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Report on Calibrated material properties database

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Deliverable D10.5

Report on Calibrated Material Properties Database

**Version 1.0
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GEO LAB

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Executive Summary

Physical modelling is usually coupled with numerical modelling to gain deeper insights into the phenomena being examined. In GEOLAB, experimental results from Transnational Access projects are stored in a database, available to other researchers for further numerical study. This ensures that the value of these data will extend into the future and will be helpful even to researchers outside of the original user groups.

To support the use and re-use of these quality experimental data, the GEOLAB consortium has developed a comprehensive 'one-stop' material properties database for the typical soils and constitutive models used in the GEOLAB facilities. This report describes this database, the information currently contained herein, and the outlook on its further development.

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List of Abbreviations	
AI	Artificial Intelligence
CI	Critical Infrastructure
CA	Consortium Agreement
DOI	Digital Object Identifiers
DMP	Data Management Plan
ERA	European Research Area
FAIR	Findable, Accessible, Interoperable and Reusable
IAB	International Advisory Board
ICT	Information and Communication Technology
IP	Intellectual Property
JIP	Joint Industry Project
JRA	Joint Research Activity/ies
MT	Management Team
NA	Networking Activity/ies
NG	Next Generation
PGA	Participants General Assembly
RI	Research Infrastructure
SME	Small and Medium Enterprise(s)
TA	Transnational Access
TRL	Technology Readiness Level
USP	User Selection Panel
EC	European Commission
SWRC	Soil Water Retention Curve

1 Introduction

1.1 About GEOLAB

The existing Critical Infrastructure (CI) of Europe in the water, energy, urban and transport sector is facing major challenges because of pressures such as climate change, extreme events, geo-hazards, aging and increased usage in combination with pivotal changes in the CI to meet long-term societal goals (e.g. energy transition). To address these challenges, scientific research and innovative solutions are needed that can only be achieved by an interdisciplinary, cross-boundary approach and by equipping expert teams with the most advanced suite of physical research infrastructure available that allows them to work across spatial scales, explore different theories that describe the pressures and adopt innovative techniques for solutions.

The GEOLAB Research Infrastructure (RI) consists of **11 unique installations** in Europe aimed to **study subsurface behaviour** and the **interaction with structural CI elements** (e.g. a bridge) and the **environment**. The overarching aim of GEOLAB is to integrate and advance these key national research facilities towards a one-stop-shop of excellent physical RI for performing ground-breaking research and innovation to address challenges faced by the Critical Infrastructure of Europe.

During the **Joint Research Activities (JRA)**, the capabilities of the integrated GEOLAB RI services are improved beyond present state-of-the-art. Topics are: (1) Harmonizing operation (2) Advancing physical modelling of the impact of climate change, aging and extreme events on CI; (3) Development of 3D-4D measurement techniques; (4) Application of new materials and new sensing techniques; (5) Data management of performed experiments for future re-use.

During Transnational Access (TA), users outside the consortium gain access to the GEOLAB installations to perform research and innovation. The scientific research community will use the enhanced capabilities of GEOLAB from the JRA to perform ground-breaking experiments. For CI managers and policy makers, the activities will result in a more comprehensive understanding of the challenges facing CI and evidence to base decision making upon. The construction industry will use GEOLAB to proof innovative solutions for the CI and so gain more leadership in the industrial and enabling technologies.

There will be close interaction with Small and Medium-sized Enterprises (SME) that develop user-friendly engineering software from numerical modelling advances which are validated in the TA projects. We will explicitly challenge SME on sensing, new materials and other niches for innovative solutions, which will have spinoff in other fields of application, contributing to the competitiveness of Europe.

Networking Activities (NA) are another core element of GEOLAB, culminating in workshops and other outreach events that foster a digital and In Real Life community, thereby providing a productive channel to communicate with different stakeholder groups.

The GEOLAB consortium is a collaboration of renowned organizations coordinated by Deltares (the Netherlands). Other consortium partners are: Delft University of Technology (the Netherlands), ETH Zürich (Switzerland), University of Maribor (Slovenia), Technical University Darmstadt (Germany), NGI Norway, CEDEX Spain, Université Gustave Eiffel (France), University of Cambridge (United Kingdom) and KPMG Future Analytics (Ireland).

More information: www.project-geolab.eu.

1.2 Joint Research Activities (JRA)

The Joint Research Activities (JRA) are an essential element of GEOLAB and contribute significantly to the declared overarching goal of the project by aiming for the following subordinate goals:

- Synergetic integration of experimental research infrastructure in the disciplines of subsurface behaviour (soil mechanics and hydrogeology), engineering (geotechnical, structural, engineering geology and environmental) and data science (ICT, advanced data analyses and virtual access)
- Improvement of physical modelling and measurements techniques beyond present state of the art that allow for studying complex and interdisciplinary effects.
- Provision of guidance on and integration of data management methods (standardization); set-up of an open access database of well-documented experiments for efficient data exchange between installations and re-use of experiment data sets.

Consequently, JRAs are crucial to create synergy and stimulate innovation of the GEOLAB RI beyond present state of the art. In alignment with the previously mentioned subordinate goals, JRAs comprise the following components:

- JRA1 “Guidance” improves and harmonizes the operation of our installations by conducting an inventory of the installations and development of GEOLAB user’s manual, among others.
- JRA2 “Innovation” enhances the capabilities of GEOLAB by: (a) advancing physical modelling of the impact of climate change, aging and extreme events on CI; (b) developing 3D-4D measurement laboratory and field techniques; (c) using new materials and applying new sensing techniques.
- **JRA3 “Data management and standardization”** offers virtual access to a database of performed experiments that is suitable for future re-use of data and easy comparison across installations.

