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MODELLING OF LOADS ON WEDGE INDENTER PENETRATING INTO SOIL

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ABSTRACT

The mathematical model for load on wedge indenter to penetrate into soil has been developed. The passive earth pressure based on Sokolovski's analysis has been used to formulate the model. Two wedge indenters of angles 20° and 75° were allowed to penetrate into two types of soil with incremental loads at the same condition. The strength parameters c and ϕ of the soil at the above conditions were determined by both the Triaxial compression and the direct shear test. Then the loads on the two indenters for those c and ϕ were predicted. The accuracy of the predicted indenter load for a given penetration depth was found to be good for both the indenters. The prediction for the values obtained from Triaxial test was found more close to the actual than that for the values obtained from the direct shear test. It appears that the model to predict the performance of the indenters may be used to describe the performance of the agricultural machine element.

INTRODUCTION

Indenters are widely used to investigate the soil properties now a days. Much efforts have been made to relate indenter resistance to soil shear strength. A variety of soil penetrating devices have been designed with the purpose of determining the soil properties. Cone is mainly used in this purpose. Consequently the two dimensional problem of steady state with wedge indenter has been used. Baligh and Scott (1976) found a solution for the wedge penetration in an ideal rigid plastic medium which is applicable to the undrained quasi-static deep penetration into clay in an ideal isotropic state of stress. An exact solution of the theoretical wedge problem has been presented by Durgunoglu and Mitchell (1973). Ayers and Bowen (1987) adapted this analysis to model the soil failure mechanism during cone penetration to predict the soil bulk density and soil moisture profile. The most rigorous approach to the method of classical soil mechanics for the solution of two dimensional soil failure is Sokolovski's analysis (1960) of the limiting equilibrium of a soil mass. Sokolovski's numerical solution, by the method of characteristics, is without doubt the best available rigorous analytical tool for the construction of the failure mechanism in two dimensional soil failure. It proves to be the central analytical treatment of many soil-machine mechanics problem. The accurate evaluation of earth pressure on structures is of considerable importance in investigating soil implement and soil vehicle mechanics. Hettiaratchi and Reece (1974) made charts for this analysis to provide easy calculation of earth pressure problem.

The present study is based on this analysis for modelling the load on the wedge indenter so as to prove the reliability of the model for practical problems. The work of 'modelling of load on wedge indenter penetrating into soil' consists of the following steps :

(a) Development of forces on wedge indenter surfaces using the extended Newcastle solution of Sokolovski's method.

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(b) Checking the performance of the solutions under laboratory conditions. This involves the accurate measurement of the load on the indenter for penetration into soil by alternative laboratory techniques.

METHODOLOGY

Modelling of Load

Determination of a failure mechanism during indentation consists of demarcating a rupture zone within which the shear and normal stresses at the boundaries are in equilibrium with the external forces acting on them. The two dimensional soil failure theory, the Sokolovski's method modified at Newcastle, was considered to determine the rupture zone in front of an indenter during penetration as shown in Fig. 1. Wedge displacing soil in two sides of it can be readily used as a two dimensional body. To meet this requirement two triangular ends of the wedge were considered to be relieved slightly towards base. The side relief will ensure that only the trapezoidal inclined faces of the wedge contact the soil. The geometric and stress boundary conditions must be formulated appropriately to apply the relationships to the problem of indentation. The load acting on the soil indenter interface is a function of both the soil failure parameters and the soil interface properties themselves. The soil interface friction angle develops as a result of relative displacement between soil and surface of indenter. It depends on the surface finish of the indenter and its magnitude is difficult to measure. Theoretically it would be ideal to make the soil contact surfaces of the indenter perfectly rough which would induce soil to soil failure rather than the soil to metal sliding. Hence the bonded sand was used to make wedge indenter perfectly rough.

