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2nd SEMINAR
ON TRANSPORTATION
GEOTECHNICS

SOIL IMPROVEMENT CHALLENGES ON ALLUVIAL ZONES

28-29 January 2019
Vila Franca de Xira, Portugal

Presentations e-Book Volume 3

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Soil Improvement Challenges
on Alluvial Zones

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CONTENTS

MODULE III - Learning from (In) Success in Soil Improvement

III.1	Ground improvement for concrete tanks built on reclaimed sand <i>Serge Varaksin (ex-Vice Chairman TC211, ex-MENARD)</i>	698
III.2	Impact of creep phenomenon on the behaviour of the soft soil of Baixo Mondego <i>António Alberto, Paulo J. Venda Oliveira (U.COIMBRA)</i>	730
III.3	European Standardization for the Shallow Treatment of Soils and Granular Materials <i>António Gomes-Correia (U.MINHO), José Neves (IST, U.LISBOA)</i>	769
III.4	Soil improvement! Where or when? <i>Baldomiro Xavier (TEIXEIRA DUARTE)</i>	795
III.5	Construction Insurance (CAR). Guarantees and Exclusions. Challenges in the Geotechnical Area - Case Study <i>Jorge Salgado (TEC, Técnicos de Peritagens)</i>	883
III.6	Monte Gordo's Slope, Vila Franca de Xira: Stabilization Solutions <i>Ana Rita Nunes (CM VILA FRANCA XIRA)</i>	908
III.7	Solutions for the treatment of the foundations soft clays of Carregado highway interchange, logistic platform of north Lisbon and respective connections to highway A1 and national road EN1 <i>José Mateus de Brito, Gonçalo Tavares, Jaime Santos (TPF)</i>	940

MODULE III

Learning from (In) Success in Soil Improvement

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GROUND IMPROVEMENT FOR CONCRETE TANKS BUILT ON RECLAIMED SAND

Serge Varaksin, M.Sc

Past Chairman TC 211

Core Member TC 102

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The Palm Jumeira

Tree trunk

Crown with 17 fronds

3 crescent islands that form an 11 km long breakwater

2 smaller islands in the shape Nakheel's logo

94 million m³ of sand

7 million m³ of rock

The Palm Jumeira

Reclamation by trailing suction hoppers & rainbow

Sewerage Treatment Plant (SPT) Tanks A-A & G-G

SPT Tanks

- Tank foundation diameter= 35.1 m

SPT: Split Spoon Sampler

Standard Penetration Test (SPT): History

- Started as a driven sampling method in 1902 by Charles Gow
- Counting blows began by Harry Mohr in the late 1920s
- In 1947, Karl Terzaghi coined the term *Standard Penetration Test* to describe the correlations assembled by Mohr over the previous 20 years.

Pressuremeter Test (PMT): History

- Patented by Louis Menard in 1952 at the age of 23.
- Menard is also the inventor of dynamic compaction and dynamic replacement.

General Scheme of a Ménard Pressuremeter

Typical PMT test report and interpretation

Ground Conditions

Foundation Alternatives

- Piling
 - Very expensive
 - Piling is generally more expensive than ground improvement
 - Marine transportation further increased the price gap between piling and ground improvement
- Ground improvement

Design Criteria for mat at depth of 1.5 m

- Allowable bearing capacity: 160 kPa with a safety factor of 3
- Differential settlement: 1/750 for a uniformly distributed load of 120 kPa

Concept

- Preliminary investigation
- Placement of instrumentation
- Placement of 4m surcharge
- Walk the crane with 1000 blows, 300 t/m around surcharge
- Remove surcharge
- Preexcavate 20m³ per print
- Dynamic replacement phase
- Quality control
- FEM analysis for acceptance
- Acceptance
- Actual settlement records

Parameters

- SPT + PMT
- Settlement plates
- Accelerometers
- Impose statics and dynamic loading
- Dynamic surcharge
- Simulate earthquake
- Prestress soil for 0,2g
- Overconsolidate silt
- Remove cemented layer screening energy
- Reach deep layer
- Reinforce top layer
- SPT, PMT, acceleration record
- Cosmos FEM with PMT parameter
- Report
- Less than specified

Dynamic Compaction

Problem: availability of heavy DC rigs

Solution: Dynamic Surcharging

DUNG QUAT PROJECT

It can be assumed that those impacts du generate a pore pressure at least equal to the pore pressure generated by the embankment load.

This new consolidation process with the final at a time t'_f , where

$$T_v = 0,848 = \frac{C'_v (t'_1 - t_1)}{H^2} + \frac{C_v T_1}{H^2}$$

With

$$C'_v = C_v \left[1 + \frac{du}{\Delta\sigma(1 - U_1)} \right]$$

the following equation allows to compare the respective times of consolidation being :

t'_f with impact
 t_f without impact

$$t'_f = \frac{du}{du + \Delta\sigma(1 - U_1)} t_1 + \frac{\Delta\sigma(1 - U_1)}{du + \Delta\sigma(1 - U_1)} t_f$$

For this considered case,

$$du = U\Delta\sigma$$

$$\text{and thus } t'_f = U_1 t_1 + (1 - U_1) t_f$$

The Table allows to compare the gain in consolidation time, at different degrees of consolidation.

U_1	10%	20%	30%	40%	50%	60%	70%	80%	90%
t_1/t_f	0.009	0.037	0.083	0.148	0.231	0.337	0.474	0.669	1.00
t'_1/t_f	0.901	0.807	0.725	0.659	0.615	0.602	0.632	0.735	1.00

Supposing primary consolidation completed

$$U = 0.9 \quad \text{or} \quad T = 0.848 \quad \text{if} \quad du = U_1 \Delta\sigma, \\ \text{then } t'_f = U_1 t_1 + (1 - U_1) t_f$$

The optimal effectiveness occurs around $U_1 = 60\%$.

One can thus conclude that, theoretically the consolidation time is reduced by 20% to 50%, what is for practical purpose insufficient.

Placement of monitoring plates

Dynamic Surcharging

Settlements

General excavation to depth of 1.2 m & excavation of prints

Dynamic Compaction

Water seeping into the crater

PMT Tank A-A

PMT Tank G-G

Finite Element Analysis using COSMOS/M

Variable foundation thickness

Maximum settlement= 21.35 mm
Differential settlement= 1/1681

Obrigado

Impact of creep phenomenon on the behaviour of the soft soil of Baixo Mondego

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Contents

- **Introduction / Description of the problem**
- **Creep model**
 - Creep behaviour
 - Taylor's law
 - Singh-Mitchell's law
- **Laboratory tests**
- **Numerical study**
 - Validation of constitutive models and creep laws
 - Numerical results
- **Conclusions**

Introduction / Description of the problem

◇ Creep settlements of an embankment on soft soil (Portugal)

A14 (IP3) – “Baixo Mondego” soft soil

◇ Effects of time on the rheological behaviour of soft soils

Geotechnical design:
couple stability-settlement analysis incorporating time effects⁷³²

Creep Model

- ◇ Material creep
 - deformation
 - irreversible
 - time dependent
- ◇ Soil creep
 - sandy soil: rearrangement of soil particles
 - soft soils: viscosity effects

Creep Model

Creep modelation

**Volumetric
component**

Taylor's law

$$\varepsilon_v^t = \int_t^{t+\Delta t} \frac{C_\alpha / 2.3}{(1+e) t_v} dt$$

C_α – Secondary consol. coefficient

e – void ratio

t_v – volumetric “age”

Oedometer creep tests

**Deviatoric
component**

Singh-Mitchell's law

$$\varepsilon_a^t = \int_t^{t+\Delta t} A.e^{\bar{\alpha}.\bar{D}} \left[\frac{(t_d)_i}{t_d} \right]^m dt$$

A , $\bar{\alpha}$, m – Singh-Mitchell's parameters

$\bar{D} = \frac{(\sigma_1 - \sigma_3)}{(\sigma_1 - \sigma_3)_{ult}}$ – deviatoric stress level

t_d – deviatoric “age”

Triaxial creep tests

Triaxial creep tests

Triaxial creep tests

Creep Model

Creep modelation

**Volumetric
component**

**Deviatoric
component**

Taylor's law

$$\varepsilon_v^t = \int_t^{t+\Delta t} \frac{C_\alpha / 2.3}{(1+e) t_v} dt$$

C_α – Secondary consol. coefficient

e – void ratio

t_v – volumetric “age”

Singh-Mitchell's law

$$\varepsilon_a^t = \int_t^{t+\Delta t} A.e^{\bar{\alpha}.\bar{D}} \left[\frac{(t_d)_i}{t_d} \right]^m dt$$

A , $\bar{\alpha}$, m – Singh-Mitchell's parameters

$$\bar{D} = \frac{(\sigma_1 - \sigma_3)}{(\sigma_1 - \sigma_3)_{ult}} - \text{deviatoric stress level}$$

t_d – deviatoric “age”

Incorporation into an Elastoplastic Soil Model (MCC + VM)

Laboratory Tests

- ◆ Unstabilized soft soil:
 - identification and characterization
 - oedometer
 - triaxial
- ◆ Stabilized soft soil with CEM I 42.5R:
 - preparation of samples with $\phi = 101.6$ and 37 mm
 - UCS
 - oedometer
 - triaxial
- ◆ Creep study:
 - oedometer
 - triaxial

Unstabilized soft soil

- ◇ Soft soil deposit of “Baixo Mondego”:
- geotechnical properties

G	w_{nat} (%)	γ_{sat} (kN/m ³)	e_{nat}	Granulom. (%)	Plastic. (%)	OM (%)	Unifined Classific.	c_u (kPa)
2.58	81	14.6	2.03	C = 8-12 M = 71 S = 17-21	$w_L = 71$ $w_P = 43$ IP = 28	8.0	OH of high plasticity	< 25

- compressibility and permeability characteristics

C_c (-)	C_r (-)	c_v (m ² /year)	k_v (m/s)
0.57	0.065	63	10^{-9}

Stabilized soft soil

- ◇ Soft soil stabilized with Portland cement CEM I 42.5R
(binder quantity = 125 kg/m³):
- chemical composition and specific surface of the binder

CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	Spec. Surface Blaine
(%)	(%)	(%)	(%)	(%)	(m ² /kg)
63.02	19.70	5.23	2.99	2.38	321.5

Sample with
 $\phi = 101.6$ mm

Sample with
 $\phi = 37$ mm

Oedometer creep tests

◇ Creep volumetric strains:

$$\sigma'_v = \sigma'_{v0} + \Delta\sigma'_v \rightarrow \text{embankment of 3m height } (\gamma = 22\text{kN/m}^3)$$

soft soil

$$C_\alpha = 0.023$$

Oedometer creep tests

◇ Creep volumetric strains:

$$\sigma'_v = \sigma'_{v0} + \Delta\sigma'_v \rightarrow \text{embankment of 3m height } (\gamma = 22\text{kN/m}^3)$$

stabilised soil

$C_\alpha = 0.0006^*$

* Depends on stress level

Triaxial creep tests

undrained consolidated compression triaxial tests with creep stage

soft soil

Triaxial creep tests

undrained consolidated compression triaxial tests with creep stage

Laboratory creep tests - conclusions

◆ Creep parameters

	C_α (-)	m (-)	$\bar{\alpha}$ (-)	A (%/min)
Unstabilized soil	0.023	0.98	0.73	0.00115
Stabilized soil	0.0006*	0.28	0.67	0.00002

* Depends on stress level

C_α depends on stress level

Laboratory creep tests - conclusions

◆ Creep parameters

	C_α (-)	m (-)	$\bar{\alpha}$ (-)	A (%/min)
Unstabilized soil	0.023	0.98	0.73	0.00115
Stabilized soil	0.0006*	0.28	0.67	0.00002

* Depends on stress level

◆ Creep volumetric strain

unstabilized soil $\approx 38 \times$ stabilized soil

◆ Creep deviatoric strain

unstabilized soil $\approx 11 \times$ stabilized soil

◆ Creep parameters have a physical meaning and could easily be evaluated from laboratory tests

Numerical study

- ❑ **Validation of the constitutive models and creep laws**
- ❑ **Prediction of the creep behaviour of an embankment**

Numerical study Validation of the model/creep laws

Parameters of the model/creep laws

	Soil type	Soft soil	Stabilised soil/DMC ^(c)
Constitutive model		MCC	MCC/VM
Elastic parameters	E'	(a)	164.7 MPa
	ν	0.3	0.3
MCC model	$e_{\lambda 0}$	2.315	5.07
	e_0	(a)	(a)
	λ	0.204	0.435
	κ	0.030	0.0074
	M	1.50	1.50
VM model	a	---	0.0013
	b	---	1.683
	R_f	---	1.0
Volumetric creep law	C_α	0.0236	(a)
	t_{vi}	1.0 min	(b)
Deviatoric creep law	A	0.001148 %/min	0.0000244 %/min
	m	0.978	0.28
	$\bar{\alpha}$	0.734	0.671
	t_{di}	1.0 min	(b)
	a	0.007	0.0013
	b	1.1033	1.683
	R_f	0.95	1.0

Validation of the model/creep laws: SOFT SOIL → Triaxial tests

Validation of the model/creep laws: DMC Triaxial tests

Validation of the model/creep laws → Oedometer creep tests

Soft soil

DMC

Numerical study

Simulation of an embankment
of infinite dimensions

Axisymmetrical analyses

Use of unit cell

Mesh of
finite
elements

350 nodal points

130 quadrilateral elements

Elements used below the water table
enable the consolidation
phenomenon to be simulated

Numerical study

Material properties

Embankment

Linear elastic
 $\nu = 0.3$, $E' = 1.0 / 7.5 / 15.0$ MPa

Stabilised soil (DMC)

Modified Cam-Clay / Von Mises
 $K_0 = 0.4$; $k_v = k_h = 3 \times 10^{-10}$ m/s

Soft soil

Modified Cam-Clay (MCC)
 $K_0 = 0.8$; $k_v = 10^{-9}$ m/s ; $k_h/k_v = 3$

Associated with creep laws

Numerical study

Material properties

Embankment

→ Linear elastic
 $\nu = 0.3, E' = 1.0 / 7.5 / 15.0 \text{ MPa}$

Stabilised soil (DMC)

→ Modified Cam-Clay / Von Mises
 $K_0 = 0.4 ; k_v = k_h = 3 \times 10^{-10} \text{ m/s}$

Soft soil

→ Modified Cam-Clay (MCC)
 $K_0 = 0.8 ; k_v = 10^{-9} \text{ m/s} ; k_h/k_v = 3$

$$C_\alpha = 1.67 \times 10^{-6} \times \sigma'_{\text{creep}} + 322.6 \times 10^{-6}$$

$$E' = 164.7 \text{ MPa}$$

$$E' = \frac{3 \times (1 + e_0)(1 - 2\nu')}{\kappa} \times p'_0$$

$$k = k_0 \times 10^{\frac{e - e_0}{0.5 \times e_0}}$$

↓
Associated with creep laws

Numerical study

Cases studied

□ Case A - DMC : No
Soil: **No creep**

□ Case B - DMC: No
Soil: **Creep**

□ Case C - DMC: **Yes**
No creep
Soil: **No creep**

□ Case D - DMC: **Yes**
No creep
Soil: **Creep**

□ Case E - DMC: **Yes**
Creep
Soil: **Creep**

Only
Soft soil

Soft soil
+
DMC

Numerical study

Settlements vs time

Numerical study

□ Settlements vs time

Numerical study

□ Settlements vs time

Numerical study

Settlements vs time

Numerical study

□ Settlements vs time: **improvement factor**

$$IF = \frac{S_{\text{soil (No DMC)}}}{S_{\text{soil+DMC}}}$$

Numerical study

□ Settlements vs time: **improvement factor**

$$IF = \frac{S_{\text{soil (No DMC)}}}{S_{\text{soil+DMC}}}$$

Numerical study

□ Settlements vs time: **improvement factor**

$$IF = \frac{S_{\text{soil (No DMC)}}}{S_{\text{soil+DMC}}}$$

Creep
phenomenon
decreases IF

Numerical study

Load on DMColumn and Soil vs time

Due to “arching effect” the stresses on the DMCs increases significantly

Numerical study

Load on DMColumn and Soil vs time

Increase of vertical stress on DMC due to creep

Numerical study

Stress concentration ratio (SSR) vs time

$$SSR = \frac{\sigma'_{V-DMC}}{\sigma'_{V-Soft\ soil}}$$

Increase of SSR
with the consideration of
creep phenomenon, which
tend to decrease with time

Conclusions

- ◆ The MCC model associated with the creep laws is able to replicate the creep behaviour of the soft soil.
- ◆ The MCC/VM model associated with the creep laws predicts a creep axial strain similar of the stabilised soil.
- ◆ Creep of the soft soil does not produce significant changes in the settlements, although this induces an increase in stresses on the DMCs in relation to the case without creep.
- ◆ Long term analysis must be evaluated with the creep phenomenon
- ◆ Through the arch effect, vertical effective stresses decreases in soil and increases in DMC columns. This behavior is slightly more marked when the creep phenomenon is considered

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Impact of creep phenomenon on the behaviour of the soft soil of Baixo Mondego

Thank you

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European Standardization for the Shallow Treatment of Soils and Granular Materials

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OUTLINE

- ☐ Treatment in Pavements
- ☐ Earthworks
- ☐ Advanced Laboratory Tests
- ☐ Design Application
- ☐ Final Remarks

SHALLOW TREATMENT OF SOILS AND GRANULAR MATERIALS

Scope and importance

Earthworks

Pavements

LCPC/SETRA, 2000

European Standardization for the Shallow Treatment of Soils and Granular Materials, A. Gomes-Correia, J. Neves

TREATMENT IN PAVEMENTS

Scope and importance

Soils and granular mixtures

Pavements

- Flexible
- Semi rigid
- Rigid

Layers

- Subgrade
- Sub base layer
- Base layer

TREATMENT IN PAVEMENTS

Organization of standardization in Portugal

TREATMENT IN PAVEMENTS

Standardization related to hydraulically bound mixtures - Specifications

EN 14227 – Specifications of hydraulically bound mixtures to be used for construction and maintenance of roads, airfields and other trafficked areas

Part 1: **Cement bound granular mixtures**

Part 2: Slag bound mixtures

Part 3: Fly ash bound mixtures

Part 4: Fly ash for hydraulically bound mixtures

Part 5: Hydraulic road binder bound mixtures

Part 15: **Hydraulically stabilized soils**

Soil treated by:

- Cement
- Lime
- Slag
- Fly ash
- Hydraulic road binder

Laboratory tests

- Strength
- Deformability
- Durability

Compaction and curing of test specimens

TREATMENT IN PAVEMENTS

Specifications for cement bound granular mixtures

EN 14227-1

Classification

- the **compressive strength** (R_c).
- the combination of the **tensile strength** (R_t) and the **modulus of elasticity** (E). The tensile strength can be evaluated by direct or indirect tensile strengths.

EN 13286

Part 40: Direct tensile strength

Part 41: Compressive strength

Part 42: Indirect tensile strength

Part 43: Modulus of elasticity

TREATMENT IN PAVEMENTS

Specifications for hydraulically stabilized soils

EN 14227-15

Soil-cement
Soil-lime

The mixture requirements are specified for:

- **Fresh material**
- Hardened material

EN 13286-47 - immediate bearing capacity index

➡ Importance of compaction conditions and binder content

European Standardization for the Shallow Treatment of Soils and Granular Materials, A. Gomes-Correia, J. Neves

TREATMENT IN PAVEMENTS

Specifications for hydraulically stabilized soils

EN 14227-15

Soil-cement
Soil-lime (3%)

Hardened material

compressive strength (R_c)

➔ **Importance of mixture conditions and curing regimes (durability)**

European Standardization for the Shallow Treatment of Soils and Granular Materials, A. Gomes-Correia, J. Neves

STANDARDIZATION IN EARTHWORKS: NEEDS (CEN/TC 396)

Earthworks represent in general 15 to 20% on average of the “public works” activity and in Europe up to 30% or even 40% of the construction costs in motorways and railways.

