Computer programming for prediction of soil bulk density effect on trencher design parameters

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Abstract: A computer program was developed in C++ language to predict the effect of soil bulk density on draft force on bottoms, share thickness, stresses distribution and maximum deflection on standards, bending stresses distribution on side plates, diameter of shear pins, and tensile stress on hitch bar. It was found that, as soil bulk density increased, stresses distribution and maximum deflection on standards, bending stresses distribution on side plates, diameter of shear pins, and tensile stress on hitch bar increased. The diameter of shear pin should be larger to meet wide range of soil density.

Keywords: trencher, computer program, soil, draft force, bulk density, prediction
DOI: 10.3965/j.issn.1934-6344.2011.04.042-049

Citation: Mohamed Hassan Dahab, Moayed Mohamed balal. Computer programming for prediction of soil bulk density effect on trencher design parameters. Int J Agric & Biol Eng, 2011; 4(4): 42－49.

1 Introduction

Trencher is used to construct trenches for oil, gas, water pipe lines, drainage ditches, sewer, cables and foundations as well as road - building jobs. Use of improved implements and agricultural machines is required to uplift farm mechanization to increase the productivity of land[1].

Quality of soil cutting procedure is of great importance in foundations and agriculture because it directly affects the quality of work and quantity of production, therefore, there is a need to improve equipment design for energy saving, wear resistance, to keep stresses and deflections of in safe limits under different soil physical conditions.

Received date: 2010-08-21 **Accepted date:** 2011-11-30

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Improving design of implement can be achieved by two techniques namely by experimental method or mathematical modeling method. Experimental method is costly, while employing mathematical modeling method can be lower in cost, if it can be established that the models give realistic results where they are to be applied. If theoretical results agree well with experimental data, the model can be adopted to investigate the important variables.

The soil–tool tillage combination should be studied to optimize the tool performance and energy efficiency. A tillage tool must reduce clods to the desired degree and manipulate the soil sufficiently. An understanding of the interaction between tillage tool and soil would allow the prediction of performance from knowledge of soil and tool parameters[2]. An evaluation of the physical disturbance imposed on the soil by tillage tool could provide step towards designing of suitable tool. The mathematical description of tool geometry may determine how to design parameters influencing energy requirements[3].

Tillage tools blades often have a complex geometry and are subjected to various kinds of loading. The stresses developed in ploughing blades are complex in nature because of the type of loading and the complex shape of the blade. An investigation into a two – dimensional mode to compute the effect of different shapes of agricultural plough blades on nodal displacements and stress distribution has been carried out. From the analysis L-shaped blades were found creating the highest displacements and stresses over the blade [4].

The objective of the present study is to develop a computer program to predict draft forces on bottoms, share thickness, stresses distribution and deflections on standards, stresses distribution on side plates, diameters of shear pins, and tensile stress on hitch bar.

2 Materials and methods

2.1 Materials

Materials used in the study consist of a computer, C++ software, and CorelDraw software.

2.2 Methods

2.2.1 Conceptual design of trencher

The basic concept involved in the design of a trenching machine is that two trench forming bottoms are placed one behind another such that they follow the same trench path (Figure 1). The two bottoms are placed in such a way that the front bottom will open a trench to specific depth from the ground surface and the rear bottom will open a trench with same depth but deeper than the front bottom, hence the rear bottom is placed lower than the front bottom[5].

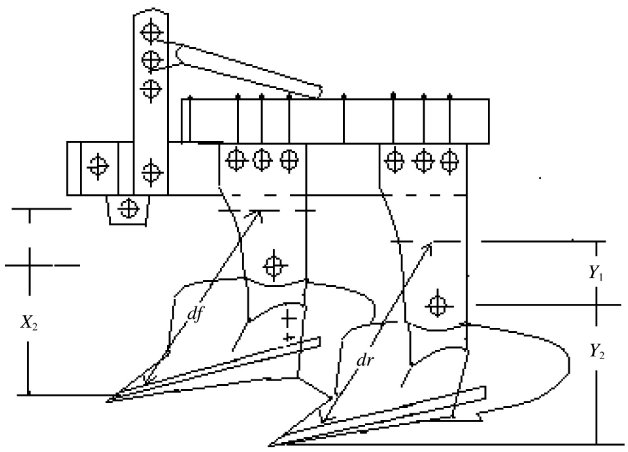

Figure 1 Design of trencher

2.2.2 Draft on trencher bottoms

Figure 2 shows one trencher bottom and its working parameters. Draft forces acting on the bottoms are calculated as follows.

$$D = b \times d \times k \tag{1}$$

$$D_f = D_r = \frac{D}{2} \tag{2}$$

Draft force on bottoms assumed to be equal because the working depth and cutting width of bottoms are equal and the rear bottom not suffered a resistance on top soil layer which was already cut by front bottom.

