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SOIL FAILURE AND ITS APPLICATION TO VIBRATING TILLAGE TOOL

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ABSTRACT

The effect of loading speed on soil failure was studied by using a high speed triaxial compression test. Tests were conducted at 0.35 - 6.2 m/s loading speed to compress soil specimens of sandy loam at different moisture contents. The axial stress at fracture increased with increase in loading speed up to certain critical speeds, however they decreased as the speed increased further.

Experiments were also conducted in the field of sandy loam soil with the vibrating tillage tool. Tests were done at 0.33 - 0.85 m/s tractor speed ; oscillating frequency 13.7 Hz and oscillating amplitude 59 mm. The maximum oscillating velocity of tillage tool was 2.5 m/s. It was observed that for the oscillating operation, initially draft slightly increased with increase in forward speed and then it decreased. For the non-oscillating operation, draft increased continuously with increase in forward speed. Approach of studying soil failure in the laboratory tests can be related to the field experiment.

Key Word : high speed triaxial compression test, fracture strength, soil failure, draft

INTRODUCTION

Tillage implements can be operated dynamically at high speed or with vibration and soil gets fractured due to high speed or vibrating force. Soil fractures under these conditions will be different from that under a quasi - static loading (1, 2). However, the information of soil failure with a high speed or vibrating loading is limited. The tool velocity has been neglected or made low to minimize strain - rate effects in many previous laboratory researches. If the general principles of soil failure at high speed or with vibration are better understood, it will be useful information to use for improving the tillage implements. The time and money can be saved in the design and development of tillage implements.

As the nature of deformation and subsequent failure depends on the initial soil condition as well as the method of loading, the effect of methods of loading on soil failure were studied both in the laboratory and in the field conditions. The first set of experiments were conducted in the laboratory by a high speed triaxial compression test. The fracture strength were investigated under high speed loading at different conditions. The second set of experiments were conducted in the field. The tillage implement used was a vibrating shank with wing shares. The experiments were conducted under different operating conditions. Test results were reported in terms of force mechanics and soil disturbance. Then approach of studying soil failure in the laboratory tests was related to the field experiment.

APPARATUS AND PROCEDURE

1. High speed triaxial compression test

The procedure for soil samples of silty loam and sandy loam soil were prepared in the laboratory according to the following procedure. The samples of silty loam and sandy loam soil were collected from the ploughed layer in a regularly cultivated field. The physical properties of the test soils are given in Table 1.

Initially the soil samples were air dried and the structural aggregates were broken and sieved through a 2 mm screen. The soil samples were then re-wetted to the desired moisture contents by spraying atomized water and mixing and stirring by hand. To get the equilibrium condition of desired moisture contents, the samples were kept in air-tight plastic bags.

The unsaturated soil specimens were compacted in a mould 50 mm in diameter and 125 mm in height. The number of blows for compaction was changed at each moisture content to result in average dry bulk density of 1.2 g/cm^3. Each sample was trimmed at both ends to a final length of 100 mm, and was kept in an air - tight plastic bag for about 2 - 3 days before testing.

For this test each soil specimen covered with a cylindrical rubber membrane was axially set in the triaxial cell of test machine. A cell pressure of 19.6 kPa acting on the soil specimen was set by adjusting the air pressure in the triaxial cell. The different loading speeds were achieved by driving a rack by a variable speed motor. The moving rack varied the ram speed in the range 0.35 - 6.2 m/s. The compressive forces were detected by the upper and lower force transducers and the signals from the transducers were amplified and recorded on a tape recorder. The axial deformation of the test soil specimen was detected by a photo

- diode displacement transducer and was recorded on a tape recorder. The signals of compressive forces and axial deformation of the test soil specimen were displayed on an oscillograph. The schematic of test apparatus and instrumentation is shown in Fig. 1.

2. Vibrating tillage tool

The vibrating tillage tool used for the experiments was a vibrating shank with wing shares. The construction of the tillage tool is shown in Fig. 2. A V-shaped share was fixed to the oscillating shank and oscillated by the oscillating mechanism with the power from PTO of tractor. The shank was of a curve shape with wedge shape on the curve to reduce soil compaction. The shape of share was not symmetrical on both sides of wing shares. The lift angles inclined from cutting edge were different on both sides of wing shares (Table 2). Two vibrating tillage tools were used for the experiments, it might be called the tillage tool "A" and "C". A four wheel drive 19 kW tractor was used for testing the tillage tool in the field.