STANDARDIZATION IN EARTHWORKS: (CEN/TC 396)

- — 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 (PrEN 16907-4:2015);**
- — Part 5: Quality control;
- — Part 6: Land reclamation with dredged hydraulic fill;
- — Part 7: Hydraulic placement of mineral waste.

Specific test standards

- Earthworks – Tests on materials
- Earthworks – Tests on fills

CONTENTS (PrEN 16907-4:2015)

- Constituents and mixtures
- Laboratory testing methodology
- Performance classification of the mixtures
- Execution and control

Notes of guidelines of good practices are also included in or presented in some of the 14 annexes.

ADVANCED LABORATORY TESTING: LOCAL STRAIN MEASUREMENTS (ON SAMPLE)

- Strain at ultimate strength obtained with the external measurement device is about three times as high as the local measurement
- $E_{tg50\%}$ determined with the local measurement is about three times as high as the $E_{tg50\%}$ determined with the external measurement

ADVANCED LABORATORY TESTING: LOCAL STRAIN MEASUREMENTS (ON SAMPLE)

- Previous investigations shown the inaccuracy of evaluating the moduli by the use of the external measurement of the deformation of the samples.

ADVANCED LABORATORY TESTING

EMM-ARM -> Elasticity Modulus Monitoring through Ambient Response Method

- Continuous and automatic monitoring of the E-modulus of concrete (originally) since casting.
- Variant to classical resonant frequency testing.
- Under development since 2008.
- Applied to concrete, cement paste, **stabilized soil**, hydraulic lime, epoxy,...

ADVANCED LABORATORY TESTING

EMM-ARM -> Elasticity Modulus Monitoring through Ambient Response Method

GENERAL PRINCIPLE

Cast a stabilised specimen inside a cylindrical acrylic tube (mould)

Immediately after casting, place the composite beam simply supported and monitor accelerations due to ambient vibration at mid-span

The measured accelerations allow the identification of the 1st resonant frequency of the composite beam at each instant (evolves with hardening)

Possibility of applying the equations of motion for the composite beam and obtain a curve of soil-mixture E-modulus *versus* time

ADVANCED LABORATORY TESTING

Study of moduli evolution with time of a silty soil treated with quicklime

ADVANCED LABORATORY TESTING

Normalized moduli E/E_{42} and M/M_{42} obtained by EMM-ARM and US – 30° C

$$E_{ri}(t) = a_{ri} \exp \left[- \frac{1}{2} \left(\frac{\tau_{ri}}{\sum_{i=1}^n \tau_{ri}} \exp \left[\left(\frac{Ea_{ri}}{R} \right) \left(\frac{1}{T} \right) - \left(\frac{1}{T_{ref}} \right) \right] \Delta t \right) \right] \beta_{ri}, i = \{1, 2\}$$

T (°C)	20	30	40
a_{r1} (GPa)	2.91		
β_{r1}	0.25		
a_{r2} (GPa)	2.15		
β_{r2}	3.13		
τ_{r1}	1514.9	477.82	138.36
τ_{r2}	189.82	30.78	8.23
E_0 (GPa)	0.413	0.450	0.547

Apparent Activation Energy: $Ea_1 = 89\,929$ J/mol and $Ea_2 = 128\,006$ J/mol

DESIGN APPLICATION

$E_{tg50\%}$ / UCS

- ❑ For design purposes, UCS and $E_{tg50\%}$ are those properties currently required.
- ❑ Due time and costs concerns, usually only compression test without strain measurement are carried out.
- Therefore, for $E_{tg50\%}$ quantification a relation between $E_{tg50\%}$ and UCS ($E_{tg50\%}/\text{UCS}$) can be very useful.

DESIGN APPLICATION

Etg50% / UCS as a function of strain level

- ❖ There is a well-defined trend between the strain and the relation $E_{tg50\%}$ (GPa)/UCS (MPa), for 28 days
- ❖ This proposal can help the design engineer to easily predict the $E_{tg50\%}$ for the design strain level based on the conventional uniaxial compressive strength test results

FINAL REMARKS

Standards

- Increase the visibility of earthworks
- Benefit from the sharing of national practices (possibly better practices in specific fields)
- Update the best practices
- Fill the gap aside existing design codes

FINAL REMARKS

Think sustainable

The construction of transport infrastructures is one of the most material demanding activities. Therefore a major field for develop more sustainable approaches.

The main commitments for companies are:

- increase reuse of local materials extracted within the project site in order to reduce the external borrow-pits and to avoid the corresponding transports,
- preserve and protect biodiversity and natural environment,
- reduce greenhouse gas emissions and consumption of energy,
- reduce water consumption,
- develop tools for assessing environmental performance.

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3rd International Conference on Information Technology in Geo-Engineering

ICITG

Sep. 29-02 Oct., 2019, Guimarães, Portugal

Website: <http://www.3rd-icitg2019.civil.uminho.pt/>

Email: 3rd-icitg2019@civil.uminho.pt

CONFERENCE THEMES

1. Data exchange (including ownership/legal aspects)
2. Use of Information and communications technologies (ICT) in laboratory and field works
3. Big data and databases
4. Data mining and data science
5. Imaging technologies
6. Building information modeling (BIM) applied to geo-structures
7. Artificial intelligence
8. Intelligent constructions
9. Optimization systems
10. Virtual reality and augmented reality
11. Intelligent geo-synthetics and health systems
12. Sensors and monitoring
13. Asset management
14. Case studies in design, constructions and maintenance

WORKSHOPS

- * **Deep Underground Engineering and Data Mining**
 - Prof. Luis Ribeiro e Sousa, Tongji University, China
 - Prof. Dominik Słezak, University of Warsaw, Poland
 - Prof. Tiago Filipe Miranda, University of Minho, Portugal)
- * **Big data and AI-based geotechnical design – from fundamentals to practical issues**
 - Prof. Chungsik Yoo, Sunkunkwan University, Korea

MAIN LECTURES

- * **iS3 (smart infrastructure system)**
Prof. Hehua Zhu (Tongji University, China)
- * **Use of Data to Map a Country: Example of the Observation Method for Scour**
Prof. Jean-Louis Briaud (Texas A&M, USA)
- * **Building Information Modelling (BIM) for Geotechnical Engineering**
Prof. David Toll (Durham University, UK)
- * **Learning from Field Measurements Through Heuristic Inverse Analysis**
Prof. Marte Gutierrez (Colorado School of Mines, UTC-UTI, USA)
- * **Intelligent Data Analysis in Geo-Engineering**
Prof. Paulo Cortez (University of Minho, Portugal)
- * **Big Data and AI-based Geotechnical Design – from Fundamentals to Practical Issues**
Prof. Chungsik Yoo (Sunkunkwan University, Korea)
- * **A Holistic Approach for Accurate Infrastructure Data Visualization Using UAV-CRP Technology**
Prof. Anand Puppala (University of Texas at Arlington, Arlington)
- * **Application of artificial intelligence in geo-engineering**
Prof. Chungsik Yoo (NIT Patna, India)

...to be updated

MINI-SYMPOSIUM

- * **Machine Learning in Geotechnics**
 - Dr. Zhongqiang Liu, Norwegian Geotechnical Institute, Norway
 - Dr. Mohammad Rezanian, University of Warwick, UK
 - Dr. Zenon Medina-Cetina, Texas A&M University, USA

Abstract Submission Extended to January 18, 2019: <https://ocs.springer.com/misc/home/ICITG2019>

2SGT2019

2nd SEMINAR
ON TRANSPORTATION
GEOTECHNICS

Soil Improvement Challenges
on Alluvial Zones

28-29 January 2019 | Vila Franca de Xira | Portugal

Soil Improvement! Where or when?

Baldomiro Xavier

Teixeira Duarte Engenharia e Construções SA

Organização

Sociedade Portuguesa
de Geotecnia

Comissão Portuguesa de Geotecnia nos Transportes

Comissão Portuguesa
de Geossintéticos

Apoios

LABORATÓRIO NACIONAL
DE ENGENHARIA CIVIL

ORDEN
DOS
ENGENHEIROS

INDEX

- **INTRODUCTION – IMPROVING THE SOIL**
- **CASE STUDIES**
 - **STRUCTURAL REHABILITATION OF AN ACCUMULATION CHAMBER –
EDP MADEIRA**
JET GROUTING
 - **SEWAGE PUMPING STATION, PARQUE DAS NAÇÕES, LISBON**
JET GROUTING
 - **SEWAGE TREATMENT PLANT, SANTARÉM**
RIGID INCLUSIONS
 - **ESCOM TOWERS, LUANDA**
RIGID INCLUSIONS AND SOIL IMPROVEMENT BY GROUTING
 - **BUSINESS TOWER, LISBON**
SEEPAGE CONTROL BY GROUTING

THE BASICS – THE ISOTROPIC STRESS FIELD

$$\sigma_I = \sigma_{II} = \sigma_{III} = p$$

$$\sigma_{ij} = 0; \text{ for } i \text{ not EQ } j$$

$$\sigma_v = \gamma h \quad \sigma_h = k \sigma_v$$

$$K$$

$$K_a$$

$$K_0$$

$$K_p$$

$$K_a = 1 / k_p$$

If a soil feels like water

$$K_a = K_0 = K_p = 1 \quad \Delta\sigma \downarrow H = 0$$

ISOTROPIC STRESS FIELD

THE MOST EFFICIENT WAY TO PROMOTE DENSIFICATION

LANDFILLS AND EMBANKMENTS

SELECTED SOILS
MOISTURE CONTROL
STEADY BASE

LANDFILLS AND EMBANKMENTS

LANDFILLS AND EMBANKMENTS: REINFORCED SOIL

LANDFILLS AND EMBANKMENTS: COMPACTION

LANDFILLS AND EMBANKMENTS: COMPACTION

DYNAMIC COMPACTION

Advantages:

- Compacts large areas of loose granular fills
- Reduces the volume of landfill waste
- Increases in situ density and collapses voids
- Increased bearing capacity
- Reduces post-construction settlements

Applications

- Port and Airport Platforms
- Heavy Storage Facilities
- Landfill sites

DYNAMIC COMPACTION

1st Phase
Compaction of
deep layers

2nd Phase
Compaction of
intermediate
layers

Levelling
Phase
Compaction of
surface layer

DYNAMIC COMPACTION

APPLIED ENERGY GUIDELINES

Type of Deposits (-)	Unit Applied Energy (kJ/m ³)
Previous coarse-grained soil	200-250
Semi-previous fine-grained soils and clays above the water table	250-350
Landfills	600-1100

AE = applied energy

N = number of drops at each specific drop point location

APPLIED ENERGY

$$AE = (N)(W)(H)(P) / (\text{grid spacing})^2$$

W = tamper mass

H = drop height

P = number of passes

DEPTH OF IMPROVEMENT

$$D = n(WH)^{1/5}$$

D = depth of improvement in meters

W = mass of tamper in Megagrams

H = drop height in meters

N = empirical coefficient that is less than 1.0

DEEP VIBRATOR

DEEP VIBRATOR

RELATIVE DENSITY

$$D_r (\%) = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \times 100$$

$$D_r (\%) = \sqrt{k \frac{(N_1)_{60}}{60}} \quad (\text{EN1997-2})$$

$$D_r (\%) = -98 + 66 \log \left(\frac{q_c}{\sqrt{\sigma'_v}} \right) \quad k_p = 1 + 0.2x \frac{D_r - 30}{60} \quad (\text{Jamiolkowski et al, 1995})$$

$$D_r (\%) = 100x(0.268x \ln(\frac{q_c / \sigma_{atm}}{\sqrt{\sigma'_v / \sigma_{atm}}}) - 0.675) \quad (\text{Jamiolkowski, 2001})$$

DEEP VIBRATOR

PREDITION OF THE SOIL SUSCEPTIBILITY TO BE TREATED WITH DEEP VIBRATOR

$$S_n = 1.7x \sqrt{\frac{3}{D_{50}^2} + \frac{1}{D_{20}^2} + \frac{1}{D_{10}^2}}$$

Depth (m)	S _n
3	25
5	14
12	18
15,6	17
20,2	13

S _n	Class
0-10	Excelent
10-20	Good
20-30	Fair
30-50	Poor

D_i is the partical size in mm, which corresponds to the cumulative percentage “i” passing in the sieve D_i

DEEP VIBRATOR

PREDITION OF THE SOIL SUSCEPTIBILITY TO BE TREATED WITH DEEP VIBRATOR

Compacção profunda
Classificação de solos baseado na distribuição
da dimensão das partículas
(adaptado de Mitchell)

STONE COLUMNS

STONE COLUMNS

Influence área = $A_s + A_c$

STONE COLUMNS

EQUIVALENT DEFORMATION MODULUS OF THE TREATED SOIL

Improvement Solution	Soil		Column				S & C	
	E_{soil} [Mpa]	E_{column} [Mpa]	$\varnothing$ [m]	[m]	Mesh		$E_{equivalent}$ [MPa]	
[-]					x	[m]		
Soil & Stone Columns	5	75	1.00	2	x	2	19	4x
Soil & Concrete Columns	5	30000	0.80	4	x	4	947	200x

ELASTIC SETTLEMENT OF THE TREATED SOIL

Improvement Solution	S & C			Embankment			δ_{center} [mm]
	$E_{equivalent}$ [MPa]	μ [-]	H [m]	B [m]	L [m]	q [kPa]	
Soil	5	0.3	20	10	10	200	313
Soil & Stone Columns	19	0.3	20	10	10	200	82
Soil & Concrete Columns	947	0.3	20	10	10	200	2

25%
<1%

DRAINS CONSOLIDATION PROCESS

NUMBER OF BLOWS
(SPT)

NUMBER OF BLOWS
(SPT)

DRAINS

CONSOLIDATION PROCESS WITHOUT DRAINS

Primary consolidation
settlement for $t = t_{\infty}$

$$\delta(t = t_{\infty}) = \frac{H_0}{1 + e_0} C_c \log \left(\frac{\sigma_f}{\sigma_0} \right)$$

Primary consolidation
settlement for $t = t_i$

$$\delta(t = t_i) = U \cdot \delta(t = t_{\infty})$$

Degree of consolidation &
time factor

$$U = \frac{(4T_v/\pi)^{0.5}}{[1 + (4T_v/\pi)^{2.8}]^{0.179}} \quad T_v = \frac{C_v t}{d^2}$$

Time factor & consolidation
time

$$T_v = \frac{\pi/4 \cdot U^2}{(1 - U^{5.6})^{0.357}} \quad t = \frac{T_v d^2}{C_v}$$

DRAINS

CONSOLIDATION PROCESS WITH DRAINS (MESH $\Delta 2.00\text{m}$)

Primary consolidation
settlement for $t = t_\infty$

$$\delta(t = t_\infty) = \frac{H_0}{1 + e_0} C_c \log\left(\frac{\sigma_f}{\sigma_0}\right)$$

Primary consolidation
settlement for $t = t_i$

$$\delta(t = t_i) = U \cdot \delta(t = t_\infty)$$

Degree of consolidation &
time factor

$$U = \frac{(4T_v/\pi)^{0.5}}{[1 + (4T_v/\pi)^{2.8}]^{0.179}} \quad T_v = \frac{C_v t}{d^2}$$

Time factor & consolidation
time

$$T_v = \frac{\pi/4 \cdot U^2}{(1 - U^{5.6})^{0.357}} \quad t = \frac{T_v d^2}{C_v}$$

DRAINS

CONSOLIDATION PROCESS WITH DRAINS (MESH $\Delta 1.00\text{m}$)

Primary consolidation
settlement for $t = t_\infty$

$$\delta(t = t_\infty) = \frac{H_0}{1 + e_0} C_c \log\left(\frac{\sigma_f}{\sigma_0}\right)$$

Primary consolidation
settlement for $t = t_i$

$$\delta(t = t_i) = U \cdot \delta(t = t_\infty)$$

Degree of consolidation &
time factor

$$U = \frac{(4T_v/\pi)^{0.5}}{[1 + (4T_v/\pi)^{2.8}]^{0.179}} \quad T_v = \frac{C_v t}{d^2}$$

Time factor & consolidation
time

$$T_v = \frac{\pi/4 \cdot U^2}{(1 - U^{5.6})^{0.357}} \quad t = \frac{T_v d^2}{C_v}$$

WEAK DRAINS DRIVING

JET-GROUTING HIGH PRESSURE JET

JET-GROUTING

COLUMNS Ø800 mm

JET-GROUTING COLUMNS AFTER EXCAVATION

JET-GROUTING

SOILCRETE

JET GROUTING WALL, REINFORCEMENT AND STEEL STRUCTURE

SOILCRETE

JET GROUTING DETAILS

SOILCRETE

SITE VIEW

SOILCRETE

INITIAL SOLUTION – DIAPHRAGM WALL

DEEP SOIL MIXING CONSTRUCTION SEQUENCE

DEEP SOIL MIXING BASE CARRIER (RG-SERIES)

17000

27400

CUTTER SOIL MIXING CONSTRUCTION SEQUENCE

CUTTER SOIL MIXING THE HARDWARE

FULL DISPLACEMENT PILES

FULL DISPLACEMENT PILES CONSTRUCTION SEQUENCE

PILE TESTS: FDP VERSUS CFA PILES

	Pile A	Pile B	Pile C
Drilling system:	FDP	FDP	CFA
	lost bit	lost bit	(comparative pile)
Pile diameter	510 mm	440 mm	500 mm
Pile length	10,0 m	8,4 m	10,0 m

PILE TESTS: HAMBURG

A series of pile load tests was carried out in co-operation with the university of Hamburg-Harburg as part of a fundamental research programme, for which a total of 17 piles were constructed with length ranging from 8 to 16 m. The load settlement curves below show the results of three load tests carried out on three different types of pile.

PILE TESTS: FDP LOADING TEST

PILE TESTS: MALAYSIA

Drilling rig:	BG 40
Drilling system:	FDP Standard
Pile diameter:	600 mm
Pile length:	13,0 m

PILE TESTS: FDP TEST BASE / SHAFT RESISTANCE

PILE TESTS: JAPAN

Drilling rig:	BG 28
Drilling system:	FDP, lost bit
Pile diameter:	620 mm
Pile length:	18,6 m

MONITORING SYSTEMS: BRIDGE OVER LIMPOPO RIVER, MOZAMBIQUE

PILE LOAD TEST (7800 KN) Ø800mm; L=33.00m

MONITORING SYSTEMS: BRIDGE OVER LIMPOPO RIVER, MOZAMBIQUE

RESUME

COMPARATIVE COSTS OF GROUND IMPROVEMENT METHODS

TREATMENT METHOD	COST BASIS		
	Volume of Treated Soil	Surface	Lenght
	(\$/m3)	(\$/m2)	(\$/m)
Dynamic compaction	0.7 - 3	4.3 - 22	
Vibro-replacement	4 - 12		30 - 52
Vibro-compaction	1 - 7		16 - 39
Excavate-replace	10 - 20		
Slurry grouting	40 - 80		
Chemical grouting	160 - 525		
Compaction grouting	30 - 200		
Jet-grouting	100 - 400		82 - 325
Freezing	275 - 650	110 - 160	