Where: D = total draft force on bottoms, kN; b = cutting width of the bottom, m; d = cutting depth of the bottom, m; k = soil resistance dependent on soil bulk density, g/cm^3 which is approximately 0.5 – 0.7 for light soil, 0.7 - 0.9 for medium soil and 1.0 - 1.3 for heavy soil; D_f = draft force on front bottom, kN; D_r = draft force on rear bottom, kN.

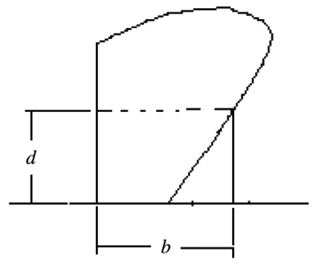

Figure 2 Trencher bottom

2.2.3 Share thickness

The maximum draft for soil cutting by either front or rear share is given as follows.

$$D_C = \frac{D}{2} \times R \tag{3}$$

where, D_C = maximum draft for soil cutting by the share, kg; R = constant expressed as ratio dependent on soil bulk density, ranging from 0.6 to 0.75.

The maximum bending moment on the share is calculated using the following equation:

$$M = D_C \times \frac{3}{4} b \tag{4}$$

Share thickness can be calculated using flexural equation as follows.

$$\frac{M}{I} = \frac{fb}{Y}$$

where, $I = \frac{Lt^3}{12}$ = moment of inertia, m^4; $Y = \frac{t}{2}$, t = Thickness of the share, mm; f_b = Allowable bending stress of the share material, kN/m^2.

2.2.4 Design of standards

The standards (Figure 1) were designed in a way that they can take up the resultant of useful and parasitic soil forces during the operation of the trencher bottoms[6]. In hard penetration the resultant force is longitudinally and laterally inclined at an angle to horizontal draft force. Both these angles may be taken as 8° to 10°. The corrected values of draft forces on front and rear bottoms were:

$$D_f = D_r = \frac{D}{2\cos\psi} \tag{6}$$

where, ψ = Angle of inclination of longitudinal and lateral resultant force, deg.

The maximum bending moment for the front and rear standard were calculated as follows.

$$M_f = D_f \times d_f \tag{7}$$

$$M_r = D_r \times d_r \tag{8}$$

where, M_f = Maximum bending moment on front standard, kN.m; M_r = Maximum bending moment on rear standard, kN.m; d_f = Distance between center of resistance to weakest section at the top edge of the front standard, m; d_r = Distance between center of resistance to weakest section at the top edge of the rear standard, m.

Bending stress on standards at any fiber is given by:

$$Fb_f = \frac{M_f \times Y_i}{A \times e \times R_i} \tag{9}$$

$$Fb_r = \frac{M_r \times Y_i}{A \times e \times R_i} \tag{10}$$

where, Fb_f = Bending stress on front standard, kN/m^2; Fb_r =Bending stress on rear standard, kN/m^2; Y_i = Distance from the neutral axis to inside fiber $=R_n-R_i$, m. R_n = Radius of curvature of neutral axis $=\frac{t}{\ln(R_o/R_i)}$, m; R_i = Radius of curvature of inside fiber, m; R_o = Radius of curvature of outside fiber, m; A = Area of standard cross section = $W\times t$, m; W = Width of standard section, m; t = Thickness of standard section, m; e = Distance from the centroidal axis to the neutral axis = $R-R_n$; R = Radius of curvature of centroidal axis = $R_i + \frac{t}{2}$, m.

The maximum deflection on front and rear standard cantilever beam with a point load acting at free end is given by:

$$MD_f = \frac{M_f \times d_f^3}{3 \times E \times I} \tag{11}$$

$$MD_r = \frac{M_r \times d_r^3}{3 \times E \times I} \tag{12}$$

where, MD_f = Maximum deflection on front standard, m; MD_r = Maximum deflection on rear standard, m; E = Modulus of elasticity for standard material, kN/m^2; I = Moment of inertia $=\frac{W\times t^3}{12}$, m^4.

