- مقارنة بين مقاومة الاختراق والقص

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COMPARATIVE STUDIES OF THREE SOIL STRENGTH METHODS ON SAND SOILS
(PART- I)

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Abstract

- This paper describes and evaluates three methods of measuring soil strength. The instruments which used in measuring are cone index, proctor penetromter and vane shear. These instruments used to measure soil penetration, proctor and shear strength, in the field at El-Qassim arid area.

The readings obtained by these instruments were analysised and compared to investigate the relationships between them and the readings accuracy. The readings from these instruments were involved in the prediction of the tillage tools draught, (Part2). The results indicated that these instruments were simple and quick to use for measuring soil strength in the field and prediction the performance of vehicles.

However, the vane shear stress gave appreciably different soil resistance profiles from other instruments. In particular, spurious “treatment effects” obtained from tillage experiment were shown to be due to inadequate instrument performance. However, the proctor penetrometer gave results comparable with those obtained from the cone penetrometer.

Reading obtained by shear vane was 0.10 of cone index; while the proctor gave values of strength have 1.5 to 1.75 times of the cone index values. All the experiments readings taken by the three tested instruments have the same trend curves.

1. LITERATURE CITED

- Few versions of hand-held equipments are commercially available. Furthermore, in the literature there appears to be a lack of comparative studies of different penetrometers, to explore the errors that might arise from the use of any particular instrument. In a long-term field experiment in U.K., U.S.A. and Egypt **(Elbanna and Witney, 1987; Elbanna and Kolarick, 1990 and Elbanna 1992),**

- **measurements** made with one of the simple hand-held penetrometers seem to indicate significantly higher cone resistance under zero tillage than under ploughing, at depths well below the usual ploughing depth. Similar anomalous results have been obtained on occasions elsewhere **(e.g. Hodgson et al., 1977 and Pidgson, 1977).**

- The main thrust in soil exploration evolved from a need to establish the bearing capacity. The maximum soil bearing pressure depends on the properties of the soil (density, deformation and shearing strength), on the water condition in the soil and on the physical characteristics of the foundation itself (size, shape and roughness).

- The classical theories of bearing capacity are based on the work of **Prandtl (1920 and Ohde (1938)** in which the stresses generated by a punch indentation in a material which deforms physically were combined by a semi-graphical analysis with the stresses due to the weight of an incompressible material within a zone of incipient failure surrounding the punch.

This failure mechanism was related to a strip foundation resting on the soil surface such as:

$$Q=\frac{c}{\tan\varphi}[\tan^{2}\psi e^{2\omega}\tan^{2}\varphi-1]+q[\tan^{2}\psi e^{2\omega}\tan^{2}\varphi]+\gamma\beta[\frac{2P}{\gamma\beta^{2}}\sin\psi-1/2\tan\varphi\tan\varphi]$$

- **<u>Where :</u>** β= foundation width, m; c = cohesive, kN/m^2;

Q = soil strength, kN/m^2; q = overburden pressure, kN/m^2;

P = passive earth pressure due to soil weight, kN/m^2:

γ = soil specific weight, kN/m^3;

ϕ = angle of internal shearing resistance, deg.; ϕ = (45+ϕ/2), deg.;

ω = angle subtended by the logarithmic spiral, rad.

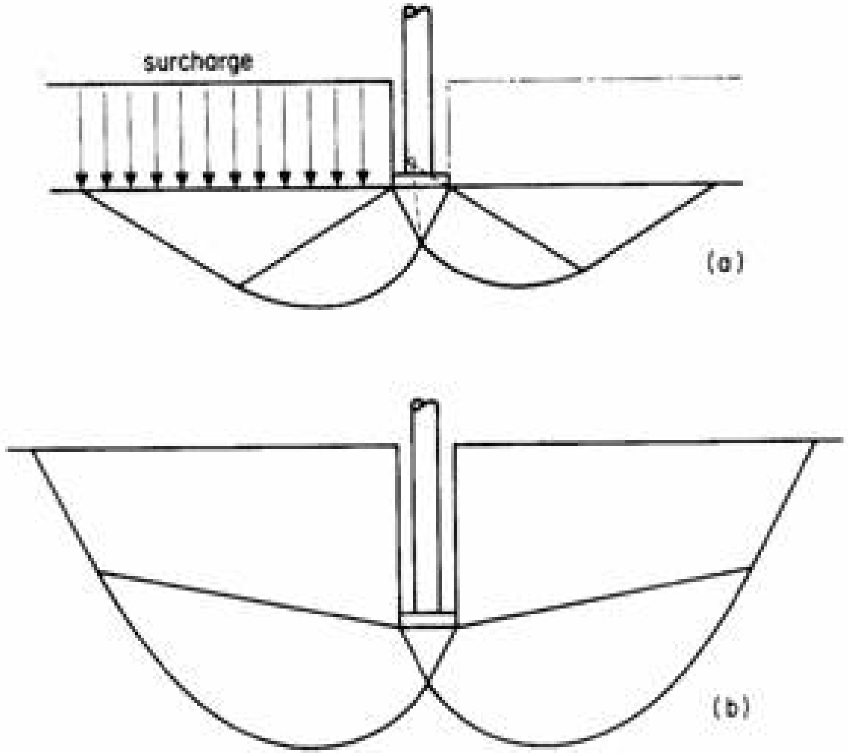


Fig. 1. Soil failure zones for a strip foundation: (a) resting on the soil surface with separate rupture geometry to account for the effect of weight (RHS) and for the effect of cohesion and a surcharge (LHS); (b) at shallow depth with the soil above the foundation level treated as an integral part of the failure zone.

- From geometry of the soil failure zone, the angle subtended by the logarithmic spiral was $\pi/2$ radians and the overburden pressure was extra depth of the soil resting on the top of the horizontal failure plane on the same level as the base of the foundation.

The passive earth pressure due to the weight of the soil is a more complex function of the size of the logarithmic spiral and is proportional neither to the exponent of the subtended angle nor to the exponent of the square of the subtended angle but to a value somewhere between.

- **Oskoui and Witney (1982)** stated that the simplification of **Kristin**'s equation **(1973)** by using only the specific weight term as an indication of soil strength as stated by **Gee-Clough et al. (1978)** eliminating the effect of the cohesive term from the cone index equation and precluded any effect of changing soil moisture content.

From the regression analysis of field data for three soil series, they proposed a cone index equation as:

$$CI = 450\ \theta^{-2} + 0.019\gamma \qquad ....1.2$$

- where CI = cone index, MPa;

q = soil moisture content, %;

g = soil specific weight, kN/m^3.

- **Elbanna (1986) and Elbanna and Witney (1987)** developed soil strength equation as a function of the soil type (in terms of the clay ratio), soil specific weight and soil moisture content, the developed soil strength equation was:

$$CI = [3.63.Cr.\, e^{-n\theta\theta/(+Cr)} + 0.0066 \frac{\gamma}{1+2Cr}]\, e^{\pi(1+Cr)} \ldots.1.2$$

- where C_r = clay ratio; = %clay/ (%silt +%sand).

f = soil internal shearing frictional angle, deg.

- The proctor penetrometer is used to determine soil moisture penetration resistance relationship of fine-grained soils using penetration needles. The penetrometer is used to determine penetration resistance of the mortar content concrete (road off vehicles). The soil specimen must be penetrated at the rate of 13-mm/ sec. (0.5 in./sec) for a distance of not less than 75 mm. (3 inches).

The corrected size of needle used should have an end area which is suitable for the condition e.g. dryness or witness, **(Söhne, 1960).** He reported that at least six penetration resistance determinations are to be made in each rate of hardening tests, the time intervals between penetration tests shall be as such to provide satisfactory rate of hardening curve, as indicated by equally spaced points.

- The vane shear test has been used to measure the strength of the soils near the surface **(Evans, 1951)** and at considerable depth (American society for test-materials, **ASAE (1957).** The vane usually is constricted so that the height of the blades is from 2 to 3 times the radius.

However, Schafer **(1960)** stated that the height of the blades is usually 1.5 to 2 times diameter of the vanes. The soil shear resistance was in the same of measuring penetration resistance and at the same depth measured according to **Schafer et al. (1968).**

- In that measuring process, the vane is driven into the soil to the desired depth, and then the vane is rotated at a constant angular velocity and thus the volume of soil contained within the blades is sheared off.

- **Schafer et al. (1968)** Showed that the soil shear stress t, (N/m^2) could be estimated from the following form:

$$\tau = \frac{T}{\pi d^2 (h/2 + d/6)} \quad ....1.3$$

- where : T = torque reading by the device, N.m;

d = vane diameter, m;

h = vane length, m.

2. MATERIALS AND METHODS

2.1. Cone Penetrometer (cone index)

- Soil strength was measured empirically in terms of the cone index, which is the force that may be applied to the handle of the cone penetrometer (Fig. 2.1a) per unit area of its cone tip in order to force it into the ground.

The right circular is 30-deg cone, has an end area of ½ sq. in. (3.226 cm^2). The cone is pushed slowly downward, and readings of the dial gauge are made at desired vertical increments which are shown by graduations on the instrument's shaft.

- **2.2 Proctor Penetrometer**

- The proctor penetrometer is used to determine soil moisture- penetration resistance relationship of fine-grained soils using penetration needles. It consists of a special spring dynamometer with a pressure indicating scale on the stem of the handle.

The scale is calibrated from 10 to 150 lbf., in 2 lbf. increments (0.0445 to 667.23 kN in 8.9 N interval) and a sliding ring indicate the applied load, which is read off at the top face of the sliding ring. The sliding stem can be connected, screwed with one of sectional circular plate of 0.01, 0.1, 0.325, 0.5, 0.75 and 1 in2.

The proctor strength was calculated in MPa by dividing the sliding manometer reading by plate sectional area, (Fig. 2.1b) shows the standard British proctor penetrometer.

- **3.3 Vane Shear Strength**

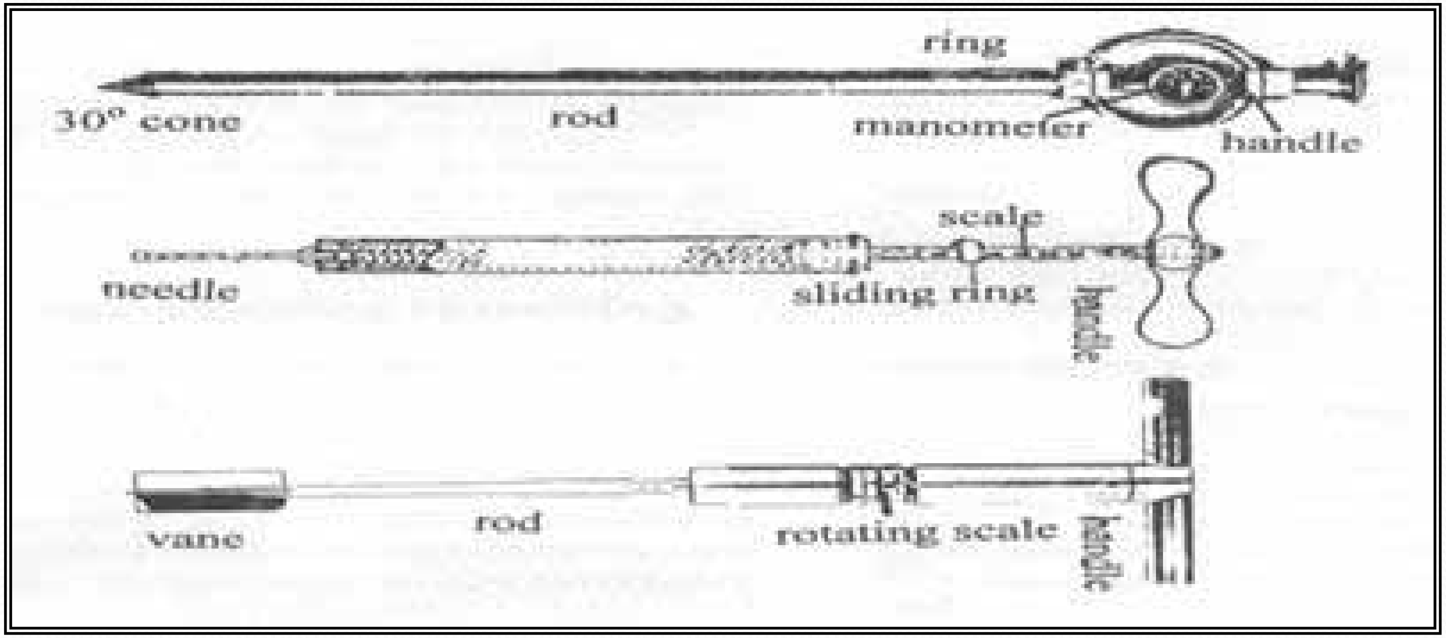
- The inspection vane borer is used to measure the in situ untrained shear strength in soil. It is primarily intended for use in trenches and excavations at a depth not influenced by drying and excavation procedure. The range of the instrument is from 0 to 26 t/m^2 when three different sizes of vanes are used. The accuracy of the instrument should be within 10% of the reading.

