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DETERMINING THE PLASTIC LIMIT OF SOIL USING THE FALL CONE TEST AND UNDRAINED SHEAR STRENGTH

ODREĐIVANJE GRANICE PLASTIČNOSTI TLA POMOĆU PADAJUĆEG KONUSA I NEDRENIRANE SMIČUĆE ČVRSTOĆE

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Keywords
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- plastic limit
- penetration
- undrained shear strength
- water content

Ključne reči
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- granica plastičnosti
- penetracija
- nedrenirana smičuća čvrstoća
- vlažnost

Abstract

Properties of fine-grained soils, such as the liquid and plastic limits, are widely used as indicators of geotechnical behaviour. Unlike the liquid limit that can be reliably determined by mechanical testing, the determination of the plastic limit is significantly more complex, and the standard thread-rolling test is increasingly criticised for its subjective nature. Therefore, there is a need for a standardised, mechanical, more reliable and reproducible method to determine the plastic limit. This study compares several alternative methods with the standard rolling test, including tests using 240 g and 400 g cones, the cone penetration index (β), and an empirical method based on undrained shear strength data. The accuracy of each method is evaluated using MAE, RMSE, and MAPE. The results show that the β method provides the highest reliability, while the empirical approach shows moderate accuracy.

Izvod

Indeksna svojstva sitnozrnih tla, poput granice tečenja i granice plastičnosti, široko se koriste kao pokazatelji geotehničkih karakteristika. Za razliku od granice tečenja, koja se može pouzdano utvrditi mehaničkim ispitivanjima, određivanje granice plastičnosti predstavlja znatno složeniji postupak, a standardni opit valjanja sve je više predmet kritika zbog subjektivnog karaktera. Zbog toga postoji potreba za novom, mehaničkom, pouzdanijom i ponovljivom metodom za određivanje granice plastičnosti. U ovom istraživanju izvršeno je poređenje alternativnih metoda s opitom valjanja, pri čemu su obuhvaćena ispitivanja s konusima mase 240 g i 400 g, metoda indeksa nagiba β, te empirijski pristup zasnovan na nedreniranoj smičućoj čvrstoći. Tačnost metoda procenjena je statističkim pokazateljima MAE, RMSE i MAPE. Rezultati pokazuju da β metoda daje najpouzdanije rezultate a empirijska veza pokazuje umerenu tačnost.

INTRODUCTION

The consistency limits of soils represent fundamental parameters in geotechnical engineering, as they provide insight into the behaviour of fine particles depending on the water content and define transitions between different states of consistency. Traditionally, the determination of the liquid and plastic limits is carried out using methods such as Casagrande's method for the liquid limit and the thread-rolling method for plastic limit. Although these methods are widely accepted, they are known for pronounced subjectivity, limited repeatability, and reliance on the experience and skill of the examiner, and it has further been shown that in specific soil types, such as dispersive soils, their interpretation can be particularly challenging and require supplementary analyses, /1/. The fall cone method has increasingly emerged as a reliable alternative to conventional procedures, particularly due to its consistency, objectivity, and ability to produce reproducible results with ease. In addition to determining consistency limits, the method also enables the estimation of undrained shear strength, which further extends its applicability in geotechnical practice. With more than fifty years of use, fall cone method has become a standardised procedure in European and British standards for determining the liquid limit, while its use for determining the plastic limit remains the subject of ongoing research and methodological development.

The liquid limit w_L can be measured with two methods: the Casagrande Cup method and the Fall Cone test, /2/. When the Casagrande apparatus is used to determine the liquid limit, a prepared and homogenised soil sample is placed into a brass cup, and a groove is formed along the centre using a standard brass grooving knife. By rotating the handle of the device, the number of blows required for the groove to close is recorded. This procedure is repeated four times, and the results are plotted on a semi-logarithmic scale. The liquid limit corresponds to the water content at 25 blows. In the fall cone test, the soil sample is likewise homogenised, placed in a metal container, and the cone penetration is measured at a given water content. The test is also repeated four times, and the results are plotted on a semi-logarithmic scale. The liquid limit (w_L) is defined as the water content for which a cone of 30°/80g achieves a penetration depth of $h = 20$ mm, or for the cone 60°/60g at penetration depth of $h = 10$ mm. In this study the fall cone test is used to determinate the liquid limit w_L.

