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Performance evaluation of modified bentlegplow using finite element approach

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ABSTRACT-This paper aims to develop a new design of a bentleg (BL) plow and to determine its performance as compared to the conventional one using finite element approach. The difference between the modified and conventional BL plows is the direction of angle between the projection of cutting blade on horizontal plane normal to plow shank and the line perpendicular to the plow shank in the same plane. The conventional (B_1), and modified (B_2) designs of BL plow were modeled at three rake angles R_1= 7.5°, R_2= 15° and R_3= 22.5°. A three dimensional nonlinear finite element model was applied using ANSYS 8.1, 2004. The variation of calculated draft force by model indicated that minimum and maximum draft forces were obtained for B_2R_2 and B_1R_3 treatments, respectively. The minimum vertical force was measured for B_1R_1 treatment. Calculated draft and vertical forces were in good agreement with measured ones. An increasing positive x-y shear stress zone in the modified BL plow causes the soil lifting increase as compared to the conventional one. Similarities of the Von Mises stress contours to stress characteristic curves emphasize the validity of the analysis. The small size of the plastic Von Mises strain contours (plastic bubble) in the modified plow emphasizes the fact that the force requirement of the modified BL plow is less than that of the conventional one. Similarity of the stress distribution contours in soil block and the stress characteristic curves show the validity of the modeling.

INTRODUCTION

Agricultural soil compaction can be caused by mechanical means like tractor wheels and some tillage tools that might cause plow pan especially where the same tillage depth is repeated in successive operations (Mckyes, 1985). Conventional subsoilers have been the only means of removing hardpans up to 20 years ago. Harrison (1988) reported on a new plow invention "bentleg" plow (BL plow). He claimed that the draft force requirement of this new deep tilling plow is less than that of conventional subsoilers. Other researchers like Harrison and Liscko, (1989), Harrison (1990), Durairaj and Balasubramanian (1997), Majidi and Raoufat (1997), Durairaj et al. (1998), and Raoufat and Firuzi (1998) conducted experimental investigations to evaluate the performance of the BL plow. They investigated the effects of parameters like rake angle, bent angle, working depth and tractor forward speed on soil reaction and soil post tilling conditions. These results showed a direct relationship between blade rake angle and draft force requirement.

Conventional analytical methods have been used by many researchers to develop two- and three-dimensional (3D) models of the soil cutting process by tillage tools (McKyes, 1985). Most of these 3D models focused on symmetrical tillage tools because of the uniform slip curve zones observed on both sides of the tools. Although the conventional analytical method is scarce to model the performance of the asymmetrical tillage tools like bentlegplow, there are several numerical methods for this purpose. The experimental study of soil-blade interaction is expensive and may be limited to certain working depths and rake angles. Results of experiments are also highly dependent on the accuracy of the measuring instruments. An alternative method is the theoretical numerical approach which will be introduced here to investigate the performance of bentleg tillage tools.

Several researchers have applied Finite Element Modeling (FEM) techniques to model soil cutting by simple tillage tools, subsoilers and disk plows (Mouazen and Nemenyi, 1999; Abu-Hamdeh and Reeder, 2003; Abo-Elnor et al., 2004; Armin et al., 2014; Naderi et al., 2014; Tagar et al., 2014;). However, very few studies on 3D FEM analysis of soil tillage by asymmetrical tillage tools can be found. This paper aims to report the finding of an investigation focused on:

1. Designing a modified prototype of the BL plow requiring lower draft force and increasing soil disturbance efficiency.

2. Modeling the tillage process by BL plow for both conventional and modified designs using the FEM approach.
3. Validating the draft and vertical forces of BL plow calculated by FEM as compared to the experimental data.
4. Investigating the effect of design parameters of BL plow on the variation of tensile, compressive and shear stresses in soil.

MATERIALS AND METHODS

Blade Geometry

The difference between conventional and proposed modified bentlegplow is the front and back orientation of the leg component with respect to shank. The defined angle (angle α) is seen in a top view and (included between) represented by the projection of cutting blade on horizontal plane and the line normal to the plow shank (Fig.1). This angle in conventional model is inclined toward the front of the shank by 25°, whereas for modified plow, this angle is inclined backward by -32° (Fig.1).

Rake angle is defined as the angle between shank blade interfaces with horizontal line parallel to travel direction. A total of four different rake angles could be obtained by rotating the plow around the horizontal axis (z-axis) using the holes on the plow shank. In order to achieve a deeper penetration and reduce the soil resistance, the cutting edge of both plows was sharped 45°. In previous studies, preliminary soil-bin tests indicated that the modified BL plow showed a better performance than the conventional one especially at rake angle of 15° (Jafari et al, 2008).