- The measuring part of the instrument is a spiral-spring (max. torque transmitted 30 kg.cm). When the handle is turned, the spring deforms and the upper part and the lower part of the instrument get a mutual angular displacement. When torque is applied, the scale-ring follows the upper part of the instrument, and when failure in the soil is obtained, the scale ring will remain in its position due to the friction in the threads.

The size of this displacement depends on the torque, which is necessary to turn the vane. By means of a graduated scale, the shear strength of the soil is obtained.

- Three sizes of four blades vanes are used: 16x32 mm (extra) multiply readings with 2, 20x40 mm (standard-direct readings) and 25.4x50.8 mm (extra) multiply readings with 0.5, which makes possible to measure shear strength of 0 to 26, 0 to 13, and 0 to 6.5 t/m^2 (254.98, 127.49 and 63.75 kN/m^2), respectively.

The “area ratio” of the vanes is 14, 16.5 and 24% (ratio of cross sectional area of vane to the area to be sheared). The vane blades are soldered to a vane shaft, which is extended by one or more 0.50 m rod (Fig. 2.1c). Threads make the connection between the shaft-rod and the instrument, to make the connections as straight as possible, the rod have to be screwed tight together and threads cleaned for dirt.



(a) cone penetrometer (ELE20-088 British standard)
(b) proctor penetrometer (ELE 24-651 British standard)
(c) vane shear strength; (GeoNorA/S Vane tester H-60).

Fig. (2.1) Three instruments used to measure soil strength forces in loamy sand and sandy soils

- **2.3 Soil and cover**

- Five soil samples were randomized taken from each of two fields. Samples were bagged and carried to soil and water laboratory where the mechanical analysis test was done, Table 2.1.

In two soil types of loamy sand and sandy loam at Al-Qassim, the mean of 10 separate measurements was determined in each five replicates from which soil samples were taken for determination of soil mechanical analysis, soil specific weight, moisture content, cone index, proctor strength and vane shear strength (Table 2.1).

Additional experimental data for five soil types were obtained from earlier investigations on sandy loam (C_r=0.24), sandy clay loam (C_r=0.26) at Bush Estate, Edinburgh, UK. **(Oskoui and Witney, 1982);** silty clay loam, (C_r=0.49) and silty clay (C_r=0.87) at Stirling, Scotland **(Elbanna, 1986);** and heavy clay (C_r=1.60) at Silsoe, Bedford, UK. **Stafford (1985).**

Table 2.1 Soil mechanical analysis, clay ratio and soil types.

Sand, %			Silt,	Clay,	Clay	Soil	Crop
Coarse	fine	total	%	%	ratio	type	cover
63.90	20.80	84.70	3.10	12.20	0.139	Loamy sand	alfalfa
62.70	22.00	84.70	2.00	13.30	0.153	sandy loam	follow barley
24.90	31.35	56.25	24.50	19.25	0.24	Sandy loam	grass
19.35	37.40	56.75	20.75	20.50	0.26	Sandy clay loam	grass
2.80	3.10	6.90	60.10	33.00	0.49	Silty clay loam	after wheat
0.50	1.00	1.50	60.80	35.00	0.87	Silty clay	
NA	NA	12.90	26.00	61.10	1.60	Heavy clay	after wheat

3. RESULTS AND DISCUSSION

- **Soil strength equation**

- Identifying the most important parameters in Eqn 1.1 quantatively, the soil strength may be presented in the form:

$$Cs = \left(k_c^{'} C_r \frac{e^{-n\theta\theta\tan}}{\tan\varphi} + k_\varphi^{'} (\gamma\gamma\tan \; e^{\pi\tan\varphi}) \right) \frac{\tan^2\varphi}{\tan\varphi} \text{.......... ....2.1}$$

- As the dimensions of the conical base, or circular proctor penetrometer have been standaraised and the soil strength measurement is specified at the median of tillage depth at which point the pressure bulb can be fully developed, they can be included in the cohesive and fricitional constants, k’c and k’ . φ

Closed inspection of the tangent ratio, $\tan 2\varphi / \tan \varphi$, also reveals that is magnitude remains relatively unaffected for angles of internal shearing resistance from 50 to 450 -the typical range for agricultural soils-and again can be absorbed into the cohesive and frictional constants.

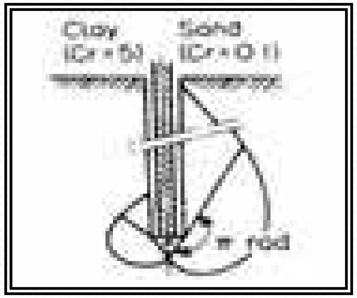
- For the tangent of frictional angle, the limiting values of 1 and 0 bound a range which is related empirically to the clay ratio. A high value of 450 is realistic from the angle of internal shearing resistance in a compact dry sand for which the clay ratio is zero. At the other end of the scale, a friction angle of 50 is only found in heavy wet clays with over 80% clay content (Table 3.1).

- This leads to adoption of the empirical clay ratio and logarithmic spiral forms such as:

$$Cr = \frac{\%clay}{\%sand + \%silt} \text{ .... } 2.2a$$

$$\tan\varphi = \frac{1}{1 + 2CR} \text{ ....} 2\ .2b$$

$$r_1 = r_o\, e^{\pi \tan\varphi} = r_o\, e^{\pi/(1+2Cr)} \text{ ......} 2.2c$$



Relative size of the pressure bulb formed at the base of cone penetrometer for clay and sand

- At high clay ratios and low moisture contents, the corresponding of the two scales values Fig. 3.1. Therefore, very high soil strength (cone index or proctor penetrometer) results from this cohesive component, decreasing virtually to zero above the liquid limit, when heavy soil turn into fluid mud, (Fig. 3.1). It was also proposed that the tangent of internal shearing angle was related to an inverse of the clay ratio, Eqn 2.2b.

This incorporated in the equation for the logarithmic spiral, Eqn 2.2c, boundary which was defined the extent of the bulb-shaped failure zone surrouding the probe (cone, proctor circular or vane)

- In order to account for the local variability in agricultural soils, the mechanical analysis of particle size provides a simple, widely available and readily understood classification method.

As the clay ratio has cohesive properties by virtue of its chemical bonds, it was proposed by **Elbanna (1986) and Elbanna and Witney (1987)** that the ratio of clay to silt and sand, Cr, could be used as a practical monitor of soil type which could be included in the soil strength equation.

Thus, the cohesive component of the soil strength becomes not only an inverse exponential function of the soil moisture content time the tangential of internal shearing frictional angle but also directly proportion to the clay ratio.

- The friction component of the soil strength becomes directly function of the soil specific weight time the tangent of internal shearing friction angle affected by the logarithmic terms, (soil failure).

Combining the two components, the complete expersion of the soil strength at tillage depth becomes:

$$C_S = k_c [Cr.\ e^{-n\theta\theta/(+2Cr)}] + k_\varphi [(\frac{\gamma}{1 + 2Cr}) e^{\pi(1+Cr)}] \ldots.2.3$$

- where :

C_s= cone index, M

θ = soil moisture content, %:

g = soil specific weight, kN/m^3;

C_r = clay ratio;

f = soil internal shearing frictional angle, deg.

C_r = % clay/ (% silt +% sand).

- By means of regression analysis of the experimental data on loamy sand and sandy loam soils at Al-Qassim, Saudi, the values of the cohesive and frictional coefficients and the exponent were found to be k_c=4.03, k_ϕ=0.0069 and n = 0.01. While using the general coefficients values of k_c=1.281, and k_ϕ=0.01309 for all soils Tables (3.2 to 3.5) using these values, the effect of soil moisture content, soil specific weight and clay ratio are shown in Figs 3.1 to 3.4. In purely frictional dry sand, the soil moisture content has no greater effect on the cone index or proctor penetrometer but the variation in soil specific weight has a considerable influence.

While, as the clay ratio increases, the effect of soil specific weight diminishes but the changes in soil moisture become increasingly more important, with lower soil strength at high moisture content and very much higher cone index and proctor penetrometer at low moisture contents compared with the purely frictional sand.

The relative contribution of the cohesive and frictional components of soil strength (e.g. cone index) was shown in Fig 3.1 for three levels of soil moisture contents and specific weight. It should be noticed that the curve for frictional component decays quickly with the clay ratio to a modest value Fig. (3.1a).

However, curves for the cohesive component all emanate from the origin and rapidly establish different levels of direct proportionality with the clay ratio, Fig. (3.1b). The drier soils contributing the high cohesive strength for the tested soil with the three instruments.

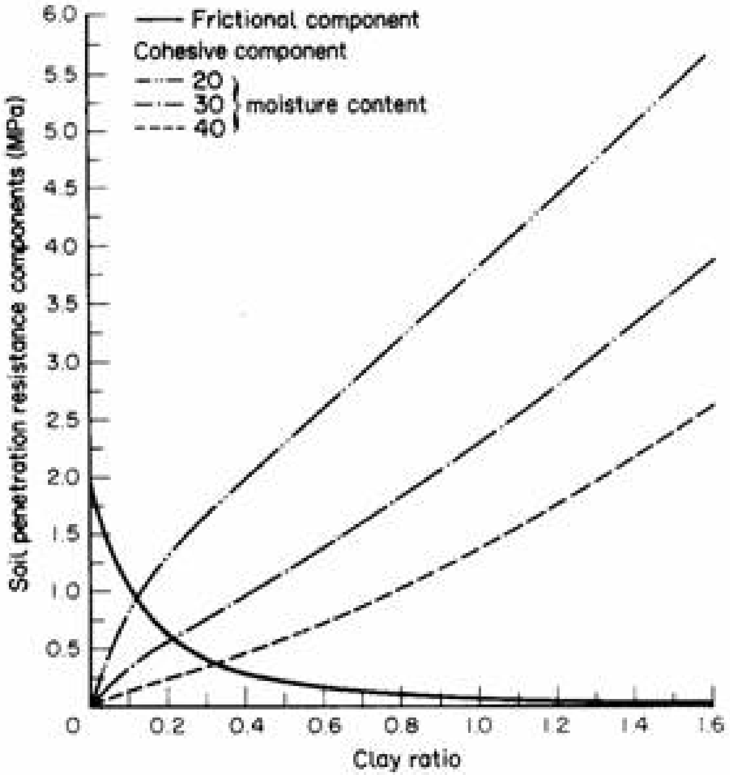


FIG. 3. The effect of clay ratio on the frictional and cohesive components of the soil penetration resistance at soil moisture contents of 20, 30 and 40% w/w and a soil specific weight of 14 kN/m^3.

