# Simulation of Soil Failure around the Subsoiler Type Curved Leg Using Computational Fluid Dynamics

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***Abstract*—Use of soil tillage tool in agricultural field wants for soil failure. Behavior of soil failure: soil deformation and soil failure depend on soil properties and action force method. The subsoiler used to change the depth of soil from the surface to the ground breaking into a small block. The objective of this research was to determine soil flow pattern around the subsoiler type curved leg used computational fluid dynamics and to study soil fracture and soil movement of subsoiler type curved leg. Simulations carried out using ANSYS Fluent 14.0 commercial CFD software. The computational fluid dynamics used predict the soil flow through subsoiler type curved leg at subsoiler operating speed constant. For a subsoiler speed of 1.02 m $s^{-1}$, with operating at 400 mm depth, rake angle of 30°. The results show, the soil failure is lateral deformation of subsoiler and soil movement on the surface of rake angle.**

***Index Terms*—computational fluid dynamics, soil failure, subsoiler, simulation, soil deformation, sandy loam**

## I. Introduction

Properties of soil dynamic had characterized by the soil movement. At the same time, the soil particles are loose arranged. It will be compress. The soil has higher resistance to failure. The soil is stronger and effects of soil change. We had explained it with mathematical equations using many parameters in the analysis. This had achieved by measuring the properties of soil dynamic.

Computational Fluid Dynamics (CFD) were an analysis of the flow phenomena such as heat transfer, particle distribution and chemical reactions using computer to find solutions and simulate the behavior. It can have said that computational fluid dynamics is a numerical method for flow. The Navier-Stokes equation is an equation for solving a viscous fluid problem.

The analysis effects of fluid within a model of an analytical system using computational fluid dynamics. In simulation, we use boundary condition such as speed and pressure results from actual measurement of the prototype by control volume of the model and make it easier to calculate. The solution was using the mathematical equation within the mass conservation equations, momentum equations and energy equations.

The subsoiler used to break open the hard pan the top soil. Usually, there are three layers of soil, name, top soil, hard pan and subsoil. The top soil may be few centimeters thick in which most of the cultivation for growing crop performed. The subsoiler improve soil structure by creating deep cracks and fissures in hard pan which results in better aeration, improves downward movement of water and deep rooting of the crops [1]. Soil deep loosening removing the impermeable soil layer (hard pan) and for allowing water infiltration in the upper layers, to determine the qualitative indices obtained with this equipment [2]. The case of three dimensional soil structure interactions used finite element analysis, where the structure is moving in the soil. The lateral soil movement was idealization as the flow of soil particle around the tool, while the vertical soil movement idealized as soil flow parallel to the soil shear failure planes [3], but finite element method is a useful tool to simulate soil failure patterns and simulation models correlated better with soil bin than with field test results [4]. Moreover, finite element method had made much progress in evaluating the tool draft, distribution position of stress and strain, displacement fields and acceleration in soil-tool interactions, software package of computer aided design of tillage tools; it will be a low cost and high efficiency assertive tool in the development procedure of tillage tools, and can applied to study and analyze the performance of resulting prototypes [5].

Soil deformation around a tillage tool using computation fluid dynamics [6], analyses has carried out using CFX 4.4 commercial CFD software. Results showed were computation fluid dynamics has a significant potential in tillage tool modeling and soil flow indicated soil deformation patterns and the effect of speed on the failure front propagation.

Dynamical analysis to choose best subsoiler shape using ANSYS [7], initial conditions and forces had exerted on the models. The models had analyzed with ANSYS software. Results showed that C shape subsoiler has biggest value of safety factor in the fatigue analysis and bear lower bending moment than the other types.

The three dimensional computational fluid dynamics simulations were perform for a clay loam soil and these conditions imposed the use of the finite volume method for the computational fluid dynamics [8].

Manuscript received March 20, 2018; revised August 8, 2018.



doi: 10.18178/joaat.5.4.266-270

Flow behavior simulation of soil through subsoiler in 3 shapes, show that soil breaking starts at the tip of subsoiler leg. The subsoiler C shape has lowest velocity through the soil; Sloping shape and L shape respective [9]. Thus, it was conclude that CFD based modeling in the area of tillage is most workable and effective for in depth study of soil tool interaction by simulating realistic soil manners [10].

