DEFORMATION AND FORCE CHARACTERISTICS CAUSED BY INCLINED TINES IN LOAM SOIL BELOW LIQUID LIMIT

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Abstract

Studies were conducted in a glass-sided laboratory soil bin. Soil deformation patterns were analysed for failure angle, soil wedges and forward rupture and surcharge profiles. They were also observed for purposes of correlation with the corresponding soil reactions. Forward rupture profiles were determined by using two parallel scales and a measuring scale while soil surcharge profiles were determined with the use of a three-way coordinate measuring system. Soil reactions (horizontal and vertical) from two identical tines (glass-sided and central) were measured by L-shaped force transducers while a ten-turn potentiometer recorded the forward speed. The data was amplified, logged and transferred to a computer for saving and further processing. Observed cyclic variations in the force-time curves of the soil reactions were analysed in terms of wave length, peak to trough ratio and amplitude. The behaviour and magnitudes of forces caused by flat rigid tines (inclined at an angle of 50 deg. to the horizontal soil surface measured in a clockwise direction) in loam soil below the liquid limit were studied using a glass-sided soil bin. The tines were moved in the soil bin in a quasi-static condition and the deformation observed through the glass. Three moisture content levels (5.2%, 21% and 33.5% (d.b.)) were used. The results under the above conditions indicated that soil reactions (horizontal and vertical) were cyclic in nature and in phase as observed from the force-time curves and matched quite well with the soil deformation characteristics. Soil force magnitudes for 5.2% and 21% moisture contents were basically the same in all aspects while those for 33.5% were relatively higher but with dying off cyclicity. Correlation of these observations with previous research showed that soil moisture content has a strong effect on force deformation and force characteristics.

Key words: Deformation, force, characteristics, tines, loam, soil, liquid

1.0 Introduction

One of the methods of reducing costs in tillage is through efficient design of tillage tools. These tools have for a long time been designed on a trial and error basis as the soil-tool interactions involved have not been defined and quantified. More research is still to be conducted to clearly understand the mechanics of the soil under the influence of agricultural tillage tools.

Classical soil failure theories which have been adapted from concepts used to describe soil behavior for civil engineering purposes have for quite sometime been relied on in various attempts to predict tillage forces under varying circumstances [1-7]. The passive soil pressure and critical state soil failure theories have been commonly used in such cases. There has been increasingly growing concern as regards to the suitability of these theories in solving the various problems experienced in agricultural engineering. Under civil engineering conditions, initial soil failure is all that is required as opposed to the need to predict continuous repeated failure in agricultural engineering. Soil failure patterns and their corresponding reactions form a basis for the development of tillage mechanics and high accuracy in defining them is therefore of vital importance.

Soil failure patterns have been reported to vary with soil and tool parameters [5, 8-23, 25]. The soil moisture content in particular has been observed to be of strong effect on variations in soil failure patterns. The patterns have also been observed quite different from those assumed by the passive soil pressure theory. Major variations in force response to tool travel velocity have been reported under a wide range of soil moisture content in various soil types and tillage tools [8-11, 16, 17, 21-24]. There is currently no theory available which can predict the variations. These observations seem to oppose the applications of the force prediction models developed on the basis of the classical soil mechanics theories in solving agricultural engineering problems. Consideration was mainly given to brittle failure and speed effects were neglected in the development of these models. Tillage machines are employed under various soil failure conditions and speed and hence ideal models should take all these into consideration.

Variations in soil failure patterns and there corresponding soil forces have been observed while working flat rigid tines [9, 21, 25] as soil moisture contents were varied from dry to wet unsaturated. Soil deformation characteristics were reported in Part I [25]. This paper reports findings on the force characteristics only. The materials and methods used in this paper and the relevant soil properties have also been described in the above referred to paper. The data is in most cases given on per unit tine area basis for homogenization purposes.