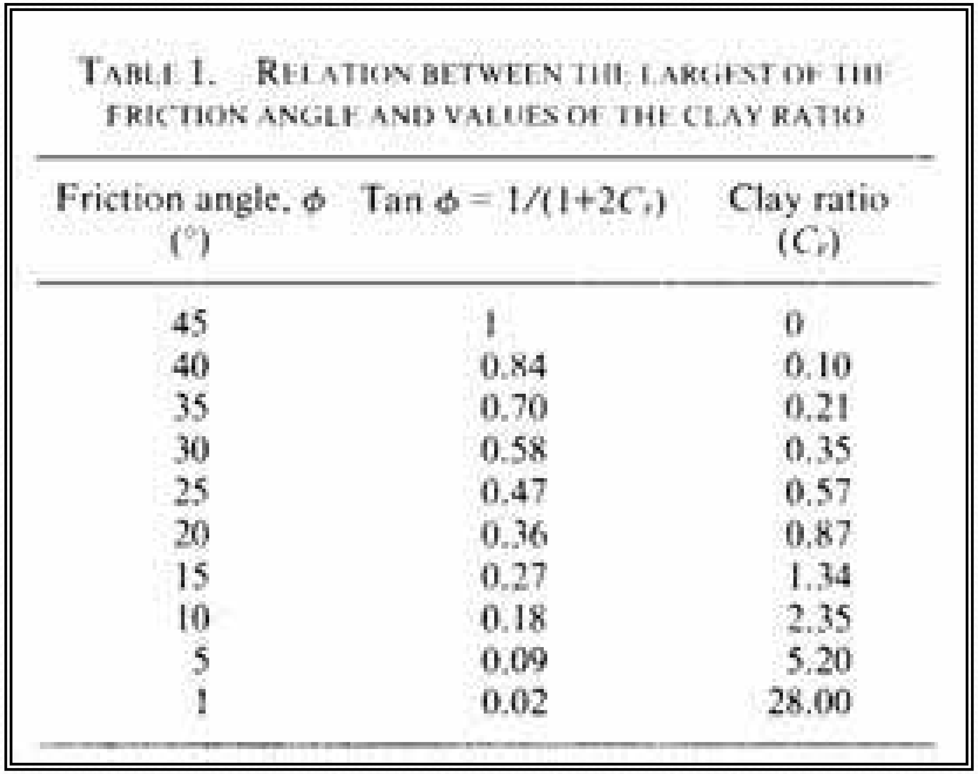


TABLE 1. RELATION BETWEEN THE LARGEST OF THE FRICTION ANGLE AND VALUES OF THE CLAY RATIO

Friction angle, ϕ (°)	$\tan\phi = 1/(1+2C_r)$	Clay ratio (C_r)
45	1	0
40	0.84	0.10
35	0.70	0.21
30	0.58	0.35
25	0.47	0.57
20	0.36	0.87
15	0.27	1.34
10	0.18	2.35
5	0.09	5.20
1	0.02	28.00

- It is postulated that any instrument that is capable of probing the soil to various depths and shearing it, in a consistent manner would have been equally successful. As a matter of fact, in field experiments on sand trials, three different instruments (named the cone penetrometer, proctor penetometer and shear vane) were used and the quality of correlation between instrument readings.

It is pointed out that the cone penetrometer’s value as a tool for measuring soil strength lays in the fact between proctor penetrometer and vane shear measurements. It has been correlated their values, the cone index measurement value was 10 times greater than the van shear strength value.

While, the soil strength readings with proctor penetrometer was 1.5 to 1.75 times the cone index value. Measured and predicted soil strength with the three instruments and soil properties were shown in Table 3.5 Figs (3.2 to 3.6).

- The experimental results for each soil type were analysis individual to obtain specific values of cohesive and friction coefficients for cone index, proctor penetrometer and vane shear strength (Tables 3.2 to 3.4). The optimum value of n was found to be 0.01 from analysis of all the soil experimental data.

The measured and predicted soil cone index, proctor penetrometer and vane shear strength by means of individual equations for each soil type is very accurate with over 98% explanation of the result in all soils, a part from the Silsoe and Edinburgh soils.

For the combined measurements undertaken in this study **Table (3.2)** for cone index, an equally high explanation was obtained despite a 10-fold increase in the range of the clay ratio, the inclusion of more data at the low end of the soil spectrum and the spread of the cone strength data increasing from 3 times at the lowest value to 10 times compared with Stirling data (Figs 3.5 and 3.6).

The overall accuracy of the general empirical equation for cone, proctor and vane shear strength was 90.40%, 98.87 and 99.66%, respectively, (Tables 3.2 to 3.4). Their values were demonstrated in a comparison of the measured and predicted values Table 3.4 and Figs 3.5 and 3.6).

Table 3.2 Values of the clay ratio, cone index resistance coefficients, their standard errors and percentage of explanation

Soil	Clay	Coefficients		Standard errors		Expl.,	DF.
type	ratio	k_c	k_f*10^{-3}	k_c	k_f*10^{-3}	%	
Loamy sandy$^+$	0.139	2.453	8.351	7.3874	6.3573	98.64	49
Sand loamy $^+$	0.153	2.929	8.129	6.7262	7.1928	98.23	49
Combined	I	4.030	6.939	1.5969	1.5730	98.43	99
Sandy loam^{++}	0.24	3.973	10.055	4.8562	11.203	98.65	23
Sandy clay loam^{++}	0.26	3.821	9.262	4.2776	1.1153	98.72	23
Combined	II	3.821	9.2617	4.2776	11.153	98,71	47
Silty clay loam*	0.49	1.116	29.670	1.4023	17.948	98.63	29
Silty loam*	0.87	1.067	30.512	1.3361	16.533	94.65	24
Combined	III	2.524	45.144	0.3892	95.815	96.28	54
Heavy dry clay**	1.60	0.323	97.344	0.4327	93.898	94.06	39
All soils		1.281	13.089	0.1128	0.7996	90.40	237

- Expl. = explanation, r^2 ;
- DF. = degree of freedom;
- +, I = Experimental work at Al-Qassim Agric. College Farm Station
- ++, II = Oskoui and Witney, (1982) Exp. work at Bush Estate, U.K;
- *, III = Elbanna, (1986) Exp. work at Bush Estate, U.K;
- **, IV = Stafford (1986) data at Silsoe, Uk.

Table 3.3 Values of the clay ratio; proctor penetrometer coefficients, their standard errors and percentage of explanation.

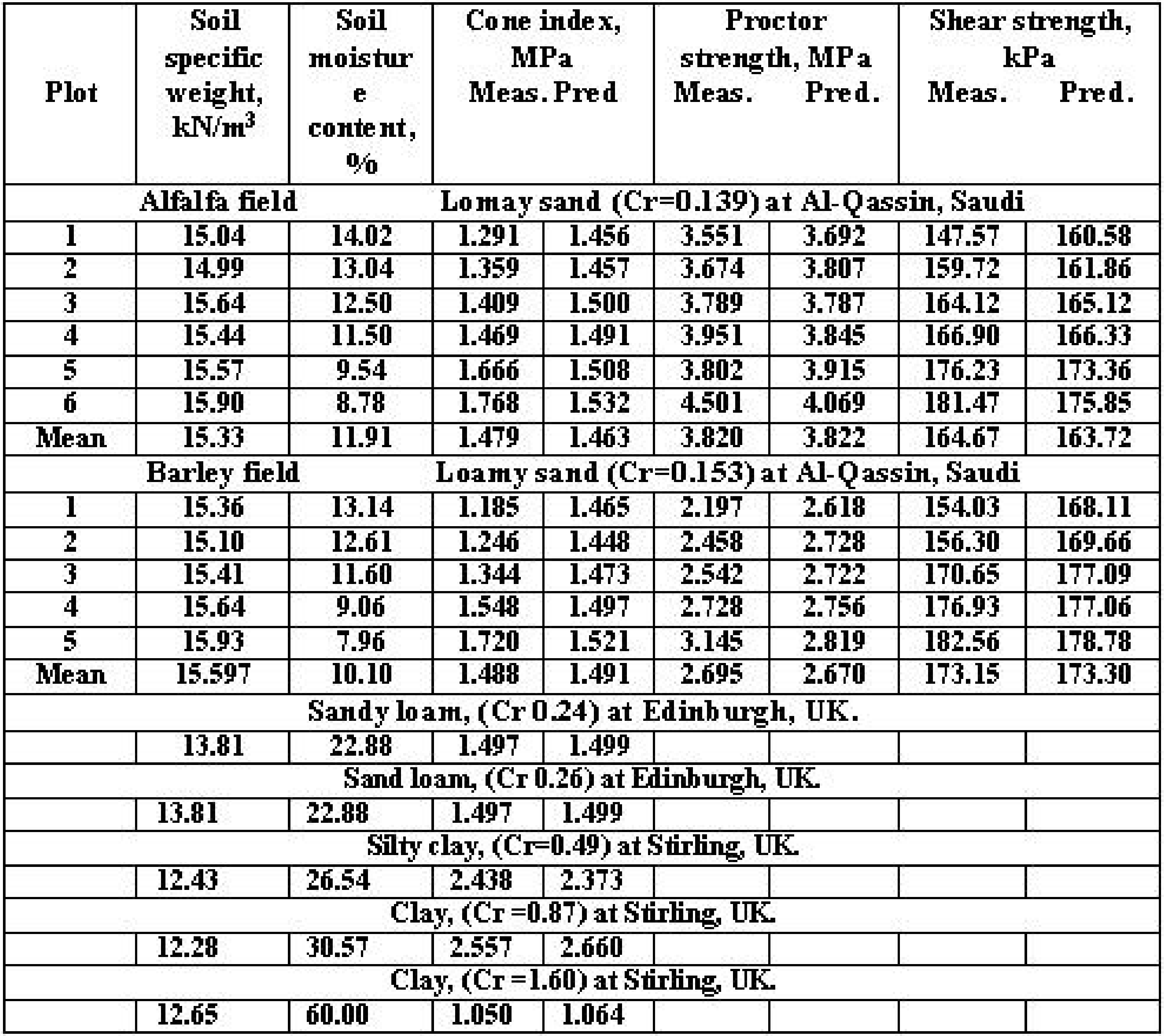
Soil	Clay	Coefficients		Standard errors		Expl.,	DF.
type\ cover	Ratio	k_c	k_f*10^{-2}	k_c	k_f*10^{-3}	%	
Loamy sandy Alfalfa $^+$	0.139	2.4008	1.76709	10.5014	9.31689	99.19	49
Loamy sand Barley fellow $^+$	0.153	2.50124	1.80043	9.07511	9.85757	98.52	49
Combined		4.40786	1.59109	2.11553	2.07992	98.87	98

* = Experimental work at Al-Qassim Agric. College Farm Station

Table 3.4 Values of the clay ratio; vane shear strength coefficientts (cohesive and friction), their standard errors and percentage of explanation.

Soil	Clay	Coefficients		Standard errors		Expl.,	DF.
type/ cover	Ratio	k_c	k_f*10^{-4}	k_c^{*1-02}	k_f*10^{-4}	%	
		0.99264		1.94736		98.19	49
Loamy sandy*	0.139		2.69787		0.16931	84.10	49
Alfalfa		0.55304	6.49658	25.6120	2.21865	99.63	49
Loamy sand*		1.02684		1.80448		98.57	49
Barley	0.153		2.09637		0.17068	76.25	49
		0.56605	7.04759	22.6350	2.42500	99.70	49
		1.01150		1.32658		98.38	
Combined			2.24996		0.12342	80.15	
		0.84082	4.05102	6.59596	0.63516	99.66	

* = Experimental work at Al-Qassim Agric. College Farm Station



Plot	Soil specific weight, kN/m³	Soil moisture content, %	Cone index, MPa		Proctor strength, MPa		Shear strength, kPa	
			Meas.	Pred	Meas.	Pred.	Meas.	Pred.
Alfalfa field	Lomay sand (Cr=0.139) at Al-Qassin, Saudi							
1	15.04	14.02	1.291	1.456	3.551	3.692	147.57	160.58
2	14.99	13.04	1.359	1.457	3.674	3.807	159.72	161.86
3	15.64	12.50	1.409	1.500	3.789	3.787	164.12	165.12
4	15.44	11.50	1.469	1.491	3.951	3.845	166.90	166.33
5	15.57	9.54	1.666	1.508	3.802	3.915	176.23	173.36
6	15.90	8.78	1.768	1.532	4.501	4.069	181.47	175.85
Mean	15.33	11.91	1.479	1.463	3.820	3.822	164.67	163.72
Barley field	Loamy sand (Cr=0.153) at Al-Qassin, Saudi							
1	15.36	13.14	1.185	1.465	2.197	2.618	154.03	168.11
2	15.10	12.61	1.246	1.448	2.458	2.728	156.30	169.66
3	15.41	11.60	1.344	1.473	2.542	2.722	170.65	177.09
4	15.64	9.06	1.548	1.497	2.728	2.756	176.93	177.06
5	15.93	7.96	1.720	1.521	3.145	2.819	182.56	178.78
Mean	15.597	10.10	1.488	1.491	2.695	2.670	173.15	173.30
Sandy loam, (Cr 0.24) at Edinburgh, UK.								
	13.81	22.88	1.497	1.499				
Sand loam, (Cr 0.26) at Edinburgh, UK.								
	13.81	22.88	1.497	1.499				
Silty clay, (Cr=0.49) at Stirling, UK.								
	12.43	26.54	2.438	2.373				
Clay, (Cr =0.87) at Stirling, UK.								
	12.28	30.57	2.557	2.660				
Clay, (Cr =1.60) at Stirling, UK.								
	12.65	60.00	1.050	1.064				

