Undisturbed block sampling and its use in the investigation of very stiff to hard residual soils and extremely weathered rock

T. M. Youngberry[1]

[1]GHD, Level 9, 180 Lonsdale Street, Melbourne, VIC 3000; PH (617) 8687-8376; email: tom.youngberry@ghd.com

ABSTRACT

Undisturbed sampling of very stiff to hard residual soils and extremely weathered rock can be problematic due to difficulty in penetrating these materials and ensuing disturbance. Traditional methods for undisturbed sampling of very stiff to hard residual soils and extremely weathered rock are reviewed in this paper. Block sampling, while not commonly used, allows greater control over sampling and often leads to less disturbance and high-quality samples for testing. A method for taking undisturbed block samples is presented. This sampling method can be completed relatively cheaply with commonly available equipment and basic training. The size of the block sample allows a wide range of laboratory tests to be completed on material exhibiting similar properties and offers the possibility of better characterisation of the soil behaviour. The discussion presented herein includes the materials and equipment used, the time required for sampling and proposed safety measures.

Keywords: block sample, residual soil, undisturbed

1 INTRODUCTION

Very stiff to hard residual soils and extremely weathered rock (i.e. material with soil-like properties) are unique when compared with other soils in that they are formed in situ by weathering, rather than being transported. The weathering profile, degree of weathering and resulting soil properties is a function of parent geology, site geomorphology and climate, thus the behaviour of these materials is often difficult to predict (Hencher, 2012). They decompose from their parent rock through chemical, physical and biological processes to form structured, heterogenous materials which, along with their relatively high strength, makes sampling problematic. Additionally, gravel and weathered rock fragments in residual soils make them particularly difficult to penetrate.

Good geotechnical engineering design requires the collection of high-quality undisturbed soil samples for laboratory testing. However, many aspects of the sampling process, no matter how precise, alter the sample from its in situ condition - often referred to as disturbance. Relict structure in weakly bonded residual soils and extremely weathered rock makes them particularly susceptible to disturbance during sampling. Best practice requires that procedures be undertaken to mitigate disturbance during sampling, packaging and transporting and to obtain a sufficient number of representative undisturbed samples from each geological unit to enable characterisation of its physical properties. The latter point is particularly relevant when sampling relatively thin layers using drill holes.

Block sampling has been used historically (Brand 1985, USBR 1998), although much less frequently than other methods of undisturbed sampling. Its slow adoption as a conventional sampling method is partly due to the manual labour required to excavate samples in very stiff to hard residual soils and extremely weathered rock. The method described in this paper combines the use of hydraulic machinery, hand excavation and the use of readily available packaging materials making it both economic and viable in hard ground.

2 SAMPLE DISTURBANCE

Sample disturbance is often difficult to avoid and can occur at all stages in the sample life-cycle; i.e. during sampling, packaging, transportation, storage, laboratory preparation and testing. Clayton et al. (1995) classified four soil disturbance mechanisms: (1) changes in stress conditions, (2) mechanical deformation, (3) changes in water content and void ratio and (4) chemical changes arising from contact with drilling fluid and/or the sampler.

When a sample is exposed and removed from the ground it undergoes stress relaxation from in situ stresses to zero total stress through the removal of overburden material and horizontal confining stress.

This is not such an issue for saturated clay soils which can maintain sufficient matric suction to resist volumetric expansion. Residual soils however are often partially saturated and have relatively large voids, causing them to lose matric suction and expand when sampled, damaging the soil structure (Fookes, 1997).

Mechanical deformation refers to the rearrangement of soil particles within a soil structure. Mechanical deformation is most commonly caused by shear strains developing at the interface between the soil and the sampler. Shear strain during sampling is most prevalent in tube sampling, even if thin-walled samplers are used. Mechanical deformation can also occur from vibrations and shock during transportation, and from extrusion, saturation and consolidation procedures in the laboratory.

Changes in water content can occur during sampling, storage and laboratory preparation. Moisture changes during sampling is a problem in partially saturated residual soils, particularly when sampling using rotary core with a flushing medium. Chemical disturbance is not often considered in practice, especially since sample storage time is typically short. However, acid and alkali soils as well as saline pore water can react with sample packaging and change pore water chemistry. This can result in changes in the observed post-failure behaviour such as sensitivity (Clayton et al., 1995).

