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Statistical Analysis of Influenced Factors Affecting the Plastic Limit of Soils

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ABSTRACT

The determination of plastic limit of soils according to ASTM Standards specifies the value of plastic limit as the moisture content of rolled soil thread at 3.2 mm diameter that begins to crumble. The reliability of test results must depend on the skill of operator and various mechanical factors. In practice, test results of plastic limit have a high variation. In this research, influenced factors on the variation of results were studied. Statistical analysis of results by multiple regression, correlation, and analysis of variance indicated that there were two primary factors affecting the plastic limit of soils. The main factor was the initial size of the soil sample, explained 40% variation of the plastic limit value. The second factor was the type of soil classified by plasticity explained 21.8 % variation of the value. The other mechanical factors such as friction, speed, and pressure explained 3.0-3.2 % variation of the plastic limit value of soils.

Key words: plastic limit, statistical analysis, soil testing, correlation

INTRODUCTION

The Atterberg's limits are useful in agricultural soil science and soil engineering. They also correlate with some important engineering properties of soil. The Atterberg's limits, which are most useful for engineering purposes are liquid limit, plastic limit and shrinkage, limit. These limits are expressed as percent water content. Atterberg (1911) defined the plastic limit as the water content at which a sample of soil begins to crumble when rolled into a thread under the palm of the hand (Casagrande, 1932). In order to standardize the test, Terzaghi (1926) set the diameter of the thread at 3.2 mm or 1/8 inch. Mechanically, this procedure subjects the soil to a very complex stress system in that it combines bar rolling distortion, cylindrical compression and lateral extrusion process. A rigorous analysis for these stresses does not exist. However, assuming full saturation and incompressibility of soil mass, plasticity theory indicates the soil yield stress to be functions of applied pressure to the soil bead, geometry of soil sample, speed of rolling and friction between soil, hand and base plate (White, 1982). None of these variables are controlled in the rolling bead test, and the known variation of results is not surprising. For example, the slightly cohesive clay in this research with mean plastic limit 28.42%, when tested by different operators, the results range from as low as 22% to as high as 34%.

In this research, statistical techniques such as multiple regression, correlation analysis, and analysis of variance were applied to identify which influenced factors are the main factors that affect the plastic limit variation. In order to parametrically control each influenced factors, a mechanical rolling device was modified from Bobrowski and

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Griekspoor (1992). The influenced factors considered in this study are applied pressure to the soil bead, geometry of soil sample, speed of rolling, and friction among soil, hand and base plate.

MATERIALS AND METHODS

Mechanical rolling device design

The mechanical rolling device was developed from Bobrowski's rolling device as shown in Figure 1. At the interior intersection between the two sides and the base, a plexiglass rail 3.2 mm high was placed. These rails will accurately dictate the exact diameter of the soil thread. In order to obtain the adjustable speed of the test, a DC motor(1) with adapter(2) was connected to the upper plate to produce the rolling action. Variation of the input voltage from 16.5 to 19.5 volts yields the rolling speed of 103 to 128 cycle/min. The plexiglas plate(3) with bolt poles attached was used to control the pressure that apply to the soil bead.

Materials and experimental design

In this research, three representative samples of soils that are very cohesive soil, moderately cohesive soil, and slightly cohesive soil were prepared for testing. Figure 2 shows the variation of control factors used in the experimental design plan.

The rolling bead test cannot be expected to provide reliable and consistent results for plastic limit since none of variables are controlled in the rolling bead test. In this experimental design plan, rate of deformation (R_d) was set to be the representative variable demonstrating the rate of shape changing due to the bar rolling distortion, cylindrical compression, and lateral extrusion process in the plastic limit test as shown in Figure 3.

The rate of deformation (R_d) was defined as

$$R_d = \frac{(L_1 / D_1 - L_0 / D_0)}{t}$$

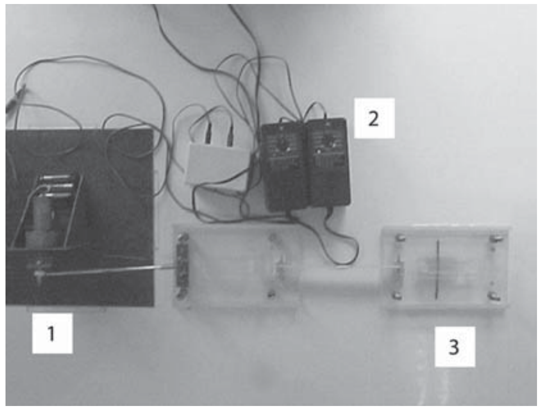


Figure 1 The mechanical rolling device.