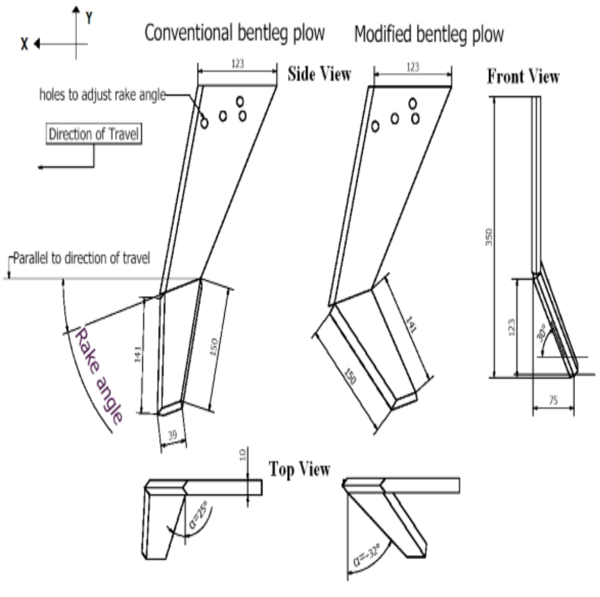

Fig. 1. Dimensions (mm) of the BL plow units used in this study

Material Model and Finite Element Formulation

The Elastic-Plastic model describes an elastic, perfectly plastic relationship. Stresses are directly proportional to strain until the yield point. Beyond the yield point, the stress-strain curve is perfectly horizontal. A function which describes the locus of the yield point is called the yield function. The yield function of the DruckerPrager elastic perfectly plastic material model (F) can be expressed as follows (ANSYS 8.1, 2004):

$$F = 3\beta\sigma_m + [\frac{1}{2}\{S\}^T[M]\{S\}]^{0.5} \quad (1)$$

where

σ_m= the mean or hydrostatic stress=

$$\frac{1}{3}(\sigma_x + \sigma_y + \sigma_z) \quad (2)$$

{S}= the deviatoric stress equation

β= material constant and is equal to

$$\beta = \frac{2Sin\varphi}{\sqrt{3}(3 - Sin\varphi)} \quad (3)$$

The material yield parameter is defined as

$$M = \frac{6cCos\varphi}{\sqrt{3}(3 - Sin\varphi)} \quad (4)$$

where

C and φ are the input soil cohesion and angle of internal friction, respectively.

Soil plasticity is formulated using the theory of incremental plasticity (Hill, 1950). Once a material begins to yield, the incremental strain can be divided into elastic and plastic components:

$$\{d\varepsilon\} = \{d\varepsilon^p\} + \{d\varepsilon^e\} \quad (5)$$

Only elastic strain increments $d\varepsilon^e$ will cause stress changes. As a result, stress increments can be written as follows:

$$\{d\sigma\} = [C_e]\{d\varepsilon^e\} = [C_e](\{d\varepsilon\} - \{d\varepsilon^p\}) \quad (6)$$

A yield function, F, is a function of normal and shear stress, so an incremental change in the yield function is given by:

$$dF = \frac{\partial F}{\partial \sigma_x}d\sigma_x + \frac{\partial F}{\partial \sigma_y}d\sigma_y + \frac{\partial F}{\partial \sigma_z}d\sigma_z + \frac{\partial F}{\partial \tau_{xy}}d\tau_{xy} = \{\frac{\partial F}{\partial \sigma}\}\{d\sigma\} \quad (7)$$

The theory of incremental plasticity dictates dF will be equal to zero when the stress state is on the yield surface. This condition is termed the natural loading condition, and can be written mathematically as:

$$dF = \{\frac{\partial F}{\partial \sigma}\}\{d\sigma\} = 0 \quad (8)$$

The plastic strain is postulated to be:

$$\{d\varepsilon_p\} = \lambda\{\frac{\partial G}{\partial \sigma}\} \quad (9)$$

where G and λ are plastic potential function and plastic scaling factor, respectively.

Finally, the incremental stress corresponding to a given incremental strain is obtained as follows:

$$\{d\sigma\} = ([C_e] - [C_p])\{d\varepsilon\} \quad (10)$$

FINITE ELEMENT MESH AND BOUNDARY CONDITIONS

The asymmetrical shape of BL plows and the narrow thickness of its blade require that the analysis be nonlinear with both geometrical and material aspects (in other words, large deformations impose geometrical nonlinearity in the present analysis). Geometrical nonlinearity in FE analysis happens when a node corresponding to an element moves larger than its elemental size. Also, nonlinear soil material model and the nature of contact element increase the degree of nonlinearity of such analysis.

It is noted that during soil failure by tillage tools, crack propagation as well as soil separation are generated at different locations throughout the entire soil body. But, as the FEM defines the material domain into a finite number of elements (connected by a finite number of nodes maintaining the continuity at all times throughout the analysis), the modeling of cracks in FE analysis is practically impossible. Therefore, positions where soil failure may occur are located by recognizing the shear distribution fields. A high shear stress generated at any given point indicates the locations where the soil failure happens as crack separation. This assumption of determination of soil failure positions will be followed in this study in order to overcome the limitations of the FEM.

The soil media was modeled as a 1000×800×500 mm, (length× width× height) rectangular prism of solid material. In the places where the BL plow contacts with soil, the shape of the BL plow is carved into the soil. The reason for such modeling is that it was impossible to model the full procedure of movement of the BL plow through soil using FEM. So, only one step of movement in which the BL plow came in full contact with soil was modeled, pushing the soil, and finally inducing a failure zone which coincided with a cracked zone in the soil. Fig. 2 shows the soil media contacting with BL plow.

