

DEEP SOIL MIXING TRIALS AT PORTO ALEGRE AIRPORT, BRAZIL

A. Ortigão, Terratek, Brazil; ortigao@terratek.com.br

E. Falk, Keller, Germany; Info@kellerholding.com

M. Felix, Keller, Brazil; felix@kellerbrasil.com.br

T. Koehler, Keller, Brazil; tammo.koehler@kellerbrasil.com.br

ABSTRACT

Ground improvement techniques such as vibro-replacement or deep soil mixing are fairly young products in the Brazilian geotechnical market. Soft soils in this country are deep, very soft, have low sensitivity and are challenging. In general, ground improvement techniques are increasingly selected as more cost-efficient and flexible solutions on infrastructure projects compared to the conventional technologies such as piled embankments, wickdrains with surcharge or jet-grouting. The geotechnical challenge expansion project for the Porto Alegre Airport, South Brazil, involved a taxiway area of five ha of 8 to 10 m of soft clay deposit. The deep soil mixing (DSM) technique was selected as a cost-effective solution to reduce settlements. As part of the design, an extensive soil investigation programme including laboratory and field trials was carried out to define the most economical slurry-recipe, DSM installation patterns and quality control specs. This paper gives details of the field and laboratory trials and present results.

Keywords: DSM, trial embankment, soft clay, instrumentation, in situ tests

INTRODUCTION

The International Airport of Porto Alegre in the state of Rio Grande do Sul in Brazil is located in an area with extensive sediments near to Guaíba Bay. During the different construction phases of the airport over the last decades, the soft clay deposits have been a challenge for the local geotechnical community as well as for the specialized contractors (Schnaid et al, 2001). As part of the most recent expansion scheme, a cargo-terminal with a five ha airplane tarmac area will be constructed.



Figure 1 Project location

SOIL CONDITIONS and DESIGN CONCEPT

The subsoil conditions are very uniform on site and had initially been assessed by a few SPTs, five CPTU's and VST's and a laboratory test programme on undisturbed samples. Figure 2 presents a typical CPTU log showing a soil profile with an upper 3 m thick fill, followed by up to 5 to 7 m thick soft clay overlying dense sands.

