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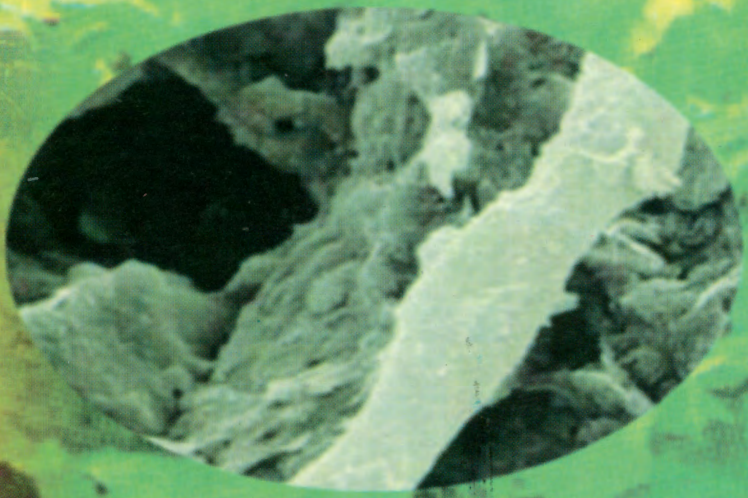

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A Simple Equation to Determine the Breakdown of Individual Aggregate Size Fractions in the Usual Wet-sieving Method (Using Nested Sieves)

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ABSTRACT

An equation was developed to estimate the breakdown of individual aggregate size fractions in the usual wet-sieving method using nested sieves. The key was to assume that aggregate breakdown happens sequentially and consistently, and that the aggregate breakdown between any two aggregates in the same aggregate size fractions is equal in percentage. Applying these two assumptions, this equation was developed : $x_i = (W_{ai} \times D_i) / W_{ai} + D_{i-l})$, where x_i is the weight of aggregate breakdown in aggregate size fraction i before wet-sieving, and D_i and D_{i-l} is the weight of aggregates that have passed through sieve i and (i-l), respectively. The equation was tested with five soil series. The soils were separated into six aggregate size fractions : 4.76 - 8.0, 2.83 - 4.76, 2.0 - 2.83, 1.0 - 2.0, 0.5 - 1.0 and 0.3 - 0.5 mm. For every soil, each of their aggregate size fraction was separately wet-sieved to determine the actual aggregate breakdown. The separate wet sievings results were then combined in such a way to simulate the usual wet-sieving method. The equation was then calibrated by simple linear regression where the calibrated equation was : $y = 100\sin^2\propto_i$; where y, is the calibrated breakdown estimate for aggregate size fraction i, and $\propto_i$ is $(0.0166x_i + 0.1)$ in unit radians. This calibrated equation was highly significant at 1%, and the $R^2 = 0.961$. The calibrated equation was validated with three additional soils. Paired sample t-test showed there was significant differences between the actual and calibrated breakdown estimate values.

INTRODUCTION

Soil aggregate stability is the ability of aggregates to resist disruptive forces (Hillel, 1980). One common method to measure aggregate stability is the wet-sieving method using nested sieves (Kemper and Chepil, 1965; Yoder, 1936). This technique breakdowns and separates the aggregates into various sizes by sieving them through a nest of sieves under water. This method, however, is insensitive to changes in individual aggregate sizes; it only considers the weight of all aggregates above a given size. It is impossible to determine the stability of individual aggregate size fractions because, in a particular sieve, there is a mixing of aggregates that were originally placed in that sieve (before wet-sieving) with the aggregates that had ruptured and fallen from the above sieves (after wet-sieving).

Therefore, the objective of this paper was to develop an equation to determine the breakdown of individual aggregate size fractions in the usual wet-sieving method (using nested sieves). By knowing the amount of breakdown in each aggregate size fraction, it would be possible to determine their respective aggregate stabilities.

