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# March 31, 2007Modelling of the Effort of Active Surfaces of the Share Plough

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**Abstract:** Taking account of the significant number of forms of active surfaces of the bodies of share plough and especially of their complexities, it is interesting to propose a mathematical model general of the effort introducing the geometrical characteristics of the bodies of share plough. For that our choice was made on the two shapes of bodies of share plough manufactured locally and most frequently used in Algeria. It is respectively about the form SACRA with cylindrical tendency and of the form ENPMA which is rather of the universal type. The determination of the effort was carried out for small-scale models of the two bodies of plough on the level of a channel of traction. The use of the channel of traction made it possible to control the conditions of soil and of work and this fact the effect of the variation of the geometrical characteristics of active surfaces of the bodies of share plough on the effort allowed the establishment of a mathematical model of the form: Ft = F (geometrical characteristics, working conditions). The model obtained is then checked by comparison with the models of Gorjatchkin and Gee Clough.

**Key words:** Ploughing, characteristics geometrical, body of plough, effort, speed, density, angle modelling

## INTRODUCTION

Requirement the assessment in energy, very significant for the ploughings, is often difficult to quantify with precision even if several mathematical models are proposed. The latter often take account of the soil mechanics physical, speed, depth and characteristics of research. The geometrical characteristics of active surfaces of the share ploughs are often neglected.

Except the model of Kuczewski (1978) the others suggested by several authors are based on the principle of the pressure tool/ground. This principle remains valid for plane active surfaces which are qualified simple forms, but is not it for the parts working on complex active surfaces like those of the bodies of share ploughes.

Several significant research tasks (Nichols and Kummer, 1932; Doner and Nichols, 1934; Gao Qiong *et al*., 1986) were carried out to describe the active surface of the mouldplow and to classify the forces produced during the execution of the ploughing as well as the relation between these forces and only the dynamic properties of the ground.

Several models predicting the effort for the plough, (Lars *et al*., 1968; Gee Clough *et al*., 1978) were developed on the basic one of the dimensional analysis. Oskoui *et al*. (1982) proposed a specific model by adapting the formula developed by Gorjatchkin, taking account of the effect of the angle of splice and by taking the cone index of the ground as bases of measurement of the force.

If the angular characteristics of the working parts of the simple agricultural tools, like the ploughshares of the farmers with teeth, were the subject of an analysis of their effects on the effort of tensile strength, the geometrical characteristics of active surfaces of the bodies of share ploughs seldom were the subject of such work.

According to Ross, if the angles and dimensions of active surfaces of the bodies of share plough were studied, it is practically within the framework of the description of these working parts or in that their effects on the qualitative indices.

The choice of the one of these models for the evaluation with precision of the effort of tensile strength is often delicate. Indeed if we consider the models of Gee Clough and of Gorjatchkin which are frequently used for the evaluation of the effort of tensile strength for the same form of active surface and under same terms of ground and employment, the values obtained will be the same ones for the two models; so not which will be the most reliable model for a precise evaluation of consumption in energy.

## MATERIALS AND METHODS

**Means:** After geometrical characterizations of active surfaces of 2 forms (ENPMA and SACRA) of share plough, three small-scale models of 1/2, 1/3 and 1/4 were carried out using two moulds for each form with the collaboration of company MAGI of Rouiba.

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The stress analysis was carried out with sensors of efforts. The principle of operation of these sensors (Fig. 1) is that of the strain gauges.

**Methodology experimental:** The efforts of tensile strength were given on a test channel of tensile of agricultural tools provided with a carriage carries tools (Fig. 2). On the props (sensor of effort) of the bodies of plough, extensiometric strain gauges are stuck, the unit is connected to a measuring equipment made up of a Wheatstone bridge with amplification of signal and of a recorder with 6 ways.

On the tool carriage, two small-scale models of the same scale and different forms are go up, the east unit animates of a movement along the channel using a steel wire rope connects to an electric motor, by means of a variable speed transmission. Before the displacement of the carriage, certain factors are maintained constant; the studied parameter will undergo a variation after each passage. The advantage which this device represents is the setting under the same working conditions of two of mouldplow.

After each passage of the carriage (Fig. 2), two curves (Fig. 3) are obtained, one for SACRA, the other for form ENPMA. Ten values of the effort of tensile strength are measured on each curve recorded.

The variations of the efforts are given on graphs obtained on a recorder to 6 ways this one allows the simultaneous recording of the two efforts of the tools assembled on the tool carriage. The shape of the recorded curves is represented in Fig. 3.

