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EVALUATION OF SOIL FORCES ON A DEEP CUTTING BLADE

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ABSTRACT

An attempt has been made to measure soil forces experimentally on a deep cutting blade at various inclinations of the interface and different direction of translation at several embedment depths. This experimental measurements are commensurable with the soil forces predicted based on theoretical models proposed by Albuquerque and Sarker at Newcastle. Soil forces predicted based on these models are carefully computed and compared with the experimental values and the theory is underpredicted.

Key words : Soil Rupture Surface and Soil Kinematics

INTRODUCTION

The prediction of forces acting on soil cutting blades is an important parameter in the design of both agricultural tillage implements and earth moving machinery. In the past two decades a considerable amount of research effort has been directed towards the development of techniques for the prediction of soil cutting forces. The interaction of the soil engaging element and the soil presents an extremely complex problem which can not be quantified by simple means. Several simplifications, particularly in respect of the mathematical model for soil as an engineering material, have been introduced to deal with this difficulty.

Pioneer work on soil cutting was carried out by Payne (1956) who developed the first pracrical theory for the prediction of forces on narrow tines. This work laid the foundation for all future anal/tical methods based on the establishment of statically acceptable rupture surface configuration. More recently this technique has been reinforced by Hettiaratchi and Reece (1975) at University of Newcastle upon Tyne by the introduction of slip-line methods based on the mathemaitcal solution of the basic equations of equilibrium proposed by Sokolovski (1960). An extension of this approach has been introduced by Albuquerque (1980) and Sarker *et al.* (1985) at Newcastle to accommodate the kinematics of the motion of the cutting blade. However, none of these theories have been extensively tested, either in the field or under laboratory conditions. In view of the many simplifications introduced into the analysis such a check is essential. The main objective of this investigation is to test the validity of the theories under laboratory conditions.

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BASIC CONSIDERATIONS

All the assumptions and simplifications set out for the analysis of soil-failure problem also apply here in their entirety and the general soil resistance equation takes the identical form :

$$P = \gamma z^2 K + czK_{ca} + qzK_q \quad \ldots \quad (1)$$

In the present context the non-dimensional soil resistance coefficient $K\gamma$, K_c and K_q are all functions of the following non-dimensional parameters :

$$K = f\ (S_c,\ S_q,\ a,\ \delta,\ \rho,\ \phi\ ) \quad \ldots \quad (2)$$

where $S_c = c/\gamma z$, $S_q = q/z$ and $\rho = h/z$ are the soil cohesion number, soil surcharge number and embedment ration. This simplification sets the soil surcharge number, $S_q = 0$ and the last term of Equation (1) is excluded from the present analysis.

RUPTURE SURFACE CONFIGURATIONS

A procedure for dealing with soil failure problem was proposed by Witney (1966, 1969) who develope I the basic analysis in the evaluation of the bearing capacity of deep footings. The essence of this approach is tha development of the modified Rankide zone OCDE shown in Fig. 1a. The geometry of this zone is determined by the position of the boundary OC which is defined by the magnitude of the angle G. Once this angle is ditermined the remaining rupture surface. This techique was adapted by Albuquerque and Hettiaratchi (1980) to deal with the force calculation of sub-surface cutting blades translating in a horizontal direction. The restriction to the horizontal translation ensured that the angle of friction on the machine element was fully mobilised, with the soil sliding up the tool face towards the soil surface. A kinematic constraint is introduced when the tool itself is allowed to translate upwards and manifests itself as a reversal of friction on the kinematic wedge formed on the machine element. The modified analysis to meet this requirement was developed by Sarker *et. al* (1985). The modified Sokolovski rupture surface for this form of soil failure is shown in Fig. 1b and is for a horizontal plate pulled vertically towards the soil surface. The critical direction of translation at which the rupture surface shown in Fig. 1b reverts to that shown in Fig. 1a can be estimated from simple kinematic consideration (Sarker *et. al*, 1985).

EXPERIMENTAL WORK

Measuring soil forces on a deep cutting blade demands labourious work, time and energy input, The apparatus and tools needed for these experiments were designed and developed. The soil tank containing Ryton sand and the carriage with equipped components were adapted and used for these experiments.

The basis of instrumentation used in this investigation was a set of two dynamometers : one (2.5 KN) for vertical force components and the (8 KN) for the horizontal component which sensored the soil loads on the blade directly and deflection was registered on the X-Y plotter.

These dynamometers were mounted separately on the carriage frame on which the sub-frame carrying the cutting blade was also mounted.