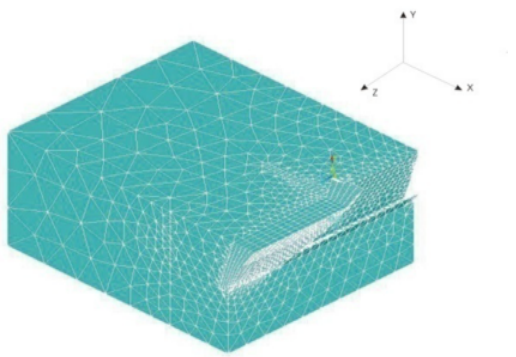

Fig. 2. Three- dimensional FEM mesh of soil cutting process by bentlegplow

For both soil and blade, the element Solid 45 was used. Solid 45 is a brick element with 8 nodes and 3 degrees of freedom at each node (U_x, U_y, U_z). This element comes in several shapes (Tetrahedral, Hexahedral…). For the BL plow and the soil in its vicinity, mapped hexahedral brick elements were used. In other parts of the soil in which this shape of element could not be used, free tetrahedral elements were placed. Since the thickness of BL plow is only 10 mm, the size of its elements could also be 10 mm at the most and the size of soil elements at the soil/plow interface should be the same; consequently, more than 21,000 elements were used in this model.

Most of the analysis was carried out through 30 mm of blade displacement in the horizontal plane along the x axis direction as shown in Fig. 2. For a typical 3D model, a solution time of about 10 hours was needed to account for the whole 30 mm displacement. The reason for choosing 30 mm blade displacement was to correspond to draft force variation. The blade forces would be expected to have reached a steady state phase during this time period as mentioned by Abo-Elnor et al. (2004). Very dense mesh was used to obtain a highly accurate quantitative analysis.

Each face of soil media was constrained so it could not move normal to the face. The nodes on the blade/soil interface had a specific displacement along the blade surface. Also, the internal nodes retained freedom in three directions. The boundary conditions applied to the BL plow were such that they prevented any displacement and rotation except in the direction of tool travel. In this direction, a controlled displacement was imposed on a pilot point. A pilot point is a point joined to the tool to which all movements and forces are applied and automatically transferred to the whole body of the tool.

To model the contact surfaces between the BL plow and soil media, flexible surface to surface contact elements were used. This kind of contact lets the soil slip on the tool surface and also transfers the loads (forces and displacements) between soil and tillage tool. It also allows soil separation from the tool. All these processes are controlled by parameters like normal and tangential stiffness. These parameters control the separation and slippage of soil relative to blade, respectively. Furthermore, these two parameters play an important role in the convergence of the analysis.

Strength behavior of contact was controlled by contact cohesion and friction coefficients and maximum shear stress (Table. 1). Tangential stiffness and soil-metal friction angle were measured by direct shear box following Coulomb's friction laws. To create a target element, it was necessary to put a target element on the target surface and a contact element on the contact surface, in order to automatically create a contact element between these two superficial elements. Targ170 and Cont174 elements were used to produce the contact.

The FE analysis was founded on a small displacement meaning that one can impose a displacement up to 15% of element size to an element (the size of each element considered for the entire blade-soil contact surfaces was limited to 5 mm). Some programs like ANSYS upgrade the geometry of element during the analysis. Therefore it is possible to generate greater displacement.

Table 1. Mechanical properties of soil and soil- metal friction data used in the experiments

Soil texture	Bulk density (kN/m^3)	Soil Young's modulus(kN/m^3)	Soil poisson's ratio	Soil cohesion (kpa)	Soil internal friction (deg)	Soil adhesion (kpa)	Soil metal friction (deg)	Angle of soil dilation (deg)
sandy loam	18.5	80×10^4	0.28	2.2	36	1.2	23.1	6

As already mentioned, the source of the non-linearity of soil medium is both due to nonlinear material properties and large deformation undergone. For nonlinear materials where the stress – strain relationship is nonlinear, the Young's modulus and Poisson's ratio need to fully represent the mechanical behavior of materials (Duncan and Chang, 1970). Also the knowledge of soil cohesion, angle of internal friction and the angle of soil dilation is necessary to determine the behavior of Drucker-Prager material model. In this study, these parameters were measured using triaxial compression and direct shear tests (Table 1). The stress-strain curve of the elastic- perfectly plastic behavior of the soil under triaxial compression test was drowned and the tangential modulus was measured. The Poisson's ratio was calculated on the basis of data of soil volume change obtained from triaxial compression tests.

FE analyses were carried out for six different treatments. Conventional (B1), and modified (B2) designs of BL plow were modeled at three rake angles (R_1= 7.5°, R_2= 15° and R_3= 22.5°). All analyses were done in 10 incremental time steps (each step 3 mm) and the stresses and forces were recorded at the end of each time step. The working depth for the FE model and in the experimental test was 250 mm.