2.0 Results and Discussion

In all the cases studied, the horizontal (draft) and vertical soil forces were observed to be cyclic in nature and in phase as shown in Fig. 1. The cyclicity could be related to the observed intervaling of the soil deformation patterns at different stages of tine travel [22, 25] and analyzed for ratio of peak to trough values (Rac), wave length (WL) and amplitude (Aac). The magnitudes of the force-distance curves were affected by localized variations in soil conditions which were very difficult to avoid even by most careful soil preparation. The reasons for the gradual building up and eventual attaining of dynamic stability of the force-time curves are a result of the corresponding behavior of the soil surcharge [21-23, 25]. The observed variations in soil forces as a result of changes in moisture content are mainly due to corresponding changes in cohesion and adhesion.

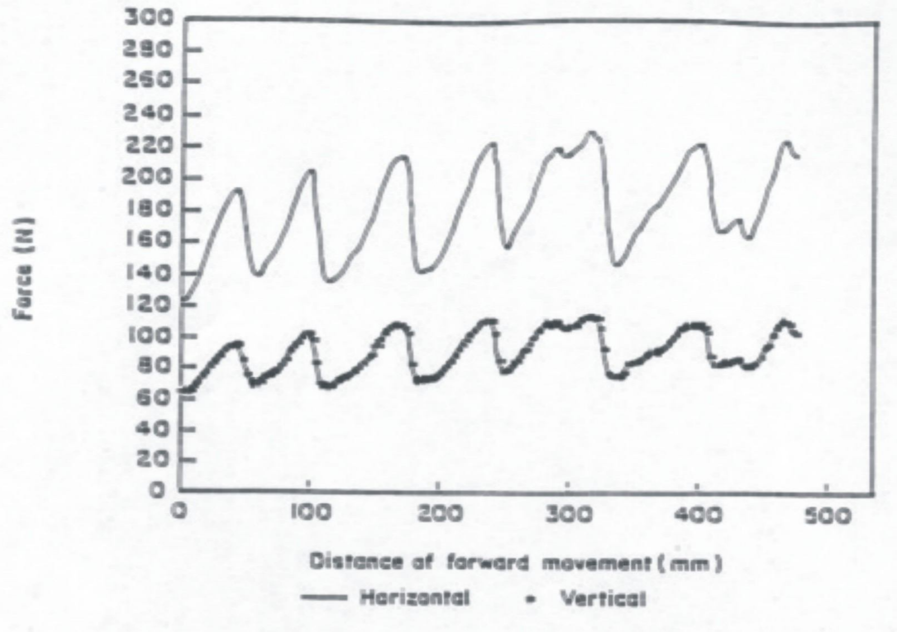


Figure 1: Force – distance curves for a tine of 10cm width, 12cm depth and 50 deg rake angle operating in a 5.2% (d.b.) soil moisture content

2.1 Soil Force Characteristics at Moisture Contents below the Plastic Limit

The soil at moisture levels of 5.2% and 21% could be considered as dry and below the plastic limit (in this case 23% (d.b.)). Observations from all the tines studied indicated that the horizontal and vertical soil reactions for the two moisture levels were basically the same in both magnitudes and characteristics. Figure 2 shows a force-time curve for a tine operating at a 21% moisture level. Comparing this figure with Fig. 1 which is for 5.2% moisture content, does not reveal any major differences in the periodic behavior of the forces. However, there was a noticeable slight rise in force magnitudes with the respective tine aspect ratios which was due to the corresponding rise in cohesion and adhesion when moisture level was increased.