Calculation of Load on Wedge Indentor

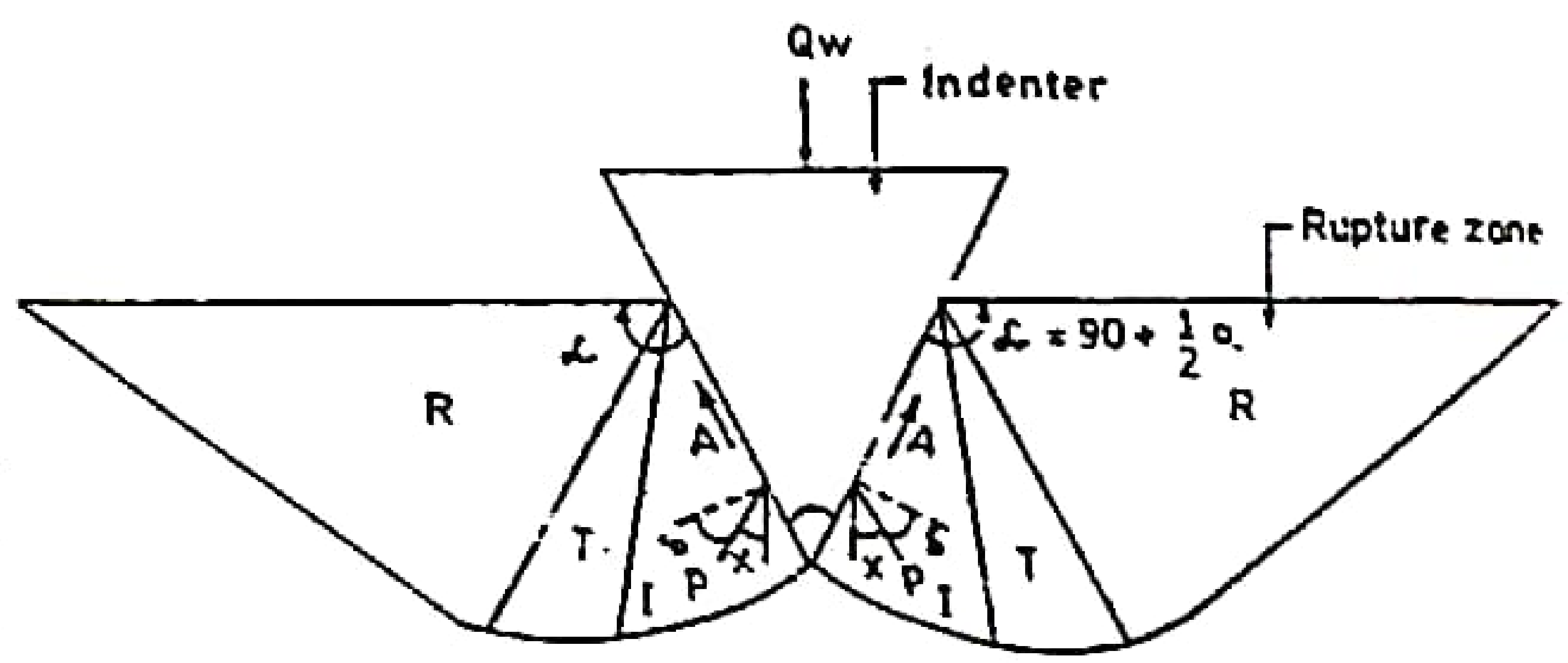
When a wedge of apex angle θ and width B is allowed to penetrate into the soil to a depth of H by applying a load Q_w at the base of it, the both sides of it make an angle of an equal angle α with the horizontal soil surface as in Fig. 1 so that

$$\alpha = 180° - \theta/2$$

The resistance force is broken into passive pressure, P acting at an angle δ with the normal to the interface and an adhesive component acting along its surface. Hence the total downward load is

$$Q_w = 2B\,(P\cos\chi + aH) \qquad \text{———(1)}$$

where $\chi = 90° - (\theta/2 + \delta)$
a = adhesion
χ = angle between the passive pressure P and the vertical



[R = Rankine; T = Transition; I = Interface]
Fig. 1 Rupture zone in front of the indenter

It is considered that the top of the indenter will always remain above the earth surface. So no surcharge force will be acting on it. Hence the Reece's equation (1965) can be introduced to this case as follows :

$$P = \gamma K_\gamma H^2 + c H K_c \qquad \text{———(2)}$$

Combining the equations (1) and (2), we get

$$Q_w = 2B\,(\gamma K_\gamma H^2 \cos\chi + c H K_c \cos\chi + aH) \qquad \text{——(3)}$$