GEOLAB will disseminate achievements of the JRA work packages through journal publications, national and international conferences, workshops, as well as through other communication channels such as social media, website and personal contacts. The results of JRA1 “Guidance” will be published on the project website as valuable information to potential new users, new generation (NG) researchers, other laboratories and academia. JRA2 “Innovation” will display advances of the GEOLAB infrastructure and demonstration projects that highlight the interaction between physical and numerical models and between physical models and the environment. Finally, JRA3 “Data management and standardization” offers virtual access to a database of performed experiments that will become available to all stakeholders to allow for re-use of data.

The current report on **Calibrated Material Properties Database** contributes to **JRA3 “Data management and standardization”** with three essential components. Firstly, the structure of the database is described, including where certain types of test data can be found within it. Secondly, a summary of the current content of the database (as of the date of submission of this report) is given. Thirdly, instructions are provided on how to contribute to the database throughout the duration of the GEOLAB project in Appendix 1. Finally, for convenience, Appendices 2 and 3 provide summaries of the experimental apparatus available at each consortium member and key contacts.

2 Rationale

Physical modelling is usually coupled with numerical modelling for better understanding and analysis of the phenomena being examined. Physical testing can be preceded by numerical simulations to determine the parameters for the appropriate design of experiments. These experiments are then often followed by further simulations to gain deeper insights into the problem. In GEOLAB, the use and re-use of data from the experimental programs is a central theme. Thus, experimental results are stored in a database, available to other researchers for additional study. This ensures that the value of the data derived from Transnational Access projects will extend into the future and they will be helpful even to researchers outside of the original user groups. Specifically, the high-quality experimental data produced in the GEOLAB facilities are expected to be used for further numerical studies and/or validation of numerical methods, as well as to continually provide means for validating new approaches and new ideas long into the future.

In general, however, use and re-use of experimental data for numerical studies is often hampered because information on the properties of the materials used is incomplete, insufficient, scattered or not readily available. Details on how these material properties are acquired (e.g., test type, standards, conditions) are also usually lacking, consequently making it difficult for users to verify the accuracy of information. Moreover, data related to material constitutive models, which are required to perform realistic simulations, are usually absent. Thus, the main motivation of Deliverable 10.5 was to develop a comprehensive 'one-stop' material properties database for the typical soils and constitutive models used in the GEOLAB facilities that addresses the above problems, which would be publicly accessible through the ZENODO platform ([DOI 10.5281/zenodo.7462287](https://doi.org/10.5281/zenodo.7462287)). This report describes the resulting GEOLAB material properties database.

3 The GEOLAB material properties database

For simplicity and ease of use, the database was built with Microsoft Excel. To standardize content and information, a template was created, which each partner was asked to fill-out for each standard material used in their facility. The GEOLAB material properties database, therefore, consists of sub-databases for each of the standard materials identified by members of the consortium. The sub-database contains information on material basic properties and data from common laboratory tests used to calibrate constitutive models for describing soil behaviour. It also includes parameters for the constitutive models commonly used in simulating experiments in the GEOLAB facilities, mainly calibrated using the said material basic properties and laboratory test data.

The sub-database is divided into five main parts: Overview, Basic Properties, Static Laboratory Tests, Dynamic Laboratory Tests and Constitutive Models. Corresponding tabs are color-coded for easy identification. In addition, a Reference sheet is included, as well as an Instruction sheet to guide current and future contributors in data entry (Annex 1). The following sections describe each of the main parts of the sub-database.

3.1 Overview

This sheet (Figure 1) contains basic information on the material (e.g., name, supplier) and a summary of the coverage of the sub-database, i.e., available soil properties and test data, and the test conditions usually available in the GEOLAB facilities. A list of basic properties and common laboratory tests to characterize constitutive behavior is given, and a dropdown 'Yes' or 'No' menu is provided to indicate information/data availability. The amount of tests/data is also indicated. Furthermore, conventions for sheet naming are given in this page.

1	
2	Organization TU Darmstadt
3	
4	Overview
5	
6	Testing material
7	Name Darmstadt Sand
8	USCS Classification abbreviation (standard)
9	Supplier Industriesandwerk Robert Hardt GmbH & Co KG
10	Langer Kornweg 28, 65451 Kelsterbach
11	Germany
12	E-Mail: info@industriesandwerk.de; https://industriesandwerk.de
13	
14	
15	Additional notes
16	
17	
18	
19	
20	
21	
22	
23	
24	Test conditions (physical model test)
25	Saturation
26	dry saturated unsaturated
27	Yes Yes No
28	Mechanical Loading
29	monotonic cyclic (N<100) cyclic (N>100)
30	Yes No No
31	Hydraulic Loading (infiltration, drying-wetting cycles, ...)
32	monotonic cyclic (N<100) cyclic (N>100)
33	Yes No No
34	Basic properties
35	Type Available Amount
36	Index properties
37	... Grain size distribution (GSD) Yes 4
38	...Atterberg Limits Yes
39	Density Parameters Yes
40	Shear Strength Parameters Yes
41	
42	
	◀ ▶ Overview Basic Properties GSD oed-1 oed-2

Figure 1. Part of an Overview sheet

3.2 Basic properties

This section contains information on soil index properties (i.e., grain size distribution and Atterberg limits), density parameters (e.g., specific gravity, maximum void ratio and minimum void ratio), shear strength parameters (critical friction angle, cohesion) and grain characteristics (e.g., particle shape, angularity, sphericity, texture). Properties not covered in the foregoing can be added under “Others”. Figure 2 shows an example of the Basic Properties sheet.