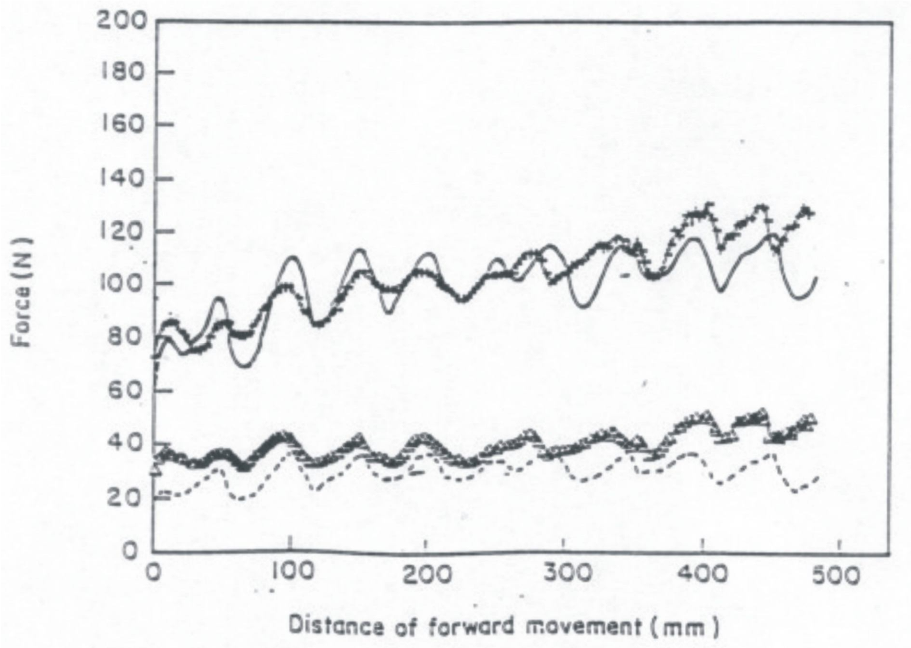


Figure 2: Force – distance curves for a tine of 11.25cm width, 9cm depth and 50 deg rake angle operating in a 21% (d.b.) Soil moisture content

2.2 Soil Force Characteristics at Moisture Contents within the Plastic Range

The soil at a moisture level of 33.5% was in the range between the plastic limit and the liquid limit (in this case 51% (d.b.)), i.e., within the plastic range. Soil deformation characteristics in this case were quite different from those observed at 5.2% and 21% soil moisture contents [25]. The observed characteristics of the force-distance curves and force magnitudes were also quite different. The forces were quite high but with dying off periodicity. Figure 3 represents one of the typical observations. This figure is quite different from Figures 1 and 2.

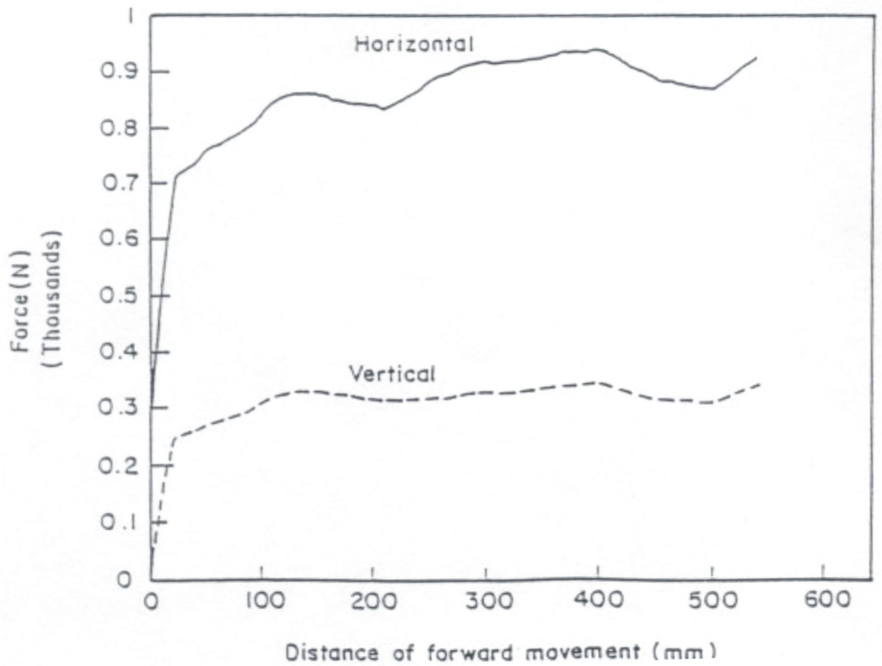


Figure 3: Force – distance curves for a tine of 11.25cm width, 9cm depth and 50 deg rake angle operating in 33.5% (d.b.) soil moisture content

