Soil Tillage

ASAE Standard EP291.2 Terminology and Definitions for Soil Tillage and Soil-Tool Relationships
ASAE Standard S414.1 Terminology and Definitions for Agricultural Tillage Implements

Tillage Equipment

- **Primary Equipment**
  - Moldboard Plows (Mouldboard Ploughs)
    - Gunnel, Share, Shin, Moldboard, Landside, Heel
    - Down Suction from the plow
  - Disk Plows
    - Gang Angle, Disk Angle(42-45 deg), Tilt Angle (15-25 deg)
    - Hard soils, non-scouring soils
    - 180-540 kg/disk
  - Chisel Plow / Subsoiler
    - Shanks, straight shanks, curved shanks
    - V-Frame
  - Rotary Tillers
    - PTO driven, High Power Requirements, Low Traction requirements
    - Single Pass operation
- **Secondary Tillage**
  - Disk Harrows
    - Single-acting, Tandem, Offset
  - Cultivators
    - Field, Row crop
  - Spike, Tine and Spring Tooth Harrows
  - Rotary Hoes and Cultivators
  - Culti-packers, Rollers

Soil Tillage : Soil Classification

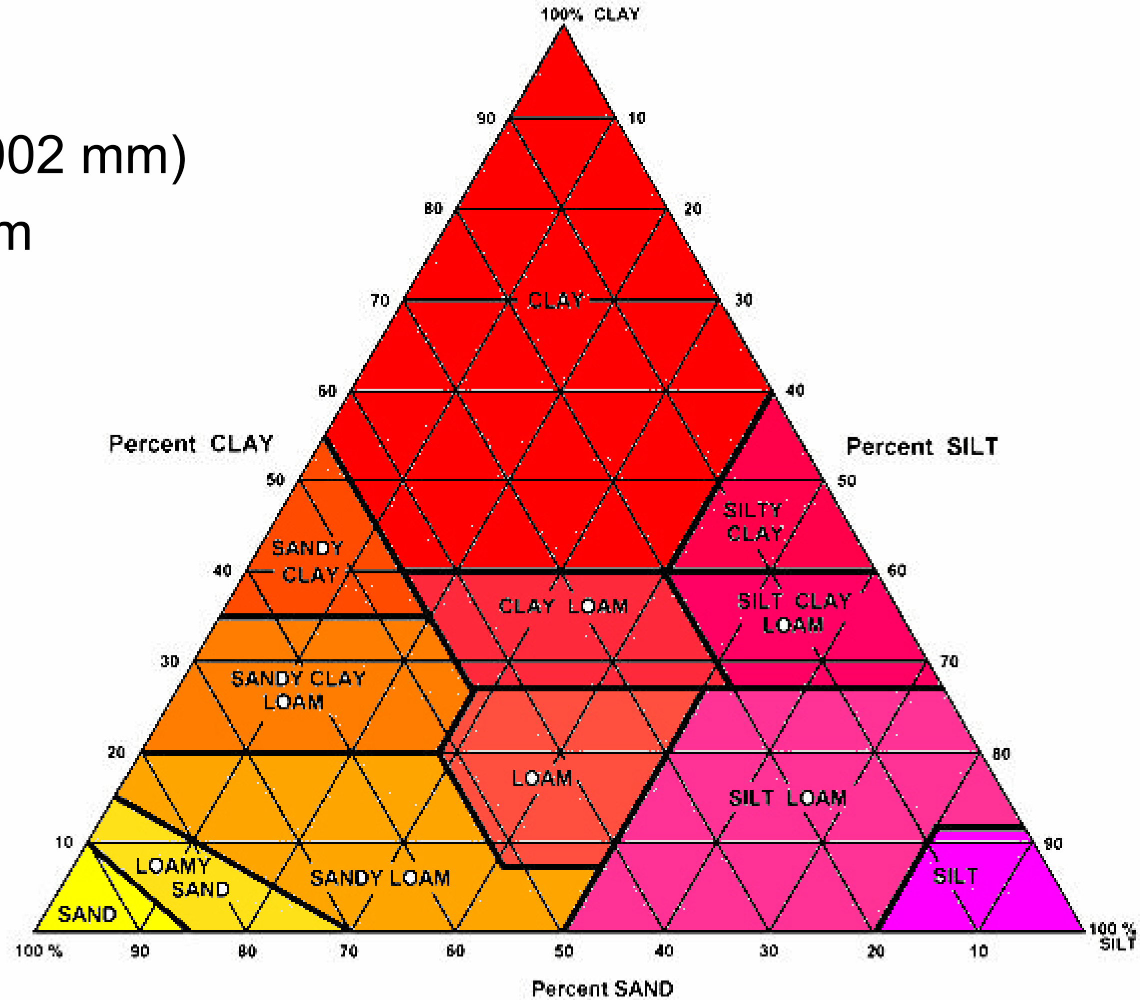
Soil Classification

Clay, 2 micron, (0.002 mm)