EXPERIMENTAL PROCEDURE

In order to verify the results calculated by FEM, soil bin tests were carried out at the soil bin laboratory of TarbiatModares University. The bin dimension was 8 × 1.5 × 0.6 m (length× width× height). The soil texture was sandy loam with 110 $g.kg^{-1}$ clay, 190 $g.kg^{-1}$ silt, and 700 $g.kg^{-1}$ sand. The compaction of soil was controlled before each experiment. The bulk density was measured at three depths and the average unplowed soil bulk density was calculated and found to be 1.85 $Mg.m^{-3}$ in the depth range of 0-300 mm. In order to check the uniformity of the soil compaction, the cone index of the soil was measured during the soil compaction process. The soil moisture content was kept at the field capacity limit (18% dry basis).

In order to measure draft and vertical forces acting on the BL plow, a special support was designed and fabricated (Fig. 3). Spherical grooves with steel balls were placed in each plate to enable free movement in the up-down and forward-backward directions. The direction of grooves was such that the central block (Fig. 3, Part 4) in which the BL plow was mounted, could only move vertically guided through middle plates (Fig. 3, Part 2) while the middle plates could only move horizontally in the direction of travel guided between rear plates (Fig. 3, Part 3).

Two 5 kN capacity load cells (DBBP, BONGSHIN) were used to measure the forces acting onto the BL plow. The force data were sampled using a digital strainmeter (TC-31K, Tokyo Sokki Kenkyuio co., Ltd) and its accessories. Since the FE analyses investigated the performance of the BL plow under quasi-static conditions, measurements were conducted at 0.8 m/s travel speed.

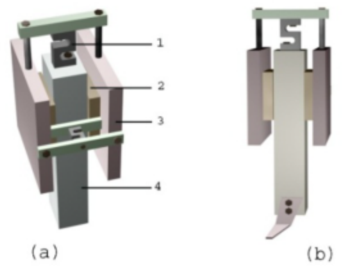

Fig. 3. Special support developed for measuring draft and vertical force, rear view (a) and front view (b).

RESULTS AND DISCUSSION

Bent leg plow draft, vertical and lateral forces were calculated from the summation of the reactions of the contact elements that acted on pilot point. Measured and predicted reaction forces data were also compared. Additionally, the soil stress and strain were compared for both designs.

DRAFT FORCE

The calculated draft force by FEM method against tillage tool displacements for the six different treatments was plotted (Fig. 4). The rate of increase of draft force was relatively high at low displacement, and leveled out as displacement further increased. The reason for this process was that the plastic strain in each element occurred under very low displacement. In the next step of tool motion, the yielded elements transferred forces to their adjacent element and their force tended to become constant. The mentioned figure showed that the predicted draft force of the conventional BL plow is more than that of the modified one, with the B_1R_3 treatment generating the maximum draft force. The same increase of draft force with rake angle was not noticed in the modified BL plow so that the B_2R_2 treatment generated the minimum draft.

In the soil bin test, the maximum draft force occurred after longer tine displacement than those predicted by FEM (Jafari et al., 2008). The reason might well be due to loose and non-homogeneous soil pile in the bin as compared to constant soil bulk density considered throughout the soil body. Practically, the soil bulk density cannot be prepared as homogeneously as assumed in the FEM.

The comparison of the measured and predicted draft forces of the conventional BL plow as a function of rake angle showed that any increase in rake angle resulted in an increase in tool draft force (Fig. 5). The predicted BL plow horizontal reaction force from the FEM model exceeded the measured ones for both plow designs. The over prediction error of draft force can be attributed to soil failure mechanism. Crack formations and fragmentation of the soil during the soil bin test were not properly accounted for in the FEM model, where the Drucker-Prager elastic-perfectly plastic model with the general flow rule of associated plasticity was adopted. The amount of draft force over prediction ranged from 9.9 to 18.3%.

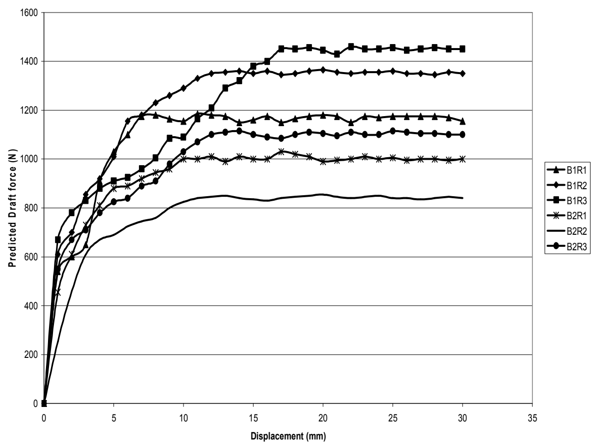

Fig. 4. FEM calculated draft force of BL plow as a function of displacement

Changing the direction of the angle □ as for the modified BL plow caused the surface of the soil to be the first point to come in contact with the cutting edge, with the soil cutting processes starting from the surface down to the subsoil, As a result, the surcharge pressure which applied to the blade was merely the weight of loose soil. Therefore, reduction in the amount of surcharge pressure acting on the blade was considered as the most important cause of draft force reduction in the modified model. Furthermore, tensile cracks appeared instead of compressive ones in modified BL plow, which further reduced the draft force.