The effect of soil moisture content on the magnitudes of soil reactions (draft only shown) is further illustrated in Figure 4 which also apparently shows the effect of tine aspect ratio. This figure indicates that raising the moisture content from 21% to 33.5% (d.b.) has the effect of multiplying the soil reactions by about five times. Hyperbolic curves were fitted to the data for this figure. The equation defining these curves could be given by:

$$D = ma^n \quad \text{………………} \quad (1)$$

Where,

D = Draft per unit tine area, N/cm^2
m = Constant
a = Tine aspect ratio (w/d)
n = Power value to which “a” is raised

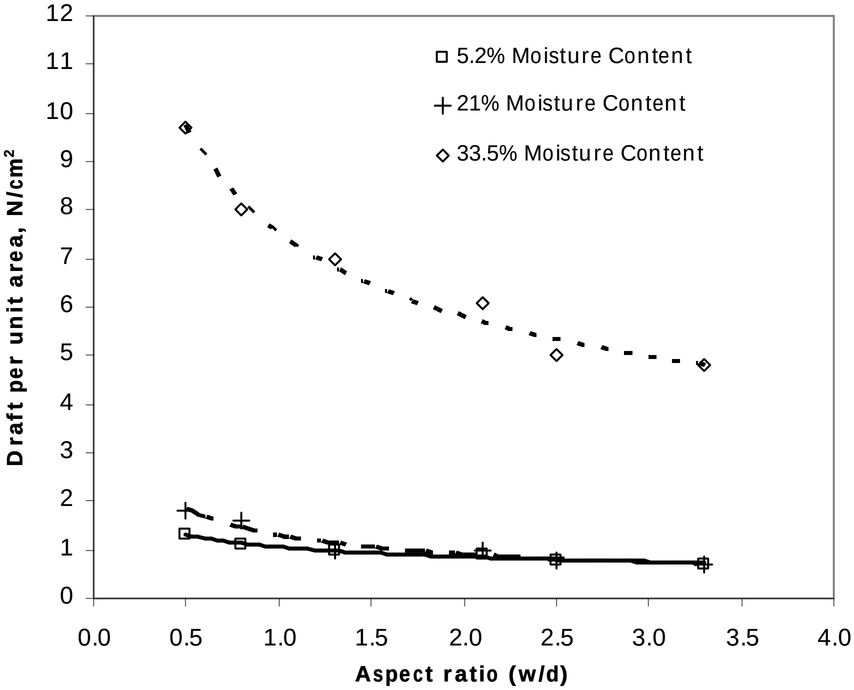


Figure 4: Relationship between draft force per unit tine area and aspect ratio for various soil moisture contents (Rake angle = 50 deg)