Experiments were conducted at tractor speed of 0.33 - 0.85 m/s ; oscillating amplitude of 59 and 77 mm ; oscillating frequency 8.7 - 13.9 Hz ; and maximum oscillating velocity 1.6 - 3.4 m/s. The non - vibrating experiments were conducted at speeds of 0.22 - 1.78 m/s. All tests were conducted in a paddy field with the same sandy loam soil used for the lab studies, at an average constant working depth of tool of 14.2 cm, moisture content 43.2% (d.b), dry bulk density 1.03 g/cm^3 and cone penetration resistance 467 kPa with a standard cone penetrometer.

Draft required to move the tool was measured by sensing compression force of the upper link and bending force of pins at the lower links of 3 points linkage hitch with strain gage. The inclination of the upper link was measured by a potentiometer attached to the shaft of the lift arm. Oscillating power was measured with a strain gage torque meter attached to the crank shaft of the oscillating mechanism. The rotational speed and angular position of the crank shaft were measured by using a magnetic pick up. Measured data were recorded by a magnetic tape recorder. During the test, the behaviour of subsurface of soil disturbance was observed and the characteristics of surface of soil disturbance was photographed after tests. The surface profile of soil was measured before and after test at the same position with a profile meter. The soil disturbance characteristics at depth was monitored by taking carefully a section across the disturbed area with a knife after each test in such a manner to avoid the change of soil structure. The disturbed soil was removed by hand for a distance of 400 - 600 mm beyond the sectional face and the undisturbed soil boundary was measured by using a profile meter. Another method of determining soil disturbance was by reporting the change in dry bulk density of the soil. For each test, the sections across the disturbed soil were taken carefully with a knife in such a manner to avoid the change of soil structure and the disturbed soil was removed by hand for a distance of 300 - 400 mm beyond the sectional faces. Then the disturbed soil of the sectional face was sampled in horizontal direction by a sampler 100 cc at center position between the center line of shank acting and the furrow wall on both sides. The changes in dry bulk density of soil before and after the test is reported in terms of percentage of decrease in dry bulk density.

RESULTS AND DISCUSSION

1. Fracture strength from test results of a high speed triaxial compression test (2)

The variation of axial stresses at different loading speeds is showed in Fig. 3. The axial stress was an average value of peak compressive stresses detected by the upper and lower force transducers. In the case of peak stress over 15% of axial strain, the average value of axial stress was calculated at 15% of axial strain (3).

For sandy loam soil at different moisture contents, the axial stress slightly increased with increase in loading speed up to the critical speed range of 1.7 - 3.6 m/s, then it decreased. The axial stress at moisture content 11.5% (d.b) increased with increase in loading speed up to a maximum stress of 138 kPa at the loading speed of 3.6 m/s and later it decreased slightly. This axial stress was higher than the axial stresses observed at other moisture contents. The axial stresses decreased with increase in soil moisture contents. For silty loam soil at moisture content 21.8% (d.b), the maximum axial stress was 228 kPa at 1.8 m/s loading speed. It was higher by about 74% than the maximum axial stress of sandy loam soil observed at 20.8 % (d.b) moisture content.

The reason for reduction of the axial stresses at higher loading speeds may be that at greater loading rates the pore pressure developed is higher than the total applied pressure when stress is applied by a very high loading speed. The increase in pore pressure has the effect of reducing the effective stress, according to equation (4).

$$\bar{\sigma} = \sigma - u$$

where

$\bar{\sigma}$: effective stress

σ : total applied stress

u : pore pressure : i.e. pressure in the pore fluid (water and air)

As lower the effective stress, the lower would be the expected shear strength because the effective stress is a function of shearing resistance according to Mohr - Coulomb failure law.

Test results showed that the mode of soil failure changed from brittle failure to plastic flow as loading speed increased.

2. Effects of total speed on draft and power requirement from test results of a vibrating tillage tool.

It was observed that the draft increased from 5 kN to 6.3 kN as the forward speed increased from 0.3 m/s to 0.7 m/s, however, further increase in speed caused decrease in the draft (Fig. 4). The reason for reduction in the draft at very high velocity of load application may be due to greater rate of increase in the pore pressure than in the total applied pressure when stress is applied at a very high loading velocity. Greater pore pressure reduced the effective stress. As lower the effective stress, the lower would be the expected shear strength.