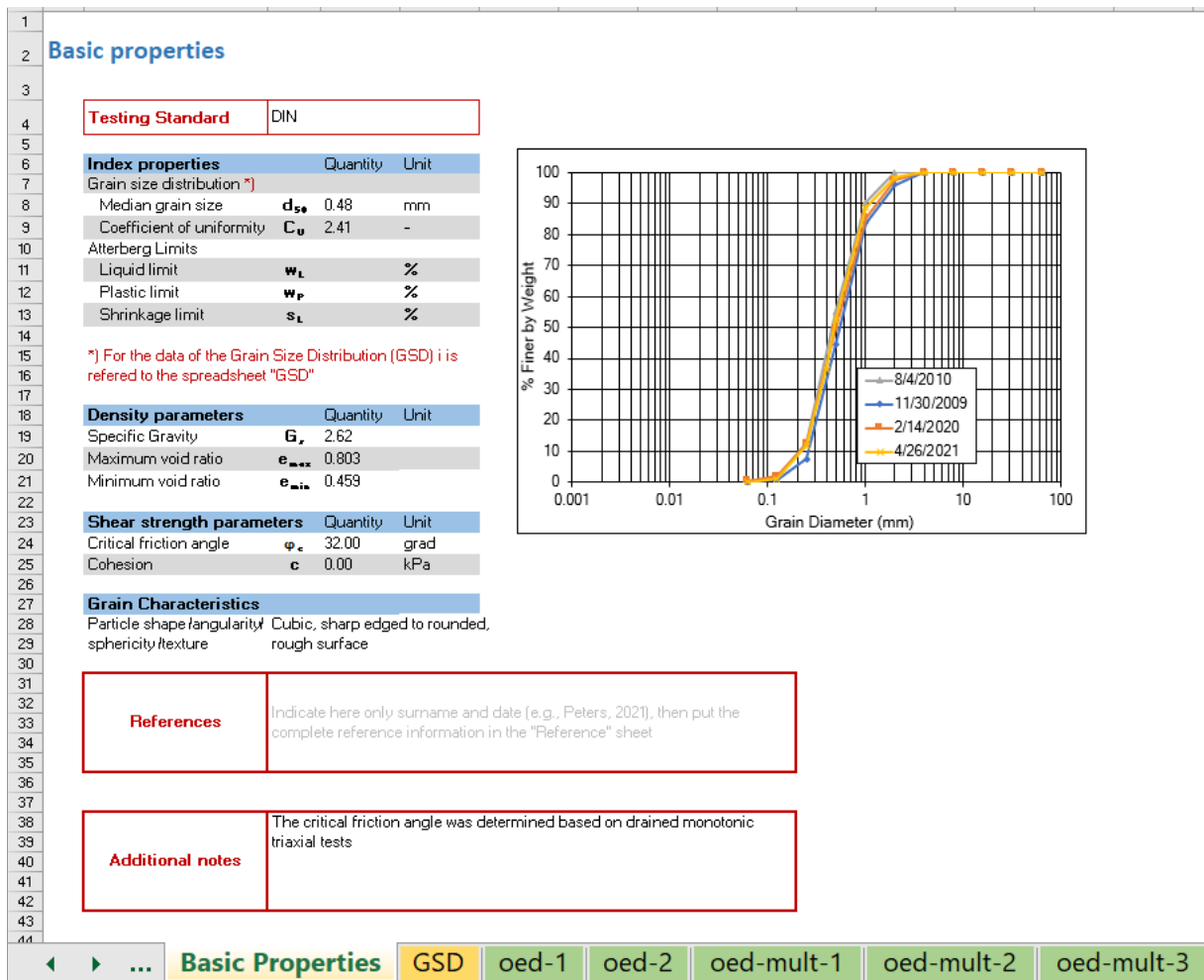


Figure 2. Example of Basic Properties sheet

3.3 Static laboratory tests

This section contains some of the most common laboratory tests to characterize the static/quasi-static constitutive behaviour of soils such as oedometer, triaxial, direct shear, simple shear, ring shear, soil water retention curve and permeability tests. Tests not covered in the list may be included by inserting additional rows. Each test is presented in a separate sheet; each sheet contains the testing standard used, information on sample and test conditions, raw test data, relevant plots, references and additional notes. Figure 3 shows an example of a static laboratory test (oedometer test).