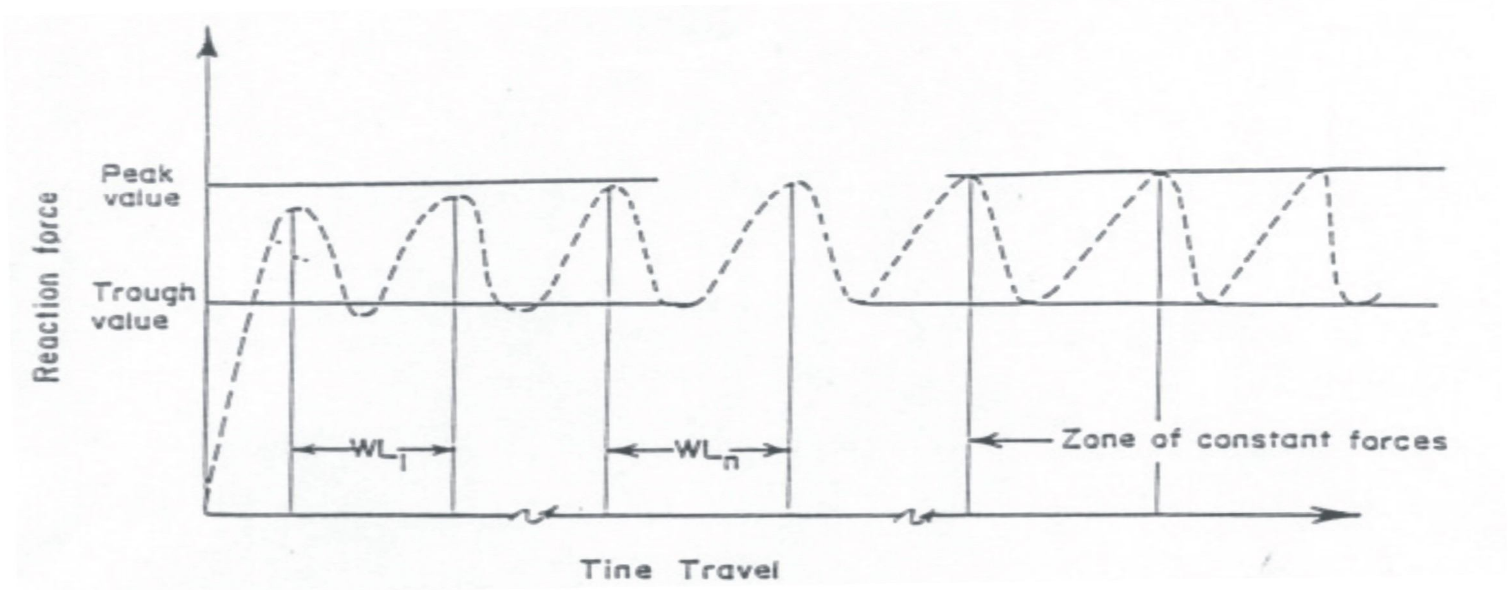
The respective m, n and the square of the coefficient of correlation (r^2) values are given in Table 1. The effect of tine aspect ratio was earlier on investigated and reported to be resulting from changes in the respective tine widths and depths [22].

Table 1: m, n and r^2 values for Figure 4

Soil moisture Content % (d.b.)	m	n	r^2
5.2	1.03	-0.43	0.99
21.0	1.22	-0.59	0.91
33.5	7.43	-0.42	0.98

2.3 Interpretation of Variations in Soil Forces

The interpretation of variations in the soil forces for the three moisture content levels was conducted for the horizontal forces (draft) only, which in general, are of major interest. The observed cyclic variations in the forces were analyzed for ratio of peak to trough values of the draft (Rac), wave length (WL) and amplitude (Aac) as defined in Figure 5.



Ratio of peak to trough values of horizontal = f_a (Peak value/Total value) n
Soil reaction averaged over all the failure cycles (R_x) Σ f_a
n = 1

Amplitude of the horizontal soil reactions averaged = f_a (Peak value – Trough value) n
Over all the failure cycles (A_x) Σ f_a
n = 1

Wavelength (WL) = f_a WL_1
Σ f_a
n = 1

Where f_a = Number of failure cycles in the test range
n = Failure cycle number

Figure 5: Definition of the parameters used in interpretation of variations in soil reactions

The effect of soil moisture content and apparently tine aspect ratio on the above parameters is shown in Figures 6 through 8 respectively. Higher peak to trough values were observed in 5.2% and 21% moisture contents as shown in Fig. 6. Straight line relationships were fitted in this set of data. The equation defining these relationships could be given by:

Rac = c + ma .... (2)

Where,

Rac = Peak to trough ratio of draft (10-2) per unit tine area
c = Constant
m = x-axis coefficient
a = Tine aspect ratio (w/d)

