

Adoption of the ‘fall cone’ as the standard method of determining the index parameters and shear strength in South Africa

**Report Progress:
April 2021 – December 2021**



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**Royal Academy
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LETABA LAB
CIVIL ENGINEERING MATERIALS LABORATORY



GEOTECHNICAL CONSULTANCY

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CONTEXT

The project was submitted to and approved by RAEng and the start date was March/April 2021. The funding was transferred to the Central University of Technology (CUT, SA). The memorandum of understanding (MoU) between University of East London (UEL) and CUT (lead university, SA) took eight months to be finalized. The UEL has requested an extension of eight months for their part of the project due to this delay in the agreement. CUT signed the final version of the MoU on 5 November 2021 while UEL signed on 23 November 2021. However, the research activities for the CUT began in April 2021 and continued by Mr SG Waters (full-time Co-I), Prof E Theron and students as submitted in the approved application. This report is a review of the progress during 2021 from April until the end of November.

Site Investigations

As part of WP1, the CUT laboratory is required to identify sites, begin sampling soil samples and assessing trial pits through site investigations. Several site investigations have already been performed by the CUT laboratory with the assistance of both Letaba Lab and GeoCalibre. Some sites ended up having soil types that could not be used for the verification of the fall cone. Please see the attached document for the data and photographs of the sites.



Figure 1 - Site investigations performed by the CUT

CUT Agricultural Farm

On the 19th of January 2021, the CUT laboratory along with GeoCalibre conducted a site investigation at the University's agricultural training farm, located approximately 30km outside Bloemfontein on the R64 road leading to Dealesville. A total of five trial pits were excavated with a TLB (Tractor-Loader-Backhoe). Numerous tests were conducted in the laboratory on the various soil layers obtained from site. Tests include Methylene Blue, Free Swell, Sieve Analysis, Hydrometer tests, Atterberg Limits, Oedometer tests, Tri-axial tests, CBR, disturbed Fall Cone and Undisturbed Fall Cone tests. Shear vane and field penetrometer tests were also conducted on trial pit two and four, on site. Approximately 350 pocket penetrometer readings were taken from two trial pits (TP2 & 4). Vane shear readings could not be taken even with the smallest

blade available. The five undisturbed Fall Cone test obtained from the two trial pits, produced approximately 250 readings.



Figure 2: CUT Agri (-28.948533, 26.35950)

Training and knowledge were shared by the industry partner (GeoCalibre; Mr Coertzen) on site. Practical students gained firsthand experience relating to soil profiling and soil identification. “Geokits” were also delivered and used for the geotechnical investigation. These kits included a geological pick hammer along with necessary stationary, sample bags and cable ties.

Bloemdal

On the 28th of September 2021, the CUT laboratory along with GeoCalibre, conducted a site investigation at Plot 54 Bloemdal, located approximately 10 km outside Bloemfontein on the R706 road leading to Jagersfontein. A total of seven trial pits were excavated with a TLB. Soil profiling was done on all the trial pits by the CUT laboratory and GeoCalibre. Approximately 450 pocket penetrometer readings were taken in total from TP 2,4,6 and 7. A few shear vane readings were done on TP4 only, as the vane shear couldn’t penetration soil layers from the other trial pits where penetrometers readings were conducted. Six undisturbed samples, two each, for the fall cone test

were collected from TP 4, 6 and 7. Undisturbed fall cone testing still needs to be done on these samples in the laboratory. Undisturbed samples for the direct shear test were taken from TP 4,5,6 and 7. The direct shear test results will be compared with the shear strength values obtained from the penetrometer and undisturbed fall cone readings. Practical students gained firsthand experience relating to soil profiling and soil identification. Total project cost amounted to £2 937,32.



