

GEOMETRIC PARAMETERS OF A DISC IMPLEMENT

M. M. Alam*

ABSTRACT

The geometry and operating parameters of a disc implement have distinct influence on soil handling capability. In this paper disc attitude angles have been redefined in relation to a reference co-ordinate system at the centre of the sphere of which disc is a part and soil-disc relationship have been analyzed in relation to disc geometry and operating parameters.

Key Words : Disc angle, Tilt angle, Width of cut and Disc scrubbing.

INTRODUCTION

One of the most difficult task in cultivation of crops is the working of soil. In addition to ploughs, disc implements can be used to advantage. A disc tool has a complex geometry with more complex manner of movement. The working parts of a disc execute not only forward motion along with the machine but also rotate on its own axis. Moreover, in field operation standard disc implement needs to be set at an angle to the direction of travel (disc angle) and at an inclination with the vertical axis (tilt angle) for better performance. Due to these complexity even an efficient field operation needs some basic information for proper setting of the disc with the variation of operating conditions. A geometric investigation of the disc tool is also needed to provide useful information for sound design.

In this paper an attempt has been made to investigate the interaction between a standard disc implement and the soil in relation to disc geometry, disc setting and working depth.

GEOMETRIC PARAMETERS

Geometry of Common Disc

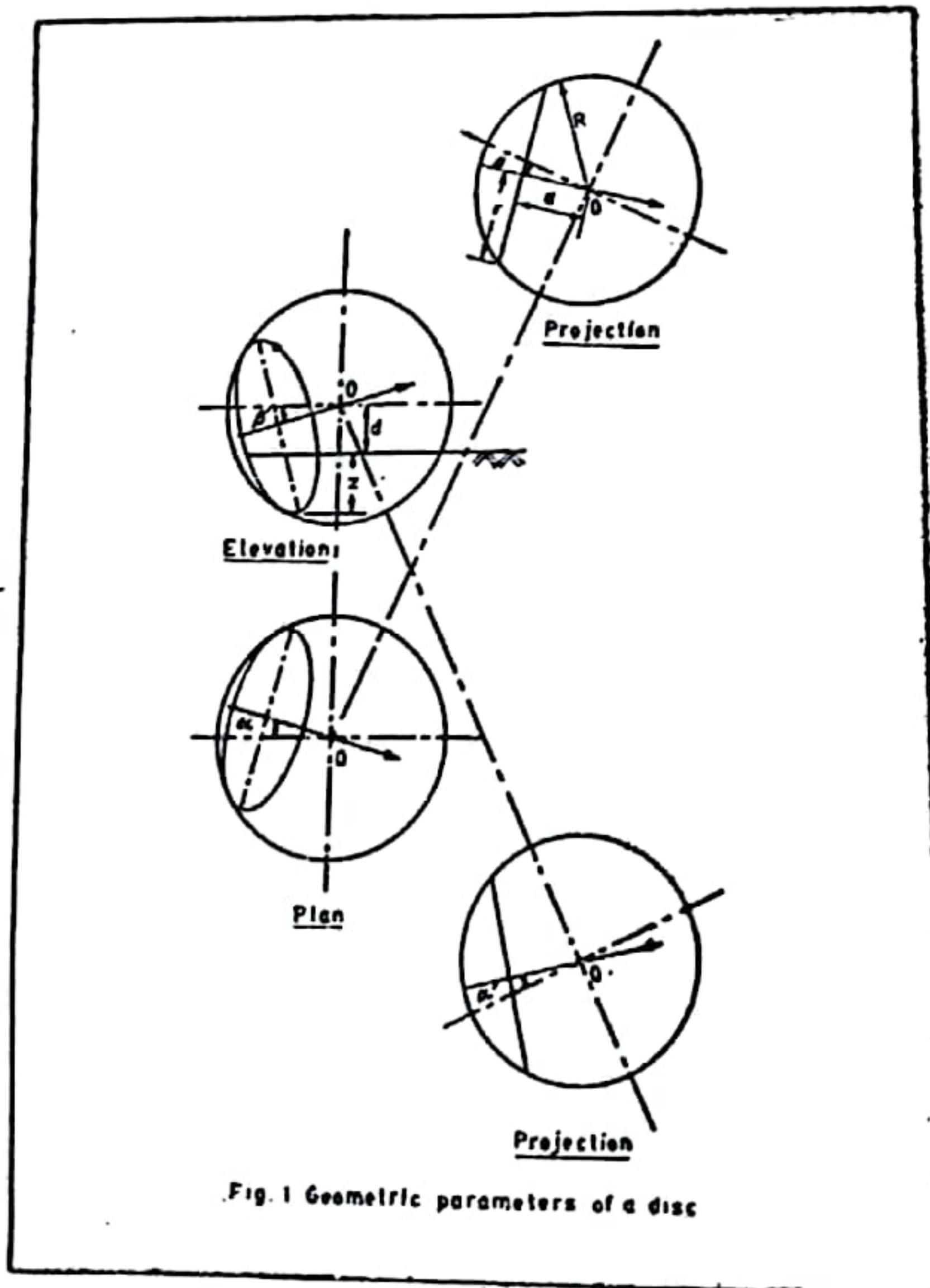
A common disc is a section of a sphere cut off by a plane (Fig. 1) and that plane is called the disc face plane. The radius of the sphere 'R' is the radius of curvature of the disc. The edge of the disc is therefore a circle and the diameter of this circle is called the diameter of the disc and the radius of the disc edge circle can be represented by 'r'. The