As the indenters are considered perfectly rough, the following simplification can be done :

$$a = c\tan\delta\,\cot\phi$$

$\delta = \phi$ so that $\tan\delta \cot\phi = 1$

and $a = c$

Now the equation (3) takes the fom

$$Q_w = 2B(\gamma K_g H \cos\chi + c H (K_c \cos\chi + 1)) \quad \text{------}(4)$$

The theoretical relationships between load, depth, soil strength parameters and indenter properties can be formulated from the above expression. The prediction of load for an indenter to penetrate to a particular depth is possible from the known soil properties. The soil properties are density γ, cohesion c, and internal friction angle ϕ. The required indenter specifications are surface roughness angle δ, apex angle θ, and its width B.

Indentation Test

Two wedge indenters of conical angles 20° and 75° were fabricated. The ends of the indenters were relieved towards the base so that the two dimensional soil failure were induced. The length and height of each indenter were 38 mm and 50 mm respectively. The surfaces of the indenters were made rough by bonding sand with araldite. An indentation apparatus was fabricated to perform test with the indenters (Fig. 2). A dial gauge was attached with the apparatus to record the penetration. The indenter was allowed to penetrate into soil by applying load on the platform. The load was applied step by step and the corresponding penetration was recorded. The load- penetration curves were obtained from these values. The tests were performed at two different densities of 1.496 and 1.553 Mg/m^3 of a well graded sandy soil at 12.5% moisture content.

Testing of the Model

The values of strength parameters c and ϕ of the soil (Table 1) at the above conditions were determined by Triaxial compression test following Bishop and Hankel (1982) and shear box test following Akroid (1969). The prediction of loads on the two indenters was done for different depths corresponding to the values of c and ϕ using equation (4). The K-factor charts (Hettiarachi and Reece, 1974) were used for these predictions. These predicted loads were then compared with those obtained from the indentation tests.