This problem is the source of the simulation of soil flow behavior through subsoiler by computational fluid dynamics. The soil failure study had used to predict the soil flow behavior. The objective of this study was to the simulation of soil failure of the subsoiler type curved leg with ANSYS Fluent commercial CFD software and soil cutting around of subsoiler type curved leg. Results of this research can help the designers of subsoiler type curved leg to reduce draft force, power requirements and soil compaction.

## II. Materials and Methods

### A. Geometry of Subsoiler

Design of Subsoiler type curved leg has rake angle of 30°, 0.038 m width (W), 0.58 m length (L) and 0.85 m height (H), as shown in Fig. 1.

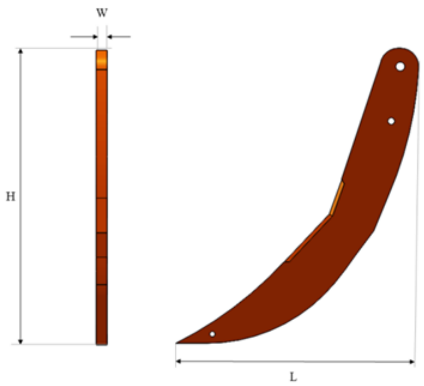


Figure 1. CAD file of subsoiler type curved leg.

### B. Computer Simulation

Prediction of flow behavior of soil through subsoiler type curved leg used numerical simulation based on the finite volume method. Use ANSYS Fluent 14.0 commercial software for analysis based on laminar flow.

### C. Mathematical Modeling

In this study used computational fluid dynamics method to analyze the flow in 2 dimensions, there are basic equations relating to flow may be called the Navier-Stokes equation is basic of numerical solutions of fluid flow [11]. The differential equations of conservation 2 equations are:

1) Assume the conservation of mass through the control volume, and continuity equation is equation (1).

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u_i) = 0 \quad (1)$$

where $u_i$ is the directional velocity of the fluid (m s$^{-1}$), t is flow time (s) and ρ is the fluid density (kg m$^{-3}$).

At any location of the flow, the local time rate of the density change is balanced by the net mass flux at that point. For initial simulations, the soil was considered incompressible, with a constant density and assumed a single phase continuous medium. Thus, the valus of ρ was bulk density with any pore water in the soil. The above equation reduced to the following simplification from, indicates the volume of the differential fluid element does not change using equation (2).

$$\nabla u_i = 0 \quad (2)$$

2) Newton's second law of motion describes the relationship between the acceleration of a fluid particle and the net force acting on it through by the following momentum equation is equation (3).

$$\rho \frac{du_i}{dt} = -\frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g \quad (3)$$

The material or substantial derivative is a function of both temporal and spatial changes is equation (4) [3].

$$\frac{du_i}{dt} = \frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} \quad (4)$$

where d/dt is the function of substantial or total derivative, P is the hydrostatic pressure (Pa), and $g$ is the acceleration of gravity (m s$^{-2}$), $\tau_{ij}$ is the shear stress tensor (Pa) and $x$ is the distance (m).

Properties of soil rheological was Non-Newtonian fluid with Bingham plastic fluid model represents the shear stress tensor in momentum equation using equation (5), equation (6), and equation (7) [3].

$$\tau_{ij} = \sigma_i = 2\mu \frac{\partial u}{\partial x} \quad (5)$$

$$\tau_{ij} = \tau_y + \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) = \tau_y + \mu \dot{\gamma}; \ \left| \tau_{ij} \right| > \tau_y \quad (6)$$

$$\dot{\gamma} = 0; \ \left| \tau_{ij} \right| \le \tau_y \quad (7)$$

where $\dot{\gamma}$ is the shear rate (s$^{-1}$), $\tau_y$ is the yield stress (Pa), $\mu$ is the plastic or dynamic viscosity (Pa s) and $\sigma_i$ is the directional normal stress (Pa).

In this research, it used a Casson fluid model that describes Non-Newtonian fluid behavior and can be represented by the shear stress and shear strain rate relationship for plastic flow. The material was developed for biological materials are equation (8).

$$\tau_{ij}^{0.5} = \tau_y^{0.5} + \left\{ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right\}^{0.5} \quad (8)$$

where $\tau_{ij}$ is the shear stress tensor (kPa), $\tau_y$ is the yield stress (kPa) and μ is the shear viscosity (Pa s).

### D. General Considerations

The simulations have found using a constant rate cone penetrometer method developed by Ref. [12]. For a sandy loam, soil with 1.45 g cm$^{-3}$ soil bulk density, 2.0 MPa cone index, and 13.62 %db moisture content, soil viscosity was found to be 991.48 Pa s, shear stress was found to be 16.14 kPa and inlet velocity of soil particle with 1.02 m s$^{-1}$.

