# The Casagrande plasticity chart – does it help or hinder the NZGS soil classification process?

K J Hind
Tonkin & Taylor Ltd, Auckland, NZ.
khind@tonkintaylor.co.nz (Corresponding author)

Keywords: Casagrande, plasticity chart, soil classification

## ABSTRACT

A routine part of any geotechnical investigation is the classification of the recovered soils. In New Zealand this should be undertaken in the field in accordance with the New Zealand Geotechnical Society's guidelines. There is a general expectation that laboratory-based methods should both verify and enhance those classifications obtained in the field, yet it is not uncommon for the two to differ significantly. Field and laboratory data for fine-grained inorganic soils from across Auckland have provided an insight into the nature, magnitude and likely origins of these differences. It is demonstrated that field logging and the plasticity chart commonly assign the same materials to different soil groups. This appears to originate from the majority of soils being fundamentally plastic in nature yet displaying physical properties noticeably different from that expected for a clay due to the significant non-clay fraction. Furthermore the plasticity chart cannot be used to classify soils in accordance with the New Zealand taxonomy. As a result intermediate soil classifications incompatible with the plasticity chart are typically assigned in the field. Recommendations are given with respect to developing a stand-alone New Zealand-specific classification system and the use of both field and laboratory data.

## 1 INTRODUCTION

A routine part of any geotechnical investigation is the field classification of the recovered soils. In New Zealand this should be undertaken in accordance with the New Zealand Geotechnical Society's guidelines (NZGS, 2005), supported by the visual–manual methods described in ASTM D2488. Laboratory testing in support of the field determinations is typically undertaken on only a very small proportion of the total available material. In the case of fine-grained soils, the Casagrande plasticity chart may be used in conjunction with the Atterberg Limit tests to distinguish basic soil types.

There is a general expectation that laboratory-based methods should both verify and enhance those soil descriptions and classifications obtained in the field. Yet it is not uncommon for the two to differ significantly. This is particularly true for Auckland's fine-grained soils, where the same material may be assigned by the two methodologies to entirely different soil groups. An expectation of convergence can encourage some practitioners to modify field logs to better reflect the laboratory data in the belief that the field classifications are somehow erroneous. Yet a close examination of NZGS (2005) and the Unified Soil Classification System (USCS) indicates that it is taxonomical differences, and not user error, that are the primary reason for the different outcomes. Rather than forcing a convergence, it is better to recognise that field and laboratory classifications are separate non-equivalent processes.

This paper uses a database of some of Auckland's fine-grained inorganic soils to investigate the nature, magnitude and likely origin of the differences that can be observed between field-based and laboratory-based classifications. In particular it evaluates whether use of the Casagrande plasticity chart is helping or hindering the soil classification process for Auckland's soils.

## 2 THE CLASSIFICATION OF FINE-GRAINED SOILS

Fine-grained soils are comprised of varying proportions of clay, silt, sand and organic matter, together with a typically minor quantity of coarser material. Early soil taxonomy was developed largely for agricultural purposes, with soil groups defined by the relative abundance of their constituent particles (Casagrande, 1948). Attempts were made to adopt these systems for geotechnical purposes, however it was evident by the mid-20th Century that the engineering behaviour of fine-grained soils was poorly correlated with grain size. Arthur Casagrande argued that plasticity was the most important characteristic of fine-grained soils and that this, rather than grain size, should be the basis of a new soil classification system to be used for engineering purposes (Casagrande, 1948). Initially developed as part of the Allied effort during WWII, Casagrande's Airfield Classification System (ACS) would eventually become the Unified Soil Classification System (USCS), the parent of many modern engineering-oriented soil classification systems including NZGS (2005), AS 1726 and BS 5930.