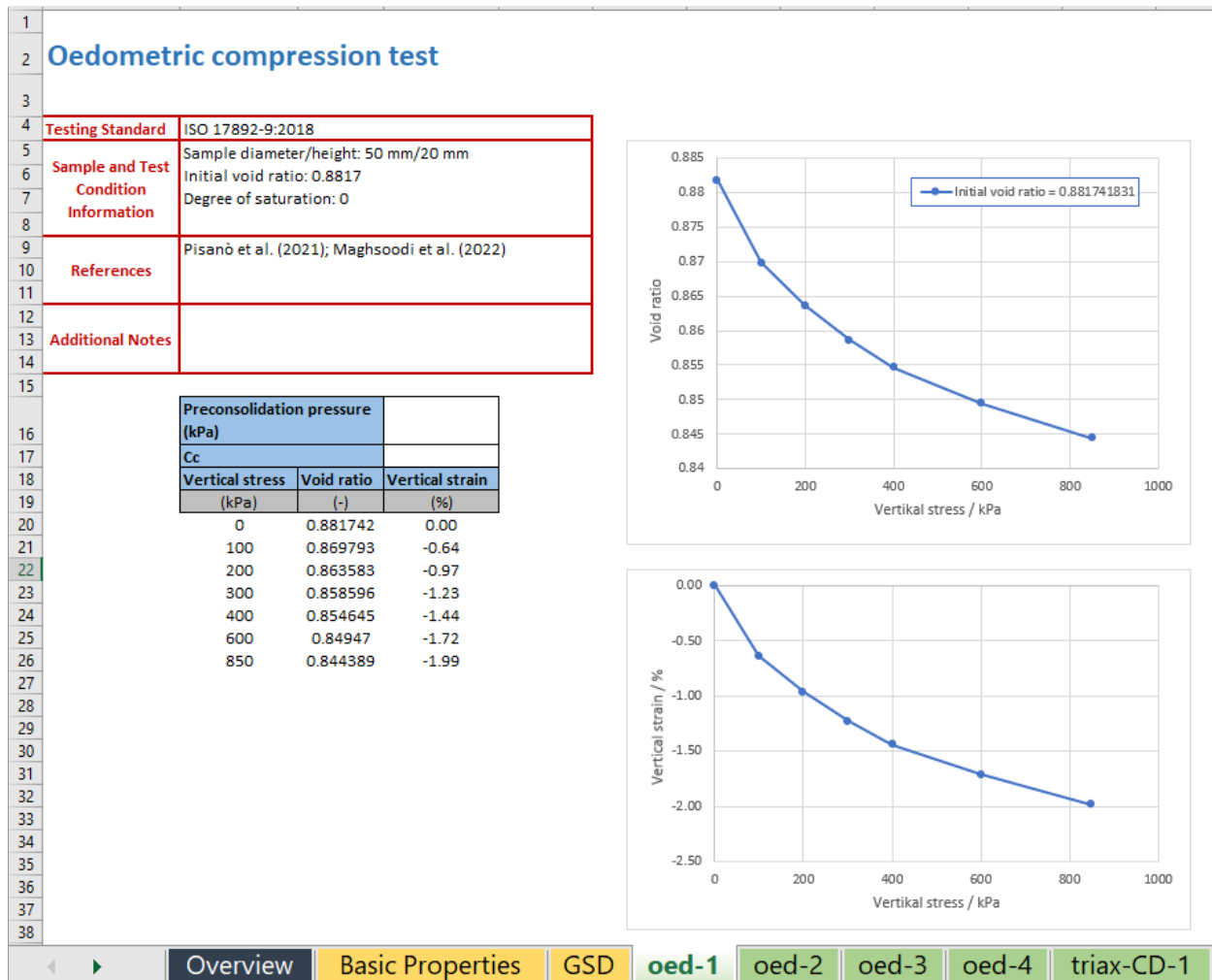


Figure 3. Example of a static laboratory test – oedometric compression test

3.4 Dynamic laboratory tests

This section contains some of the most common laboratory tests to characterize the dynamic constitutive behaviour of soils such as cyclic triaxial, cyclic direct shear, cyclic simple shear, cyclic ring shear, resonant, and bender element tests. Tests not covered in the list may be included by inserting additional rows. Like in static tests, each test is presented in a separate sheet; each sheet contains the testing standard used, information on sample and test conditions, raw test data, relevant plots, references and additional notes. Figure 4 shows an example of a dynamic laboratory test (cyclic direct simple shear test).