Silt, 0.002 – 0.05mm

Sand, 0.05 – 2mm

Gravel, 2- 64 mm



Textural Classification

Soil Tillage: Physical Properties

Porosity (n) is the ratio of the void volume (V_v) to the total volume (V) of the soil

$$n = (V_v) / (V)$$

Void Ratio (e) is the ratio of the void volume (V_v) to the solid volume (V_s) of the soil

$$e = (V_v) / (V_s)$$

Water Content (w) is the ratio of the mass of water (m_w) to the mass of solids (m_s)

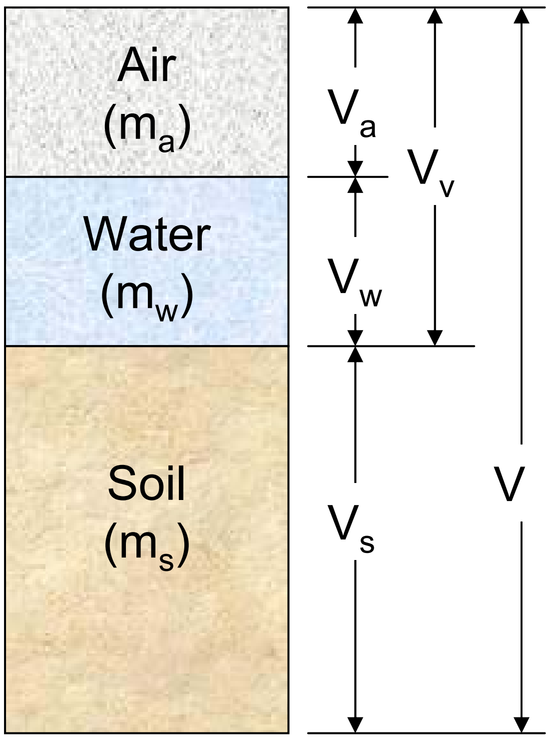
$$w = (m_w) / (m_s)*100$$

Degree of Saturation (S_r) is the percent of void space (V_v) occupied by water (V_w)

$$S_r = (V_w) / (V_v) *100$$

Field Capacity: Field capacity is the water content of a soil at which the gravitational pull on the water is matched by the capillary action (33 KPa).

Wilting Piont: Is the moisture content at which the plant cannot remove any further water from the soil (1.5 MPa)



Soil Tillage: Physical Properties

Bulk Density (γ) is the total mass (m) of the soil divided by the total volume (V) of the soil

$$\boldsymbol{\gamma} = (m) / (V) = (m_s + m_w) / V$$

Dry Bulk Density (γ_d) is the mass of the soils (m_s) of the soil divided by the total volume (V) of the soil

$$\gamma_d = (m_s) / V$$

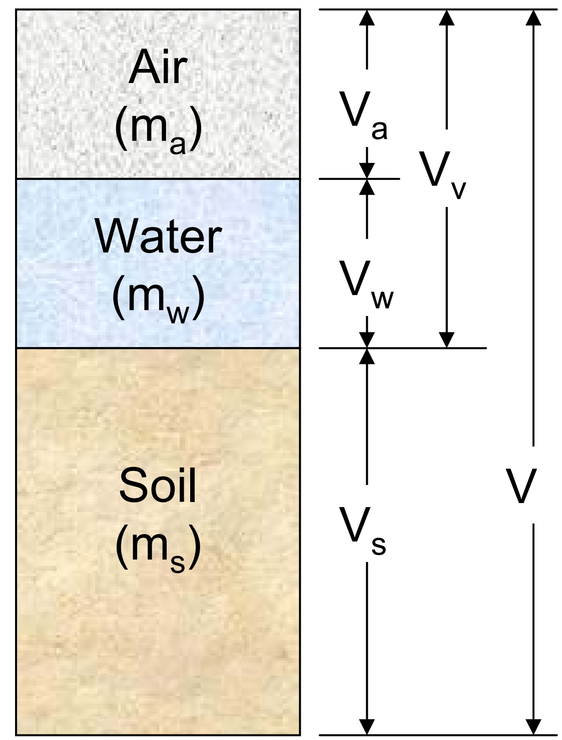
Particle Density (γ_s) is the mass of the soils (m_s) of the soil divided by the solid volume (V_s) of the soil