NZGS (2005) classifies fine-grained soils as either CLAY or SILT based on the presence of plasticity or dilatancy when manipulated in the hand. Intermediate or hybrid soil names are assigned to those soils that exhibit distinct physical characteristics associated with a subordinate fraction. Examples given in NZGS (2005) include Sandy CLAY, Silty CLAY and Clayey SILT. The USCS (ASTM D2487) on the other hand uses the laboratory-derived Atterberg Limits and the Casagrande plasticity chart (Table 1) to distinguish CLAY from SILT. Clays generally plot above the plasticity chart's A-Line, whereas silts generally plot below it. Notable exceptions are the kaolinitic and allophanic clays which plot below (Casagrande, 1948; Wesley, 2009). The USCS does not use intermediate soil names in the same manner as NZGS (2005), although the term Silty CLAY is used for the very narrow zone in the lower corner of the plasticity chart where two soil groups overlap. ASTM D2488 provides some guidance on the field description of fine-grained soils, however the USCS is fundamentally a laboratory-based process.

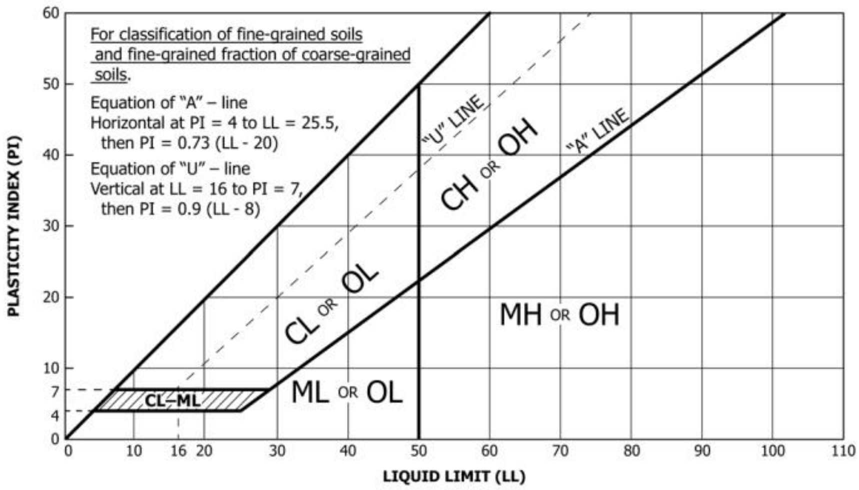
It is important to note that the terms clay and silt refer to the clay-like and silt-like characteristics of a soil rather than grain size. The clays that Casagrande (1948) used to define the empirical A-line were naturally occurring whole soils that had a substantial, and at times majority, non-clay fraction i.e. a majority clay content is not a prerequisit for a soil to plot above the A-Line. Although NZGS (2005) states that it is based on the USCS (ASTM D2487), there are a number of fundamental differences between the two including the following:

- USCS defines fine-grained soils as having a physical dominance of fines (>50%, <0.075mm), whereas NZGS (2005) requires only a 35% fines content (<0.060mm) for a soil to be classified as fine-grained.
- Soil group boundaries are clearly defined in USCS, whereas in NZGS (2005) they are not. The former is based directly on the Atterberg Limits, whereas the latter are based primarily on perceived material behaviour (e.g. CLAY or SILT) with some recognition of composition (e.g. Sandy CLAY).
- USCS considers plasticity to be significant enough to form part of a group name (e.g. Lean Clay, Fat Clay), whereas NZGS (2005) has plasticity only as a qualifying term in the description and not in the classification itself (e.g. CLAY. High plasticity).
- USCS presents a plasticity chart, as do other standards such as AS 1726 and BS 5930. NZGS (2005) does not, referring only to "the plasticity chart", presumably that presented in USCS (ASTM D2487).

The lower fines content threshold used in NZGS (2005) is an acknowledgment that some soils exhibit the fine-grained characteristics even though coarse-grained material is physically more abundant. This difference means that clayey or silty soils with a 50 to 65% sand content will be classified as coarse-grained according to the USCS, but fine-grained according to NZGS (2005). Casagrande (1948) would not have included such soils in the development of the plasticity chart.