Theory

Description of the parameters and assumptions of the model

Fig. 1 illustrates the breakdown and movement of aggregates in each sieve during wet-sieving. In Fig. 1a and 1b, i denotes the sieve number (i = 1 to n) so that sieve no. 1 is the sieve with the largest aperture size, followed by sieve no. 2, and so on. Aggregates that are placed in each sieve before wet-sieving are referred to as *original aggregates*. The weight of the original aggregates in sieve i is W_{ai}. On the other hand, W_{bi} is the weight of all aggregates in sieve i after wet-sieving.

Variable x_i is the weight of the original aggregates in sieve i that had ruptured or brokendown. This is the variable of great interest because (W_{ai}-x_i) refers to the weight of the original aggregates in sieve i that had resisted breakdown. Hence, (W_{ai}-x_i) can be aptly referred to as the weight of the *intact aggregates*. However, except for the uppermost sieve, x_i cannot be determined with absolute certainly because of the intimate mixing between the intact and ruptured aggregates in every sieve (Fig. 1a). x_i, however, can be estimated in two steps. First, one needs to determine the *total* weight of aggregates that *have* passed through sieve i, or D_i.

$$
\begin{aligned}
D_1 &= (W_{a1} + D_0) - W_{b1} \\
&= (W_{a1} + 0) - W_{b1} \\
&= \blacktriangle W_1
\end{aligned}
$$

$$
\begin{aligned}
D_2 &= (W_{12} + D_1) - W_{b2} \\
&= \blacktriangle W_1 + \blacktriangle W_2
\end{aligned}
$$

$$
\begin{aligned}
D_3 &= (W_{a3} + D_2) - W_{b3} \\
&= \blacktriangle W_1 + \blacktriangle W_2 + \blacktriangle W_3
\end{aligned}
$$

which can be re-expressed as :