3 TRADITIONAL SAMPLING METHODS

3.1 Thin-walled tube sampling

Thin-walled tube sampling (a.k.a. Shelby tube or push tube) is used almost universally in site investigation as the principal method of obtaining undisturbed samples. Steel or stainless-steel tubes with an area ratio (defined as the ratio of the net projected area of the sampler and the projected area of sample core) < 10 % and a bevelled cutting edge are standard (Standards Australia, 2015). To collect a sample, the tube is pushed into the ground, typically from the base of a pre-drilled hole. In very soft to soft soils, piston tube samplers provide higher quality samples as they prevent water or loose soil from entering the tube when sampling, and the piston seal creates a vacuum preventing sample loss when retrieving. When retrieved, often only the lower end of the tube can be logged. Molten microcrystalline wax, mechanical seals, tightly fitting end caps or a combination of these methods are used to seal the tube against moisture loss. Tube sizes that are commonly used in site investigations are 50 mm, 63 mm and 75 mm diameter and collect samples up to 450 mm in length.

Although tube sampling is an appropriate method for sampling very soft to stiff transported cohesive soils, strains can still develop at the sample-tube interface. Computed tomography (CT) scans are being increasingly used to assess sample quality prior to testing (Pineda et al., 2016a). In residual soils, side shear strains are significant and can damage soil structure resulting in misrepresentation of in situ properties in the laboratory. Refusal of the tube is common in hard residual soils and extremely weathered rock due to the limited hydraulic push capacity of the drilling rig. This can lead to insufficient sample for testing. Gravel or weathered rock fragments in these materials can deform the tube cutting edge leading to mechanical disturbance and refusal.

3.2 Rotary coring

In rotary coring, a coring bit attached to the bottom of the core barrel cuts an annulus of material (kerf) while the central material remaining enters the core barrel as the coring bit advances. While the drilling bit rotates and advances, a flushing medium is pumped down the drill rods and out through holes in the drill bit to cool the bit and to flush out cuttings up the outside of the core barrel and rods. NQ3 size (45.1 mm core) is used as a minimum, although better recovery is experienced with PQ3 size (83.1 mm core) as there is less potential for erosion from drilling fluid. The larger core size also reduces the depth of moisture penetration into the sample.

Initially, single and double tube core barrels were used, however triple tube core barrels are now the method of choice due to their superior core recovery and better-quality samples. The triple tube configuration consists of an outer barrel, to which the drilling bit is attached, which rotates while the inner barrel containing a third liner remains stationary. The benefit of the triple tube system is that the inner barrel does not rotate with the drill rods and the flushing medium flows between the outer two barrels instead of between the sample and the inner barrel. The inner liner to the triple tube core barrel is typically a split steel liner, although cylindrical polycarbonate liners are used in softer materials.

In very stiff to hard residual soils and extremely weathered rock, sample disturbance during coring can occur in many ways – principally by contact with the drilling fluid as the sample enters the inner barrels resulting in erosion or a change in moisture (Nicholls, 1990). The use of drilling foam as a flushing medium can be employed to reduce moisture changes (Fookes, 1997). In addition to contact with the drilling fluid, expansion of the sample can also occur as the inside diameter of the coring bit is slightly smaller than the inside diameter of the liner.

3.3 Specialist coring techniques

Numerous specialist coring techniques have been developed; one of which is the Mazier core barrel. The Mazier core barrel is a triple tube rotary coring apparatus with an inner retractor barrel and a heavy-duty cutting shoe that protrudes slightly beyond the end of the outer barrel. The amount of protrusion depends on the stiffness of the ground; further for soft soils and less in harder ground. Since the inner barrel protrudes beyond the cutting bit, the sample is protected from erosion by the flushing medium unlike conventional coring techniques. Sample recovery can be improved by using a foam flushing medium (Phillipson and Chipp, 1982). The advantage of this specialist coring technique is that samples of very stiff to hard ground and soft rock can be taken, where a conventional thin-walled tube would be damaged or refused. This specialist coring technique is useful for weathering profiles that decrease in weathering with depth. However, deposits with interbedded soft and hard layers such as metasedimentary formations can restrict the use of this method, as time-consuming alternating between conventional rotary coring techniques and Mazier sampling may be required (Haw and Seng, 1990).