Vertical Force

The total vertical force calculated by FEM also increased with BL plows displacement and leveled after reaching the maximum. The total vertical reaction force was positive indicating that this force pushed the BL plow upwards. The variation of computed vertical forces became steady as it reached maximum value. In the steady-state stage, the magnitude of vertical force continued to increase slowly or remained constant (Fig. 6). Comparison of measured and predicted vertical forces showed that the relative error between the finite element model and soil bin tests values ranged from 5.5 to 13.3% (Fig. 7). Non-homogeneous soil body in the soil bin was an important reason for the over prediction of vertical force by finite element approach.

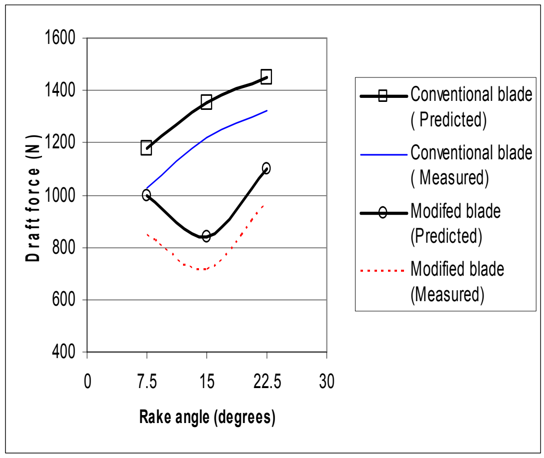

Fig. 5. Measured and predicted draft forces of BL plowversus rake angle

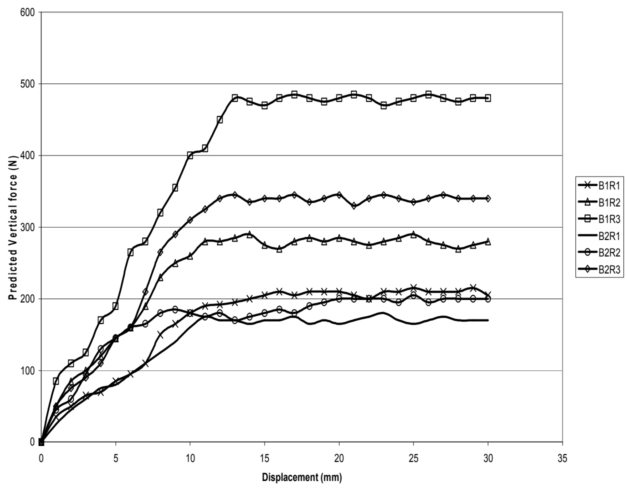

Fig. 6. FEM calculated vertical force of BL plow as a function of displacement

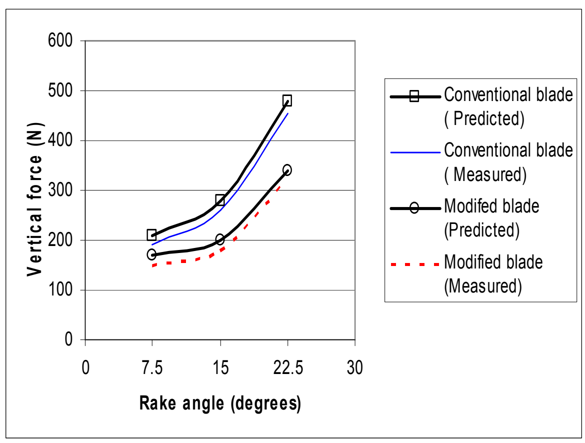

Fig. 7. Measured and predicted vertical forces of BL plow versus rake angle

Soil Displacement

The distribution of the vertical and forward soil displacement were calculated by FEM model after 20 mm blade displacement. The soil particles in front of the BL plow shank and above the cutting blade moved upward, forward and sideways with respect to its original position. Such motions indicated that shear distortion occurred throughout the zone. Figs. 8 and 9 show upward soil displacement distribution contour due to typical conventional and modified BL plows. Maximum upward soil displacement usually occurs within a little distance in front of the plow shank, and makes a wedge-shaped soil upheaval. The soil slope in the small gap from the maximum surface upheaval point down to the front edge of the shank can be interpreted by the resistance action of the interface friction against the upward sliding of the shank adjacent to soil particles. The maximum upward soil displacement could be an indicator of the ability of the plow to cut and loosen the soil. The comparison of the amount of maximum soil upward displacement in front of the shank showed that the modified BL plow could move the soil upward more than the conventional one (Table. 2). The FEM results indicated that the maximum soil loosening and upward displacement was seen in modified BL plow at rake angle of 15°.

