superstructure behaviour with the appearance of severe buckling defects. With the aim of maintain the safety of the railway traffic, a number of urgent measures were taken: speed restriction to 30 km / h, filling all cracks with cement grout, waterproof plastic liner placement and study of temporary retaining measures.

Photo 1. Instability of the embankment slope close to the railway (2011)

Photo 2. Instability in the embankment base slope (2011)

With the ongoing instability process and the need to keep the rail line operating, it was not possible to use heavy equipment on the platform, which would allow the implementation of more immediate and effective solutions for the global stabilization of the embankment slope. In this scenario, the stabilization work took place in two phases. In the first phase (April to June 2011), topographic surveys, geotechnical and geological works, design and execution of a temporary retaining solution of the railway superstructure were carried out. The retaining solution was carried out using light equipment, which constituted small overloads on the slope, and consisted on a micropile wall of 67.1mmx4.5mm metal tubes, spaced 50cm apart, with grout bond length located on the bed rock, supported by high strength steel strands that were tied to nails executed on the opposite side of the rail line in a schist rock with good quality. The temporary retaining solution was effective in the immediate stabilization of the railway superstructure, minimizing significantly the occurrence of anomalies in the geometric parameters of the rail line.

In a second phase, the permanent solution was executed and concluded in July 2012. The design of the permanent solution was supported on a complementary geological and geotechnical campaign, which was carried out at the end of 2011, and included DPL, boreholes with SPT aligned in a cross section profile at the middle of the affected railway

section. Given the restrictions of the site, it was decided to stabilize the embankment by minimising excavation work that would endanger the embankment. Thus, to stop the instabilization movement, a 600mm reinforced concrete pile wall, spaced 1.0 m apart, was executed at the base of the embankment, on an extension of about 40 m, with a reinforced concrete capping wall of 40 cm, anchored to the ground. The stability of the embankment mass was guaranteed by two anchored reinforced concrete retaining walls, with 30 cm thick and micropiles foundations (88.9 x 7.5), one at half height and another at the top of the slope. With the construction of the permanent solution, the slope stability was guaranteed with adequate global safety factors for the operating conditions demanded on a railway ($FS_{Static} \approx 3.6$; $FS_{Sism} \approx 2.0$).

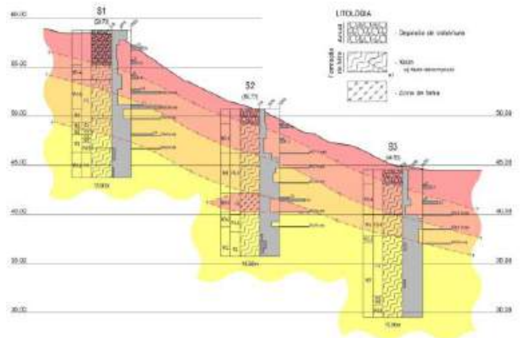

Figure 1. Slope geological cross section

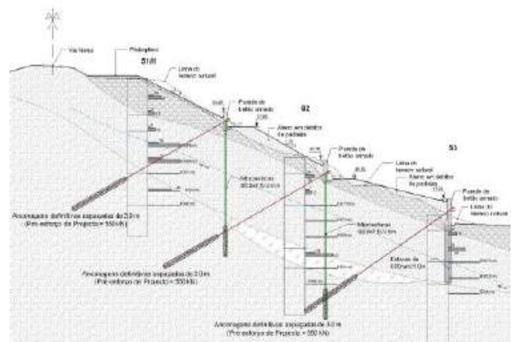

Figure 2. Slope stabilization permanent solution

Photo 3. Temporary retaining solution (2011)

Photo 4. Permanent stabilization solution(2012)

The beginning of the works on the embankment base, from the existing path, ensured adequate working conditions in terms of platform and access stability. The anchored intermediate and superior retaining walls, were carried out from working platforms made with quarry waste material. The stabilization elements were complemented with a drainage system, that leads the collected waters to the Mira River. On the top of the embankment, at the railway platform, a rockfill layer was placed to avoid the superficial erosion of the soil.

The works were carried out with the South Line operating and with frequent observations of the instrumentation devices, which allowed to control the embankment and the structures behaviour, not only during the construction phases but also in railway operating conditions. Currently the embankment and the retaining structures are still being observed, maintaining the required stability conditions.