Figure 3: Bloemdal Site Map

Somerton

On the 6th of October 2021 a site investigation was conducted in a newly built estate. Three trial pits were excavated by a TLB on three adjacent properties. Soil profiling was done on all three trial pits and in situ field testing was only done on trial pit number two (TP2) since all three the trial pits had the same soil characteristics. Testing was only done on the first layer since this was the only cohesive layer with layer two being weathered dolomite. Approximately 200 penetrometer readings and 15 vane

shear readings were taken on TP2 L1. Six undisturbed samples were taken for the undisturbed fall cone testing in the laboratory. Approximately 140 undisturbed fall cone readings were done on the six samples taken from site. Overall, the site went provided useful information and several students gained firsthand experience in soil profiling and in situ field testing. Dr. Stott is also doing soil suction tests on samples obtained from this site.



Figure 4: Somerton Estate Map

Groenvlei

On the 14th of October two students from the CUT laboratory joined the industry partner, GeoCalibre, on a site investigation. The site is located adjacent to the N1 freeway in the Groenvlei area. A total of 20 trial pits were done laid out over the 20-hectare property. Samples were only taken from two trial pits for laboratory testing for the CUT laboratory. Soil from these two trial pits were the only interesting trial pits considered for sampling, since most of the trial pits were mainly dolomite and

weathered dolomite with trial pit depths rarely exceeding a meter. Testing will be done in the laboratory for both trial pits. Trial pit two (TP2) was the only trial pit with noticeable clay present and an undisturbed sample was taken for tri-axial testing/direct shear testing.

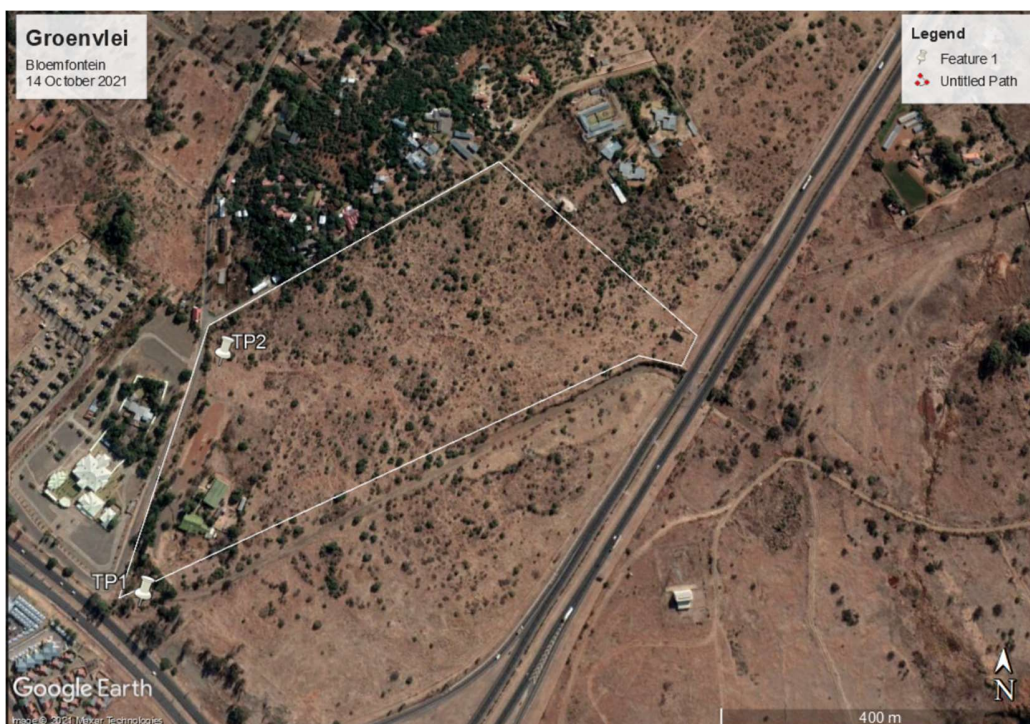


Figure 5: Groenvlei Farm Map

Project goals for the project, as stated in the proposed project, include the following:

- Conduct full-scale proving trials, facilitating extensive translation of the modified fall cone (FC) technology developed through Royal Academy of Engineering IAPP2\100195 TASMIP project – single point test for determination of index parameters for a wide range of clayey soils across the Free State and beyond;
- Deployment of the FC technology – and refinement if needed – for measurement of suction-controlled undrained shear strength clayey soils, within the confines of stochastic and probabilistic models which then avails determination of reliable characteristic strength value, as stipulated in EC7, SANS, and BS EN 1997;
- Verification of method through correlating modified FC outcomes and CU/UU triaxial results to estimate characteristic values from these tests.