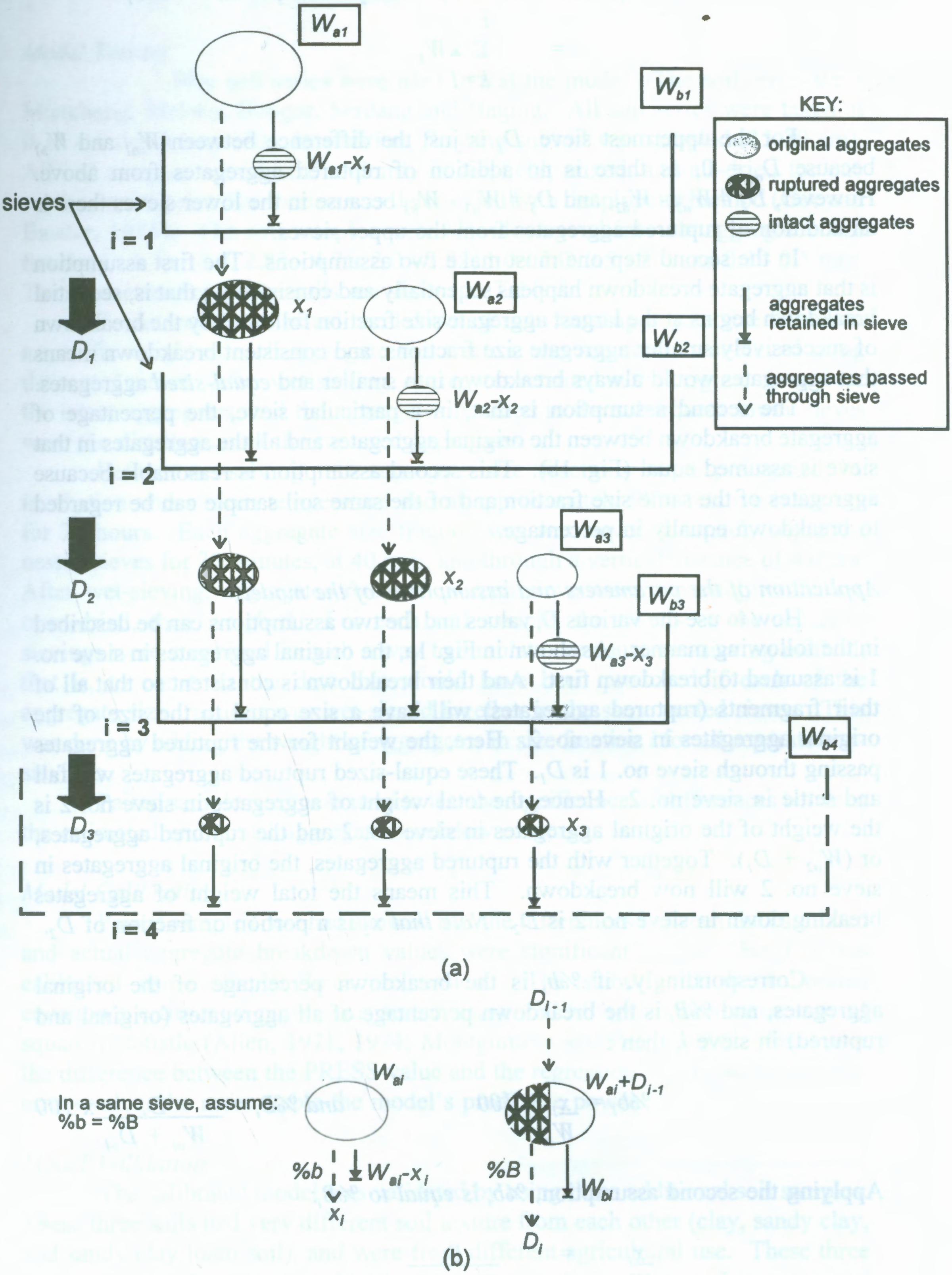

Fig. 1. A flow chart showing the breakdown and movement of aggregates.

$$D_i = \blacktriangle W_1 + \blacktriangle W_2 + \blacktriangle W_3 + ... + \blacktriangle W_i$$

$$= \sum_{k=1}^{i} \blacktriangle W_k$$

For the uppermost sieve, D_1 is just the difference between W_{a1} and W_{b1} because $D_o = 0$, as there is no addition of reptured aggregates from above. However, $D_2 \# W_{a2} - W_{b2}$, and $D_3 \# W_{a3} - W_{b3}$ because in the lower sieves there is an addition of ruptured aggregates from the upper sieves.

In the second step one must make two assumptions. The first assumption is that aggregate breakdown happens seqentially and consistently; that is, seqential breakdown begins at the largest aggregate size fraction followed by the breakdown of successively smaller aggregate size fractions; and consistent breakdown means that aggregates would always breakdown into smaller and *equal-sized* aggregates.

The second assumption is that, in a particular sieve, the percentage of aggregate breakdown between the original aggregates and all the aggregates in that sieve is assumed equal (Fig. 1b). This second assumption is reasonable because aggregates of the same size fraction and of the same soil sample can be regarded to breakdown equally in percentage.

Application of the parameters and assumptions of the model

How to use the various D_i values and the two assumptions can be described in the following manner. As shown in Fig. 1a, the original aggregates in sieve no. 1 is assumed to breakdown first. And their breakdown is consistent so that all of their fragments (ruptured aggregates) will have a size equal to the size of the original aggregates in sieve no. 2. Here, the weight for the ruptured aggregates passing through sieve no. 1 is D_1. These equal-sized ruptured aggregates will fall and settle in sieve no. 2. Hence, the total weight of aggregates in sieve no. 2 is the weight of the original aggregates in sieve no. 2 and the ruptured aggregates, or $(W_{a2} + D_1)$. Together with the ruptured aggregates, the original aggregates in sieve no. 2 will now breakdown. This means the total weight of aggregates breaking down in sieve no. 2 is D_2. *Note that* x_2 is a portion or fraction of D_2.