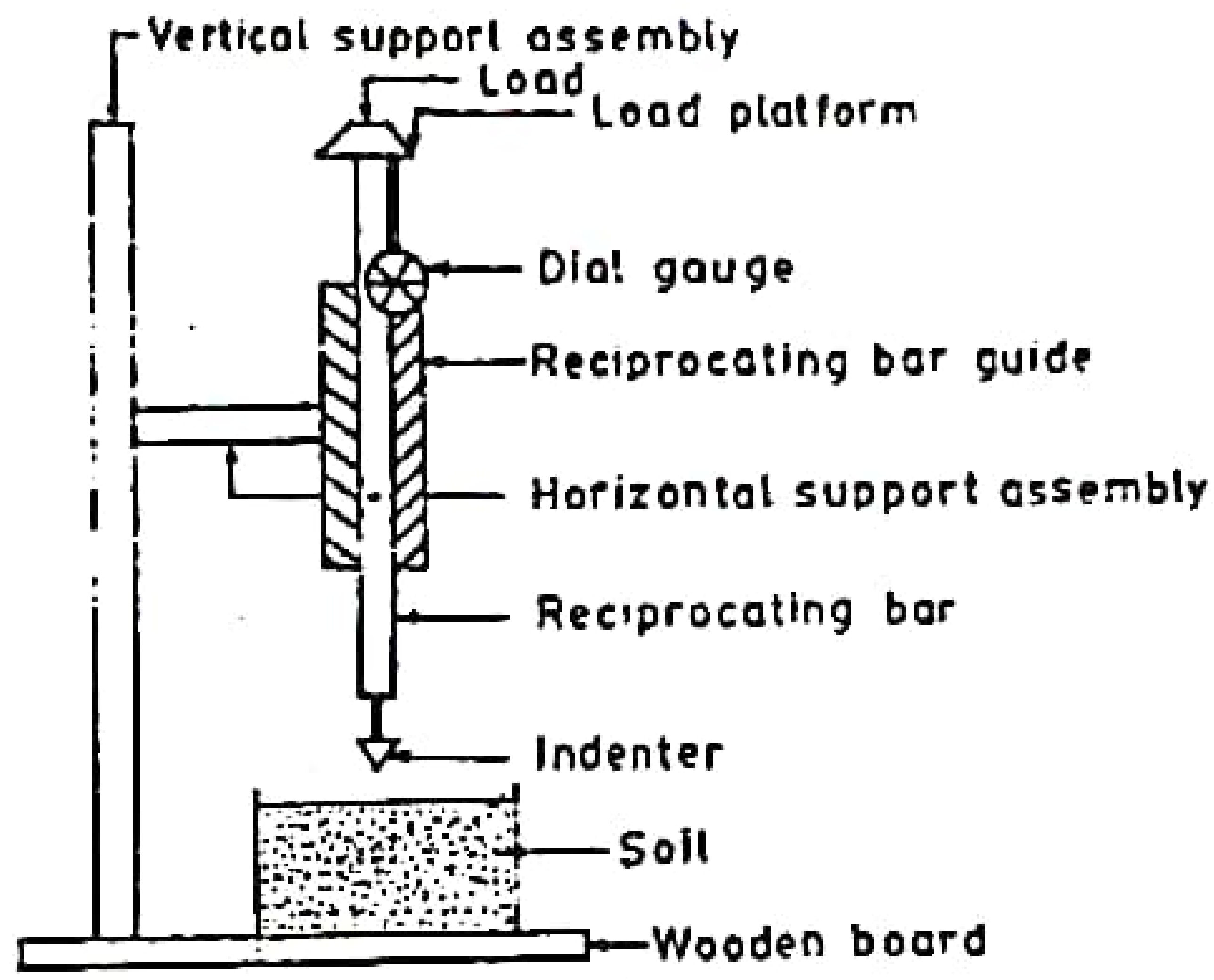


Fig. 2 Schematic diagram of an indentation apparatus

RESULTS AND DISCUSSION

The values of soil strength parameters c and ϕ at two different densities obtained from Triaxial and shear box tests are presented in Table 1. The predicted loads on the 75° and 20° wedges for the above c and ϕ are shown in the load-penetration depth curves (Fig. 3-6). These figures also show the corresponding actual loads on the indenters. It is observed that the actual load on the 75° wedge indenter is almost linear with penetration but in case of the 20° wedge indenter it deviates slightly. Hence the two dimensional failure as assumed to be induced by the indenters can be considered good. It has been found that there is a great difference in predicted loads for the strength parameters obtained from the Triaxial and shear box tests. This might be due to the difference in the failure pattern in the two systems. In case of Triaxial test the failure pattern is considered mostly compressive while it is due to shear in case of shear box test. At density 1.496 Mg/m^3 of sandy soil, the actual load was found

[Sandy soil; density = 1.496 Mg/m^3]

