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EU Creep (PIAG-GA-2011-286397)

Survey of benchmark field tests for validation of creep models

Jelke Dijkstra[1], Minna Karstunen[1]

[1] Chalmers University of Technology (CTH)

Creep of Geomaterials

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Preface

This report is part of the documentation of work package 2, WP2, (FE benchmark) in the EC funded CREEP project (PIAG-GA-2011-286397). The main aim of this WP is to identify the most relevant model mechanisms in soft soil creep modelling through FE benchmark exercises involving commonly available soft soil modelling frameworks. This particular document presents an qualitative assessment of the suitability of publicly available field data, i.e. site investigation, laboratory data and test data, on the long-term performance of embankments and shallow foundations on soft soils (serviceability limit state). The report will be a starting point for further validation of advanced time dependent models. Therefore, the interpretation of the laboratory data and reported measurement data from the field test, as appended to this report, is left to the specific model developer.

Summary

This report presents nine (9) selected cases on instrumented embankments on clay and peat and one (1) selected case of an instrumented shallow foundation on clay, which potentially enable the validation at boundary value level of advanced time dependent non-linear constitutive models for soft soils. Three of those cases are recommended due to the quality of the available test data on the field test, the site investigation, the sampling campaign and subsequent high quality non-standard laboratory testing. These are the Onsøy (Norway) and Murro (Finland) test embankments on clay, and the long-term response of a shallow foundation on clay, Bothkennar (UK). Out of those three cases the Onsøy field test should be considered first, as this site offers the highest quality data for which no benchmark comparisons with advanced constitutive models on boundary value level have been published.

Contents

1 | Description of work

WP2 deals with modelling of creep in clayey soils. Classical creep concepts are compared by defining simple benchmark examples with the purpose of assessing the capabilities of the most common creep formulations through finite element analysis. Assessment of the outcome will constitute the basis for developing a clay model that unifies other concepts in their response.

WP2-1 To identify the most relevant model mechanisms in soft soil creep modelling through FE benchmark exercises involving commonly available soft soil modelling frameworks – Milestone M5, Deliverable D2

WP2-2 To formulate, implement, and validate a user-friendly time dependent soft clay model relevant to engineering practise that adapts and unifies the most suitable frameworks identified through Objective 2-1. Input parameters shall be derived from standard soil testing. Small strain stiffness, destructuration, and anisotropy shall be incorporated as standard into the newly defined creep model – Milestone M6, Deliverable D3.

1.1 Deliverables

1.1.1 General

D2 Clay model benchmark report (Publication).

D3 Compiled model code for enhanced soft clay creep model and technical report on its usage (user guideline with examples)

1.1.2 This document

Fulfills part of WP 2-1 and D2.

1.2 Risk Analysis

1.2.1 General

Software may not be as stable as anticipated by industry within the duration of the project. If coding issues cannot be resolved in a timely manner, the consortium will jointly decide on simplifications in the software, e.g. not all investigated features of soil behaviour may be included in the final software.

1.2.2 Additional considerations

At present benchmarking of FE models in the numerical domain, i.e. for a theoretical case as outlined in WP2-1, is unsatisfactory. The performance of a model needs to be compared to real field data of a well documented test at boundary value level where high quality site investigation is available in order to improve the current models and have any degree of acceptance among practicing engineers.

2 | Benchmark Cases

2.1 Introduction

With the advent of readily available computing capabilities and the development of a multitude of advanced non-linear models for soils and soft soils in particular the need of benchmark comparisons arises. These models are typically compared to well established models for a non-existing theoretical benchmark case or alternatively compared to field data without considering other suitable constitutive models. This document sets out to identify suitable publicly documented field cases at boundary value level to which the existing (and newly developed) models will be compared. Ultimately, this leads to an assessment of the model performance for real world cases for prediction accuracy and ease of use (model parameter derivation, stability of the implementation, calculation time, etc.). The current report limits to identifying cases to benchmark the long-term soil response with a focus on the evolution of the soil behaviour associated to creep.

