Transport Roads & Maritime Services

# TECHNICAL GUIDE L-G-003

## Plasticity testing

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# About this release

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# Contents

# Plasticity Testing

## Preface

This guide covers the following test methods;

T108 Liquid Limit of Road Materials

T109 Plastic Limit and Plasticity index of Road Construction Materials.

T113 Linear Shrinkage of Road Construction Materials

## 1. Introduction

Plasticity testing is a basic measure of the nature of fine particles of a soils, <0.425 mm. Depending on the moisture content of a soil, it will appear in one of four states; solid, semi solid, plastic and liquid. If sufficient water is mixed with a soil it can be made into a slurry and behaves as a thick or viscous liquid. This is known as the liquid state. If the moisture content is reduced by drying out slowly, the soil eventually begins to hold together and offers some resistance to deformation. This is known as the plastic state. With further loss of moisture the clay shrinks and stiffness increases until there is no plasticity and it becomes brittle. This is known as the semi solid state. After drying continues the clay shrinks in proportion to the amount of water loss, until it reaches a minimum volume. This is called the solid state. The change from one state to another is not observed as a distinct boundary, but takes place gradually. The arbitrary boundary from the semi-solid state to the plastic state is known as the plastic limit and is defined as its moisture content. The arbitrary boundary from the plastic state to the liquid state is known as the liquid limit and is defined as its moisture content.

In each state the consistency and behaviour of a soil is different and so are its engineering properties. Plasticity testing quantifies the boundaries between semi solid and plastic – the Plastic Limit (PL) and plastic and liquid – the Liquid Limit (LL).

**Table 1: Basic engineering principals of soils relating to plasticity**

| High plasticity soils | Low plasticity soils |
|---|---|
| Usually exhibit large volume change with change in moisture content | Exhibit small volume change with changes in moisture content |
| Generally have very low permeability | Generally have higher permeability |
| Have high clay content | Have low clay content |

The Plasticity Index (PI) is a measure of the plasticity of a soil. The PI is the difference between the Liquid Limit and the Plastic Limit (PI = LL – PL). Soils with a high PI tend to be clays, those with a lower PI tend to be silts and those with a PI of 0 (non-plastic) tend towards sands with little or no clay or silt.

# 2. Definitions

| | |
|---|---|
| Liquid Limit: | The moisture content where the material changes from a plastic to a liquid state. |
| Plastic Limit: | The moisture content where the material changes from a plastic to a solid state. |
| Plasticity Index: | The difference between the Liquid Limit and the Plastic Limit. |
| Linear Shrinkage: | The decrease in length of the dry specimen expressed as a percentage of the original length of the wet specimen. |

# 3. Test Methods

## 3.1 T108 – Liquid limit of road materials

This test method determines the Liquid Limit of a soil, this is the moisture content where the material changes from a plastic to a liquid state.

This test is identical to AS1289.3.1.1 with extra amendments generally related to further mixing of the sample.

The test is a four point test that uses the material at four different moisture contents to graph and then determine the liquid limit.

To conduct the test the following apparatus is required:

- A thick, rigid, mixing plate that is non-absorbent, usually etched glass (see Figure 1)
- A suitable mixing bowl with a close fitting lid to prevent the material drying out (see Figure 2)
- Palette knives of a suitable size for mixing and spreading of the sample.
- A Liquid Limit device that conforms with the Australian Standard AS1289.3.1.1, this is commonly called a Casagrande device after the developer of the equipment (see Figure 3)
- A grooving tool and 10 mm gauge, generally together on the same tool (see Figure 4)
- A thermostatically controlled oven with good air circulation, capable of maintaining a temperature with the range of 105° to 110°C
- Potable water (Note: Beware that some types of clay can be affected by poor quality water).