The system was idealized with the following assumptions: The subsoiler operates at a constant depth. Soil flow type is laminar and the state of flow is transient. The soil was homogeneous continuum. The soil was an incompressible material and soil pore spaces are negligible. The soil behaves as a Bingham plastic fluids material with definite yield stress, in this study used Casson fluid model with definite shear stress.

### *E. Boundary Conditions and Domain Size*

Appropriate boundary conditions have required to full defining the flow simulation, as the flow equations have solved subject to boundary condition. The common fluid boundary conditions include the inlet, outlet, opening, wall, and symmetry plane.

The boundary conditions imposed in the simulation on the flow domain are: Inlet velocity specified 1.02 m $s^{-1}$, the outlet specified as pressure boundary, no slip wall boundaries specified at the bottom and the sides of the channel and the top of the flow domain specified as free surface with pressure boundary and grid movement confined.

Determination of optimum domain size for 3 dimension simulation in ANSYS Fluent. A subsoiler type curved leg with 0.58 m thickness (L) and 0.03 m width (W), operating at 0.40 m depth (H) considered for the study. The flow geometry consisted of an open channel of 0.24 m width (8W), 4.64 m length (8L) and 1.60 m depth (4H).

The flow domain simulations of soil, the domain width has 10 times of width of the subsoiler, it divided into length of the domain have 5 times of width of left of the subsoiler and the domain have 5 times of width of right of the subsoiler. The domain height has 4 times of height of the subsoiler. The domain length has 8 times of length of the subsoiler, it divided into length of the domain was 3 times of length of front of the subsoiler and the domain was 5 times of length of rear of the subsoiler. The numerical simulation assumes that the active part is stationary, while the viscous soil is flowing around the subsoiler type curved leg, as shown in Fig. 2.

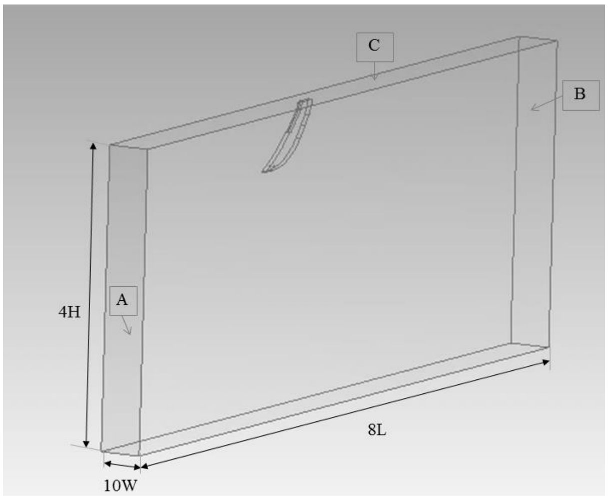


Figure 2. Domain size and boundary conditions by A: Inlet, B: Outlet, C: Free surface

### *F. Meshing*

The grids used for modeling in the flow simulation have a special resolution at the surface and the surface layer of a subsoiler type curved leg. It was the surface of interest. Prediction was the flow behavior and determined the forces on the subsoiler. In creating the meshes, the model constructed with the resolution. The experimental using the tetrahedron grid and due to the complexity constraints. At the subsoiler type curved leg body level, the computational mesh was unstructured. The CFD modeling of a subsoiler used tetrahedral grid with 110,193 elements, as shown in Fig. 3.

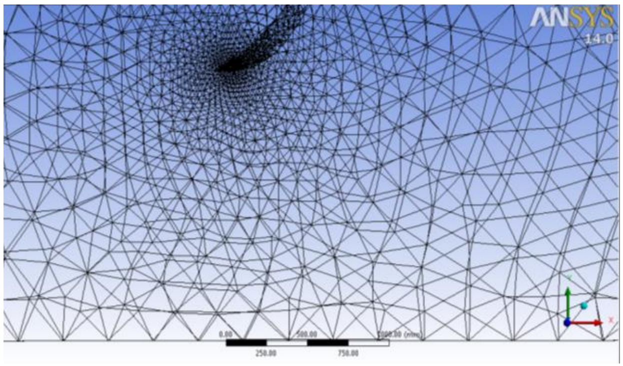


Figure 3. Mesh for flow domain.