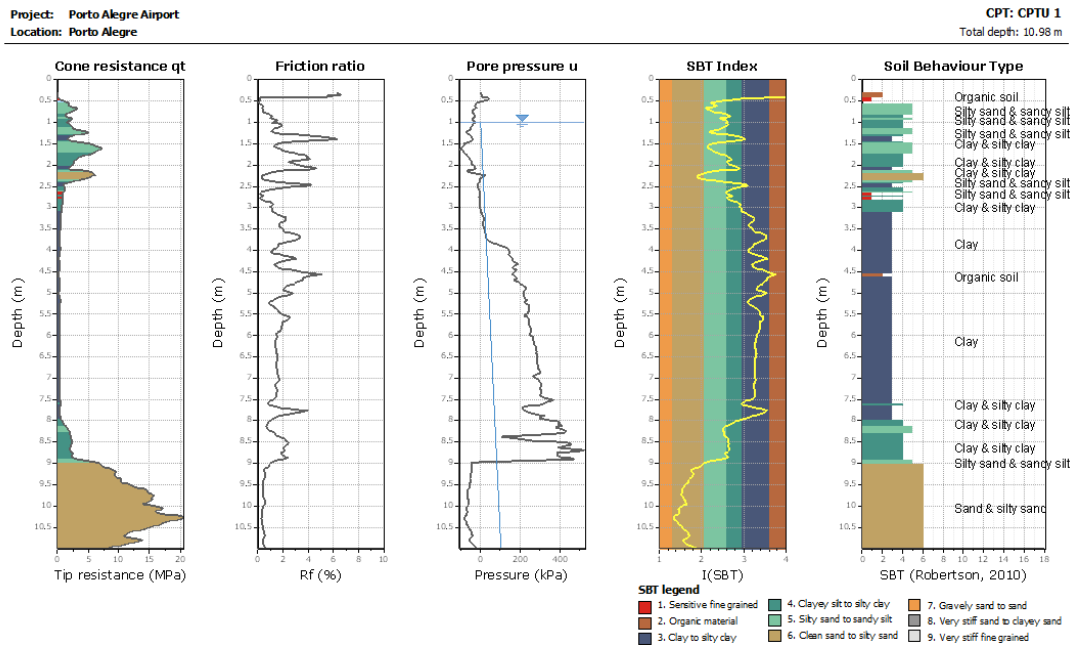


Figure 2 Typical CPTU log

Table 1 and Table 2 summarise geotechnical properties of the soft clay.

Table 1. Clay properties and Atterberg limits

Property	Symbol	Unit	Mean value
Water content	w	%	86
Plastic Limit	PL	%	36
Liquid Limit	LL	%	74
Plasticity Index	PI	%	39
Unit weight	γ	kN/m ³	15
Organic matter content		%	10
pH			5

Table 2 Geotechnical parameters

Layer	γ	ϕ	c_u	E_{50}
	kN/m ³	°	kPa	MPa
Fill	18	30	0	10
Soft clay	15	0	8	0.8
Sand	19	30	0	40

Where: γ is the unit weight, ϕ the peak friction angle; c_u is the undrained strength of the clay and E_{50} , the Young's modulus obtained at a stress level of 50%.

The tarmac pavement structure to be designed to fulfil the following requirements (Topolnicki, 2004):

- Reduce the absolute settlements to an acceptable limit
- Minimize differential settlements along the surface of the pavement
- Avoid long periods of consolidation
- Substantially reduce the scope of excavation, avoid dewatering and pile-cap works
- Minimize removal of construction debris or spoil material
- Cost-effective solution to cope with time frame and budget

The DSM technique was selected as the ground improvement solution. Figure 3 presents a typical cross-section. The columns were 800 mm in diameter and 2.5 m spaced in a rectangular grid pattern.

