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ORIGINAL PAPER

# Field tests for the identification of silts

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**Abstract**
Accurately identifying soil texture and understanding soil behaviour in terms of plasticity is a crucial initial step in properly characterizing a site, which in turn facilitates appropriate sampling and scheduling of laboratory tests. Soil identification techniques in literature are effective at assessing pure clays and silt–clay mixtures. This paper presents a comparative study between field tests, soil plasticity classifications, Atterberg limits, mineralogical and chemical data, SEM imagery, and stereographical microscopy. Natural residual soils comprising varying quantities of clays, silts, and sands were used and subjected to the same field and laboratory protocols. The findings of this study demonstrate that a series of field tests can effectively characterize and classify soils ranging from coarse soils to fine soils exhibiting non- to highly plastic indices with particle sizes less than 2.00 mm. By employing a single list of field tests that only necessitate water and commonly available stationery materials on-site, the researchers have presented a valuable tool for on-site determination of soil texture and inference of the Unified Soil Classification System (USCS). This approach streamlines the process and provides professionals with an efficient means of assessing soil properties and determining problem soils at an early stage of the investigation and during construction of high fills.

**Keywords** Plasticity · Soil texture · Cohesive soils · Soil identification · Unified Soil Classification System · Residual soils · Engineering geology

## Introduction

Understanding soil behaviour is of paramount importance in any geotechnical investigation as it forms the foundation of all subsequent geotechnical models. Soil, being a complex and variable material, exhibits unique characteristics that directly impact the stability and performance of structures. Furthermore, soil does not allow itself to be easily classified into a material type based on one parameter or test result, both on-site and in the laboratory. Many authors discussed the difficulties in determining the silt and clay percentages using the hydrometer method (e.g. Savage 2007; Stott and Theron 2016; Moreno-Maroto and Alonso-Azcárate 2022).

There is usually high confidence in the mechanical sieving to determine the gravel and sand percentages of a sample. However, when sampling residual soil with relict rock structure and weathered rock fragments present, the final sieving analysis results are dependent on the energy applied and methodology used during the sample preparation (Rabot et al. 2018).

Due to the doubts in the particle size analysis, especially the fine-grained portion, authors have proposed to class soils based on their plastic behaviour, mineralogy and the grading, rather than the quantities of individual grain sizes only (Guggenheim and Martin 1995; Moreno-Maroto and Alonso-Azcárate 2018, 2022). This behaviour is based on the Atterberg limits which empirically define changes in material characteristics due to variation in water content. One of the most widely used methods to classify soil into groups based on their expected engineering properties is the Unified Soil Classification System (USCS). This system classes soils based on the grading characteristics, liquid limit (LL), and plasticity index (PI) (ASTM D2487–17ε1 2020).

Stott and Theron (2015) discussed the uncertainties and operator biases of testing the liquid limit and plasticity limit using the Casagrande apparatus method and thread rolling method, respectively. The SANS 3001-GR10 (2013a, b), GR11 (2013c) and GR12 (2013d) documents provide

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three methods to determine the Atterberg limits, namely the one-point method, two-point method and three-point flow curve method, respectively. Stott and Theron (2015) stated there is ambiguity in who is responsible to decide the correct method, be it the commercial laboratory or the geotechnical engineer managing the project. Usually, both these parties are financially restrained on geotechnical investigation projects and the most cost-effective method is used, even if it is not the appropriate one.

Being able to confidently determine soil plasticity and assess the grading using field identification techniques allows engineers to anticipate and mitigate potential geotechnical hazards early on, and during construction of large fills where a variety of material sources are used. Liang et al. (2022) found a primary cause for high fill settlement is the lack of effectively controlling and selecting appropriate filling material from multiple sources, causing zones of soil with unfavourable grading and plastic behaviour to be placed in the earthworks. The Committee of Transport (COTO) (2020) defines and states the requirements for fill layers to be used in earthworks in South Africa.

Normal fill is made up of sand, gravel, and cobbles, and may include only inactive clay and silt. Identifying potential problem soils while conducting on-site investigations and construction audits provides a significant advantage to the project team. This proactive approach allows for more accurate determination of individual soil horizons, correct targeting of the most critical soil materials and scheduling the correct geotechnical laboratory tests. Consequently, a thorough understanding of soil behaviour and the ability to identify problematic soils on-site are crucial for successful geotechnical investigations. Additionally, the results of the laboratory testing can be compared to the results of the on-site field, which reduces the dependence and checks for any major errors of the hydrometer, mechanical sieving, and Atterberg limit testing done in the laboratory.

Salley et al. (2018) showed that only 66% of professional soil scientists in USA and Namibia can accurately determine soil texture by feel using a single ribbon technique as described by Thien (1979). The components of a fine-grained soil (fine sand, and silt) and the plasticity and quantity of clay material can be determined when using a series of field tests as described by Burmister (1949), Hunt (2005) and Norbury (2020), and as stated in ASTM D2488-09a (2009). The limiting constraint of the existing field tests is in the preparation steps of the sample, where the medium sand and coarser (> 0.425 mm grain size) particles need to be removed before conducting the tests. This preparation step cannot be practically done on-site as most natural soils, especially residual soils, comprise varying quantities of clay, silt, and fine to coarse sand. The recommended identification tests listed by Burmister (1949), Hunt (2005), and Norbury (2020) are comprehensive and well described. However, from the years of field experience of the authors, a full suite of tests is needed to confidently distinguish between a range of soil types which may occur on the same site. From inorganic, highly plastic, pure, clays to non-plastic, medium sands, and especially be able to identify inorganic, non-plastic to plastic, silts.

The field tests are based on well understood characteristics and behaviours of a pure clay, silt, and fine to medium sand. Significant plasticity is a principal characteristic of clay that separates them from silt. Pure clays within the plasticity index are able to deform without cracking or crumbling and hold onto water through adsorption and capillary tension. Silts are able to possess very slight plastic behaviour but deform and typically dilate during deformation (Paniagua et al. 2013) and only typical hold onto water through capillary tension. Sand possesses no plastic behaviour and cannot hold onto water when grading as a medium sand.

The research aims to determine if currently accepted field identification techniques can be used to assess the expected engineering behaviour and soil texture of naturally occurring soils that contain particle sizes up to approximately 2.00 mm. The hope is to draw up a methodology of tests that can be used during any geotechnical site investigation where a wide range of soils are encountered, namely clays, silts, and fine- to medium-sands. Furthermore, the tests can be conducted with only the use of hands, typical stationary taken with to site and small quantities of water, therefore keeping costs low and no need for extra equipment. The tests are also to be done in a reasonably amount of time, which is usually limited on site.

## Methods and materials

Samples were taken in areas where the regional geology and climatic conditions are expected to form thick, generally fine-grained, residuum. Existing road cuttings allowed for easy sampling of residual material from the Magoebaskloof-Tzaneen and Dullstroom-Mashishing areas. The residuum retrieved formed from parent rock of the Goudplaats Gneiss and Turfloop Granites (Robb et al. 2006) in Magoebaskloof-Tzaneen area and from the andesitic to dacitic lavas of the Dullstroom Formation, found in the lower Rooiberg Group (Buchanan 2006). Both these sample sites fall within a moisture-surplus climatic area where chemical decomposition dominates along the eastern escarpment of South Africa (Weinert 1980).

The degree of desiccation and pedogenic alternation of the residual soil at each road cutting varied widely. All soil samples were air-dried and mechanically broken down by hand to remove any weak interparticle cementation and soil structure. This was done to reduce the influence of the varying states that the samples may have on the results of the field testing and laboratory testing by normalising the state of disturbance and alternation of the sample, and to ensure minimal energy is required by the laboratory to break down the samples during the preparation steps as stated in the relevant standards. Furthermore, this initial preparation step allows any meta-stable minerals in the residuum to oxidize and weather to more stable minerals more commonly found in surface soils.

The Atterberg limits and soil grading were measured according to the testing procedure outlined in the SANS 3001 series. Due to the uncertainties of the hydrometer test, these results were supplemented with the visual inspection of the soil grains using a stereomicroscope and a scanning electron microscope (SEM).