- Table 3.5 Average values of soil strength (measured with (cone penetrometer, proctor and vane shear) together with their predicted values and soil moisture content and specific weight in a wide range of soil types

الملخص العربى

- والطب البيطرى بالقصيم فى موسمى٢٠٠١/٢٠٠٠ ذات المناخ الجاف لمقارنة إستخدام ثلاثة أجهزة لقياس مقاومة التربة (soil strength) وهى cone index, proctor penetrometer and vane shear فى نوعين من التربة الرملية (Loamy sand and andy loam) عند نسب مختلفة من الرطوبة وعمق عمليات الحراث المتوسط،

وجمعت بيانات لنتائج الدراسات السابقة لخمس أنواع أخرى من الترب الزراعية من الدراسات السابقة لترب في الولايات المتحدة وإنجلترا ومصر ورغم الاختلاف في المناخ السائد في تلك الدول من الرطب إلى الشبه الجاف إلى الجاف وتراوح الاختلاف في رطوبة التربة الطينية ٥ أمثال الرملية بالمملكة بينما تراوح الاختلاف في **clay ratio $C_r = 0.0.1$ to 1.6** أي ١٦ ضعف، حلل النتائج المتحصل عليها لكل منهم منفصلا لإيجاد علاقة خاصة لكل من أنواع الترب السبعة من الرملية الخفيفة إلى الطينية الثقيلة

وكل النتائج أيضا لإيجاد علاقة عامة باستخدام المعادلة المقترحة بالصورة :-

$$C_s = k_c[Cr.\, e^{-n\theta\theta/(+2Cr)}] + k_\varphi[(\frac{\gamma}{1+2Cr})\, e^{\pi(1+Cr)}]$$

- Where : CI = cone index, MPa;

θ = soil moisture content, %:

g = soil specific weight, kN/m^3;

Cr = clay ratio= %clay/ (%silt +%sand);

f = soil internal shearing frictional

tanϕ = 1/(1+2Cr) angle, deg.

- تم اختبار المعادلة في مدى واسع من أنواع الترب (من الرملية الخفيفة إلى الطينية الثقيلة داخل وخارج المملكة أمكن إيجاد معاملي المعادلة لكل نوع من التربة على حده وتراوح معامل الارتباط r٢=٩٨% والأنواع السبعة معا وكانت r٢=٩٠% للمعادلة العامة) . أيضا إيجاد العلاقة بين قياسات ثلاثة أجهزة لقياس قوة مقاومة التربة وهى (**Cone and proctor penetromters and vane shear strength**) وأعطى **Cone index** قراءة تعادل ١٠ أمثال **vane shear** بينما قراءة **proctor** تعادل ١,٥-١,٧٥ مرة **cone index**.

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TRACTOR DYNAMIC WEIGHT MODEL

- ***Prof. Dr. E. B. Elbanna;***
- **2.1 Mobility Number Freitasg (1965)** proposed tyre mobility number in sandy and clay soils. **Turnage (1972)** extended **Freitasg's (1965)** work and produced a mobility number; **Gee-Clough (1980) and Dwyer (1984 and 1990**) developed the previous mobility number by including an additional correction terms for the width/diameter ratio and tyre deflection in ideal soils.

- The mobility number, M_n, can be represented as in the form :

$$M_N = \frac{CI.b.d}{WD}\sqrt{\frac{\delta}{h}}\left(\frac{1}{1+(2b/d)}\right) \qquad \text{2.1}$$

- where :

M_n = wheel mobility number; W = wheele load, kN.;

h = wheel section height, m; b = wheel section width, m;

d = overall wheel diameter, m; δ = wheel deflection, m

CI = soil strength, kPa.

- From regression analysis of field data, a significant correlation was obtained by using the cone index value as a measure of soil stress.

- The tractor tractive parameters were predicted using the soil strength equation in stubble, ploughed and cultivated fields, from the empirical relationships developed by Wismer and Luth (1973) in the USA or from the following derived **by Gee-Clough (1980)** in the UK.

$$C_{RR} = \frac{R}{W} = 0.049 + \frac{0.287}{M_N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

$$(CT)_{max} = \frac{(TH)}{W} = 0.796 - \frac{0.92}{M_N} \ldots\ldots\ldots\ \ldots\ldots\ldots .2.3$$

$$k(CT)_{max} = 4.838 + 0.061 MN \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

$$k = k(CT)_{max} + 0.061 M_N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

$$CT = \frac{T_h}{W} = (CT)_{max}(1 - e^{-sk}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

$$s = 9 + \frac{19}{M_N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.7$$

- where:

CRR = coefficient of rolling resistance;
W = wheel load, kN;
(TH)max = maximum driven wheel thrust, kN;
CT = coeff of traction;
(CT)max = max coefficient of traction;
Tη = net driven wheel thrust,
R = rolling resistance force, kN;
k = rate constant;
MN = wheel mobility number;
s = wheel slip.

- The previous equations may be used to calculate rolling resistance of the wheels and the thrust available from the driving wheels as a function of slip. The drawbar pull, D_p, is then the difference.

- **2.2 Soil Strength**

- **Oskoui and Witney (1982)** stated the simplification of Krastins's equation by using only the specific weight term as an indication of soil strength **as stated by Gee-Clough et al. (1978)** eliminating the effect of the cohesive term from the cone index equation and precluded any effect of changing soil moisture content.

- From the regression analysis of field data for three soil series, they proposed a cone index equation as in the form:

$$CI = 450\ \theta^{-2} + 0.019\ \gamma \qquad ....2.8$$

\- where CI = cone index, MPa;

θ = soil moisture content, %;

γ = soil specific weight, kN/m^3.

- **Elbanna (1986); Elbanna and Witney (1987) and Elbanna (2001)** developed soil strength equation as a function of the soil type (in terms of the clay ratio), soil specific weight and soil moisture content, the developed soil strength equations were :

- General form (for a wide range of soil types (sandy to Heavy clay):

$$CI = [1.281Cr.e^{-0.01\theta.0(1+Cr)}] + [0.0131\frac{1}{1+2Cr}e^{\pi(1+Cr)}]...2.9.1$$

- **Specific equation for sandy soil (for arid condition):**

$$CI = [4.03.Cr.e^{-0.01\theta.01+Cr)}] + [0.00694\frac{1}{1+2Cr}e^{\pi(1+Cr)}]...2.9.2$$

- where :

CI = cone index, MPa;

ϕ = soil internal shearing frictional angle, deg.;

θ = soil moisture content, %;

γ = soil specific weight, kN/m^3;

tan ϕ = 1 / (1+2Cr);

Cr = clay ratio =%clay / (% silt + % sand).

- The logarithmic spiral or soil zone failure term, $\exp(\pi \tan\phi)$, affects both the cohesive and frictional components of the cone index equation, when the soil is fully formed around the cone base bulb and can be represented the failure zone of soil bearing capacity.

- **2.3 Draught Forces**

- From field experimental (**Hunt ,1974; ASAE, 1978 and Collins, 1978)** concluded that the relation between the unit draught and speed for moulboard ploughs tends to increase with speed, and presented a quadratic form of plough draught.

Morever, **Summers et al ., (1984)** concluded that plough draught varies linearly with speed for chisel ploughs, discs and sweep ploughs and is a quadratic functions of speed for moulboard ploughs, and linear with depth for all tillage.

- The draught force of a mouldboard plough is a combination of the quasi-static soil shearing resistance and the dynamic component increasing with the square of the velocity influenced by the lateral direction angle of the mouldboard tail angle.

- **Söhne (1960)** adapted an equation developed by **Goryachkin (1940)** to express the draught and speed relation of tillage tools in the form :

$$Z = zo + k\,V_a^2\,(1 - \cos\,\Phi\,P) \text{.......2.10}$$

- where:

Z = specific plough draught, kN/m^2;

V_a = forward speed, m/s;

zo = quasi-static component of specific draught, kN/m^2;

k = coefficient constant;

$\Phi\,p$ = lateral direction angle of the mouldboard plough, deg.

- Using a similar form of algebraic equation, Voorhees and Walker (1977) identified the effect of soil moisture-content, θ, on the quasi-static draught component as in the form :

$$Z = k_1 + k_2 \theta + k_3 V_a^2 \text{.................} 2.11$$

- where:

k_1, k_2 and k_3 = constant depend on soil type and its parameters.

- In a more extensive study using field data, **Gee-Clough et al. (1978)** proposed an empirical mouldboard plough draught equation based on the dimensionaless groups identified by **Krastin (1973)** such as in the form :

$$Z = 13.3a\gamma + \frac{3.06\gamma V^{2}a}{g} \quad .... \quad .... \quad 2.12$$

- where:

Z = specific draught, kN/m^2;

γ = soil specific weight, kN/m^3

V_a = forward speed, m/s;

a = cut depth, m;

g = gravitational constant, 9.807 m/s^2.

- It was argued further, however, that the soil stress paramter could be eliminated from the draught equation to give the quasi-static component dependent only on the specific weight, Epn 2.12. **Oskoui and Witney (1982)** found that the simplification of Krastins's equation by using only the specific weight term as an indication of soil strength, eliminating the cohesive term from the equation and precluded any effect from changing soil moisture content.

- They proposed that because the cone index values incorporate cohesive and frictional components of the soil, there is practical validity for the assumpation plough on that the quasi-static component of plough draught is a function of cone index, thus the specific plough draught equation was:

$$Z = \{\ 0.05\, CI + [9.66\, \gamma\, V_a^2 (1 - \cos \Phi_p]\ \} \ldots\ldots\ldots\ldots\ldots\ldots 2..13$$

- In more a comperhence of theoretical and experimental field data, **Elbanna (1989); Elbanna (1992) and Elbanna(2002)** validated the assumption in equations 2.10 to 2.12 and showed evidence that the quasi-static component of the specific plough draught not either the soil specific weight, (Eqn 2.12) nor the cone index value (Eqn 2.13).

There is practical validity for the assumpation, the quasi.-static component of the plough draught depends on the soil cohesive which is a function of the clay ratio (soil type) and it moisture content. While, the dynamic component of the plough draught is function of soil friction, tillage velocity, and blade parameters (eg. tail or apex angle, share width, and depth, etc).

The frictional component is affected by logarthemic or soil zone failure terms. So, the chisel and mouldboard ploughs'; field cultivator; disk harrow and disk plough specific draught are given by the following equations and these equations are considered form the basis the present study.

$$Z_c = \left\{\left[30.27 Cr \; e^{-0.01\,\theta}\right] + \left[0.72\,\gamma\,V_a \sqrt{\frac{w}{g}}(1 - \cos\Phi_c)\right]\right\} e^{\pi \tan\varphi} \quad ....2.\ 14$$

$$Z_m = \left\{\left[35.55 Cr \; e^{-0.01\,\theta}\right] + \left[\frac{0.72\,\gamma\,V_a^2}{g}.(1 - \cos\Phi_m)\right]\right\} e^{\pi \tan\varphi} \quad ....\ .2.15$$

- where :

Zc; Zm = chisel and mouldboard specific ploughs draught, kN/m^2;

Cr = soil type =clay/(silt+sand);

γ = soil specific weight, kN/m^3;

ϕC and ϕM = chisel and mouldboard tail angle, deg.

V_a = actual forward speed, m/s;

- The draught force can be evaluated by multiplying the specific chisel and mouldboard ploughs draught (Eqns 2.14 and 2.15) time ploughing sectional area, such as :

$$P_{DC} = Z_c \cdot a \cdot \{[((N_b + 1)/2).F_w)]\} \text{.......... } 2.16$$

$$P_{DM} = Z_m \cdot [a \cdot (N_b F_w)] \text{........ ....} 2.17$$

\- Where:

F_w = furrow cut width,m;

a = cut depth, m;

N_b = number of plough shares or bottoms.