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RAILWAY INFRASTRUCTURE - ASPECTS OF CHARACTERIZATION AND REHABILITATION SOLUTIONS

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EXTENDED ABSTRACT

The performance currently required for rail transport, and therefore for railway tracks, regarding service quality, volume and type of traffic to be carried, durability and economic efficiency of the infrastructure, demand that its design and construction are based on a mechanistic approach and that maintenance and rehabilitation processes are conducted efficiently, based on real needs and knowledge of the structure performance. However, scarcity of economic resources and physical, legal and environmental constraints require consideration of a number of factors when making decisions regarding investment in construction, maintenance and rehabilitation of these infrastructures (Fortunato, 2016).

The railway track has a nonlinear behavior resulting from the complex interaction between its elements under applied train loading. The train circulation causes dynamic vertical and horizontal forces (both transverse and longitudinal) and vibrations of different characteristics on the railroad track. The dynamic effect resulting from the passage of trains depends on: irregularities in the track geometry, both vertical and horizontal; irregularities in the rail surface; irregularities in the surface of the wheel; speed of trains; and the physical and mechanical characteristics of infrastructure and vehicles (Dahlberg, 2003).

The resilient behavior of the granular materials that usually constitute the support layers of the railway track (ballast and sub-ballast) provides the almost complete recovery of the deformation suffered by the track at each load cycle. Under normal conditions, after the application of the first load cycles, the resilient response stabilizes, and from that moment on, it behaves independently of the loading history, as long as the material is not subjected to higher stress levels (Fortunato, 2005). With respect to the plastic behavior, small permanent deformations occur in each load cycle, which by accumulation resulting from a considerable number of applied load cycles can lead to undesirable levels of permanent deformation of the track. In addition, the mechanisms of degradation of the ballast layer and the settlements of the embankments can lead to important permanent deformations (Selig & Waters, 1994; Melis Maynar, 2006).

In addition to the normal degradation on open track, it is known that there are zones where the degradation rate is relatively higher, namely transition zones of vertical stiffness of the track and places where permanent differential settlements occur. To try to minimize these problems, the technical community has used several techniques, among them the construction of wedge-shaped backfills comprising layers of selected materials and specific geometry (Fortunato *et al.*, 2013).

In order to develop a mechanistic approach in the analysis of the railway track, it is necessary to understand how the structure works and to know its dynamic response when the trains pass by. This knowledge can be obtained either using physical and numerical models, or through the analysis of the results of the monitoring of the behavior of the track to the passage of the trains, as well as the characterization of its dynamic response to load tests such as that presented in Figure 1 (Paixão, 2014). In addition, it is necessary to know the characteristics of the materials that are used in the track, which can be done by carrying out laboratory characterization tests or "in situ" tests. The evaluation of the behavior and the characterization of the track and its elements are fundamental processes for the maintenance management and for the decision making regarding rehabilitation interventions (Fortunato, 2005). These tasks can be performed using various methods that can provide different kind of information, complementing each other.

The rehabilitation of railway lines in service, either because they present significant deficiencies in the face of current use or because of the prospect of more demanding requirements, has been one of the aspects that has aroused more interest in the technical and scientific community. The type of technique to be used depends on the physical and mechanical characteristics of the materials, the technology available and the conditions of implementation, in particular as regards the physical environment and the restrictions related to the operation of the track (INNOTRACK, 2008). When it is possible, one of the most appropriate techniques to carry out the rehabilitation of the track substructure in open track it is replace the superstructure, laying new support layers and, in some cases, improving the subgrade soils (Fortunato *et al.*, 2010).

In this work, the dynamic response of the track is analyzed and the aspects that influence its behavior and the respective mechanisms of deterioration are discussed. Methods of elements characterization and for monitoring of the behavior of the infrastructure are described. Some of rehabilitation techniques commonly used to improve performance and reduce infrastructure lifecycle costs are presented and discussed.