Three specific objectives are:

- Verify that the technology (modified FC) holds true for the majority of South African soils
- Presentation of the verified technology and its advantages to the South African geotechnical sector, policymakers and professional bodies for the eventual inclusion in the SANS.
- Streamlined the technology to offer stochastically independent undrained shear strength and index parameters.

Specific outcomes include:

- Fall cone as standard method for determination of index properties of soils in South Africa
- Determination/estimation of the characteristic value as required by the standard code
- Conference proceedings
- Accredited journal papers
- Bachelor and PG degrees
- Workshops
- Community/student engagement

The CUT laboratory has expanded physically and has expanded its workforce. Almost fifteen students have been trained in the laboratory as part of the experiential training for their Diplomas in Civil Engineering. These students have been taught how to properly perform standard geotechnical tests and now assist in the tests that are correlated to the fall cone. An additional student has started full-time training with GeoCalibre where the student is taught specific skills in profiling trial pits which are skills that have already contributed to site investigations performed and will also contribute to the next site investigations. Three research assistants have completed their Advanced Diplomas in Civil Engineering. These students plan to continue to Honours Degrees in 2022 where further research for the project will be done.

Mr de Villier's Master of Engineering in Civil Engineering protocol has also been accepted by the University's Civil Department. The dissertation will evaluate different shear strength testing procedure which will take inherent soil variability into account. The three main testing procedure being evaluated is the Shear Vane, Penetrometer and Undisturbed Fall Cone test. Sampling of soil will be conducted on identified sites which forms part of the RAEng Grant. Mr Waters will finalize his Master of Engineering in Civil Engineering in 2021 and start writing the proposal for his Doctorate in Civil Engineering in the beginning of 2022.



Figure 6 - Students being trained in standard tests

The CUT laboratory itself has seen a lot of improvement in 2021. An additional testing area has been built (with the assistance of the students as part of training). This is shown in the annexure. A shade port was built above the area and a fence around it for security of the equipment. Additional shelves were also added to the storerooms for extra storage of soil samples and equipment.



Figure 7 - Addition of testing area (built by students)



Figure 8 - Completed testing area

Three large bins have also been rebuilt to store aggregates. These bins protect the aggregates from any weathering. Additionally, the logos of all the partners in this project will be added to the bottom section of these bins.



Figure 9 - Aggregate storage bins

More equipment has been bought or contributed that will further assist in testing and site investigations. This was contributed by the CUT. The following has been added to the CUT laboratory:

- Generator
- Non-nuclear density test equipment
- “Geokits” which include all the required equipment needed for extensive site investigations (wrap, foil, geotechnical pick hammers, clipboards, pens, profiling sheets etc.)



Figure 10 - Geokit for site investigations

- Equipment was professionally calibrated (including the CBR machine, auto-compactor, triaxial testing apparatus)
- New sieves and brushes for Sieve analysis
- Methylene blue test consumables
- Mavic 2 Enterprise Advanced Drone (to assist with site investigations)
- Anti-vibration table and balance

The testing for the more advanced tests (such as the CU/UU triaxial and consolidation tests) have been slowly progressing. Unfortunately, small fixes had to be made and this impeded progress and some parts had to be delivered which took several months. The CUT laboratory has become more confident in their advanced testing. Please refer to the attached documentation for examples of completed triaxial and consolidation tests.