**Figure 1: Glass mixing plate and palette knives**

**Figure 2: Mixing and curing bowl with a secure lid (Note sample curing with an identification label)**

**Figure 3: Liquid Limit (Casagrande) device**

**Figure 4: Two different types of Grooving Tool (left end) and 10 mm Gauge (right end)**

The Liquid Limit test starts with the sample preparation. The sample must be dried to the extent it can be crumbled such that the aggregations in the material can easily be broken between one's fingers. It is not necessary or desirable to completely dry the sample as materials with gypsums and organic silts may undergo drastic changes if dried to constant mass.

The crumbling stage requires the material to be placed in a mortar and rubbed with a rubber pestle until all aggregations have been broken. This material is then placed over a 19 mm sieve, with the +19 mm material brushed to remove any adhering fines. It is extremely important for all fines to be included in the test portion, clayey material tends to stick to the larger particles and this material needs to be removed from larger particles to ensure it is included in the test. The -19 mm material is divided to provide sufficient material and then crumbled again with screening over the 2.36 mm sieve. The -2.36 mm material is then crumbled and screened over the 425 µm sieve to provide sufficient material for the test. The last stage of the preparation process is to divide the material until about 250 g remains.


**Figure 5: Liquid Limit material after preparation, now ready for testing**

The next part of the process is to mix water into the sample until the material becomes a thick homogeneous paste (ie when the material is placed in the Liquid Limit device the groove closes at about 30 – 40 blows). To ensure the paste is homogeneous it is very important that the mixing regime is strictly followed. Water must be added to the prepared material in small increments with at least three minutes of thorough mixing, after each additional increment, by using firm pressure of the palette knife against the side of the bowl or the mixing plate. Clays may require longer mixing of five minutes or more to obtain uniform distribution of moisture. When the moisture content is sufficient to close the groove at 30 to 40 blows the material is put in the bowl, covered and allowed to cure at room temperature for at least twelve hours. Heavy clays may require several days to adequately cure. After an adequate curing period the material is once again thoroughly mixed.

Check the drop height of the liquid limit device cup is 10 mm ± 0.25 mm. This is checked using the height gauge at the end of the grooving tool. At the same time check the contact between the cup and rubber base is clean and free from any soil or water that may affect the actions of the blows.

A portion of the cured sample is now placed in the cup of the liquid limit device and the cup must be resting on the rubber base. The mixture is levelled off parallel to the base using firm downward pressure with the palette knife (see figure 6). This downward pressure must be sufficient to prevent the inclusion of air voids within the sample and result in a depth of about, but not greater than, 10 mm of material in the cup.

**Figure 6 Liquid Limit material placed in the cup ready for testing.**

Divide the soil pat by drawing the grooving tool along the diameter of the centre line of the cup. The creation of this groove must be done in one continuous movement, repeatedly drawing the tool backwards and forwards to form the groove may, especially in lower plasticity soils, redistribute moisture in the soil cake and lead to an incorrect determination of the liquid limit.

**Figure 7: Liquid Limit material with groove ready for cranking**

The device is to be held on the bench and the crank turned at the rate of two revolutions per second until the two parts of the soil come into contact along the bottom of the groove for a distance of 10 mm. The contact length can be checked with the end of the grooving tool. The number of blows required to close the groove for 10 mm is recorded and for the start of this test should be between 30 and 40 blows. If more blows are required another increment of water must be added, material mixed for at least three minutes and the test repeated. If less than 30 blows closes the groove the soil must be air dried (including thorough mixing) prior to repeating the test. If dry fines need to be added due to the material being too wet, a further 12 hours of curing must be completed before the test proceeds.

When the groove closes at 30 to 40 blows the material is put back into the mixing bowl, remixed for 30 seconds and then retested. The entire liquid limit device must be cleaned prior to every test stage. If the number of blows required to close the groove to 10 mm varies by more than one blow, indications are the material has not been mixed sufficiently and the test must be fully repeated.

**Figure 8: Liquid Limit material with the groove closed at 10mm**

When we have a sample where the groove closes between 30 to 40 blows and the repeat test varies by no more than one blow the moisture content is determined. The moisture content sample is taken from the zone of the groove where the two portions have flowed together.