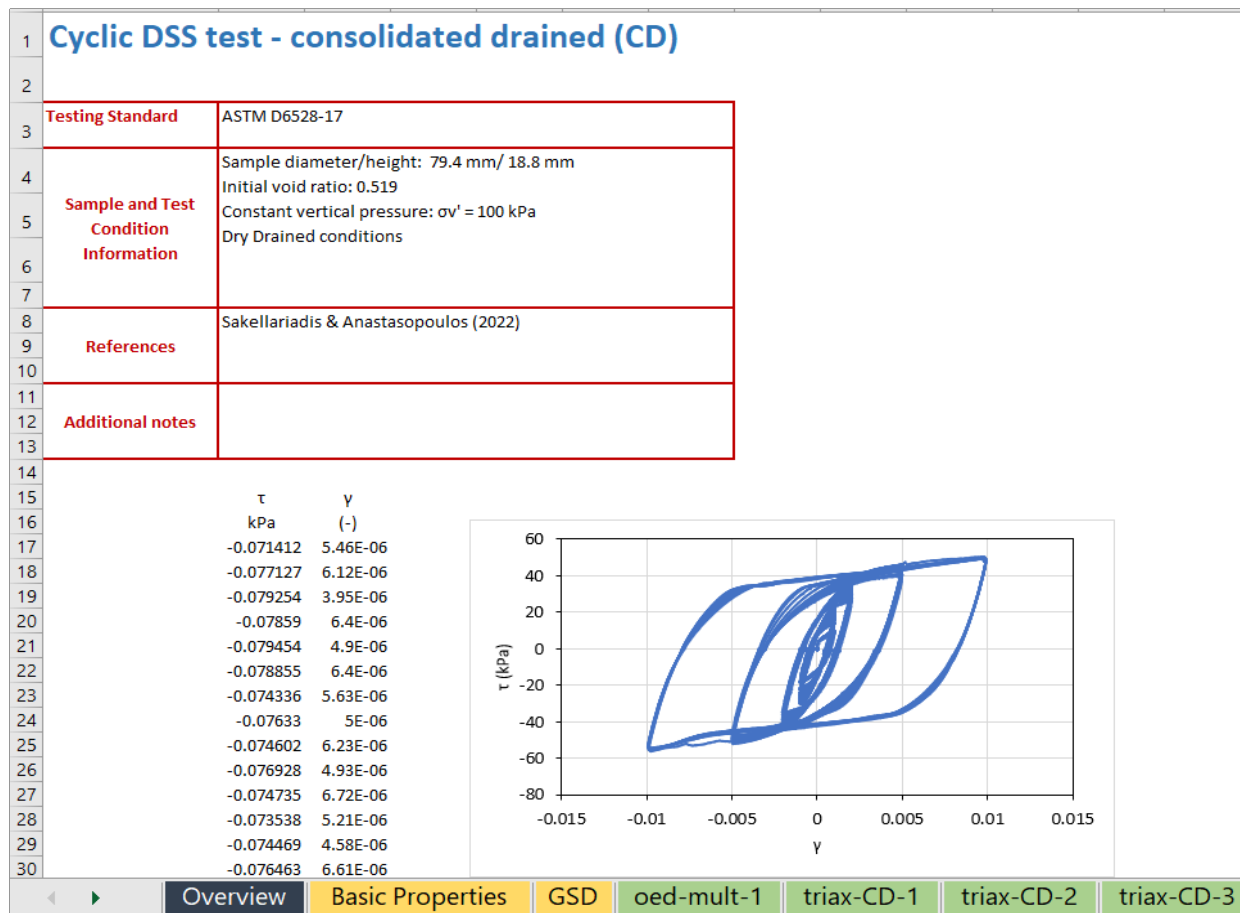


Figure 4 Example of a dynamic laboratory test-cyclic direct simple shear test

3.5 Constitutive models

This section contains the common constitutive models used in numerically simulating experiments in the respective GEOLAB facility, as well as the parameters of these models, calibrated using mainly the information on material properties and test data contained in the database. The section also contains information on the availability of the implementation, version of the constitutive model, comparison of simulation results with laboratory data, notes on parameter calibration and references. Figure 5 shows an example of a Constitutive Model sheet.

1					
2	Constitutive models: stress-strain				
3					
4	Specify here your commonly used material model/s to describe stress-strain				
5	behavior and create a list of the model parameters calibrated with the				
6	standard material.				
7					
8	Please also provide any additional information such as the availability of the				
9	implementation, version of the constitutive model, comparison of simulation				
10	results with laboratory data, notes on parameter calibration and references.				
11					
12	Models covered:	Hypoplasticity (basic version)			
13					
14					
15					
16	1	Hypoplasticity			
17		Hypoplasticity: original version of "von Wolffersdorff" (Ref. 4)			
18	Version				
19					
20	Availability	https://soilmodels.com/hyposand/			
21	Alternatives				
22		Calibration has been performed using the results of triaxial tests			
23		on Baskarp sand in different confining pressures as reported in			
24		the following paper:			
25	Notes	<i>Phuong et al., (2016); Ref. 3</i>			
26					
27					
28					
29	Parameter	ϕ_c	(grad)	31	Basic Hypoplasticity model without the intergranular strain concept
30		h_s	(GPa)	4	
31		n	(-)	0.42	
32		e_{d0}	(-)	0.548	
33		e_{c0}	(-)	0.929	
34		e_{j0}	(-)	1.08	
35		α	(-)	0.12	
36		β	(-)	0.96	
37		m_s	(-)	-	
38		m_r	(-)	-	
39		R	(-)	-	
40		β_s	(-)	-	
41	χ	(-)	-		
42					
		Overview	Basic Properties	GSD	triax-CD-1

Figure 5 Example of a Constitutive Model sheet

4 Summary of Current Database Content

Table 1 summarizes the content of the GEOLAB material properties database as of the date of submission of this report. Note that CEDEX is not included in the database because numerical simulation is not usually done in its facility. Moreover, for experiments, they use Hostun Sand, which is already described by UCAM. NGI is also not included in the current database because numerical studies have not been done yet in its testing sites, these sites having been established just relatively recently.

As can be seen from Table 1, the basic properties of the standard materials in all facilities are well-defined. Most of the constitutive models in the database were calibrated using static laboratory tests; thus, the database is rich with these data. Dynamic tests are, however, uncommon and available only in a few facilities (ETHZ, TU Delft and University of Cambridge).

All the constitutive models currently in the database are focused on the stress-strain behaviour of soil. Table 2 provides a list of these constitutive models. Models describing soil hydraulic behaviour (e.g., SWRC, permeability) are largely unavailable. These shortcomings provide obvious areas for future laboratory activities across the consortium members, especially given that the modelling of climate change and extreme events is a key focus of GEOLAB.