## III. Results and Discussion

Computational fluid dynamics method and finite element simulations have a significant potential in modeling and simulate of soil flow behavior through a subsoiler type curved leg. When viewed from the top view, it flows out to the around of a subsoiler at the free surface, as shown in Fig. 4. When viewed from the front view, it flows out around the subsoiler. Soil flow through the end leg of a subsoiler, as shown in Fig. 5. The end leg of a subsoiler was soil movement occurs in the shear lateral and lateral direction of the soil, as shown in Fig. 6. The critical depth at a subsoiler can cause the soil breaking apart on the side with a width of about 1.5 times the width of a subsoiler, as shown in Fig. 7. The soil breaking and soil structure after cutting by the rake angle of a subsoiler type curved leg, as shown in Fig. 8.

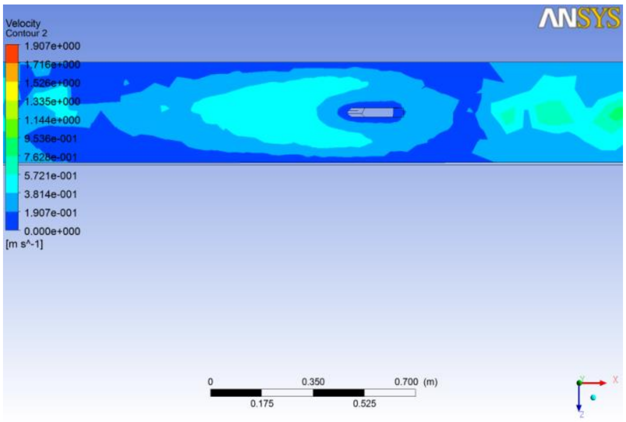


Figure 4. Soil flow around a subsoiler at the free surface (top view of the channel).

Fig. 4 shows the soil flow around the subsoiler at the free surface. It was found that the low velocity at the around of a subsoiler can also be seen in the fringe area describing the variation of the velocity of soil particle at the free surface and the soil flow side of the subsoiler. The same trend was report for the simulation of soil deformation around a tillage tool [6].

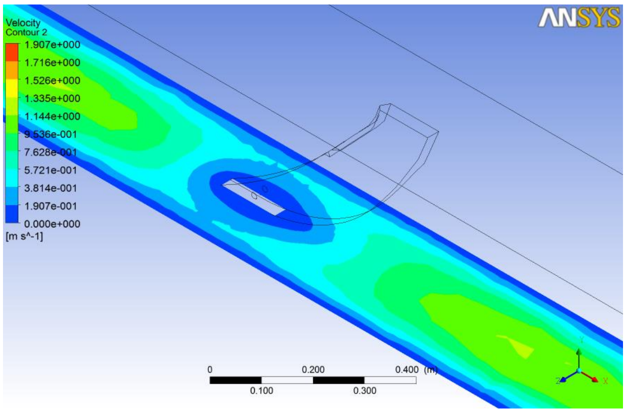


Figure 5. Soil flow through the end leg of a subsoiler.

Fig. 5 shows the velocity of soil through the end leg of a subsoiler. This area has the highest pressure. Because soil flow through the end leg of a subsoiler was collision caused a stagnation point. The contour area was blue, flow behavior of the plastic flow. The same trend was report for the velocity just in front of and behind the tool is zero because of the stagnation points in the flow domain [6].

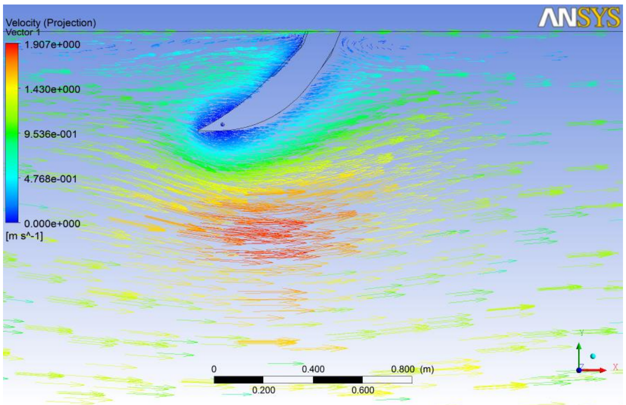


Figure 6. Soil movement.

Fig. 6 shows the soil movement from the simulation of soil flow through the subsoiler. It was found that the velocity of the soil at the end leg of a subsoiler was higher than that of other plots. Because the soil flow at the end leg of a subsoiler has compressed to less flow profile compared the flow domain, thus velocity is increasing. The same trend was report for the variation of the soil speed; the soil is disturbed in front of the active body and the distribution pattern of the flowing speed clearly indicates the region where the cracks appear [8].

