The MUSE Network: sharing research expertise on unsaturated soils across Europe

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Abstract

The paper presents the MUSE project to academics and practitioners who have an interest in the area of unsaturated soil mechanics. The MUSE ("Mechanics of Unsaturated Soils for Engineering") project is a major research and training network funded by the European Union involving six European universities and five industrial partners. Further details can be obtained visiting the MUSE website (2005).

The project started in December 2004 with a planned duration of four years. It aims at undertaking a comprehensive programme of research on unsaturated soils divided in the following four main tasks: laboratory testing, constitutive modelling, numerical analysis and application to practical problems.

An equally important objective of the project is to offer training to a new generation of engineers and scientists in the area of unsaturated soil mechanics by involving them in the planned research activities and encouraging transnational mobility through participation in a programme of workshops, schools, hands-on training sessions and secondments/visits organized at the different participating institutions.

The paper outlines the main targets that the project intends to achieve in terms of both research outcomes and training activities. Due to the early stage of the project, it is currently not possible to present any detailed scientific results from the collaborative research programme. The paper, however, gives a description of the proposed benchmarking exercises that will be undertaken in the areas of laboratory testing and constitutive modelling.

Introduction

MUSE is the acronym for "Mechanics of Unsaturated Soils for Engineering" and is the name of a Research Training Network funded with an overall budget of 1.25 million Euros by the 6th Framework Programme for Research and Technological Development of the European Union. Further details on the EU 6th Framework Programme can be found on the CORDIS FP6 website (2005). The project is funded under the "Marie Curie" actions, which are aimed at promoting transnational mobility of researchers for training purposes and to foster transfer of knowledge especially between different sectors of science.

The project started in December 2004 and has a planned duration of four years. It aims at undertaking a comprehensive programme of research and training in the area of unsaturated soil mechanics by means of international collaboration between academic and industrial institutions across Europe. Updated information about the activities of the network is regularly published on the MUSE website (2005).

The MUSE network involves six universities and five industrial partners. The academic institutions are: Durham University in the UK, Università di Trento in Italy, Ecole Nationale des Ponts et Chaussées in France, Universitat Politècnica de Catalunya in Spain, University of Glasgow in the UK and Università di Napoli "Federico II" in Italy. In addition, the following industrial partners will contribute to the training activities envisaged during the course of the project: Geomod in Switzerland, Geotechnical Observations in the UK, Provincia di Bolzano in Italy, Terrasol in France and Wykeham Farrance in the UK. The project is coordinated by Durham University.

The academic and industrial institutions participating in the MUSE network had already experienced close research contacts and some form of collaboration prior to this project but this happened mainly through bilateral agreements. Some academics participating in the project have also worked at more than one partner institution either as long-term visitors or as employees. This is, however, the first attempt by these institutions to establish a multi-lateral project with the intention to create a critical mass of expertise in unsaturated soil mechanics and to undertake a large training programme for disseminating the advances achieved worldwide in this particular area of research. To the authors' knowledge, there have not been previous initiatives of international cooperation on a similar scale targeted to research and training in the area of unsaturated soil mechanics.

The general purpose of the MUSE project is to enable exchange of knowledge and good practice across different academic and industrial institutions to address the lack of recognized standards in the procedures for measurement, testing and modelling of unsaturated soils. Within this general scope, a series of specific tasks have been established with the objective of promoting international transfer of knowledge through a two-fold mechanism involving research and training initiatives undertaken collaboratively by academic and industrial institutions. One of the main objectives is the benchmarking of the different methodologies and techniques for experimental and theoretical research in use at the different participating institutions.

The following part of the paper presents a detailed description of the various activities planned during the course of the MUSE project in both areas of research and training. The project is currently in its early stages and it is therefore not possible to discuss in the present contribution any result from the planned research programme. The partners of the MUSE network are currently agreeing the details of the benchmarking exercises to be undertaken in the areas of laboratory testing and constitutive modelling. The outline for such benchmarking exercises is presented in the paper.