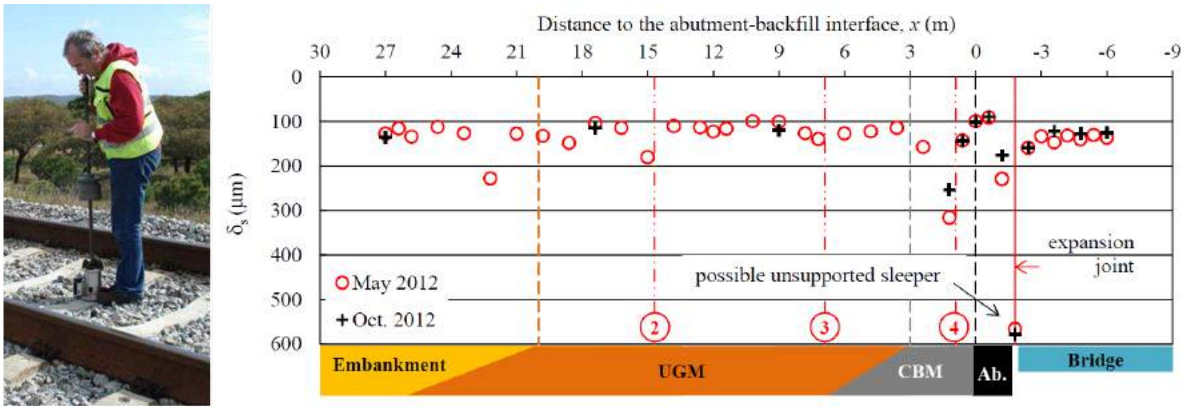

Figure 1. Example of some results obtained by Light falling weight deflectometer tests (Paixão, 2014).

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EXPANSION OF THE PORT OF LA GUAIRA (VENEZUELA) - IMPROVEMENT OF THE HYDRAULIC LANDFILL OF THE CONTAINER TERMINAL

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ABSTRACT

The objective of this communication is to present the new Container Terminal in La Guaira Port, more precisely to describe the procedure used in the landfill treatment to improve the load capacity of the soil. The structure of the pier is composed by a concrete platform supported by piles with an extension of 693m. Since the area where containers are moved and parked consists of a hydraulic landfill situated on a seismic zone, it was necessary to define what kind of treatment would be more suitable to overcome the possibility of a liquefaction phenomenon. Since the embankment was made with sandy soils, the chosen procedure was vibroflotation.

INTRODUCTION

The Port of La Guaira is located in the central coast of Venezuela, north of the capital Caracas. This infrastructure has a water level protected by a breakwater 1.300m long and several piers. In operational terms it is characterized by fractional general cargo and containers movements in the North Quay, with strong operating constraints resulting from the embankment with only 50m wide.

To improve the port performance, the national state-owned company that manages the Port – Bolipuertos – signed a contract with the Portuguese company Teixeira Duarte in EPC mode (Engineering – Procurement – Construction). The contract established under the Portugal –Venezuela Agreement included:

1. Execution of a pier;
2. Container Park (rehabilitation and area conquered to the sea);
3. Port equipment (STS's and RTG's);
4. Administrative buildings;
5. Complete formation in all port operations, from the vessel arrival to the shipment of goods (intern or extern exportation);

Figure 1. New Container Terminal in La Guaira Port

The geometry of the pier consists of modules of 60m length, each one formed by 8 transverse alignments distanced 7.50m. Each transverse alignment is supported by 5 concrete piles with 1.20m diameter. The transverse alignments are connected by beams of 1.70m high and 1.30m wide.

SOIL TREATMENT

The expansion and modernization project of the new container terminal was made with a hydraulic landfill conquered to the sea. To achieve this new area, it was necessary to materialize two marginal retentions (West-East) and a frontal rock prism (with rock core), longitudinal to the pier building, up to retain the embankment. It becomes important to refer that this hydraulic landfill was materialized through the existing sandy soils dredged in the area of the Port of La Guaira. This led to an increase of the port draft (-15.20) thereby allowing access to Post-Panamax vessels.

The project was developed along with the Contractor in order to provide a solution involving a combination of precast and concreted "in situ" elements in order to enable the advancing of the pier, from East to West. Through this process it was possible to materialize the hydraulic embankment in stages and consequently the treatment of the soil, thus ensuring the necessary conditions for the implementation of service networks and paving the treated area.

Figure 8: Sequence and stages of the embankment

Figure 9: Execution of vibroflotation

To materialize the landfill, were used 1.1 million m^3 of sand. Given the existing conditions and materials, the chosen solution to carry out the treatment of the landfill was vibroflotation. Thus, after the execution of part of the landfill several *in situ* tests were performed since it was necessary to determine the characteristics and depths of treatment, including the mesh, the up speed of the equipment and the treatment time per level. It is important to refer that SPT and CPTU tests were performed as well as granulometric analysis and plate bearing tests. These were made prior and during the treatment in order to control and corroborate the improvement process inputs of vibroflotation.

CONCLUSION

The need for landfill treatment depends both on the type of use and the risk of liquefaction. The choice of the treatment (replacement soils, preload deep vibration, dynamic compaction, drain installation or rigid structures) will have to take into account several factors:

1. Nature of soil to be treated;
2. Desired improvement;
3. Deadline of achieving the results;
4. Cost/Benefit analysis for each kind of treatment;
5. Local conditions for execution.