3.4 Block sampling

Block sampling produces the highest quality samples of residual soils (Fookes, 1997). Block sampling (using the Sherbrooke sampler) has also been shown to produce the highest quality samples in soft clays due to less change to the micro and macrostructure when compared with samples taken using thin-walled tubes (Pineda et al., 2016b). The traditional block sampling method involves carefully carving a block of soil from an exposure or an excavation. Historically this has generally been completed using hand tools (USBR, 1998). Due to the effort required in taking a block sample, samples are usually taken when the material type and location are known, hence it is commonly completed as a supplementary activity to a site investigation program. Due to the size and near surface location of block samples (typically < 5 m depth) stress relaxation is typically far less than samples taken at depth from drill holes. As with all undisturbed samples, block samples are susceptible to moisture loss during and after sampling. Many techniques, including covering with wax and cheesecloth and packing with moist sawdust or damp sand have been proposed to minimise this problem (Fookes 1997, USBR 1998, Standards Australia 2015).

4 BLOCK SAMPLING METHODOLOGY

4.1 Overview

The following block sampling methodology is an effective technique to obtain high-quality undisturbed samples of very stiff to hard residual soils and extremely weathered rock. The block size enables multiple essentially similar samples to be cut from the block in a controlled laboratory environment and the selective nature of the sampling methodology enables relict features to be targeted or avoided. This method uses a combination of hydraulic machinery and hand digging, thereby minimising time and cost. Once excavated, the block sample must be carefully packaged to retain moisture and protect it from shocks and impacts during transport. While the method detailed below is for sampling from a test pit, it could easily be modified for sampling from an exposure or the floor of a larger excavation.

4.2 Materials and Equipment

Sampling materials and equipment are listed in Table 1. A schematic of the box showing materials and indicative dimensions is provided in Figure 1.

4.3 Procedure

The first step is to select an appropriate sample location. This requires an understanding of the site geology and is best undertaken once preliminary investigations have been completed and there is an understanding of which materials require sampling and physical characterisation. Prior to commencing the block sampling, the packaging box should be partially assembled by securing the four sides together and fastening the handles. The pilot holes for the top and bottom lids should be drilled and countersunk along with the holes in each lid which are used to release excess expanding foam.

To begin, the excavator progressively removes material by scraping away thin layers with the excavator bucket. Once the target material is exposed, the engineer should inspect the material and select the location where the block sample will be taken. This can be done by entering the excavation but only after appropriate safety measures are in place. Finding suitable material to sample may require a large surface area to be exposed due to variable composition and weathering, the presence of core stones or relict discontinuities. Once the approximate location has been identified, the excavator then cuts two slots leaving a pillar approximately 600 mm wide and 600 mm high (Figure 2a). The pillar from which the block will be taken is then closely inspected for features that may require sampling (relict joints) or those that need to be avoided from the perspective of laboratory testing (rock fragments or gravel). In some instances, it may be necessary to cut deeper slots or move to the side and excavate a new slot.

Once the sample location has been selected, the remainder of the excavation is completed using hand digging tools. Two cuts are made in the pillar, leaving a column of material approximately 600 mm square. Material is progressively removed from the top and sides so that a column 300 mm square and approximately 450 mm high begins to take form (Figure 2b). This part of the exercise can be challenging when sampling gravelly or blocky materials so care should be taken not to over excavate. While cutting the sample, it is important to work quickly to reduce moisture loss. If possible, the block should be shaded from direct sunlight. The block should be carved so that there is approximately 15 mm between the block and the box on all sides – test the fit by sliding the partially assembled box over the block. Once sized correctly, the block should be logged and photographed from all sides before wrapping. Small disturbed samples of trimmings should be kept for initial moisture content and index testing.

Table 1: Block sampling materials and equipment list (materials for 1 box)

Item	Qty	Item	Qty
Formply 15 to 18 mm thickness (m^2)	0.7	Cling wrap (450 mm roll)	1
Cordless drill	1	Aluminium foil (450 mm roll)	1
Countersinking bit	1	Expanding polyurethane foam (can)	2
Pilot hole drill bit (1.6 mm)	1	Paint scraper	2
Driver bit	1	Shovel	1
Auger drill bit (8 mm)	1	Fencing bar	1
Timber screws (8G x 50 mm)	28	Excavator / backhoe	1
Heavy duty box handles (with screws)	2		