- **2.4 dynamic weight transfer**

- In additional to soil-implement characteristics, dynamic weight transfer is a critical issue in field performance. **Dwyer et al. (1975)** reported in NIAE yearbook recommmended load and dimension of each wheel. It should be noted, “The recommended loads on the tractor wheels include the implement weight”.

However, under field conditions, the recommendations are not adequate, due to the changing implement forces acting on the rear wheels, as a result of changing of operating depth and soil strength.

- In order to estimate the dynamic weight on each tractor axle, **Domier and Friesen (1969) and Bashford et al. (1985)** reported that a ballast distribution with 35%, 42% 60% for 2-WD, FWA and 4-WD drive tractors, respectively, of total static tractor weight on the front axle was resonable.

These figures were used in the present model. For developing a systems level of tillage performance, suitable for equipment selection, is to integrate soil and implement characteristics, so that dynamic weight transfers could be determined.

- It is very important to model dynamic weight transferred from the front wheels to the rear wheels of the tractor, as well as weight transferred from the implement to the rear wheels of the tractor, to calculate the dynamic driven wheel load. It is necessary also to realize the dynamic weight transfer affects the torque required to overcome the rolling resistance of the driving wheels.

Zoz (1970) used dynamic weight coefficient, D_v, to represent curves, within each soil type, for three tillage implements named: an intergral hitch mounted ($C_{DW} = 0.65$), a semi-integral type ($C_{DW} = 0.45$) and towed implement ($C_{DW} = 0.25$), the dynamic weight coefficient was:

$$C_{DW} = \frac{v}{W_{bas}} + \left(1 + \frac{h}{W_{bas}}\right) \tan \beta an\beta .\ldots\ldots 2.17$$

- where:

C_{DW} = dynamic weight coefficient;

W_{bas} = wheelbase

h, v = horizontal and vertical coordinates of point of application of mplement force resultant, m ;

β= draught angle below horizontal plane.

- **Dwyer (1984)** assumed that the recommended wheel load included implement weight. However, this assumpation can only be matched with a specific mounted implement.

- The net thrust from the driving wheels is equivalent to the drawbar pull plus the rolling resistance of any undriven wheels.

When the implement draught force is developed by a fully mounted plough, all the forces act in approximately the same horizontal plane and do not affect weight distribution between the axles. In addition, however, it necessary to take account ot the weight transfer from the front axle to rear axle due to the torque required to overcome the rolling resistance of the driven.

he dynamic rear wheels weight of the tractor, W_r, is given by:

$$W_r = W_{rs} + \frac{Q_{rr}}{W_{bas}} \text{.......... ....}2.18$$

- Where :

Q_{rr} = torque overcoming rolling resistance of the driving wheels, kN.m, and

W_r = static weight on the rear axle, kN;

W_{rs} = static weight on the rear axle, kN

W_{bas} = tractor wheel base; m.

→ For a 2-WD tractor

$$W_R = W_{RS} + \left[W_R \, (C_{RR})_R \right] \frac{r_r}{W_{bas}} \quad \text{.......... ....} \quad 2..23$$

- where $(C_{RR})_R$ = coefficient of rolling resistance of rear wheels

→ For a four- wheel drive tractor

$$W_R = W_{RS} + \left[W_R (C_{RR})_R + W_F (C_{RR})_F \right] \frac{r_r}{W_{bas}} \text{...........2..24}$$

- where :

$(C_{RR})_F$ = coefficient of rolling resistance on front wheel;

W_F = dynamic weight on front wheels

= $W - W_R$, kN;

W = total weight of the tractor, kN

- Equations 2.23 and 2.24 may be solved for W_R and W_F. If the tractor is two wheel drive, WR is then used in equation 2.8 to find the slip, s.

- Equations (2.21 and 2.22) represent a simple approach to dynamic weight transfer coeefficients.

However, the values of its parameters are not constant, they are a functions of the actual implement used (light, heavy, close couple, and so forth) and thus, vary with implements weight, coupling and vertical penetration and soil charactersitics. The Dwyer equations (2.22 to 2.23) provide an alternative approach to dynamic weight transfer, but fail to fully consider implement draught, soil conditions and tractor implement geometry.

- **TILLAGE MODEL DEVELOPMENT**

- In order to develop the tillage-machinery computer model, it is assumed that the rolling resistance, the pull from driven wheels and the implement acting force all act in the same horizontal plane, as shown in Fig. 1 To add more realistic implement and soil characteristics to the tractor model under dynamic conditions a new model is proposed, based on equations (2.3 to 2.9 and 2.23 & 2.24). In the new model, weight transfer estimates consider the tractor, implement and soil criteria (which are included in the acting resultant force, R_H). The vertical force V_F, is the sum of the soil reaction force, V_S, and the implement load, W_I. The acting force, R_H, is the resultant of both the horizontal, P_D, and vertical, V_F, component of the plough draught forces.

The draught force, actiong from the implement on the tractor, acts to add weight to the rear of the tractor and at the same time decrease weight from the front axle. These forces, in ploughing operation, are shown in Fig. 2 and modeled by taking the moment about A and B (Fig. 1) for W_R and W_F, which represent the dynamic weight on the rear and front wheels, respectively.

$$W_R = \frac{1}{W_{bas}}\left(W_T X_3 + R_H \ell_2\right)$$

$$W_F = \frac{1}{W_{bas}}\left(W_T X_2 + R_H \ell_1\right) \text{.......... ....3. .1}$$

- where :

→ W_F, W_R = dynamic weight on the front and rear wheels, kN;

→ R_H = implement resultant force, = P2D+V2F, kN;

→ V_F = vertical force acting on the implement due to implement weight and soil reaction, kN;

→ P_D = horizontal component of draught force, kN;

→ $\ell_1 = X_1 \sin(\beta)$;

→ $\ell_2 = (X_1 + W_{bas}) \sin(\beta) - a \cos(\beta)$;

→ X_1 = distance behined rear axle to implement point actiong force,m;

→ X_2 = distance from rear axle to tractor centrer of gravity, m;

→ X_3 = Distance from front axle to tractor center of gravity, m;

→ W_{bas} = wheel base = $X_2 + X_3$, m;

→ W_T = tractor static weight, kN;

→ β = angle below horizontal plane = arctant (PD/VF); Deg.

- Fig. 1b represents the weight transfer due to the tiling cuased bt the two furrow-side wheels running in the furrow bottom. The rear axle load, W_R, will be divided into W_{R1} and W_{R2} on the landside and furrow-bottom side, respectively. The values of W_{R1} and W_{R2} can be determined from Fig. 1b by taking the moment about C and D:

$$W_{R2} = W_R \left\{ \left(\frac{H}{X} \right) \tan \Phi + \frac{1}{2} \right\}$$

$$W_{R1} = W_R \left\{ \frac{1}{2} - \left(\frac{H}{X} \right) \tan \Phi \right\} \text{.......... .... } .3.2$$

\- where :

→ W_{R1}, W_{R2} = dynamic weight on the rear landside, furrow-bottom wheels, kN;

→ W_{F1}, W_{F2} = dynamic weight on the front landside, furrow-bottom wheels, kN;

→ $\Phi = \arctan(a/x)$;

→ a = depth of cut, m;

→ H = tractor center gravity height, m;

→ X = wheel track, m.

- The same procedure can be applied to obtain the weight on each of the tractor front wheels:

$$W_{F2} = W_{F}\left\{\left(\frac{H}{X}\right)\tan\Phi + \frac{1}{2}\right\}$$

$$W_{F1} = W_{F}\left\{\frac{1}{2} - \left(\frac{H}{X}\right)\tan\Phi - \right\} \text{.......... .... .3.3}$$

- where :

→ W_{R1}, W_{R2} = dynamic weight on the rear landside, furrow-bottom wheels, kN;

- → W_{F1}, W_{F2} = dynamic weight on the front landside, furrow-bottom wheels, kN;

- → Φ = arcsin (a/x);
- → a = depth of cut, m;
- → H = tractor center gravity height, m;
- → X = wheel track, m.

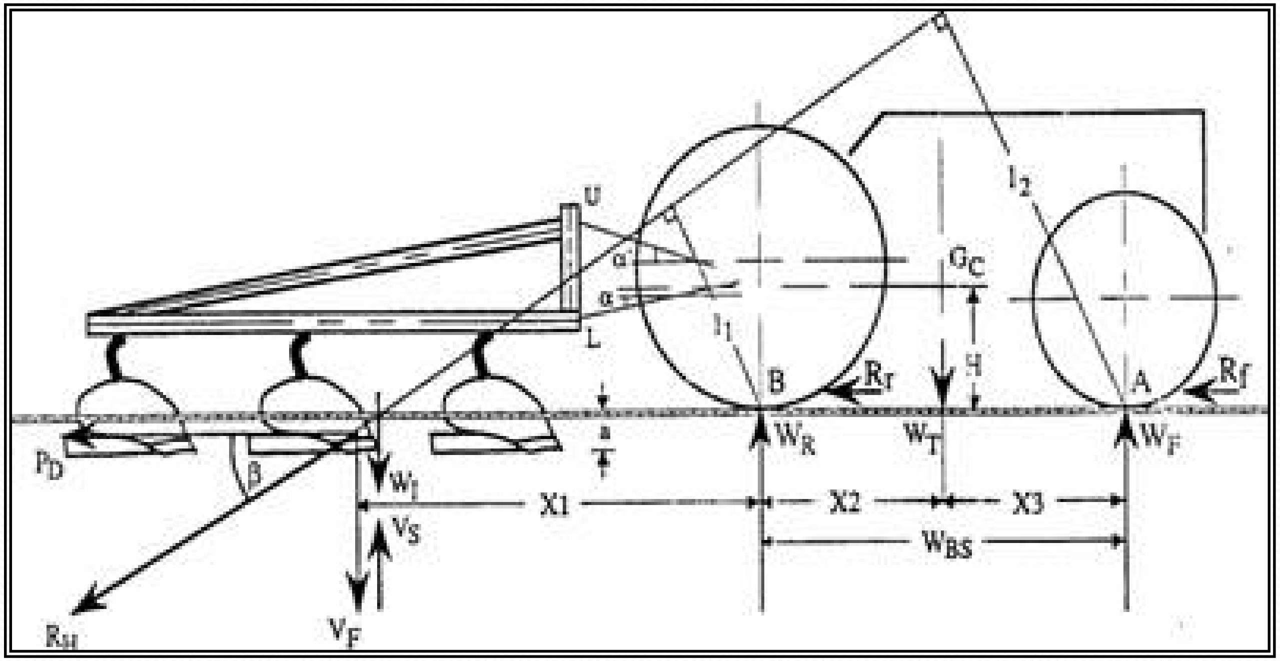


Fig. (1.a) Dynamic weight distribution on the rear and front tractor axles, weight transfer from implemt and front axle to rear axle,

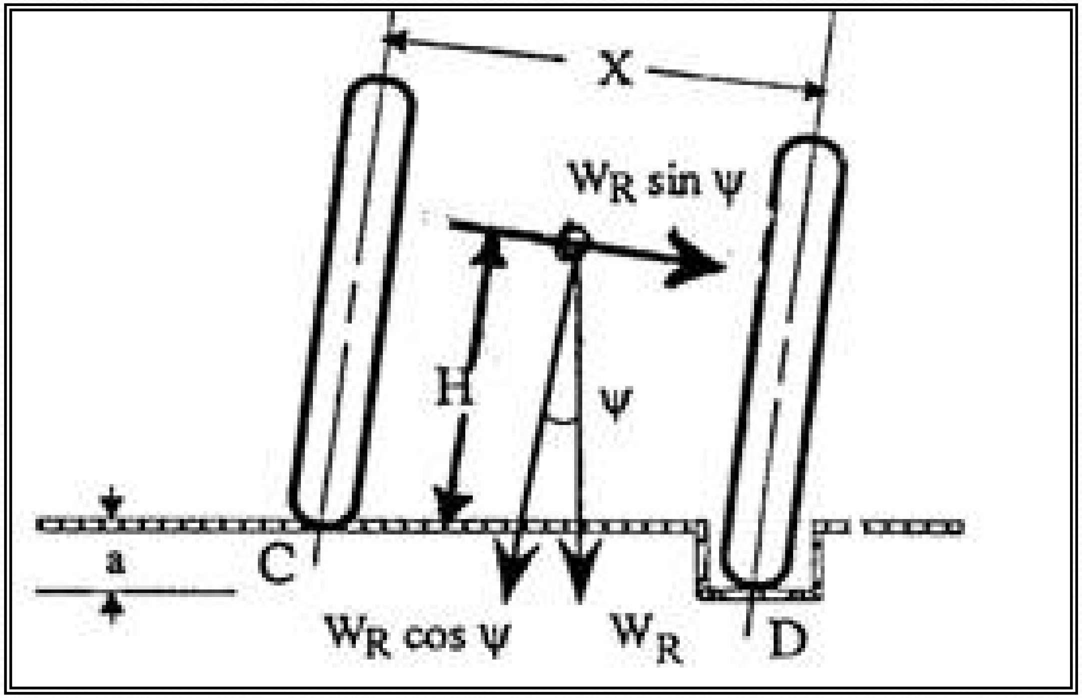


Fig. (1b) Rear wheel weight transferred due to tilling, caused by running wheels in furrow and landside.