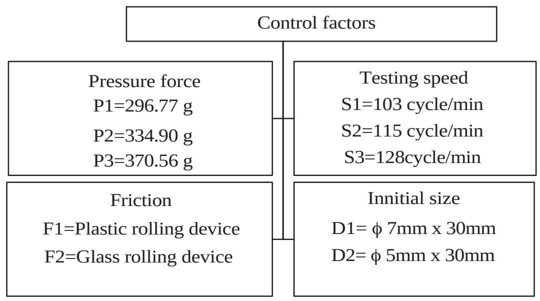
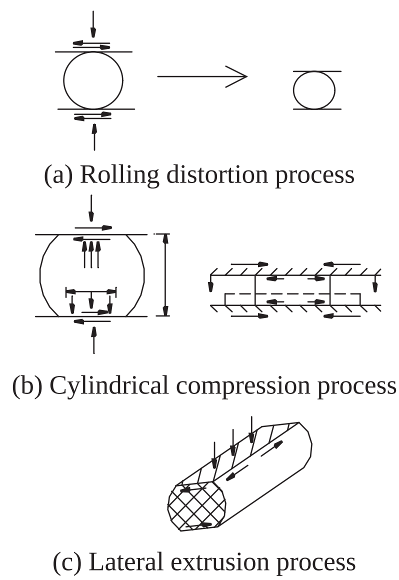


Figure 2 The variation of control factors used in experimental design plan.



(a) Rolling distortion process

(b) Cylindrical compression process

(c) Lateral extrusion process

Figure 3 Plastic limit testing as a mechanical process.

In which

R_d = rate of deformation (sec^{-1})
L_0 = initial length of sample (mm)
D_0 = initial diameter of sample (mm)
L_1 = final length of sample (mm)
D_1 = final diameter of sample (mm)
t = testing time (sec)

The rate of deformation was calculated in various conditions (Table 1). The analyses of results by multiple regression, correlation, and analysis of variance were applied to identify which factors are the primary factors affecting the plastic limit variation.

RESULTS AND DISCUSSION

From a total of 216 tests, the plastic limit values and the rate of deformation were determined. Statistical analyses were carried out using the Minitab and SPSS package, which include multiple regression, correlation analysis, and analysis of variance. In this way, factors affecting the results can be identified separately (Lyman, 1993). The results from analyses were demonstrated in Figure 4 and Table 2. From the illustration, it can be noticed that

1. Rate of deformation will increase if the applied pressure and rolling speed is increased.
2. Rate of deformation will increase when the initial diameter decreases (From D1 to D2).
3. Rate of deformation of very cohesive soil (soil type 1) is greater than the moderate (soil type 2) and slightly cohesive soil (soil type 3).
4. Rate of deformation in coarse surface rolling device (plastic plate) is greater than the smooth rolling device (glass plate).

The results analyzed by multiple regression and correlation in Table 2 indicated that there were two primary factors affecting the plastic limit. The main factor was the initial size of the soil sample, explained 40% variation of plastic limit value. The second factor was the type of soil classified by plasticity explained 21.8 % variation of the value. The other mechanical factors such as friction, speed, and pressure explained 3.0-3.2 % variation of plastic limit value.

In order to ensure the statistical analysis

Table 1 Testing condition for R_d in experimental plan.

Rolling device material	Initial size of sample	Testing time (sec)	Pressure force (g)	Testing speed (cycle/min)		
				S1	S2	S3
Translucent plastic (Coarse surface, F1)	ϕ 7mm × 30mm (D1)	15	296.77 (P1)	103	115	128
			334.90 (P2)	103	115	128
			370.56 (P3)	103	115	128
	ϕ 5mm × 30mm (D2)	5	296.77 (P1)	103	115	128
			334.90 (P2)	103	115	128
			370.56 (P3)	103	115	128
Plexiglass (Smooth surface, F2)	ϕ7mm × 30mm (D1)	15	296.77 (P1)	103	115	128
			334.90 (P2)	103	115	128
			370.56 (P3)	103	115	128
	ϕ 5mm × 30mm (D2)	5	296.77 (P1)	103	115	128
			334.90 (P2)	103	115	128
			370.56 (P3)	103	115	128