The determination of the plastic limit w_P is performed using the standardised rolling-thread method, /2/. This method is highly subjective and biased by the individual who performs it. According to Whyte (1982), during this test the soil is subjected to certain stresses and therefore depends on many factors, such as the pressure applied during the shaping of the soil thread between the hand and the sample, the angle and geometry between the sample and the hand, as well as between the sample and the glass plate, and the speed at which the test is performed, /3/. Haigh et al. described this in terms of stresses in their study, /4/. The pressure from the hand acting on the sample represents a shear stress that is very small compared to the vertical stress. The total and effective stresses acting on the tested sample can be illustrated as shown in Fig. 1.

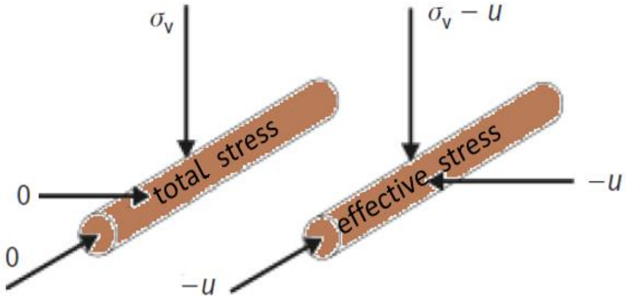

Figure 1. Total and effective stresses during rolling thread method (after Haigh et al. /4/).

In this paper, several alternative and non-standardised methods for determining the plastic limit are presented and analysed with the aim of comparing their reliability and practical applicability to the standard plastic limit test method.

MATERIAL AND METHODS

Soil samples selected for this analysis are part of a project involving the construction of a bypass around Belgrade and Pančevo, located on the left bank of the Danube. The soil samples are classified as quaternary sediments, comprising both alluvial and aeolian deposits. Geomechanics laboratory tests are conducted on eight soil samples. The liquid limit is in the range of $w_L = 40\text{-}50$ % and the plastic limit is in the range of $w_P = 19\text{-}24$ %. The plasticity index value is in the range of $I_p = 18\text{-}27$ % and the consistency index value is in the range of $I_c = 0.44\text{-}1.0$. According to the plasticity chart in EN ISO 14688-2 /5/, based on the liquid limit and plasticity index values, the samples belong to class ClM and according to USCS classification they belong to medium plasticity CI. A summary of the basic identification parameters for the soil samples are shown in Fig. 2, /5-8/.

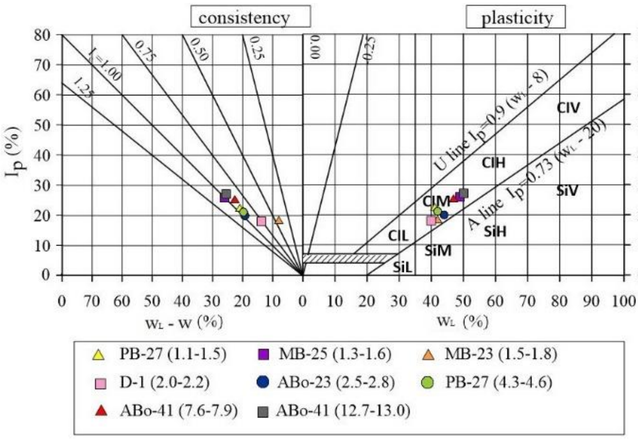

Figure 2. Identification and classification indicators of tested samples.

The fall cone test

The fall cone method represents one of the most reliable methods for testing soil consistency, as well as a rapid and accurate method for determining the undrained shear strength and soil sensitivity, /9/. The method is based on allowing a metal cone of a specified mass and apex angle to penetrate a soil sample, either directly or into a specimen prepared in a cylindrical container (Fig. 3). The depth of cone penetration after a specified time interval (most commonly 5 s) is used to determine the plastic limit, the liquid limit, and the undrained shear strength /10, 11/. The undrained shear strength of soil is expressed by the following equation:

$$c_u = \frac{cQ}{h^2}, \qquad (1)$$

where: c_u is undrained shear strength of a remoulded or undisturbed soil sample; c is a constant that depends on the type of cone (apex angle, mass, standard); and Q is the weight of the cone.

Figure 3. Fall cone test with weights of different masses and cones.