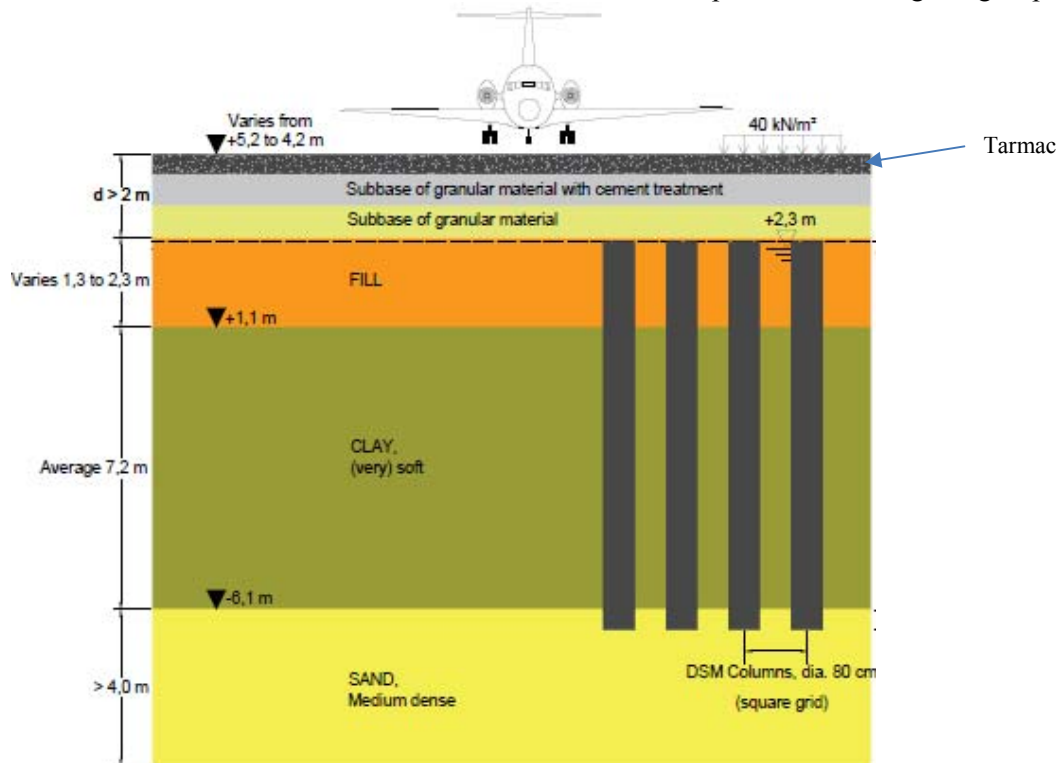


Fig. 3. DSM design model

PRELIMINARY STUDIES and Trial Embankment

During the design phase, an extensive laboratory test programme was carried out to optimize the mix design and cement content. The European Standard EN 14679 was adopted for the test programme.

The laboratory testing enabled to analyse the following characteristics

- Cement types: CP II - Z (Cement Portland with 6-14% of pozzolanic material) and CP IV (Cement Portland with 15 - 50% of pozzolanic material)
- Cement content: ranging from 150 to 500 kg/m³
- Addition of lime due to acid environment
- Addition of fine-sand
- Testing age ranging from: 3, 7, 14, 28 to 56 days

In total, more than 170 samples (diameter 75mm x height 150mm) have been prepared, subjected to, and unconfined compression tests (UCS). Figure 4 summarises the results

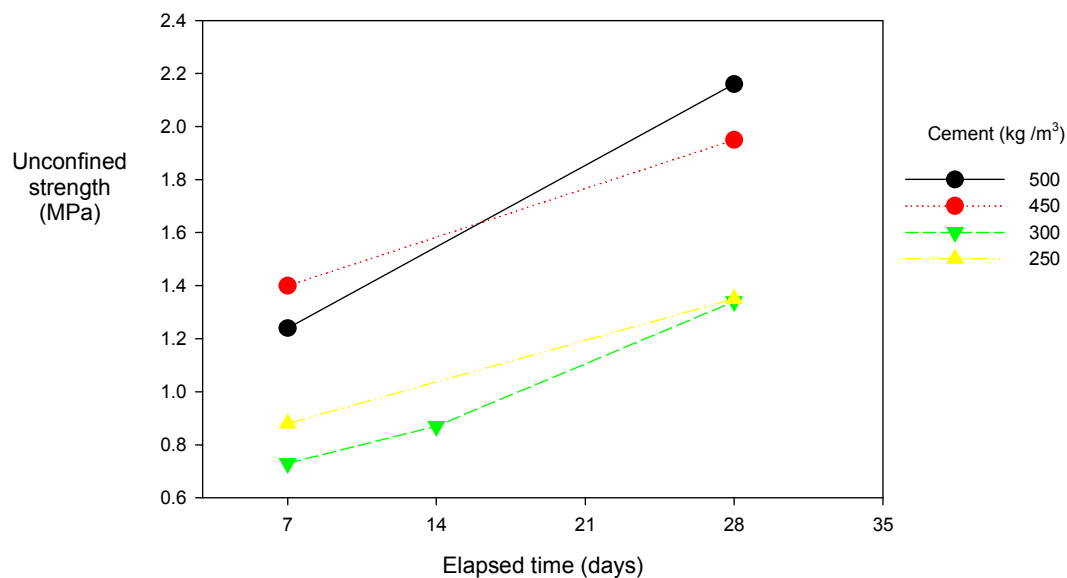


Fig. 4. Unconfined strengths a function of time (clay mix with CP II-Z-32)

Neither lime nor sand had a significant impact on the strength results and were, then, disregarded for the final slurry-mix design. Fig. 5 photo shows laboratory prepared samples. All samples were immersed in water until the test started.



Fig. 5 photo. Laboratory test samples cylinders



Fig. 6 Unconfined compression test

The laboratory test programme enabled to select the cement content of 350 kg/m^3 . In addition, a fully monitored trial embankment was then designed and built to check design assumptions.