Permissible deflection on front and rear standards is calculated as follows.

$$PD_f = \frac{d_f}{K} \tag{13}$$

$$PD_r = \frac{d_r}{K} \tag{14}$$

where, PD_f = Permissible deflection on front standard, m; PD_r = Permissible deflection on rear standard, m; K = Dimensionless constant dependent on material.

2.2.5 Design of side plates

Side plates are the intermediate component, which connect the bottoms of the trencher to the frame through the standards (Figure 3). The maximum draft force acting on each side plate is:

$$D_m = \frac{D_f}{2} = \frac{D_r}{2} \tag{15}$$

where, D_m = Maximum draft force acting on each side plate, kN; D_f = draft force on front bottom, kN; D_r = draft force on rear bottom, kN.

Maximum bending on front and rear plate were:

$$fb_f = \frac{D_m \times L_1}{Z_{XX}} \tag{16}$$

$$fb_r = \frac{D_m \times L_2}{Z_{YY}} \tag{17}$$

where, fb_f = Maximum bending stress on front side plate, kN/m^2; fb_r = Maximum bending stress on rear side plate, kN/m^2; L_1 = Length of the front side plate, m; L_2 = Length of the rear side plate, m; Z_{XX} = Cross section index of front side plate $=\frac{t_P \times h_f^2}{6}$; Z_{YY} = Cross section index of rear side plate $=\frac{t_P \times h_r^2}{6}$; t_P = Thickness of side plates, mm; h_f = Height of the front side plate, m; h_r = Height of the rear side plate, m.

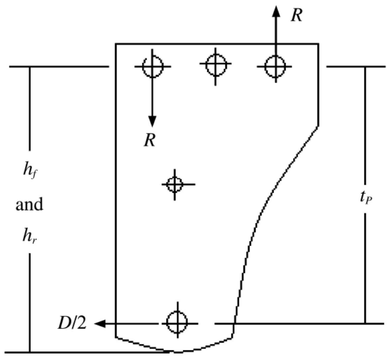

Figure 3 Dimensions and forces on side plates

2.2.6 Design of safety shear pin

A shear is provided for the safety of the trencher bottom to avoid the damage due to big stones (Figure 3). Draft forces acting on front and rear pins sections were calculated as follows.

$$D_{fPin} = \frac{D \times X_1}{2 \times X_2} \tag{18}$$

$$D_{rPin} = \frac{D \times Y_1}{2 \times Y_2} \tag{19}$$

where, D_{fPin} = draft force on front pin, kN; D_{rPin} = draft force on rear pin, kN; X_1 = distance from the front share to front pin, m; X_2 = distance from the front pin to center of resistance of front plate, m; Y_1 = distance from the rear share to rear pin, m; Y_2 = distance from the rear pin to center of resistance of rear plate, m.

Diameter of shear pin to meet the shearing force is calculated as follows.

$$Diam_{fPin} = \sqrt{\frac{4D_{fPin}}{\pi \times Fs}} \times S \tag{20}$$

$$Diam_{rPin} = \sqrt{\frac{4D_{rPin}}{\pi \times Fs}} \times S \tag{21}$$

where, $Diam_{fPin}$ = Diameter of front shear pin, m; $Diam_{rPin}$ = Diameter of rear shear pin, m; Fs = allowable shear stress of pin material, kN/m^2; S = safety factor.

2.2.7 Design of main parallel hitch bar

The hitch bar is designed on the basis of maximum drawbar pull of the tractor to withstand tension failure against the maximum pull. The tensile stress on hitch bar can be calculated as follows.

$$F_t = \frac{DBP}{(w - d_b) \times t_b \times s} \tag{22}$$

where, F_t = tensile stress on hitch bar, kN/m^2; DBP = drawbar pull force, kN; w = depth of hitch bar, m; d_b = maximum diameter of hole on the hitch bar, m; t_b = thickness of the hitch bar, mm; s = safety factor.

2.2.8 Development of the computer program

A computer program is developed in C++ to simulate a proposed design of a trencher, the input parameter for the program were shown in Table 1. The program used to predict draft forces on bottoms, share thickness, bending stresses distribution and maximum deflections on standards, bending stress on side plates, diameters of shear pins, and tensile stress on hitch bar. These variables were predicted under different values of soil bulk density. The flow chart of the program is shown in Figure 4.