**Figure 9: Taking a representative sample for moisture content**

The moisture content sample must be at least 10 g and determined in accordance with Roads and Maritime test method T120. The minimum mass requirements of T120 are smaller in plasticity testing as the mixing process ensures that moisture is uniformly distributed throughout the entire sample.

T108 is a four point method, and when one point is achieved all the above is repeated at slightly higher moisture contents. The intent of the test is to have four evenly spaced moisture contents over a range of between 40 and 15 blows.

The test always proceeds from a drier to a wetter condition of the sample and after each addition of extra increments of water the material must be mixed for at least 3 minutes.

When the four moisture contents have been determined the results are plotted to determine the Liquid Limit of the sample (see Figure 10)

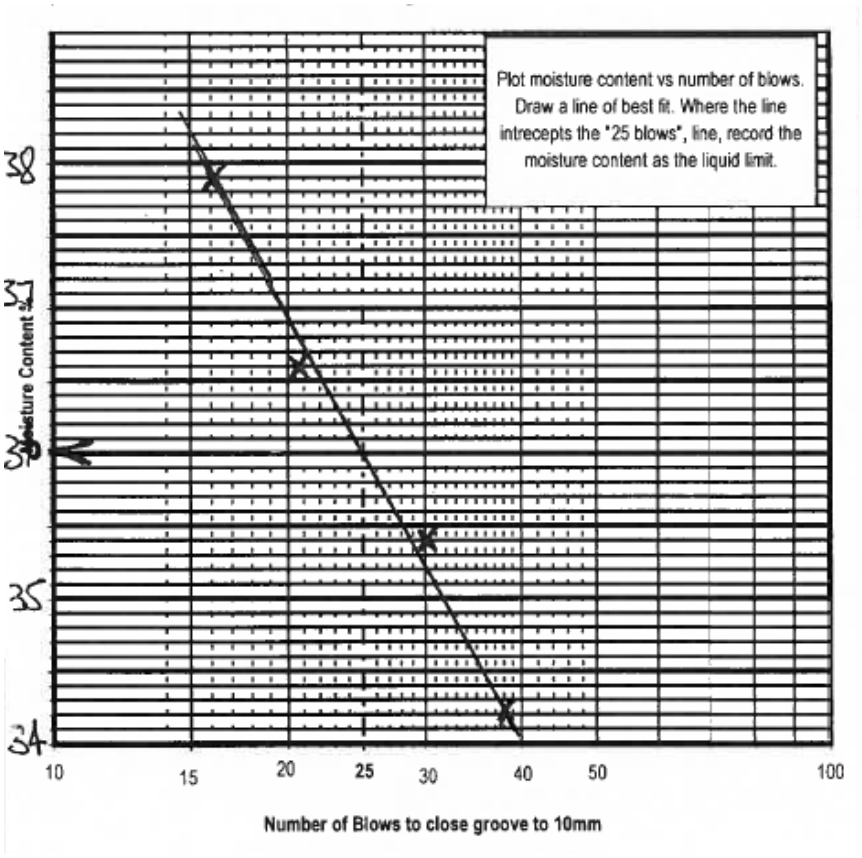


**Figure 10: A plot of the moisture content against the number of blows to close the groove at 10 mm**

The moisture contents and corresponding number of blows are plotted on a semi-logarithmic graph as shown in figure 10, with the moisture content on a linear scale and the number of blows on a logarithmic scale. A line of best fit is drawn through the plotted points and the moisture content that equates to 25 blows is the Liquid Limit and reported to the nearest whole number. In the example shown in Figure 10 the Liquid Limit is 36%.

## 3.2 T109 – Plastic limit and plasticity index of road construction materials

This test method determines the Plastic Limit of a soil, where the moisture content of the material changes from a plastic to a solid state. This test is identical to AS1289.3.2.1 (PL) and AS1289.3.3.1 (PI).