This treatment led to a clearly average increase in relative density. It is important to refer that were introduced 8.650m^3 of additional material (sand and stone aggregates).

REHABILITATION OF UNDERGROUND TRANSPORTATION INFRASTRUCTURES IN URBAN AREAS

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EXTENDED ABSTRACT

The rehabilitation of underground transportation infrastructures is a complex problem that is often exposed to the Owner of the Work, due the nature of the work itself and its implementation. The rehabilitation problems are linked to the volume of work, the type of intervention and the strong constraints on exploitation and sometimes with consequences on the surface on the existing structures. To minimize these difficulties, in addition to implementing systematic inspections when in service, it is also necessary to act on construction stage to increase the life cycle of such infrastructures.

ÁGUAS SANTAS NEW TUNNEL

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EXTENDED ABSTRACT

With the completion of much of the Portuguese national road network, the challenge now is to maintain the built heritage, which results in the need for a paradigm shift of road infrastructure concessionaires.

In this context, the improvement, reinforcement and rehabilitation works become particularly important, adding to the required accuracy to evaluate and define adjusted technical solutions the need to assure that their implementation is developed in line with the management of the infrastructure in service.

Consequently, the main challenge on this type of interventions is to guarantee the adoption of the best technical solutions minimizing simultaneously the impact caused by their effective implementation in the transport infrastructures users with the least possible loss of efficiency.

The Águas Santas New Tunnel presentation intends to introduce a construction case, the first stage of the A4 – Porto / Amarante highway enlargement and improvement for 2x4 lanes, currently with 2x2 and clearly insufficient to the amount of actual traffic, in an extension in which the carriage ways were already developed in tunnel section, through two contiguous galleries in service.

Figure 1. A4 highway present traffic situation.

The founded and designed solution meant the construction of an additional gallery, north of the existent one, with capacity to accommodate the future 4 lanes of the Amarante / Porto direction.

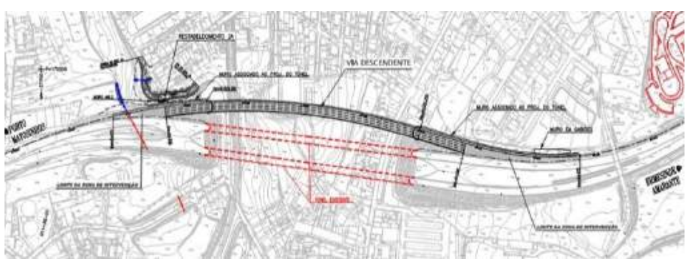

Figure 2. Designed solution.

Implying a high level of technical skills, due to the geological and geotechnical caracterization of the interfired rocky zone (Porto's granitical deposit), most of the tunnel extension was excavated using explosives in controlled and scheduled detonations, making necessary to predefine, plan and implement a set of measures to develop the

construction works, given its location in a dense urban mesh area and in close proximity to in-service road and rail infraestructures.

Figure 3. Excavation surface aspect (granitic rocky deposit).

With the purpose of ensuring a more efficient service level when concluded the second stage of the A4 – Porto / Amarante highway enlargement and improvement, the presentation intends to approach the issues related to the set of measures implemented for the construction works development, with particular focus on the recognized advantages of planning all operations. This is a required condition to not compromise the final objective and the works' expected progress, reinforcing the primordial importance of the permanent geotechnical monitoring, both in the in situ rocky deposits evaluation, and in the interpretative analysis of the results obtained from the installed instrumentation, fundamental to ensure the works expected evolution.

Figure 4. Águas Santas New Tunnel present situation.

RESTORATION AND REHABILITATION OF THE HERCÍLIO LUZ BRIDGE IN FLORIANÓPOLIS – SANTA CATARINA: FOUNDATIONS REINFORCEMENT

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EXTENDED ABSTRACT

The works regarding the Restoration and Rehabilitation of the Hercílio Luz Bridge, in Florianópolis/SC, comprise the foundations reinforcement of some towers on the inland and island side, of the main towers' pylons over the sea and of the staying block from the mainland side, which will be fully replaced.

The solutions are differentiated, covering both the definitive and the provisional stage: new foundation blocks supported on root-type piles, excavated piles with recoverable wrapping or with stabilizing fluid and also reinforcements with vertical and horizontal ties.

Two viaduct towers are supported on new blocks founded on 4 (four) 450mm diameter root-type piles with a 355mm pin driven into rock, totalling 32 units. All piles were submitted to a static load test using an expansive cell and to PIT integrity tests.