The values of constant c are adopted based on theoretical and experimental analyses conducted in various research centres. In this study, a remoulded soil sample and two types of cones are used to measure the undrained shear strength c_u: a cone of mass 80 g and apex angle of 30° with a constant $c = 0.81$; and a cone of mass 60 g and apex angle of 60°, with a constant $c = 0.27$. In addition, a 240 g cone with a 30° apex angle and a 400 g cone of the same angle are used for the analysis of the plastic limit, /9-12/.

The undrained shear strength is 1.57 kPa for the 30°/80 g cone and 1.59 kPa for the 60°/60 g cone. To ensure that undrained shear strength values at the liquid limit are equal for both cones, a constant value of $c = 0.81$ is adopted for the 30°/80 g cone. Consequently, the undrained shear strength at the liquid limit for both cone types is 1.59 kPa, and the adopted value is 1.6 kPa.

Statistical analysis

To evaluate the agreement between alternative methods and the reference method, a statistical analysis is performed. The rolling test is adopted as the reference measurement. Three widely used statistical indicators are calculated: mean absolute error (MAE), root mean square error (RMSE), and mean absolute percentage error (MAPE).

MAE represents the average absolute deviation between the values obtained by the alternative method and the reference method and provides a straightforward measure of the overall error. RMSE is more sensitive to large deviations and therefore highlights methods that occasionally produce higher discrepancies. MAPE expresses the error in percentage terms, allowing a relative comparison between methods regardless of the magnitude of measured values.

These indicators enable an objective and quantitative assessment of the accuracy and reliability of applied methods for determining plastic limits.

ALTERNATIVE METHODS FOR DETERMINING THE PLASTIC LIMIT

One of the first alternative approaches was proposed by Wood and Wroth /13/. To determine the plastic limit, they used a heavier cone (240 g) instead of the standard one and calculated the difference in water content obtained from both cones using the following equation:

$$w_P = w_L - \frac{\Delta w}{\log \dfrac{m_2}{m_1}}\,, \tag{2}$$

where: w_P is plastic limit; w_L is liquidity limit; Δw is water content difference; m_1 and m_2 are cones of different masses. The application of this concept is illustrated in Fig. 4, which presents the results obtained in the present study.

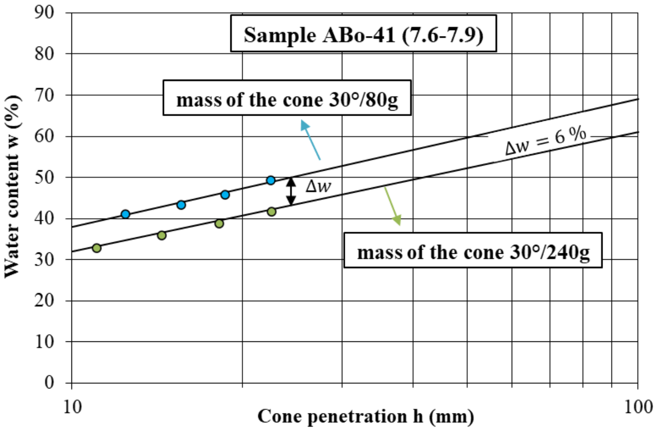

Figure 4. Measuring plastic limit using a cone of 30°/240g.

Feng /14/ proposed that the plastic limit should be determined using the standard cone, the same as for the liquid limit (30°/80g), but with a smaller sample cup to avoid the influence zone of the cup itself when determining the plastic limit of stiffer soils.

The cup has a diameter of 20 mm and a depth of 20 mm, and the plastic limit is calculated at a penetration depth h = 2 mm, /14/. Sivakumar et al. /15/ propose applying additional force of 54 N to the standard 80 g cone by means of a pneumatic system and determining the plastic limit at a penetration of 20 mm, /15/. More recent methods use empirical correlations to obtain the plastic limit. One of the more developed approaches is the introduction of the parameter β, known as the index representing the slope of the line that connects the experimental data points of water content and penetration (‘cone penetration index’), /16-18/. The parameter β is often presented as the flow index I_f /19-22/. The slope index β is analogous to the flow index I_f in the Casagrande method which is the slope of the w-$\log_{10}N$ relationship.

According to Harrison /22/, Feng /16/, and Shimobe and Spagnoli /18/, the liquid limit and plastic limit obtained from the fall cone test using the standard 30°/80 g cone can be defined by the following expressions /16, 18, 23/:

$$w_L = C_0(20)^{\beta}\,, \tag{3}$$

$$w_P = C_0(2)^{\beta}\,, \tag{4}$$

where: C_0 represents water content at a penetration depth of h = 1 mm; and β is slope index of the line. The plastic limit is determined at penetration depths of h_{WL} = 20 mm and the liquid limit at penetration depths of h_{WP} = 2 mm. This relationship for the standard cone is shown in Fig. 5.