**Table 1: USCS – inorganic fine-grained soils component only (ASTM D2487, ASTM D2488 and Casagrande, 1948)**

| Liquid Limit | Plasticity Index relative to A-line | Soil class and plasticity | Code |
|---|---|---|---|
| Liquid Limit <50% (L) | On or above | **Lean Clay**<br>Inorganic clays, sandy clays, silty clays, lean clays. Low to medium plasticity, no or slow dilatancy. | CL |
| | Below | **Silt**<br>Inorganic silts and very fine sands, rock flour, silty or clayey fine sands. Slight plasticity to non-plastic, slow to rapid dilatancy. | ML |
| Liquid Limit >50% (H) | On or above | **Fat Clay**<br>Inorganic clays, fat clays. High plasticity, no dilatancy. | CH |
| | Below | **Elastic Silt**<br>Micaceous or diatomaceous fine sandy and silty soils, elastic silts. Low to medium plasticity, no to slow dilatancy. | MH |
| Liquid Limit <30% (L) Plasticity Index 4 to 7% | Not applicable | **Silty Clay**<br>Mixed zone where both CL and ML soils plot | CL-ML |




It is not clear from a reading of NZGS (2005) whether intermediate soil names represent a continuum between CLAY and SILT or whether they are subsets of them. For example, does a Clayey SILT first have to satisfy the dilatancy requirement of SILT before "Clayey" is added in recognition of some minor cohesive component, or can it be a term applied to a plastic clay-silt mixture in which silt is clearly dominant but dilatancy is not a characteristic? The former would likely plot below the A-Line whereas the latter would likely plot above it. As a "low plasticity Clayey SILT" (with no reference to dilatancy) is presented as an example classification in NZGS (2005), it would appear that the soils are considered to be a continuum.

## 3 THE IMPORTANCE OF SOIL PLASTICITY

Plasticity is the putty-like property of a cohesive soil that allows it to be remoulded without rupture. Because higher plasticity soils exhibit this characteristic over a much wider range of moisture contents than do low plasticity soils, the Atterberg Limits are typically the basis on which plasticity determinations are made. Some classification systems define plasticity solely on the basis of liquid limit (e.g. AS 1726 and BS 5930) whereas others take into account both the liquid and plastic limits in the form of the plasticity index (e.g. Sowers, 1979). NZGS (2005) does not define plasticity with respect to a measurable parameter, referring instead to a soil's dry strength and ability to be remoulded.

NZGS (2005) defines plasticity as being either low or high, yet it is very common in New Zealand for the terms "moderate" or "medium" plasticity to be used in field descriptions. AS 1726 has long used such a three tier plasticity classification and its plasticity chart has commonly been used in New Zealand. Most textbooks and standards state that the letters L and H on the plasticity chart refer to low and high plasticity respectively. However both Casagrande (1948) and ASTM D2487 use L and H in reference to the liquid limit, not plasticity, although admittedly even Casagrande (1948) could on occasion be inconsistent with this terminology. It should be noted that medium plasticity is used within USCS (ASTM D2488) and Casagrande (1948) (see Table 1). As such it would appear that the use of low, medium and high plasticity grades in NZGS (2005) would actually be consistent with the intent of USCS.

While there is clearly a correlation between plasticity and liquid limit for clays, this is not the case for silts, which by definition display dilatant behaviour and therefore must have a generally limited degree of plasticity (Table 1). The literature typically describe silts as being dilatant yet USCS (ASTM D2487) defines elastic silts as having "no to slow" dilatancy, and both AS 1726 and BS 5930 allow for high plasticity silts. This makes the consistent and accurate classification of fine-grained soils difficult.