With the above setup signals of soil load on the cutting blade from each of these dynamometers were carried through electrical cables through a two channel amplifier, to X-Y plotter which registered the deflection upto the maximum peak load at failure. Thus, as the cutting blade translated in the soil bin, the dynamometers mounted as described above, monitored the horizontal (H) and vertical (V) force components which were plotted simultaneously on the X-Y plotter.

RESULTS AND DISCUSISON

This investigation being carried out has two main objectives :

a) To measure soil forces directly on a deep cutting blade (interface) at various interface inclinations ($\alpha=0^0—90^0$) and directions of translation ($\beta=0^0—90^0$).

b) To compare the experimentally measured soil forces on the interface with the theoretical computed values based on Albuquerque and Sarker models.

1. Vertical Upward Pull

a) For $\alpha=0^0$ and $\beta=90^0$, the resultant soil force on the cutting blade increases with increase in the embedment depth. This relationship when presented on a graph, it is seen to be a non-linear curve and compared good with the theoretical values as shown in Fig. 2a. However, the experimental values are proportionally higher than the theoretical computed values.

b) For $\alpha=45^0$ and $\beta=90^0$, the resultant soil reaction at same embedment depth as in (a) above, was observed to he higher than when the blade was inclined at $\alpha=45^0$ and translated vertically upwards. This also is in line with the theoretical prediction when compared with theoretical values.

2. Horizontal Translation

For $\alpha=90^0$ and $\beta=0^0$, the resultant soil resistance on the blade was much greater than the cases when the blade was translated in any other direction ($\beta=0\text{-}90^0$) and the peak force/embedment ratio relationship on the graph compared fairly good with the

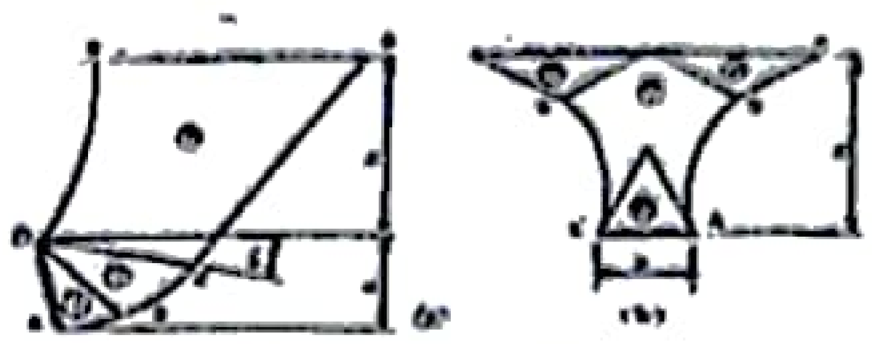

Fig. 1 (a) [illegible] surface for a soil-surface cutting blade translating horizontally [illegible]. (b) [illegible] surface for a soil-surface cutting blade translating vertically [illegible]