Fig. 1: Sensor of effort

Fig. 2: Small-scale models assembled on tool carriage

## ESTABLISHMENT OF THE PARAMETERS INTRODUCED INTO THE MODEL AND WORKING CONDITIONS

**Parameters of forms of the plough:** Among the many characteristics of the body of share ploughs having been the subject of our analyses, the selected angles are respectively: The angle of penetration ($\alpha$), the angle of attack ($\gamma$) and the angle of curve or slope ($\theta$), considering the importance of their effects on the qualitative and especially energy indices. The values of these angles are mentioned in Table 1-3.

Other geometrical characteristics introduced into the mathematical model, were determined, it acts of the reports/ratios various lengths of active surfaces of the two of share plough. These ratios are, respectively:

- k = Depth/width of work, coefficient of inversion of the strip of soil
- k1 = Maximum Length/maximum height
- k2 = Width postpones mouldplow/width at the point of maximum curve of the mouldplow

**Characteristics of the soil**

**Texture and moisture:** The soil chosen during our tests is a soil with (sand 49%, 24.5% of silt and clay 26.5%), to

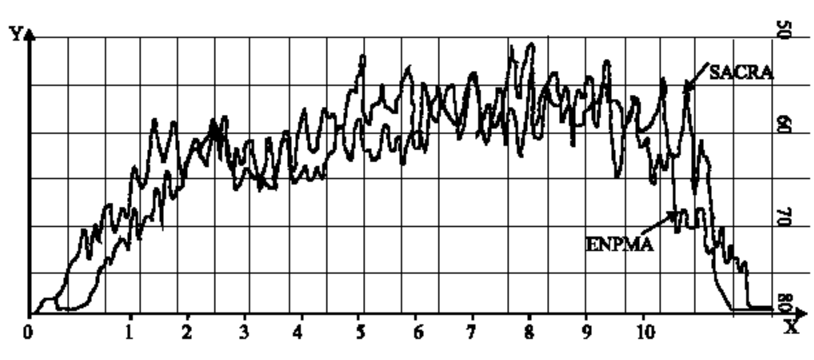


Fig. 3 : Graphic recording of the efforts

Table1: Constructive angles of the two bodies of plough

| Shape | Angles (rad) $\alpha_0$ | $\gamma_0$ | $\theta_0$ |
|---|---|---|---|
| SACRA | 0.297 | 0.698 | 0.576 |
| ENPMA | 0.506 | 0.663 | 0.611 |

Table 2: Coefficient (k) of inversion of the strip of soil

| b (m) | Echelle1/4 | Echelle1/3 | Echelle1/2 |
|---|---|---|---|
| 0.09 | 0.333 | 0.556 | 0.778 |
| 0.13 | 0.308 | 0.462 | 0.692 |
| 0.16 | 0.438 | 0.563 | 0.750 |

Table 3: Characteristics dimensionally (k1 and k2)

| Forme | Echelle | k1 | k2 |
|---|---|---|---|
| SACRA | 1/4 | 2.702 | 1.173 |
| ENPMA | 1/4 | 2.324 | 1.242 |
| SACRA | 1/3 | 2.746 | 1.290 |
| ENPMA | 1/3 | 2.279 | 1.243 |
| SACRA | 1/2 | 2.559 | 1.274 |
| ENPMA | 1/2 | 2.256 | 1.015 |

avoid the interactions due to the anisotropy of the ground, on the effort, this ground was filtered using a sieve having square mesh of one centimetre with dimensions. After two watering, two values of moisture were obtained 3.69 and 13.76%.

**Compression:** This characteristic is quantified by the apparent density of the soil. The various values of compressing were obtained using a roller of 75 kg width 0.80 measures (roughly the width of the channel which is one meter). For the first compressing, one passage of the roller, for the second compressing, two passages and for the third compressing three passages. The values of the apparent densities are respectively $t_1$=$d_1$ = 1.02 g cm$^{-3}$, $t_2$: $d_2$ = 1.35 g cm$^{-3}$ for $t_3$: $d_3$ = 1.63 g cm$^{-3}$ true density of the ground determined by the traditional method which consists with the displacement of a volume of water by a sample of ground dry and crushed whose weight is known, is of 2.32 g cm$^{-3}$.

**Parameters introduced into the mathematical model and working conditions**

**Depth of work (a):** Three depths were taken into account, the first, with the height of the ploughshare, the second with semi-height of the mould board and the third with the total height of the body of plough, these values are consigned in the Table 4.

