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# Engineering Properties of Clay Seams within the Waitemata Group Rocks of Auckland


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**Summary:** Soft, extremely weak, bedding-parallel clay seams have been identified in investigation bores, shafts and excavations in Waitemata Group rocks throughout Auckland. The seams (<1mm to 15mm thick) are likely to have formed by flexural slip at the time of folding and, in combination with other joints, faults and bedding planes, exert some control on site stability. Testing indicates an average shear strength of c' = 13 kPa and o' = 13" and lower bound parameters of c' = 0 kPa and o' = 8 kPa.


## INTRODUCTION

The Waitemata Group comprises a series of weak alternating sandstones and mudstones of Miocene age underlying much of the Auckland Region. Bedding dip ranges 0" to 20" or more, but is commonly in the order of 0" to 7°, and is variable in direction both locally and regionally. Steeply dipping tectonic joints and faults with vertical displacements ranging from millimetres to several metres are common. Slope instability including block sliding within the weak rock is common. Studies of similar rock masses elsewhere in New Zealand and exposure of the rocks at a number of construction sites within the Auckland Region have confirmed that bedding parallel clay seams or clay coated slickensided fractures, often associated with blocksliding (Prebble, 1995), are widespread.

This paper describes the clay seams and the shear strength parameters derived from shear box and triaxial testing of clay seam samples less than one to several millimetres thick, collected from cut faces and shafts.

## GEOLOGY

### Waitemata Group Rocks

Rocks of the Waitemata Group are typically very weak to weak interbedded sandstone and mudstone dipping 0" to 7" in various directions. Locally, bedding dips more steeply as a result of deformation prior to consolidation and uplift. Steeply dipping tectonic joints and faults with small vertical displacement are common. Typical effective shear strength parameters for the weathered rock are c' = 5 kPa and o' = 30" with a *dry* density of 16.5 $kN/m^3$. Parameters for the slightly weathered to fresh rock are typically c' = 20+ kPa and o' = 30" to 34°.

### Clay Seams

Clay seams range in thickness from less than 1mm (clay coated fracture) up to about 30mm thick and typically comprise a light to dark grey very soft to soft highly plastic clay (Figure 1). Seams have been observed to vary in thickness over a site and within a single exploratory shaft diameter. In all cases, clay seams have been observed to be bedding-parallel and often are also wavy with bedding surfaces exhibiting an undulation of up to ± 50mm. Clay seams and diverging and rejoining splays are commonly offset by minor steep faults, suggesting that they are old tectonic features which may facilitate more recent block sliding or movement during earthworks once toe support is removed, by providing a low-angle basal slide plane or a potential basal rupture surface.

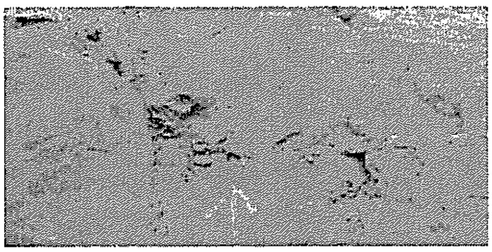

Figure 1. Arrow points to clay seam encountered in excavations in Grafton Gully, Auckland.

**Formation**
Thin clay seams or clay-coated fractures have been identified during investigations for several major developments within Waitemata Group rocks located on sloping or hill top sites (for example, the proposed Manukau Sanitary Landfill near Whitford, tunnel and basement foundation excavations as part of the Sky City development, the Grafton Gully project and the Waikato Pipeline). In most cases, more than one clay seam has been identified and these have been able to be traced across any one site by correlation with marker horizons.

The clay seams occur along bedding planes and it is considered likely that they have formed as a result of relative movements between adjacent beds (ie by flexural shear or slip) at the time of folding. The physical contrast between the sandstone and mudstone probably assists shearing and clay seam development as a result of flexural slip during folding of the beds. No clay seams were identified as part of investigations for the Britomart Transport Centre, located on flat lying ground, where bedding is subhorizontal and not folded.

In general ridges are formed over anticlines and streams along synclines in the openly folded weak bedrock. Bedding parallel clay seams have been found to form basal ruptures of blockslides at some sites.

**Similar Rocks from Other Areas**
A flexural slip origin for bedding plane shears was reported by Fell, Sullivan and MacGregor (1988) in gently dipping claystone and siltstone. The shears provided rupture surfaces for slope failures. Hutchinson (1988 and 2000) considers that the capability and potential of flexural slip has been underestimated as an origin for pre-existing shears, which develop into basal ruptures of landslides.