For non - oscillating tillage tool, draft increased continuously with increase in forward speed. The draft for non - oscillating tool was higher than the draft for oscillating tool at any forward speed. The ratio of draft during oscillating to non - oscillating of forward speeds of 0.34 and 0.85 m/s was 0.63 and 0.93 respectively (Fig. 4).

Drawbar power of oscillating operation increased with an increase in forward speed. The ratio of drawbar power during oscillating to non - oscillating at forward speeds of 0.34 and 0.85 m/s was 0.57 and 0.89 respectively. The power required for oscillating was almost the same as the forward speed increased from 0.34 to 0.85 m/s. Total power required for oscillating operation was 4.3 and 8.2 kW at forward speeds of 0.34 and 0.85 m/s respectively. It was greater than the power required for non - oscillating operation by about 45 and 41% at the 0.34 and 0.85 m/s forward speeds respectively (Fig. 5).

3. Characteristics of soil disturbance

During experiments, the behaviour of soil disturbance was observed. During oscillating operation, it was observed that soil surface cracked in the characteristics of lifting up of soil clods. The soil was disturbed by the oscillation of shank at the center. The soil disturbed by the oscillation of wing share was in area between the center line of oscillating shank and the furrow side wall on both sides of disturbed soil (Fig. 6). During non - oscillating mode, soil cracks on the surface were not evident. It showed the characteristics of soil flow.

The width of soil cutting was very large compared to the working depth. The ratio of working depth and width of cut was 0.3 (Fig. 7). The type of soil failure was considered to be the same as "wide tine or blade failure" (5). As the tool moved forward, the soil may be separated in front of wing shares and slided forwards and upwards along the failure surface. The mass of soil in furrow slice was disturbed upon the direction of the resultant tool force acting on soil. For the lift angles less than 45 degree, the tool force has an upward vertical component and tends to lift the soil upwards producting a loosening effect (6). For that reason, the disturbed soil surface profile was risen from the original surface (Fig. 7).

4. Effects of operating condition on soil disturbance

Investigations were carried to determine soil disturbance in more details. It was observed that the increase of the boundary of disturbed soil surface profile did not show clearly the effect of increasing in oscillating frequency. Where as the oscillating amplitude showed significant effect on soil disturbance. The boundary of disturbed soil surface profile tend to increase as compared with non - oscillating condition (Fig. 8).

Test results of soil loosening are shown in Figure 9. The values of decreasing of dry bulk density tend to increase with increase in oscillating frequency. It increased by about 5.3 - 13.8% at frequency 8.7 Hz to 17 - 20% at frequency 13.9 Hz and 5% for non - vibration. It slightly decreased with increase in oscillating amplitude from 59 mm to 77 mm (Fig. 10). The reason of increase in soil loosening with increase in oscillating frequency was due to the disturbed soil from previous cycle of oscillated path of tool was still pulverized from next cycle at higher oscillating frequency than at lower oscillating frequency. The less loosening of soil at higher oscillating amplitude was due to the loose soil may be more compressed at higher oscillating amplitude than at lower oscillating amplitude during the lifting up of soil at backward motion.

5. Approach of studying soil failure in the laboratory tests related to the field experiment.

The soil failure characteristics under high speed loading were different from that under a quasi - static loading (1 , 2). During high speed loading of triaxial compression test, the axial stress at fracture increased with increase in loading speed up to the critical speed and then it decreased. This characteristic was the same as the characteristic of draft force for the tests of the oscillating tillage tool in the field. The draft force slightly increased with increase in forward speed up to the critical speed then it decreased. For non - oscillating operation, the draft force increased continuously with increase in forward speed. As the models of Smith et al.[7] (1972), Yow and Smith[8] (1976), the tool oscillates sinusoidally in the direction of the tool carrier travel. The tool force is a linear function of tool velocity. They analyzed experimentally at low loading speed acting on soil. For these experiments of the non - oscillating tillage tool, it follows the above models. However, at high loading speed with impact acting of the triaxial compression test and/or oscillating tillage tool, the relationship between force and loading speed do not follow these models. Therefore, the difference in the force - loading speed relationships was due to a change in the mode of soil failure. Then the models of Smith et al ; Yow and Smith may not be applicable at high loading speeds.

CONCLUSIONS

The results of high speed triaxial compression tests showed that the axial stress at fracture increased with increase in loading speed up to the critical speed range 1.7 - 3.6 m/s and then it decreased as the loading speed increased further.