Additional to the visual inspection, the chemical and mineralogical compositions of the soil were investigated. Residual soils comprise clay and silt size particles that may have active mineral surfaces. These minerals can have an influence of the plasticity of the soil mass. X-ray fluorescence spectroscopy (XRF) was used to determine elemental compositions of the soil. X-ray diffraction (XRD) analyses were undertaken to provide information on the unit cell dimensions of the crystalline material in the soil. This data was then used to determine the mineralogical compositions of the sampled material.

## Laboratory tests

### XRF and XRD

The samples from each locality were oven dried and mechanical milled down into a fine powder in the laboratory at the University of Pretoria.

The XRF samples were analysed using the Thermo Fischer ARL Perform'X Sequential and Uniquant software.

The XRD samples were prepared according to the standardized Panalytical backloading system, which provides nearly random distribution of the particles. The samples were analysed using a PANalytical X'Pert Pro powder diffractometer in θ–θ configuration with an X'Celerator detector and variable divergence- and fixed receiving slits with Fe filtered Co-Kα radiation ($\lambda = 1.789$ Å). The phases were identified using X'Pert Highscore plus software. The relative phase amounts (weight%) were estimated using the Rietveld (1969) method.

### Stereomicroscope

A stereomicroscope is an optical microscope (model: Zeiss Stereo Discovery V20) designed for low magnification for observation of a sample's inter-particle relation and shape and size of grains, using reflected light from the surface. The samples were analysed at various magnifications and photographs of the most representative sections of the samples were taken.

### SEM

The soil grains of disturbed samples were observed using a Zeiss Gemini SEM under different magnifications best suited for the material. The SEM scans the material surface with the use of a focused beam of electrons, producing an image revealing the surface topography. Investigating the microscopic structure of the soil grain may build an understanding of the sample grading and typical minerals present.

### Particle size analysis and Atterberg limits

The samples underwent particle size analysis according to SANS 3001-GR10 (2013a). The Atterberg limits testing was conducted using the one-point method as stated in SANS 3001-GR10 2013a, b). In this standard, the LL and plasticity limit (PL) are determined using the Casagrande cup and the thread rolling method, respectively. The Atterberg limits testing was duplicated to ensure accurate readings were achieved. The laboratory Unified Soil Classification System (USCS) description was determined as stated in the ASTM D2487–17ε1 (2020).

## Field tests

In response to the discussed limitations of standardised laboratory testing and the authors' extensive field experience in geotechnical investigations, a series of field tests have been created and modified based on the existing recommended tests from Burmister (1949), Hunt (2005) and Norbury (2020). Developed over time, these new and modified tests are a result of the authors' first-hand knowledge and observations in the field. By continually refining and expanding the range of field tests, the authors have sought to enhance the accuracy and comprehensiveness of geotechnical soil identification and profile logging.

Each recommended test is listed in the subsections below. Each subsection explains the test methodology, typical features to look for during preparation, testing and analysing of results as well as the range of description criteria. The result of each test is determined by comparing the sample's response to the criteria listed, and the best fitting description is chosen. The description is then compared to the possible outcomes listed in the identification table presented in this paper. The column with the most results corresponding with the sample's response to each test, is the field test soil texture and inferred USCS.

For this research, all the field tests were conducted by one of the authors, which will be referred to as the operator hereinafter, and in one location to reduce the chance of operator and environmental bias in the results.

### Preparation of the sample

The operator selected a cup-size, representative, sample of the defined horizon in the profile. From this sample, particles and aggregates greater than 2.00 mm (i.e. fine to coarse gravel) was removed as best as possible. Once completed, the sample was wetted and knead to destroy any soil structure and to breakdown the material into individual grains as much as possible. This was done until a palm-full amount of the selected material was ready to be tested.

### Ball forming test

From the prepared sample, a 30-mm diameter ball was formed by hand. Water was added or removed, through evaporation by kneading ball, as necessary to achieve a soil consistency that formed a wet ball with a shiny surface. The colour of the sample was recorded in the moist state when no secondary colour (mottles, blotches, or streaks) that would have altered the primary colour when mixed together. The difficulty or ease of wetting, forming, and handling of the ball was noted by the operator as described in Table 1.

When no ball could be formed due to the grains being too coarse, the material was described as medium to coarse sand.

### Shaking and dilatancy test

Once the ball was formed, one hand was dried and cleaned as much as possible, and the ball was placed in the palm of the clean hand. The ball was vigorously shaken in a horizontal direction by tapping the side of the hand with the open palm of the other hand. The resultant shape of the ball, and the movement of water to the surface of the soil and into the palm of the operator's hand beneath the ball, was noted. The ball was then squeezed or pinched between a finger and thumb before making note the speed at which the water moves back into the soil. The typical results are described in Table 2.

### Ball pickup/drop test

The test was used to determine the behaviour of soils with a minor to major sand component and soils that were described as 'weak ball' and 'rapid' in Tables 1 and 2, respectively. A few of the samples needed additional water to reform a ball after the shaking and dilatancy test. Once the ball was formed at the correct consistency, the ball was picked up using only an index finger and thumb on either side of the ball. The ball was picked up to a height of 10 cm above the palm and dropped onto a stretched out, firm, open hand. The ball was picked up again by placing the index finger and thumb in the same position as before, picked up and dropped from the same height. The process was repeated two more times, when possible, with the index finger and

**Table 1** Criteria for describing ball forming test

| Description | Criteria |
|---|---|
| No ball | If no ball can form, the material may comprise high amounts of medium to coarse sand. The sample may be described as SW, SP and no other tests are needed |
| Weak ball | No apparent cohesion when sample is dry to slightly moist. Water drains out rapidly when added to soil, washing out soil particles. Weak ball formed with difficulty |
| Soft ball | No apparent cohesion when dry. Water drains out initially when soil is very dry, but fairly maintains moisture when ball is formed and handled at correct consistency. Some time and water are needed to reach the correct consistency and shiny surface from a dry state. Ball easily handled and moulded at correct moisture content |
| Cohesive ball | Cohesion causes material to be firm to stiff when dry. Considerably time and water are needed reach the correct consistency and shiny surface to mould material into ball from a dry state. Soil maintains moisture when handling ball. Ball easily handled and moulded at a wide range of moisture contents |

**Table 2** Criteria for describing shaking and dilatancy test

| Description | Criteria |
|---|---|
| None | Ball maintains shape during shaking and no visible movement of water during shaking and squeezing |
| Slow | Ball slightly flattens during shaking with water appearing slowly at surface. Some moisture gathers between palm and ball. Water slowly drains into sample when squeezed |
| Rapid | Ball deforms due to liquefaction during shaking and water rapidly appears on surface and in palm of hand. Water rapidly disappears from surface when squeezed |

**Table 3** Criteria for describing ball pickup/drop test

| Description | Criteria |
|---|---|
| Sand | – Ball cannot be picked up between index finger and thumb without crushing<br>– Medium to fine sand forms weak ball with difficulty<br>– Medium sand and coarser cannot form a ball |
| Silty sand | – Ball picked up with difficulty. Ball cannot be picked up between index finger and thumb without crushing after first or second drop (~20% silt)<br>– Ball readily picked up. Only breaks between finger and thumb after few (~3) drops (35–50% silt) |
| Sandy silt | – Ball readily picked up between index finger and thumb even after 3 or more drops, though cracks may form |

**Table 4** Descriptive criteria for thread pickup test

| Description | Criteria |
|---|---|
| Non-plastic | – 5-mm thread cannot be picked up |
| Slight | – 5-mm thread can be picked up with much difficulty |
| Low to medium | – 5-mm thread can be picked up readily<br>– 3-mm thread can be picked up with much difficulty |
| Medium to high | – 3-mm thread can be picked up readily |

thumb in the same position. The results were described in accordance with the criteria presented in Table 3.