Table 1. Summary of the current content of the GEOLAB material properties database

Organization	Material	Basic Properties					Static Laboratory Tests									
		Index Properties	Density Parameter	Shear Strength Parameter	Grain Characteristic	Others	Oedometer Compression Test	Unconfined Compression Test	Isotropic Compression Tests	Triaxial Compression Test	Triaxial Extension Test	Direct Shear Test	Simple Shear Test	Ring Shear Test	Soil Water Retention Curve	Permeability
Deltares	Baskarp Sand No. 15	✓	✓	✓	✓					✓						
	OVP Clay	✓	✓	✓		✓	✓			✓	✓	✓				
ETHZ	Perth Sand	✓	✓				✓			✓						
	Nevada Sand		✓	✓	✓				✓							
TUDa	Darnstadt Sand	✓	✓	✓	✓		✓			✓						
TU Delft	Geba Sand	✓	✓	✓	✓		✓			✓						
	Hostun Sand	✓	✓	✓	✓					✓						
UCAM	Speswhite Kaolin	✓	✓	✓	✓		✓		✓							
Uni Eiffel	NE34 Fontainebleau Sand	✓	✓	✓	✓		✓			✓						
ZAG	Loče Silty Clay	✓	✓	✓			✓	✓				✓				✓

Table 1. cont'n...

Organization	Material	Dynamic Laboratory Tests						Constitutive Models		
		Cyclic Triaxial Compression Test	Cyclic Direct Shear Test	Cyclic Simple Shear Test	Cyclic Ring Shear Test	Resonant Column	Bender Element	Stress-Strain	Soil Water Retention Curve	Permeability
Deltares	Baskarp Sand No. 15							✓		
	OVP Clay							✓		
ETHZ	Perth Sand			✓				✓		
	Nevada Sand							✓		
TUDa	Darmstadt Sand							✓		
TU Delft	Geba Sand						✓	✓		
UCam	Hostun Sand							✓		
	Speswhite Kaolin	✓						✓		
Uni Eiffel	NE34 Fontainebleau Sand							✓		
ZAG	Loče silty clay							✓		

*ETHZ: Eidgenössische Technische Hochschule Zürich

TUDa: Technical University of Darmstadt

TU Delft: Technical University of Delft

UCAM: University of Cambridge

Uni Eiffel: Université Gustave Eiffel

ZAG: Slovenian National Building and Civil Engineering Institute

Table 2. Constitutive models included in the GEOLAB material properties database

Constitutive Model	Organization
Modified Cam Clay	UCAM
Mohr Coulomb Hardening Softening	ETHZ
Hardening Soil (basic version)	ZAG
Hardening Soil with small strain stiffness	TU Delft
Hypoplasticity (basic version)	Deltares, Uni Eiffel
Hypoplasticity + Intergranular Strain	TU Darmstadt
Pastor-Zienkiewicz-III	UCAM
Sanisand	TU Darmstadt; Uni Eiffel
Soft Soil Creep	Deltares
Creep S-Clay 1	Deltares

5 Concluding remarks

This report presents the material properties database for the standard materials used in GEOLAB experiments, with the aim to support further numerical studies on the results of these experiments. This database currently contains mainly the already existing data in each facility prior to GEOLAB, but this will be expanded throughout the duration of GEOLAB. It is thus an evolving document that will be regularly updated to include material test data from our TA and related projects. In particular, the Dynamic Laboratory Tests section may be improved, as well as the Constitutive Model section, to include models describing soil hydraulic behaviour. The GEOLAB Material Properties Database is accessible through the ZENODO platform ([DOI 10.5281/zenodo.7462287](https://doi.org/10.5281/zenodo.7462287)).

6 Appendix 1: Instructions in Filling-out the Database

Instructional Guidelines

1. Partners will each have their own excel file. This excel file needs to be replicated for **EACH reference/standard material**. This may include fabricated materials like clays produced in a so-called “clay factory”.
2. File naming protocol: Material Properties Database_Institute Name_Name of Reference Material
3. The file/database is divided into 5 main sections, color-coded for easy identification:
 - Overview containing information on the test material and a checklist of available data
 - Basic Properties
 - Static Laboratory Tests
 - Dynamic Laboratory Tests
 - Constitutive Models
4. For the sections Static Laboratory Tests and Dynamic Laboratory Tests, the rule is: **One sheet per test**. For example, if there are 3 oedometer tests, then each of this test should be presented in 3 separate sheets.
5. When adding sheets, please follow the color codes.
6. Feel free to add tests/sub-tests that are not included in the checklist, and when you do, please make sure that you also add them in the Overview sheet.
7. There are templates available for the oedometer and triaxial tests. Where possible, use these templates. For those tests that don't have templates, just copy-paste your data as you wish. Additional templates will be developed later, for standardization and easy future additions.
8. For those who don't have their own reference material, please also fill out the database, indicating references and also including the tests that you have done on the material, if any. These data will eventually be integrated and reconciled with the data of those using the same material.
9. For each sheet, references are asked (if available). To avoid clutter, please only indicate surnames and dates, e.g., Peters (2021). Then provide the complete reference details in the “Reference” sheet. Arrange the references in this "Reference" sheet alphabetically.
10. Specific instruction can be found in specific sheets.