Correspondingly, if $\%b_i$ is the breakdown percentage of the original aggregates, and $\%B_i$ is the breakdown percentage of all aggregates (original and ruptured) in sieve i, then :

$$\%b_i = \frac{x_i}{W_{ai}} \times 100 \qquad \text{and } \%B_i = \frac{D_i}{W_{ai} + D_{i-1}} \times 100$$

Applying the second assumption, *$\%b_i$ is equal to $\%B_i$:*

$$\frac{x_i}{W_{ai}} = \frac{D_i}{W_{ai} + D_{i-1}}$$

$$x_i = \frac{W_{ai} \times D_i}{W_{ai} + D_{i-1}}$$

MATERIALS AND METHODS

Model Testing

Five soil series were used to test the model. The soil series were Munchong, Melaka, Bungor, Serdang and Baging. All soil series were taken at 0-15 cm depth (topsoil). In addition, Serdang subsoil was sampled (15-30 cm). All soil samples were taken randomly in the field, mixed, and air-dried for one week. Particle-size distribution was determined with the pippette method (Gee and Bauder, 1986). The soil samples were also dry-sieved into six aggregates size fractions : 4.76 - 8.0, 2.83 - 4.76, 2.0 - 2.83, 1.0 - 2.0, 0.5 - 1.0 and 0.3 - 0.5 mm. The characteristics of the soils are shown in Table 1.

To determine the actual breakdown of individual aggregate size fractions, a specific weight of each aggregate size fraction was separately wet-sieved using the nested sieves. After wet-sieving, aggregates retained in the original sieve were the intact aggregates, and the aggregates retained in the subsequent lower sieves were the distribution of the ruptured aggregates.

Before wet-sieving, all aggregate size fractions were pre-wetted by incubation under room temperature and at approximately 98% relative humidity for 24 hours. Each aggregate size fraction was wet-sieved separately using the nested sieves for 30 minutes, at 40 rpm, and through a vertical distance of 4.0 cm. After wet-sieving, aggregates retained in each sieve were separately collected, oven-dried, then weighed. For each soil sample, the results of the separate-sievings were combined in such a way to simulate the usual wet-sieving method; that is, to construct the data that would have been produced if each of the aggregate size fractions was wet-sieved together in the same nested sieves. This was done by adding the weight of aggregates in size fraction *i* for all separate wet-sievings.

Paired sample *t*-test was used to test the significance of differences between the estimated and actual aggregate breakdown values.

Model Calibration

Paired sample *t*-test had showed that the differences between the estimated and actual aggregate breakdown values were significant at 5%. Eq. (1) was calibrated using simpler linear regression. The stability of the calibrated equation's estimation power was tested using PRESS (prediction error sum of squares) statistic (Allen, 1971, 1974; Montgomery and Peck, 1982). The lower the difference between the PRESS value and the regression's SSE (sum square of error) value, the more stable the model's predictive power.

Model Validation

The calibrated model was validated by using three additional soil samples. These three soils had very different soil texture from each other (clay, sandy clay, and sandy clay loam soil), and were from different agricultural use. These three soils were samples and treated in the same way as the previous soil samples, and also dry-sieved into the same six aggregate size fractions.

Table 1. Characteristics of the soils used to test the model

Soil Series	Taxonomy	Particle size distribution (%)		
		clay	silt	sand
Munchong	Typic Hapludox	72.65	9.37	17.98
Melaka	Xanthic Hapludox	52.80	26.57	20.63
Bungor	Typic Paleudult	26.14	16.22	57.65
Serdang (topsoil)	Typic Paleudult	30.22	24.39	45.39
Serdang (subsoil)	Typic Paleudult	36.23	25.56	38.21
Baging	Typic Quartzipsamment	1.22	0.92	97.86

RESULTS AND DISCUSSION

Paired sample *t*-test revealed that the differences between the actual and estimated breakdown values were significant at 5% ($t = 7.35$; $p < 0.001$). This can also be seen in Fig. 2, where eq. (1) was accurate only when the actual aggregate breakdown the actual aggregate breakdown.

Nevertheless, The actual breakdown values correlated very strongly with the estimated values ($r = 0.974$; $p < 0.001$). This means the error of estimation was constant, and therefore could be calibrated by linear regression. Simple linear regression between the actual and estimated variable had violated two assumptions of regression : the assumption of normality and homogeneity of variance. To correct for these violations, the actual breakdown variable was transformed by $ty = \sin^{-1}[\sqrt{(y/100)}]$.