*Assistant Professor, Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh, Bangladesh.

depth of the disc from its face plane along the sphere radius passing through the centre of the disc edge circle 'C' is called the concavity of the disc. The disc radius 'r' and the depth of concavity depends on the distance 'a' between the centre of the sphere 'O' and the centre of the disc edge circle 'C' (Fig. 1). Thus, the relation between sphere radius 'R', disc radius 'r' and the distance 'a' between the centers of the disc and sphere can be expressed as :

$$r = \sqrt{R^2 - a^2}$$

In common practice a disc implement operates at an angle with the direction of travel in horizontal plane, which is called disc angle. In addition to disc angle standard disc implement operates with an inclination with the vertical axis in vertical plane, which is called tilt or inclination angle. In this investigation the two attitude angles have been worked out in relation to the co-ordinate axes at the centre of the sphere so that, the geometrical interaction between disc implement and the soil could be explained with respect to a reference co-ordinate system. The centre of the sphere 'O' has been taken as the origin of the reference co-ordinate system and directions are chosen in accordance to the right-hand rule (Fig. 1). The disc angle α is defined as the projected angle



on the horizontal plane made by the line joining the centre of the disc edge circle and the centre of the sphere with the x-axis of the reference co-ordinate system at the centre of the sphere. The tilt angle or the angle of inclination β is defined as the angle made by the line joining the centre of the disc edge circle and the centre of the sphere with the horizontal plane.