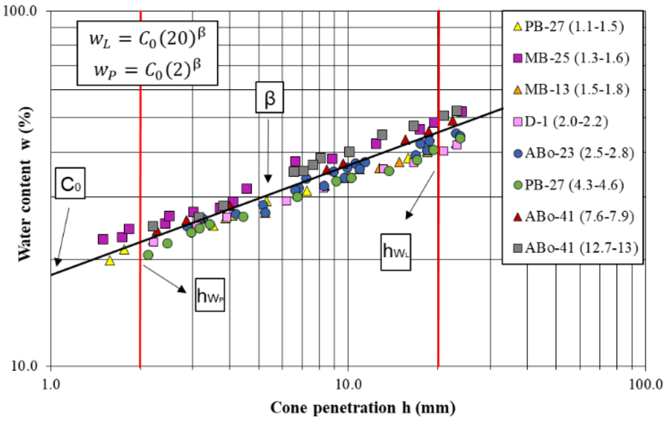

Figure 5. Relationship between cone penetration h and water content w for the 30°/80g cone.

If a 60°/60 g cone is used, the liquid limit and the plastic limit are determined at penetration depths of h_{WL} = 10 mm and h_{WP} = 1 mm, respectively. Their relationship is shown in Fig. 6, while the corresponding equations are given as:

$$w_L = C_0(10)^{\beta}\,, \tag{5}$$

$$w_P = C_0(1)^{\beta}\,. \tag{6}$$

All these assumptions are based on the premise that the logarithmic relationship between cone penetration h and water content w is linear over the entire range of obtained values, and that the undrained shear strength at the plastic limit is 100 times greater than that at the liquid limit /13, 24, 25/. Another group of authors, however, does not agree that the undrained shear strength at the plastic limit is 100 times greater than the undrained shear strength at the liquid limit. They argue that the undrained shear strength at the liquid limit is in the range of 1.6-1.7 kPa, whereas the magnitude of the undrained shear strength at plastic limit varies from 70 to 300 kPa, /26-28/.

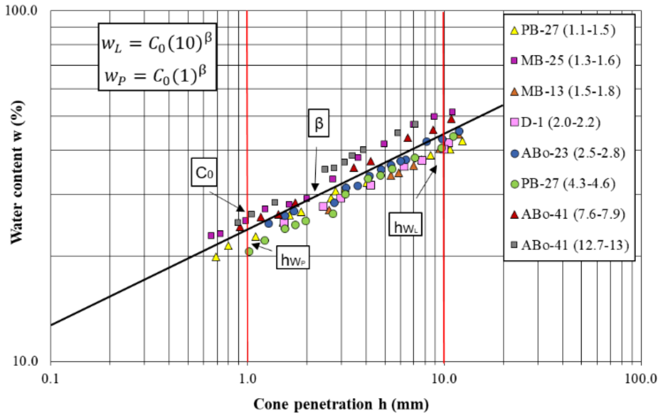

Figure 6. Relationship between cone penetration *h* and water content *w* for the 60°/60g cone.

In their research, Sharma and Bora /25/ suggested that the plastic limit can be determined at a penetration depth h = 4.4 mm using a 400 g cone. In their study, they obtained a correlation coefficient of 0.97. The liquid limit for 55 soil samples ranged from 33.8 to 82 %, including the results of tests on 6 bentonite clay samples, which ranged from 210 to 460 %, /25/. Sharma and Sridharan /29/ applied the theory that the undrained shear strength at the liquid limit is 100 times smaller than undrained shear strength at the plastic limit, using 43 soil samples. They adopted this approach for determining the plastic limit and expressed it by the following equation:

$$w_{P100} = 0.39 w_L \cdot \tag{7}$$

RESULTS AND DISCUSSION

To determine the plastic limit of the tested samples, the standard rolling test in accordance with /2/ and alternative methods based on the fall cone test are used. All results are presented in the summary Table 1, where M1 denotes the value obtained from the standard rolling test, M2 is the value obtained using the 240 g cone, M3 is obtained using the 400 g cone, M4 is obtained from the slope index β for the 30°/80g cone, M5 is obtained from the slope index β for the 60°/60g cone, and M6 is obtained based on the empirical correlation derived from the undrained shear strength. The results are correlated to identify the methods that provide similar values and to evaluate the differences between the obtained results.