Figure 1. Execution of root-type piles

In two other viaduct towers on the mainland side, the new blocks are founded on 2 (two) 800 mm diameter excavated piles and a 700 mm pin driven into rock, carried out by resorting to a provisional tube casing, totalling 16 units. A static load test was run using an expansive cell, as well as two cross-hole integrity tests and PIT tests were run in the remaining piles.

In the anchoring block on the mainland side, which will be completely demolished and rebuilt, the execution of 30 (thirty) 1,500mm diameter excavated piles, driven into rock, is foreseen, to be performed with bentonite clay. The running of a static load test using an expansive cell, three cross-hole integrity tests and PIT tests in the remaining piles are foreseen.

For tower T6 foundations, which will be completely new due to its high degradation level, a solution with vertical ties aiming at reinforcing the existing cyclopean concrete bridge piers has been planned, introducing 4 (four) φ36mm Dywidag bars into each bridge pier, in φ4'' drillings injected with cement grout by gravity flow. The aim of the injection is also the filling of existing cracks inside the bridge piers. This solution also foresees the execution of locking beams in-between the bridge piers, which structural continuity shall be granted through 600 kN horizontal protension, applied to φ47mm Dywidag bars, both in the transversal and in the longitudinal direction.

Figure 2. Execution of the blocks foundation

The 4 foundation blocks of the two main towers are reinforced at their top, at approximately 7m high, with a 30cm casing of reinforced additivated concrete (waterproofing additive) over the existing structure. To carry out this casing, a metal cofferdam shall be installed in order to carry out the services in a dry manner under the sea level. Each pylon block reinforcement also includes the execution of 8 ties with φ36mm Dywidag bars in φ4'' drillings injected with cement grout, with the objective of also filling the existing cracks.

Figure 3. Metal cofferdam shall during the reinforcement foundations of one of the main towers over the sea

There are also other cases, where the purpose is just to extend durability, which solution consists of increasing the size of the existing blocks, applying a reinforced concrete layer involving the existing cyclopean concrete block. Due to the provisional loads of the installed tower cranes, it was also necessary to carry out rock sealed vertical ties, where required.

We should also highlight the sub-horizontal ties anchored on rock for the provisional staying block of the main towers, on each edge, as well as the sub-horizontal ties to be executed in the abutment reinforcement on the island side.

GROUND IMPROVEMENT SOLUTIONS FOR TRANSPORT INFRASTRUCTURE: PHILOSOPHY AND CASE HISTORIES

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EXTENDED ABSTRACT

Ground improvement is an old discipline, which has been growing fast since forty years. Many techniques are now available. Chu et al. 2009 suggested the following classification:

- Category A: Ground improvement without admixtures in non-cohesive soils or fill materials (e.g.: Dynamic Compaction, Vibrocompaction)
- Category B: Ground improvement without admixtures in cohesive soils (e.g.: Replacement, Preloading using fill)
- Category C: Ground improvement with admixtures or inclusions (e.g.: Microbial Methods, Stone Columns, Rigid Inclusions)
- Category D: Ground improvement with grouting type admixture (e.g.: Deep Mixing, Jet Grouting)

The choice of a ground improvement technique depends on several key parameters.

First, the *ground conditions* are of course fundamental. The nature of the soil, generally established from the sieve analysis curves and the Atterberg limits, helps to guide the choice of the technique. For this purpose, the classification from Chu et al. 2009 is useful since it separates the techniques dedicated to granular soils from the techniques dedicated to cohesive soils. Specific attention must be paid if organic soil is detected. The thickness of soft soil impacts also the choice of the technique. For example, depth of Dynamic Replacement pillars (C2. as per Chu et al. 2009) is generally limited to 6.5 m. Finally, the compressibility and shear strength parameters of the soft soil must be analysed and viewed in parallel with the *technical specifications of the project*.

The *technical specifications of the project* are indeed the second key parameter. They are generally expressed in terms of bearing capacity and/or settlement (absolute and/or differential, immediate and/or post-construction). The objective of the ground improvement solution may also be to mitigate liquefaction. The technical specifications have a direct impact on the choice of the ground improvement technique. For example, Rigid Inclusions (C5.) may be favoured where settlement criteria are strict, since they allow for a high settlement reduction factor (in general from 2 to 10). Where the main purpose is to mitigate liquefaction, Stone Columns (C1.) may be chosen, since they can densify the surrounding soil, reduce the seismic shear stress acting on the soil and act as drainage elements.