The regression model was highly significant at 1% ($F = 766.039$; $p < 0.001$), with the values fitting very tightly along the regression line, and with a very narrow 95% confidence band (Fig. 3). The calibrated equation was as follows (std. error of the regression coefficient and constant are shown in brackets):

$$ty = \underset{(0.0006)}{0.0166x} + \underset{(0.0092)}{0.1000} \qquad R^2 = 0.961$$

std. error = 0.023

c.v. = 0.205%

which can be re-expressed as :

$$y_i = 100 \sin^2 \alpha_i$$

where y_i is the calibrated breakdown estimate for aggregate size fraction i, α_i is $(0.0166x_i + 0.1)$ in unit radians, and x_i is taken from eq. (3).

SSE and PRESS value for eq. (2) were 0.0163 and 0.0183, respectively. This is an increase in error of only 1.12 times. This small increase in prediction error means the predictive power of eq. (2) was very stable, and would not degrade much in predicting future observations.

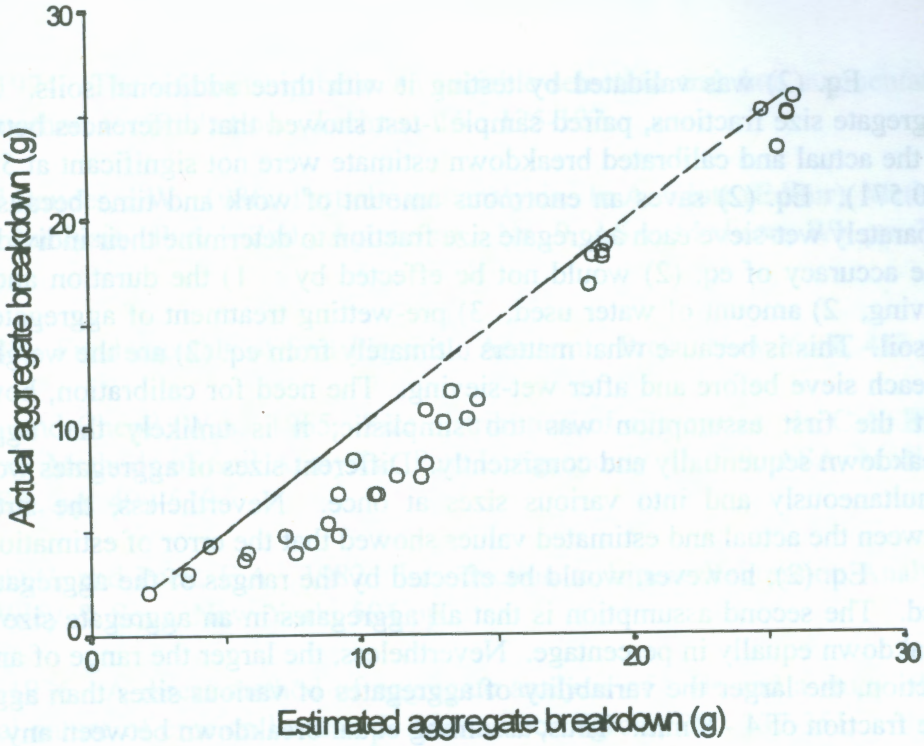

Fig. 2. Comparisons between the estimated and observed (actual) aggregate breakdown values