Fig. 7 shows the soil flow around the subsoiler at the inlet of channel. It was found that the width of disturbed area increased, when the depth of the leg of subsoiler was increased. The rupture distance of the soil was increased, when the tillage at greater depths. The depth-width ratio of the subsoiler was very high, while subsoiler has act to soil will cause the soil loosening and soil failure.

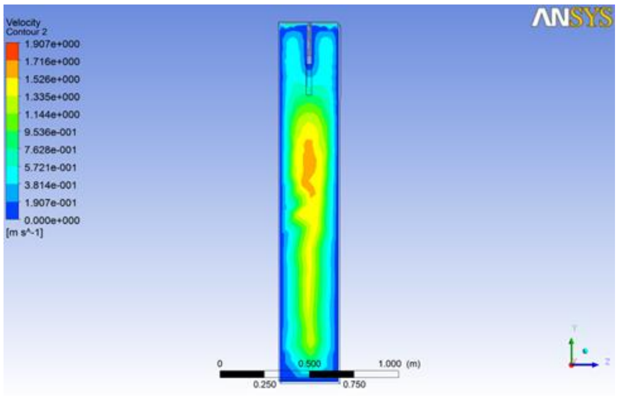


Figure 7. Soil flow around the subsoiler at the inlet (front view of the channel).

Fig. 8 shows the changes in the soil structure after cutting. It was found that the soil was much pulled and was moved. It will cause structural changes and soil density. The new structure will appear in the soil and increase the air gap in the soil. It can be said that the volume of soil cut.

Considering a real subsoiler operating condition, a particular full had developed velocity can considered as the subsoiler operating speed in the same flow domain with stationary soil. Thus, the soil failure front can determined from the longitudinal velocity profile, as shown in Fig. 9.

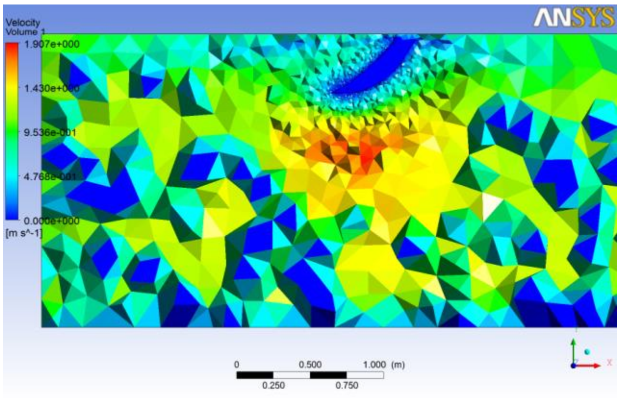


Figure 8. Changes in the soil structure after cutting.

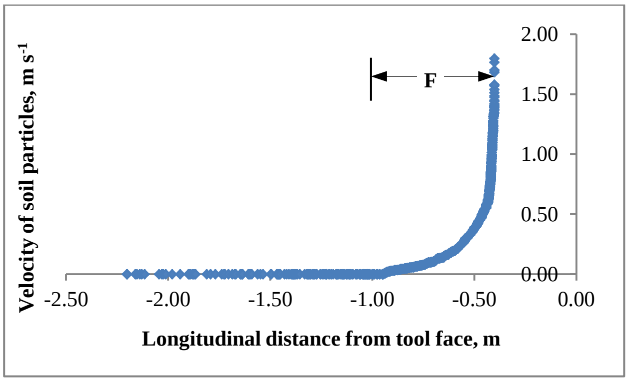


Figure 9. Soil failure front (F) for the moving tool.

## IV. CONCLUSION

Simulation of soil flow behavior through subsoiler type curved leg. When viewed from the top view, it flows out to the side of the subsoiler. When viewed from the front view, it flows out around a subsoiler and critical depth at the subsoiler type curved leg can cause the soil to break apart on the side with a width of about 1.5 times the width of the subsoiler. The rake angle of a subsoiler, soil failure occurs in the lateral and lateral direction of the soil. Soil breaking and soil loosening moved on the surface at the rake angle of a subsoiler. Computational fluid dynamics simulation complements experimental testing, helps reduce cost and turnaround time for design iterations, and has become an indispensable tool whenever practical design involving fluids was required.

## ACKNOWLEDGMENT

The authors wish to thank Suranaree University of Technology for supported this study.

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