Figure 11 - Advanced testing equipment

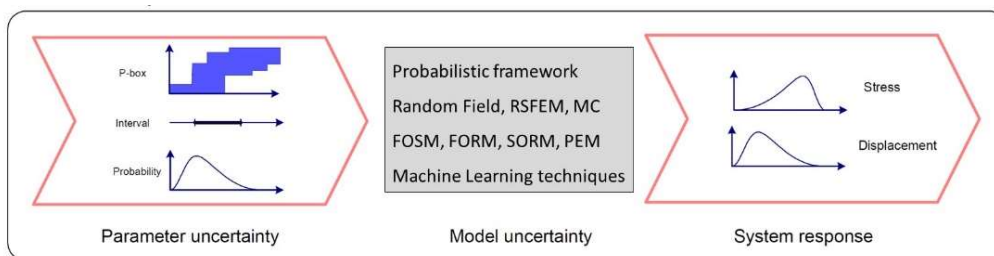
CCWP1:

Deliverable: A prototype proof-of-concept DSS: Spatial variability

Outlines: Serviceability of structures that are built on, with, or into earth is dependent on subsurface geohydrological properties. These have some attendant uncertainty. Deployment of safety factors is an established mitigating approach. The arbitrary nature of these 'factors', however, compromises a quantitative understanding of uncertainty, the analysis of its implications for decisions, and an ability for its effective communication among stakeholders. This CCWP works towards creating and trialling an intelligent 'risk-based decision-making' soft tool drawn from in-house datasets (geochemical and geomechanical) and mathematical idealizations methods. The soft tool - from this CCWP - will introduce a wholly novel way of thinking, that will impact all of disciplines associated with groundworks, and advance cross-disciplinary thinking between them. Importantly, it will help shape the knowledge of how best to interpret test data to avoid unforeseen serviceability problems, and in particular, how to relate data from the in-house modified fall cone to evaluate shear strength in fine-grained soils; feeding directly into urban planning, resource and land management, urban service provision and construction management, and through this, developments in the field of sustainability and resilience, particularly in the context of housing projects across South Africa.

Objectives: The principal objectives here are,

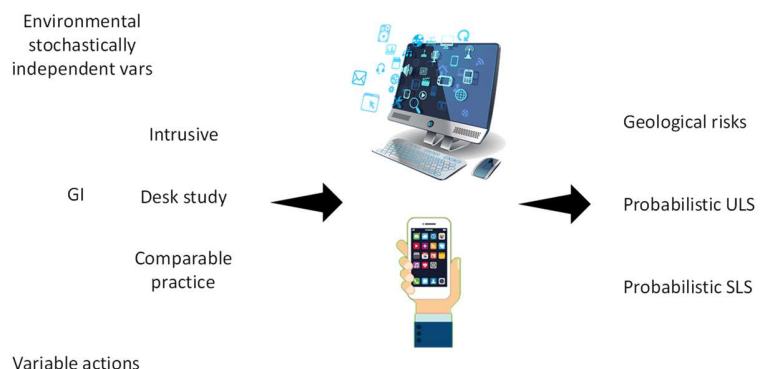
- (1) to establish in practice factors causing spatial and temporal variability of clay soils consistency and undrained shear strength. These factors will be stochastically independent, interdependent, epistemic and aleatory factors.
- (2) To develop an intelligent technology to understand, measure and assess these factors;



This leads to develop a decision-making framework for clays, underpinned by new statistical principles, machine and deep learning techniques, trusted in-house experimental data, software and digital capture, and potentially field monitoring data (for verification and validation). The 'product' from this CCWS allows assessment of essential spatial and temporal clay properties as integral component of informed and intelligent earthworks.

End-byproduct [product on the side]: The

end-byproduct will be a soft tool that (1) receives small and basic index parameters and outputs a quantified value of geological risks – measured by significance & likelihood of occurrence - including compressibility, collapsibility, heave and swelling. It also informs on the value of steady states, including undrained strength at small and large strains; (2) receives big and variable index data and outputs a decision-support system for determining foundation size and embedment (for given foundation type, shape and actions, and varied hydrological



and geological conditions), displacements of engineered fills and embankments (for given geometry, and varied hydrological and geological conditions); (3) receives index data and outputs a probabilistic-based serviceability for a select number of conventional support of excavation systems (dry or submerged). The team in UEL comprise Dr Arya Assadi-Langroudi Geotechnics, Dr Bamdad Ayati Geochemistry, Dr Fahimeh Jafari AI & Machine Learning.