Table 1. Comparison of plastic limit values obtained by different methods.

Sample ID	M1	M2	M3	M4	M5	M6
PB-27 (1.1-1.5)	19	20	20	22	23	20
MB-25 (1.3-1.6)	23	20	22	24	25	24
MB-13 (1.5-1.8)	24	21	12	21	20	21
D- 1 (2.0-2.2)	22	19	19	22	22	22
ABo-23 (2.5-2.8)	24	19	20	22	23	21
PB-27 (4.3-4.6)	21	21	19	21	21	23
ABo-41 (7.6-7.9)	22	22	22	23	24	25
ABo-41 (12.7-13)	23	21	22	23	26	20

The first approach applied is the use of a cone with total mass of 240 g, according to Wroth and Wood, /13/. This approach requires the use of both an 80 g and 240 g cone, with penetration and water content measured for each cone type. Figure 4 illustrates the procedure for determining the plastic limit for sample ABo-41 (7.6-7.9) and Fig. 7 shows all eight samples. The same procedure is applied to all other samples, and the plastic limit for all eight samples is calculated using Eq.(2). The standard rolling test yields values in the range of 19-24 %, while the values obtained using the 240 g fall cone method range from 19-22 %. Differences between these two methods are generally 1-5 %, indicating that the fall cone method with a 240 g cone gives lower values than the standard rolling test.

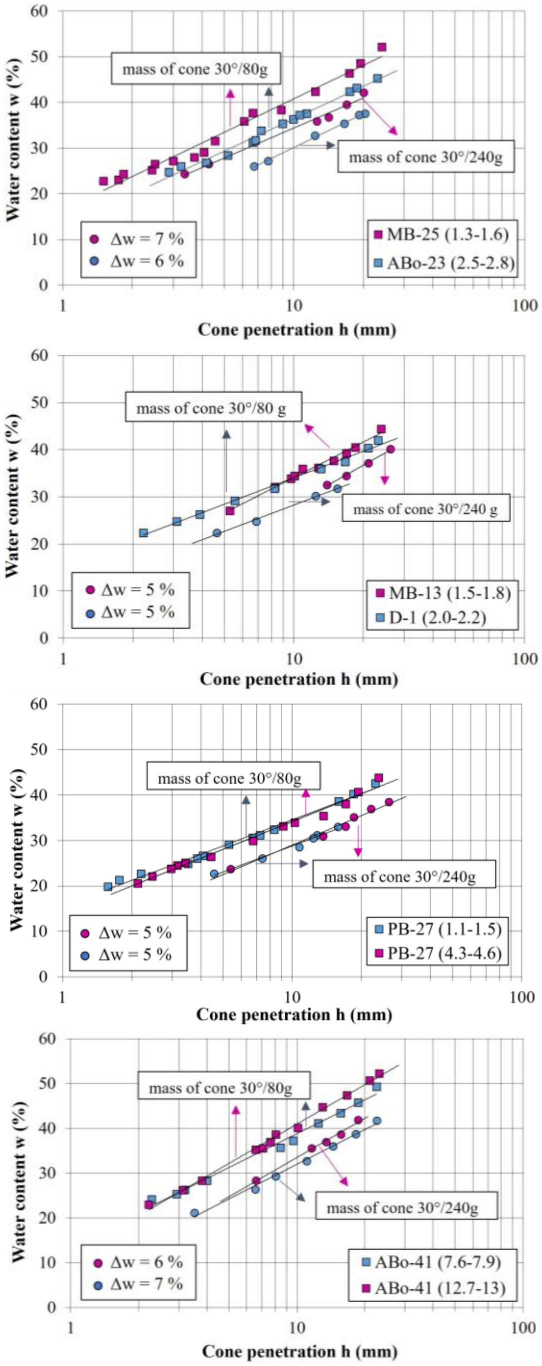

Figure 1. Measuring the plastic limit with cone of 240 g.

The second approach involves using a 400 g cone, where the plastic limit is read at a penetration of 4.4 mm. The results closely follow those obtained by the other methods, except for sample MB-13 (1.5-1.8) which shows a significantly lower value. This deviation is justified because the natural water content of this sample is higher than in others, and its undrained shear strength is very low. Differences between this method and the standard rolling test range from 1-4 %, except for sample MB-13 (1.5-1.8), where the difference reaches 12 %. Figure 8 shows the testing results for all samples using the cone of 400 g.