## Thread pickup test

Once the first two to three tests were completed a quarter of the existing soil ball was broken off with the rest of the ball set aside. The broken off piece was used to roll the material into a thread. The material was rolled on an open palm, starting at the one end moving along the tread, letting the bigger side break off as the thread got thinner. Water was added or removed, through evaporation by kneading the soil, to achieve the plastic limit water content. Once the thread was rolled to 5.00-mm diameter and 50.0 mm in length, and making sure the thread was not crumbling, the thread was gently picked up on one side (approximately 10.0 to 20.0 mm from one end). The difficulty in picking up the 5.00-mm thread without breaking was noted. If the 5.00-mm diameter thread did not break, the thread was rolled to a 3.00-mm diameter thickness. The thread pickup test was repeated on the 3.00-mm diameter thread. The descriptive criteria for the thread pickup test are presented in Table 4.

## Plasticity test

The plasticity test was done immediately after the thread pickup test. The thread rolled in the previous test was rolled and worked until the thinnest thread possible was rolled at the soil's plastic limit water content. Kneading and working the material dried out the soil through evaporation. Once the thinnest possible thread was formed, the diameter was recorded, and the material was remould into a lump or small ball. When possible, the lump was rerolled into a thread, without adding water, to assess the plasticity. The plasticity of the sample was described using the criteria presented in Table 5.

## Toughness

The toughness test was based on the pressure required to mould the material during the plasticity test. The pressure required to roll the thread and kneaded the material near the plastic limit was recorded. Also, the strength needed from strong fingers to flatten and spread the thread was noted. After the thread crumbled at moisture content less than the plastic limit, the pieces were lumped together and kneaded until the lump crumbled as well. The pressure required to knead lump at the moisture content lower than the plastic limit was observed. The descriptive criterion to assess the toughness is presented in Table 6.

**Table 5** Criteria for describing plasticity

| Description | Criteria |
|---|---|
| Non-plastic | A thread thinner than 3 mm cannot be rolled at any moisture content. A 4–5 mm can be rolled with difficulty |
| Low | A 3-mm thread can be rolled difficulty when at plastic limit. Material crumbles when lump is formed from thread drier than plastic limit |
| Medium | A 3-mm thread is easily rolled, and a 2-mm thread can be rolled with difficulty. Lump can be formed from thread, but thread cannot be rerolled when drier than plastic limit |
| High | A thread smaller than 2 mm can easily be rolled. Material can be kneaded into lump and rerolled when soil is drier than plastic limit |

**Table 6** Criteria for describing toughness

| Description | Criteria |
|---|---|
| Low | Very slight pressure needed to roll and knead material near plastic limit. The thread is weak and lumps soft |
| Medium | Medium pressure is required to roll and knead material near plastic limit. Lumps are soft to firm and some pressure is needed to flatten thread |
| High | Strong pressure is needed to roll and knead material near plastic limit. Lumps and thread are firm to stiff when material is near plastic limit |

## Dry strength

The material left over from the original ball, before the thread pickup test had been conducted, was moulded into a cube (length–width–height: 15.0 mm × 15.0 mm × 20.0 mm) with smooth surfaces. This cube was placed in the sun to dry out. The speed at which the sample dried out was dependent on the soil type and surrounding environment. These parameters were considered when deciding when the cube had 'dried out'. The 'dried out' cube did not feel moist or cool to touch, and there was a noticeable colour difference, usually paler, to the moist ball colour. Once the operator was sure the material had dried out, the operator picked up the cube and applied a vertical compressive pressure by holding the cube between finger and thumb. If the cube did not break between a strong finger and thumb, the cube was placed on a hard, flat, surface and a vertical pressure vertically downwards was applied with a strong thumb. The descriptive criteria for the dry strength test are presented in Table 7.

## Feel

The feel of the soil was mainly assessed during the sampling and handling of the material. It is recommended that the feel for grittiness on teeth to distinguish silt from clay should not be done. The influence of anthropogenic contamination in soil and the potential hazard to human exposure is not well understood. The grittiness was assessed using a knife and spatula, both of which worked well.

The following feel was noted for each major soil type:

- Sand was gritty and rough, much like sandpaper. When dry, a pinch of the soil was rubbed between a finger and thumb. The fine sand and silt fell out as coarser material separated the finger and thumb. A knife running through the soil made a gritty sound.
- Silt felt silky and soft when dry and wet. A 'fat' silt felt slightly sticky when wet. A knife running through a moist ball of silt sounded slightly gritty, and the cut face was smooth and dull.
- Clay felt smooth and sticky when wet. A knife running through the material gives off no sound, and the cut face was smooth with a slightly shiny to shiny surface as plasticity increased.

The feel test had a range of results between the sand, silt and clay responses listed. The most relevant response can be assessed in Table 8.

## Behaviour in air

The way clay, silt, and sand dried out differed due the presence of intermolecular forces in clay, and relatively higher surface area of silt compared to the typically inert sand grains. When the selected sample material was initially wetted up and formed into a ball, considerable amount of the wet soil was smeared on the back of one hand. The operator let the material dry out while going through the various tests. Once the soil was dry, the time taken for the material to dry out was noted as well as the following:

**Table 7** Criteria for describing dry strength

| Description | Criteria |
|---|---|
| None | The cube breaks down into powder during handling or very slight pressure |
| Very low | The cube rapidly breaks down into powder with slight pressure between fingers |
| Low | The cube crumbles or breaks down to powder with slight to moderate finger pressure |
| Medium | The cube breaks into pieces with moderate finger pressure |
| High | The cube cannot be broken between fingers. Specimen will break into pieces between a strong thumb and a hard surface |
| Very high | The dry specimen cannot be broken between a strong thumb and a hard surface |

**Table 8** Identification table for inorganic, fine to coarse grained, soils from field tests

| Inferred USCS class | CH | CL, MH, CL-ML | MH, ML, CL-ML | ML | SC, CL | ML | SC, SW-SC, SP-SC | SM, SW-SM, SP-SM | SW, SP |
|---|---|---|---|---|---|---|---|---|---|
| Texture | Clay | Silty clay | Clayey silt | Silt | Sandy clay | Sandy clay | Clayey silt | Silty sand | Sand |
| Test | Soil response | | | | | | | | |
| Dilatancy | None | None to slow | Slow | Slow to rapid | Slow to none | Rapid, weak ball formed with some difficulty | Slow to rapid | Rapid, weak ball formed with difficulty | Rapid or material to coarse for test. Weak ball formed with difficulty |
| Ball pickup/drop | - | - | - | - | Readily picked up between finger and thumb | Readily picked up between finger and thumb (breaks after more than 3 drops) | Readily picked up between finger and thumb | Picked up with difficulty, breaks when picked up after drop (~ 20% silt). Picked up readily after few (~ 3) drops (30–50% silt) | Medium to fine sand forms weak ball. Cannot be picked up. Medium sand only cannot form ball |
| Thread pickup | Readily picked up at < 3 mm diameter | Readily picked up at 5 mm diameter to picked up with difficulty at 3 mm | Readily picked up at 5 mm diameter to picked up with difficulty at 3 mm | Picked up with difficulty or cannot be picked up at 5 mm` | Readily picked up at 5 mm | Breaks, cannot be picked up at 5 mm | Picked up with difficulty or cannot be picked up at 5 mm | Only thread > 5 mm can form. Breaks, cannot be picked up | - |
| Plasticity | High | Medium | Low | Non-plastic | Low to medium | Non-plastic | Low to non-plastic | Non-plastic | - |
| Toughness | High | Medium | Low to medium | Low or thread cannot be formed | Medium | Very low | Low or thread cannot be formed | Very low or thread cannot form | - |
| Dry strength | High | Medium | Low to medium | None to low | Low to high | None to very low | None to low | None to very low | - |
| Feel | Smooth, sticky (when wet) | Smooth and slightly sticky; possible chance of slight gritty sound | Silky to smooth, sounds slightly gritty | Silky, sounds gritty | Smooth with slight "sand paper feel", slightly gritty | Smooth with slight "sand paper feel", slightly gritty | Smooth to silky with gritty feel | Gritty, sandy | - |
| Behaviour in air | Dries slowly with shrinkage | Dries slowly with shrinkage | Dries quickly, brushes off | Dries quickly, brushes off | Dries slowly with shrinkage | Dries quickly, brushes off | Dries quickly, brushes off | Dries rapidly, brushes off | |
| Cohesion | Deforms without rapture | Deforms without rapture. Maintains shape during handling | Rupture | Rupture. Difficult to shape when very dry | Deforms, rapture possible. Maintains shape during handling | Rupture. Difficult to shape when very dry | Rupture. Difficult to shape when very dry | Rupture. Difficult to shape when very dry | - |