Research objectives

The project's research programme encompasses a wide-ranging investigation of the engineering behaviour of unsaturated soils that is classified according to four broad tasks: Laboratory Testing (Task A), Constitutive Modelling (Task B), Numerical Analysis (Task C) and Application to Practical Problems (Task D). There are four general aims of the MUSE project, corresponding to each task of the research programme:

a) The generation of a large database of experimental results on the engineering behaviour of different categories of unsaturated soil.

This will be achieved by classifying data from laboratory tests performed on different types of unsaturated soils according to well-defined sorting criteria and will involve collection of existing data available in the public domain as well as additional experimental programmes where suction is either controlled or measured. Additional tests will also be performed to evaluate specific features of unsaturated soil behaviour such as the effect of de-saturation on small strain stiffness and the role played by degree of saturation and temperature on the engineering response of the soil.

b) The development and validation of constitutive models for unsaturated soils improving current proposals.

The proposed constitutive models will enhance current representation of particularly complex material features, such as for example the coupling between the hydraulic and mechanical response of the soil and the behaviour under cyclic or dynamic loading. Different constitutive models will also be developed to accommodate specific material characteristics corresponding to different categories of unsaturated soils, such as for example anisotropic soils, bonded soils and soils presenting a "double structure".

c) The development and validation of enhanced numerical techniques applicable to the general problem of coupled hydro-mechanical analysis of three-phase porous materials.

Developments will include the proposal of new algorithms for the integration of complex elasto-plastic stress-strain relationships, such as those mentioned under point b), and their implementation in finite element codes. Further investigation will focus on enhancing current finite element codes by coupling the mechanical response of the soil with the hydraulic, thermal and chemical behaviour.

d) Application of the constitutive and numerical modelling capabilities for unsaturated soils to a range of practical problems in civil engineering.

This will involve the application of modelling and analysis capabilities to geotechnical and geoenvironmental cases where knowledge of unsaturated soil behaviour plays an important role, e.g. the disposal of nuclear waste, the analysis of underground pollutant migration and the prediction of slope instability hazards. There will also be at least one original case history for which field instrumentation data will be made available to partners for comparison with model predictions. This should be a Class A prediction.

Table 1 provides a list of the various research sub-tasks that MUSE partners are planning to undertake together with the corresponding estimated schedule during the project. An additional key objective that spans all four tasks is the "benchmarking" of research techniques and methodologies used at different participating institutions. Many of the basic methods of engineering analysis in the area of unsaturated soil mechanics are still evolving and engineers lack standards in the procedures for measurement, testing and modelling of unsaturated soils similar to those for the analysis of saturated soils.

The MUSE project therefore aims at comparing different procedures, models, techniques or computer codes used at different partner institutions to assess the robustness of a particular approach in comparison with alternatives. Most importantly, the project will show whether the same results can be achieved for the analysis of the same problem by different research groups, or by using different procedures, models or codes.

The ultimate intention of the planned benchmarking exercises is to obtain indications about the appropriateness of a specific approach to be used for a particular research task, e.g. a suitable suction-control technique to be used for a given soil subjected to a given range of suctions, or a convenient numerical algorithm to be used for a particular category of boundary value problems and constitutive models. Benchmarking activities will be undertaken under all four tasks of the MUSE project and will involve testing techniques, constitutive models and finite element codes. A description of the planned benchmarking activities related to laboratory techniques and constitutive modelling will be provided later in the paper.

Table 1. List of research sub-tasks of the MUSE project

Tasks	Sub-tasks		Estimated schedule (Months from start)
TASK A : LABORATORY TESTING	A1:	Documentation and circulation of existing test	1 - 12
	A2:	Controlled-suction testing	
		- reconstituted non-expansive clay	1 - 24
		- compacted non-expansive clay	1 - 48
		- compacted highly expansive clay	1 - 36
		- natural clay	12 - 48
		- compacted granular soil	1 - 36
		- artificial cemented soil	1 - 42
		- natural cemented soil	1 - 36
		- pyroclastic soil	1 - 24
	A3:	Benchmarking methods of suction control	12 - 36
	A4:	Testing to investigate the role of degree of saturation	12 - 48
	A5:	Resonant column testing and bender element testing	1 - 48
	A6:	Non-isothermal testing	1 - 36
	A7:	Improved methods of suction measurement	1 - 24
TASK B : CONSTITUTIVE MODELLING	B1:	Interpretation with existing constitutive models	1 - 36
	B2:	Development of "double-structure" models	1 - 36
	B3:	Development of models incorporating the role of degree of saturation	1 – 48
	B4:	Incorporation of plastic anisotropy	1 – 18
	B5:	Incorporation of bonding and de-structuration	12 - 48
	B6:	Models for cyclic and dynamic loading	1 - 36
	B7:	Models incorporating thermal and/or chemical effects	1 - 48
	B8:	Benchmarking of parameter determination procedures	1 - 24
	B9:	Benchmarking of constitutive models	24 - 48