Plus \$2 to \$10.75 per sq.meter/week to maintain frozen zones

CONSTRUCTION UNDER AN EXISTING BUILDING

EXECUTION OF MICROPILES

EXECUTION OF THE NEW PILE CAP

CAST IN SITU DISPLACEMENT PILES

DENSE MESH OF PILES

STRUCTURAL REHABILITATION

ACCUMULATION TANK, MADEIRA – EXISTING SITUATION

STRUCTURAL REHABILITATION

ACCUMULATION TANK, MADEIRA – EXISTING SITUATION – TRANSVERSE SECTION

STRUCTURAL REHABILITATION

ACCUMULATION TANK, MADEIRA – EXISTING SITUATION – TRANSVERSE SECTION

STRUCTURAL REHABILITATION

ACCUMULATION TANK, MADEIRA – EXISTING SITUATION – SOLUTION WITH MICROPILES

PRIMEIRA SOLUÇÃO DE REFORÇO ESTRUTURAL

MICROESTACAS INCLINADAS ENCASTRADAS NO COMPLEXO VULCÂNICO RIJO

ACCUMULATION TANK, MADEIRA – FORCE BALANCE

STRUCTURAL REHABILITATION

ACCUMULATION TANK – FOUNDATION REFURBISHMENT - JET GROUTING COLUMNS

STRUCTURAL REHABILITATION

ACCUMULATION TANK – FOUNDATION REFURBISHMENT - JET GROUTING COLUMNS

STRUCTURAL REHABILITATION

ACCUMULATION TANK – TESTING PHASE

STRUCTURAL REHABILITATION

ACCUMULATION TANK – TESTING PHASE

STRUCTURAL REHABILITATION

ACCUMULATION TANK – IN OPERATION

STRUCTURAL REHABILITATION

ACCUMULATION TANK – IN OPERATION

SANTARÉM SEWAGE TREATMENT PLANT

SANTARÉM

RIO TEJO

SANTARÉM SEWAGE TREATMENT PLANT

ETAR DE
SANTARÉM

RIO TEJO

SANTARÉM SEWAGE TREATMENT PLANT

SANTARÉM SEWAGE TREATMENT PLANT

SANTARÉM SEWAGE TREATMENT PLANT

SANTARÉM SEWAGE TREATMENT PLANT

SANTARÉM SEWAGE TREATMENT PLANT

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

ESCOM

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

NUMBER OF BLOWS (SPT)

0 20 40 60

ESCOM TOWER

GEOLOGICAL PROFILE

PLEISTOCENE - MUCEQUE FORMATION

C1 LOOSE TO MEDIUM CLAYED SAND

MIOCENE - LUANDA FORMATION

C2A LIMESTONE

C2B MEDIUM SAND (NSPT≈30 BLOWS)

C2C MEDIUM TO DENSE SAND (NSPT≈40 BLOWS)

C2E DENSE SAND (NSPT≈50 BLOWS)

C2F DENSE TO VERY DENSE SAND (NSPT≈60 BLOWS)

ESCOM TOWERS - LUANDA

Settlements prediction by
Timoshenko & Goodier (1951)

$$\Delta H = q_0 \cdot B' \cdot \frac{1-\nu^2}{E_S} \cdot m \cdot I_S \cdot I_F$$

$$I_S = \left(I_1 + \frac{1-2\mu}{1-\mu} I_2 \right)$$

$$I_1 = \frac{1}{\pi} \left[M \cdot \ln \left(\frac{(1+\sqrt{M^2+1})\sqrt{M^2+N^2}}{M(1+\sqrt{M^2+N^2+1})} \right) + \ln \left(\frac{(M+\sqrt{M^2+1})\sqrt{1+N^2}}{M+\sqrt{M^2+N^2+1}} \right) \right]$$

$$I_2 = \frac{N}{2\pi} \arctan \left(\frac{M}{N\sqrt{M^2+N^2+1}} \right) \quad (\arctan \text{ em radianos})$$

em que: $N = \frac{H}{B'}$ e $M = \frac{L'}{B'}$, com

$L' = \frac{L}{2}$ para o centro; $L' = L$ para o canto

$B' = \frac{B}{2}$ para o centro; $B' = B$ para o canto

PLANTA

FUNDAÇÃO DOS PISOS ELEVADOS

CORTE

PERFIL DE CÁLCULO
AO NÍVEL DA BASE DA LAJE

ESCOM TOWERS - LUANDA

PLATE LOAD TEST

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

SOIL IMPROVEMENT WITH RIGID INCLUSIONS

ESCOM TOWERS - LUANDA

SOIL IMPROVEMENT WITH RIGID INCLUSIONS

ESCOM TOWERS - LUANDA

SOIL IMPROVEMENT WITH RIGID INCLUSIONS

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

ESCOM TOWERS - LUANDA

MARAVILHA BUILDING - LUANDA

SOIL IMPROVEMENT WITH RIGID INCLUSIONS

NÚMERO DE PANCADAS (SPT)

PERFIL GEOTÉCNICO INTERPRETATIVO

LEGENDA

FORMAÇÃO DE LUANDA

- C1A AREIAS GROSSEIRAS, ARGILOSAS
- C1B CALCÁRIOS
- C1C AREIAS FINAS A MÉDIA (NSPT=30 PANCADAS)
- C1D AREIAS GROSSEIRAS (NSPT=40 PANCADAS)
- C1E AREIAS MÉDIAS A GROSSEIRAS (NSPT=50 PANCADAS)
- C1F AREIAS DE GRANULOMETRIA VARIÁVEL (NSPT=60 PANCADAS)

UNDERGROUND CONSTRUCTIONS – LATE DECISIONS

THE SOLUTION - GROUTING

A SOLUTION FOR LOAD TESTING OF REINFORCED SOILS

Construction Insurance (CAR) Guarantees and Exclusions Challenges in the Geotechnical Area - Case Study

Jorge Salgado

ISEL – Eng.º Téc.º Eletrotecnia e Máquinas (1973)

CNPR - Câmara Nacional de Peritos Reguladores (ACR 57)

FUEDI - European Federation of Loss Adjusting Experts (ELAE-European Loss Adjusting Expert)

Organização

Sociedade Portuguesa
de Geotecnia

Comissão Portuguesa de Geotecnia nos Transportes

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FAILURE – During Excavation Works – **Construction Period**

Initial Slope Sliding
Zone of Failure (?)

Following Slope Sliding
Replica at a Zone of Failure
(?)

FAILURE – During Operation Stage – **Maintenance Period**

New slope slidings in both sides of lane
in areas where repairing works had
already been completed and slope
surfaces had been rebuilt

Successive alterations of
Design Solutions in 300 m
of Road

Consequences

High Costs in Endless Works
Extra Costs with Expropriations
Traffic Restrictions
Loss of Profit

FAILURE – During Earthfilling Works – **Construction Period**

Backfill Land Slide
Instability at an early stage
affecting 1/4 of the track width

Backfill removal covering about
2/3 of the total volume

Consequences

- Construction additional costs
- Backfill dismantling
- Alteration in the foundation solution
- Backfill reconstruction
- Delay in the Works
- Contractual Penalties due to delay in works completion

The Construction All Risks Insurance - CAR

OBJECT OF INSURANCE CONTRACT – SCOPE OF GUARANTEE

1 – **Guarantee covering Material Damages in Temporary and Final Works** to be carried out for the execution of a Construction Contract - **SECTION I**

Optionally the Insurance Contract can also cover:

2 – **Third Party Liability - SECTION II**

3 – **Construction Auxiliary Plant/Equipment** (Group of facilities, machinery and auxiliary equipment aimed at the execution of the contract works) – **SECTION III**

4 - **Other Guarantees** (for ex. Advanced Loss of Profit) – **SECTION IV**

The Construction All Risks Insurance - CAR

- **EXCLUSIONS APPLICABLE TO ALL COVERAGES**

Are excluded damage caused directly or indirectly by several risks, among which:

- War, invasion, act of foreign enemy, insurrection, rebellion, unexpected deflagration of explosive or incendiary devices
- Military uprising or act of military power
- Confiscation, requisition, destruction or damages caused to insured property and works by order of a lawfully or a de fact government or any other designated authority
- Sabotage and terrorism
 - Explosion, heat release and radiations resulting from atoms division or radioactivity, radiations caused by artificial acceleration of particles and exposure to magnetic fields as well

The Construction All Risks Insurance - CAR

- **EXCLUSIONS APPLICABLE TO ALL COVERAGES**

- Fraudulent Acts or omissions of the Insured or executed under the influence of drugs or when intoxicated.
- **Total or partial cessation of works**, except if the technically recommended precautions to avoid losses or damages are guaranteed and the cessation does not exceed 30 days or, any other term settled in the particular conditions of policy
- **Foreseeable Damages**, considering the nature and the method of execution of the works
- Environmental Damages as considered in the legislation applicable
- The payment of **finances, penalties, securities and contractual penalties** of any nature as well as **losses resulting from delays** or non completion of works, esthetical defaults, output or capacity deficiencies, **non fulfillment of specifications** and rescission of contracts

The Construction All Risks Insurance - CAR

PLACE OF RISK

The place or premises, duly identified in the particular conditions, where the construction works have to be executed and any other places used as sites or any other purpose related to the works.