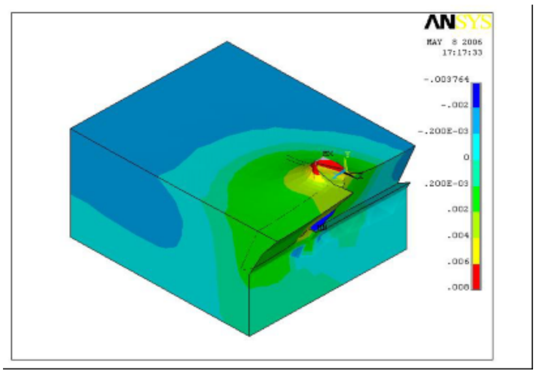

Fig. 8. Upward soil displacement distribution contour for conventional BL plow at 22.5° rake angle after 20 mm blade displacement (displacements are in meter)

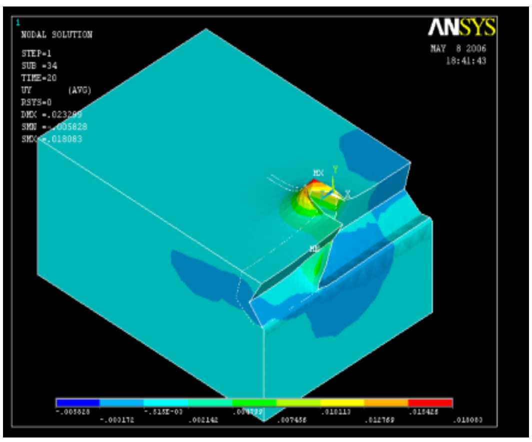

Fig. 9. Upward soil displacement distribution contour for modified BL plow at 15° rake angle after 20 mm blade displacement (displacements are in meter)

Table. 2. Comparison of maximum upward soil displacements in front of plow shank for various rake angles (displacements are in millimeter)

Rake angle	Blade design	
	B2 (Modified blade)	B1 (Conventional blade)
R_1 (7.5°)	2	15.3
R_2 (15°)	8	18.1
R_3 (22.5°)	9.3	16.7
Mean soil upward displacement	6.47	16.7

Soil Stress and Strain

Shear stress, Von Mises stress and Von Mises plastic strain distribution contours were studied by nodal solution after 20 mm BL plow displacement. At this stage, most of the soil elements in front of the tool were in the plastic stress state. Study of shear and normal stress distributions can be simplified by defining the zone in which the soil is in the plastic mode. This zone that is called "plastic bubble" is seen in the Von Mises plastic strain contours. The contour of zero Von Mises plastic strain is the boundary of plastic bubble; so, the size of plastic Von Mises strain contours determines the size of plastic bubble generated in the soil body.

Two distinct shear stress zones in the 2-D x-y plane were seen in each treatment. Negative high shear stress contours expanded in front of the cutting blade. In this zone, the shear stress contour went clockwise, indicating that this soil zone was under a lifting action. The amount of negative shear stress was larger than positive shear stress (Fig. 10). Another shear stress zone of positive contours spread in front of the plow shank. The direction of shear in this zone was counter-clockwise. A comparison of the shear stress, t_{xy} zones showed that the negative shear stress zone caused by modified BL plow was larger in size than the negative shear stress zone caused by the conventional plow. Although the magnitude of maximum x-y shear stress in both designs of BL plow was the same, the FE models predicted that the modified BL plow could affect the deeper zone under shearing (Fig. 10).

Horizontal shear stress zones in the x-z plane near the half of the working depth were also studied. The results showed two distinct shear zones in this plane (Fig. 11). The first zone was a positive shear stress zone located in front of the wide face of the cutting blade. The amount of positive shear stress varied from 50 kPa in the points next to the shank and decreased further away from the plow shank. Negative shear stress zones were generated on the opposite side. The negative shear stress contours made a zone similar to a Rankine passive earth pressure zone (McKyes, 1985). The difference between the sign of shear stress showed that the soil had been under shear distortion.

Finally three dimensional Von Mises stress and plastic strain contours were investigated (Fig. 12).

Results revealed that the shape of Von Mises stress contours in x-z plane was similar to stress characteristic curves, and in x-y plane, it was similar to logarithmic spiral curves as proposed in conventional analytical methods of soil cutting process (McKyes, 1985). An examination of the Von Mises plastic strain contours revealed that the plastic strain contours had been spread near the plow. Furthermore, the shape of contours was similar to the shape of stress characteristics curves. In the vicinity of the plow, strain was near 0.3 and decreased to zero as we moved away. As mentioned before, the boundaries of zero Von Mises strain indicated the size of plastic bubble emerging in the soil body (Fig. 13). Results showed that the size of the plastic bubble in modified BL plow was smaller than that of the conventional one. In other words, for similar horizontal blade displacements, the conventional blade required more energy than the modified one.

CONCLUSIONS

Three dimensional nonlinear finite element analyses were carried out to simulate soil-blade interaction and study the effect of design parameters of a bentleg plow on predicted cutting force in both horizontal and vertical directions and soil stress-strain values. The results from finite element method and experimental trials support the following conclusions:

1. The FEM is a good tool for the development and analysis of the performance of tillage tools, particularly for BL plows.

The amount of draft force reduction in modified BL plow ranged from 25 to 40%.