Similar clay seam type features have been found to contribute to slope movement in similar rock masses elsewhere in New Zealand (eg Stout 1977; Thompson 1981; Pettinga 1987). The well-documented Abbotsford landslide in Dunedin comprised movement of a block some 18 ha in extent about 50m on a 7" bedding plane (Coombs & Norris 1981).

## SHEAR STRENGTH

Undisturbed clay seam samples have been collected as part of investigations of several sites within the Auckland Region, for shear strength testing. Shear strength testing has been carried out to assess resistance to sliding. Results of shear box and ring shear tests are summarised in Table 1 and presented in Figure *2* (refer to Addendum for test details). In general, intact rock tested in the shear box apparatus shows a well-defined peak, followed by a rapid and then gradual fall off. Because the clay seams are planes formed by tectonic shearing, the curve rises more gradually and asymptotes to a "residual" value. This is indicative of a material that has sheared in the past. In some cases, where the clay seam is very thin (a clay coated fracture), shearing occurs in part through the fracture and in part through rock. When this happens, the curve continues to rise and gives a high value of shear strength. Such test results have not been considered in further evaluation of the test data.

Regression analysis suggests an average shear strength of $c' = 13$ kPa and $\sigma' = 13°$. The lowest parameters measured were $c' = 0$ kPa and $\sigma' = 8$ kPa. These parameters correspond with those back-analysed for the Abbotsford landslide (Coombs & Norris 1981) and it is considered possible that they reflect the properties of a montmorillonite rich clay.

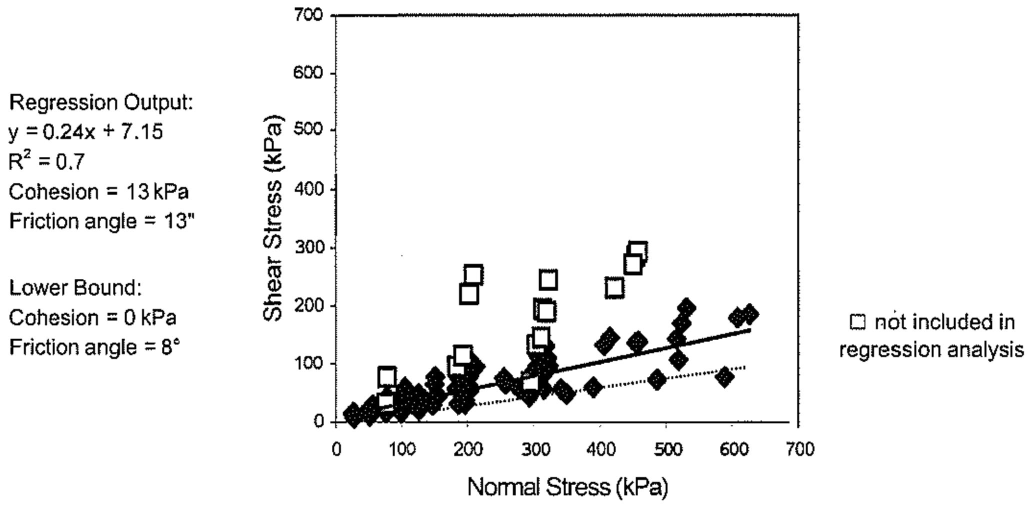


Figure *2*. Shear box test results for clay seams and clay coated fractures.

Table 1. Shear Test Results.

| Site | Stresses for 0.5mm Displacement | | Residual Stresses' | |
|---|---|---|---|---|
| | Normal (kPa) | Shear (kPa) | Normal (kPa) | Shear (kPa) |
| Proposed Manukau Sanitary Landfill (Howick – Alfriston Hills, SE Auckland | | | 349 | 48 |
| | | | 589 | 77 |
| | 202 | 77 | 205 | 85 |
| | 406 | 132 | 415 | 145 |
| | 609 | 179 | 627 | 185 |
| | 127 | 48 | | |
| | 254 | 75 | | |
| | 126 | 35 | | |
| | 256 | 66 | | |
| | 519 | 107 | | |
| | 127 | 40 | | |
| | 524 | 170 | | |
| | 102 | 49 | | |
| | 321 | 110 | | |
| | 516 | 143 | | |
| | | | 341' | 56 |
| | | | 196' | 36 |
| | | | 100' | 21 |
| | | | 293' | 48 |
| | 102 | 41 | | |
| | 303 | 70 | | |
| | 531 | 196 | | |
| | 454 | 136 | 458 | 138 |
| | 308 | 64 | 315 | 57 |
| | *454* | *285* | *457* | *293* |
| | *313* | *194* | *322* | *244* |
| | 151 | 64 | 152 | 77 |
| | 307 | 111 | 318 | 130 |
| | 151 | 43 | 156 | 45 |
| | 314 | 81 | 323 | 97 |
| | *202* | *220* | *209* | *253* |
| | *422* | *231* | *450* | *271* |
| | 202 | 62 | 208 | 100 |
| | 76 | 26 | 78 | 43 |
| | 183 | 57 | 186 | 77 |
| | 296 | 82 | 305 | 96 |
| | 76 | 20 | 79 | 40 |
| | 186 | 31 | | |
| | *295* | *69* | *311* | *145* |
| | *76* | *31* | *78* | *77* |
| | *184* | *95* | *193* | *114* |
| | *304* | *133* | *319* | *190* |
| | 277 | 57 | 286 | 67 |
| Hampton Downs, South of Auckland' | | | 27 | 7 |
| | | | 51 | 11 |
| | | | 76 | 16 |
| | | | 100 | 22 |
| | | | 124 | 27 |
| | | | 51 | 11 |
| | | | 76 | 16 |
| | | | 100 | 21 |
| | | | 124 | 26 |
| | | | 148 | 29 |
| Grafton Gully, Central Auckland | | | 100' | 16 |
| | | | 196' | 31 |
| | | | 293' | 44 |
| | | | 486' | 72 |
| | | | 100 | 17 |
| | | | 196 | 31 |
| | | | 293 | 45 |
| | | | 390 | 59 |
| | | | 486 | 74 |
| | 27 | 16 | 26 | 14 |
| | 56 | 28 | 51 | 23 |
| | 105 | 59 | 104 | 33 |
| | 212 | 95 | 203 | 54 |

