Similitude Studies of Soil Dynamic Properties in Puddling Field

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The dynamic properties of puddling soil were subjected to experiment and analyzed with the similitude method based on dimensional analysis. After pre-testing, the cone penetro-resistance, the falling cone depth and the inclination angular velocity of bar were measured for the representative dynamic properties of puddling soil.

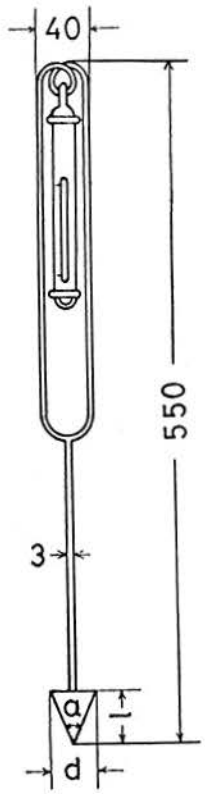

Fig. 1. Cone penetrometer

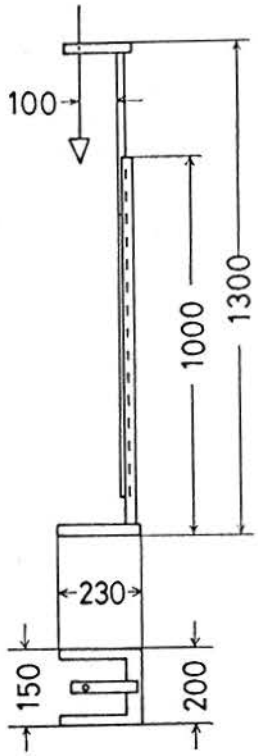

Fig. 2. Falling cone test device

Device and measurement

In the cone penetro-resistance test, the resistance force was measured with the light cone penetrometer, 230 gr total weight, which was composed of the wire frame and the penetrating cone. The cone was made of bakelite and was designed with nine exchangeable cones. The penetration cone depth was based on the base area of the cone and the resistance was recorded at each 1 cm depth by 1 cm/sec penetration speed.

Table 1. Dimensions of cones used in cone penetrometer

Cone No.	Diameter d (cm)	Length l (cm)	Base area A (cm²)	Angle α (degree)
6–30	2.8	5.2	6.0	30
6–45	2.8	3.3	6.0	45
6–60	2.8	2.4	6.0	60
10–30	3.6	6.7	10.0	30
10–45	3.6	4.3	10.0	45
10–60	3.6	3.1	10.0	60
14–30	4.2	7.9	14.0	30
14–45	4.2	5.1	14.0	45
14–60	4.2	3.7	14.0	60

In the falling cone depth test, nine cones were used, all of the same shape as used in the penetration test, but made of brass with weights respectively 69, 115, 161 gr of 2.8, 3.6, 4.2-cm diameter. They were falling from 65–153-cm height and the position of the cone edge as the penetration depth of falling cone was measured.

In the bar inclination test, the 0.5-cm square steel bars, which were 30, 40, 50 cm long and each having the semicircular protractor, were penetrated down to 5, 10, 15 cm deep with 10–50 degrees of initial inclination angle.

Experiment design

Each test was conducted in the two general paddy field of clay loam, the seedling bed field and the soil bin of clay loam and at three times (the puddling day, one day after puddling, three days after puddling).

Relationship among the factors in the falling cone depth test was shown as the following equation using π terms derived by dimensional analysis.

$$\frac{y}{d}=F\left(\alpha, \frac{s}{d}, \frac{W}{qd^2}, \frac{W}{\rho d^3}, \frac{D}{d}, \frac{h}{d}, \frac{g\eta^2 d^3}{W^2}\right)$$

where, y=penetration depth of falling cone (cm)
d=cone diameter (cm)
α=cone apex angle (degree)
s=depth of water (cm)
W=cone weight (g)
q=cone index (g/cm^2)
ρ=bulk density of soil (g/cm^3)
D=pan depth (cm)
h=falling height (cm)
η=viscosity of soil (g·sec/cm^2)
g=gravitational acceleration (cm/sec^2)

In the falling cone depth test, the measurements were conducted for 30, 45, 60 degrees of apex angle π terms (3 levels) combined with 0.75–4.7 water depth π terms (s/d: 3 levels), 0.04–0.91 cone index π terms (W/qd^2: 12 blocks), 2.6–5.9 pan depth π terms (D/d: 12 blocks), 24–36 falling height π terms (h/d: 3 levels) and 3.4–1050 ($\times 10^3$) viscosity π terms, and the falling cone depth π terms y/d were calculated.

Results and discussion

The cone index, the falling cone depth and the bar inclination angular velocity were each considered to show the soil hardness of puddling field generally. Average cone indexes of 0–6 cm depth were 10–227 gr/cm^2 and increased as the soil became hard.

The falling cone depths were 7.5–15.2 cm and increased as the soil became soft. The bar position beginning to incline down were 0–60 degrees at 30 cm bar length and 10 cm penetration depth, and increased as the soil became hard. The values of soil viscosity by the cylindrical viscosity measuring device were 35–500 gr sec/cm^2.