WP2:

Within the first activity, four sites are identified across Kent, including Cliffsend, Pegwell Bay, Ramsgate, and Reculver. A fifth site is identified in Seaford, Sussex. Soil is a particular air-fall low-plasticity loamy soils, in places calcareous, generally loose, porous and water-sensitive. Sampling is planned during early Spring to benefit from daylight. Sampling will be done through U100 and window sampling. The lengthy agreement between CUT and UEL has been a barrier against the start of sampling activities and an extension request is put in place to compensate.



WP3:

Workshop materials have been under development over the months past, and AAL from UEL is offering series of virtual training, between February and April 2022, covering areas including but not limited to

- Risk Assessment & Management:
- Screening & Scoping
- Baseline studies

Spatial variability and Probabilistic-based mitigation

Work is underway for a workshop and panel discussion organised in September 2022, in Kyrenia, North Cyprus. Emphasis will be put in ‘refined testing regimes’ for clays, in particular South Africa clays, of high plasticity and variability. The workshop will be conveyed in partnership with the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), IMO Chamber of Civil Engineers, Middle East Technical University (METU), and University of East London (UEL). The workshop is planned for 17-September-2021 in the Acapulco Resort Convention SPA Hotel.

Dissertation (Mr de Villiers)

Evaluation of different soil shear strength testing procedures taking inherent soil variability into account (See attached accepted protocol “LS 262a review_de Villiers_Civil”)

The research project aims to evaluate shear strength testing procedure which seeks to take inherent soil variability into account.

Geotechnical designs are founded on two main design approaches. The Work Load Design (WLD) approach and the Limit States Design (LSD) approach. The WLD method does not take variability into account and only requires a representative value from soil samples. Eurocode 7 (LSD) accounts for variability by selecting a characteristic value that largely accepts a confidence level of 95% reliability. Both concepts rely on the same conventional field and laboratory tests to obtain various soil parameters for design calculations. The shear strength being one of the more variable parameters due to soil variability caused by geological and environmental processes.

Variability is best addresses by probability density functions and statistical methods. Three testing methods, based on previous research done at the CUT laboratory, are suggested to assess and obtain a reliable shear strength probability density function in a more economical and less time dependable way. These tests will be utilized to measure actual variability observed from soil samples. This will lead to an improved way of measuring soil shear strength and ultimately to more precise and safer designs of geotechnical structures.

South Africa is currently in the procedure to adopt the Eurocode (7) standards for the South African context/environment in the geotechnical field. The research dissertation will highlight the importance of obtaining a large dataset of shear strength readings for input of the Eurocode 7's design method. The three testing methods used for the research project is the pocket penetrometer, vane shear and undisturbed fall

cone. These tests are cheap and readily available and can obtain a large dataset of readings. South Africa is a developing country with largescale low-cost housing developments across the country and can this not rely on traditional shear strength procedures (Direct shear and triaxial test) which are very expensive and time consuming for low-cost housing projects. Therefore, it is important to evaluate cheaper alternative testing methods which is aligned with the new testing standards and procedures (Eurocodes) soon to be implemented in South Africa.

The protocol was accepted by FRIC on the 25th of June 2021. The student is busy with the completion of Chapter 1 and made progress with the literature review. Numerous site visits were conducted, and data was obtained from the above-mentioned site investigations. The student is currently busy with analyzing the data/readings with his co-supervisor.