7 Appendix 2: List of GEOLAB Providers and Facilities

Table 1 GEOLAB experimental facilities: list of key features

Provider	Key Equipment
<p>1. University of Maribor</p>	<ul style="list-style-type: none"> ▪ Large-scale triaxial apparatus ▪ Infrastructure for experimental pavement structure research ▪ Traffic Load Simulator (TLS) <ul style="list-style-type: none"> ➤ pavement soil-structure interaction <p><u>Services currently offered by the infrastructure:</u> Realistic and inexpensive simulation of pavement structure, analysis of short and long-term behaviour of different pavement structures, optimization of pavement design, testing of multiple scenarios in a timely fashion</p>
<p>2. TU Delft</p>	<ul style="list-style-type: none"> ➤ TU Delft Geotechnical Centrifuge <ul style="list-style-type: none"> ➤ Radius: 1.3 m ➤ Max model weight 300N (volume of 150 (h) x 400 (l) x 400 (w) mm³), subjected to max g level of 300g <p><u>Services currently offered by the infrastructure:</u> Soil-structure interaction, offshore foundations, dykes and embankments, tunnelling, slope stability, dynamic effects on geotechnical structures and surface subsidence</p> <p><u>Examples of the recent services offered are listed below:</u></p> <ul style="list-style-type: none"> • Sliding behaviour spudcan foundations • Installation and bearing capacity of suction caissons • Effect of ship/wall collision • Determination crater depth due to gas blowout • Behaviour of sheet pile walls • Widening of (transport and river) sand embankments on soft soil • Failure mechanism of dykes (water infiltration, uplift pressure, loading) • Pollution transport simulations (DNAPL, LNAPL, Cleaning processes) • Flow slides of submerged slopes composed of loose sands • Role of scour protection on the prevention of static liquefaction induced flow slides
<p>3. ETHZ</p>	<ul style="list-style-type: none"> ▪ Drum and Beam Centrifuge <p>Drum Centrifuge</p> <ul style="list-style-type: none"> ➤ Radial acceleration of 440g on a test payload of 2 tons ➤ soil channel dimensions: 2.2m diameter x 30cm deep x 70cm wide and 5.0m long ➤ In-flight model creation, including saturation is possible <p>Beam Centrifuge</p> <ul style="list-style-type: none"> ➤ Radial acceleration of 250g on a test payload of 2 tons (or equivalently 5tons at 100g) ➤ Each swing has a platform of 1.25 x 1.25 m, where the soil container is placed ➤ The setup offers the possibility of a soil container of up to 2 m length ➤ A custom-designed by Actidyn BC-5810 earthquake simulator is installed in one of the two platforms ➤ Capability of performing horizontal seismic ground motions of any target waveform (recorded or artificial) at up to 0.5 g peak ground acceleration on packages of up to 700 kg mass over a wide frequency band, at a maximum centrifugal acceleration of 100g

	<p><u>Services currently offered by the infrastructure:</u> Soil-structure interaction, monotonic and cyclic loading of shallow and deep foundations, slope stability, rockfall, rainfall-induced landslides, and “sturzstroms”</p>
4. TU Delft	<ul style="list-style-type: none"> ▪ TU Delft Large Scale Geotechnical Physical Modelling Facility <ul style="list-style-type: none"> ➤ 5 x 2 x 2 m <p><u>Services currently offered by the infrastructure:</u> <u>Examples of the recent services offered are listed below:</u></p>
5. Uni Eiffel	<ul style="list-style-type: none"> ▪ Uni-Eiffel Geo-Centrifuge <ul style="list-style-type: none"> ➤ Radius 5.5 m ➤ Max. acceleration 100 g (@ 5m) for 2t models ➤ Swinging basket L x l x h : 1.40 x 1.15 x 1.5m ➤ Remotely controlled 4-axes robot, earthquake simulator ➤ Investigation tools : mini-CPT, mini-Tbar, mini vane test, mini pressumeter ➤ Circular containers, rectangular strongboxes, transparent face strongboxes <p><u>Examples of the recent services offered are listed below:</u> Wind turbines founded on a jacket pile structure (2013-2016), Monopiles (2017-2020), floating Wind turbines (2017-2021), and behaviour of Piles subjected to cyclic loading (2008-2017). Reinforcement and improvement of soft soils with Rigid Inclusions (1998-2001, 2005-2013, 2019-2023), reinforcement with geogrids, helical piles, unsaturated soils and installation of piles</p>
6. Deltares	<ul style="list-style-type: none"> ▪ GeoModel container <ul style="list-style-type: none"> ➤ 4.0 m x 2.5 m x 1.2 m; which can be downsized if required ➤ Equipped with a fluidisation system for building homogeneous sand models at the required density. ➤ Possibility to simulate phreatic flow, confined groundwater flow and effective stress at very large depths. ➤ Several other containers, both for atmospheric pressure and elevated pressure (several bars), are also available.
7. Deltares	<ul style="list-style-type: none"> ▪ Geo-Centrifuge <ul style="list-style-type: none"> ➤ Radius: 5 m ➤ Capacity: 260g-tons ➤ Platform dimensions: 1.2 x 1.2 x 1.8 m ➤ 4D-robot for in-flight tooling ➤ Hydraulic actuators, high resolution (48 MPix) cameras, high speed (2500 fps) video system, pore pressure, total stress, displacement and force transducers ➤ Clay mixing and consolidation facilities <p><u>Examples of the Services currently offered by the infrastructure:</u></p> <ul style="list-style-type: none"> • Embankment stability, Piled embankments, Backward erosion piping, Tunnelling, Jacked Pile Installation, Lateral Pile Loading
8. University of Cambridge	<ul style="list-style-type: none"> ▪ Schofield Center <ul style="list-style-type: none"> ➤ Beam Centrifuge ➤ Radius: 5 m ➤ Capacity: 150g-tonne <p><u>Services currently offered by the infrastructure:</u> Installation of shallow foundations and piles in-flight, subjected simultaneously to axial, cyclic lateral and moment loading, seismic loading of buildings and underground</p>