The results of vibrating tillage tool in the field showed that at oscillating frequency of 13.7 Hz, oscillating amplitude of 59 mm and the maximum oscillating velocity of tillage tool 2.5 m/s, the draft slightly increased with increase in forward speed up to a critical speed of 0.7 m/s then it decreased. For non - oscillating operation, draft increased continuously with increase in forward speed. The ratio of draft during oscillating and non - oscillating was 0.63 and 0.93 at forward speeds of 0.34 and 0.85 m/s respectively. Total power required for oscillating operation was 4.3 and 8.2 kW at forward speeds of 0.34 and 0.85 m/s respectively. It was greater than the power required for non - oscillating operation by about 45 and 41 % at the same forward speed.

During the oscillating operation, soil surface cracked showing the characteristic of lifting soil clods up. For non-oscillating mode, soil cracks on surface were not evident. It showed the characteristic of soil flow.

The values of decreasing dry bulk density tended to increase with increase in oscillating frequency. It increased by about 5.3 - 13.8 % at frequency of 8.7 Hz and 17 - 20 % at frequency of 13.9 Hz and only 5 % for non - vibration. It slightly decreased with increase in oscillating amplitude from 59 mm to 77 mm.

Approach of studying soil failure in the laboratory tests can be related to the field experiment. When the axial stress at fracture as varying of impact loading speed of triaxial compression test is considered with the characteristic of draft force for the tests of the oscillating tillage tool in the field.

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Table 1. Physical properties of the soil used for the experiments

	Silty loam	Sandy loam
Particle size distribution	(per cent)	(per cent)
Coarse sand (0.42 - 2 mm)	15	10
Fine sand (0.074 - 0.42 mm)	20	40
Silt (0.005 - 0.074 mm)	58	42
Clay (< 0.005 mm)	7	8
Consistency limits		
Plastic limit	28.2	28.2
Liquid limit	49.5	38.0
Plasticity index	21.3	9.8

Table 2. Details of lift angles of shares

Tillage tool	R-side of wing share (degree)	L-side of wing share (degree)
"A"	13	6.5
"C"	13	9

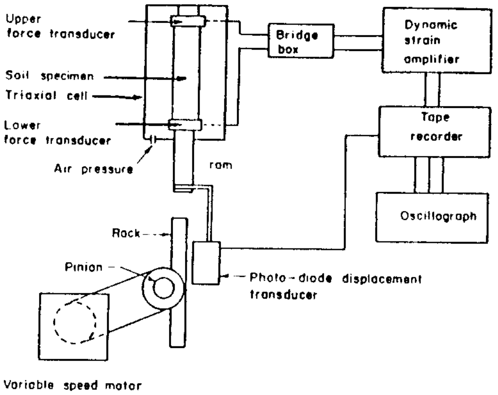

Fig.1. A schematic of test apparatus and instrumentation.

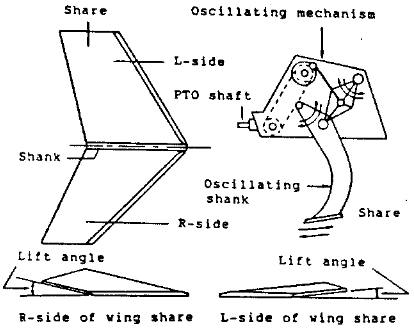

Fig.2. Vibrating tillage tool

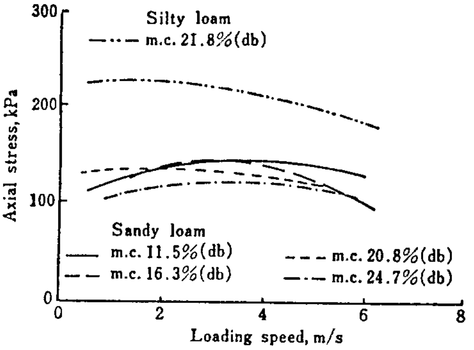

Fig. 3 Variation of axial stresses at different loading speeds and soil moisture contents