WHO CAN BE INSURED

- The Contractor, sub-contractors, jobbers and suppliers
- The Employer
- The Engineering designer
- The Site Supervision

INSURED PERIODS

Construction Period till Handover or Beginning of Operation

Maintenance Period after Handover or Beginning of Operation (warranty period)

The Construction All Risks Insurance - CAR

SECTION I – MATERIAL DAMAGE (Damage caused to the Works)

- **INSURED VALUE**

This shall correspond to the value of the insured property in the moment of completion of contract, **including** the cost of materials and equipment supplied by the Employer

- **SCOPE OF GUARANTEE**

Up to the limit settled in the Particular Conditions, the losses and material damage caused to works and/or insured property in consequence of the loss, whatever cause it may have, with the exception of the exclusions set forth in the policy, when it is required its repairing, replacement or restoring to the initial condition it was in at the moment immediately prior to the occurrence of the loss

- **SPECIFIC EXCLUSIONS**

This policy excludes the losses or damages that result directly or indirectly from:

Costs with **alterations, additions or improvement** of insured property

Normal wear and tear

The Construction All Risks Insurance - CAR

SECTION I – MATERIAL DAMAGES (Damage caused to Works)

SPECIFIC EXCLUSIONS

Damages that, considering the nature of the work to be executed or the manner of its execution, can be reasonably predicted as **inevitable**

Default of the material used or imperfect execution due to **defective workmanship**. This exclusion covers only the replacement or repairing of the part directly affected by the default (defective part), not applying to the remaining parts of the property insured damaged as a consequence of accident resulting from such circumstances (**exclusion of defective part**)

Loss of Profit, business interruption or other **consequential losses** of any nature

Any facts that are **foreseen within the scope of policy guarantees** of several **Special Conditions**, except when these have been contracted

Let us approach some Special Conditions that being contracted annul the respective exclusion:

The Construction All Risks Insurance - CAR

SECTION I – MATERIAL DAMAGE (Damages caused to Works)

SOME SPECIAL CONDITIONS– **Extension of guarantees**

Strikes, riots and civil commotion

Vandalism acts

Earthquakes, Tsunamis and Volcanic Eruptions

Storms, Typhoons, Cyclones, Hurricanes, Floods and Landslide

Consequences of defective design

Adjacent property

Expenses with **debris removal**

Expenses with **overtime** and special freights

Professional fees

Consequences of Defective Design

Guarantees the damages to insured property by Section I – Material Damages, as a consequence of **error, omission or deficiency of conception, design, drawing or calculation.**

Are excluded the costs with replacement, repairing or rectifying of part of the works direct consequence of error (exclusion of defective part), being guaranteed the costs of repairing, replacement or rectifying of parts of the works which being correctly executed have sustained damages as a consequence of such error.

The Construction All Risks Insurance - CAR

SECTION I – MATERIAL DAMAGES (Damages caused to Works)

SOME SPECIAL CONDITIONS– **Extension of guarantees**

Adjacent Property

Guarantees the losses or damages caused to property adjacent to the works site belonging and/or in charge of or under control of the Insured and that are directly caused by the execution of the insured works.

Debris Removal

Guarantees the expenses with debris removal to waste from site.

The debris can be composed by damaged parts of the insured property, any strange substances such as soils, stones, mud, sand, water, trees or remains or even auxiliary means for the execution of the works (site buildings and contents, equipment).

The removal of debris may imply accessory works more or less complex (ex. temporary shoring). The insured capital shall be defined according to the value of the works contract, type of works and the maximum value estimated for removal of debris – analysis of the critical points.

Expediting Expenses

Guarantees the exceptional expenses incurred with the purpose of reduce the period of repairing of material damages covered under Section I (ex. overtime, airfreight).

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SOME SPECIAL CONDITIONS – **Restriction of Guarantees**

72 Hour Clause;

Any loss or damage resulting from Nature Phenomena, occurring within a continuous 72 hours period shall be deemed to be one claim either for purpose of applying one sole deductible in each period or to determine the contractual limits of damage indemnity.

Security Measures against – precipitation, flooding, overflow, waving (Return Period)

The loss or damage caused to insured property by the indicated risks is covered if, in the design and during the execution of the works, the proper protection and security measures have been taken.

Such is understood as being observed the historical values of the official statistics related to the works site and for the period of validity of the policy, considering the return period set forth in the particular conditions of policy.

Return Period – probability of occurrence of a phenomenon with specific evaluation (wind intensity, rainfall index, flood level, significant swell, etc.) at least once in XXX years.

Schedule of Works

It is excluded the loss or damage caused or worsened as a consequence of deviations or alterations of the schedule of execution of insured works that exceed the number of weeks indicated in the particular conditions, except if before the occurrence of accident the Insurer has given its agreement.

The Construction All Risks Insurance - CAR

SECTION I – MAINTENANCE PERIOD (After Handover or Beginning of Exploitation)

In the **Maintenance Period** the risks the policy can guarantee **are restricted** to:

Damages to works caused by Contractor during the works required to fulfill the guarantee of the works contract (ex. repairing of defaults) - **Simple Maintenance**

Together with Damages to works resulting from actions executed in the place of risk during the construction period – **Full Maintenance**

*Note – even if **SC – Consequences of Defective Design** is contracted, damages resulting from defective design are not guarantee during this period.*

SECTION I – BASES OF INDEMNITY

Insurer indemnifies at **real cost** the repairing or replacement of damaged property or works, **having**, however, as **maximum limit**, the **value** defined by the direct applying of contractual **unit prices** foreseen in the works contract, re-adjusted based on the escalation formula fixed thereon (formation base of the value for the works contract, to which the insured value should correspond).

The costs with improvements, corrections, modifications or alterations of the original design, are not Indemnifiable, nor the costs that constitute any form of compensation by errors or omissions of budgeting or due to situations of “dumping”.

The Construction All Risks Insurance - CAR

ASPECTS OF POLICY'S LIABILITY - DAMAGE AND/OR DEFAULT (?) – DEFECTIVE PART

The exclusion of the DEFECTIVE PART is comprised:

in Specific Exclusion of SECTION I – Material Damages

- **Defect of material** used or of imperfect execution due to **defective workmanship**. This exclusion comprises only the replacement or repairing of the part directly affected by the defect (**defective part exclusion**), not being applied to the remaining parts of the insured property (part correctly executed) damaged as a consequence of the accident caused by such circumstances.

in Special condition – Consequences of Defective Design

- Guarantees the damages in the insured property as a consequence of error, omission or deficiency of conception, design, drawing or calculation.

Are excluded the costs with replacement, repairing or rectifying of part of the works direct consequence of error (**defective part exclusion**), being included the costs of repairing, replacement or rectifying of parts of the works which being correctly executed have sustained damages as a consequence of such error.

So, we can say that: **POLICY INDEMNIFIES THE DAMAGES BUT NOT THE DEFECT**

Penalizes the error (defective part) but guarantees the damages that are consequence of such defect in the parts correctly executed.

The Construction All Risks Insurance - CAR

ASPECTS OF POLICY'S LIABILITY - DAMAGE AND/OR DEFAULT (?) – DEFECTIVE PART

- *“Damage” can be considered as the occurrence of an adverse change in the physical characteristics of the Insured Object.*
- *“Defect” is a condition not an occurrence*

Conclusion

The Insured Object can be defective (defective condition) without being damaged according to the Insurance Contract point of view.

Policy indemnifies the damages but not the defects. Penalizes the error (defective part) but guarantees the damages that are consequence of such defect in the parts correctly executed

Repairing of the defective part is excluded.

Repairing of damage in the correctly executed parts is included.

Let us see some examples

The Construction All Risks Insurance - CAR

ASPECTS OF POLICY'S LIABILITY - DAMAGE AND/OR DEFAULT (?) – DEFECTIVE PART

Some Examples:

Example A (Defect of workmanship or of material used with damage consequences)

Cause – A building is constructed laying on a foundation made of defective piles due to error of workmanship or due to defect of material (concrete) used.

Consequence – Due to such defect the building collapsed.

Policy Liability – Within the scope of reconstruction, the rectifying works of the defective part (foundation) are excluded from the indemnity but, the costs of reconstruction of the remaining part of the building shall be indemnified.

The Construction All Risks Insurance - CAR

ASPECTS OF POLICY'S LIABILITY - DAMAGE AND/OR DEFAULT (?) – DEFECTIVE PART

Example B (*Defect of workmanship without damage consequences*)

Cause – Due to error of workmanship a wall is built out of the correct alignment.

Consequence – The wall has to be demolished and rebuilt in the correct place

Policy Liability - This is a defective part in which there is no damage, and therefore no indemnity under the policy

The Construction All Risks Insurance - CAR

ASPECTS OF POLICY'S LIABILITY - DAMAGE AND/OR DEFAULT (?) – DEFECTIVE PART

Example C (Defective Design with Damage consequences)

Cause – In the design of a building an error occurred in the dimensioning of the reinforced concrete structure.

Consequence – At the final stage of the works, with the finishing works already completed, fissures appeared ranging the totality of the apartments implanted in a specific vertical block of the building. It was necessary to demolish the parts of the works affected by the damages, build a structural reinforcement to guarantee the stability condition and remake the finishing works.

Policy Liability– The costs with the structural reinforcement works to repair the defect and guarantee the required stability condition are excluded.

The cost of repairing the damages in the parts correctly executed and that have sustained damages in consequence of the defective design – walls (masonry, plaster, stucco and painting) shall not be indemnified unless the special condition of **Consequences of Defective Design** is contracted in the policy.

The Construction All Risks Insurance - CAR

CASE STUDY

In this example the liability of the construction insurance (CAR) in the Geotechnical area is addressed with the example of a real case study where a circular sliding surface at a earth fill slope was mobilised and considered as the main reason for the slope loss of stability.

THE CONTRACT WORKS

Within a road construction contract, the works under question covered an extension of about 300m. The main works implied the several earth works, including excavations and earth fills. The 10 m high earth fill was implanted in an area crossed by a water line, being constructed an hydraulic underpass. It should be pointed out that at the location area of the mentioned earth fill, at the initial design stage, no geological and geotechnical investigation works were proposed.

FOUNDATION SOLUTION

The solution defined at the final design stage, already during the construction schedule on site, after the execution of geological and geotechnical investigation shafts, was the vegetation removal and the direct application of a draining layer (stone material) with around 0,5m of thickness.

The Construction All Risks Insurance - CAR

CASE STUDY

THE LOSS

The loss corresponded to the mobilized circular earth fill slope sliding, occurred at the final stage of the fill execution, when it was just about 1m to achieve the crest level. The sliding surface at the earth fill slope was assumed as circular, as showed in the figure.

The Construction All Risks Insurance - CAR

CASE STUDY

SLOPE OVERAL LOSS OF STABILITY

The earth fill foundation, with low bearing capacity, which was not properly accessed at the design stage, induced the mobilizing of a circular sliding surface, being considered as the main reason for the slope loss of stability. This shows a **CONCEPTION ERROR** of the solution adopted in the earth fill foundation.