**Table 8** (continued)

| Inferred USCS class | CH | CL, MH, CL-ML | MH, ML, CL-ML | ML | SC, CL | ML | SC, SW-SC, SP-SC | SM, SW-SM, SP-SM | SW, SP |
|---|---|---|---|---|---|---|---|---|---|
| Drain test | Maintains moisture during handling. No moisture front | Maintains moisture during handling. Very small moisture front | Moisture drains slightly during handling. Small moisture front | Moisture drains readily during handle. Moderate moisture front | Maintains moisture during handling, small moisture front possible | Moisture drains quickly during handling. Moderate to large moisture front | Moisture drains slightly during handling. Small moisture front | Moisture drains rapidly. Large water front | - |

- Sand dried out rapidly with the coarser material falling of the hand while the operator worked through the tests. The dried soil brushed off easily with no staining left behind.
- Silt dried out quickly, within a few minutes, with most of the material remaining on the hand. The dry silt was brushed off easily leaving hand clean. Some silt remained in the wrinkles and some staining was left on hand. It is believed the staining and settling into wrinkles depends on chemical constituents of the silt as an inert silt particle brushes off easily, like a sand.
- Clay dried out slowly with obvious shrinkage cracks formed. Some clay brushed off, but most of the soil did not brush off easily. The clay particles settled into pores of the skin and were only washed off by rubbing hands under running water. Pieces of clay stuck to hairs on the hand.

The behaviour in air test had a range of results between the sand, silt and clay responses listed. The most relevant response can be assessed in Table 8.

## Cohesion

The cohesion of the soil was assessed during the handling of the soil during the previously mentioned tests. Generally, more water was needed in coarse soils to keep soils at the correct consistency to perform the shaking and dilatancy, plasticity and toughness tests. The coarser the soil, the more difficult it was to keep soil together in a dry to slightly moist state. Sand required apparent cohesion from the presence of water to stay together, where clay generally had its own cohesion due to the presence of intermolecular forces.

The material left over from the original ball was rolled into a smaller ball with a smooth surface, by adding or removing water as needed. With an index finger and thumb the ball was gently squeezed until the distance between the finger and thumb was the radius of the original ball and following was noted:

- A ball with a major sand component ruptured and broke apart once the pressure was released.
- A ball with a major silt component ruptured but, the material stayed together after pressure was released.
- A ball with a major clay component deformed but, did not rupture with some cracks forming on surface.

The term rupture means the smooth ball surface broke open due to low cohesion between soil particles. The cohesion had a range of results between the sand, silt and clay responses listed. The most relevant response can be assessed in Table 8.

### Drain test

The ease of water to drain out of the soil was assessed during the handling of the soil while performing the recommended tests. Generally, moisture was maintained in clay but drained from sand during handling. The drain test was conducted when performing the dry strength test. The dry strength test cube was placed on a piece of writing paper on top of a dry surface (e.g. rock or roof of a vehicle). After a few minutes, the moisture front on the porous paper surface was assessed as follows:

- Water drained out of sand resulting in a large moisture front in the surface around the cube.
- Water was held in silt due to capillarity, but a small moisture front was present in the paper.
- Water was readily held by clay and a large moisture front was not seen or expected, but a very small front was present immediately around the cube for some samples. It is expected most removal of water was through evaporation.

The drain test had a range of results between the sand, silt and clay responses listed. The most relevant response can be assessed in Table 8.

### Overall identification table

Once all field tests were conducted and the material had been described according to the criteria in each test, reference was made to the rating table presented in Table 8 to assess the soil type. This overall rating table was used to determine the typical grading and the inferred USCS class. The resultant criteria or sample responses from each test was scored against the table by selecting the most correct description. It must be noted that the result of each test from one sample scored across different columns which is expected to naturally occurring soils. Therefore, the column that scored the highest amount of most relevant descriptions indicated the typical grading and typical USCS class for the tested soil.

## Results

The samples were retrieved from existing road cuttings along the eastern escarpment of South Africa. The ground profiles at the sample locations were logged and photographed by the operator. The sample material was generally desiccated residuum with the road cutting (RC) generally standing near vertical without any support. A typical sample location is presented in Fig. 1.

All the samples were taken to a storage area where the soil was mechanically broken down by hand into generally a fine powder and allowed to air dry in the sun and overnight for 48 h. This step normalised the condition of each sample by breaking down any existing very weak rock fragments and allowing minerals to weather into more stable phases.

The samples were then submitted to a commercial geotechnical laboratory in Pretoria, South Africa, to undergo the laboratory tests mentioned in the “Particle size analysis and Atterberg limits” section. The remainder of the samples were taken to the X-Ray Analytical Facility housed in the Stoneman Building at the University of Pretoria to undergo XRD, XRF, SEM, and microscopy testing, and field-testing techniques described in the “Field tests” section.

**Fig. 1** Typical sample location

## Laboratory test results

### Particle size analysis and Atterberg limits

Figure 2 presents the percentage of material that was retained by and passed through the 0.075 mm sieve. The Atterberg limits test results and the laboratory assigned USCS classes for each sample are summarised on Fig. 2. Moreno-Maroto and Alonso-Azcárate (2018) proposed the use of the clay factor which is the ratio of plasticity index (PI) and the liquid limit (LL) (i.e. PI/LL), which is an indicator of clay characteristic in the soil. Soils with values greater than 0.50 indicates the presence of plastic clays, values between 0.33 and 0.50 indicates moderate to slightly plastic behaviour in soils made up on clay, silt and sand, while values less than 0.33 suggests the soil comprises silts and sand with low to non-plastic behaviour. The clay factor and summary of particle size for each sample is presented in Fig. 3.

### XRF and XRD results

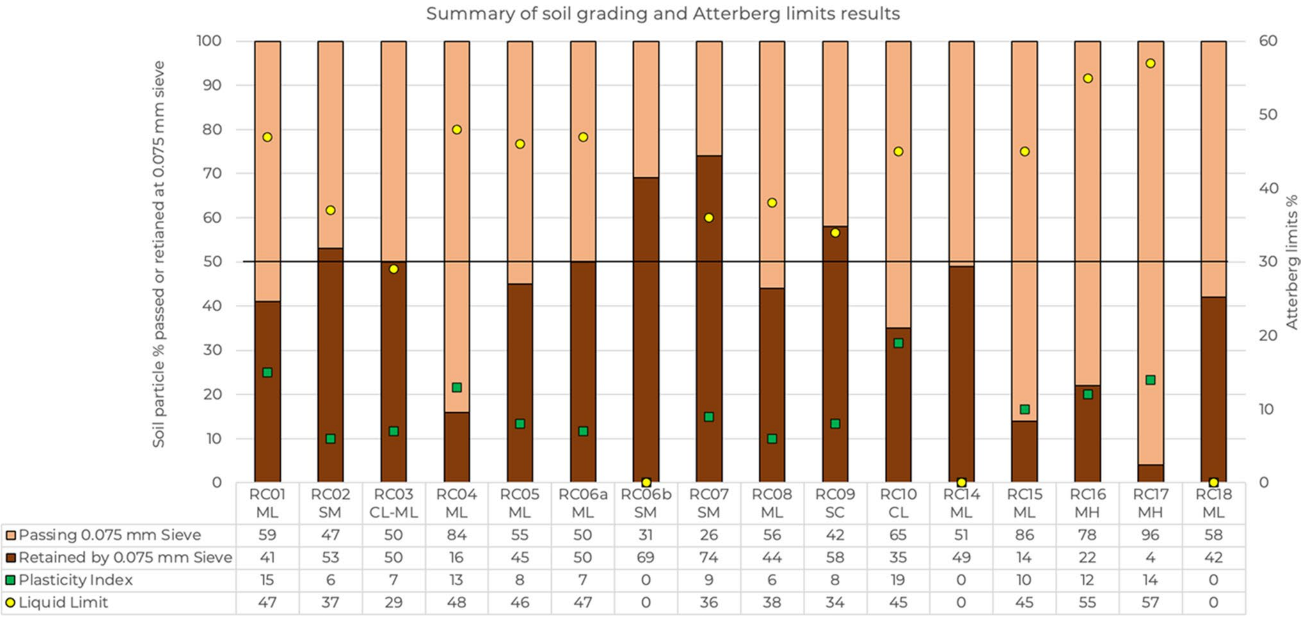
The XRF results revealed the samples are generally made up of $SiO_2$ and $Al_2O_3$ and lesser MgO, $Fe_2O_3$ and $K_2O$. The XRD test results are presented in Fig. 4. The samples are generally made up of quartz and kaolinite which is typical of deeply weathered residual soils which formed from felsic bedrock. Varying quantities of original parent rock minerals, such as muscovite, microcline, albite and rutile, still exist in the soil and these are expected to occupy the silt and sand portions of the soil. Gibbsite, hematite and goethite are typical of highly weathered soils and are expected to occupy the clay portion of the soil and as surface coating of silt and sand size particles.