Table1 Inputs for the program

Input	Value
1- Soil parameters	
Soil bulk density range	1.3-2.0 g/cm^3
2- Implement parameters	
a- Bottom working variables	
Depth of cut	0.30 m
Width of cut	0.30 m
Share thickness	4.9 mm
Allowable stress of share material	33150 kN/m^2
Safety factor	4
b- Standards variables	
Distance between center of resistance to weakest section at top edge of the front standard	0.56 m
Distance between center of resistance to weakest section at top edge of the rear standard	0.63 m
Width of standard section	0.020 m
Thickness of standard section	0.128 m
Radius of curvature of outside fiber	0.035 m
Radius of curvature of inside fiber	0.025 m
Maximum bending stress for standard material	1224 kN/m^2
Modulus of elasticity of standard material	122.4E6 kN/m^2
c- Side plates variables	
Height of the front side plate	0.362 m
Height of the rear side plate	0.442 m
Length of the front side plate	0.362 m
Length of the rear side plate	0.442 m
Thickness of side plates	12 mm
d- Shear pins variables	
Distance from the front share to front pin	0.348 m
Distance from the front pin to center of resistance of front plate	0.190 m
Distance from the rear share to rear pin	0.421 m
Distance from the rear pin to center of resistance of rear plate	0.190 m
Shear stress of pins material	4783.8 kN/m^2
e- Hitch bar variables	
Width of the hitch bar	0.13 m
Depth of the hitch bar	1.8 cm
Thickness of hitch bar	18,6 mm
Allowable tensile stress of hitch bar material	3213 kN/m^2
Safety factor for hitch bar	12

