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FALL CONE METHOD USED TO DETERMINE THE LIQUID LIMIT OF SOIL

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16. ABSTRACT

This study investigated the use of the fall cone as a viable means for determining the liquid limit of soil. A literature review was performed, and the results of that review were summarized. The fall cone method has several advantages over the traditional Casagrande method. It is slightly easier to maintain, it is less sensitive to manufacturing variations, it yields more reproducible results, it is less operator sensitive, and it can be used to determine the liquid limit on certain low plasticity soils which the Casagrande method will not accommodate. The method has potential uses in both plastic limit determination and in shear strength measurement.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*-- soil/soil tests/ Atterberg limits/ liquid limit/ plastic limit/ drop cone/ fall cone cone penetrometer/ shear strength/ drop cone penetrometer

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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INTRODUCTION

For many years, the liquid limit of soils has been determined using Casagrande's liquid limit device. This method is still the standard in the United States, but in other parts of the world, the fall cone* has, in recent years, become widely used. The fall cone method is said to eliminate most of the drawbacks of the Casagrande method, and results in improved accuracy and repeatability. Since the method has the potential for improving the test, and is receiving widespread attention in other parts of the world, it was determined that the Bureau (Bureau of Reclamation) should evaluate the potential benefits of using the fall cone method for liquid limit determination. That is the purpose of this report.

CONCLUSIONS

1. The fall cone method does not result in a significantly faster testing turn-around time than is possible with the Casagrande method.

2. The fall cone apparatus is slightly easier to maintain in correct adjustment than the Casagrande apparatus.

3. Both the fall cone method and the Casagrande method are sensitive to equipment manufacturing variations. The fall cone method appears to be less sensitive to these variations than the Casagrande method.

4. The fall cone method yields more reproducible results than the Casagrande method.

5. The fall cone method allows a liquid limit determination to be made on certain low plasticity soils which cannot be tested using the Casagrande method.

6. The fall cone method is less operator sensitive than the Casagrande method.

7. It might be possible to correlate the plastic limit with some penetration value using the fall cone apparatus.

8. Use of the fall cone method has the potential to enhance understanding of soil shear strength near the liquid limit.

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* The term "fall cone" is used in this report. There are a number of other terms in common use, including "cone penetrometer", "drop cone", and "drop cone penetrometer", which refer to the same test method. The term "fall cone" was selected to avoid possible confusion with cone penetrometer equipment used to determine in-situ strength properties.

RECOMMENDATIONS

In consideration of the above conclusions and the fact that the fall cone method is enjoying a growing acceptance (particularly in Europe), it is recommended that the Bureau acquire a fall cone apparatus and that correlation studies be conducted.

It is also recommended that a study be conducted to investigate the possibility of using the fall cone apparatus to determine the plastic limit of soil.

CASAGRANDE METHOD

When Atterberg developed the liquid limit test in 1911, it was extremely susceptible to operator error. In 1932, Casagrande developed a mechanized apparatus with which to run the test which reduced the operator sensitivity of the test [1]*. The apparatus is still in use today and is the basis for the Bureau's liquid limit test (USBR Designation E-7) [2] (see fig. 1).

The liquid limit of a soil is determined, using the Casagrande apparatus, by measuring the moisture content at which a standard groove in a minus No. 40** (425 µm), pre-moistened soil pat, will flow together for a distance of 13 mm (½ in) under the impact of 25 blows. The Bureau typically uses the one-point method (alternate procedure) which allows the test to be completed much more rapidly than the original method requiring 3 to 5 points.

Although the Casagrande method has served the geotechnical engineering community well for many years, it is not without its limitations and inaccuracies. Some of the faults of the present test are:

- The difficulty of cutting a groove in certain soils.
- The tendency of low plasticity soils to slide along the surface of the cup rather than flow plastically.
- The tendency of certain low plasticity soils to liquefy when subjected to impact.
- Sensitivity to small manufacturing or wear differences in the apparatus.
- Sensitivity to operator technique in preparing the soil, adjusting the apparatus, and performing the test.

These and other problems have been identified by a number of investigators [3, 4, 5].

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* Numbers in brackets refer to entries in the Bibliography.
** U.S.A. Standard Series Sieve Designation.

FALL CONE METHOD

In the fall cone method, the liquid limit is taken as the moisture content at which a standard 30 degree, 80 g cone will penetrate the soil sample a distance of 20 mm in approximately 5 sec. [6]. Although various cone configurations have been used, the cone described above is the one used by the British Standards Institute, and is by far the most widely used (see fig. 2).

Advocates of the fall cone method have reported a number of advantages of that method over the Casagrande method. They include the following:

1. The fall cone method is quick and simple to perform.
2. The fall cone apparatus is easier to maintain in correct adjustment.
3. The fall cone method is less sensitive to equipment manufacturing variations.
4. More reproducible results are obtained with the fall cone method.
5. The fall cone method yields more reliable liquid limit values for low plasticity soils.
6. The fall cone method is less operator sensitive.

COMPARISON OF THE METHODS

In the following paragraphs, the Casagrande and fall cone methods will be compared in relation to the points mentioned above.