Thirdly, the *available period of preparation and construction* is a key point. For example, Preloading with fill (B2.) associated with vertical drains in soft soils to accelerate the consolidation process, is generally the cheapest solution. However, it requires time (period of consolidation) which may be not compatible with the schedule of the client. Faster and probably more expensive solutions are then preferred. Similarly, ground improvement solutions economically and technically suitable for a project, but which would require a long period to mobilize supply or equipment on the jobsite (because they are not available locally) may be eliminated.

The *surroundings and the environment* may influence the solution. For example, Dynamic Compaction (A1.) is easily applicable in open areas but may require some adaptations in urban areas: reduction of the compaction energy in the vicinity of existing sensitive structures guided by vibrations measurements, creation of anti-vibration trenches around the site to limit the Rayleigh waves transmission, combination with other techniques close to the existing building such as Rapid Impact Compaction (Lauzon et al. 2011). The presence of polluted soils needs also to be taken into account; in such conditions, it is worth mentioning that ground improvement solutions can be combined with soil remediation techniques.

Last but not least the *price of the solution* is important. Considering similar technical achievement, the cheapest ground improvement technique will be generally given priority. It must be pointed out that it is not possible to establish a classification of these techniques from the cheapest one to the most expensive one; indeed, the price is local and depends, among other things, on the availability and costs of labour, equipment and supply.

The purpose of the presentation is to confront these key parameters through three different case histories involving transport infrastructure. The choice of the solution will be justified. Then, the design, construction and quality control will be described. Special attention will be paid to the on-going Mexico Airport project.

Embankment on soft soil reinforced by Dynamic Replacement pillars for the M7 highway (Hungary)

The M7 highway in Hungary connects Budapest to Croatia. It runs alongside the Balaton lake on a portion of its alignment. It is built on the top of an embankment which reaches 8 m. It became operational in 2006 after construction works which included ground improvement.

The soil investigation campaign showed at this location a layer of peat and organic clay of 5 m thick over medium dense to dense sandy soils.

The technical requirements for the regular parts of embankment, far away from the bridges were:

- Maximum differential settlement of 5 cm over 50 m under live loading from road traffic, after opening of the road;
- Factor of safety against slope failure higher than 1.3 at short and long-term.

Dynamic Replacement pillars appeared to be the most suitable solution to achieve these requirements. They reduced the total settlement by a factor of 2 and they allowed for a quasi-full consolidation under the weight of the embankment as they are drained elements, thus limiting the post-construction differential settlement to the allowable values. Moreover, they ensured the stability of the embankment by increasing the global shear strength capacity of the reinforced soil.

Embankment on soft soil reinforced by CMC rigid inclusions for the high-speed railway SEA (France)

A new high-speed railway 300 kilometres long between Tours and Bordeaux in France became operational in July 2017. Close to Bordeaux, a railway viaduct crosses now the Dordogne River. The viaduct is installed on deep foundation piles and is bordered by two embankments at each extremity. The embankment height varies from 10 m at the abutment location to 5 m over a distance of 300 m.

The alluvial plain of the Dordogne river is composed of very soft clay with interbedded organic material up to 7 m depth. Layers beneath consist of a dense gravelly sand over a very stiff marl. In order to ensure a smooth transition at the abutment location between the viaduct and the Engineering Fill abutment, the technical requirement has been set to maximum 1 cm settlement at 25 years after railway opening.

Considering the creep settlement potential of the upper organic layers and the stringent technical requirement, Controlled Modulus Columns (CMC) rigid inclusions have been installed before the installation of the Engineering Fill. The Load Transfer Platform has been reinforced by steel meshes panels in order to control the lateral displacements at the embankment toe. Finally, a preloading fill has been maintained during a few weeks in order to anticipate the settlement due to the service load (30 kPa).

Monitoring has been implemented to follow settlement and lateral displacements of the Engineering Fill during the construction. The monitoring results have highlighted lower values than the ones predicted. Conservative assumptions regarding the thickness of the soft soil and the CMC/soil interaction can explain those differences.

On-going Vacuum zone load test at the new Mexico City International Airport

The new Mexico City International Airport is being constructed. The new airport will replace Benito Juárez International Airport, which is at full capacity. It is to have one large terminal of 743 000 m^2 on a total lot of 4 600 hectares. It will have three runways to start when opening in 2020.

The new airport is being built in the lakebed of Lake Texcoco, east of the current airport, in the State of Mexico. The soil conditions are particularly poor in this region with a cumulated thickness of about 40 m of soft clay exhibiting water content up to 275%, void ratio up to 9.5 and Young modulus from 0.3 to 0.5 MPa.