### Stereomicroscope

Each soil sample was visually analysed to support the findings of the laboratory and field-testing results. This was done by qualitatively examining the coarse silt to sand particle size distributions, which minerals exist as either a silt or sand and the possible surface coating of the sand and silt particles. Photographs taken of representative samples indicate all the soils are dominantly made up of silt, clay and fine sand material. The silt and sand are mainly quartz grains and other rock forming minerals and are typically coated by clay minerals and metal oxides. Figure 5 presents a photograph taken of typical grains found in the residual soils formed from felsic bedrock. Figure 6 shows a photograph of a highly weathered soil sample that has undergone pedogenic alteration with relatively large amounts of metal oxides.

### SEM

Similar to the stereomicroscope, the SEM was used to qualitatively assess the soil grains in the clay and silt portion of the samples. Figures 7 and 8 present scans taken at high-magnification, and they show the fine-grained portion of the soil comprises assemblage of kaolinite clays and other similar clays.



| | RC01<br>ML | RC02<br>SM | RC03<br>CL-ML | RC04<br>ML | RC05<br>ML | RC06a<br>ML | RC06b<br>SM | RC07<br>SM | RC08<br>ML | RC09<br>SC | RC10<br>CL | RC14<br>ML | RC15<br>ML | RC16<br>MH | RC17<br>MH | RC18<br>ML |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 🟧 Passing 0.075 mm Sieve | 59 | 47 | 50 | 84 | 55 | 50 | 31 | 26 | 56 | 42 | 65 | 51 | 86 | 78 | 96 | 58 |
| 🟫 Retained by 0.075 mm Sieve | 41 | 53 | 50 | 16 | 45 | 50 | 69 | 74 | 44 | 58 | 35 | 49 | 14 | 22 | 4 | 42 |
| 🟩 Plasticity Index | 15 | 6 | 7 | 13 | 8 | 7 | 0 | 9 | 6 | 8 | 19 | 0 | 10 | 12 | 14 | 0 |
| 🟡 Liquid Limit | 47 | 37 | 29 | 48 | 46 | 47 | 0 | 36 | 38 | 34 | 45 | 0 | 45 | 55 | 57 | 0 |