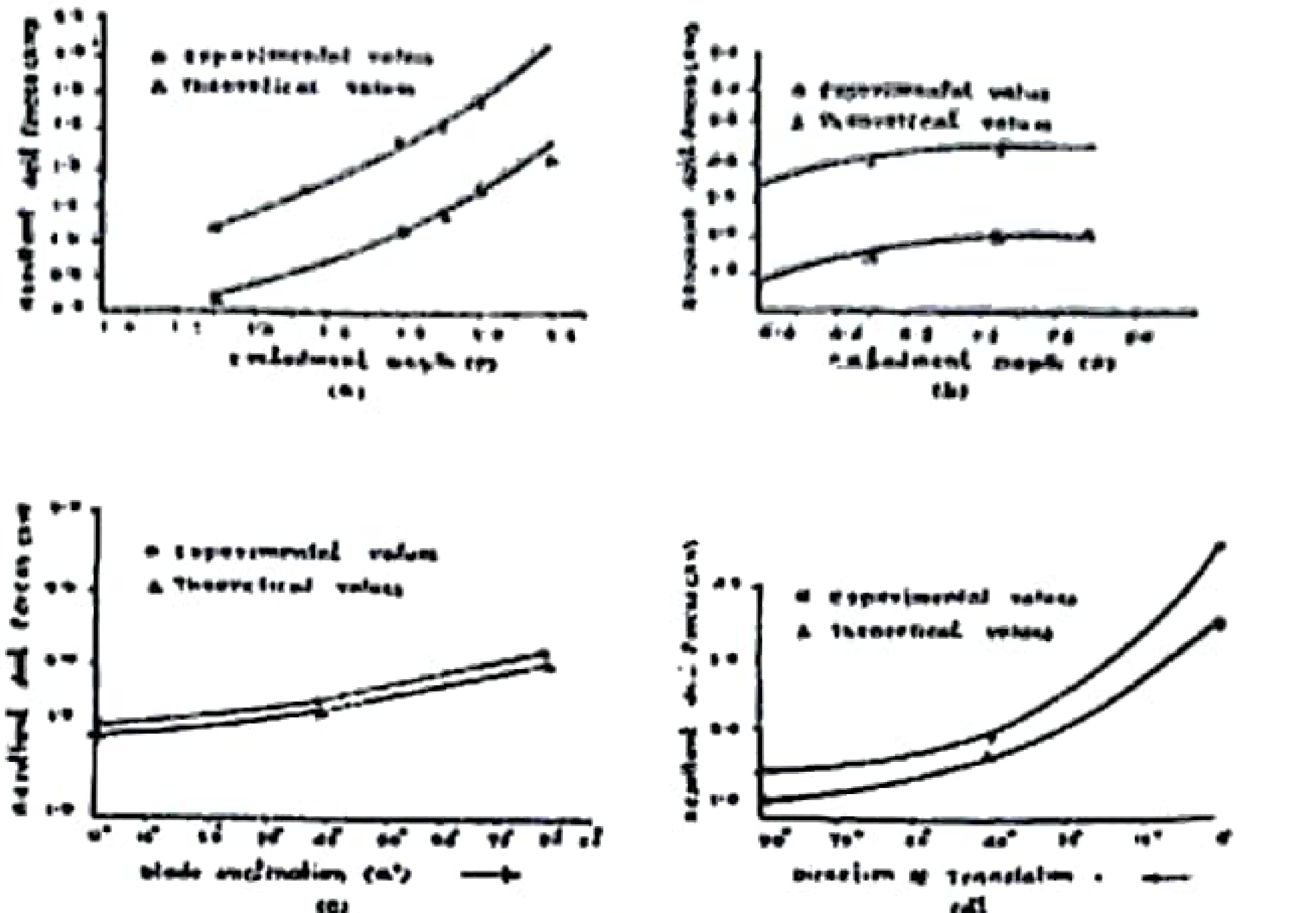

Fig. 2 (a) Variation of soil forces on interface inclination with embedment depth [illegible] (b) variation of soil forces on interface with embedment depth [illegible]. (c) effect of interface on soil forces [illegible]. (d) Effect of direction of translation on soil forces [illegible].

theoratical predicted values. Here again, the theoretical predicated values were under predicted as shown in Fig. 2b.

3. Transverse Translation

For $\alpha=45^0$ and $\beta=45^0$ the effect of the cutting blade inclination in transverse translation on the soil forces compared closer both in magnitude and direction to the theoretical prediction as can be seen in Fig. 2c. However, the predicted values were once again slightly lower in magnitude than the measured values.

The resultant soil resistance force on the cutting blade was generally observed to increase from the blade inclination $\alpha=0^0$ to $\alpha=90^0$, with the cutting blade direction of translation decreasing from $\beta=90^0$ to $\beta=0^0$ as shown in Fig. 2d.

CONCLUSIONS

From experimental study, the following conclusions were drawn :

1. The magnitudes of the soil resistance forces increased non-linearly as the interface inclinations increased from the horizontal ($\alpha=0^0$) to vertical ($\alpha=90^0$).

2. The peak soil forces on the interface increased as the direction of translation of the tool decreased from horizontical, the values of soil loads being minimum at translation in the vertically upward position ($\beta = 90°$).

3. The magnitude of soil resultant forces on the interface also increased non-linearly with the embedment depth for all directions of translation of interface.

The above experimental observations were basically in agreement with the theoretical prediction of Albuquerqe (1980) and Sarker (1985). However, it was clearly seen from the comparisions of the measured and theoretical values as presented also on the graph that the theory was underpredicted.

NOTATION

Symbols not defined in the text are listed below :

a	adhesion in $\tau = a + \sigma \tan\phi$
c	cohesion in $\tau = c + \sigma \tan\phi$
Ca	adhesion on interface $\tau = Ca + \sigma \tan\phi$
h	embedment depth of interface. Refer to Fig. 1b.
z	length of interface. Refer to Fig. 1b.
α	rake angle
β	direction of translation from horizontal (+ve upwards)
γ	soil unit weight
δ	mobilised angle of friction ($-af < a < +af$)
G	inclination of fixed wedge face with direction translation
ϕ	angle of internal friction in Mohr-Coulomb condition $\tau = c + \sigma \tan\phi$

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