**Width of work (b):** Width of work is the same one for the two of the same forms scale, which is practical for our tests because that highlights the difference of the effect of the 2 shapes of mouldplow. The values are respectively de: For scale 1/4, b = 0.09 m ; for scale 1 / 3, b = 0.013 and for scale 1/2,b = 0.16 m.

Table 4: Depth of work (a)

| Scale of mouldplow | 1/4 | 1/3 | 1/2 |
|---|---|---|---|
| Depth (m) | | | |
| a1 | 0.03 | 0.05 | 0.07 |
| a2 | 0.04 | 0.06 | 0.09 |
| a3 | 0.07 | 0.09 | 0.12 |

**Speeds of the tools (v):** Four speeds were chosen, they are, respectively: $v_1$=0.23 m s$^{-1}$, $v_2$ = 0.29 m s$^{-1}$ $v_3$ = 0.43 m s$^{-1}$ and $v_4$ = 0.87 m s$^{-1}$.

## MODELLING OF THE EFFORT

The choice of the whole of these parameters (2 forms SACRA and ENPMA, 3 Scales, 4 speeds, 3 density apparent of the soil and 3 depths of work) allowed obtaining on channel of 216 values of the effort. Establishment of a mathematical model of the effort by Vachy-Buckingham method (Langhaar, 1954) requires the following stages.

**Establishment of the equation without dimensions, Vachy-Buckingham's theorem:** Once these terms defined, the relation of Buckingham will be form:

$$\pi_1 = f\,(\pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7)$$

When replacing ($\pi$) terms by their expressions, we obtain:

$$\frac{Ft}{d\ .g.b^3} = f(\frac{v^2}{gb}, k, k_1, k_2, \alpha_0, \theta_0)$$

According Kuczewski's (1978) relation, this equation is also written in the form of a product of ($\pi$) terms exponent:

$$\frac{Ft}{d\ .g.b^3} = (\frac{v^2}{gb})^a.\ (k)^b.(k_1)^c.\ (k_2)^d.\ (\alpha_0)^e.\ (\theta_0)^i.\ e^{Cste}$$

The problem thus amounts determining the values of the exponents: a, b, c, d, e, f and the constant, for that the use of logarithms properties is necessary.

The mathematical model of the effort Ft will be thus of the form:

$$Ft = e^{cste}.\ (\frac{v^2}{gb})^a.\ (k)^b.\ (k_1)^c.\ (k_2)^d.\ (\alpha_0)^e.\ (\theta_0)^f.\ d.\ g.\ b^3$$

The problem thus amounts determining the value of all these exponents. For that the use of the properties of

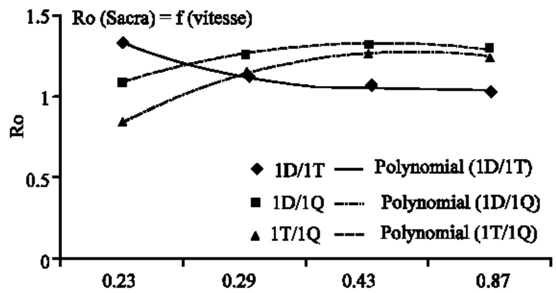


Fig. 4: Ratio of proportionality in relation to speed for the form SACRA

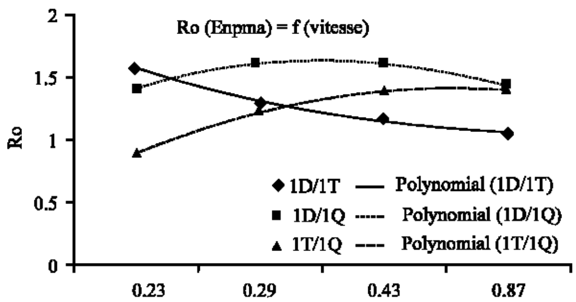


Fig. 5: Ratio of proportionality in relation to speed for the form ENPMA

the dimensional analysis and those of the logarithms is essential. The initial model obtained is :

$$Ft = e^{-14.54}.\left[\frac{v^2}{g.b}\right]^{0.15}. E^{4.13}.\alpha^{5.94}. \theta^{-16.01}. k^{0.98}.(k_1)^{12.98}. (k_2)^{2.74}. g. d. b^3$$

For the extrapolation of this model to the plough of real size, this relation will be affected by proportionality factors establish by the method of the combinations which stipule:

$$F_{1/n} = f(F_{1/n-1})$$

With : *F* = Effort Ft.