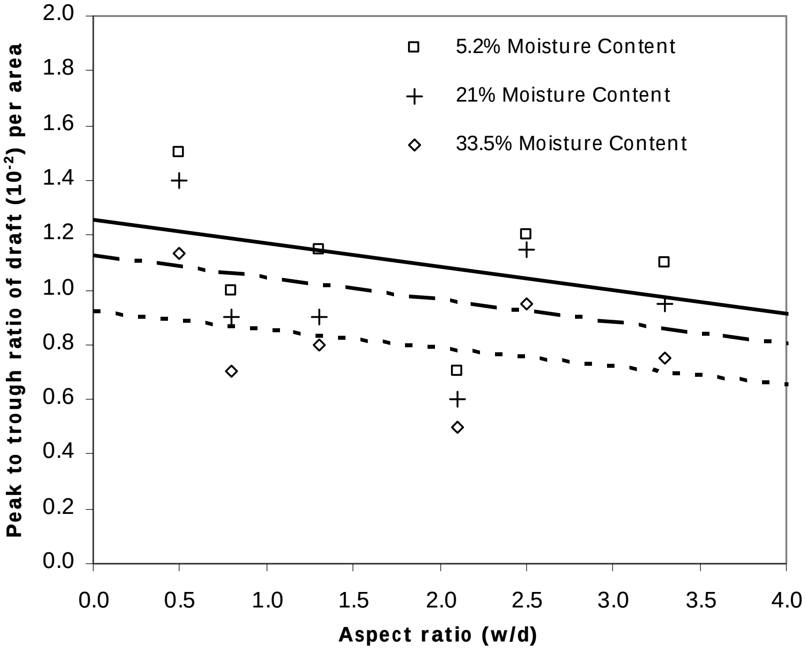


Figure 6: Relationship between peak to trough ratio of draft force per unit area and aspect ratio at different soil moisture contents (Rake angle = 50 deg)

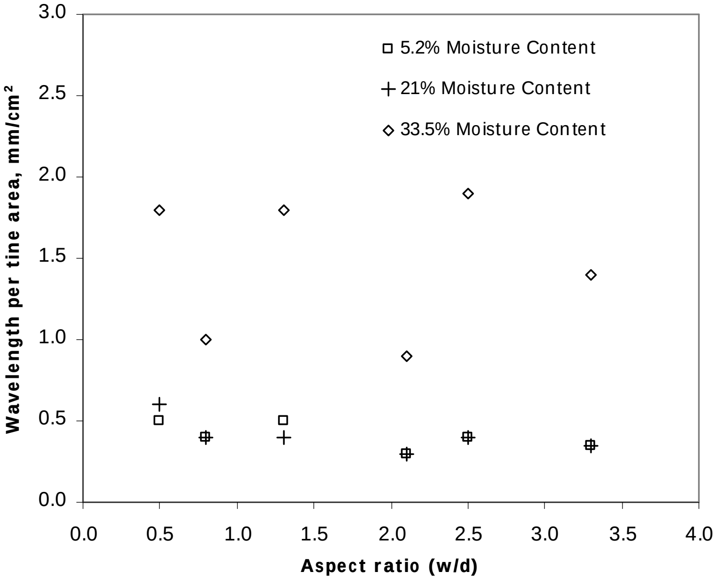


Figure 7: Relationship between wavelength of draft force per unit tine area and aspect ration at different soil moisture contents (Rake angle = 50 deg)