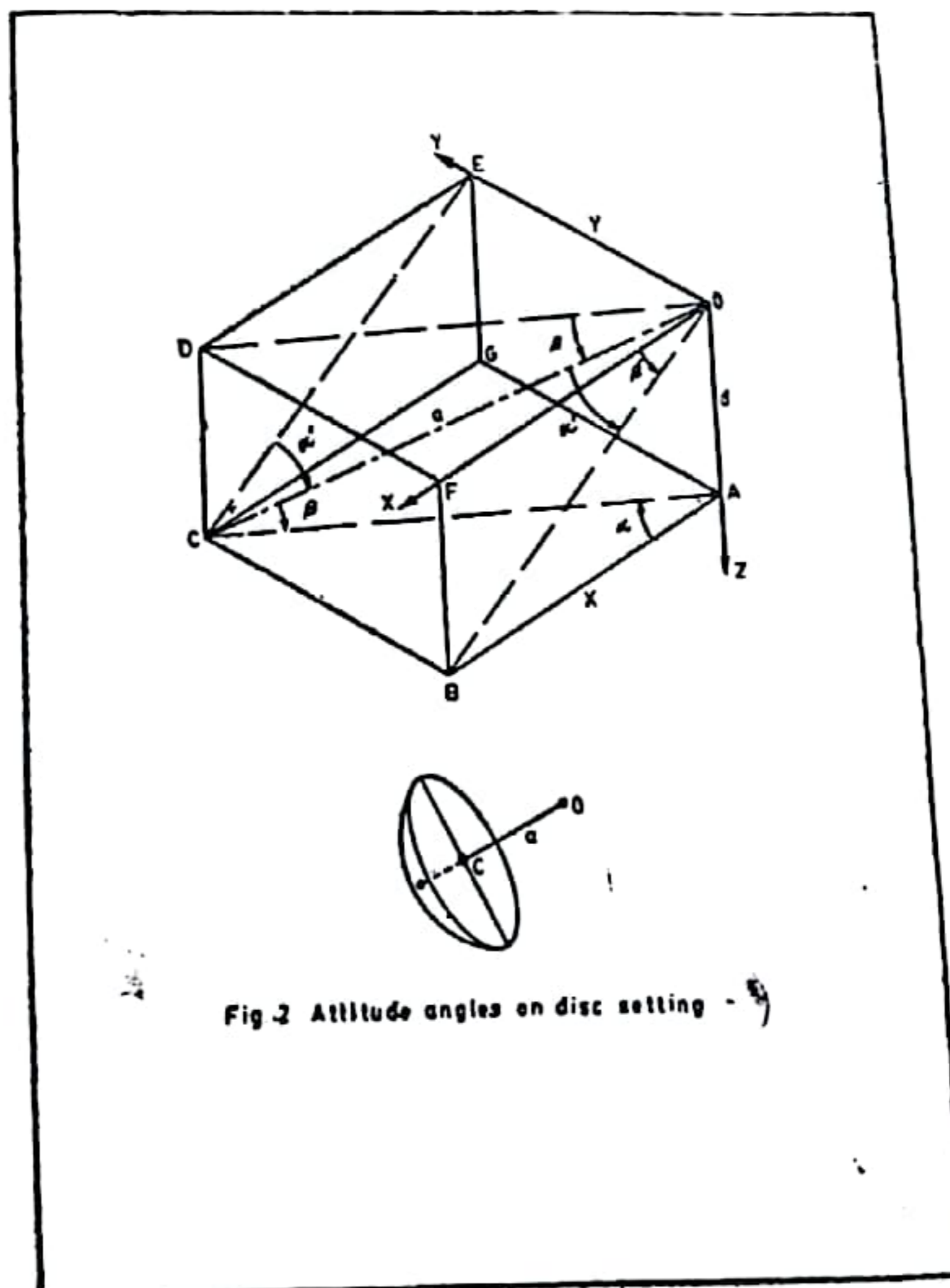
Co-ordinates of Disc Centre

A geometrical analysis in three dimensions has been attempted to determine the co-ordinates of disc centre 'C' with reference to the co-ordinate axes at the centre of the sphere (Fig. 2). The co-ordinates of the disc centre can be written as :

$$\begin{aligned} X_c &= a \cos \alpha \cos \beta \\ Y_c &= a \sin \alpha \cos \beta \\ Z_c &= a \sin \beta \end{aligned}$$

Distance between Sphere Centre and Horizontal Soil Surface

At any instant, when disc is engaged with soil at a predetermined depth of cut, the distance 'd' between horizontal soil surface and the centre of the sphere (Fig. 1)



is constant but, the depth of cut along the disc periphery varies with the disc geometry. To predict the soil reaction forces on a disc implement analytically, the knowledge of varying depth at various points on disc periphery in contact with the soil is very important. A particular setting of disc is fixed by the disc angle, inclination angle and the depth of cut (z). Among them the depth of cut and the inclination angle have an influence on 'd'. The relation between above mentioned variables and 'd' (Fig. 3) can be expressed as ;

$$d = R \sin \left(\beta \cos^{-1} \frac{a}{R} \right) - z$$

Width of Cut

In operation a particular setting of a disc implement is fixed by the disc angle, inclination angle and depth of cut. These variables have a significant influence on the width of cut. The relation between the above mentioned variables and the width of cut 'W' (Fig. 4) can be expressed as ;

$$W = \frac{2 \cos \alpha}{\cos \beta} \sqrt{z (2r \cos \beta - z)}$$

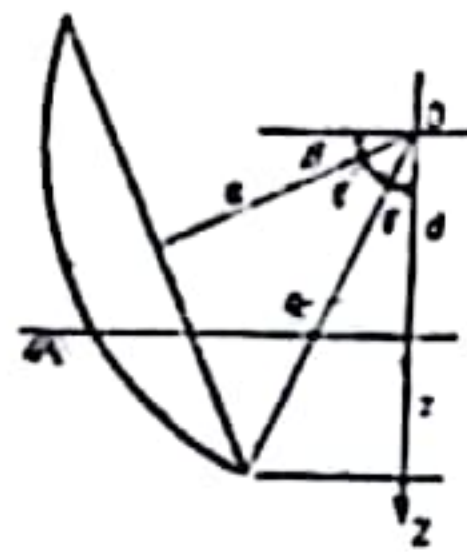


Fig 3 Determination of d with respect to disc setting.