2.2 Considered field tests

Pre-screening of the literature and an informal survey among selected members of the project team lead to the list of case studies on the long-term response of an embankment. The pre-screening already excludes poorly instrumented sites, sites without a proper site investigation, and sites where long-term observations were not performed. Two exceptions are made to the latter condition as these cases without long-term observations are still considered due to the very well instrumented and well controlled embankment failure tests on problem soils (peat and sensitive clay). The following test embankments are selected:

- Antoniny, Poland, test embankment on peat Wolski et al. (1989), more info in Appendix B (copyrighted material for project members only)

- Booneschans, The Netherlands, the IJkdijk test embankment on peat (only failure test) overview scientific papers: Zwanenburg et al. (2012) & den Haan and Feddema (2013), original reports on the site investigation and laboratory data Zwanenburg (2008a) and field tests Zwanenburg (2008b) in Appendix C (copyrighted material for project members only)

- Boston Blue, United States, the original test embankment reported by Ladd et al. Ladd et al. (1994), more info from the original Thesis (Whittle 1974) in Appendix D (copyrighted material for project members only)

- Gloucester, Canada, the tests performed at the Gloucester site. See McRostie and Crawford (2001) for an overview and a recent paper by Zdravković et al. (2002) for a summary of the embankment test, more info in Appendix E

(copyrighted material for project members only)

- Haarajoki, Finland, the official Haarajoki benchmark case for soft soils. See Vepsäläinen et al. (2002) for an overview, more info and all laboratory data as published for the benchmark in Appendix F (copyrighted material for project members only)

- Murro, Finland, the Murro test embankment to assess the performance on sulfite rich soft soils. See Koskinen et al. (2002) for an overview, more info and the relevant scientific papers where some model parameters are already extracted (Karstunen et al. 2005, Karstunen and Koskinen 2008, Karstunen and Yin 2010, Karstunen et al. 2012 and Yin et al. 2011) are listed in Appendix G (copyrighted material for project members only)

- Three Swedish test embankments in Nödinge, Stora Viken and Surte, to assess the performance of deep mixing in Sweden. See Alén et al. (2006) for an overview report in Swedish, more info and some related scientific papers (Alén et al. 2005b, Alén et al. 2005a, Baker et al. 2005) in Appendix H (copyrighted material for project members only)

- Onsøy, Norway, the benchmark embankment test on the extensively documented Onsøy test site. See the recent paper of Berre (2013) on the essentials of the field test and the appended laboratory data report of NGI (Berre 2010) in Appendix I (copyrighted material for project members only)

- Perniö, Finland, most recent Finnish embankment test on sensitive clay (only brought to failure). English summary reported in Lehtonen (2011) full detail in Finnish report Lehtonen (2010). More detailed laboratory data will be available in the theses of Mansikkamäki (201x) & Mataic (201x). See Appendix J for more info (copyrighted material for project members only)

Additionally, one well documented field test for long-term settlements of a shallow foundation on clay is identified:

- Bothkennar, UK, long term load test on shallow foundation on clay (Jardine et al. 1995, Lehane and Jardine 2003), all relevant publications on characterization of the Bothkennar site and the laboratory tests on Bothkennar clay (Nash et al. 1992a, Nash et al. 1992b, Paul et al. 1992, Hight et al. 1992a, Hight et al. 1992b, Clayton et al. 1992, Smith et al. 1992, Leroueil et al. 1992, Allman and Atkinson 1992, Atkinson et al. 1992, Lehane and Jardine 1992, Jacobs and Coutts 1992) are reported in the Appendix K (project members only);

2.3 Assessment criteria

The field tests are compared following two main quality measures, i.e.:

- The quality of the instrumented field test with respect to the minimum instrumentation plan: vertical deformations at the centre line and horizontal deformations at the toe, embedded pore pressure transducers. Additionally, the spatial density of the embedded instrumentation (various depths and cross sections), the temporal resolution of the logging and the general accuracy of the measured physical quantity of the sensor is qualitatively taken into account.

The following subgroups are compared: *long term test* yes/no, *other instrumentation* yes/no. The assessed data quality (very poor – very good) for the *geometry, pore pressures, vertical displacements, horizontal displacements.*

- The quality of the site investigation: the number and quality of the in-situ tests (e.g. vane or CPT tests), the number of boreholes and the soil sampling method used (e.g. small diameter piston or block sampler) and subsequent laboratory tests for characterisation and assessment of the mechanical and hydraulic parameters. The advanced models require at least reliable determination of creep parameters from incremental load tests as well as that for an advanced features as anisotropy also additional triaxial tests in extension are required. Additionally, for model development non-standard stress path triaxial tests will provide the necessary information to establish, e.g. the yield envelope (and its evolution).