1. The fall cone method is quick and simple to perform [4,6,7].

   While actual performance of the test appears to be somewhat quicker and simpler with the fall cone, the more time consuming parts of the test such as mixing, curing and drying the soil are the same for both tests. The overall time required to complete the liquid limit test by the two methods is not significantly different.

   The fact that the one-point variation of the Casagrande method is widely accepted [8] would seem to give that method a clear overall time advantage. However, a one-point fall cone liquid limit test [9] has been proposed. If this proves viable, a clear time advantage of one method over the other is not apparent.

2. The fall cone apparatus is easier to maintain in correct adjustment [6].

The use of the Casagrande apparatus requires that the operator check or adjust the following items: height of drop, cup wear, base wear, and grooving tool wear. Use of the cone apparatus requires that the operator check the cone for wear and that the dial gage be properly calibrated. The cone procedure seems to have the advantage in this case, but it is not difficult or time consuming to maintain either apparatus correctly.

3. The fall cone method is less sensitive to equipment manufacturing variations [3,5].

It is well documented that manufacturing variations have produced test data variation with the Casagrande device [1,3,10,11]. Such differences as base hardness, cup thickness, cam follower variation, and grooving tool differences can have a significant impact on test results. In the case of the cone method, manufacturing tolerances have been judged to cause less severe variation in test results than with results obtained using the Casagrande method [3,5]. However, Houlsby [12] found that manufacturing variations could also have a significant effect on test results using the cone method. He found that the allowed cone-angle tolerance of $\pm 1°$ can affect the resistance by ± 6 percent while the cone bluntness allowed in reference [6] can increase resistance by up to 9.5 percent. (This bluntness-related error can be virtually eliminated by beginning the test with the mathematical apex of the cone at the soil surface.) He also found that the roughness of the cone surface was a potential source of even greater variation than either the cone apex angle or the bluntness, and recommended that the cone be made of polished stainless steel, cleaned and lightly oiled.

Although there is some disagreement on this matter, it appears that the fall cone method is less sensitive to manufacturing variations than the Casagrande method.

4. More reproducible results are obtained with the fall cone method [4,5].

A review of the above sources indicates that the fall cone method yielded more reproducible results within individual laboratories (see table 1). Although comparison of results between different laboratories was not reported, it is expected that a similar increase in reproducibility would occur with the fall cone method.

Table 1. — Results of liquid limit tests carried out by the Casagrande apparatus and fall cone on three soils by different operators (after Sherwood and Ryley [5]).

Operator	Casagrande method			Fall cone method		
	Soil No.					
	2	9	11	2	9	11
A	32.0	63.8	73.8	35.5	65.5	73.3
B	30.1	67.4	73.2	33.4	64.8	73.4
C	35.2	66.6	75.7	35.7	64.8	73.4
D	37.0	67.7	76.4	36.9	64.4	73.6
E	38.1	69.8	76.8	35.9	66.2	73.2
F	35.4	68.7	75.5	36.7	65.6	73.1
G	36.5	70.2	76.1	37.4	65.9	72.6
H	38.0	69.1	76.3	37.0	66.0	73.4
Mean	35.3	67.9	75.5	36.1	65.4	73.5
Standard deviation	2.67	1.98	1.22	1.20	0.61	0.89
C.O.V.	7.5	2.8	1.6	3.3	0.93	1.2

5. The fall cone method yields more reliable liquid limit values for low plasticity soils [3,5,13,14].

   There are several problems associated with the use of the Casagrande device with low plasticity soils. These are: (a) difficulty in cutting the groove, (b) tendency of the soil to slide in the cup, rather than flow together, and (c) tendency of some soils to liquefy with shock rather than flow plastically [3,5,6,13]. The fall cone method eliminates problems (a) and (b), but it has been found that certain low plasticity soils which tend to liquefy in the Casagrande apparatus, also tend to liquefy (near the surface) when they are placed in the fall cone cup and struck off [3,5,13,14].

6. The fall cone method is less operator sensitive [3,5,6].

The fall cone method has a clear advantage in this case. When cutting the groove in the soil sample using the Casagrande apparatus, a fair amount of operator variation can occur. The major source of error when using the Casagrande method, however, is judging exactly when the groove has closed over a distance of 13 mm (½ in). With the fall cone method, the operator must position the cone properly at the start of the test, and must accurately read a dial gage. Neither operation involves the degree of operator sensitivity present with the Casagrande method.

PLASTIC LIMIT DETERMINATION

Since the liquid limit is related to a cone penetration of 20 mm, it is possible to reason that perhaps the plastic limit could be determined, using the same apparatus, through correlation with some smaller penetration. The concept has been investigated with mixed results. Mitchell [13] was unable to satisfactorily determine the plastic limit using the cone apparatus, and reported difficulty preparing suitable specimens. Allbrook [7], however, reported a correlation between the plastic limit and a penetration of 2.8 mm for a range of soils from New Zealand (see fig. 3). Towner [15] also found the fall cone method to be potentially useful for determining the plastic limit.

Although this report deals primarily with the determination of the liquid limit, the plastic limit determination using the same equipment is a potentially significant development and has been included for that reason.