MAIN REPAIRING WORKS

A slope and earth filling repairing solution was defined, including the following main works:

- a) Site investigation bore holes to access the geological and geotechnical scenario;
- b) Removal of the backfill body, including the hydraulic underpass;
- c) Removal of the drainage layer at the foundation level;
- d) Replacement of the foundation natural and soft ground by crushed stone material to a depth of 5m;
- e) Execution of a new earth fill, as well as a new drainage system: gravel protected by a geotextile.

The Construction All Risks Insurance - CAR

CASE STUDY

LOSS ADJUSTMENT – VALUE TO BE INDEMNIFIED UNDER THE POLICY

The loss was caused by a defective conception of the earth fill foundation, being under the terms of the Policy attributable to **DEFECTIVE DESIGN**.

Once the loss occurred during the Construction Period and that the policy had contracted the **SC – Consequences of Defective Design**, the risk that originated the loss was guaranteed under the Coverage, being the loss to be indemnified under the terms of such **SC**.

The costs with the repairing of the “Defective Part”, as well as the costs with additions, alterations and improvements of the original design, **are excluded**.

The costs with the repairing of damages in the parts of the works that had been properly executed and sustained damages, as the error consequence, **are included**.

So, being confirmed that the earth fill body was correctly executed (adequate materials and compacting level) the final result corresponds to the one indicated in *Table 1*:

The Construction All Risks Insurance - CAR

CASE STUDY

Table1 – Repairing Works and Policy Liability (values in Euros)

Repairing Works		Policy Liability			
Item	Total Cost	SC Debris Removal	SC Consequences of Design Errors	Excluded	Remarks
Site investigation bore holes and new Design Solution to be adopted	17.800			17.800	Design Alteration
Removal of earth fill body and Hydraulic Underpass	130.000	130.000			Debris removal
Removal of stone material applied to reinforce the foundation	7.000			7.000	Defective Part
Additional excavation down to 5 m beneath the base level of earth fill and filling with stony material / draining layer	195.000			195.000	Design Alteration
Execution of soil internal gutters and draining masks	36.000			36.000	Design Alteration
Additional expropriation for trenches opening to conduct the water of the draining layer	8.500			8.500	Design Alteration
Re-construction of backfill, Hydraulic Underpass and slope descents	220.000		220.000		Reconstruction of Parts Proper Executed and have sustained Damage
Total	614.300	130.000	220.000	264.300	
		350.000		Loss to be indemnified	
		Deductible	80.000		
		Indemnity	270.000	<> 44% of Total Cost	

The Construction All Risks Insurance - CAR

CASE STUDY

FINAL REMARKS

Further to what was described, the following main aspects should be highlighted:

A loss in a Construction Contract corresponds, in the majority of situations, to a **Failure of the Construction Solution**

A Construction Insurance Policy **never covers All the Losses** resulting from a loss

The **Risk** should be duly evaluated at the **design stage** and followed up during the **construction stage** in order to **Prevent the Loss**, as a **Failure Prevention** approach

Talude no Monte Gordo, Vila Franca de Xira Análise de soluções de estabilização

Monte Gordo's Slope, Vila Franca de Xira: Stabilization Solutions

Ana Rita Nunes

Câmara Municipal de Vila Franca de Xira

Organização

Sociedade Portuguesa
de Geotecnia

Comissão Portuguesa de Geotecnia nos Transportes

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Table of Contents:

1. Case Study: Monte Gordo's Hill slope, Vila Franca de Xira
 - History of the slope events
 - Geological and Geotechnical Scenario
 - Description of the final solution and constructions stages
2. Numerical Modelling
 - Slope Stability evaluation on each construction phase
3. Conclusions

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

(80's Decade)

Quarry deactivation and anthropogenic placement of materials
(Initial Ground Conditions)

1980

1982

Buildings Construction

1990

1999

2000

2002/2003

Mechanically Stabilized Earth (MSE) with geogrids

2013

February

Immediate Intervention

2014

June / July

Final Solution

2017

Actual Situation

2019

Time

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Quarry deactivation and anthropogenic placement of materials (Initial Ground Conditions)

Legend:

- Slope unstable area
- Set of buildings
- Rejected quarry
- Tectonic Fault

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

(80's Decade)

Quarry deactivation and anthropogenic placement of materials
(Initial Ground Conditions)

1980

1982

Buildings Construction

1990

1999

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2002/2003

Mechanically Stabilized Earth (MSE) with geogrids

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June / July

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Actual Situation

2019

Time

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Buildings Construction at slopes base

Aerial view of the unsteady slope location area

Buildings
Plant and cut

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

(80's Decade)

Quarry deactivation and anthropogenic placement of materials
(Initial Ground Conditions)

1980

1982

Buildings Construction

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Actual Situation

2019

Time

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Mechanically Stabilized Earth (MSE) with geogrids

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Mechanically Stabilized Earth (MSE) with geogrids

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

(80's Decade)

Quarry deactivation and anthropogenic placement of materials
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February

Immediate Intervention

2014

June / July

Final Solution

2017

Actual Situation

2019

Time

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Actual Situation (2019)

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Geologic and Geotechnical Scenario - Immediate Intervention

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Geologic and Geotechnical Scenario

Legend:

C/MG - Limestone Rock Mass

M - Marl-Limestone Complex

G - Sandstone-Marl Complex

At/1 - Clay Landfill with limestone blocks

At/3 - Mechanically Stabilized Earth (MSE) with

Jurassic

Landfills

920

Characteristic value of			
	-	39	-
	12	-	123

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution

Final Solution Plan

Stabilization Final Solution

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution - Initial project adaptations

Undiscovered Limestone Rock
Mass area

Undiscovered Limestone Rock
Mass area

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution - Initial project adaptations - Zone 2.1

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution - Initial project adaptations - Zone 2.3

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution - Initial project adaptations - Zone 2.2

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution - Initial project adaptations - Zone 2.2

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution - Initial project adaptations - Zone 2.3 and Zone 3

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution - Construction techniques and stages

Case Study: Monte Gordo's Hill slope, Vila Franca de Xira

Stabilization Final Solution – Year 2015

Numerical Modelling

Critical Section

• Methods:

- Finite Elements (*Plaxis 2D*, version 8.2)
- Limit Equilibrium (*GeoStudio – Slope/W* (2007), version 7.2.3)

Numerical Modelling

Modelling Phases of the slope events

1. Initial ground before the buildings construction

2. Buildings construction excavation

3. Buildings construction

4. Mechanically Stabilized Earth (MSE) with geogrids excavation

5. Mechanically Stabilized Earth (MSE) with geogrids

6. Immediate Intervention

7. Stabilized Final Solution

Numerical Modelling

Geotechnical Parameters

Hardening Soil Model – Plaxis 2D Parameters		Geological Scenario			
		Aterros	Aterros	Grés ()	Margas ()
General Properties	()	18	18	21	21
	Material Type	Drained			
Resistance Parameters	()	10	10	0	200
	()	32	32	39	25
	(	0	0	0	0
Stiffness Parameters	()	5500	15000	130000	200000
	()	5500	15000	130000	200000
	()	16500	45000	390000	600000
	(-)	0,5			
Interface Reduction Factor		Rigid ()			

Linear Elastic Model – Plaxis 2D Parameters		Maciço de calcário rochoso ()
General Properties	()	25
	Material Type	Drained
Stiffness Parameters	()	250000
		0,15
Interface Reduction Factor		Rigid ()

Mohr-Coulomb Model – Slope/W Parameters				
()	18	21	21	25
()	10	0	200	107
()	32	39	25	46

Numerical Modelling

Slope Stabilization Global Safety (EC7)

- Finite Element Method (Plaxis)**

$$FS = \frac{\tan \Phi'_{initial} / \tan \Phi'_{reduced} = c'_{initial} / c'_{reduced}}{\text{Phi/C Reduction}}$$

- Limit Equilibrium Method (Slope/W)**

Morgenstern-Price slice method

Circular Slip Surface (Grid and Radius)

$$A_{d \leq R_d}$$

A_d - Design Action

R_d - Design Resistance

Design Approach:

AC1-Comb.2: A2 + M2 + R1

FEM - Plaxis

LEM - Slope/W

Numerical Modelling

Slope Stabilization Global Safety (EC7)

FS (EC7)	Initial Ground	Buildings Construction	Mechanically Stabilized Earth (MSE) with geogrids Excavation	Mechanically Stabilized Earth (MSE) with geogrids Construction	Immediate Intervention	Final Solution
FEM - Plaxis	1,1	1,5	1,0	1,2	1,3	2,1
LEM -Slope/W	1,2	0,6	1,1	1,4	1,7	2,4

Plastic Points (FEM - Plaxis)

Critical Slip Surface (LEM - Slope/W)

Numerical Modelling

Slope Stabilization Global Safety (EC7)

FS (EC7)	Initial Ground	Buildings Construction	Mechanically Stabilized Earth (MSE) with geogrids Excavation	Mechanically Stabilized Earth (MSE) with geogrids Construction	Immediate Intervention	Final Solution
FEM - Plaxis	1,1	1,5	1,0	1,2	1,3	2,1
LEM -Slope/W	1,2	0,6	1,1	1,4	1,7	2,4

Buildings Construction

Critical Slip Surface (FEM - Plaxis)

Numerical Modelling

Slope Stabilization Global Safety (EC7)

FS (EC7)	Initial Ground	Buildings Construction	Mechanically Stabilized Earth (MSE) with geogrids Excavation	Mechanically Stabilized Earth (MSE) with geogrids Construction	Immediate Intervention	Final Solution
FEM - Plaxis	1,1	1,5	1,0	1,2	1,3	2,1
LEM -Slope/W	1,2	0,6	1,1	1,4	1,7	2,4

Mechanically Stabilized Earth (MSE) with geogrids

Final Solution

Plastic Points (FEM - Plaxis)

Plastic Points (FEM - Plaxis)

Conclusions

- The buildings at the slopes base promoted the slope stability;
- Importance of the Instrumentation and Observation Plan, during both the construction and the exploration stages;
- Importance to consider all possible slip surfaces at the slope stability safety assessment.
- Social and economical evaluation of all the stabilization solutions at the preliminary design stage;
- Definition of a rigorous Ground Urbanization Planning, taking into account the geological, geotechnical and hydrogeological conditions.