The third approach applied is based on the relationship between cone penetration *h* and water content *w* to calculate the cone penetration index *β*.

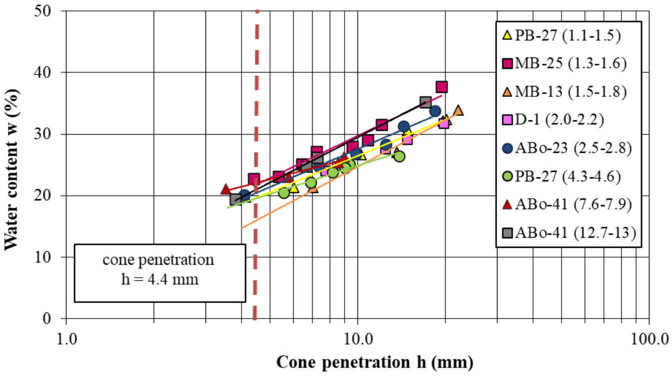

Figure 8. Measuring plastic limit with cone of 400 g at the penetration of 4.4 mm.

The analysis is performed on all eight samples for two cone types: 30°/80g and 60°/60g. Diagrams are shown in Figs. 5 and 6 from which the values for parameters C_0 and *β* are obtained (Table 2). Plastic limit values are calculated using Eqs. (4) and (6). The deviation between these two approaches is around 2 %. Difference between the standard rolling test and 30°/80g cone range from 0.4 to 3.4 %, while for the 60°/60g cone from 0.2 to 4 %.

Table 2. Values of coefficients C_0 and *β* for all samples.

Type of cone:	30°/80g			60°/60g		
Sample ID	C_0	*β*	R^2	C_0	*β*	R^2
PB-27 (1.1-1.5)	17.96	0.277	0.998	22.56	0.256	0.993
MB-25 (1.3-1.6)	19.72	0.304	0.991	25.11	0.306	0.990
MB-13 (1.5-1.8)	16.61	0.309	0.984	19.99	0.315	0.990
D-1 (2.0-2.2)	18.31	0.26	0.998	21.82	0.269	0.996
ABo-23 (2.5-2.8)	18.01	0.291	0.967	22.64	0.281	0.987
PB-27 (4.3-4.6)	17.20	0.289	0.993	20.56	0.313	0.990
ABo-41 (7.6-7.9)	18.48	0.312	0.999	24.35	0.297	0.996
ABo-41 (12.7-13)	18.58	0.334	0.994	25.87	0.316	0.997
Mean value:	18.08	0.30	0.99	23.01	0.256	0.99

The final approach involves calculating the plastic limit based on undrained shear strength. For both cone types, 30°/80g and 60°/60g, data analysis is performed on a total of 94 and 87 samples, in respect. The undrained shear strength is calculated for different water contents, after which the undrained shear strength value is divided by 1.6 kPa (corresponding to the undrained shear strength at the liquid limit) and the water content is reduced by liquid limit (Fig. 9).

$$w_{P100} = 0.5005 w_L \,, \tag{8}$$

$$w_{P100} = 0.5152 w_L \,. \tag{9}$$

The equations obtained for plastic limit are as follows: Eq.(8) is derived using the 30°/80g cone, and Eq.(9) using the 60°/60g cone. Since the equations are almost identical, the coefficient is rounded to 0.5, and the resulting plastic limit values are highlighted in Table 1. The absolute error between the standard rolling test and the method based on undrained shear strength is 2-3 %.

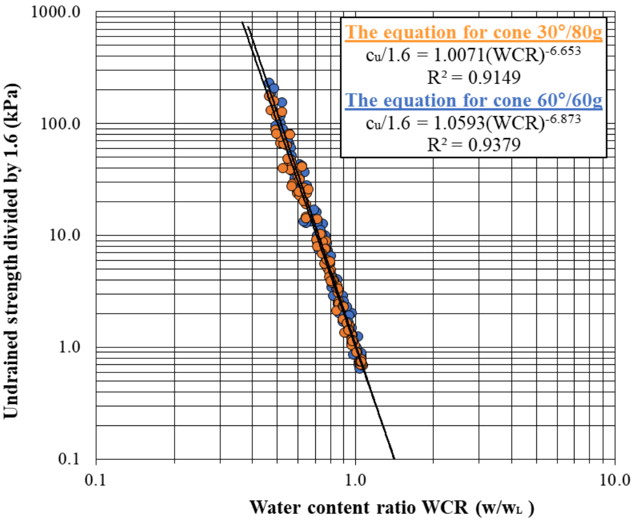

Figure 2. Relationship between divided undrained shear strength and water content ratio.