- From analysis of draught forces, it was found that the angle of the resultant, RH, line below the horizontal plane, for a fully mounted moulboard plough, was 30^o, a semi-mounted plough was 25^o and a towed plough was 20^o.

It is possible to calculate the amount of dynamic weight on eachtractor wheel by defining the necessary dimensions (Fig, 1a) from tractor and implement manufacturer’s specifications and assuming the half-lengthof the implement for the Rh point.

$D_p = T_h$ (driven wheels) – R (undriven wheels)

…………..2.10

- The torque, Q, required at driving wheels is:

$Q = [(T_h$ (driven wheels) – R (driving wheels)]$.r_r$

……. ….. 2.11

- where r_r = rolling radius of the driving wheels.

- and the input power, P_i , required is:

$$P_i = Q.\omega = \frac{QV}{r_r} \text{..............................} 2.13$$

- where : ω = rotational speed of driving wheels

V = theoretical forward speed without slip

- Therefore,

$$P_i = (T_h + R)\, V \qquad \text{....................} 2.14$$

- The corresponding output power, Po is:

$$P_o = D\, V\, (1\text{-}s) \qquad \text{..................} 2.15$$

- The problem therefore, is to find the maximum value of P_o which is possible in each gear without exceeding the maximum available value of P_i

- It is now necessary to distinguish between two possible situations. In the higher gears output power will be limited by the engine power available, whereas in the lower gears output power will be limited by slip.

For each gear, therefore, the maximum output power possible with either of these limitations must be calculated and the lower of the two is the actual maximum power available in that gear.

- The coefficient of rolling resisitance, maximum coefficient of traction, coefficient of traction and wheel slip can be determined by using equations (2.3-2.8). Then, available thrust, T_η, developed at the driven wheels can be calculated.

- The actual drawbar pulls D_P, can be determined from :

$$D_p = T_\eta - R_f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.4$$

- where :

D_p = net drawbar pull, kN;

T_η = available thrust developed at driven wheels, kN;

R_f = rolling resistance of undriven wheels, kN.

- The torque required from the driven wheels can be determined as:

$$Q_D = (T_\eta + R_r)\, r_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.5$$

- where :

Q_D = torqure required at driven wheels, kN.m;

r_r = rolling radius of driven wheels, m;

R_r = rolling resistance of driven wheels; kN.

-The output and input power required at the drawbar and driven wheels can be calculated as :

$$P_o = D_B V_t (1-s) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 3.6$$

$$P_i = Q_D \omega = \frac{Q_D V_t}{r_r} = (\eta_T - R_r) V_t \quad \ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

- where :

P_o = output power at drawbar, kW;

V_t = non slip speed, m/s;

P_i = input power at driven wheels, kW;

ω = rotational speed of driven wheels, rpm.

- At this point, the problem is to find available power value of Pi. Since at the gears, the output power will be limited by slip and the maximum output power possible, each of these limitations must be calculated and the lower of the two is the maximum power availabe in that gear, Dwyer (1984). The calculation of maximum slip-limited power is more complicated.

If the tractor is 2-WD, front wheel assisted or 4-WD the following equations will yield the maximum output power. For a 2-WD tractor such as result is:

$$(P_o)_{max} = [W_r(C_T)_{max} - W_f(C_{RR})_r]_r \; V_t (1-s)$$

..........3.8

- And likewise for a front wheel assisted or a 4-WD tractor the result is:

$$(P_o)_{max} = W_f[C_T)_{max}]_f + W_r(C_T)_{max}]_r \; V_t (1-s)$$

..........3.9

- The rolling resistance of the undriven wheels is sunstracted from the available driven wheel thrust to calculate drawbar, D_B. The rolling resistance of the driven wheels is added to the available driven wheel's thrust to calculate the required thrust. The rolling radius of driven wheels to calculate the driven wheel torque simplifies the thrust developed at the driven wheels.

This torque is simplified by the transsimation efficiency and approprite gear/driven wheel ratio to find the maximum engine torque required. Then, torque is multiplied by engine spped to calculate maximum engine power requirements.

- The above equations were incorporated in a tractor-implement computer model. The model was coded in Fortrant 77 and is available from the first author in materic and English units. A flowchart is shwon in Fig. 2. The model is capable of developing tillage machinery performance parameters for various tractor types, fleet and implements sizes, for a wide range of soil types and conditions.

The model is designed to provide support for tractor – implement selection under field conditions. It can be used to asses performance requirements for a given set of tractor-implenemt specifications and field conditions or it can be used to perform sensitivty analysis with respect to soil conditions and fieldwork requirements. The model also has the potential to be expanded beyond ploughing applications to primary tillage operations.

4- EXAMPLE

- A simple example has been developed and modeled in order to demonstrate the model as well as to compare the results the Dwyer model. A summary of results is shown in Table 1. Additional input data required for the new model is furnished below. It should be noted that the Dwyer model does not make use of these data.

- **1-Tractor :**

- wheel track :

2WD =1.62 m;   FWA = 1.62 m;

- distance behained rear axle acting force :

2WD = 2.5 m;   FWA = 2.5 m;

- distance from reart axle to tractor center of gravity :

2WD = 0.79m; FWA = 0.79m;

- distance from front axle to tractor center of gravity :

2WD = 1.31m; FWA = 1.35m;

- hieght of center of gravity :

2WD = 0.88; FWA = 0.88m.

- **2- Plough :**

- type : mounted (seni-mounted); tail angle = 35°;
- furrow width: 0.41m;
- cut depth = 0.23 m;
- field efficiency: 80%
- pull angle below horizontal plane: 30°.

- **3-Soil :**

- bulk density : clay soil 1.00 gm/cm^3; sandy soil 1.60 gm/cm^3.

- moisture content (farily cond.): clay soil = 0.27%; sandy soil = 22%;

- soil texture: clay (50% clay, 40% silt, 10% sand), sandy soil (60% sand, 30% silt, 10% clay).

CONCLUSION

- A model has been developed to predict tractor performance in tillage operations for 2 WD, front wheel assisted and equal 4-wheel drive tractors undel field conditions. The field conditions are modeled using soil and climate in the form of the soil strength as a function of the clay ratio, soil moisture content and specific weight.

The chisel and mouldbaord ploughs' equations were used to predict the drught forces for both of these implements as a functions of a cone index, forward speed, soil specific weight and plough mouldboard tail or apex angle (for molboard and chisel ploughs).

The model predicts the weight transfer from the front axle of the tractor to the rear axle and from the implement to the rear wheels, based on tractor – implemet manufacturers’ specifications. Model inputs and outputs have been structured to support practical considerations and available data in order to support equipment decisions relative to available options.

- The dynamic characteristics of a tractor's driven wheels, under field ploughing conditions, were determined by summing the static rear wheels load and the amount of weight transferred from the front wheels and the acting implement resultant force on the rear wheels, due to implement draught forces and vertical soil force, as the combined result of implement weight and soil reaction forces.

The equations used in this model include both original equations and other equation taken from the review of literature. The complexity of the model requres a computer aids. The computer code is available from the first author in both English and metric units. The model was demonstrated through an example.

The model can be used to predict field performance for various soil types and conditions for farm tractors with pneumatic tyres in a plouhing task. Minimal tractor, implement and soil data are required to drive the model. The model compares favorably with the Dwyer model and extends the capability to estimate dynamic weight transfer under field conditions, including soil composition and moisture content, as well as tractor and implement geometries.

REFERENCES

- **1-Basford, L.L.; G.R. Voerman and G.J. Shropshire (1985)** Wheel assit tractor performance in two and four-wheel drive modes. Trans of the ASAE. 28(1): 28-29.

- **2-Domier, K.W. and O.H. Friesen (1969)** Performance parameter of tractor equipped with singles, duals and four wheels drive. Can. Agric. Engng. 11(1): 16-19.

- **3-Dwyer, M.J. (1984)** Computer models to predict the performance of Agricultural tractor on heavy draught operations. Proc. 8th Intrn Conf. Intn. Soc. Terr. Vel. Systems., Cambridge, England. 833-852.

- **4- Dwyer, M.J.; Comely, D.R. and D.W Evernden (1974)** The Field performance of some tractor tyres related to soil properties. J. Agric. Engng. Res. 19: 35-50.

- **5- Dwyer, M.J.; Comely, D.R. and D.W Evernden (1975**) The development of a handbook of agricultural tyre performance. Proc. 5th Intn. Conf. Intn Soc. Terr. Veh. Systems. Detroit, USA. 2: 678-699.

- **6- Elbanna, E. B. (1986)** Agricultrual machinery selection: Soil strength and Operational Timeliness. Unpul. Thesis, Edinburgh Univ., UK.

- **7- Elbanna, E. B. (1989)** Prediction of specific mouldboard plough draught. Misr J. Agr. Eng. 4(4): 189-201.

- **8- Elbanna, E.B. and B.D. Witney (1986)** Cone penetration resistance equation as a function of the clay ratio, soil moisture conetent and specific weight. J. Terramech. 24(4): 41-56.

- **9- Freitag, D.R. (1965)** Dimentional analysis of the performnce of pneumatic tyres on sand. Trans of the ASAE. 11(5): 669-672.

- **10- Gee-Clough (1980)** Selection of tyre size for agricultural vechicles. J. Agric. Engng. Res. 25: 261 – 278.

- **11-Gee-Clough (1978)** A comparison of the mobility number and Bekker's approach to traction mechanics and recent advances in both methods at the N.I.A.E. Proc. 6th Intn. Conf. Intn. Soc. Terr. Veh. Systems, Vienna, Austria. 2:735-745.

- **12-Gee-Clough ;M. McAllister; G. Person and D.W. Evernden (1978)** The empirical prediction of tractor-implement field performance. 15(2): 81-94.

- **13-Krastin, E.N. (1973)** The use of methods of theory of dimensional analysis for evaluation of the draught characteristic of the plough during operating in different conditions. Dokady Milsp 8(1): 61 (Translation Gill 1333, Natn. Tillage Mech. Lab., Aurbun, Alabama, USA.).

- **14- Manby, T.C.D. and J. Mathews (1973)** Development and operation of OECD tractor test code. ASAE Paper No. 73062.

- **15- Placket C.W.; K. Clements; M.J. Dwyer and P. Febo (1987)** The ground pressure of agricultural tyres. Veh. And Cul. Division Dept. Note. No. 49 N.I.A.E., Silsoe, England.

- **16- Splinter, W.E. D.E. Steinbrugge; D.E. Lane and L.F. Larson(1973)** Nebraska tractor test. Programs and philosophy. ASAE. Paper No. 730763.

- **17-Turnage, G.W. (1973)** The selection and performace prediction for off-road wheeled vechile operation. Proc. 4th Intn Conf. Intn. Soc. Terr. Veh. Systems.Stockholm, Sweeden. 1: 6183.

- **18-Wismer, R.D. and H.J. Luth (1973**) Off-road traction for wheeled veicles. J. Terramch. 10(2): 49-61**.**

- **19- Zoz, F.M. (1972)** Predicting tractor field performance. Trans of the ASAE. 15(2): 249-225.

- **20- Downs H.W. ; T. K. Ranlad and A. Al-Janobi (1990).** Decision aid for optimizing tractor-implement systems. ASAE Paper No. 90-1569. ASAE, St. Joseph, MI 49085.