## 4 THE NATURE OF AUCKLAND SOILS

In simplified terms the soils of Auckland consist of residually weathered Miocene flysh (Waitemata Group), Pliocene to Recent alluvium (Tauranga Group) and weathered Quaternary basaltic pyroclastics (Auckland Volcanic Field). Although significant areas of the Auckland Isthmus have a thin or partial covering of weathered volcanic ash, these soils represent only a small minority of the field and laboratory data available. To aid interpretation, the database has been limited to the fine-grained soils from the Waitemata Group and the Tauranga Group. Organic soils and fills have also been excluded. The database consists of 124 samples for which both Atterberg limit and hydrometer data are available. Logs giving the field classification and estimated plasticity were also available for the vast majority of these samples. Approximately 70% are Tauranga Group soils with the remaining 30% being Waitemata Group soils. All samples come from projects undertaken within the Auckland urban area.

The textural composition of the soils is summarised in Figure 1. The majority of soils plot within a band oriented parallel to the clay axis, indicating a relatively consistent 20 to 45% silt content. Both the clay and sand contents are significantly more variable than silt. Relatively few samples show a substantial dominance of one component over the others. The mean clay, silt and sand contents of the database is 34%, 37% and 29% respectively. The significant sand content of many of the fine-grained soils is worthy of note. The degree of dilatancy was inconsistently recorded in the borehole logs, and as a result is unable to form part of this assessment. The vast majority of the database (85%) has at least 15% clay (Figure 1), the approximate level where cohesive characteristics might be expected.

The field-derived soil classifications (Table 2) are dominated by SILT, with 69% of the soils being classified as either SILT, Clayey SILT or Sandy SILT. Only 6% of the database was classified in the field as CLAY, all of which were also described as being highly plastic. This indicates that a low to medium plasticity state is interpreted in the field as being due to the presence of silt rather than clay with a lower activity.

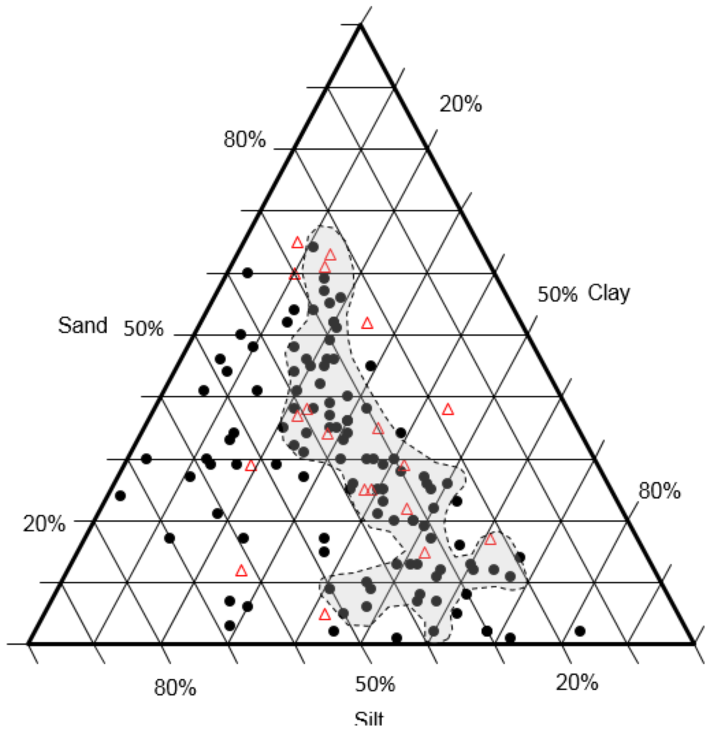



**Figure 1: Textural plot of soils used in this study. Contour encloses 4 or more data points per 10% triangle. Circles plot above the A-Line, triangles below.**

All samples in the database have been classified according to the USCS (ASTM D2487) plasticity chart (Figure 2 and Table 3). Two significant observations can be made. Firstly, the two systems give fundamentally different results in the majority of cases, with classifications determined by the plasticity chart being dominated by CLAY (82%) whereas field classifications, as we have already seen, are dominated by SILT (69%). Secondly, those soils that plot above the A-Line cannot be distinguished on the basis of their composition from those that plot below (Figure 1). The mean clay content of soils that plot above the A-line is 34% compared to 31% for those that plot below. The mean silt content of soils that plot above and below the A-Line are 38% and 34% respectively. Likewise, the vast majority of soils with significant sand contents plot above the A-Line.