The trial consisted of a square grid of 9 m long, 2.5 m spaced, 800 mm diameter DSM columns (Figure 7). The instrumentation consisted of settlement plates, a hydraulic settlement profiler, earth pressure cells, and electrical vibrating wire (VW) piezometers. The test area included additional site investigation: CPTU, VST and SPT's were carried out.

Loading on the test area consisted of applying 2.5 m of compacted fill.

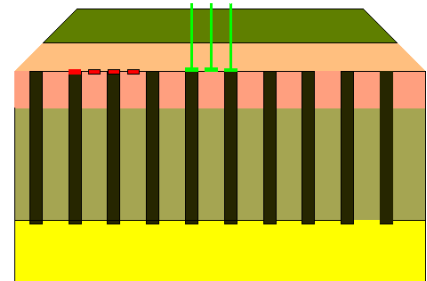
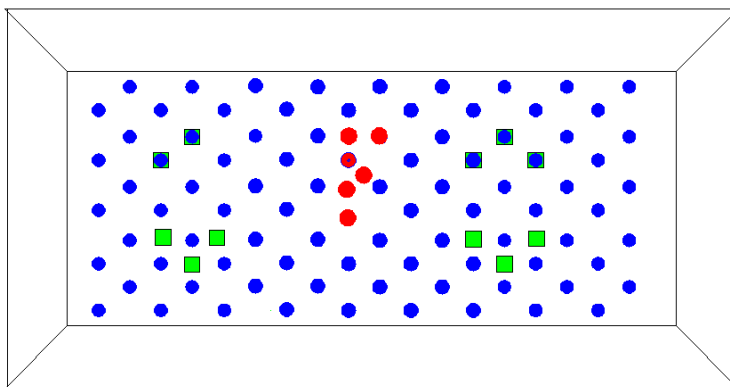


Fig.7. Trial embankment instrumentation layout

Column Exhumation

Exhumed columns enable a check on the final geometry and quality. Therefore, a few columns were excavated down to 3 m depth (Figure 8) and checked.

The DSM machines were fitted with a monitoring system to check rotation speed of the mixing tool and cement content. Figure 9 presents a typical log.



Fig.8 photo. Excavated DSM-column

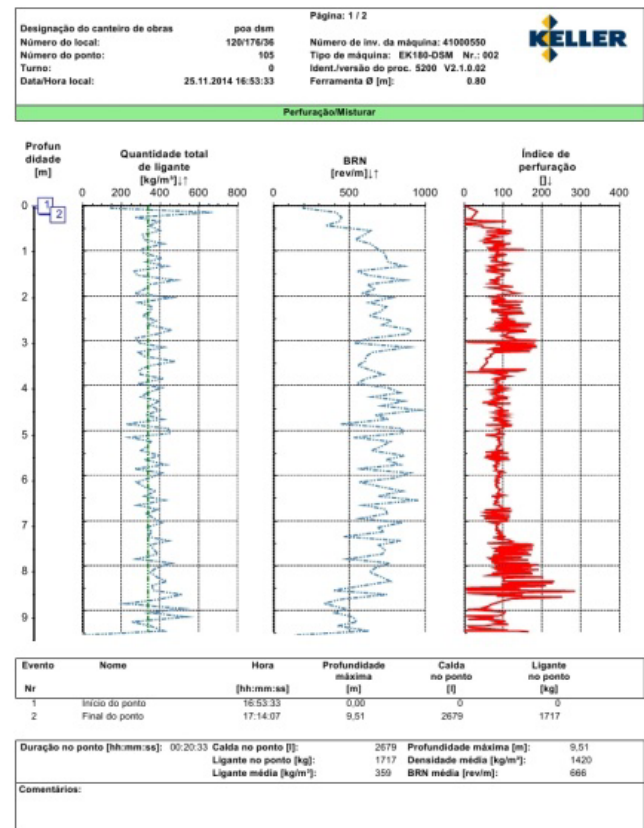


Fig.9. Printout of monitoring system

EXECUTION and QUALITY CONTROL

The QC plans for the five ha area will be based on the results from the laboratory and field tests. The QC design will include additional site investigation and a settlement-monitoring programme. The quality of the mix will also include mix sampling and testing at every 200 m of columns.