Preparation of the sample is identical to the preparation for T108. Current practise is to use the T108 sample to produce material for the Plasticity testing after the sample has been mixed and cured

To conduct the test, similar apparatus to T108 is required, with the exception of a liquid limit device and the addition of a rod of 3 mm diameter and about 100 mm long. Sometimes this rod is attached to a glass plate as shown on Figure 11.


**Figure 11: Glass plate to roll threads and another glass plate with two 3 mm rods used as a 3 mm gauge. (Note the asset number on the glass rolling plate which provides traceability to the calibration checks of the 3 mm rods)**

Approximately 40 g of material is kneaded between fingers and palm or rolled between the glass plate and hand. This manual kneading slowly reduces the moisture content of the material but ensures that the soil remains homogeneous. The kneading process continues until slight cracks appear on the surface.

This cracking indicates the material has dried back sufficiently to check for the Plastic Limit. About 8 g of material is rolled into a thread and if the material crumbles before it reaches 3 mm diameter, it is too dry and more water is added to the entire sample, remixed and kneaded thoroughly. If the thread rolls down to 3 mm without crumbling the material requires more kneading to slowly dry back a little more.


**Figure 12: Material is rolled to 3 mm and in this case the material is still too wet and more kneading and rolling is required**

When the thread crumbles at 3 mm diameter the Plastic Limit has been reached. The broken threads are collected into a tared moisture content container, which should be covered to prevent moisture loss. Another approximately 8 g of material is taken, rolled until it also crumbles at 3 mm, this material is added to the moisture content container until between 5 g and 20 g of material is collected. This is then weighed and a moisture content determination (T120) is carried out.

When threads of 3 mm cannot be rolled owing to the lack of cohesion of the material the Plastic Limit cannot be determined and this is reported.

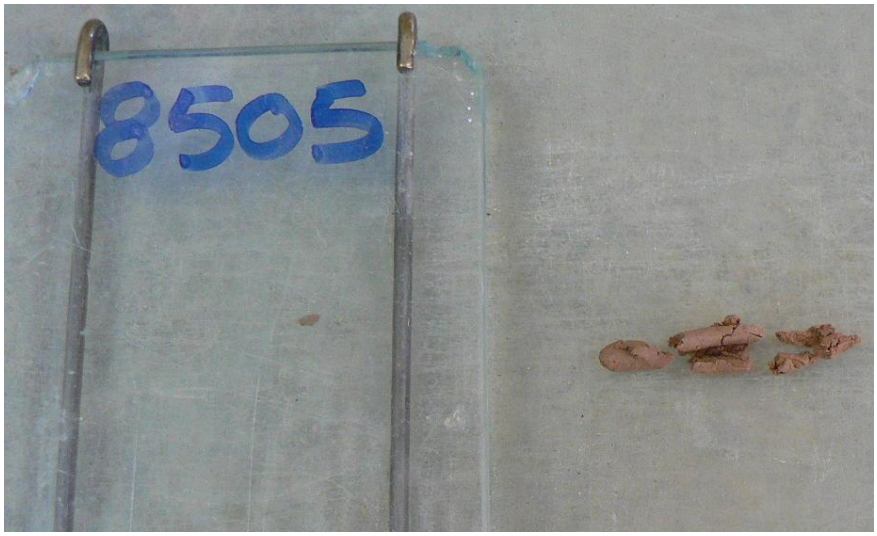


**Figure 13: Material at the Plastic Limit, when crumbled at 3 mm diameter**

A completely separate duplicate Plastic Limit determination as above must be made. If the results differ by more than 2% in their moisture contents the entire test must be repeated.

The two conforming moisture contents are averaged to produce the Plastic Limit of the material and this is reported to the nearest whole number.

Plasticity Index is not a test method but a simple calculation where **PI = LL – PL**

When the liquid limit or the plastic limit cannot be determined the plasticity index should be reported as NP (non-plastic), together with the liquid or plastic limit, which ever result has been determined.

When the plastic limit is equal to or greater than the liquid limit the plasticity index should be reported as 0 and both the liquid limit and plastic limit reported.