Based on statistical analysis, the cone penetration index *β*, also referred to as the slope index method, exhibits the smallest deviations in comparison to the reference thread-rolling test (Table 3). This is consistently confirmed by the lowest values of MAE, RMSE, and MAPE among all analysed methods, indicating high accuracy and stability of this approach. Determining the plastic limit using the empirical formula derived from undrained tests has also proven to be a good alternative method.

The remaining alternative methods show larger deviations, particularly in terms of RMSE, which suggests the occurrence of occasional larger discrepancies in the determination of consistency limits. Such deviations may be attributed to differences in testing principles, operator influence, or sensitivity to variations in water content.

The obtained results indicate that the *β* method provides the most reliable approximation of the standard thread-rolling test and can therefore be considered a suitable alternative for practical applications. The symbols of the applied methods are consistent with those presented in Table 1.

Table 3. Statistical measures of error.

	M2	M3	M4	M5	M6
MAE	2.13	2.88	1.37	2.11	1.69
RMSE	2.67	4.66	1.81	2.48	1.86
MAPE	10.74	19.43	6.26	9.24	7.65

CONCLUSION

The aim of this paper is to identify an alternative and accurate method for determining the plastic limit. Multiple laboratory procedures for assessing the plastic limit are compared, and their reliability is evaluated in relation to the standard thread-rolling test. Analysis of experimental results, supported by statistical error indicators (MAE, RMSE, and MAPE), show that the tested methods differ by 1 to 5 % in terms of agreement with reference values. The smallest deviations are consistently observed for the relationship between cone penetration h and water content w (β method) using the 30°/80g cone, which emerged as the most accurate and stable alternative to the thread-rolling test. Additionally, the method based on the analysis of undrained shear strength also demonstrates high accuracy. The results obtained using the newly derived equations show a moderate level of precision, while other analysed procedures, involving the 240 g and 400 g cones, exhibit more pronounced deviations and lower repeatability.

These results confirm that the choice of methodology has a crucial impact on the determination of the plastic limit and that different methods cannot be regarded as equivalent. Overall, the use of the slope index (β) provides the most reliable values within the scope of this paper, indicating its potential as a valid alternative to the standard testing procedure under specific laboratory conditions.