TASK C: NUMERICAL MODELLING	C1:	Formulating improved algorithms and numerical techniques	1 – 24
	C2:	Implementation in F.E. codes and development of a new F.E. code	12 – 36
	C3:	Implementation of new constitutive models in F.E. codes	24 – 48
	C4:	Further development of F.E. codes with thermo-chemical capabilities	1 – 48
	C5:	Benchmarking of F.E. codes	24 - 36
	C6:	Benchmarking of constitutive models in boundary value problems	12 - 48
TASK D: APPLICATIONS	D1:	Slope instabilities and flowslides	1 - 48
	D2:	Containment of nuclear waste	1 - 48
	D3:	Embankments and earth dams	1 - 36
	D4:	Seismic analysis of dams and response to ground vibrations	1 – 36
	D5:	Benchmarking of numerical modelling of a case history	36 - 48
	D6:	Propose improvements to existing design methods	36 - 48
	D7:	Develop or validate equipment and procedures for in-situ monitoring	12 – 36
	D8:	Dissemination of results	1 - 48

A particular advantage of the project is given by the geographical spread of network partners across Europe, which is reflected in the variety of unsaturated soil types studied by the different research groups.

Research groups from southern Europe, where the climate is relatively arid and water table is at a considerable depth, have larger direct experience of natural unsaturated soils in comparison with research groups from northern Europe, where natural soil formations tend to be saturated almost up to ground level due to regular precipitation. On the other hand, research groups from northern European countries have a stronger tradition of studying compacted soil, which is widely used in construction and can remain unsaturated while experiencing significant suction changes during its life.

In this respect, the project contributes to the transfer of knowledge between different research groups working with different categories of unsaturated soils and, therefore, experiencing different aspects of material behaviour.

Training objectives

A significant part of the MUSE project focuses on the training of junior researchers in the area of unsaturated soil mechanics. Training and research carry equal weight in the rationale for these types of project. The importance of the training aspect is reflected in the official name of "Research Training Network" given to these projects by the funding institution and in the requirement that at least 65% of the entire network expenditure must pay for the recruitment of researchers by participating universities. Most of the recruited researchers must also be at the early stage of their career and must not hold a doctoral degree. Only a limited number of experienced researchers can be appointed and this must be justified by the necessity of supporting existing senior academics at partner institutions in the transfer of knowledge towards junior researchers.

In the MUSE network the training of junior researcher takes place both at individual and network level.

Training at individual level falls mainly under the responsibility of the institution where the researcher is recruited. It is implemented by involving researchers in the various investigation tasks under the supervision of senior academics. Training through teaching is also offered in the form of lecture courses on different aspects of unsaturated soil mechanics run by network partners. Finally researchers are strongly encouraged to undertake secondments or visits at those institutions within the network that have significant expertise in their particular area of research.

Training at network level falls under the responsibility of the whole network. It is implemented through the organization of annual workshops, schools and hands-on training sessions attended by all researchers within the network and organized by different partners in rotation. Workshops give researchers the opportunity to present their investigation to all partners. On the other hand, schools and hands-on sessions offer training on theoretical and practical aspects of unsaturated soil mechanics through a series of lectures and applied tutorials. Researchers are also invited to participate to periodic management meetings held by senior academics to evaluate the overall progress of the project. Participation in management meetings is intended to provide junior researchers with some form of training in the area of research management.