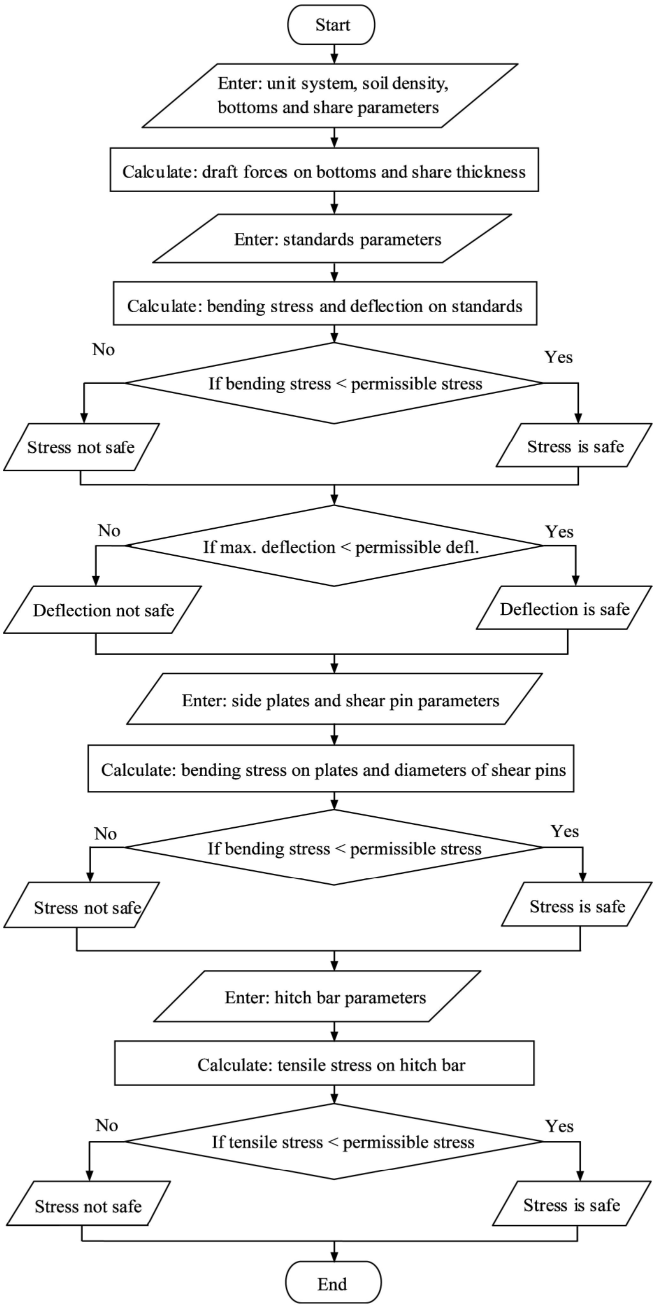

Figure 4 Flow chart of the program

3 Results and discussion

It was found that both predicted draft force and share thickness were increased as soil bulk density increased. The maximum draft on each bottom was 5.89 kN and it was recorded at 2 g/cm^3 soil density (Table 2, Figure 5) while the share thickness was increased from 4.9 mm at 1.3 g/cm^3 soil density to 8 mm at 2 g/cm^3 soil density (Table 3, Figure 6). It was concluded that as the soil bulk density increased, draft force and share thickness increased, therefore, soil density plays a considerable role in share wearing and effectiveness.

Table 2 Effect of soil bulk density on draft force of trencher

Soil bulk density/g · cm^{-3}	Draft force/kN
1.3	2.45
1.4	3.11
1.5	3.10
1.6	3.36
1.7	4.41
1.8	4.81
1.9	5.70
2.0	5.89

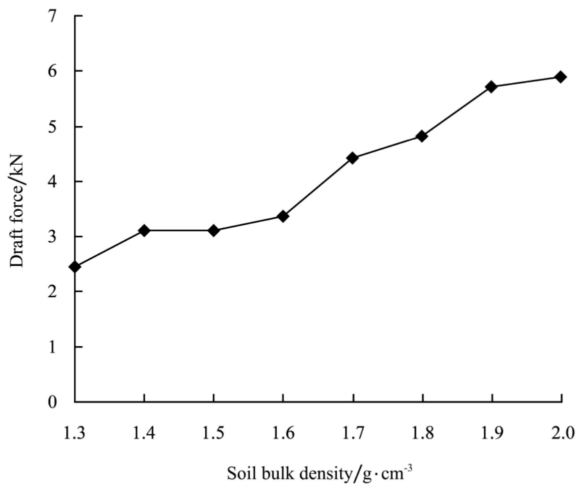

Figure 5 Effect of soil bulk density on draft force

Table 3 Effect of soil bulk density on share thickness

Soil bulk density/g · cm^{-3}	Share thickness/mm
1.3	4.9
1.4	5.2
1.5	5.4
1.6	5.8
1.7	6.9
1.8	7.2
1.9	7.5
2.0	8.0

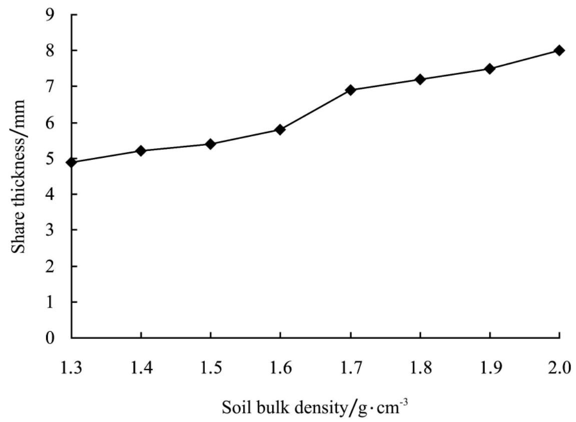

Figure 6 Effect of soil bulk density on share thickness

The effect of soil density on standard design was shown in Table 4 and Figure 7. It was found that as soil density increased, the predicted stress on standard increased and the stress distribution on rear standard was higher than the stress on front standard. As the soil bulk density was increased from 1.3 to 2.0 g/cm^3, the stresses distribution on front and rear standards increased from 269.28 and 321.3 kN/m^2 to 591.6 and 724.2 kN/m^2 respectively. The predicted stress at different values of soil density was at safe limit. The maximum deflection was found to increase with soil density and the rear standard showed higher deflection (0.75 mm) than front standard (0.44 mm) as shown in Table 5 and Figure 8, but it was within the safe limit.