**Table 2: Summary of field classifications (NZGS, 2005)**

| Sample Group | No. of Samples | Clay (%) | Silty Clay (%) | Clayey Silt (%) | Silt (%) | Sandy Silt (%) |
|---|---|---|---|---|---|---|
| All samples | 113 | 6 | 25 | 32 | 21 | 16 |
| Waitemata Group | 37 | 5 | 19 | 27 | 25 | 24 |
| Tauranga Group | 76 | 7 | 30 | 33 | 13 | 17 |
| Low plasticity | 42 | 0 | 0 | 7 | 11 | 14 |
| Moderate plasticity | 26 | 0 | 6 | 13 | 2 | 3 |
| High plasticity | 32 | 6 | 18 | 11 | 5 | 5 |

Note: not all laboratory samples had corresponding field plasticity descriptions

**Table 3: Summary of laboratory classifications (USCS, ASTM D2487)**

| Geology | No. of Samples | CL (%) | CH (%) | ML (%) | MH (%) | CL-ML (%) |
|---|---|---|---|---|---|---|
| All | 124 | 16 | 66 | 2 | 15 | 1 |
| Waitemata Group | 39 | 10 | 74 | 3 | 13 | 0 |
| Tauranga Group | 85 | 19 | 63 | 1 | 16 | 1 |