The industrial partners have also an important role in the training activities of the Network. During the annual MUSE school, industrial partners are invited to deliver "industrial" lectures, which focus on the practical aspects of the geotechnical engineering profession. They are also a source of expertise for those research tasks which are clearly linked to engineering applications and would therefore benefit from a practical perspective. The annual schools attended by both academic and industrial partners offer en excellent forum for such transfer of knowledge. Additional exchange of visits between academics and industrial partners are also envisaged where necessary for closer collaboration.

The first MUSE school, entitled "Fundamentals of Unsaturated Soils" was held at the Universitat Politècnica de Catalunya in Barcelona, Spain during June 2005 and was open free of charge to people from outside the network. It was attended by a total of 79 participants including 31 participants from outside the network, some of them from countries outside Europe. The programme of the school included lectures given by speakers from both academia and industry, including invited speakers from outside the network. Electronic copies of the presentation slides for the full set of lectures given during the school have been made available free of charge to the wider scientific community via download from the MUSE website (2005).

The MUSE network intends to make an effort to maintain annual schools open free of charge to participants from outside the network as this is consistent with the training aims of the project. The next MUSE school is scheduled to take place at the Ecole Nationale des Ponts et Chaussées in Paris, France during May 2006.

Unsaturated soil mechanics is seldom taught to civil engineering students during undergraduate courses. This is often the case even for postgraduate courses in geotechnical engineering, which generally tend to focus on saturated soil mechanics. The training activities taking place within the MUSE project intend to improve understanding of unsaturated soil mechanics among the future generation of researchers and geotechnical engineers and, therefore, to promote awareness of the important role of this discipline in civil engineering. The junior researchers employed by the project will go on to become the academics of the future, and will be able to teach unsaturated soil mechanics from their own in-depth experience. Other academics and researchers who attend the MUSE schools may also be inspired to devote more time to teaching unsaturated soils.

Benchmarking of laboratory testing

Suction control and/or monitoring are key aspects in laboratory testing of unsaturated soils and this will be the main focus of the benchmarking activity under sub-task A3. Different techniques and procedures for applying and measuring suction will be compared by carrying out tests with increasing level of complexity. At the first stage, the experimental tests will involve the determination of the water retention characteristics of the same soil under zero total stress.

Design of the experimental benchmarking exercise involves two critical aspects, the selection of the soil type and the procedure for sample preparation. These must ensure that 'identical' specimens are tested by all laboratories. A choice was first made between natural soils and artificial mixtures. Natural soils with a significant percentage of fines are typically retrieved in lumps. These need to be manually crushed and sieved, and the resulting soil powder then needs to be carefully mixed to obtain a homogenous soil. Considering that a large mass of soil is required for the benchmarking exercise (to be distributed to six different laboratories), this option was abandoned. The soil used in the exercise will be a mixture of well graded sand, sodium bentonite (active clay), and kaolinite (non-active clay), which are all commercially available. These soils will be purchased in single batches by one institution and distributed to all other partners. Some preliminary tests will be carried out to determine the proportions of these three soils in order to obtain a 'suitable' water retention curve (WRC). The air-entry suction should not exceed 100-200 kPa, as the suction range of several axis-translation apparatuses used in the benchmarking exercise are limited to 500-600 kPa. The slope of the WRC beyond the air-entry suction should not be steep, as small errors in the determination of water content and suction will produce very scattered data over the WRC. The WRC should develop over a large range of suction so that the same samples can be used for matric suction measurement/control (equilibrium via liquid transfer) and total suction measurement/control (equilibrium via vapour transfer).

Samples will be normally consolidated from slurry under one-dimensional conditions (consolidometer) to a given vertical stress. This is perhaps the most reproducible procedure for sample preparation provided the initial water content of the slurry, the total height and the diameter to height ratio of the samples are maintained approximately the same in the different laboratories. As the samples will be initially saturated or quasi-saturated, the water retention characteristics will be investigated along a drying path. Samples will be de-saturated by applying increasing suction when using axis translation technique, osmotic method, and vapour control or de-saturated by air-drying when suction will be measured using tensiometer, psychrometer, and filter paper.

The water retention characteristics will first be investigated in the low suction range (0-1000 kPa) using axis-translation pressure plates, axis-translation oedometers, and high-suction tensiometers. The oedometers will allow the measurement of both gravimetric and volumetric water content and tensiometers will be installed on specimens that are sampled using oedometer cutting rings, so that both gravimetric and volumetric water content can also be measured. At least two institutions will be using the same measuring/control device to determine the same WRC. This overlapping will help cross-check the experimental data.