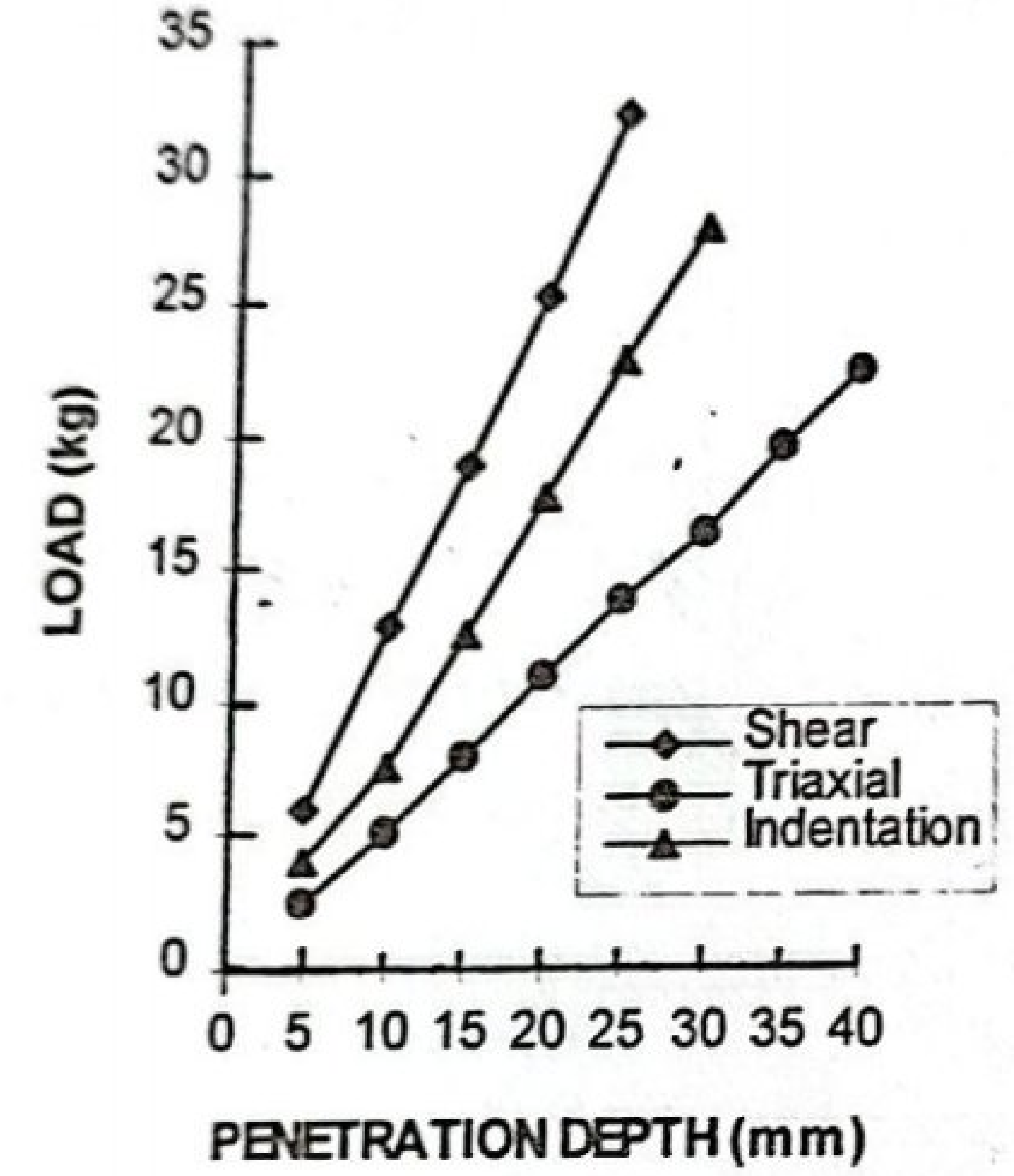


Fig. 3 Comparison of penetration of 75° wedge indenter with models

[Sandy soil; density = 1.553 Mg/m^3]