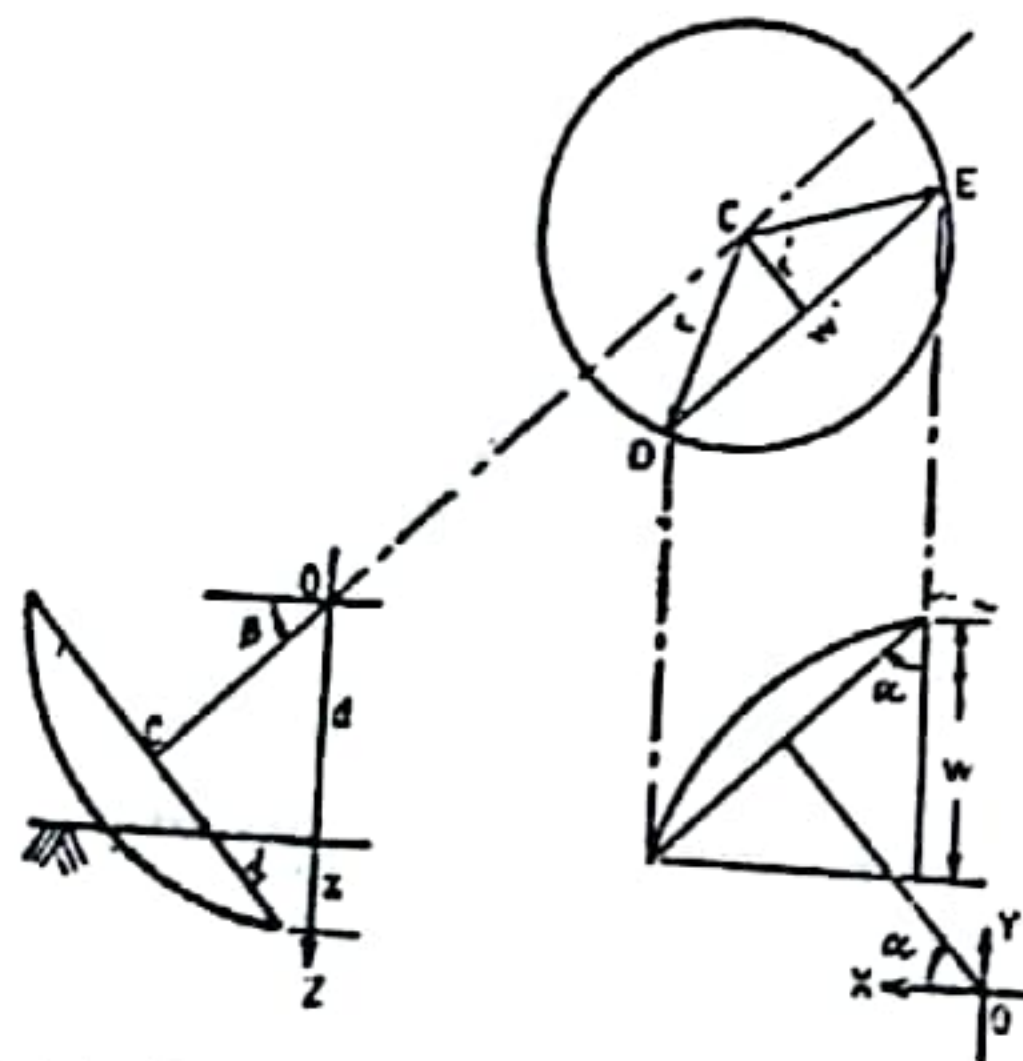


Fig 4 Width of cut in relation to disc setting.

Disc Rear Face Scrubbing

The disc working surface is a part of a sphere. At any instant the lower part of the disc face cuts the soil layer, deforms it and moves along its working surface. When a disc operates at large disc and inclination angles the rear face of the disc starts scrubbing with furrow wall or at the bottom of the furrow. Under these circumstances compaction takes place rather than soil loosening, which causes a great increase in draught force as well as vertical and lateral force requirements. Thus, the nature of soil reaction on a disc implement mainly depends on the disc setting, which is fixed by the disc angle, inclination angle and depth of cut. The disc geometry has also an effect on the nature of soil reaction. The transition between the concave to convex section soil reaction can be explained from Fig. 5. In Fig. 5a, the disc setting is such that the total soil reaction is on the concave side, in Fig. 5b, the disc setting is such that the rear face scrubbing is about to start and in Fig. 5c, the disc has both concave and convex (scrubbing) soil reaction. So, it is evident that if any point on the disc edge circle in contact with the soil crosses the Y-Z axis plane the rear face of the disc starts scrubbing.