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REFERENCES

1. Đoković, K., Šušić, N., Ćosić, M. (2023), *Dispersive soils: properties, identification, classification and stabilization*, Struct. Integr. Life 23, Sp. Issue: S47-S52.
2. SRPS EN ISO 17892-12:2018/A1:2022. Geotechnical investigation and testing - Laboratory testing of soil - Part 12: Determination of liquid and plastic limits - Amendment 1. Institute for Standardization of Serbia
3. Whyte, I.L. (1982), *Soil plasticity and strength: A new approach using extrusion*, Ground Eng. 15(1): 16-24. doi: 10.1016/0148-9062(82)91670-9
4. Haigh, S.K., Vardanega, P.J., Bolton, M.D. (2013), *The plastic limit of clays*, Géotechnique, 63(6): 435-440. doi: 10.1680/geot.11.p.123
5. ISO 14688-2:2017. Geotechnical investigation and testing - Identification and classification of soil - Part 2: Principles for a Classification
6. Ćorluka, S., Rakić, D., Živanović, N., et al. (2024), *A correlation relating the residual strength parameters to the proportions of clay fractions and plasticity characteristics of overburden sediments from the open-pit mine Drmno*, Appl. Sci. 14(22): 10325. doi: 10.3390/app142210325
7. SRPS EN ISO 17892-1:2015/A1:2023. Geotechnical investigation and testing - Laboratory testing of soil - Part 1: Determination of water content - Amendment 1. Institute for Standardization of Serbia
8. SRPS EN ISO 17892-4:2017. Geotechnical investigation and testing - Laboratory testing of soil - Part 4: Determination of particle size distribution. Institute for Standardization of Serbia
9. Hansbo, S. (1957), *A new approach to the determination of the shear strength of clay by the fall-cone test*, Royal Swedish Geotechnical Institute, Proc. No.14.
10. EN ISO 17892-6:2017. Geotechnical investigation and testing - Laboratory testing of soil - Part 6. Fall cone test
11. BS 1377-2:1990, Methods of test for soils for civil engineering purposes - Part 2: Classification tests
12. Đurić, T., Rakić, D., Pantić, J.J., et al. (2025), *Relationships between undrained shear strength and moisture content of soil measured by the fall cone method*, In: Int. Sci. Forum GAGiEE 2025, Vrnjačka Banja, Serbia, 2025, pp.163-170. doi: 10.46793/GEOAG25.163DJ (in Serbian)
13. Wroth, C.P., Wood, D.M. (1978), *The correlation of index properties with some basic engineering properties of soils*, Can. Geotech. J, 15(2): 137-145. doi: 10.1139/t78-014
14. Feng, T.-W. (2004), *Using a small ring and a fall-cone to determine the plastic limit*, J Geotech. Geoenv. Eng. 130(6): 630-635. doi: 10.1061/(ASCE)1090-0241(2004)130:6(630)
15. Sivakumar, V., Glynn, D., Cairns, P., Black, J.A. (2009), *A new method of measuring plastic limit of fine materials*, Géotechnique, 59(10): 813-823. doi: 10.1680/geot.2009.59.10.813
16. Feng, T.-W. (2000), *Fall-cone penetration and water content relationship of clays*, Géotechnique, 50(2): 181-187. doi: 10.1680/geot.2000.50.2.181
17. Koumoto, T., Houlsby, GT. (2001), *Theory and practice of the fall cone test*, Géotechnique, 51(8): 701-712. doi: 10.1680geot.2001.51.8.701
18. Shimobe, S., Spagnoli, G. (2020), *Fall cone tests considering water content, cone penetration index, and plasticity angle of fine-grained soils*, J Rock Mech. Geotech. Eng. 12(6): 1347-1355. doi: 10.1016/j.jrmge.2020.02.005
19. Fall, D.A. (2000), *A numerical model for rapid determination of plasticity of fine-grained soils*, Ground Eng. 33(9): 43-45.
20. Soltani, A., O'Kelly, B.C. (2022), *Reappraisal of fall-cone flow curve for soil plasticity determinations*, Geotech. Test. J, 45(1): 225-243. doi: 10.1520/GTJ20200312
21. Haigh, S.K., Vardanega, P.J. (2014), *Fundamental basis of single-point liquid limit measurement approaches*, Appl. Clay Sci. 102: 8-14. doi: 10.1016/j.clay.2014.10.011
22. Spagnoli, G., Feinendegen, M., Di Matteo, L., Rubinos, D.A. (2019), *The flow index of clays and its relationship with some basic geotechnical properties*, Geotech. Test. J, 42(6): 1685-1700. doi: 10.1520/GTJ20180110
23. Harison, J.A. (1988), *Using the BS cone penetrometer for the determination of the plastic limit of soils*, Géotechnique, 38(3): 433-438. doi: 10.1680/geot.1988.38.3.433
24. Feng, T.-W. (2001), *A linear log d - log w model for the determination of consistency limits of soils*, Can. Geotech. J, 38 (6): 1335-1342. doi: 10.1139/t01-061
25. Sharma, B., Bora, P.K. (2003), *Plastic limit, liquid limit and undrained shear strength of soil - reappraisal*, J Geotech. Geoenv. Eng. 129(8): 774-777. doi: 10.1061/(ASCE)1090-0241(2003)129:8(774)
26. O'Kelly, B.C. (2013), *Atterberg limits and remolded shear strength - water content relationships*, Geotech. Test. J, 36(6): 939-947. doi: 10.1520/gtj20130012
27. O'Kelly, B.C. (2021), *Review of recent developments and understanding of Atterberg limits determinations*, Geotechnics, 1(1): 59-75. doi: 10.3390/geotechnics1010004
28. Vardanega, P.J., Haigh, S.K., O'Kelly, B.C., et al. (2023), *Use of fall-cone flow index for soil classification: a new plasticity chart*, Géotechnique, 73(7): 648-654. doi: 10.1680/jgeot.21.00268
29. Sharma, B., Sridharan, A. (2018), *Liquid and plastic limits of clays by cone method*, Int. J Geo-Eng. 9: 22. doi: 10.1186/s40703-018-0092-0