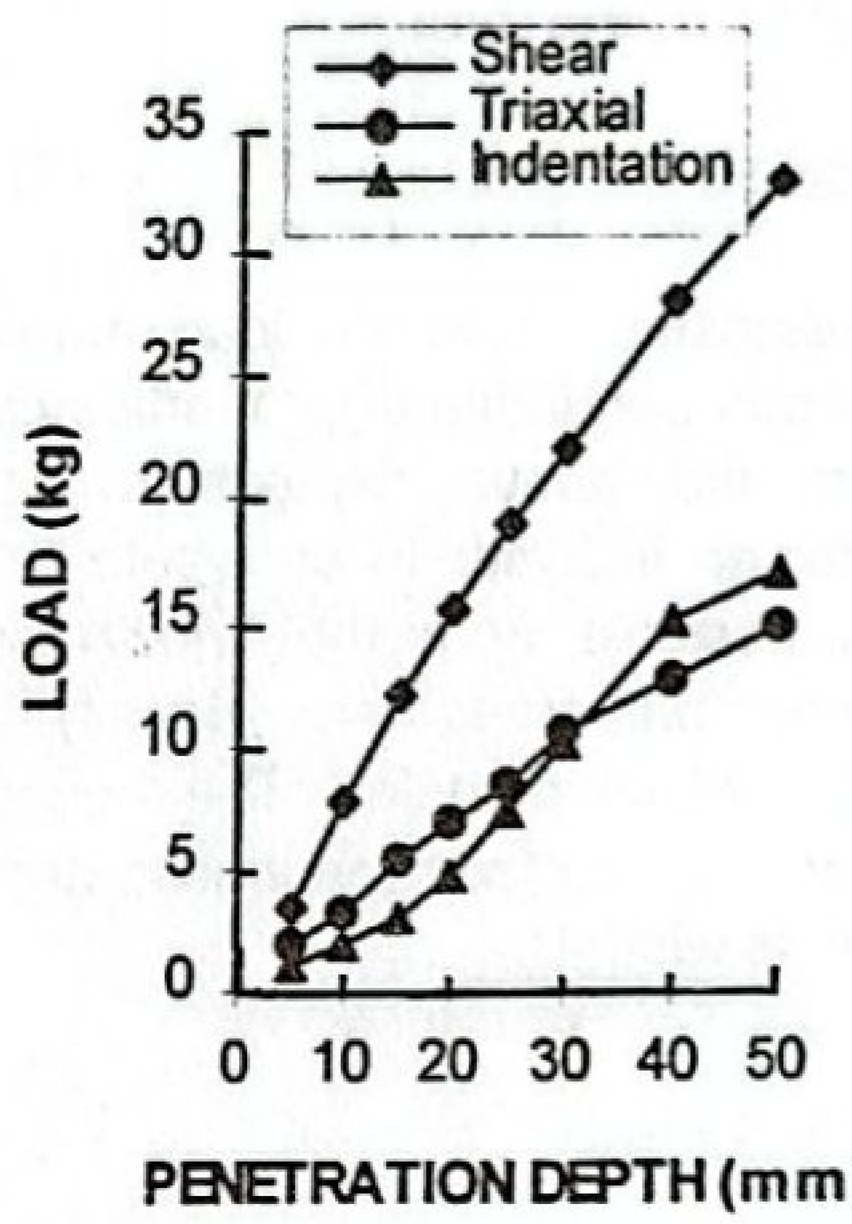


Fig. 5 Comparison of penetration of 75° wedge indenter with models

[Sandy soil; density = 1.496 Mg/m^3]