SHEAR STRENGTH AND THE LIQUID LIMIT

In supporting the use of the fall cone method for determining the liquid limit, Sowers, Vesic, and Grandolfi [3] state:

> "Essentially the liquid limit test is a measure of the viscous resistance or shear strength of a soil that is so soft it approaches the liquid state. The impact of the soil-filled cup on the base induces a dynamic stress in the soil which results in shear and forms a miniature landslide in the sloping walls of the groove. While a "landslide" can be a measure of soil shear strength, it is a crude one at best; certainly some more direct method would be more consistent."

Also consider the following quote from Woods [16]:

> "It is evident that in making a radical change in the method to be used to determine the liquid limit the values determined by the new and old methods will not necessarily correspond precisely. Indeed, whereas the Casagrande apparatus was an attempt to standardize the procedure described by Atterberg (1911) for detecting the moisture content of soils at which a transition between liquid and plastic types of behavior occurred, the cone penetrometer is more plausibly detecting the moisture content at which soils have a certain strength. Perhaps it is incorrect to call this the liquid limit, but what use is actually going to be made by an engineer of a liquid limit, however it has been determined? Equally, we may ask what use is actually going to be made by an engineer of a plasticity index as traditionally determined? We can argue that the "pseudo" plasticity determined with the cone penetrometer by the method described by Wood and Wroth (1978) is an indication of the change in moisture content which will give a hundred-fold change in strength. Perhaps this a measure which <u>will</u> be of direct usefulness to the engineer."

It seems that a potentially significant use of the fall cone method lies in an enhanced understanding of the shear strength of soil near the liquid limit. This is a subject which will undoubtedly receive more attention in the future.

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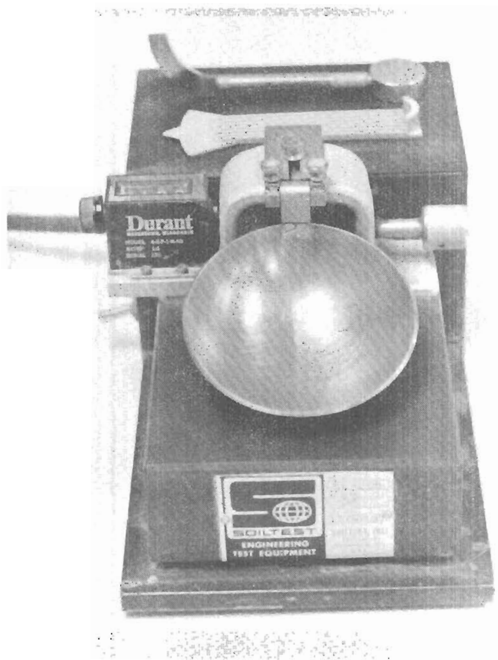

Figure 1. – Casagrande liquid limit apparatus. P801-D-80825.

Figure 2. – Fall cone liquid limit apparatus. P801-D-80826.

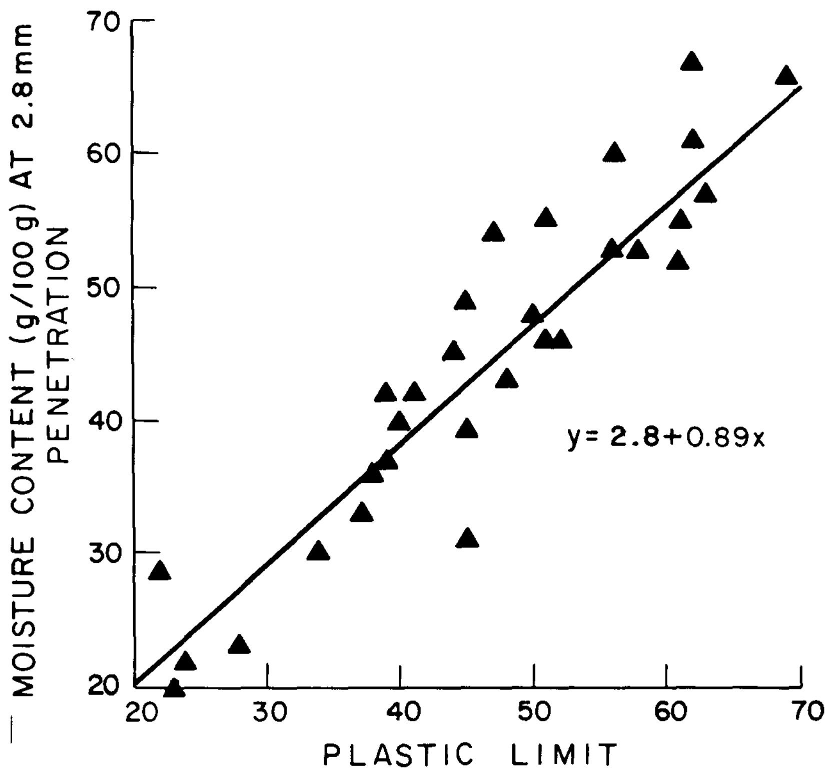

Figure 3. – Relation between plastic limit and moisture content corresponding to 2.8 mm penetration (after Sherwood and Ryley [5]).

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