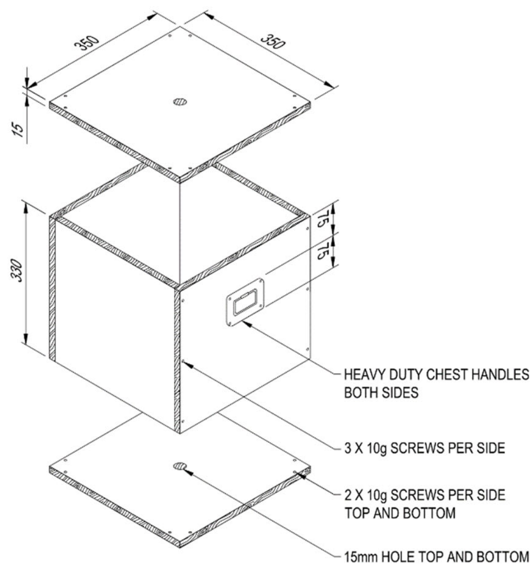

Figure 1: Block sample box (dimensions are indicative only and could be modified to suit site conditions or materials)

(a) (b)

Figure 2: An excavated pillar (a) and a carved block (b)

The top and sides of the block are then carefully wrapped with alternating layers of cling wrap and aluminium foil. It is good practice to use three to four layers of each to protect against moisture loss through tear holes in the film or foil. The top of the block should be draped first before wrapping the sides to 'lock in' the top film and foil. When the block is sufficiently wrapped, the box is placed around the block. Loose soil is placed around the base of the box to elevate the top of the box approximately 15 mm above the sample (Figure 3a). The orientation of the box is marked on the sides. Polyurethane foam is then injected between the block and the sides of the box in accordance with the manufacturer's instructions. The top of the block is sprayed with foam before quickly securing the lid. Slight pressure should be applied to the lid of the box to avoid the box being lifted by the expanding foam while letting excess foam out of the release hole in the lid.

When the foam has set – something that may be affected by low temperatures, the block is very carefully undercut at its base and inverted. This step requires at least two people to ensure the block remains intact and it is not mishandled while inverting. Excess material at the base of the block is carefully removed to form a neat, flat base approximately 15mm below the top of the timber. The base is then wrapped with a similar alternate layering of cling film and aluminium foil, taking care to tie in the wrapping at the sides as much as possible. Any remaining gaps in the expanding foam can be filled from the base before spraying the wrapped base itself, quickly securing the bottom lid and, once the foam has set, restoring the block the right way up. The box should be labelled with relevant information. The block is now ready for transport (preferably on a pallet) together with the disturbed samples of trimmed material.

(a) (b)

Figure 3: Partially wrapped block prior to spraying foam (a) and the base of a block prior to final wrapping (b)

4.4 Safety

A risk assessment should be undertaken prior to commencing the block sampling and appropriate control measures implemented to manage any hazards. Typical hazards that need to be managed and controls are listed in Table 2.

Table 2: Typical hazards and control measures

Hazard	Control
Engulfment	Excavations deeper than 1.5 m to be benched
Unsafe egress from excavation	Gently slope or step one side of the excavation to provide access
Working at heights	Barricade excavations deeper than 1.8 m
Heavy objects	Perform two-person lifts for heavy items, e.g. packaged blocks
Chemicals (polyurethane foam)	Follow instructions on the Material Safety Data Sheet (MSDS)
Manual excavation	Personal Protective Equipment (PPE) including gloves, safety glasses etc.
Working around heavy machinery	Establish exclusion zones, positive communication between operator and workers

4.5 Sampling Duration

The time taken to recover an undisturbed block sample depends on the depth of the sample, the difficulty in selecting a suitable block location and the difficulty in trimming a block. Provided the excavator is not required to create a bench to achieve the desired sampling depth, sampling takes between 2 and 4 hours. When scheduling an investigation program, a sampling rate of 2 blocks per day is a good estimate. The minimum number of workers required is 2; a machine operator and an engineer or engineering geologist. However, it is preferable to have 2 additional labourers to assist with hand digging and handling the box.

5 CONCLUSION

Traditional undisturbed sampling methods are reviewed and a current undisturbed block sampling method for very stiff to hard residual soils and extremely weathered rock is presented in this paper. Drawing on work by others on soft clays, the block sampling method presented has the potential to produce samples that exhibit less disturbance than other methods of undisturbed sampling in these materials. The block sample can be specifically selected by the geotechnical engineer or engineering geologist to be either representative of the bulk properties of the material under investigation or specific features. The size of the undisturbed block sample also allows sub-samples that are essentially similar to be taken for laboratory testing in a controlled laboratory environment. The undisturbed block sampling methodology presented in this paper minimises the labour-intensive methods of block sampling that have been used historically. In addition, the use of commonly available materials makes block sampling in hard ground both efficient and cost effective. While no sampling method eliminates sample disturbance entirely, if all steps involved are carried out with due care the highest quality undisturbed samples can be collected, enabling the first steps to be taken towards good engineering design.

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