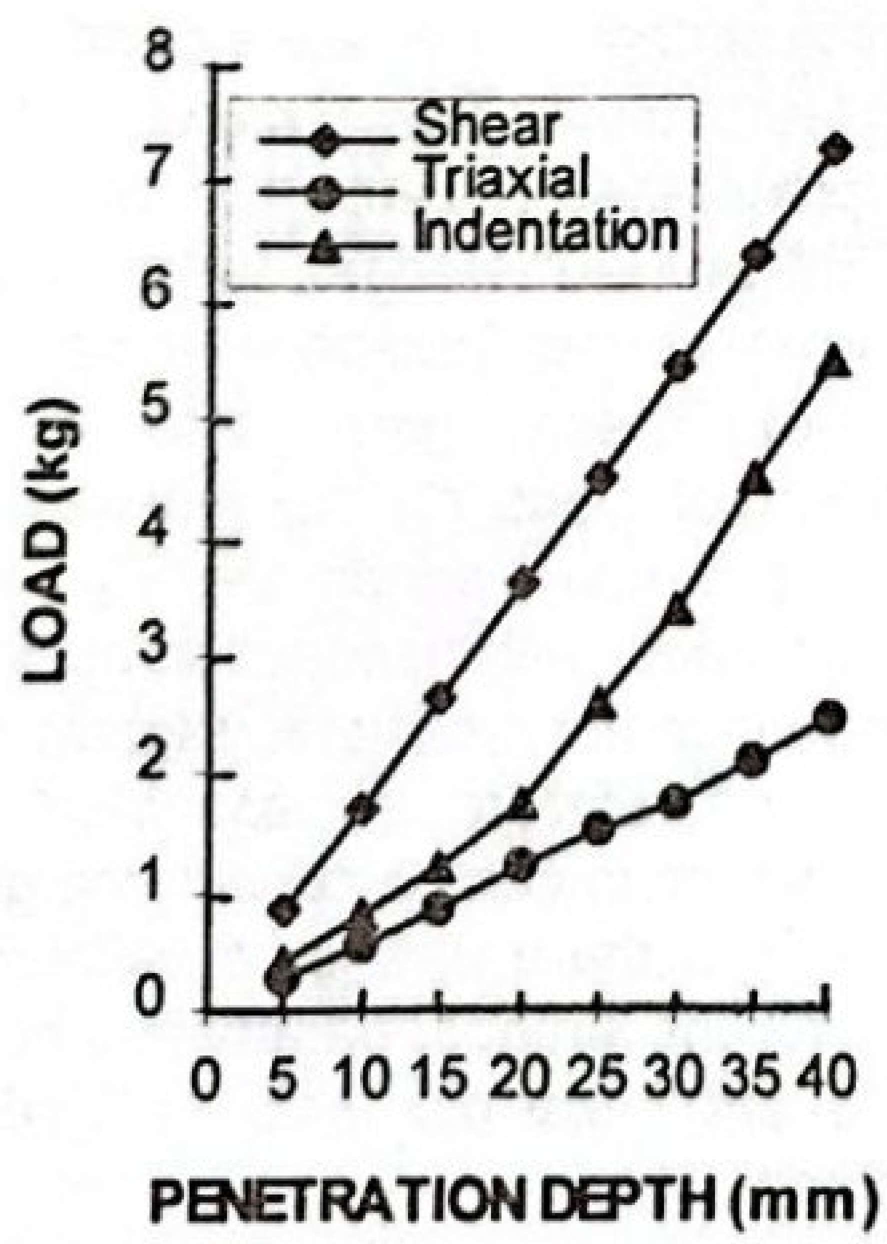


Fig. 4 Comparison of penetration of 20° wedge indenter with models

[Sandy soil; density = 1.553 Mg/m^3]