A moving co-ordinate system $CXYZ$ (Fig. 6) can be used to study the scrubbing criteria with the changes in disc angle, disc inclination and depth of cut. Assuming the origin coincides with the centre of circular cutting edge of the disc (disc centre); CX is the direction of travel of the assembly; CY and CZ are the transverse and vertical directions respectively. An auxiliary system of co-ordinates CX_1Y_1Z can be formed by rotating the axes CX and CY through an angle $90^\circ - \alpha$ with respect to the Z axis and the system of co-ordinate $CX_1Y_2Z_1$ can be formed by rotating the axes CY_1 and CZ through an angle of β with respect to CX_1 . Axes CX_1 and CZ_1 are in the plane of the disc cutting edge.

Each point on the edge of the disc describes a circle and 'r' is the radius of that circle. Taking any point on the disc circle at an angle θ measured clockwise from the horizontal disc radius. Therefore, the co-ordinates of the point in $CX_1Y_2Z_1$ co-ordinate axes can be determined as :

$$X_1 = r \cos \theta$$

$$Y_2 = 0$$

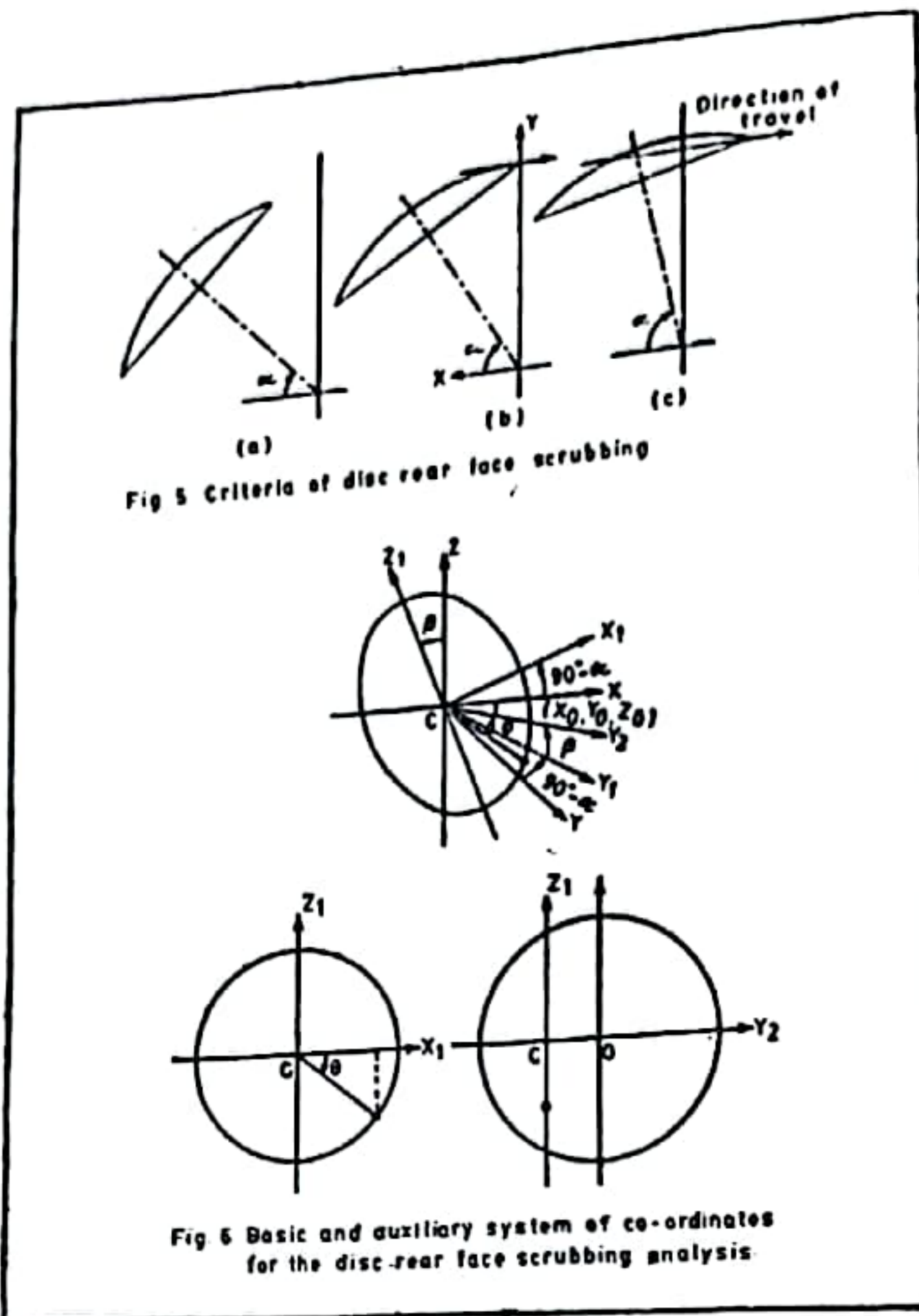
$$Z_1 = -r \sin \theta$$

Rotating co-ordinate axes CY_2 and CZ_1 with respect to CX_1 axis through an angle β and then axes CX_1 and CY_1 about the CZ axis through an angle $90^\circ - \alpha$ (Fig. 6), the co-ordinates of the given point on the disc cutting edge in the system of co-ordinates $CXYZ$ can be found out as :

$$X_0 = r \cos \theta \sin \alpha + r \sin \theta \cos \alpha \sin \beta$$

$$Y_0 = r \sin \theta \sin \alpha \sin \beta - r \cos \theta \cos \alpha$$

$$Z_0 = -r \sin \theta \cos \beta$$



The co-ordinates of the disc centre (X_c, Y_c, Z_c) with respect to the co-ordinate axes at the centre of the sphere have been determined earlier. Now, the co-ordinate of the given point on the disc cutting edge with respect to the reference co-ordinate axes at the sphere centre can be determined as :

$$\begin{aligned} X_o &= X_c - X_0 \\ Y_o &= Y_c - Y_0 \\ Z_o &= Z_c - Z_0 \end{aligned}$$

It has been observed from the cutting action of a disc implement, that scrubbing on the rear face of the disc occurs when any point on the disc cutting edge crosses the Y-Z axes plane. The situation occurs only when the value of X_o is negative for any point at the edge of the disc cutting surface in contact with the soil. Therefore, scrubbing will occur when the value of X co-ordinate of any point on the disc cutting edge in contact with soil is less than zero ($X_o < 0$). The maximum disc or tilt angle at which the disc rear face starts scrubbing may be called as the critical disc or tilt angle.