*1 / n* = Model reduces scale

*1 / n-1* = Scale higher than the preceding one

To this end, the coefficient of correction or the ratio of the effort, noted R is to be determined, it is equal:

$$R_0 = \frac{F_{1/n}}{F_{1/n-1}}$$

The first relation putting the effort of tensile strength with the selected parameters will be:

$$Ft = R_0.e^{-14.54}.\left[\frac{v^2}{g.b}\right]^{0.15}. E^{4.13}.\alpha^{5.94}. \theta^{-16.01}. k^{0.98}.(k_1)^{12.98}. (k_2)^{2.74}. g. d. b^3$$

The values of $R_0$ are defined starting from the values of the effort and this for each speed and the density connect highest d = 1.63 g $cm^{-3}$ to approach the real working conditions. The results are illustrated in the Fig. 4 and 5.

The regression equations of the ratio of proportionality in relation to speed for the third compressing are respectively:

For SACRA form

Rs1 (1D/1T) $=0.05 v^2 + 0.35 v + 1.61$ avec $R^2 = 0.76$

Rs2 (1D/1Q) $= - 0.05 v^2 + 0.33 v + 0.77$ avec $R^2 = 0.95$

Rs3 (1T/1Q) $= - 0.07 v^2 + 0.53 v + 0.36$ avec $R^2 = 0.95$

For ENPMA form

Re1 (1D/1T) $=0.04 v^2 - 0.35 v + 1.89$ avec $R^2 = 0.95$

Re2 (1D/1Q) $= - 0.08 v^2 + 0.43 v + 1.04$ avec $R^2 = 0.70$

Re3 (1T/1Q) $= - 0.07 v^2 + 0.54 v + 0.42$ avec $R^2 = 0.99$

If the small-scale model used is of scale 1 / 4, Ro = 3.876 for the form SACRA, it is 4.065 for form ENPMA. So on the other hand the model used is of scale 1 / 2, the values of Ro will be respectively Ro = 1.931 for the form SACRA and 1.976 for form ENPMA.

The various parameters of this model are easily given. We will also note that the values of the exponents of the various parameters confirm the order of the importance of their effects on the effort.

Two cases are considered for the analysis of this model:

If this model is used by an agronomist, for the evaluation of the effort necessary for the realization of the ploughing, some of the parameters of the relation are constant (constructive parameters) such as the angles, the parameter k (depth/width), the parameters $k_1$ and $k_2$. The agronomist will be interested in the choice the speed of work, the unit weight of the earth in order to correctly choose the best working conditions to reduce the requirements in energy at the time of the realization of the ploughings.

So on the other hand, this relation is used by an originator of agricultural tools, this last will be interested more particularly in the constructive parameters to conceive, obviously by taking account of the working conditions and the technical agro requirements of the ploughings, of the plough adapted to these conditions while seeking the most adequate form to meet the needs for the farmer. The objective of the engineer originator will be thus to minimize this equation by seeking the optimal constructive parameters.

On the basis of these remarks, the model suggested can be broken up into two parts:

The first relation one to the working conditions (speed of work and soil density) and noted $C_T$ which has for valour:

$$e^{-14.54}.\left(\frac{v^2}{g.b}\right)^{0.15}.g.d_a = C_T$$

The second one to the geometrical characteristics of the active surface noted $C_G$ which has for valour:

$$\alpha^{5.94}.\ \theta^{-16.01}.\left(\frac{a}{b}\right)^{0.98}.\ (k_1)^{12.98}.(k_2)^{2.74}.b^3 = C_G$$

The finale relation will be:

$$Ft = R_0\ .\ C_T\ .\ C_G$$

In order to check the reliability of the model, a comparative analysis of the values of the effort measured on channel with those calculated starting from the model was carried out. The results showed that the model is reliable with a correction by a dimensional proportionality factor noted ε the values of this coefficient are respectively 10 for form ENPMA and 1000 for the form SACRA.