As in the past data, the soil properties in these tests showed likewise a hardening trend as the number of days after puddling increased.

The cone index increased as the penetration depth increased and steeply increased when it reached the pan layer. Also, the cone index increased as the cone diameter increased and the cone apex angle decreased.

The falling cone depth increased as the cone diameter increased, the cone apex angle decreased and the falling height increased. But the falling cone depth did not increase when the falling height was too high ($h>20qd^3/W$).

Also, the falling cone depth decreased as the water depth increased and it was significantly affected by the water depth with smaller cone diameter, larger cone apex angle and lower falling height.

Introducing the effective falling height, which is calculated by deducting the theoretical loss height caused by the water resistance to the cone, the results were explained

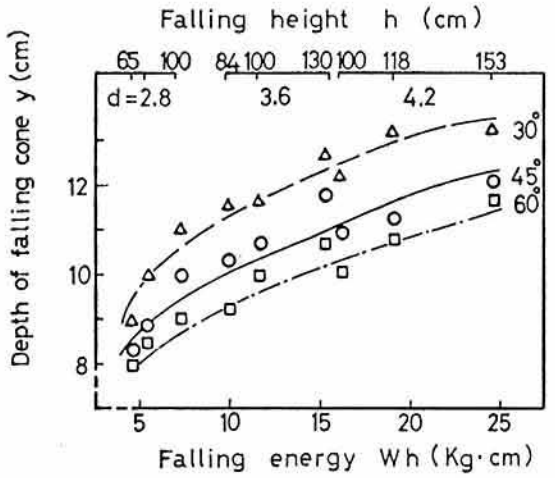

Fig. 3. Falling cone depth vs. falling energy

very well.

The falling cone depth was significantly affected by the falling energy of cone. It was analyzed that 55–35 per cent of the falling energy were absorbed by soil resistance, of which the cone index is representative, and 10–20 per cent of the falling energy were absorbed by the water resistance. The rest of the falling energy (35–45 per cent) must have been absorbed by the dynamic penetro-resistance and the resistance at air-water and water-soil boundary planes.

Neglecting the soil density π term and the viscosity π term, and using multiple regression analysis, the experimental equation of the falling cone depth is shown as follows.

$$\frac{y}{d}=\left(\tan\frac{\alpha}{2}\right)^{-0.22}\left(\frac{D}{d}\right)^{0.4}\left(\frac{Wh}{qd^3}\right)^{0.27}\left(\frac{s}{d}\right)^{-0.07}$$

$$y=1.2D^{0.4}W^{0.27}h^{0.27}q^{-0.27}s^{-0.07}l^{0.22}d^{-0.36}$$

The falling cone depth was not affected by the cone weight and the falling height as far as the falling energy was constant; namely, the dynamic penetro-resistance was not affected by the cone penetration speed in the range of 65–153 cm falling height (3.6–5.5 m/sec initial penetration speed).

By the principal component analysis, there was the consistent relationship between the bulk density of soils and the cone indexes of large diameter cones.

The cone penetro-resistance test is efficient to show the dynamic properties of soil at every depth and the cone index can be representative of the dynamic properties of puddling soils collectively.

Moreover, there is an advantage in that the cone index can predict the penetration depth of falling cone, the bar inclination angular velocity and the soil viscosity but there is a disadvantage in that this test is not so easy to conduct compared to the falling cone test and the results are a little difficult to be shown as one value.

The falling cone depth test is the easiest measuring method and the results are easily shown as one value for the dynamic properties of each puddling soil collectively. Also, the average cone index from the soil surface to the point of the penetration depth of falling cone was obtained by the simple equation, including the penetration depth of falling cone.

The cone penetrates to the pan layer and the penetration depth of falling cone is apt to show the pan depth if the falling cone has a comparative large falling energy especially in soft soils.

Therefore, it is necessary to drop the cone from a lower height than 100 cm in current use, especially in order to show the dynamic properties of the surface soil which directly affects the transplanting performance.

The bar inclination test, which is a simple measuring method, is considered to be excellent to predict the supporting force of soil for rice seedling.

After considering all the above results, the author proposed that the means and the standard deviations of the water depth, the pan depth and the penetration depth of the 3.6 cm diameter, 45 degree apex angle and 115 gr weight cone falling from 50 and 100 cm height, should be measured and reported in order to indicate the dynamic properties of puddling soils affecting the performance of the rice transplanters.

If necessary, the cone index of the 3.6 cm diameter and 45 degree apex angle cone should be also measured and reported at every depth. Besides, in the case of the experiment mainly for the transporting performance, it is desirable to conduct the bar inclination test using the 10 cm length and 0.5 cm square steel bar at 5 cm penetration length.

References

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2) Konaka, T.: On the measurement of the soil dynamic properties in the puddling field. *The Bulletin of the Faculty of Agriculture, Mie University*, **43**, 171–178 (1972).