Earth Pressure Cells (EPC)

EPC were installed on the top of the columns and in the centre of them to analyse arching effect (Figure 10 and Figure 11). Additionally, they were placed below and above the geogrid.

Figure 12 presents the results, which show higher values for cells on the top of the columns, as expected.



Fig.10 photo. Load cell installed on top of a column



Fig.11 photo. Load cell installed on top soil between columns

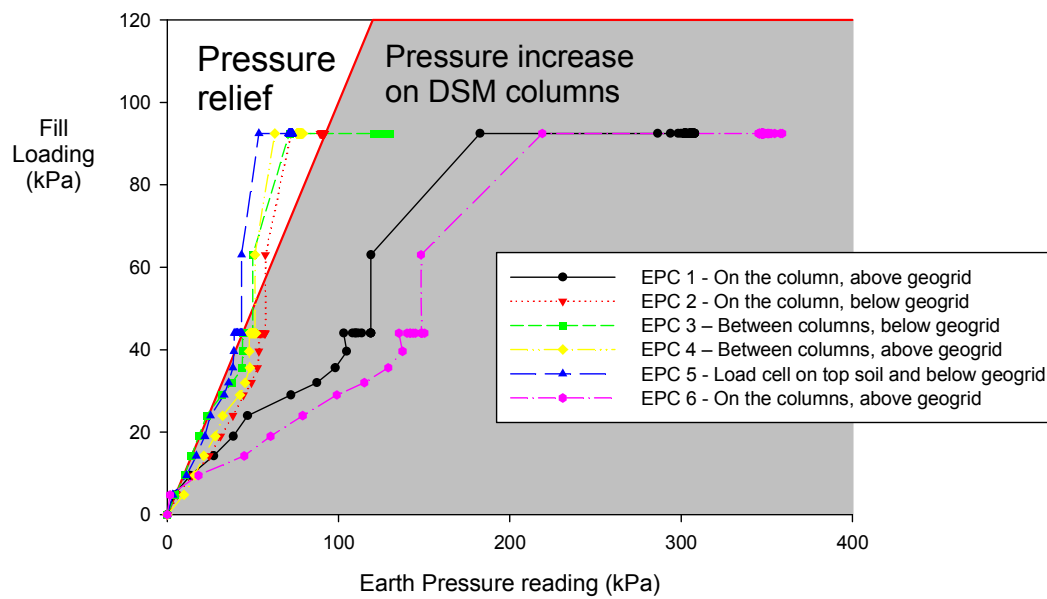


Fig.12. Earth pressure cell results

Settlement Monitoring

Settlement monitoring was carried out through settlement plates installed on the top of the columns and centred between them. The Figure 13 shows the results. Plates PR-2 and PR-10 on the column top yielded less settlements than those centred between columns.