**Fig. 2** Summary of particle size analyses and Atterberg limit test results

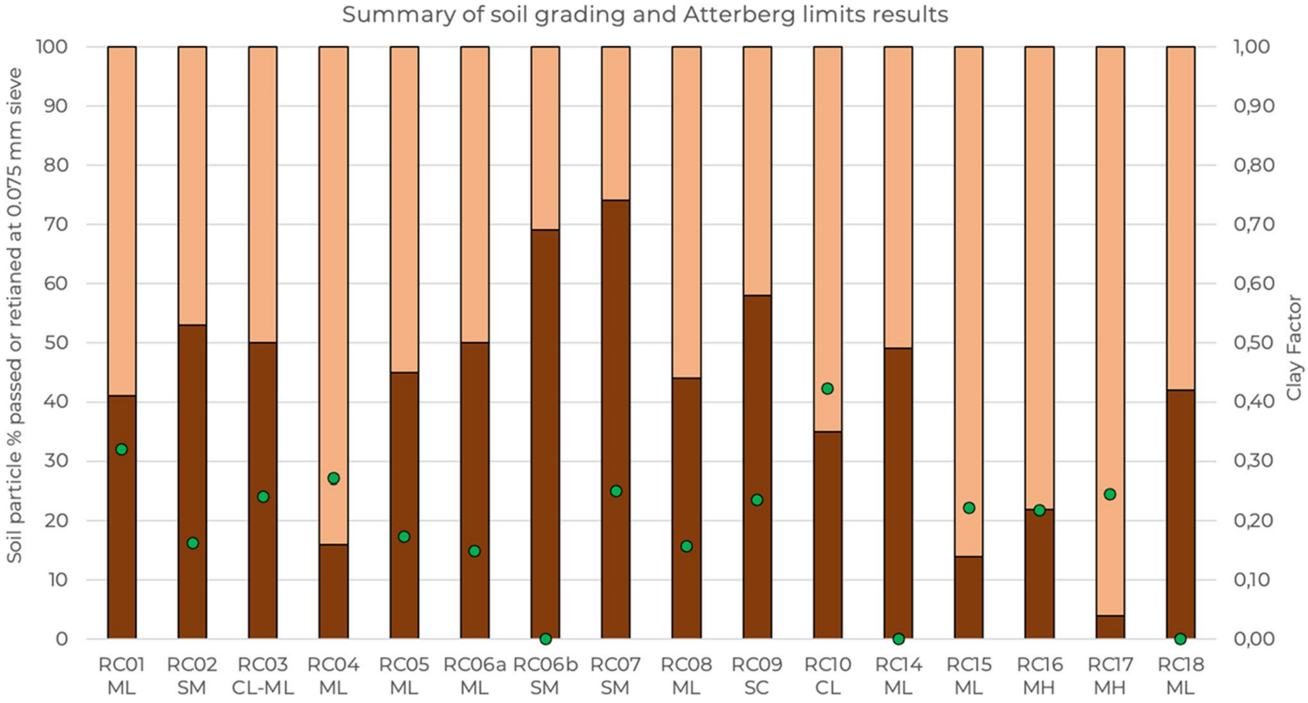


**Fig. 3** Summary of particle size analyses and clay factor

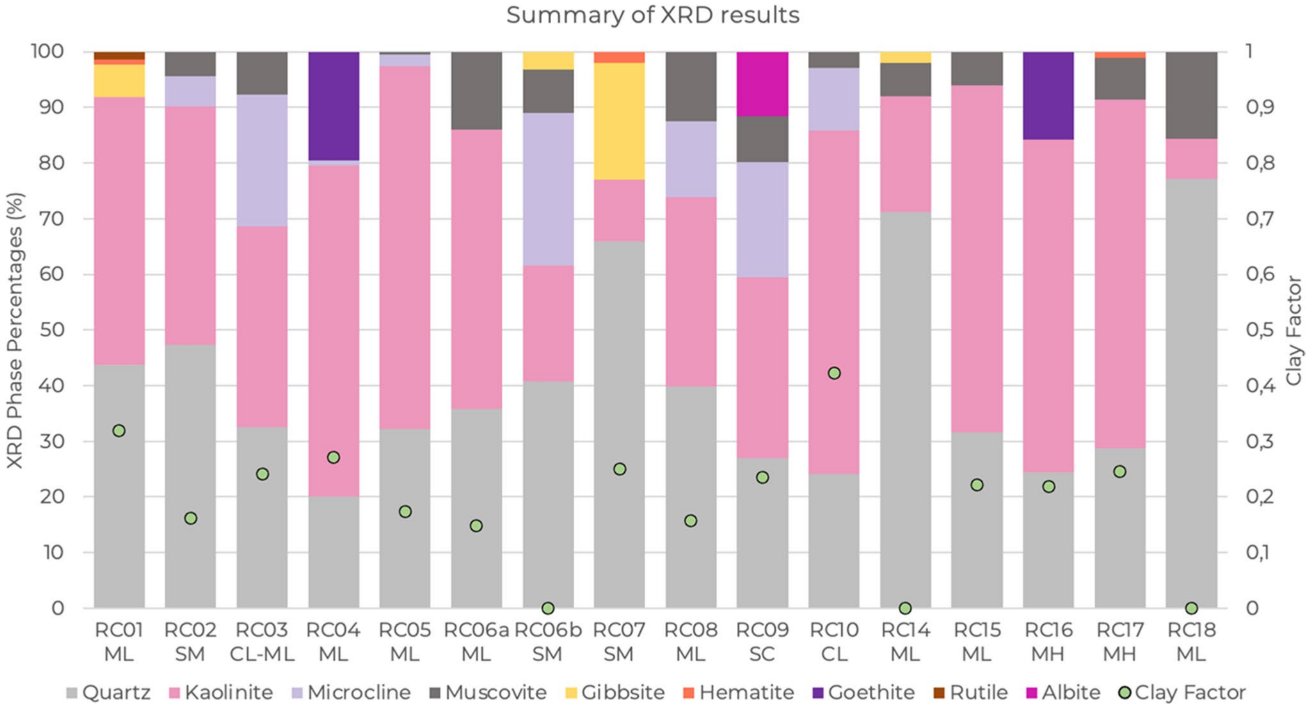


**Fig. 4** Summary of XRD results and clay factor

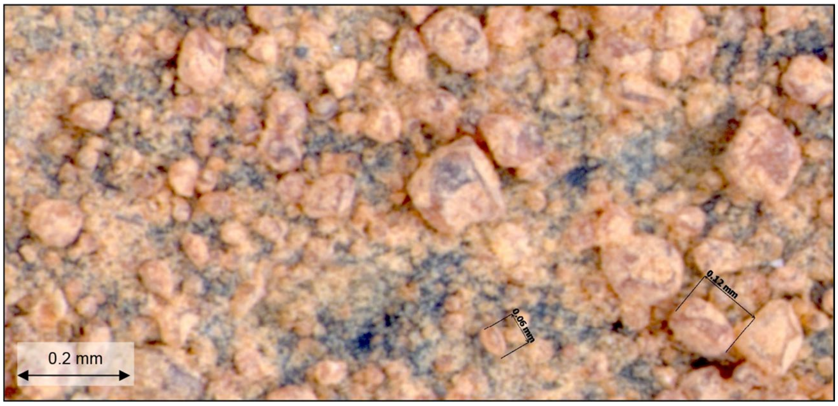


**Fig. 5** Photograph taken of typical residual soil particles

**Fig. 6** Photograph taken of highly weathered residual soil

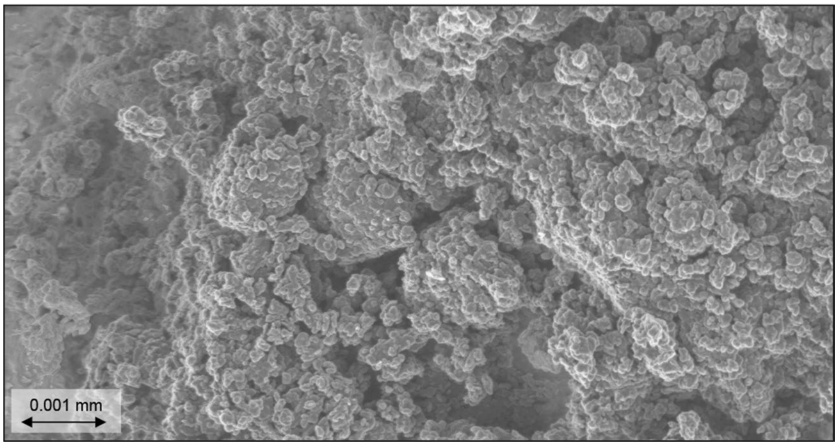


**Fig. 7** Scan taken at 11.27 K magnification

## Field test results

Every sample underwent all recommended field tests described in the "Field tests" section, and the responses of each sample during all tests were documented and photographed. Figures 9 and 10 show the a few test responses of a ML and SM soil, respectively. The thread in the photographs is the thinnest thread that could be rolled.

The final soil responses were 'scored' using the identification table, presented as Table 8. The scoring results are summarised in Fig. 11. There are ten (10 No.) tests with defined criteria for each possible response. The ball pickup/drop test is only used for samples where rapid water movement is observed in the shaking/dilatancy test, or a weak ball is formed during the ball forming test which is the eleventh (No. 11th) test but is not listed in the identification table. Typically, weak balls and rapid water movement will occur in samples where silt and sand are the major components with very little clay. Therefore, the ball pickup/drop test will not be conducted on soils with majority silts or clays only.

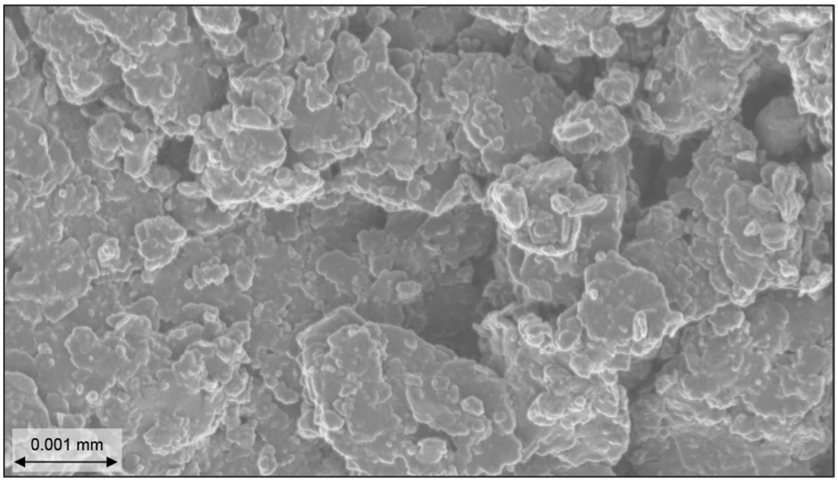


**Fig. 8** Scan taken at 14.61 K magnification

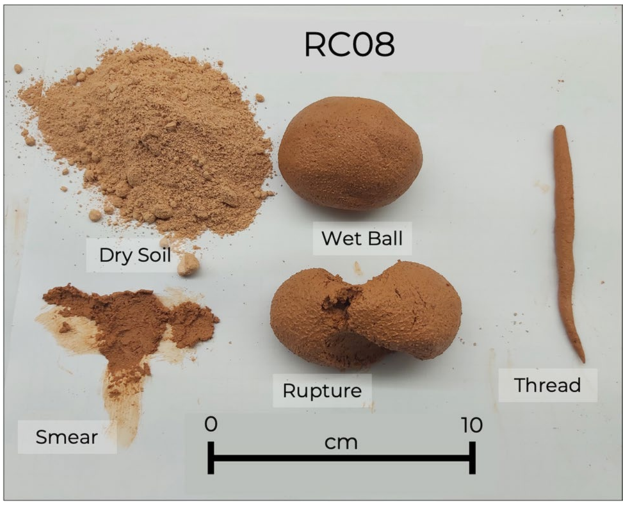


**Fig. 9** Typical soil responses of a ML (RC08) soil

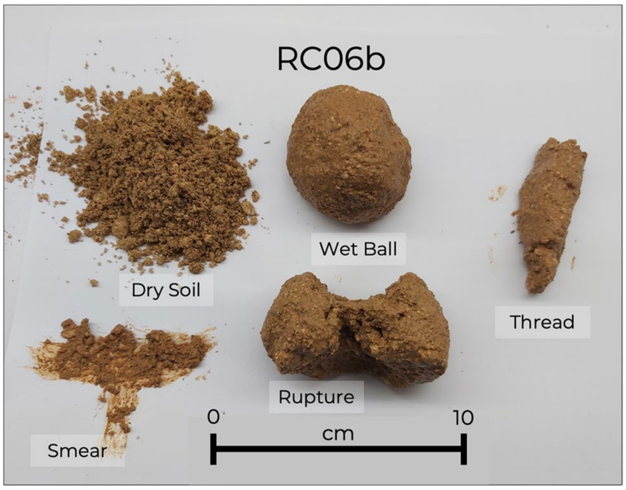


**Fig. 10** Typical soil responses of a SM (RC06b) soil

A tested sample can therefore have either a total scoring of nine (No. 9) or ten (No. 10) with the inclusion or exclusion of the ball pickup/drop test.