The final model selected will be thus form:

$$Ft = \varepsilon.R_0.e^{-14.54}.\left[\frac{v^2}{g.b}\right]^{0.15}.\ E^{4.13}.\alpha^{5.94}.$$
$$\theta^{-16.01}.\ k^{0.98}.(k_1)^{12.98}.\ (k_2)^{2.74}.\ g.\ d.\ b^3$$

Units of the various parameters of this model are:

Speed: v ($m\ s^{-1}$)

Angles: α and θ (radians)

Apparent Density: d ($kg\ m^{-3}$)

Gravity: g ($m\ s^2$)

Width: b (m)

Characteristics of the form: k, k1 and k2 without unit

The established model becomes:

$$Ft = \varepsilon.\ R_0\ .\ C_T\ .\ C_G$$

**Application, checking and correction of the model:** Application of the model established for bodies of plough of real size and under real working conditions is necessary; this model is compared with the models suggested by Gorjatchkin and Gee Clough. To approach the real working conditions, certain parameters are fixed like:

Table 5: Average values of K and ε of the model

| Schape | K ($daN\ m^{-2}$) | ε ($daN.s^2\ m^{-4}$) |
|---|---|---|
| SACRA | 3500 | 200 |
| ENPMA | 3500 | 150 |

**Real working conditions**

- Mean velocity of ploughing: V = 1,5 $m\ s^{-1}$ (5,4 $km\ h^{-1}$)
- Densité connect at the time of the ploughing d = 1.29 $g\ cm^{-3}$ or 1290 $kg\ m^{-3}$ or 12.9 $kN\ m^{-3}$, this last transformation are necessary for the application of the models of Gorjatchkin and Gee Clough.
- Width of ploughing: b = 0.31 m for SACRA and b = 0.35 m for ENPMA
- Average depth of ploughing: a = 0.25 meters
- Rapport k = a / b: k = 0.806 for the form SACRA and k = 0.714 for ENPMA

**Geometrical characteristics of surfaces active:**

Ratio k1 = L1 / h : $k_1$ = 1.714for SACRA and $k_1$ = 2.136 for ENPMA

Ratio $k_2$ = d1 / d3 : k2 = 1.290for SACRA and $k_2$ = 1.464 for ENPMA

**Angles:**

**Form SACRA**

$\alpha_0$ = 17 degrees = 0.297 radian

$\gamma_0$ = 39 degrees = 0.681 radian

$\theta_0$ = 33 degrees = 0.576 radian

**Form ENPMA**

$\alpha_0$ = 29 degrees = 0.506 radian

$\gamma_0$ = 38 degrees = 0.663 radian

$\theta_0$ = 35 degrees = 0.611 radian

**Average values of K and ε of the model of Gorjatchkin:** As regards the values K (specific resistance of the soil) and ε (coefficient of the shape of the mouldplow) used in the relation of Gorjatchkin are shown in Table 5.

**Results of the checking:** The values of the effort by applying the model suggested are, respectively represented in the Table 6 and this for various speeds used and each of the two forms of active surfaces:

In order to check the reliability of the established model, a comparative analysis with the models frequently used with knowing the models of Gorjatchkin and Gee Clough was realized. For that some parameters used in these two models are to be defined. The relations of the effort of these two researchers are, respectively:

Table 6: Effort Ft calculated from the model suggested for the real mouldplow

| Speed (m $s^{-1}$) | 0.23 | 0.29 | 0.43 | 0.87 | 1.5 |
|---|---|---|---|---|---|
| SACRA Ft (daN) | 104.50 | 112.03 | 126.08 | 155.76 | 183.42 |
| ENPMA Ft (daN) | 304.38 | 326.30 | 367.23 | 453.69 | 534.23 |

Table 7: Effort Ft calculated from the model Gorjatchkin

| Speed (m $s^{-1}$) | 0.23 | 0.29 | 0.43 | 0.87 | 1.5 |
|---|---|---|---|---|---|
| SACRA Ft (daN) | 272.07 | 272.55 | 274.11 | 282.98 | 306.12 |
| ENPMA Ft (daN) | 306.94 | 307.35 | 308.67 | 316.18 | 335.78 |

Table 8: Effort Ft calculated from the model Gee Clough

| Speed (m $s^{-1}$) | 0.23 | 0.29 | 0.43 | 0.87 | 1.5 |
|---|---|---|---|---|---|
| SACRA Ft (daN) | 334.03 | 334.99 | 338.07 | 355.57 | 401.25 |
| ENPMA Ft (daN) | 377.13 | 378.21 | 381.69 | 401.45 | 453.02 |

$$F_t = f.G + k.a.b + \varepsilon.a.b.v^2 \text{ Model of Gorjatchkin}$$

$$F_t = a.b.\left\{13.30.\gamma.a + 3.06.\gamma.\frac{v^2}{g}\right\} \text{Model of Gee Clough}$$

The tests being realized on the same type of soil, the value of K is the same one; K= 3500 daN m2, this average value is the higher limit for the light soil and the limit inferior for the soil.