## 3.4 T113 – Linear shrinkage of road construction materials

The linear shrinkage is defined as the decrease in length expressed as a percentage of the original length when a sample of soil is oven-dried from a moisture content at approximately the liquid limit.

Although not part of any Roads and Maritime Services specification, linear shrinkage is a very important test. It can be used as a control medium for road construction materials and also as an index of susceptibility to volume change. The test is reasonably simple to perform and is usually run in conjunction with the plasticity tests.

To conduct the test the following apparatus is required (see Figure 14);

- A thick, rigid, mixing plate that is non-absorbent, usually etched glass or mixing bowl

- A metal shrinkage mould, in the form of a semi-circular trough, 250 mm internal length (nominal) and 25 mm internal diameter
- Palette knives of a suitable size for mixing of the sample
- Small airtight sealable containers
- A ruler
- Mould release agent (e.g. petroleum jelly, castor oil)
- A thermostatically controlled oven with good air circulation, capable of maintaining a temperature with the range of 105° to 110°C.

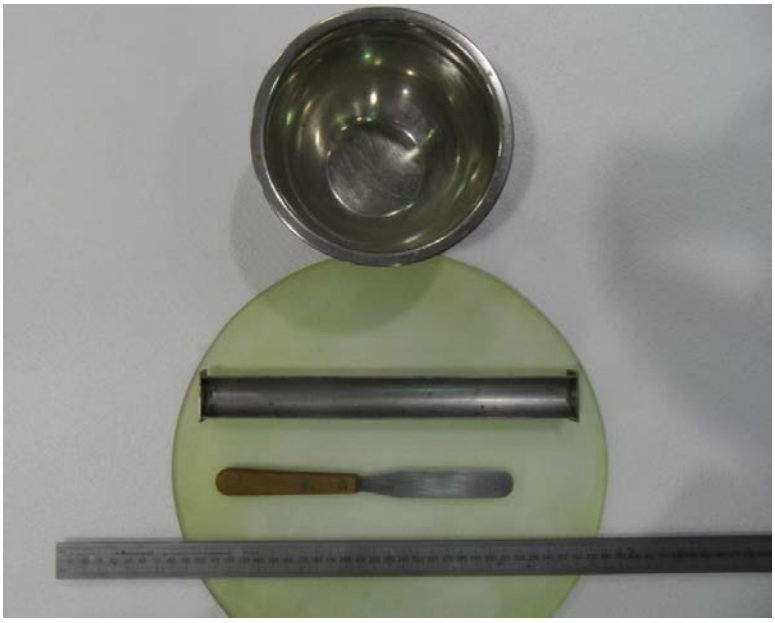

**Figure 14: The shrinkage testing apparatus**

The material required for testing is the same as for plasticity testing, the fraction of soil passing the 0.425 mm sieve, and should be prepared exactly the same way. The material has small increments of water added, then well mixed, more small increments of water & more mixing until an assessment in the Casagrande bowl shows the groove to close 10 mm at 25 ±3 blows. Then the material is sealed in a container and allowed to cure for at least 12 hours. Heavy clays may require a longer curing period.

After curing the material is thoroughly mixed for at least 1 minute, then checked again in the Casagrande bowl. The addition of small increments of water and extra mixing may be needed to bring the material close to its Liquid Limit.

This test can be done in conjunction with T108.

**Figure 15: Wet specimen in mould before drying**

Fill the lightly lubricated shrinkage mould with the soil sample, overfilling the mould slightly. Give the mould some light taps on the bench to remove air bubbles. Then screed off the excess material and clean off any material adhering to the edges of the mould.