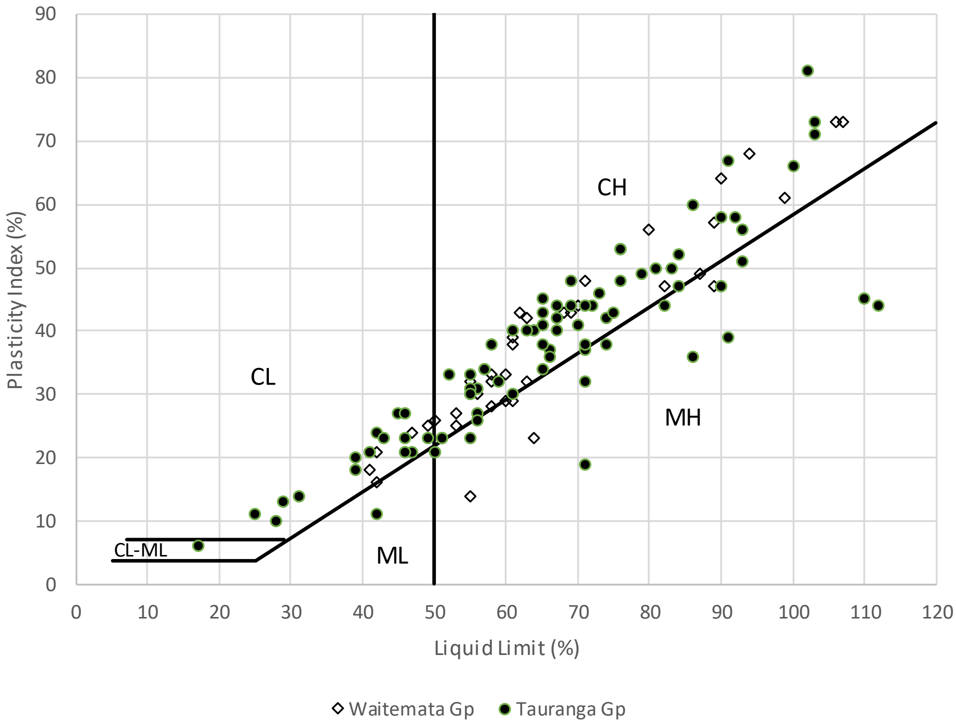



**Figure 2: Plasticity chart for all samples**

The NZGS (2005) soil groups do not form distinct fields within the plasticity chart but overlap along the length of the A-Line (Figure 3). It might be expected that as the silt fraction becomes significantly greater than the clay fraction, soils would be observed plotting below the A-Line, however there is no evidence of this occurring for Auckland's soils. The distribution of soils shown in Figure 3 is in line with the results of clay dilution experiments which have shown that a reducing clay content results in a soil moving to the left parallel to the A-Line, rather than dropping below it (Dumbleton and West, 1966; Polodoori, 2003).

The data supports the author's experience that even though Auckland's fine-grained soils are typically plastic enough to plot above the A-Line, they have a sufficient silt and sand component to noticeably depart in their physical properties from what can be considered a typical clay. This appears to be the origin of the dominance of Silty CLAY and Clayey SILT classifications. The plotting of so many soils logged as SILT above the A-Line does raise the question as to whether dilatancy is being taken into account sufficiently when such determinations are being made. Potentially many of these soils should be Clayey SILT or possibly even Silty CLAY.

## 5 A ROLE FOR THE PLASTICITY CHART WITH NZGS (2005)

With the NZGS (2005) soil groups not being based on the Atterberg Limits, it is apparent that the plasticity chart cannot fulfil the same classification role that is does in the USCS. Not only can NZGS (2005) soil names such as Clayey SILT not be derived from the plasticity chart, there is no means by which USCS soil groups derived from it can be converted into NZGS (2005) equivalents.

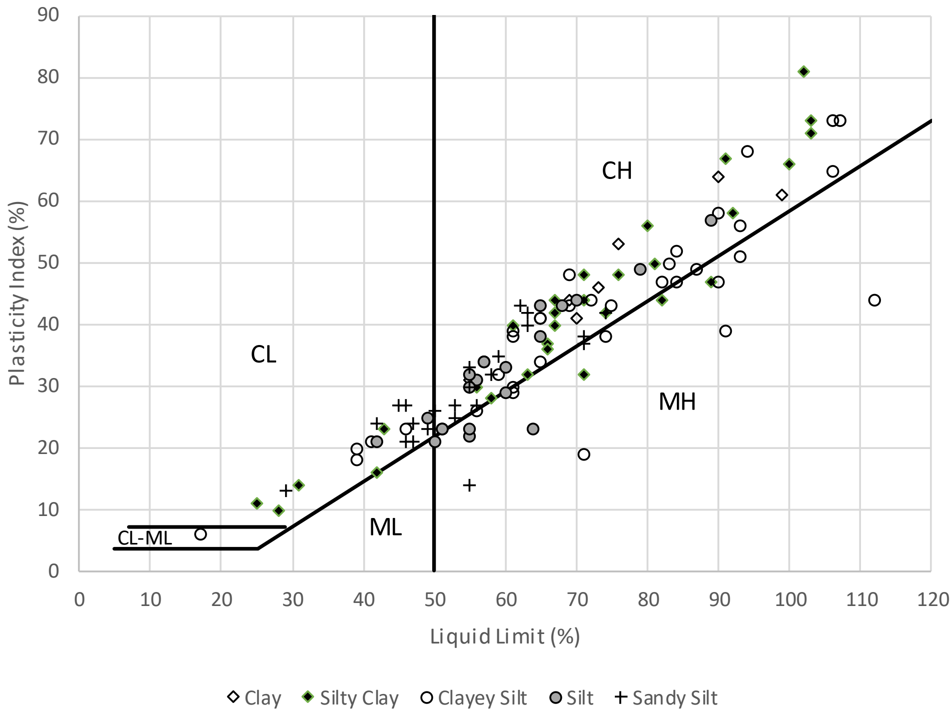



**Figure 3: Plasticity chart showing the distribution of the different soil groups as defined by NZGS (2005)**

NZGS (2005) suggests that if laboratory data is available, the plasticity chart can be used to distinguish clays from silts in the manner of USCS (ASTM D2487). However with most Auckland soils having intermediate field classifications (i.e. Silty CLAY and Clayey SILT), the plasticity chart can only be a half measure in terms of the classification process. Also, as has been demonstrated, the plasticity chart often does not correlate at all well with the field determinations. A choice of which to believe subsequently results.