  The following subgroups are compared: *clay or peat.* The assessed data quality (very poor – very good) for the *in-situ tests, sample quality, characterisation, standard laboratory tests* and *non-standard laboratory tests* .

These scores will allow to categorize the field tests in three quality classes, i.e. doest the data allow:

- Class 1: Using the model with most parameters derived from real lab data and benchmark the performance with well documented field test results (horizontal/vertical deformations, pore pressures over a long period). These field tests should have exquisite lab data (non standard stress paths to capture anisotropy) and an 'easy' soil profile (i.e. not a complicated stress history from previous building activities, or geological processes)

- Class 2: Similar to Class 1, with less and/or lower quality site investigation data and field test data available, as a result in the calibration of advanced models more model parameters need to be estimated
- Class 3: Similar to Class 2 with additional complications in the field test (i.e. complex geometry or local ground improvement, long-term measurements not functioning properly)

where, class 1 will be a recommended test case for further benchmarking of advanced time-dependent models, class 2 is worth considering when particular features of a model can be tested and class 3 is only to be considered if the additional complexity in the test setup is part of the research question.

3 | Evaluation Tables

3.1 Introduction

The following rating is used in the score chart:

++ very good – state of art level of execution and reporting

\+ good – better than standard test level, academic research lab

0 fair – the standard what you can expect in a competently designed and executed experimental programme

– poor – substandard performance, data missing, poor execution

– – very poor – erroneous execution, outdated procedures, or missing information on essential aspects of the process and or test

3.2 Comparison of field test data

Table 3.1: Instrumented field test data; *vertical drains; **deep mixing

Site	long-term	geometry	pore pres.	vert. displ.	hor. displ.	other instr.
Antoniny	yes	+	0	+	0	no
Booneschans	no	+	0	+	+	yes
Boston Blue	yes	+	0	+	0	no
Bothkennar	yes	+	+	+	+	no
Gloucester	yes	+	0	+	0	no
Haarajoki	yes	0*	0	+	0	no
Murro	yes	+	+	+	+	no
Nö/SV/Su	yes	–**	-	0	-	yes
Onsøy	yes	+	+	+	+	no?
Perniö	no	0	+	++	+*	yes

where: long-term refers to the fact that long term settlement observations are available; geometry refers to the complexity of the embankment (drains, deep mixing); pore pres. hor. displ. & ver. displ. refers to the quality of respectively the pore pressure readings, the horizontal displacements and the vertical displacements taking into account the number of instrumentation levels the temporal resolution and the accuracy of the employed method; Other instr. is flagged if more types of instrumentation are employed (i.e. accelerometers, optic fibre cables, etc).

3.3 Comparison of SI and laboratory data

Table 3.2: SI and lab data score chart; n/a data is not available; *expected results thesis work Mansikkamäki (201x) & Mataic (201x)

Site	clay/peat	in-situ test	sample quality	characterization	std lab tests	non-std lab tests
Antoniny	peat	0	– –	0	0	n/a
Booneschans	peat	+	–	+	0	n/a
Boston Blue	clay	0	– –	0	0	n/a
Bothkennar	clay	+	+	++	+	+
Gloucester	clay	0	+	+	0	n/a
Haarajoki	clay	0	–	0	+	n/a
Murro	clay	0	–	+	+	++
Nö/SV/Su	clay	0	–	0	–	n/a
Onsøy	clay	++	++	++	++	+
Perniö	clay	0	–	0	+*	n/a*

3.4 Final Ranking & Concluding Remarks

The suitability for benchmark testing of most test embankments fall short on the available laboratory data and/or sample quality required for the accurate determination of the creep parameters, anisotropy and destructeration in advanced models. Additionally, field instrumentation is generally poor and sparsely spaced.

3.4.1 Class 1

Onsøy (embankment on clay), Murro (embankment on clay), Bothkennar (foundation on clay)

3.4.2 Class 2

Haarajoki (embankment on clay), Perniö (failure test embankment clay)

3.4.3 Class 3

Antoniny, Booneschans, Boston Blue, Gloucester, the three Swedish sites (Nödinge, Stora Viken and Surte). In all cases no proper triaxial data was available.