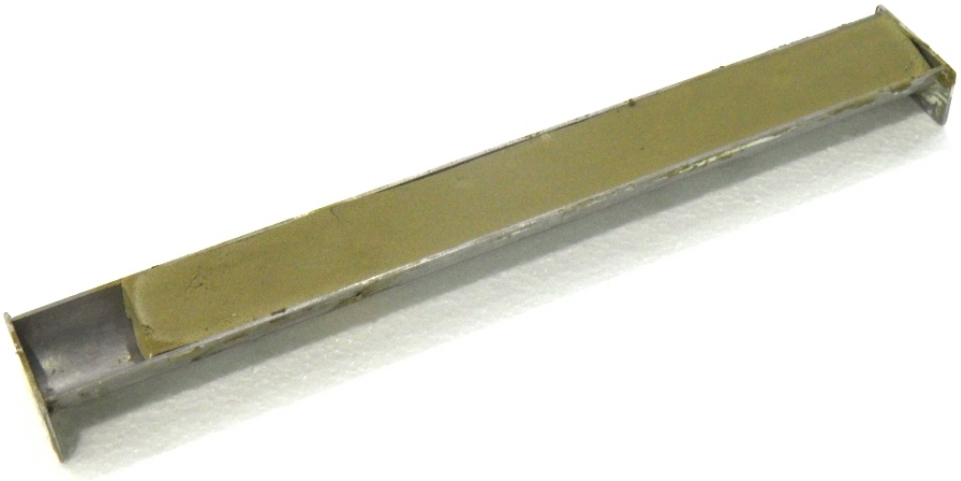

**Figure 16: Dry specimen in mould with a 12% shrinkage value**

The mould and material is then allowed to air dry for at least 24 hours and then placed in the oven for at least 16 hours.

**Figure 17: Dry specimen curled in the mould indicating fast drying**

If the wet sample is not allowed to air dry the material is likely to curl and break (refer to Figure 17), making the measurement of the shrinkage determination difficult. The air drying should continue beyond 24 hours if a change in colour has not been seen.

After oven drying a measurement of the dry specimen is made, if there are cracks, the separate parts should be pushed together gently before measuring, to the nearest 1 mm. If the specimen has curled significantly, both inside and outside of the specimen should be measured and the average taken.

The calculation for linear shrinkage is:

$$LS = \frac{(L - L')}{L} \times 100\%$$

Where:

$LS$ = Linear Shrinkage of the specimen (%)

$L$ = Internal length of shrinkage mould (mm)

$L'$ = Length of dry specimen (mm)

Reporting of the shrinkage is to the nearest 0.5%.

# 4. Conclusions

The following are key features of testing of soils for plasticity:

- The bulk sample must be divided properly and simply scooping out of a mass of material is not correct sample division. A bulk sample must be reduced by a recognised method (T105 A3) so that the portions for testing have identical properties as the original sample.
- At the preparation stage materials should not be dried completely. Some materials, especially those with organic silts, are very hard to get the moisture back into it.
- Fines adhering to coarse material must be collected by brushing at the preparation stage. These fines are very likely to be highly plastic fines and must be included in the test.
- Moisture increments must be mixed into the material properly and at least three minutes mixing and longer for highly plastic materials.

- Equipment must be calibrated properly and checked regularly for excessive wear.
- The 10 mm drop of the liquid limit device cup must be checked frequently.
- If the material for the Plastic Limit test is too wet, the material should be spread thin on the glass plate and allowed to dry back with frequent mixing. Dry fines must not be added unless the sample is cured for a further 12 hours, because of mixing and curing problems.
- Some materials, especially those that are cohesionless, tend to slip in the cup instead of flowing so that the groove closes at a false, lower number of blows. If this occurs, the results should be discarded and the test repeated. If slipping still occurs more water should be added until this slipping ceases. If slipping continues to occur the liquid limit cannot be determined the soil is considered to be non plastic and the plastic limit need not be determined. If unsure if the material is slipping (or not) Figure 8 shows a closure at 10 mm, this is evidenced by the bulging of the material. Materials that slip generally do not bulge.
- Soil with low plasticity usually indicates a high content of silt, while high plasticity corresponds to high clay content
- Linear shrinkage specimens must be initially dried slowly before being placed in an oven. This initial drying prevents cracking and curling.

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