- **21-Oskoui, K. E.; O.M. Morgan and.W.B. Voorhees (1990**). Manage – An expert system for machinery management ASAE Paper no. 90-1643. ASAE St. Joesph, MI 49085.

- **22-Kotzabassis C.; B. A. Stout and H.T. Wiedemann (1990**) Farm machinery selection and management expert system. ASAE paper no. 90-7018. ASAE St. Joesph, MI 49085.

الملخص العربى

الشد الرطوبى ومعامل التوصيل الهيدروليكى فى التربة الزراعية

د . الشحات بركات المغازى البنا

لما للصرف الزراعى من أهمية كبرى للتربة الزراعية من توفير التهوية والمحتوى الرطوبى اللازمين لنمو النبات والحدية الإنتاجية للمحصول الزراعى . والصرف أو رشح التربة للماء. يعتبر أساس معادلة الإتزان المائى للتربة الزراعية خصوصا فى المناطق ذات الرطوبة النسبية العالية عندما تزل كمية الماء. المفقودة من سطح التربة والنبات Evapotranspiration إلى حد يمكن إهماله وكذا تسرب الماء. من الطبقة السطحية إلى الماء. الإرضى. لذا أجرى هذا البحث لإيجاد علاقة الشد الرطوبى بكمية الرطوبة بالتربة الزراعية ، وكمية مياه الصرف كدالة للمحتوى الرطوبى للتربة الزراعية فى أربعة أنواع من الترب الزراعية هى : سلتية طينية طمية ، وسلتية طمية ، وسلتية طينية ، والطينية الثقيلة فى بنى عبيد - دكرنس ، منية النصر ، تمى الأمديد بمحافظة الدقهلية ، والوسطانى - كفر سعد بمحافظة دمياط على الترتيب.

وقد تم قياس المحتوى الرطوبى للتربة عند (0.001(Saturation), 0.1, 0.33(Field capacity) 0.66, 1.0, 5 and 15 (Wilting point) Atmospheric pressure أى من حالة تشبع التربة بالماء. إلى نقطة الذبول. وقد تم قياس كمية المياه المنصرفة من الأربعة أنواع الترب الزراعية من التشبع الى مابعد السعة الحقلية للتربة على مدى عشرة أيام من حالة تشبع التربة بالماء. فى القطاع السطحى والتحت سطحى للتربة. وقد تم تحويل الضغط الرطوبى إلى ملليمتر ماء. (Soil tension head, mm) ونسبة الرطوبة بالتربة إلى (Head mm/mm depth of soil profile) وذلك بإستخدام نسبة الرطوبة وكثافتى التربة والماء. وعمق القطاع الأرضى وتم إستنتاج العلاقتين التاليتين:

١) الشد الرطوبى والمحتوى المائى للتربة الزراعية:

$$\ln \theta_{mm} = -\beta \ln(P_h) \quad \text{or} \quad \theta_{mm} = e^{-\beta \ln(P_h)} \qquad (1)$$

where θ_{mm}=soil moisture content, mm/mm depth of soil;

P_h=tension pressure head, mm; β=exponent constant=0.021215

٢) والصرف وعلاقة بالمحتوى المائى للتربة:

$$\ln Q_r = k\{\theta_{(n-1)}/h\} \quad \text{or} \quad Q_r = e^{k\{\theta_{(n-1)}/h\}} \qquad (2)$$

where Q_r=drainage flow, mm/day; k =exponent=5.660;

$\theta_{(n-1)}$= soil moisture content on previous day, mm

ويتضح من التحليل الإحصائى أن المحتوى المائى للتربة الزراعية يتناقص سريعا من التشبع عند شد رطوبى منخفض حيث يكون الماء. الأرضى حرا حتى مابعد السعة الحقلية وبزيادة الضغط يقل معدل تناقص المحتوى الرطوبى للتربة لزيادة جذب الحبيبات للماء. فى صورة أغشية خصوصا عند نقطة الذبول وما بعدها يصعب إزالة الماء. الأرضى لقوة جذب الحبيبات الأيجروسكوبى. كما بالمعادلة (١) وقد وجد معامل إرتباط بين تلك العاملين (R^2 = 93.928) فى الصورة العامة للأربعة أنواع تربة تحت الدراسة وأعلى فى حالة تلك الأنواع منفردة كما بجدول (٤-٢). وعلاقة المياه المنصرفة من التربة الزراعية وكمية الرطوبة بها عند (n-1) يوم من التشبع علاقة لوغاريتمية أو أسية كما بالمعادلة (٢) ومن التحليل الإحصائى للبيانات الحقلية وجد معامل إرتباط عالى بينهما (R^2=95.338) جدول (٤-٥) فى حالة الأربعة أنواع للتربة عند القطاع السطى والتحت سطحى ، وأعلى فى حالة كل تربة على حده. وقد مثلت البيانات المقاسة والحقلية فى جداول ومنحنيات واتضح أن المعادلتين يمكن إستخدامهما للتنبأ بالمحتوى الرطوبى Soil moisture content والصرف Soil hydraulic conductivity وأن المحتوى الرطوبى بين نقطة التشبع والسعة الحقلية للتربة الزراعية يتناقص سريعا (يرشح) حتى تحت ضغوط الشد المنخفضة ويبطء من السعة الحقلية إلى نقطة الذبول.

أستاذ الميكنة الزراعية المساعد - كلية الزراعة - جامعة المنصورة.

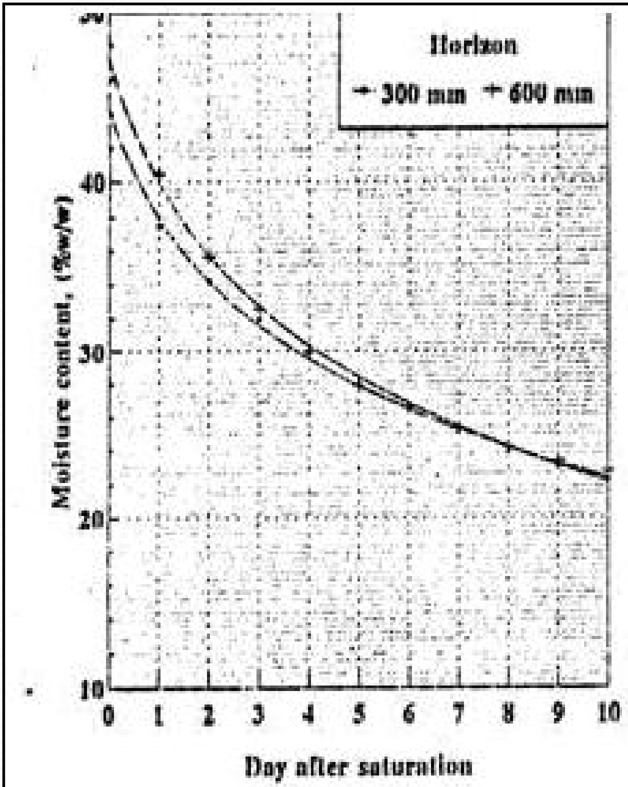


Fig. 4.4b Variation of soil moisture content with time after saturation, for silty loam soil at Menyit El-Nasr, Dakalia.

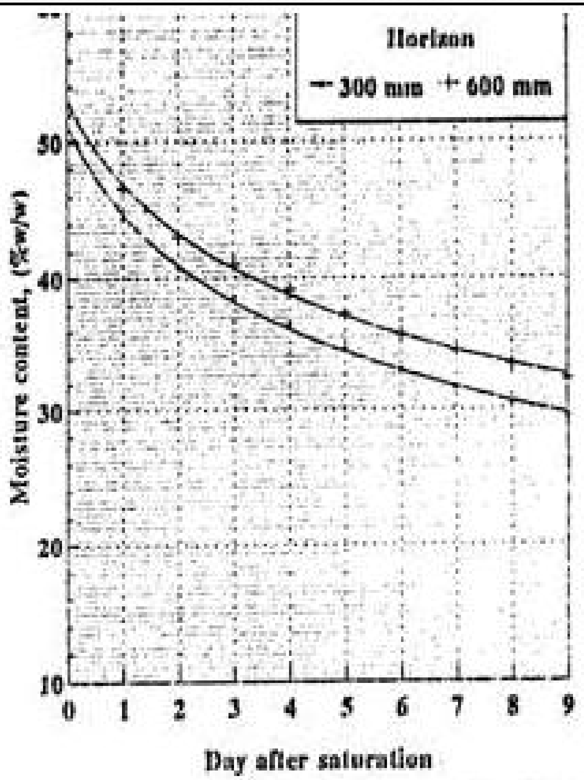


Fig. 4.4c Variation of soil moisture content with time after saturation, for silty cly at timy El-Amdded, Simbillawein, Dakahlia.

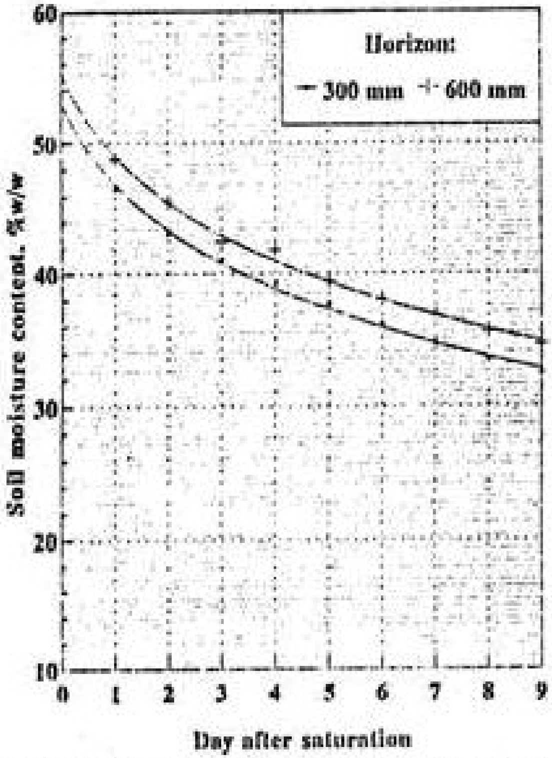


Fig. 4.4d Variation of soil moisture content with time after saturation, for clay soil at El-Westany, Karf Saad, Domiatta.

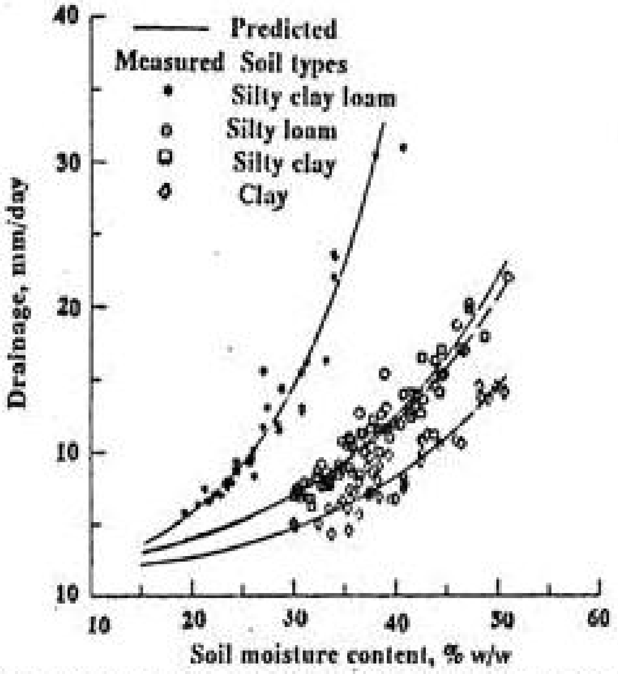


Fig. 4.5 Effect of soil moisture content on drainage flow for various soil types at 300 horizon level.