The terminal is being built on deep piles.

After several trial areas testing different ground improvement solutions (sand drains, pre-fabricated wick drains, rigid inclusions), it has been decided to build the runways after preloading including the use of Prefabricated Vertical Drains (PVD). Execution of PVD (see Figure 1) and installation of preloading are currently on-going under the runways.

Figure 1. Execution of PVD below the future runways

A transition area is planned between the terminal and the runways. Its purpose is to smoothen the settlement between a rigid area (terminal on piles) and a more flexible area (runways improved by preloading). One option being considered is to use Preloading with Vacuum in this transition area.

The Menard Vacuum Consolidation method is an atmospheric consolidation system used for preloading soft saturated fine-grained soils. The procedure consists of installing a vertical and horizontal draining and vacuum pumping system under an airtight impervious membrane.

A Vacuum zone load test (55 m x 55 m) is being carried out by Menard to test the efficiency of the technique. The first monitoring results (settlement, pore water pressure and lateral displacement) will be available early in September 2017. They will be compared with the predicted values.

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DEEP GROUND IMPROVEMENT SOLUTIONS WITH SOIL – CEMENT FOR TRANSPORT INFRASTRUCTURES

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1. INTRODUCTION

The aim of this presentation is to underline the use of some ground improvement techniques as an alternative concept to the traditional deep foundations solutions, as the conventional piling. Ground improvement techniques with soil – cement mixtures, as for instance jet grouting and the deep soil mixing (cutter soil mixing panels) are adopted as foundation solutions in Portugal since, at least, the last 25 years. Those techniques take the maximum profit of the soil characteristics mobilizing low stresses, close to the ones supported by the soil with low deformations, consequently, leading to a more balanced solutions. Sometimes they can be combined with steel profiles, like micropiles tubes, in order to increase both the tensile and bending strength and ductility. Their construction process, sometimes similar to the typical piling techniques, makes it difficult for structural engineers to draw a boundary between deep foundation by piles and ground improvement. This issue is generally caused by a misuse of the foundation engineering concept and by a missed understanding of their behavior and failure mechanisms. If the design of foundation piles transmitting the structural loads to the ground is now relatively well established, mainly due to the development of the international standards and codes of practice, the way to design ground improvement solutions still remains less clear, demanding big investments on QC/QA.

In this framework, some projects where ground improvement with soil – cement foundation solutions for transportation infrastructure were successfully adopted are presented. Based on these practical examples the main advantages of those solutions, comparing with the more traditional ones are pointed out.

2. GROUND IMPROVEMENT FOR FOUNDATIONS SOLUTIONS: A NEW CONCEPT

In the classical piling concept, the foundation pile with high strength and low deformability manufactured materials, as concrete and steel, is used to transmit the structural loads to deeper rock or firm soil layers by point strength at scenarios presenting soft/weak/compressible soils at shallow depths and to support loads by shaft strength. On the other hand, the ground improvement solutions with soil-cement, the soil is improved with a binder, in this case the cement, being part of the solution, generally, both and well balanced point and shaft strength, and comparing with the bored piles solution, no soil excavation will be necessary, which is a great advantage from the environmental point of view. At the jet grouting process, the ground is hydraulically eroded and after mixed with cement, while at the deep mixing process, the ground is mechanically mixed in place, with cement. In generally, if the ground improvement concept involving soil mix elements is usually selected instead of the pile foundation solution, there is sometimes a drawback highlighting the unbalanced design and execution requirements for soil mix elements and reinforced concrete products and the unfair competition between both techniques and concepts.

3. VIADUCTS FOUNDATIONS

Two cases are presented related with the foundations of big span viaducts, transmitting axial service loads to the foundation higher than 100.000kN and where the thickness of the shallow layers, fills and compressible materials underlying much stiffer materials, where to small to justify the use of the conventional solution of large diameter bored piles, but also big enough to a soil replacement solution. In both situations the treatment of the fills and compressible materials with jet grouting columns was performed allowing the execution of a shallow foundation resting over the treated ground. Complementary, micropiles were installed close to the footing external perimeter in order to accommodate the tension loads due to the bending moments binary (Figure 1).