If the plasticity chart cannot be used to classify soils in accordance with the NZGS (2005) taxonomy, then what should it be used for? The general rule still holds true that soils which plot below the A-line have more favourable engineering characteristics than those that plot above it (Wesley, 2009). As such the plasticity chart is a means of identifying potentially problematic geotechnical characteristics. Casagrande (1948) originally used the plasticity chart to characterise a soil's potential for compressibility. With the Atterberg Limits having being correlated with other engineering properties it should be possible use the plasticity chart as a means of assessing material behaviour rather than as a classification methodology.

## 6 CONCLUSIONS

The Casagrande plasticity chart has been used for more than 70 years to classify fine-grained soils in accordance with the USCS. New Zealand's soil classification system (NZGS, 2005) is largely field-based, however the plasticity chart remains part of the assessment process when laboratory data is available. Although NZGS (2005) is largely a derivative of the USCS, the plasticity chart is unable to classify soils according to the NZGS (2005) taxonomy because it effectively uses a continuum of soil groups incompatible with the binary system used in USCS (ASTM D2487). An assessment of soil data from across Auckland has shown that the field and laboratory-based systems typically classify fine-grained soils very differently. The majority are classified in the field as SILT, whereas these same soils are classified by the plasticity chart as CLAY. It would appear that the departure in behaviour of many of these soils from what would be considered typical of clay is resulting in plastic soils being classified as silts or silt-clay mixtures. Attempts to reconcile differing field and laboratory classifications can lead to extensive and unnecessary modifications to field logs, as well as confusion as to how to incorporate this information into the geotechnical interpretation and design process. In a number of respects therefore, the plasticity chart is not assisting and is potentially hindering the classification process. As a means of addressing these issues, it is recommended that the NZGS guideline document be revised to present the following:

- A stand-alone classification system fully independent of the USCS (ASTM D2487).
- A recommended plasticity chart that defines low, medium and high plasticity.
- A definition as to whether soil groups form a continuum between CLAY and SILT or whether they are subsets of them. In particular, the dilatancy or plasticity characteristics of soils such as Clayey SILT should be clearly defined.
- Guidance on the use and interpretation of the plasticity chart, although this is outside of the description and classification process for which NZGS (2005) was developed.

## REFERENCES

Standards Australia, AS 1726-2017. Geotechnical site investigations

British Standard, BS 5930:2015. Code of practice for site investigations

ASTM D2487-06.Standard Practice for Classification of Soils for Engineering Purposes (unified Soil Classification System)

ASTM D2488-09a. Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)

Casagrande, A. Classification and identification of soils. Transactions, ASCE, vol.113, 901-930.

Dumbleton, M.J. and West, G. (1966). Some factors affecting the relation between the clay minerals in soils and their plasticity. *Clay Minerals*, No. 6, 179-193

New Zealand Geotechnical Society (2005). *Field description of soil and rock. Guideline for the field classification and description of soil and rock for engineering purposes*. New Zealand Geotechnical Society Inc.

Polidori, E. (2003) Proposal for a new plasticity chart. *Geotechnique,* vol 53, No. 4, 397-406.

Sowers, G.F. (1979). *Introductory soil mechanics and foundations: geotechnical engineering,* 4th edition. Macmillan, New York.

Wesley, L. (2009) *Fundamentals of soil mechanics for sedimentary and residual soils*. John Wiley & Sons.