Data in *italics:* shearin ıas occurred in part through the fracture and in part through rock
'Residual stress here i the highest stress achieved after 0.5mm displacement
'Ring shear

## SITE INVESTIGATION TECHNIQUES

Initial investigations should comprise photogeology, mapping of surface features and drilling of narrow conventional cored boreholes to assess slope movement types, obtain information on defects, and establish the soil/rock profile and broad soil and rock properties.

Where the potential for clay seams to exist is identified, consideration should be given to excavation of long trenches across topographic lineaments and drilling of inspection shafts (minimum 900mm ID) to provide exposure for direct inspection of subsurface conditions and allow collection of undisturbed samples for shear testing.

Alternatively, provision may be made in design for the presence of clay seams. This assumption can then be reviewed on visual observation of cuts during construction.

## IMPLICATIONS FOR STABILITY ANALYSES

Although the dominant bedding dip in Waitemata Group rocks is near horizontal, the dip direction varies widely. These variations in bedding orientation are consistent with either folding or faulting (or both) of the beds. It is considered likely that in some places they are due to rotational displacement across near-vertical faults. It is clear from both regional and site evidence that the continuity of bedding and of clay seams is disrupted by small scale near vertical faults. This disruption means that clay seams are unlikely to form very long continuous surfaces, but instead will be stepped into shorter sections. The steps and variations in dip will cause the clay seam to be "wavy", thus increasing its resistance to sliding movement. Where clear evidence of such 'waviness' is observed, we consider the use of average strength parameters for the clay seam to be appropriate for use in stability analyses.

In developments affecting shorter lengths of slopes or where investigation techniques do not allow the waviness of bedding planes to be confirmed, it is recommended that analyses consider the lower bound shear strength parameters.

## CONCLUSIONS

Folding and subsequent shaping of the land by erosion have resulted in bedding within the Waitemata Group, and the clay seams which parallel them, dipping gently downslope in most places. As a result, the potential for sliding on clay seams needs to be addressed as part of site investigation and design for development on or adjacent to Waitemata Group slopes. Where it can be demonstrated that such clay seams are stepped and exhibit 'waviness' both in orientation and continuity, the use of average shear strength parameters (c' = 13 kPa and o' = 13°) is considered appropriate. However, where short distances are affected or where investigations are not able to prove waviness, lower bound parameters should be used (c' = 0 kPa and o' = 8 kPa).

## ACKNOWLEDGEMENTS
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**ADDENDUM**

Triaxial compressive strength and shear box shear strength tests were carried out with the aim of providing a direct measure of the soil/rock strength for application to land stability analyses. A large number of the samples were tested for residual strength beyond the point of failure using the shear box testing apparatus. The aim was to measure the likely residual strength following initial shearing. Tests were carried out by a range of laboratories in New Zealand and the United States, including Envirolab-Geotest, Worley (now Meritec), Babbage, Geotechnics, University of Auckland and Georgia Tech. Consequently sample size and test method has varied according to the nature of each sample and in-house standards applied by each laboratory. All in-house standards for shear box tests are however based on ASTM D3080. In general, extruded samples were trimmed to 75mm or 60mm diameter depending on the apparatus used. Loading rates of 0.01to 0.02 mm/minute were used.