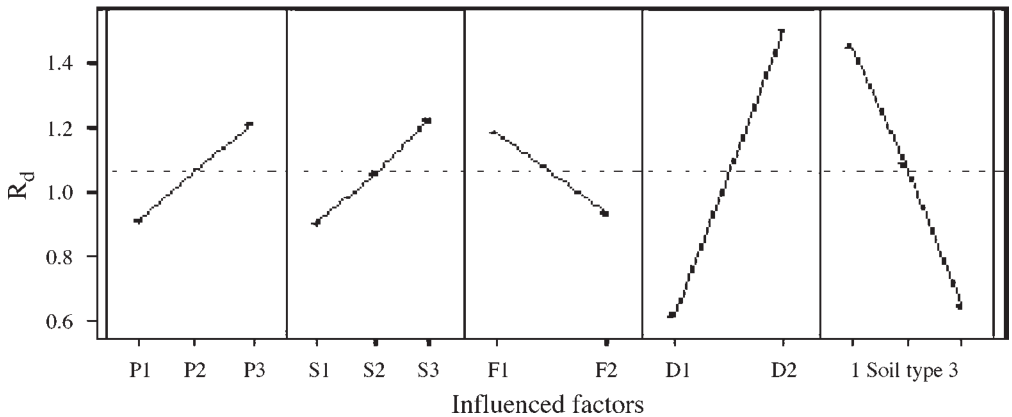


Figure 4 Relation between rate of deformation and influenced factors from analysis of variance.

Table 2 Results of multiple regression and correlation analysis by Stepwise method.

Model	R	R Square	Adjusted R Square	Incremental Adjusted R Square (%)
1	0.635	0.403	0.400	40.0
2	0.789	0.622	0.618	21.8
3	0.809	0.655	0.650	3.2
4	0.829	0.688	0.682	3.2
5	0.848	0.718	0.712	3.0

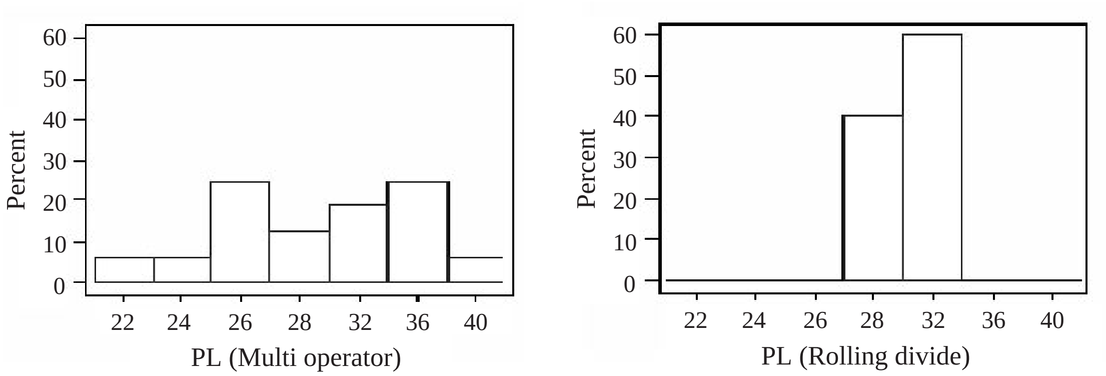
Note Model 1: R_d = f (**Diameter**)
Model 2: R_d = f (Diameter 1, **Soil type**)
Model 3: R_d = f (Diameter 1, Soil type, **Speed**)
Model 4: R_d = f (Diameter 1, Soil type, Friction 1, **Friction**)
Model 5: R_d = f (Diameter 1, Soil type, Friction 1, Speed 1, **Pressure**)

results, variation of plastic limit value before and after controlling main influenced factors were determined in Figure 5. From the figure, it can be noticed that the range of plastic value reduces from 22-34 % to 28-30%.

CONCLUSION

The analysis from multiple regression, correlation, and analysis of variance of the plastic limit test results with various controlling factors and soil types, found that there were two primary factors affecting the plastic limit of soils. The main factor was the initial size of the soil sample, explained 40% variation of plastic limit value. The second factor was the type of soil classified by plasticity explained 21.8 % variation of the value. The other mechanical factors such as friction, speed, and pressure explained 3.0-3.2 % variation of plastic limit value.

The results of the plastic limit test with controlling main influenced factors demonstrated a significantly reduction in variation. It can be recommended that the plastic limit test could be



(a) Before controlling influenced factors. (b) After controlling influenced factors.

Figure 5 Variation of plastic limit results before and after controlling the main influenced factors.

standardized to give more reliable and repeatable results by the initial diameter of the soil thread sample.

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