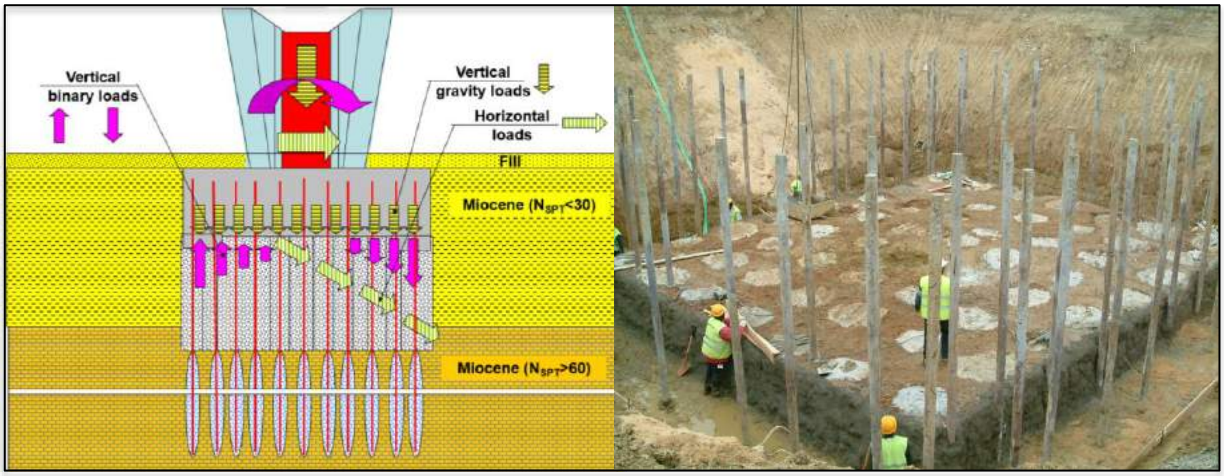

Figure 1. Cross section of the adopted solution with loads transition scheme and view of the jet grouting columns under the future footing.

4. MSE WALL FOUNDATIONS

The case study is related to the foundation of a 13m high mechanical stabilized earth (MSE) wall, built in order to allow the enlargement of an existent mountain motorway, where CSM panels, reinforced with steel profiles, under a load transfer platform (LTP), were used as a foundation alternative to more conventional solutions: viaduct founded over piles or a mass replacement of the soft fills, associated with temporary earth retaining solutions (Figure 2).

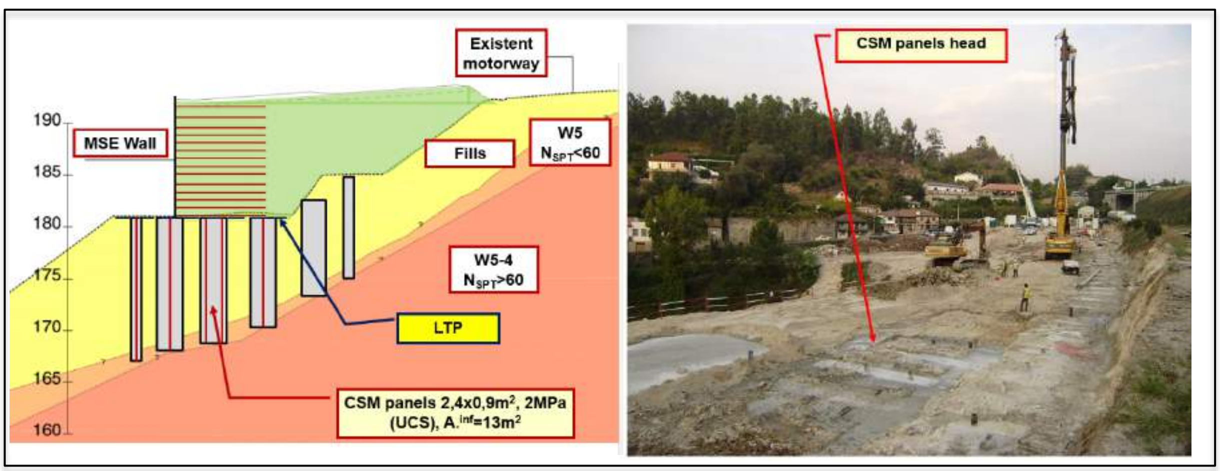

Figure 2. Cross section of the adopted solution and view of the CSM panels execution works.

5. FINAL REMARKS

The replacement of conventional foundation piles by ground improvement solutions involving soil mix elements should be considered as a different concept for foundation engineering, leading, in some scenarios, to a more balanced, economic and environmental friendly solutions, where the soil becomes part of the solution. However the lack of design rules still represents an obstacle to the sustainable growth of this kind of alternative solutions. To compensate it, a huge investment on QC/QA, including load tests and monitoring, as well as codes of practice, is still necessary.

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