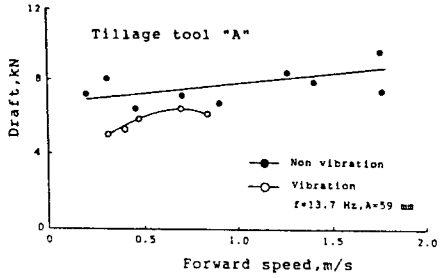

Fig.4. Variation of draft

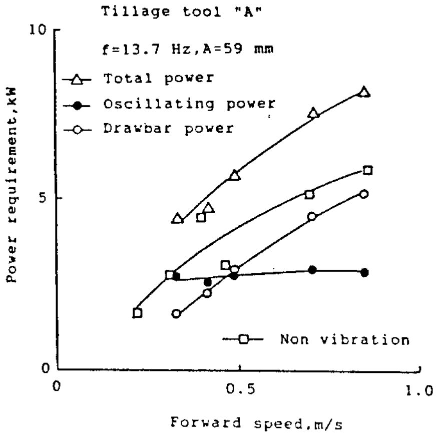

Fig.5. Variation of power requirement

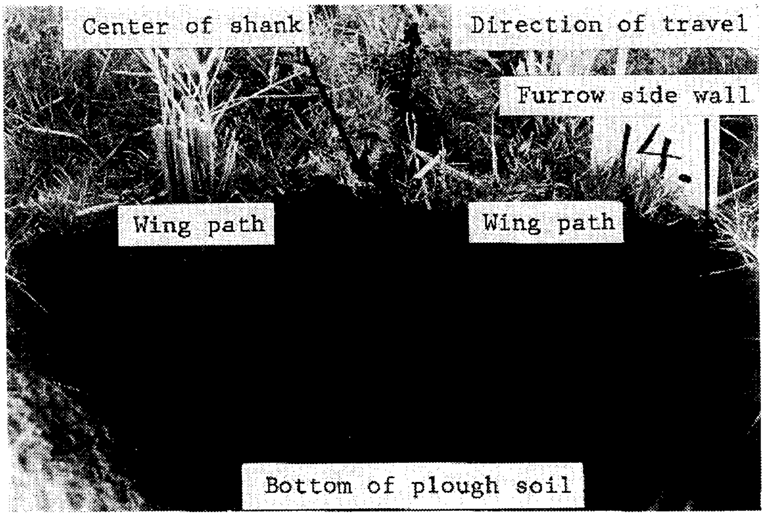

Fig 6. Cross section of disturbed Soil by vibrating tillage tool f = 11.6 Hz, A = 59 mm, s = 0.34 m/s

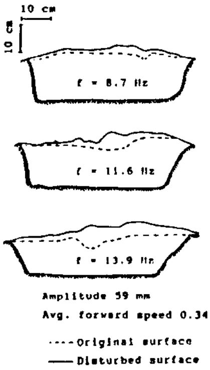

Fig.7. Soil boundary disturbance

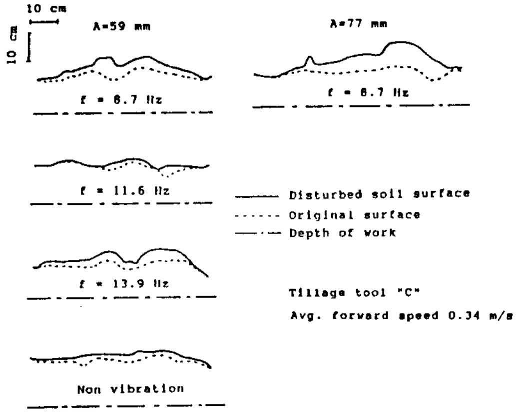

Fig.8. Effect of oscillating operation on soil surface disturbance

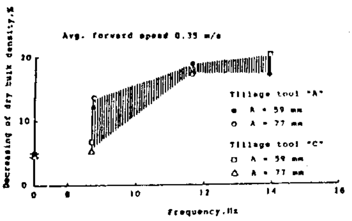

Fig.9. Effect of oscillating frequency on decreasing of dry bulk density

-○- Tillage tool"A" for non vibration
△ Tillage tool"C" for non vibration

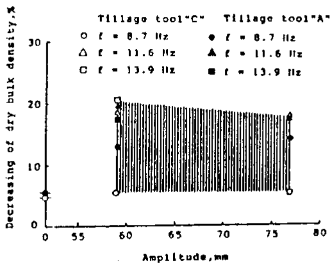

Fig.10. Effect of oscillating amplitude on decreasing of dry bulk density

-○- Tillage tool"C" for non vibration
-●- Tillage tool"A" for non vibration

Avg. forward speed 0.35 m/s