Obrigada pela atenção

Thank you

Solutions for the treatment of the foundations soft clays of Carregado highway interchange, logistic platform of north Lisbon and respective connections to highway A1 and national road EN1

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Summary

- Works location
- Geological conditions
- Adopted solutions for foundation treatment
- A1/A10 Interchange
- PLLN road accesses constrains
- Adopted solutions and construction costs
- Preloading with wick drains
- Logistic platform of north Lisbon
- 2nd order effects in settlement analysis
- Creep settlement

Lisbon road network. Works Location

Localization plan of Carregado Interchange A1/A10, PLLN and accesses to A1 and EN1

Lisbon area geological map (Scale 1:50.000)

Tagus river crossings geological sections

Geological longitudinal profiles

- a2 - soft clays
- a1 / a3 - silty-clays
- a4 – sand and gravel

A1 in the interchange zone

PLLN access from A1

Soft clays geotechnical characteristics

- %<0,074 mm - 62 to 90%; %<2 μm - 30 to 67; LL - 60 to 82%
IP - 32 to 48%; w_n - 44 to 80%; S_r - 91 to 100%
- Saturated bulk weight - 15,4 to 17,3 kN/m³
Dry bulk weight - 8,6 to 12 kN/m³
- c_u - from 0 to 4 m: 15 to 20 kPa - lower: between
 $c_u = 7,14+1,96 h$ and $c_u = 11,34+2,13 h$ (vane test and DMT)
- C_c - 0,55 to 1,00 (most frequently lower than 0,70);
 $C_c/1+e_0$ - 0,21 to 0,32 (most frequently lower than 0,25)
- C_v - $1,5 \times 10^{-8}$ to $4,6 \times 10^{-8}$ m²/s (oedometer test)
 k - $1,0 \times 10^{-8}$ to $3,2 \times 10^{-10}$ m/s (oedometer test)
- C_h - $5,9 \times 10^{-8}$ to $10,0 \times 10^{-8}$ m²/s (dissipation tests CPT_u)

Type of solutions used for foundation treatment

- preloading embankment
- preloading embankment with vertical wick drains
- preloading embankment with vertical wick drains and with lightweight expanded clay aggregate in the definitive embankment
- load transfer platforms with geogrids on concrete precast driven piles
- load transfer platforms with concrete slabs on bored piles
- preloading embankment with stone columns

Plan and aerial view of A1/A10 interchange

Existing old fills widening foundation solution

Load transfer platforms with geogrids on concrete precast driven piles

Existing old fills widening foundation solution

Ramp C – Special transition zone to the viaduct abutment

Preloading for consolidation of the soft clays, in order to reduce the vertical and horizontal soil pressures on the piles

Precast driven piles for soft clays reinforcement and embankment foundation

Load transfer platforms with geogrids on concrete precast driven piles

PLLN road accesses constrains

Adopted solutions for foundation treatment

- preloading embankment
- preloading embankment with vertical wick drains
- preloading embankment with vertical wick drains and with lightweight expanded clay aggregate in the definitive embankment
- load transfer platforms with geogrids on concrete precast driven piles
- load transfer platforms with concrete slabs on bored piles, over the gas pipeline and on the toll area

Indicative construction costs (€/m²)

- [1] Preloading embankment with vertical wick drains and without lightweight aggregate
- [2] Preloading embankment with vertical wick drains and with lightweight aggregate
- [3] Load transfer platforms with geogrids on driven piles
- [4] Load transfer platforms with concrete slab on bored piles

Zones treated with preloading with or without wick drains

Preloading with wick drains

- Wick drains triangular grids of 1,0, 1,1 and 1,2 m
- About 1 600 km of wick drains
- Installation rate of about 10 km/day

Preloading with wick drains

- Preloading maximum height of 4,5 m
- Definitive embankments maximum height of 2,5 m, using, in some zones, lightweight expanded clay aggregates
- 41 000 m³ of lightweight expanded clay aggregates

FINAL PHASE

PRELOADING PHASE

Monitoring devices

- 113 Levelling plates
- 14 Electrical piezometers
- 3 Stand pipe piezometers
- 6 Vertical extensometers
- 9 Inclinometers

Consolidation results

- Due to some overconsolidation of the soft clays the measured consolidations settlements were smaller than the estimated values

Consolidation results

- Complementary analysis of the consolidation results based on the excess pore pressure

Logistic platform of north Lisbon

- preloading embankment with stone columns

Challenges

There have been reports of situations in which:

- The observed settlements are **larger** than the predicted values.
- The **settlement rate remains high** after treatment (consolidation) and throughout lifetime.

Challenges

To highlight two factors that must be taken into account when designing embankments on soft soils:

- **Second order effects** that increase the embankment landfill height to compensate the soft soils settlement.
- **Creep settlement** (particularly when vertical drains are used).

Second order effects

Creep

$$C_{\alpha} = \alpha C_c$$

Example

Embankment construction: height h , density $\gamma=20\text{kN/m}^3$

Stiff material

Soft soil

Constrained modulus $M'=1/m_v=1000\text{kPa}$

height $H=20\text{m}$

$e_0=2,0$; $C_c=0,6$; $C_\alpha/C_c=0,06$

Rigid bedrock

Situation I – Consolidation without drains; Situation II – Consolidation with vertical drains

2nd order effects

Consolidation settlement induced by embankment construction:

$$\Delta\sigma_o = h \gamma \quad \Delta h_o = \Delta\sigma_o m_v H = h \gamma m_v H$$

To compensate this settlement a layer with equal height Δh_o is added, which will induce a new settlement:

$$\Delta h_1 = (\Delta h_o \gamma) m_v H$$

And so on:

$$\Delta h = \Delta h_o + \Delta h_1 + \Delta h_2 \dots + \Delta h_n$$

$$\Delta h = \Delta h_o + (\Delta h_o \gamma m_v H) + (\Delta h_o \gamma m_v H) \gamma m_v H + \dots + \Delta h_o (\gamma m_v H)^n$$

$$\Delta h = \sum_{n=0}^{\infty} \Delta h_o (\gamma m_v H)^n$$

2nd order effects

The geometric series is convergent if the ratio is less than 1:

$$\Delta h = \lim_{n \rightarrow \infty} \sum_{n=0}^{\infty} \Delta h_o (\gamma m_v H)^n = \Delta h_o \times \frac{1}{1 - \gamma m_v H}$$

For this example:

$$\gamma m_v H = 0,4 < 1$$

And the increase of settlement due to 2nd order effects is equal to:

$$\frac{\Delta h}{\Delta h_o} = \frac{1}{1 - \gamma m_v H} = \frac{1}{1 - \frac{20 \times 20}{1000}} = 1,6$$

not considering water tabel

$$\frac{\Delta h}{\Delta h_o} = \frac{1}{1 - \gamma m_v H} = \frac{1}{1 - \frac{10 \times 20}{1000}} = 1,25$$

considering water tabel

Creep

Creep – deformation rate

- Creep settlement:

$$\Delta h = \frac{C_\alpha}{1 + e_0} H \log \left(\frac{t}{t_p} \right)$$

- Settlement rate at time t after primary consolidation:

$$\frac{\partial \Delta h}{\partial t} = \frac{\partial}{\partial t} \left[\left(\frac{C_\alpha}{1 + e_0} H \right) \log t - \left(\frac{C_\alpha}{1 + e_0} H \right) \log t_p \right] = \left(\frac{C_\alpha}{1 + e_0} H \right) \times \left(\frac{1}{t \times \ln 10} \right)$$

- Deformation rate at time t:

$$\dot{\varepsilon} = \left(\frac{C_\alpha}{1 + e_0} \right) \times \left(\frac{1}{t \times \ln 10} \right)$$

Creep – Example

- Creep settlement:

For each logarithmic time cycle:

$$\Delta e = C_{\alpha} = 0,06 C_c = 0,036$$

$$\varepsilon_a = \frac{\Delta h}{H} = \frac{\Delta e}{1 + e_o} = 0,012H$$

The vertical deformation would be equal to 1,2%, i.e., for each logarithmic time cycle the settlement would be equal to 24cm (=0,012x2000)

Creep – PLLN road accesses

Creep – PLLN road accesses

- Creep settlement:

$$\Delta h = \frac{C_\alpha}{1 + e_0} H \log \left(\frac{t}{t_f} \right)$$

- Settlement rate:

$$\frac{\partial \Delta h}{\partial t} = \frac{\partial}{\partial t} \left[\left(\frac{C_\alpha}{1 + e_0} H \right) \log t - \left(\frac{C_\alpha}{1 + e_0} H \right) \log t_f \right] = \left(\frac{C_\alpha}{1 + e_0} H \right) \times \left(\frac{1}{t \times \ln 10} \right)$$

Considering $C_c/(1+e_0)=0,22$; $C_\alpha/C_c=0,06$; $H=25m$; $t=8 \text{ months}$

$$\frac{\partial \Delta h}{\partial t} = (0,0132 \times 25) \times \left(\frac{1}{(8 \times 30) \times \ln 10} \right) = 0,6 \times 10^{-3} \text{ m / day}$$

Creep & OCR

Situation I – without drains (t_p – many decades)
Situation II – with vertical drains ($t_p < 1\text{ano}$)

Creep & OCR

An efficient way to reduce creep settlement rate is to overconsolidate the soil by preloading

Situation II – with vertical drains ($t_p \approx 1$ ano)

Creep – PLLN road accesses

Final conclusions

- The ground improvements solutions can have economic advantages and are particularly suitable for **large areas of intervention** and **less demanding structures** (from the point of view of allowable movements).
- Several solutions are available and can be **efficiently combined** according to each particular situation.

Final conclusions

When designing embankments on soft soils two important factors are usually forgotten but shall be taken into account:

- **Second order effects**, which increase the embankment landfill height to compensate the soft soils settlement.
- **Creep settlement**, particularly when vertical drains are used, which is not negligible but can be reduced if preloading is used to slightly overconsolidate the soil.