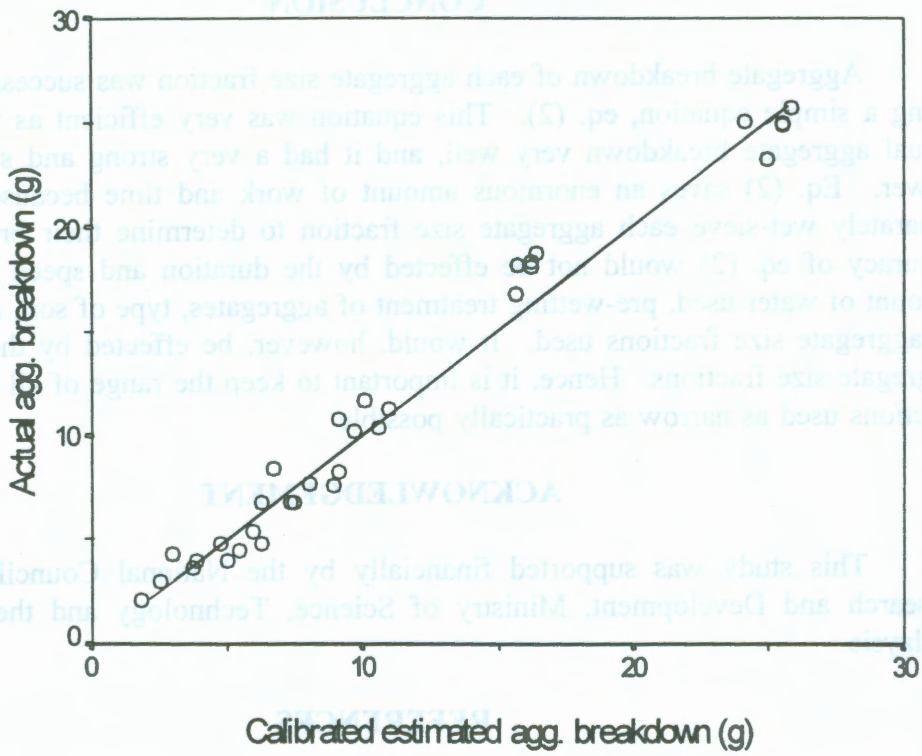

Fig. 3. Comparisons between the estimated (after calibration) and observed (actual) aggregate breakdown values

Eq. (2) was validated by testing it with three additional soils. For the full six aggregate size fractions, paired sample *t*-test showed that differences between the values of the actual and calibrated breakdown estimate were not significant at 5% ($t = 0.580$; $p < 0.571$). Eq. (2) saves an enormous amount of work and time because one need not separately wet-sieve each aggregate size fraction to determine their individual breakdown. The accuracy of eq. (2) would not be effected by : 1) the duration and speed of wet-sieving, 2) amount of water used, 3) pre-wetting treatment of aggregates, and 4) type of soil. This is because what matters ultimately from eq. (2) are the weight of aggregates in each sieve before and after wet-sieving. The need for calibration, however, showed that the first assumption was too simplistic; it is unlikely that aggregates would breakdown sequentially and consistently. Different sizes of aggregates would breakdown simultaneously and into various sizes at once. Nevertheless, the strong correlation between the actual and estimated values showed that the error of estimation was constant.

Eq. (2), however, would be effected by the ranges of the aggregate size fractions used. The second assumption is that all aggregates in an aggregate size fraction would breakdown equally in percentage. Nevertheless, the larger the range of an aggregate size fraction, the larger the variability of aggregates of various sizes than aggregates from a size fraction of 4 - 8 mm. Thus, assuming equal breakdown between any two aggregates in the former aggregate size fraction would be more unreasonable than in the latter size fraction. Therefore, it is important to keep the range of all aggregate size fractions as narrow as practically possible.

CONCLUSION

Aggregate breakdown of each aggregate size fraction was successfully estimated using a simple equation, eq. (2). This equation was very efficient as it estimated the actual aggregate breakdown very well, and it had a very strong and stable predictive power. Eq. (2) saves an enormous amount of work and time because one need not separately wet-sieve each aggregate size fraction to determine their breakdown. The accuracy of eq. (2) would not be effected by the duration and speed of wet-sieving, amount of water used, pre-wetting treatment of aggregates, type of soil, and the number of aggregate size fractions used. It would, however, be effected by the ranges of the aggregate size fractions. Hence, it is important to keep the range of all aggregate size fractions used as narrow as practically possible.

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