Table 4 Effect of soil bulk density on stress distribution on trencher standards

Soil bulk density /g·cm^{-3}	Stress on front standard/kN·m^{-2}	Stress on rear standard /kN·m^{-2}	Safety
1.3	269.28	321.30	Safe
1.4	354.96	387.60	Safe
1.5	354.96	389.60	Safe
1.6	373.32	453.90	Safe
1.7	461.04	561.00	Safe
1.8	530.40	612.00	Safe
1.9	564.06	663.00	
2.0	591.60	724.20	Safe

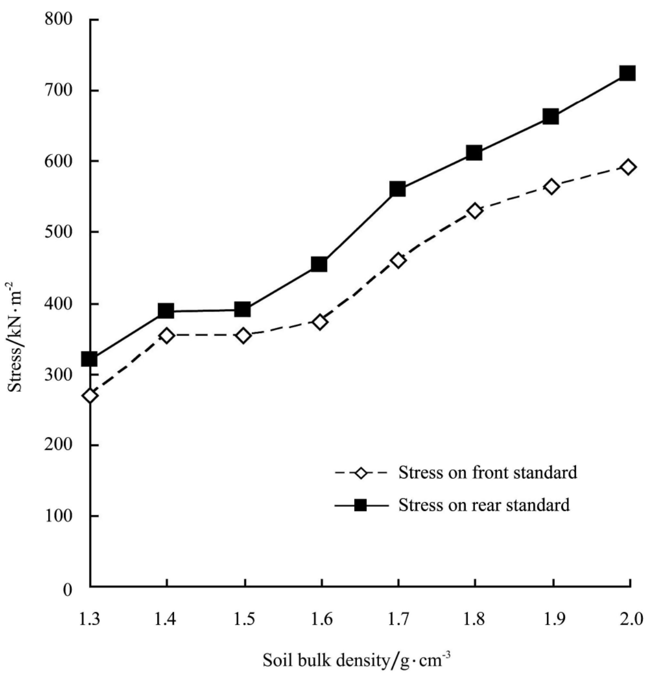

Figure 7 Effect of soil bulk density on stresses on standards

Table 5 Effect of soil bulk density on maximum deflection of trencher standards

Soil bulk density /g·cm^{-3}	Deflection on front standard/mm	Deflection on rear Standard/mm	Safety
1.3	0.19	0.33	Safe
1.4	0.24	0.40	Safe
1.5	0.24	0.40	Safe
1.6	0.28	0.45	Safe
1.7	0.34	0.58	Safe
1.8	0.37	0.62	Safe
1.9	0.40	0.69	
2.0	0.44	0.75	Safe

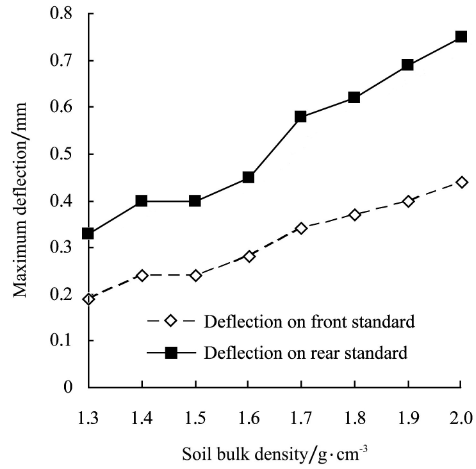

Figure 8 Effect of soil bulk density on maximum deflection on standards

The predicted maximum bending stress on each side plate found to increase with soil density (Table 6, Figure 9), it was recorded that the front side plate was subjected to higher bending stress as compared to rear plate, and they are at safe limit. Increasing the soil bulk density from 1.3 to 2.0 g/cm^3, the predicted bending stresses on side front and rear plates increased by 170.7% and 110.1% respectively. It was also found that the diameters of front and rear shear pins increased as soil density increased (Table 7, Figure 10).

Table 6 Effect of soil bulk density on bending stress on side plates of trencher

Soil bulk density /g·cm^{-3}	Stress on front standard/kN·m^{-2}	Stress on rear standard /kN·m^{-2}	Safety
1.3	7.91	7.65	Safe
1.4	10.71	8.67	Safe
1.5	11.22	8.72	Safe
1.6	12.75	10.20	Safe
1.7	16.32	13.77	Safe
1.8	17.85	14.69	Safe
1.9	18.87	15.81	
2.0	21.42	16.07	Safe