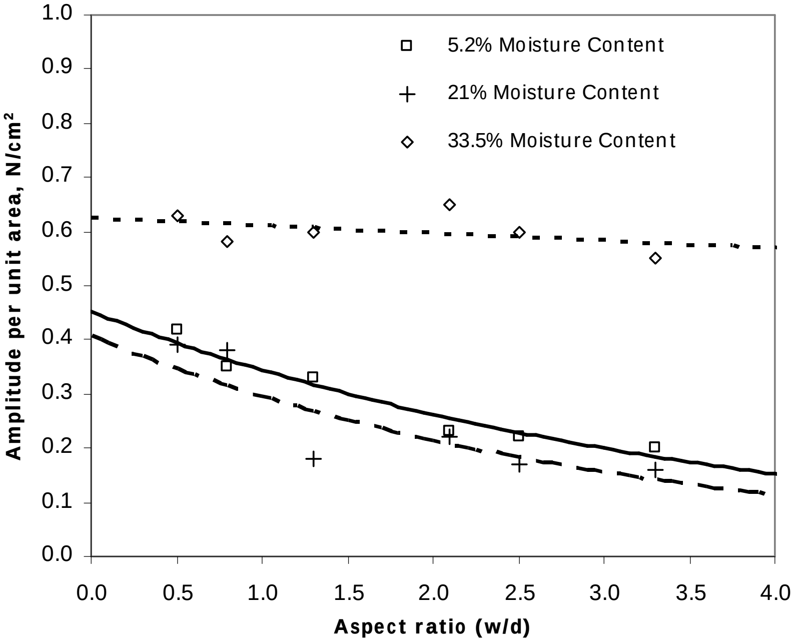


Figure 8: Relationship between amplitude of draft force per unit tine area and aspect ratio at different soil moisture content (Rake angle = 50 deg)

The respect c, m and r^2 values are given in Table 2. The force-distance curves for these moisture contents indicated that periodicity persisted and hence differences in peak and trough values were higher compared to those observed in 33.5% moisture content where periodicity had started dying off.

Table 2: c, m and r^2 values for Figure 6

Soil moisture Content % (d.b.)	c	m	r^2
5.2	0.21	-0.87	0.88
21.0	0.21	-0.87	0.88
33.5	0.08	-0.72	0.96

The effect of moisture content on wave length is shown in Figure 7. There was no definite trend particularly at 33.5% soil moisture content. As the periodicity was dying off in case of the 33.5% moisture content, this meant less failure numbers per given time and hence higher wave lengths. Wave lengths for 5.2% and 21% were lower and almost the same. Periodicity persisted in these cases and hence there were comparatively many failure numbers per given time and therefore lower wave lengths. Soil reactions were quite high in case of the 33.5% moisture content and even though periodicity was dying off, the differences between peak and trough figures were quite high. This accounted for the higher amplitude figures observed for the 33.5% moisture content as shown in Figure 8. Amplitudes for 5.2% and 21% moisture contents were lower and almost the same as soil reactions were comparatively lower. Hyperbolic curves seemed to fit fairly well for the 5.2% and 21% moisture contents. These could again be defined by Eqn. 1. The corresponding m, n and r^2 values are given in Table 3. For 33.5% moisture content data, a straight line relationship defined by Eqn. 2, seemed to be fitting even though the r^2 value was quite low (0.37). The c and m values were 0.65 and 0.032 respectively.

Table 3: m, n and r^2 values for soil moisture contents of 5.2% and 21% (d.b.) in Figure 8

Soil moisture Content % (d.b.)	m	n	r^2
5.2	0.32	-0.42	0.93
21.0	0.28	-0.52	0.87

3.0 Conclusion

The results and discussion as given above have shown that soil force magnitudes and characteristics are strongly affected by variations in soil moisture content. There are however, negligible variations as moisture levels change from pure dry up to just before the plastic limit. Soil moisture content was also reported to have a strong effect on soil deformation characteristics [25]. It has also been observed that deformation and force characteristics can be matched quite well [9, 10, 16, 21, 22, 25]. This aspect is of vital importance in the design of field operation systems particularly tractor-tillage tool systems, e.g., draft control systems.

Correlation of these observations with previous research [9-11, 13-17, 21-23, 25] shows that the effect of moisture content is well pronounced in cohesive and cohesive-frictional (loam) soils particularly within the plastic range. Previous and present studies therefore indicate that clay and loam soils basically have the same trend of deformation characteristics but with differences in force magnitudes. Deformation and force characteristics for frictional soils are mainly affected by tool design parameters [10, 11].

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