The investigation in the low suction range will be complemented by the osmotic technique (suction control) and the filer paper technique (suction measurement). The high suction range will be explored using filter paper and transistor psychrometers (suction measurement), and vapour equilibrium technique.

Benchmarking of constitutive modelling

Two benchmark exercises related to constitutive modelling are planned. Sub-task B8 will involve benchmarking of parameter determination procedures for a single constitutive model, whereas sub-task B9 will involve benchmarking of the performance of different constitutive models by performing blind predictions of laboratory test results.

In sub-task B8 each of the six research groups within the network will be provided with the same set of experimental data from a programme of controlled-suction laboratory tests on a compacted non-expansive clay. The test data will cover a limited number of tests but will include isotropic loading, wetting under isotropic stress states and shearing to failure at constant suction. Each group will use the experimental data to determine values for the various model parameters within the Barcelona Basic Model (BBM) of Alonso, Gens and Josa (1990) (the most widely used elasto-plastic constitutive model for unsaturated soils). The parameters concerned will be the various soil constants appearing within the model and the initial size of the yield surface. Each group will submit their set of parameter values to the coordinator of the exercise. The coordinator's group will then use the six sets of parameter values to produce six sets of simulations for a range of different stress and strain paths (including paths that are radically different to any of those followed in the experimental tests employed for parameter determination).

The objective of this first benchmarking exercise is to investigate whether different groups employing different parameter determination procedures arrive at similar or widely different sets of parameter values from the same set of experimental data. This will address the widespread concern that when deriving multiple parameter values from a limited set of experimental data it may be possible to arrive at widely different results depending upon the precise details of the procedure employed. The subsequent simulations will demonstrate the implications of the resulting differences in model parameter value sets for predictions or numerical modelling. A final objective will be to draw conclusions on the robustness of parameter determination procedures and to provide recommendations on preferred determination procedures.

In sub-task B9 all six research groups will again be provided with a single set of experimental data. This time, however, the different groups will employ different constitutive models (some groups will employ more than one model and there will be some overlap between groups). Having used the initial set of experimental data to determine parameter values for their specific model or models, each group will then be required to produce blind predictions of further laboratory tests on the same soil. These tests for which predictions are required will follow significantly different stress paths to those used for parameter determination. They will include stress paths designed to investigate model performance under a wide range of conditions relevant to practical problems involving unsaturated soils. Simulations from all groups will be submitted to the exercise coordinator, who will then present comparisons of the model simulations with corresponding experimental results.

The objective of this second benchmarking exercise is to investigate the strengths, weaknesses and limitations of various constitutive models for unsaturated soils.

Conclusion

The MUSE network is a major research and training project funded by the European Union in the area of unsaturated soil mechanics and involves several academic and industrial partners across Europe. The general objectives of the project are to undertake a wide-ranging multidisciplinary investigation programme and, at the same time, providing training for a new generation of geotechnical researchers and practitioners.

The research programme encompasses four broad areas of activity, namely laboratory testing, constitutive modelling, numerical modelling and application to boundary value problems. Unsaturated soil mechanics is a relatively new area of research and there is a pressing need to compare novel techniques. An important characteristic of the MUSE research programme is the benchmarking of testing and modelling techniques that have been developed during the last decade at the different participating universities. An equally important aspect of benchmarking is the comparison between model predictions and actual observations in the field. The ultimate aim of all benchmarking activities is to demonstrate the reliability of modelling and testing techniques for unsaturated soils and consequently to promote their use within the industrial sector.

The training programme includes activities mainly targeted at junior researchers and undertaken at both individual and network level. Training activities at network level involve participation in workshops, schools and hands-on training sessions held annually at participating universities in rotation. The MUSE network endeavours to maintain attendance to schools open free of charge to all people from outside the network interested in unsaturated soil mechanics.

The training programme of the MUSE network will also contribute to promote the role of unsaturated soil mechanics as an important discipline within the academic curriculum of future generations of civil engineers.

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