2. Total draft force calculated from the FEM model for all treatments ranged from 840 - 1450 N. The modified BL plow performed satisfactorily and exhibited lower draft force requirement than the conventional one mainly due to the special soil failure mechanism induced by the blade geometry.
3. Unlike the conventional BL plow, the draft force of the modified BL plow did not increase directly with increasing rake angle. Minimum draft force for modified BL plow was seen at a rake angle of 15°.
4. The amounts of predicted and measured vertical forces of the modified BL plow were less than those of the conventional one. The minimum vertical force for the modified BL plow was found at the lowest rake angle of 7.5°.
5. Maximum theoretical upward soil displacement in front of the plow showed that the best treatment in cutting and turning the soil was the modified design at 15° rake angle. The increased area of the positive x-y shear stress zone in modified BL plow was the main reason for more soil upheaval.
6. Similarity of the Von Mises stress and strain contours to stress characteristic curves in this study was an important indicator of the accuracy of the analysis. A smaller plastic bubble appeared in the soil body due to the modified BL plow confirming its low draft force requirement.

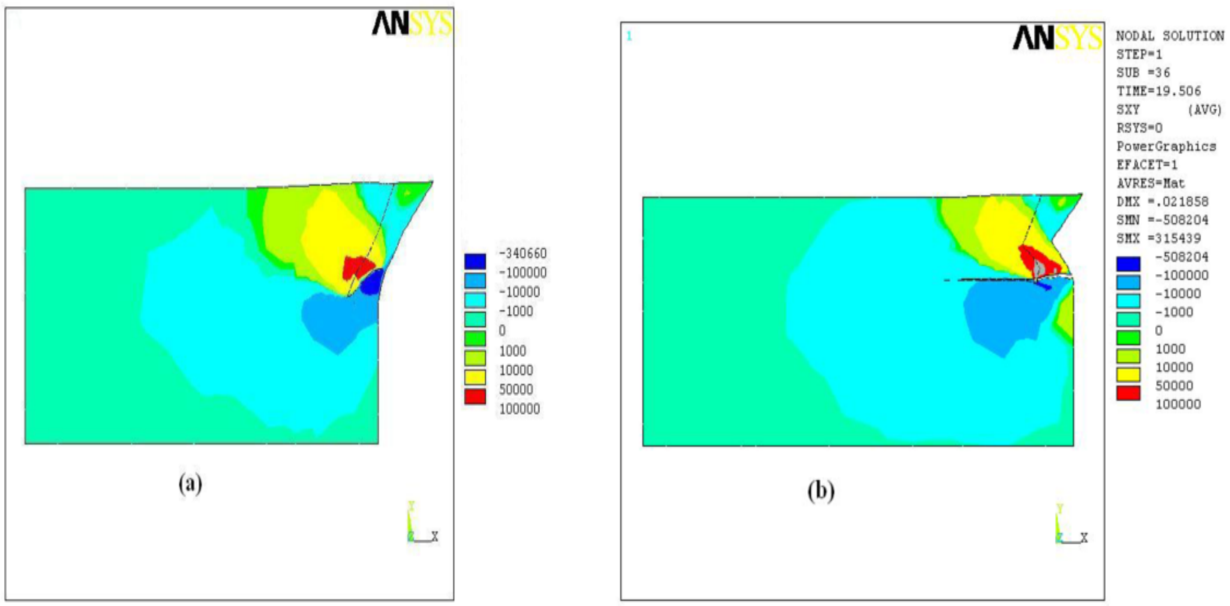

Fig. 10. x-y shear stress distribution contours for BL plow at a rake angle of 22.5° after 20 mm blade displacement, in conventional (a) and modified (b) BL plows.

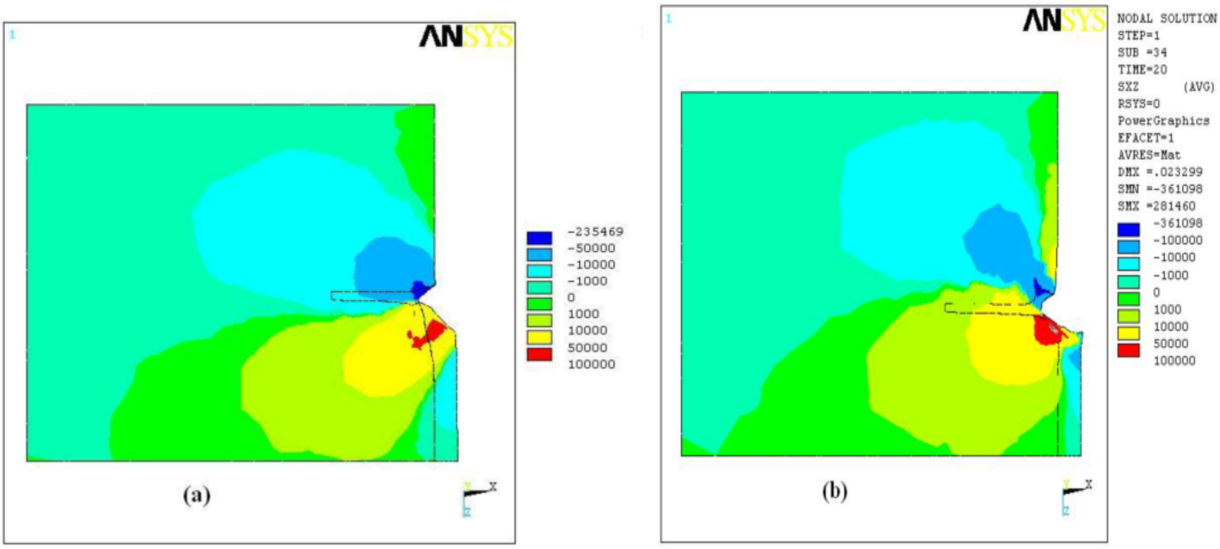

Fig. 11. 2D x-z shear stress distribution contours for BL plow at 15° rake angle after 20 mm blade displacement, in conventional (a) and modified (b) BL plows