	<p>structures, mono-pile foundations for wind, energy applications, deep foundations under complex loading, energy activated geo-structures, tunnelling, Rayleigh wave propagation ahead of high-speed trains, and seismic performance of quay walls</p> <p><u>Examples of the recent services offered are listed below:</u></p> <ul style="list-style-type: none"> • Miniaturised Earth pressure balance TBM to capture three-dimensional tunnelling effects on existing structures • Thermoelectric heat pumps to simulate energy activated deep foundations • Transparent laminar box for seismic testing
<p>9. TU Darmstadt</p>	<ul style="list-style-type: none"> ▪ TUDa Geotechnical Test Pit (GTP) <ul style="list-style-type: none"> ➤ Infrastructure for medium- to large-scale model testing of soil-pile interaction ➤ Total dimensions of testing platform: 19.4 m x 5 m (L x W) ➤ Consists of two parts: <ul style="list-style-type: none"> - deep pit with dimensions 5 m x 4.35 m x 6 m (L x W x D) - shallow pit with dimensions 14.5 m x 5 m x 3 m ➤ Mobile walls in the shallow pit can create smaller sections to allow for smaller-scale tests ➤ Steel cylinder 4.3 m in diameter and 3 m deep is also available for wet testing ➤ Vertical and horizontal actuators can transmit static and dynamic force or displacement to the pile/foundation ➤ Only for sand/sandy soils in dry and saturated conditions <p><u>Services currently offered by the infrastructure:</u></p> <p>In the main, high-quality static and dynamic soil-structure analyses of vertically and laterally loaded piles, testing of pile groups, investigation of pile installation effects. However, investigation of other geotechnical problems are possible as well such as testing of new installation techniques, prototype foundation or ground improvement methods, or the behaviour of other geo-structures such as shallow foundations, (reinforced) embankments and buried structures like pipes or cables</p>
<p>10. CEDEX</p>	<ul style="list-style-type: none"> ▪ CEDEX Track Box (CTB) <ul style="list-style-type: none"> ➤ 21 m long, 5 m wide and 4 m deep ➤ testing at 1:1 scale complete railway track sections up to 400 km/h ➤ possibility of performing fatigue tests <p><u>Services currently offered by the infrastructure:</u></p> <p>Analysis of short- and long-term behaviour of the components of railway tracks, determination of the response to innovations to be implemented in railway tracks</p> <p><u>Recent main works performed in CTB:</u></p> <ul style="list-style-type: none"> • Behaviour of High-Speed Lines subjected to mixed traffic (2012) • Optimization of the thickness of the bituminous sub-ballast layer (2013) • Behaviour of a ballasted track fouled with desert sand (2014) • Standard tests on prefabricated slab track (2015) • Analysis of the influence of the embankment on the critical speed (2016) • Determination of Track Lateral Stability (2016) • Innovations in railway track elements in Very High-Speed Lines (up to 400 km/h) (2017) • Tests on new slab tracks for mixed traffic (2018)
<p>11. NGI</p>	<ul style="list-style-type: none"> ▪ Geotest sites (NGTS), consisting of 6 well-documented sites for field experiments <ul style="list-style-type: none"> ➤ soil conditions ranging from soft clay, silt, sand, quick clay to frozen soil (permafrost) and one test site for snow avalanche ➤ detailed characterisation of soil conditions at each site

	<p>➤ variety of permanent monitoring systems in the fields (earth pressure cells, piezometers, thermistor strings, inclinometers, weather station etc.)</p> <p><u>Services currently offered by the infrastructure:</u></p> <p>Various problems can be explored at these test sites include (but are not limited to):</p> <ul style="list-style-type: none"> • Testing and benchmarking of in situ investigation/testing methods and instrumentations (CPTU, sampling methods, nonintrusive tomographical methods...etc) • Field testing of foundation prototypes (monopiles, suction bucket, energy piles...etc) • Field testing of soil-structure interaction (piles, retaining wall ...etc) • Field testing of geotechnical engineering structures (fill, cut, slopes, embankments...) • Field testing of soil stabilisation methods (lime-cement stabilisation, salt injection in quick clay, innovative stabilisation methods and materials, etc) • Experiments for collecting geotechnical parameters to validate constitutive/numerical models (soil-structure interactions...etc) • Full-scale testing of snow avalanches and safety measures (dams, screens)
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8 Appendix 3: Contact details of GEOLAB RI

Table 2 Contact details of GEOLAB RI representatives

Installation	Location	Name of Representative	Telephone	Email
Deltares	Delft, The Netherlands	Suzanne van Eekelen	+31 88 335 7287	Suzanne.vanEekelen@deltares.nl
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U Maribor	Maribor, Slovenia	Stanislav Lenart	+386 31 347 826	stanislav.lenart@zag.si
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