- زيادات ربما تستخدم

- أنواع اختبار الضغط الثلاثي

TYPES OF TRIAXIAL TESL

- الأنواع الرئيسية لاختبار الضغط الثلاثي تتمثل في الآتي :

- ١- اختبار عدم التصرف :

- حيث توضع العينة بين رأسين معدنيين بحيث ينعدم التصرف منها . وبعد الوصول إلى ضغط الخلية يزاد الضغط المحورى بسرعة حيث لا يعطى ذلك فرصة المياه من العينة ويجب أن يستمر الاختبار في حدود ١٠ـ ١٥ دقيقة . وهذا الاختبار يستخدم لتعيين معاملات عدم التصرف **Cu, φ'** **(Undrained)**

- ٢ـ اختبار التصلب ـ عدم التصرف :

Consolidated – Undrained

- يسمح في الاختبار أولا بالتصرف لحدوث التصلب تحت ضغط الخلية ثم يقفل التصرف (عند توقف خروج المياه عند التصلب) ويحمل بالحمل المحورى (في حالة عدم التصرف) . ويترك أحد وصلات تصرف المياه مفتوحة ليقاس فيه ضغط المياه الحرة. ومرحلة التصلب عادة تأخذ ٢٤ ساعة ومرحلة القص تأخذ من ١٠ دقائق إلى ساعتين حسب نوع التربة . وفى هذا الاختبار تقاس معاملات الإجهاد المؤثر وكذلك معاملات عدم التصرف.

- ٣- اختبار التصرف DRAINED :

- يسمح للعينة بالتصريف لتتصلب تحت حمل الخلية إلى أن يتوقف خروج المياه الحرة منها وحينئذ يزاد الحمل المحورى مع السماح بالتصرف بمعدل بطيء يجعل الزيادة في ضغط المياه الحرة مساويا الصفر.

- التصلب الابتدئى في هذا الاختبار يستغرق ٢٤ ساعة ومرحلة القص البطيء تستغرق زمنا يصل إلى أسبوعين . وفى هذا الاختبار تقاس معاملات التصرف.

استخدامات جهاز الضغط الثلاثي

- استخدامات جهاز اختبار الضغط الثلاثي فيما يلي :

- ١ـ اختبارات القص (السابق ذكرها في الفقرة السابقة)
- ٢ـ اختبار تعيين معاملات ضغط المياه الحرة.
- ٣ـ اختبار التصلب الثلاث الاتجاهات .
- ٤ـ اختبار النفاذية

- مصادر الخطأ في اختبار الضغط الثلاثي

Souses of error in the triaxial test

- (أ) اختبارات عدم التصرف :

- ١ـ تشوهات العينة الناتجة عن المناولة والتركيب في الجهاز.
- ٢ـ فقاعات الهواء التي قد تتواجد بين الغشاء المطاطي والتربة.

- ٣- فقاعات الهواء التي قد تتواجد بين رؤوس النهايات والتربة.

- ٤- المياه المتناثرة التي قد تتواجد عند القاعدة السفلية أو العلوية.

- ٥- التربة قد تكون غير مشبعة ولذا فإنها تحتوى على فراغات هوائية قد تضغط.

- (ب) اختبارات التصرف :

- ١ـ ضغط المياه الحرة لا يبقى على الصفر عند السرعة الملاحقة الضغط.
- ٢ـ وجود مياه المتناثرة يؤثر في دقة قياسات التغير الحجمي.
- ٣ـ عدم وجود الضغط الجيد للحمل المحورى بسبب عدم دقة قياسات الضغط المحورى.

اختبار الضغط الغير محدود (الغير محصور)

The unconfined compression test

- اختبار الضغط الغير محدود (الغير محصور) هو حالة خاصة من اختبار الضغط الثلاثي حينما يكون ضغط الخلية مساويا الصفر ويمكن رسم علاقة مور ـ كولوم للنتائج كما في الشكل (٧ـ٢٦) ، (٧ـ٢٧) وهنا يمكن اختبار عينة واحدة بدائرة واحدة . ويجرى الاختبار فقط في حالة الطين التغير متشقق المشبع.

- ويمكن أن يجرى اختبار الضغط الغير محصور باستخدام جهاز قياس معدل من جهاز الضغط الثلاثي ولكن بدون خلية البرسبكس وبدون الغشاء المطاطي . كما أن الجهاز بذلك يصبح بسيطا مما يمكن من استخدامه في الموقع . شكل (٧-٢٨) .

- **تغير المساحة والحجم في اختبار الضغط الثلاثي :**

- **مع زيادة الضغط الرأسي على العينة ينقص ارتفاعها ويزيد قطرها في حالة السماح بالتصريف فإن الحجم ينقص . ومقياس الانفعال dial gauge يبين التغير في ارتفاع العينة أنه بتوصيلات معينة على الجهاز يمكن قياس التغير في الحجم V وعلى ذلك يحسب التغير في مساحة مقطع العينة من العلاقات الآتية :**

أنوع علاقة مور ـ كولوم للحالات المختلفة لاختبار الضغط الثلاثي :

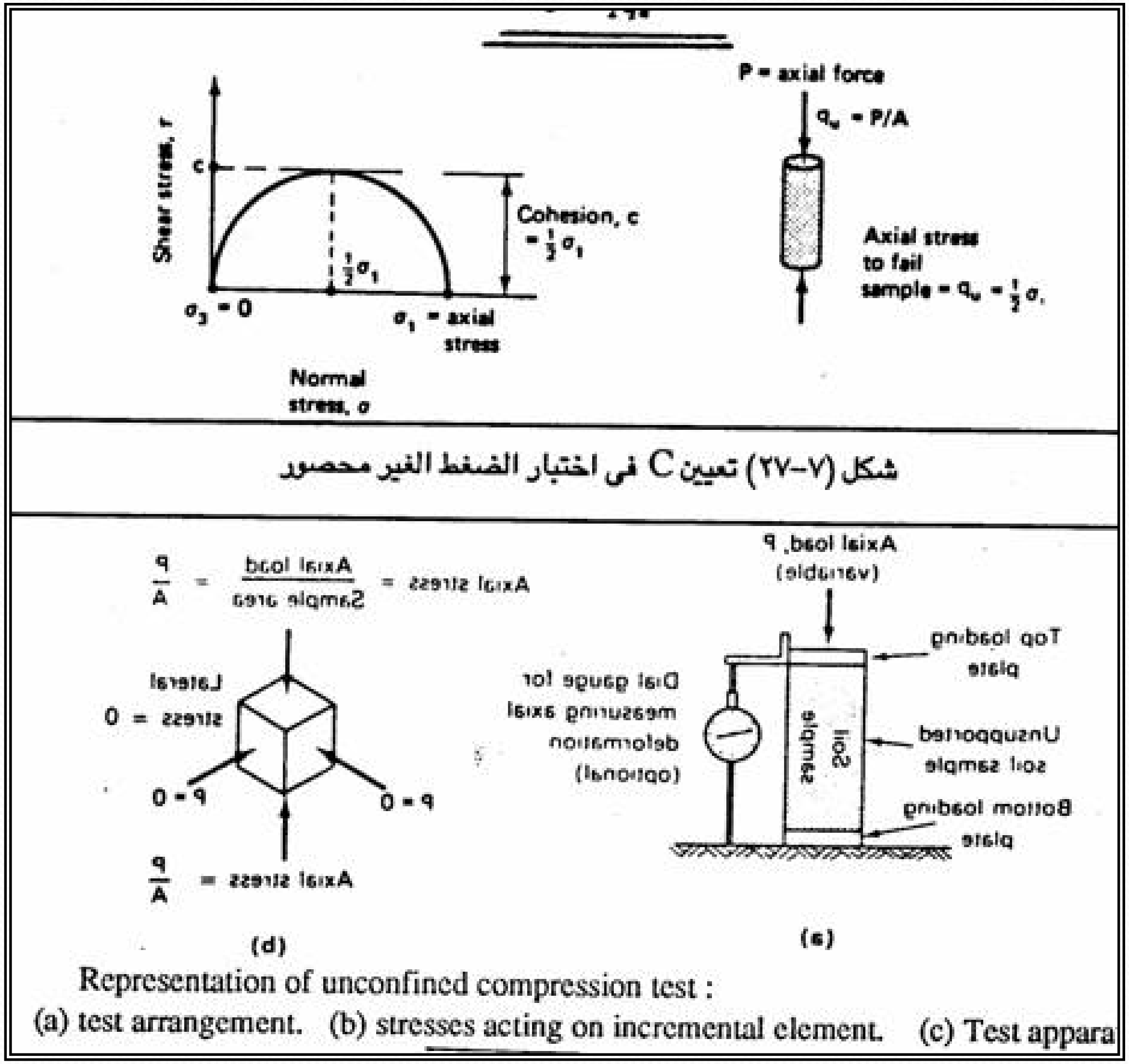
- ثلاثة أشكال لدائرة مور يمكن رسمها في الاختبار الواحد عند ضغط خلية معين .
- فإن كان الاختبار في حالة التصلب ـ عدم التصريف ـ وضغط المياه الحرة يقاس أثناء مرحلة القص ـ فإن يمكن رسم الدائرتين لمور : الأولى الاجهادات الكلية والأخرى الاجهادات المؤثرة الفعالة . شكل (٧ ـ ٢٩)

- ولو أجرى اختبار حالة التصرف على نفس العينة ونفس ضغط الخلية تنتج دائرة واحدة لمور الاجهادات المؤثرة الفعالة لأن التصلب يأخذ مكانه أثناء مرحلة القص في اختبار حالة التصرف ويكون الفرق بين الاجهادات الرئيسية عند الانهيار أكبر من تلك المسجلة في حالة التصلب ـ عدم التصريف .

- ويبن شكل (٧-٣٠) العلاقات لكل من الاجهادات الكلية والفعالة effective للاختبار في حالة التصلب - عدم التصرف. ومنها يمكن إيجاد كما يمك إيجاد واللذان يؤخذان كمعاملات غير التصرف الحقيقة true والتي تعتبر قيم استر شادية لمقاومة القص الغير منصرف للتربة.

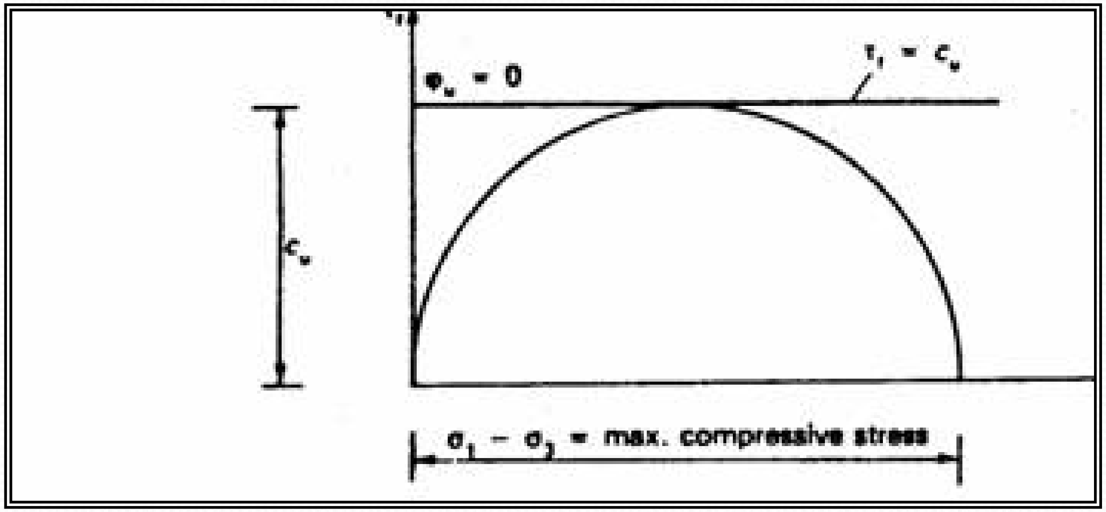
- ومشكلة قياس القص الغير منصرف تظهر في شكل (٧-٣٠) حيث يتبين في الشكل توقيع نتائج الاختبار وفى الفوري لعينة متماسكة . وفى الأول قد يظهر أن القص تعطى من :

- ولكن هذا غير صحيح لأن قيم مختلفة أخرى يمكن الحصول عليها لو أجريت الاختبارات عند سرعات مختلفة أو عند ضغط خلية مختلف . وهذا لاختلاف يرجع أساسا إلى أن الهواء الموجود في العينة يتسرب مع المياه الحر ويزيد بذلك ضغط الخلية . والقيمة المفيدة التي تستخدم لتمثيل الحالة الطبيعية : وهى لحالة التشبع التام.



شكل (٧-٢٧) تعيين C فى اختبار الضغط الغير محصور

Representation of unconfined compression test :
(a) test arrangement. (b) stresses acting on incremental element. (c) Test appara


τ
φu = 0
τf = cu
cu
σ1 − σ3 = max. compressive stress