These values will be applied to the models of Gorjatchkin. The values chosen, for the coefficient ε, are respectively of 200 daN.$s^2$ $m^{-4}$ for the form SACRA which is a form which approaches much more than one cylindrical form and of 150 daN.$s^2$ $m^{-4}$ for the form ENPMA which approaches rather a mixed form with flat back. The choice of this parameter is often very delicate to determine, the number of forms of active surfaces being very significant. The selected values correspond to those given by Gorjatchkin for the speeds ranging between 1 and 2,4 m $s^{-1}$ (Table 7 and 8).

Values of the effort obtained with these models, for the same speed and soil conditions are:

The application of these two models for the determination of the effort, confirms the results of our research, namely that form ENPMA is more demanding in energy for the realization of the ploughing, this is accentuated more to the level of the results obtained with the established model. The effort also increases with the speed of work. That thus highlights the importance of the geometrical characteristics of the active surface of the bodies of plough introduced at the level of the model which we established; these results are illustrated on the following graphs. The simplification of the model of Gorjatchkin, in the form Ft = K.a.b, i.e., without taking account the speed and form of active surfaces, will give the same value for Ft some is the form of active surfaces of the bodies of plough.

## RESULTS AND DISCUSSION

In addition to the observations made previously, Fig. 6 shows that the evolution of the curve of the effort obtained with the model establishes is appreciably the same one as those of the curves obtained with the models of Gorjatchkin and Gee Clough, that confirms the validity of our model.

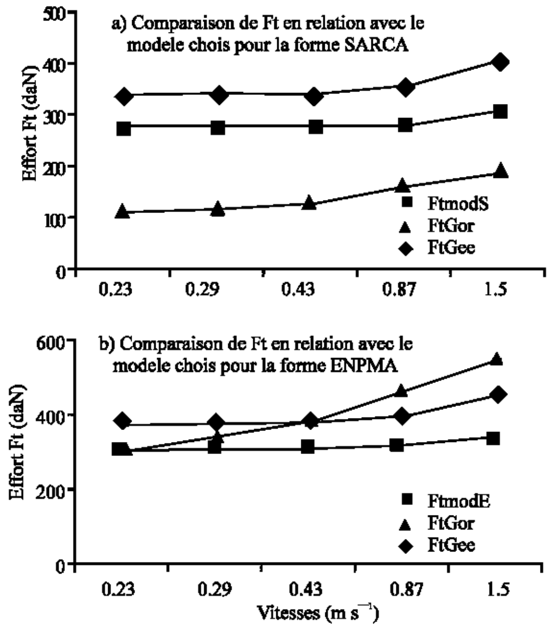


Fig. 6: Comparative analysis of the Ft efforts according to the rate of advance for each model and each form a) SACRA and b) ENPMA

Through our results, it appears that:

- The measured values are different from the computed values with the models of Gorjatchkin and Gee Clough.
- The values of the efforts of tensile strength obtained with the model of Gorjatchkin are larger for the first depth (0.07 m) that those obtained with the model of Gee Clough.
- A the second depth (0.09 m), the values of the efforts of tensile strength are practically the same ones for the two models.
- A the third depth (0.12 m), the efforts are more significant when they are calculated with the model Gee Clough.

In addition, when the precision of consumption in energy is required, the choice of the model to use to calculate the effort must thus be the subject of a detailed attention. In our case, for the bodies of plough made in Algeria, we recommend the model of Gorjatchkin for the form SACRA and Gee Clough for form ENPMA or generally for the mould boards with cylindrical tendency we will use the model of Gorjatchkin and for the mould boards with farming tendency we will propose the model of model Gee Clough.

The analysis of the model suggested shows the order of importance of the effect of the various confused parameters (working condition and characteristics geometrical) is:

- L' angle of curve of active surface
- L' angle of penetration
- Density of the soil dry
- k
- k1
- k2

For the realization of this classification, before optimization of activates surfaces, the adjustment by multiple regression did not take account of the depth of work which is the most significant parameter on the level of all the models, this one being maintained constant in this study, but on the level of the model the depth of work is included in the parameter k which is the relationship between the depth of research and its width. These observations justify the optimization of the active surface of the bodies of share plough and the establishment of a mathematical model of the effort in relation to the geometrical characteristics of this surface.

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