3.4.4 Concluding Remarks

As a result the three cases in class 1 are recommended for further benchmarking. These are the Onsøy and Murro (Finland) test embankments on clay, and the long-term response for the performance of a shallow foundations on clay, Bothkennar (UK). Out of those three cases the Onsøy field test should be considered first, as this site offers the highest quality data additionally to the fact that no benchmark comparisons of advanced models have been published for this site (comparison of model performance against the Murro site data has multiple publications by Karstunen and co-workers).

A | Acronyms

CRS Constant Rate of Strain

IL Incremental loading

CPT Cone Penetration Test

CAUC Anisotropically consolidated undrained triaxial test in compression

CAUE Anisotropically consolidated undrained triaxial test in extension

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B | Antoniny

This is a place holder for the copyrighted additional information on the Antoniny field case Wolski et al. (1989). For personal use of project members only.

C | Booneschans

This is a place holder for the copyrighted additional information on the Booneschans field case. Overview scientific papers: Zwanenburg et al. (2012) & den Haan and Feddema (2013), original reports on the site investigation and laboratory data Zwanenburg (2008a) and field tests Zwanenburg (2008b). For personal use of project members only.

D | Boston Blue

This is a place holder for the copyrighted additional information on the Boston Blue field case, the original test embankment reported by Ladd et al. (1994), more info from the original Thesis (Whittle 1974). For personal use of project members only.

E | Gloucester

This is a place holder for the copyrighted additional information on the Gloucester, Canada field tests. Overview paper of McRostie and Crawford (2001) & Zdravković et al. (2002) reported here. For personal use of project members only.

F | Haarajoki

This is a place holder for the copyrighted additional information on the official Haarajoki benchmark case for soft clay. Vepsäläinen et al. (2002) for an overview, plus additional material from the original benchmark. All material is public, due to size constraints not attached (600+ pages)

G | Murro

This is a place holder for the copyrighted additional information on the Murro test embankment to assess the performance on sulfite rich soft soils. The following is reported in the Appendix: Koskinen et al. (2002) for an overview of the test site. More info and the relevant scientific papers where some model parameters are already extracted (Karstunen et al. 2005, Karstunen and Koskinen 2008, Karstunen and Yin 2010, Karstunen et al. 2012 and Yin et al. 2011. For personal use of project members only.

H | 3 Swedish

This is a place holder for the copyrighted additional information on the three Swedish test embankments in Nödinge, Stora Viken and Surte. The tests were designed to assess the performance of deep mixing in Sweden. The following is reported: Alén et al. (2006) a public overview report in Swedish. Other related copyrighted scientific papers also reported (Alén et al. 2005b, Alén et al. 2005a, Baker et al. 2005). Those are for personal use of project members only.

I | Onsøy

This is a place holder for the copyrighted additional information on the Onsøy benchmark embankment test on the extensively documented Onsøy test site. Attached the recent paper of Berre (2013) on the essentials of the field test and the appended laboratory data report of NGI (Berre 2010). For personal use of project members only.

J | Perniö

This is a place holder for the public additional information on the most recent Finnish embankment test on sensitive clay (only brought to failure). English summary Lehtonen (2011) and full Finnish report Lehtonen (2010) appended. More detailed laboratory data will be available in the theses Mansikkamäki (201x) & Mataic (201x). For personal use of project members only.

K | Botkennar

This is a place holder for the copyrighted additional information on the long term load test on shallow foundation on the Bothkennar test site (Jardine et al. 1995, Lehane and Jardine 2003). All relevant publications on characterization of the Bothkennar site and the laboratory tests on Bothkennar clay from the special Géotechnique publication are listed as well (Nash et al. 1992a, Nash et al. 1992b, Paul et al. 1992, Hight et al. 1992a, Hight et al. 1992b, Clayton et al. 1992, Smith et al. 1992, Leroueil et al. 1992, Allman and Atkinson 1992, Atkinson et al. 1992, Lehane and Jardine 1992, Jacobs and Coutts 1992). Those are for personal use of project members only.

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