## Discussion

Many of the field tests in literature are based on plasticity of the soil because the identification of a clay-silt mixture is not necessarily based on grain sizes only, but on the plastic behaviour. The identification tests recommended by Hunt (2005) and Norbury (2020), and ASTM D2488-09a (2009) are aimed at identifying soils particle sizes less than 0.425 mm. Natural soils generally have sand size particles to some extent. Burmister (1949) described tests to determine the quantity of silt and sand particles in a silt-sand mixture; these were incorporated into this study.

All non-duplicated tests described and recommended in Burmister (1949), Hunt (2005) and Norbury (2020) were first reviewed to determine its usability is this study. Any test that required the operator to place soil in the mouth was not used and not included in the testing list. Soil contamination is not well understood, and the operator could be exposed to harmful contaminates found on brownfield and greenfield sites. Any tests requiring stationary not typical of site investigations, such as hydrochloric acid (HCI) to test for calcium carbonate content, was excluded for practicality purposes. The remaining list of tests was assessed using the soil samples.

Where necessary, the methodology or criteria of a test was modified to accommodate for responses that were not describable in the existing literature. When this was done, all the samples were retested with the new methodology or criteria to ensure the written criteria would allow for all possible soil test responses. Field tests that were included in the initial testing list but excluded from the

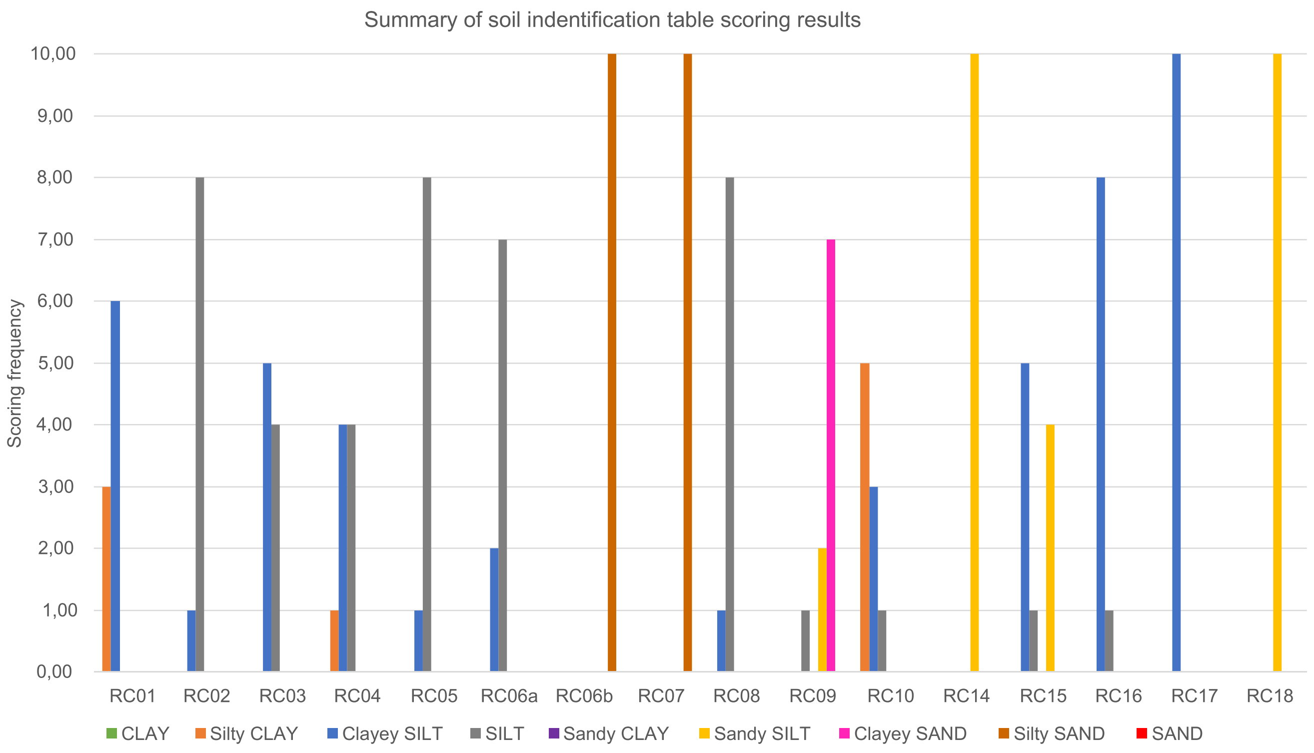


**Fig. 11** Summary of soil identification scoring results

final proposed testing list in the "Field tests" section, were behaviour in water/dispersion test and the smear test. The behaviour in water/dispersion test assesses the reaction of a ball of soil after being gently placed into a beaker of water. The ball will hold its shape, disintegrate, or disperse either immediately or over some time, which is expected of a pure clay or a silt and sand, respectively. To include this test requires a significant increase in the amount of available water on site as well as a beaker and therefore is not recommended. Although the smear test, an example of it is shown in Figs. 9 and 10, is useful to feel texture of a sand particles in a clay or silt matrix, it did not aid in determining the plasticity or overall grading of the soil and therefore, was excluded from the recommended field tests.

The existing field test descriptors in literature did not typically include a criterion for a sand portion in a clay or silt dominated soil because the initial step in these methodologies was to remove the medium sand and coarser particles (> 0.425 mm particle size). The samples were tested with this in mind, and the test descriptors were modified to allow for the presence of a sand portion that may influence the test result. The test result for each sample was assessed using the data from the particle size analysis, Atterberg limits testing, the visual inspection from the stereo microscope and SEM, and the chemical test results, as well as the experience of the operator. The final test descriptors and criteria listed in the "Field tests" section allow for the testing of soils ranging from a pure clay, a sandy, clayey silt to a medium sand.

The sample tested will be assigned the soil texture in the column with the highest scoring frequency. Once the soil texture has been defined, the inferred USCS class can be assigned to the sample. This inferred USCS class can be done because the sample's response to changing water contents and under load (pressure under strong fingers) were tested, grading was assessed by feel and visual observation, and plasticity was investigation during the field tests. It must be noted that the USCS is based on quantitative grading percentages and that these series of field tests are not meant to replace the steps required to class the soil using the USCS in the laboratory. For most soil textures in Table 8, a range of possible USCS classes are given and therefore is termed as the inferred USCS class.

If the scoring is evenly spread across multiple columns/soil texture, in the case of RC04, the operator must decide the soil texture based on the overall testing responses. The RC04 sample responded as a silt and clayey silt for four (No. 4) tests each and responded as a silty clay for the dry strength test. Considering the overall behaviour of the soil, the sample had slight to medium plasticity and therefore some clay must be present in the soil, and the soil was designated a clayey silt.

The soil textures listed in the identification table are based on the visual particle size classes as per the Massachusetts

Institute of Technology Classification system (Gilboy 1930), the soil identification recommendations stated in Burmister (1949), Hunt (2005) and Norbury (2020), and ASTM D2488-09a (2009) from which the tested were modified, and the field and consulting experience of the authors. The field test soil texture for each sample was assessed by comparing the soil texture based on the clay factor, and the sand percentage (retained by the 0.075 mm sieve), presented in Fig. 12, as proposed by Moreno-Maroto and Alonso-Azcárate (2018).