CONCLUSION

The attitude angles of a disc implement have been redefined in reference to the co-ordinate axes at the centre of the sphere. This provides an analytical basis for determining the disc operating parameters e. g. width of cut, disc rear face scrubbing, critical range of disc and tilt angles. It is hoped that this analysis will provide a better understanding about the influence of disc geometry and operating parameters on soil-disc interaction.

NOTATION

- a Distance between the disc and sphere centres.
- C Centre of the disc face circle.
- d Distance between the horizontal soil surface and the sphere centre.
- O Origin of the reference co-ordinate system (at sphere centre).
- R Radius of the disc sphere.
- r Radius of the disc face circle.
- W Width of cut.
- X X-axis in physical plane.
- Y Y-axis in physical plane.
- Z Z-axis in physical plane.
- z Depth of cut.
- X_0 X co-ordinate of a given point on disc cutting edge with reference to sphere centre.
- Y_0 Y co-ordinate of a given point on disc cutting edge with reference to sphere centre.
- Z_0 Z co-ordinate of a given point on disc cutting edge with reference to sphere centre.
- X_c X co-ordinate of the disc centre.
- Y_c Y co-ordinate of the disc centre.
- Z_c Z co-ordinate of the disc centre.
- X_θ X co-ordinate of a given point on the disc edge circle with reference to CXYZ axes.
- Y_θ Y co-ordinate of a given point on the disc edge circle with reference to CXYZ axes.
- Z_θ Z co-ordinate of a given point on the disc edge circle with reference to CXYZ axes.
- X_1 X co-ordinate of a given point on the disc edge circle with reference to $CX_1Y_2Z_1$ axes.
- Y_2 Y co-ordinate of a given point on the disc edge circle with reference to $CX_1Y_2Z_1$ axes.
- Z_1 Z co-ordinate of a given point on the disc edge circle with reference to $CX_1Y_2Z_1$ axes.
- α Disc angle.

- α' Projected disc angle.
- β Disc inclination angle.
- β' Projected inclination angle.
- θ Angle of any point on the disc circle measured clockwise from the horizontal disc radius.

REFERENCE

- Alam, M. M. (1989). "Soil Reaction Forces on Agricultural Disc Implement". Ph. D. thesis, University of Newcastle upon Tyne, NE1 7RU, England, United Kingdom.