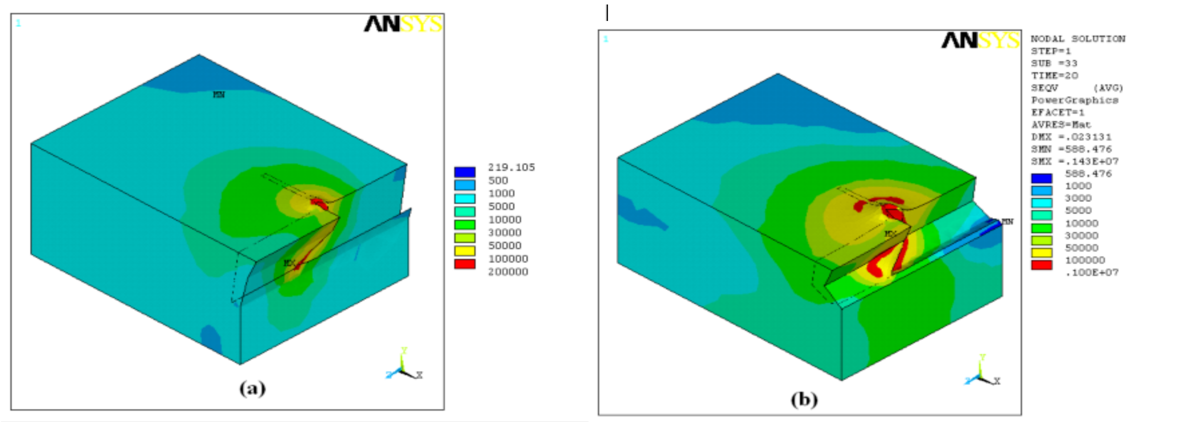

Fig. 12. 3D Von Mises stress for conventional BL at 7.5° rake angle after 20 mm blade displacement, in conventional (a) and modified (b) BL plows

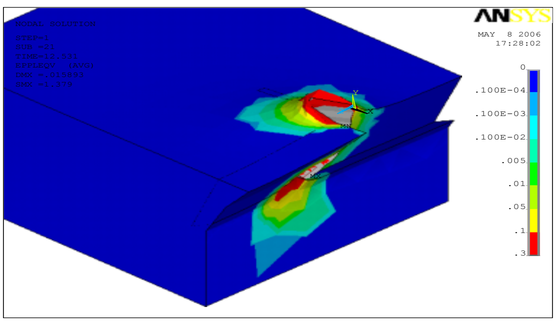

Fig. 13. 3D Von Mises plastic strain for conventional BL plow at 22.5° rake angle after 20 mm blade displacement

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ارزیابی عملکرد گاوآهن کج ساق بهینه شده به کمک روش اجزای محدود

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واژه‌های کلیدی:
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چکیده- هدف از تحقیق حاضر معرفی و ارزیابی عملکرد طرح بهینه گاوآهن کج ساق و مقایسه آن با طرح سنتی به روش اجزا محدود می‌باشد. تفاوت گاوآهن کج ساق بهینه و مرسوم در جهت زاویه بین تصویر تیغه برش در صفحه افقی عمود بر ساق گاوآهن و خط عمود بر ساقه در همان صفحه می‌باشد. دو تیغه مرسوم و بهینه در سه زاویه حمله °۷/۵، °۱۵ و °۲۲/۵ به کمک نرم‌افزار Ansys مدلسازی شده و عملکرد آن‌ها مورد بررسی قرار گرفت. نتایج مدلسازی نشان داد که کمترین نیروی کشش مربوط به تیغه بهینه در زاویه حمله °۱۵ و بیشترین آن مربوط به تیغه مرسوم در زاویه حمله °۲۲/۵ بوده است.کمترین نیروی عکس العمل عمودی نیز در تیمار تیغه مرسوم در زاویه حمله °۷/۵ بدست آمد. مقادیر محاسبه شده نیروی کشش افقی و نیروی عمودی با مقادیر اندازه‌گیری شده تطابق مطلوبی داشت. بزرگتر بودن ناحیه تحت تاثیر تنشهای برشی افقی در گاوآهن بهینه نسبت به نوع مرسوم آن تاییدی بر حمل بیشتر خاک به سمت بالا در این طرح است. کوچکتر بودن حباب پلاستیک ایجاد شده در گاوآهن بهینه مدل شده نسبت به نوع مرسوم آن دلیلی بر کمتر بودن نیروی کشش مورد نیاز این طرح می‌باشد. نزدیکی منحنی‌های توزیع تنش در بلوک خاک و منحنی‌های مشخصه خاک تاکیدی بر صحت مدلسازی می‌باشد.