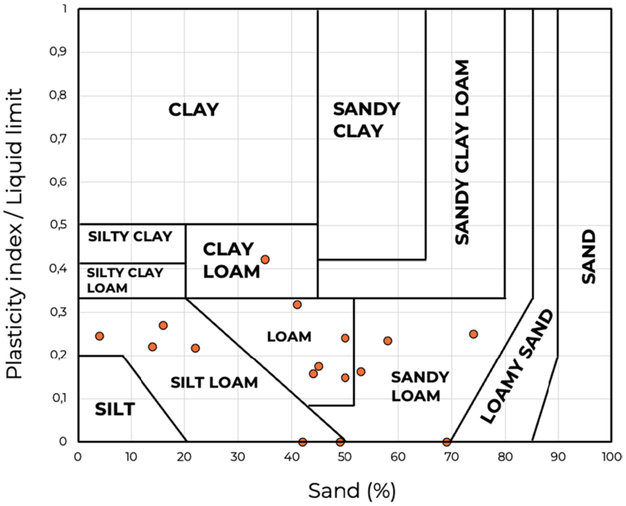


**Fig. 12** Representation of field-tested soil samples in the texture classification based on clay factor and sand percentage

Table 9 presents the summary of results for the laboratory USCS classes, the field testing results, and the texture based on the clay factor and sand percentage. Though this a qualitative comparison of results, it can be seen the field test inferred USCS classes and soil texture compares1 well with the laboratory USCS classes and soil texture based on the clay factor and sand percentages, respectively.

During the reviewing and modifying of tests, an effective sequence to perform each test was established that allows for multiply tests to be done at one time. The flow chart recommending the testing sequence is presented in Fig. 13.

## Conclusion

This study presents a practical and convenient approach to assess soils on any site where soils have particle sizes up to 2.00 mm. By employing a single list of field tests that only necessitate water and commonly available stationery materials on-site, the authors have presented a valuable tool for on-site determination of soil texture and inference of the Unified Soil Classification System (USCS).

The description of possible soil responses listed in each test allows for the assessment of low to high plasticity clays and silts, and completely inert silts and sands, as well as a wide range of particles sizes typically found in natural soils. The recommended test sequence opens the possibility to conduct multiple tests simultaneously, resulting in effective soil identification while on site.

**Table 9** Summary of the laboratory and field test results, and texture based on clay factor and sand percentage

| Sample | Laboratory USCS | Field test inferred USCS | Clay factor | Sand particle % (retained by 0.075 mm sieve) | Field test soil texture | Texture based on clay factor and sand (%) |
|---|---|---|---|---|---|---|
| RC01 | ML | MH, ML, CL-ML | 0.32 | 41 | Clayey silt | Loam |
| RC02 | SM | ML | 0.16 | 53 | silt | Sandy loam |
| RC03 | CL-ML | MH, ML, CL-ML | 0.24 | 50 | Clayey silt | Loam |
| RC04 | ML | MH, ML, CL-ML | 0.27 | 16 | Clayey silt | Silt loam |
| RC05 | ML | ML | 0.17 | 45 | Silt | Loam |
| RC06a | ML | ML | 0.15 | 50 | Silt | Loam |
| RC06b | SM | SM, SW-SP, SP-SM | 0.00 | 69 | Silty sand | Sandy loam |
| RC07 | SM | SM, SW-SP, SP-SM | 0.25 | 74 | Silty sand | Sandy loam |
| RC08 | ML | ML | 0.16 | 44 | Silt | Loam |
| RC09 | SC | SC, SW-SC, SP-SC | 0.24 | 58 | Clayey sand | Sandy loam |
| RC10 | CL | CL, MH, CL-ML | 0.42 | 35 | Silty clay | Clay loam |
| RC14 | ML | ML | 0.00 | 49 | Sandy silt | Silt loam |
| RC15 | ML | MH, ML, CL-ML | 0.22 | 14 | Clayey silt | Silt loam |
| RC16 | MH | MH, ML, CL-ML | 0.22 | 22 | Clayey silt | Silt loam |
| RC17 | MH | MH, ML, CL-ML | 0.25 | 4 | Clayey silt | Silt loam |
| RC18 | ML | ML | 0.00 | 42 | Sandy silt | Silt loam |

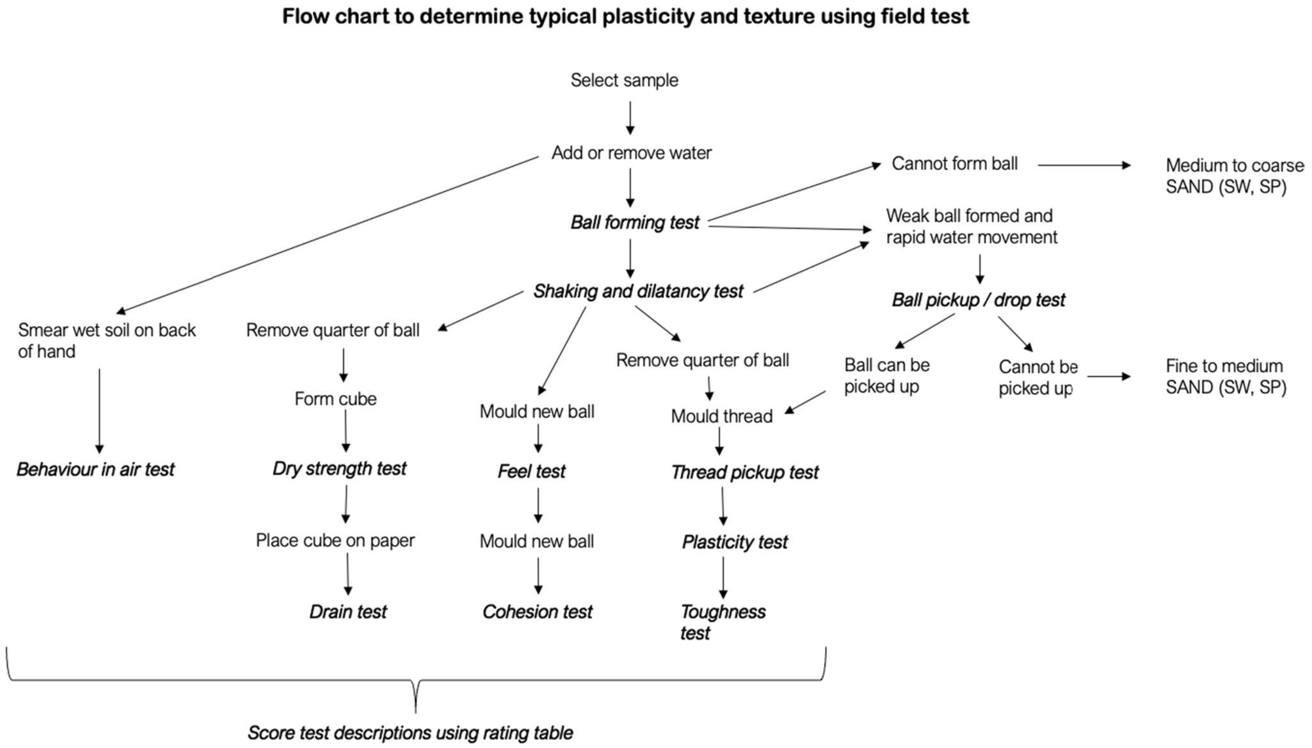


**Fig. 13** Recommended sequence of testing for effective soil identification using field tests

During this research, it became clear that soils with major components of clay and silt should be classed by the plastic behaviour and not only by the grading of individual particles. A new texture classification was used in this study which identifies soils based on the clay factor and sand particle percentages. The field identification results in this research seem to agree well with the soil textures on the chart proposed by Moreno-Maroto and Alonso-Azcárate (2018).

The incorporation of these field tests in soil profiling significantly streamlines the site data collection process and provides professionals with an efficient means of assessing soil properties and determining problem soils at an early stage of the investigation and during construction of large fills without the need for extensive laboratory testing.

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**Data Availability** Data will be published in Duan Swart's PhD thesis, articles published from the work, and the final report published by the Water Research Commission (www.wrc.org.za).

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