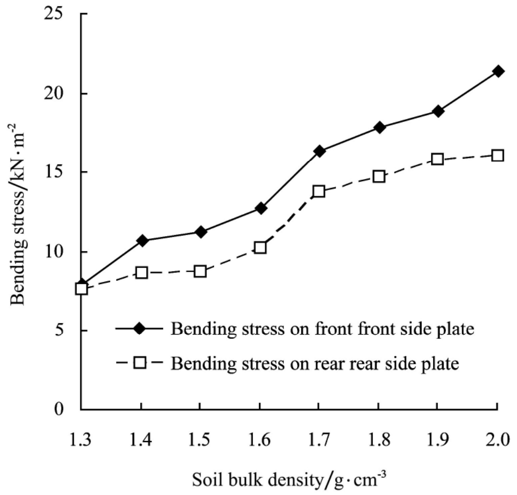

Figure 9 Effect of soil bulk density on bending stress on side plates

Table 7 Effect of soil bulk density on diameter of shear pin.

Soil bulk density /g·cm^{-3}	Diameter of front pin /mm	Diameter of rear pin /mm
1.3	3.5	4.0
1.4	3.9	4.2
1.5	4.0	4.3
1.6	4.1	4.8
1.7	4.8	5.2
1.8	5.0	5.5
1.9	5.1	5.7
2.0	5.2	6.0

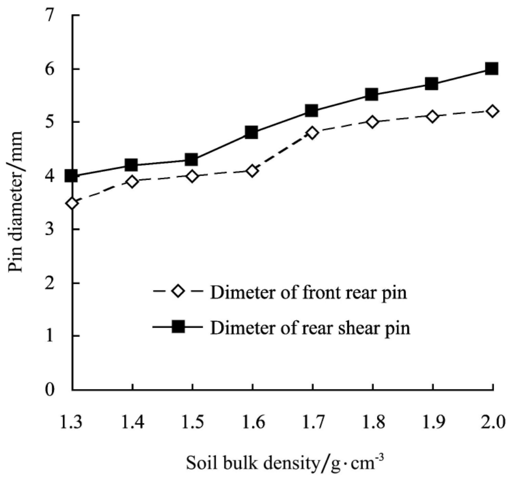

Figure 10 Effect of soil bulk density on diameter of shear pin

It was recorded that as soil density increased, the tensile stress on hitch bar tends to increase (Table 8, Figure 11). The maximum tensile stress was shown at 2 g/cm^3 soil density (4.85 kN/m^2), while the minimum tensile stress was (2.04 kN/m^2) was demonstrated at 1.3 g/cm^3 soil density, and the stresses were found to be at safe limit.

Table 8 Effect of soil bulk density on tensile stress on hitch bar of trencher

Soil bulk density/g·cm^{-3}	Stress/kN·m^{-2}	Safety
1.3	2.04	Safe
1.4	2.55	Safe
1.5	2.57	Safe
1.6	3.06	Safe
1.7	3.62	Safe
1.8	4.08	Safe
1.9	4.34	Safe
2.0	4.85	Safe

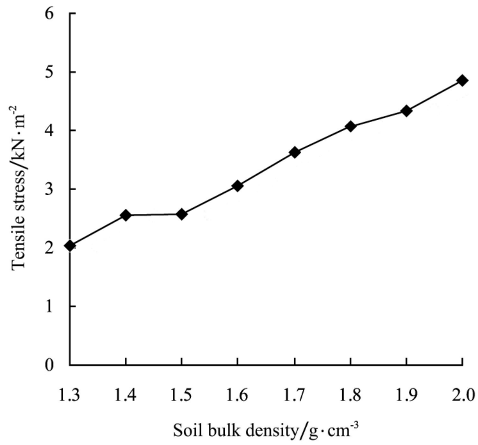

Figure 11 Effect of soil bulk density on tensile stress on hitch bar

4 Conclusions

1) Draft force on bottoms of trencher increased with soil bulk density. The share of bottom needs to be thicker as soil density increased, therefore soil condition plays a major role in share wearing.

2) The present design of the trencher showed that the stress and deflection on standard dependent on soil density but they are within the safe limit.

3) Bending stress on side plates increased with soil density and the stresses on front and rear plate are safe.

4) The diameter of shear pin should be designed large enough to meet different soil conditions.

5) Tensile stress on hitch bar was proportional to soil density.

6) A computer simulation could be useful method and should be used to design and test the performance of a machine before being manufactured, this will save resources and cost.

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