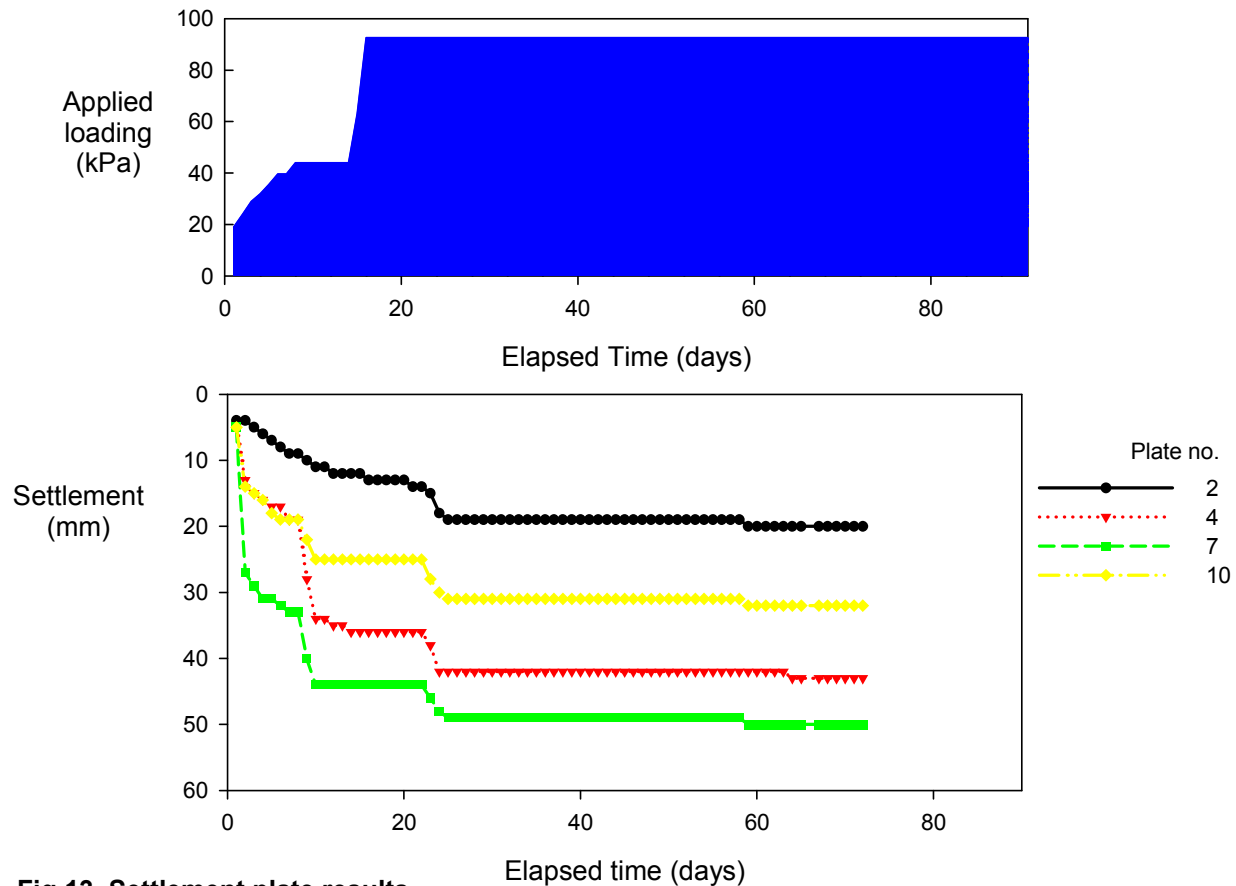


Fig.13. Settlement plate results

CONCLUSIONS

The work presented herein described a comprehensive laboratory and field-testing programme for the design of a five ha area of ground improvement by means of DSM. The work consisted of site investigation, drilling and sampling, field-testing by means of CPTU and VST.

The laboratory-testing programme aimed at optimising the mix design and cement content. The selected value was 350 kg/m^3 . Columns individually monitored during mixing by means of instruments that enable to check cement content and blade rotation. In the end, a few were exhumed for visual inspection. The trial embankment on a 2700 m^2 area reproduced conditions expected at the final structure and the observed behaviour was good.

REFERENCES

EN 14679: Execution of special geotechnical works: Deep Mixing, European Standard

Schnaid, F; Nacci, D & Milititsky, J (2001) Aeroporto Internacional Salgado Filho: Infra-Estrutura Civil e Geotécnica, Ed. Sagra, Porto Alegre, Brazil

Topolnicki, M (2004) In situ Soil Mixing. Chapter 9 in Ground Improvement book, Editors M. Moseley and K. Kirsch, Spon Press, pp. 331-428, 3rd Edition, 2013, ISBN 978-0-415-59921-4