Proposed Budget

The proposed budget is the following:

CUT Staff: (time as a % of full project duration of 24 months) PI Prof Theron (20%) PI whole project, co-lead WP1,3 and CCWP2 and Mr. S. Waters (2 years 100%);

CUT Resources: Training programme (UG and PG students – capability and capacity building) at £15,000 for project duration (including all linked expenses – all directly incurred) – paired with £7,200 match funding, Stakeholder Workshops (£150 venue hire/£150 catering each/£100 dissemination materials)=£800, Networking at relevant SA scientific/technical meetings and consultations with project partners (£1000/pa for years 2)=£2000 (of which £1000 is match funded), International conference for PI (1*(£1000+5days*120£+£300 registration)=£1,150 (ditto for 1 Co-I but match-funded), Lab Tests & Consumables: geotechnical testing, Tools; Test vessels;

Consumables = £1,000 (+ditto match funded), General field works (site fees, power and water supplies, Harris fencing, excavator and operator hire, window sampling rig for UD sampling, etc.) & Field kit (bags pegs etc.) = £4,000, Shear testing, triaxial maintenance & transducers incl. software, consumables, etc. = £5,000 (paired with match funding totally £13,000), shear rings, FC cups, troughs, moisture tins, weights, riffler pans, balances, suction kit = £2,500 (paired with £1,500 match funding).

UEL Staff: (time as a % of full project duration of 24 months) Co-I Dr Langroudi (10.67%) lead WP2 and CCWP1 and inputting into EP days and WP3. Rapid suction measurement (Environmental chamber updating, maintenance and consumables) = £3,000, General molecular & geochemical soft analysis tools = £3,500, Triaxial testing instrumentation (transducers, bender elements, etc.) = £2,000, 8% - 1.5 months on project - Hiring technicians and support test operators at Grade D (6 weeks * 3 hrs * £25) = £399.82, International conference for Co-I (1*(£1000+5days*120£+£300 registration) and travel and subsidence against field = £2,300, Estate costs (fully match funded at £4,190.56)

Current Accumulated Expenses

Expenses Incurred (April 2021 to November 2021) – Please refer to attached document “IAPP_Expenditure Statement_November_2021”.

Funder Total Contribution for project = £ 79 551.84

Funding of the amount of £71596.66, has been paid from Royal Academy of Engineering (RAEng) to the CUT on the 29th of March 2021

The following expenses were incurred (from funder contribution):

UEL:

The University of East London have not received their part of the contribution yet, due to the delay in finalisation of the MoU but will receive £15,921.47 as their initial contribution.

CUT:

In kind contribution:

Prof Theron	= £4 000.00
Dr Stott (Mentoring / Supervision)	= £2 666.67
Mr Coertzen (GeoCalibre / student training)	= £823.22
Letaba Lab (duplicate testing)	= £444.44

Total expenditure (April 2018 – December 2019): = £19 792.58

Training and hiring of UG students = £7 664.31

General field works = £2 937.32

Mr SG Waters (FT Researcher), from April 2021 to October 2021 = £9 190.95.

REQUESTED EXTENSION

21

Due to the eight-month delay of the finalisation of the MoU between the CUT (Lead University) and UEL (UK partner University), the UEL has not been able to progress in the project. For this reason, it is requested that the duration of the project is extended by eight months so that the project can be completed by 1 December 2023.

A proposed new work plan has been attached for the extension of the project. CCWP1 and WP2 have both been adjusted by eight months for the UEL (UK Partner University). CCWP2, WP1 and WP3 have seen minor adjustments or extensions to fit the new extension. The dates for meetings have also been rescheduled to suit the adjusted dates.

The partners have agreed to meet before the end of 2021 to discuss the next steps in 2022. The project, if extended as requested, will be on schedule until the 1 December 2022. Several groups in the engineering community have been engaged and the CUT has several new promising sites throughout South Africa that will contribute to the project for 2022.