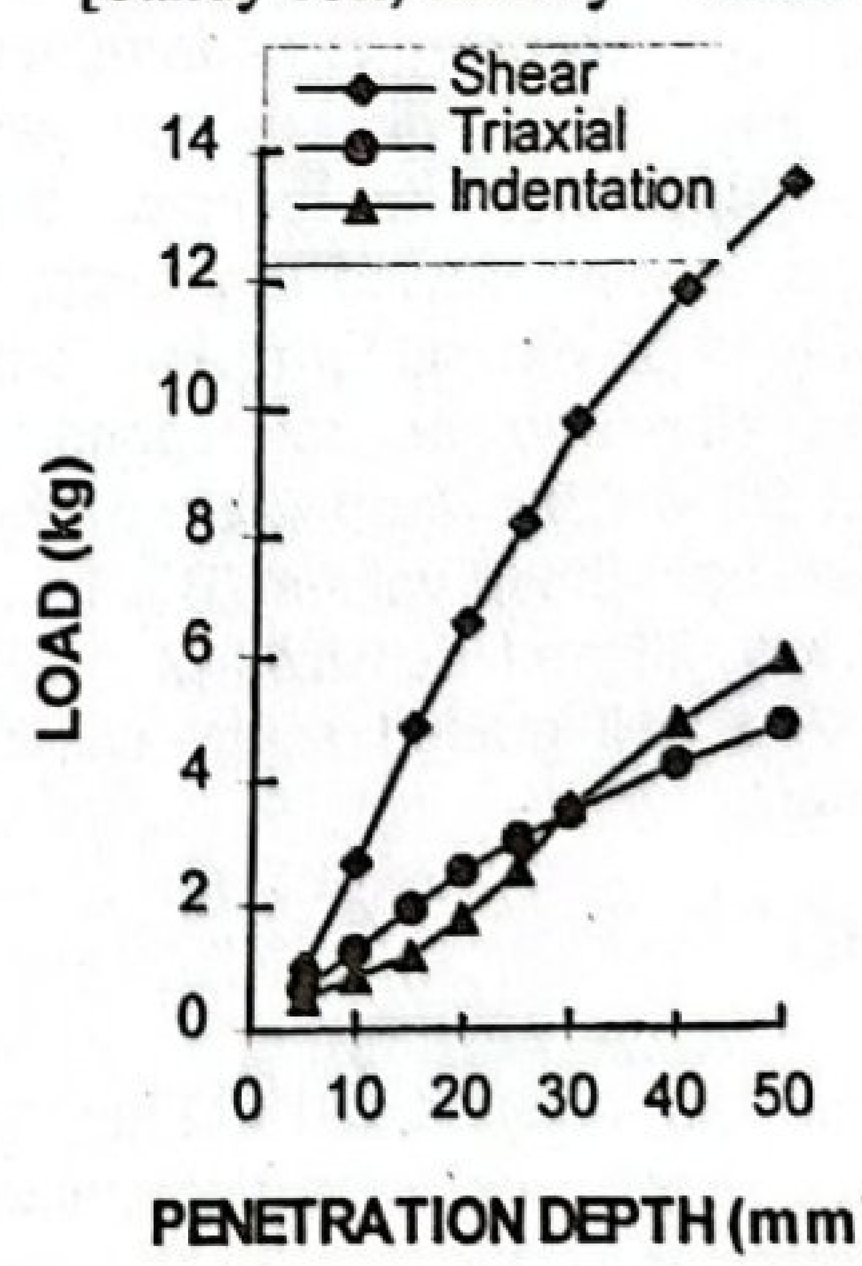


Fig. 6 Comparison of penetration of 20° wedge indenter with models

Table 1 Soil strength parameters at different conditions

Soil Type	Moisture content	Soil Density	Strength parameters			
			Shear box test		Triaxial test	
	(%)	(Mg/m^3)	ϕ^o	c (kPa)	ϕ^o	c (kPa)
Sandy	12.5	1.496	35.5	4.3	21.0	4.5
	12.5	1.553	35.2	4.5	22.5	5.2

mostly in between the predicted loads (Fig. 3 and Fig. 4) for both the wedges while at density 1.553 Mg/m^3 it is closer to that of Triaxial than to the shear box (Fig. 5 and Fig. 6). This indicates that the failure pattern during indentation follows neither the fully compressive nor shear but in between these two at lower densities. At higher densities the indentation induces mostly compressive failure.

It is widely considered that both the compressive and shear failure occur during indentation. So the prediction cannot be relied upon only on Triaxial or shear box test but results from both the tests must be considered.

The accuracy of the predicted indenter load for a given penetration depth was found to be good for the wedge indenters. The wedge indenters induce a two dimensional failure system which is clearly in accord with assumptions of the Sokolovski method. Above all, the failure conditions obtainable in the Triaxial compression test and the shear box test are not necessarily identical to the failure conditions on the face of the indenters and within the rupture zone developed by them. The conditions induced by a machine element failing soil is, perhaps, closer to that developed by an indenter than that found in a Triaxial or direct shear specimen. In addition the nature of failure predicted by the model and that by the indenter are very similar (both are based on Sokolovski's analysis).

CONCLUSION

On the basis of the findings the following general conclusions may be made :

1. Modelling of load on the wedge indenters is possible from the Sokolovski's analysis inducing two dimensional soil failure.
2. The actual load-penetration curve for the 20° wedge indenter is almost linear while that for the 75° wedge indenter is non-linear.
3. The predicted loads for c and ϕ from the shear box and Triaxial test hold good with the actual load for the wedge indenter.
4. It appears that the Sokolovski's analysis can be used to describe the performance of the agricultural machine element.

REFERENCES

Akroid, T.N.W. (1969). Laboratory Testing in Soil Engineering. The Chameleon Press Limited, London.

Ayers, P. D. and H.D. Bowen (1987). Predicting soil density using cone penetration resistance and moisture profiles. Transactions of the ASAE. American Society of Agricultural Engineers. Vol. 30 (5) : 1331-36.

Baligh, M.M. and R.F. Scott (1976). Analysis of wedge and penetration in clay. Geotechnique, 26(1): 185-208.

Bishop, A.W. and D.J. Hankel (1982). The measurement of soil properties in the Triaxial test. Edward Arnold Ltd., London.

Durgunoglu, H.T. and J.K. Mitchell (1973). Static penetration resistance of soils. Space Science Laboratory, University of California, Berkeley.

Hettiaratchi D.R.P. and A.R. Reece (1974). The calculation of passive soil resistance. Geotechnique, 24(3) : 289-310.

Reece, A.R. (1965). The fundamental equation of earth moving mechanics. Proc. of a Symposium on Earth Moving Machinery, March 1965, Automobile Div., Ins. Mech. Eng. London. Auburn University.

Sokolovski, V.V. (1960). Statics of Soil Media. Butterworth, London.