SUPPORTING DOCUMENTS

- IAPP_Expenditure Statement_November_2021
- LS 262a review_de Villiers_Civil
- Proposed Work Plan - Adoption of the 'fall cone' as the Standard Method of determining the Index Parameters in South Africa (TASMIP)
- R102615 Collab Agreement & Schedules (Executed)
- Example Consolidation Test Results
- Example Direct Shear Test Results

ANNEXURES

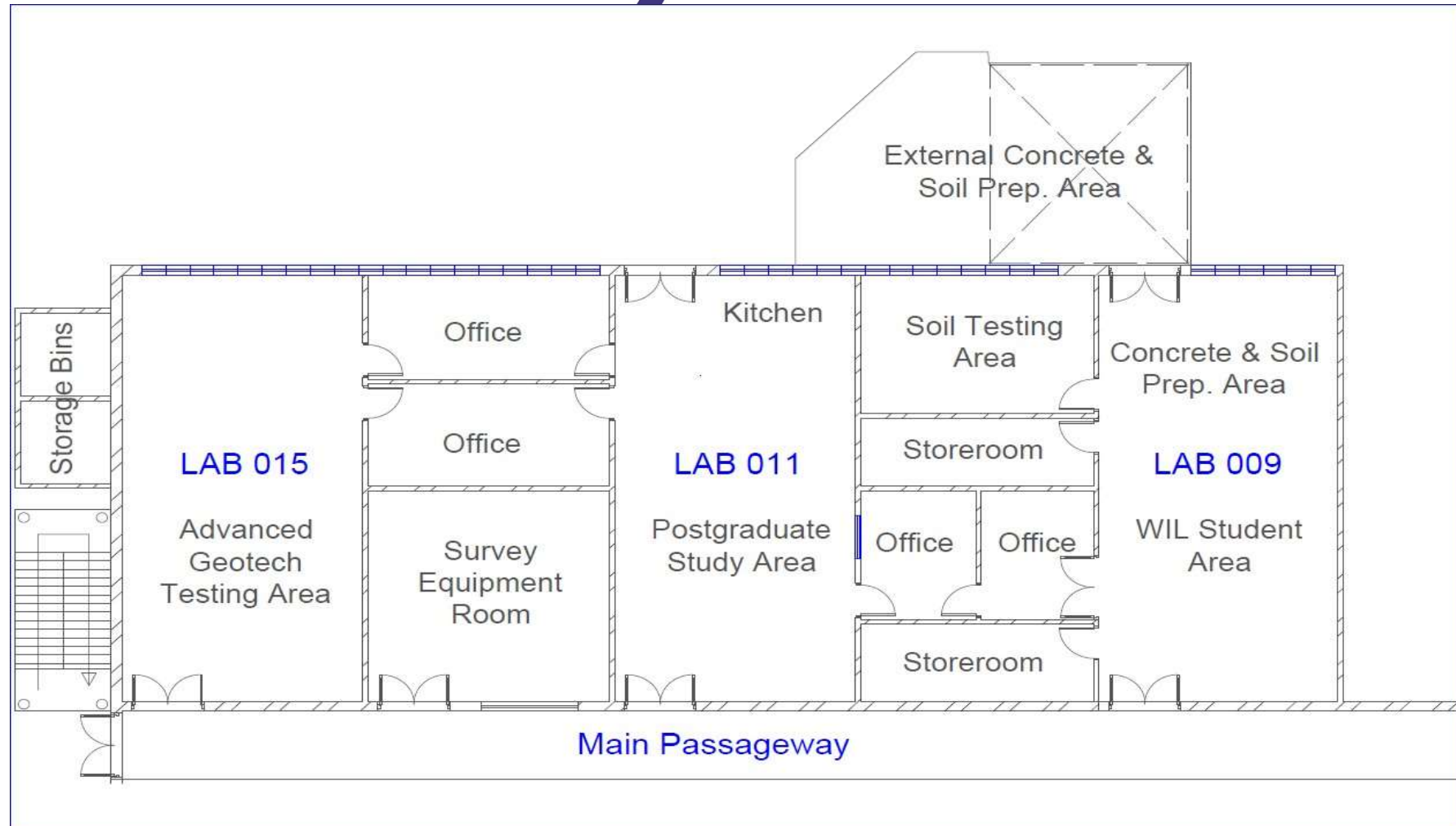


Figure 12 - Layout of CUT Laboratory