$$\gamma_d = (m_s) / V_s$$

Particle density is approx. constant at 2.6 – 2.8 g/cm^3

Sand/Silt ≈ 2.65 g/cm^3 Clay ≈ 2.75 g/cm^3

Organic Matter ≈ 1.37 g/cm^3



Root Limiting Bulk Density

Sand ≈ 1.8 g/cm3

Loam ≈ 1.55 g/cm3

Clay ≈ 1.4 g/cm3

Mechanical Properties of Soil: Shear Strength

Mohr-Coulomb Failure Theory: Failure in a material occurs if the shear stress on any plane equals the shear strength (s) of the material, and is a function of the normal stress (σ) on the plane

$$s = c + \sigma \tan(\Phi)$$

S = Shear Stress

c = cohesion

Φ = angle of internal friction

Mechanical Properties of Soil: Shear Strength

Mohr-Coulomb Failure Theory: Failure in a material occurs if the shear stress on any plane equals the shear strength (s) of the material, and is a function of the normal stress (σ) on the plane

$$s = c + \sigma \tan(\Phi)$$

S = Shear Stress

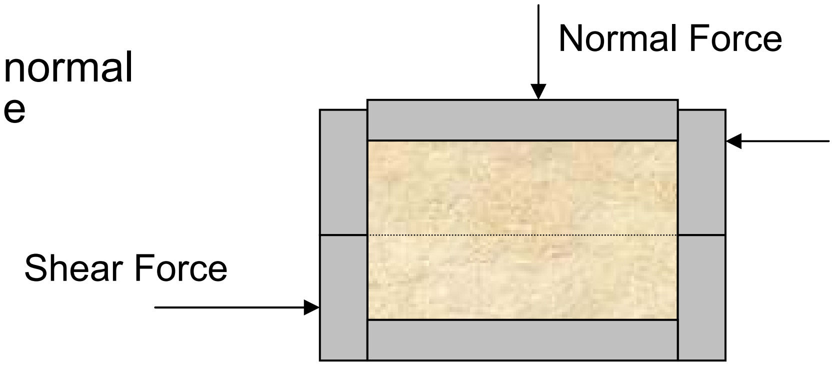
c = cohesion

Φ = angle of internal friction

Mechanical Properties of Soil: Shear Strength

Direct Shear Test: Number of tests with different normal stress are conducted and a straight line fitted to the information.

$$s = c + \sigma \tan(\Phi)$$

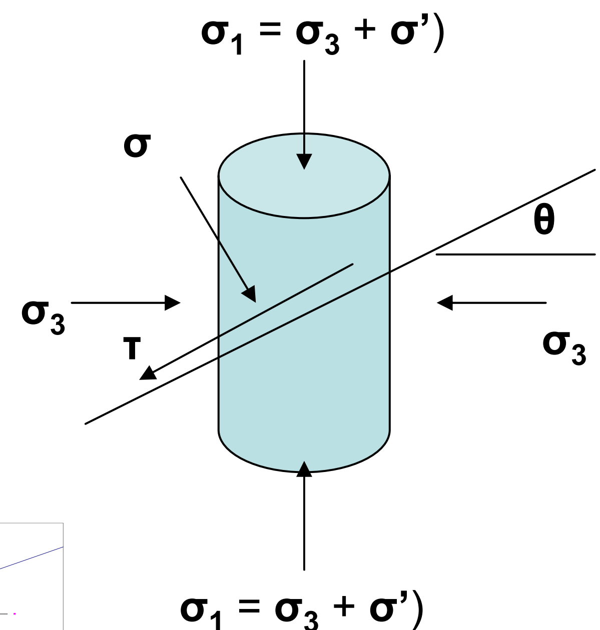


Triaxial Test: Expensive test apparatus used to apply a hydrostatic stress (σ_3) around the core, then and total normal stress ($\sigma_1 = \sigma_3 + \sigma'$) applied until failure, and the angle of the failure plane measured (θ).

$$\sigma = (\sigma_1+\sigma_3)/2 + (\sigma_1-\sigma_3)/2 * \cos(2\theta)$$

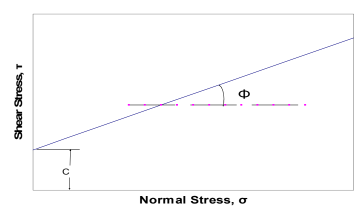
$$\tau = (\sigma_1-\sigma_3)/2 * \sin(2\theta)$$

$$\theta = (\pi/2+\Phi)/2$$



Must be repeated with hydrostatic pressures, and fitted to line.

$$s = c + \sigma \tan(\Phi)$$



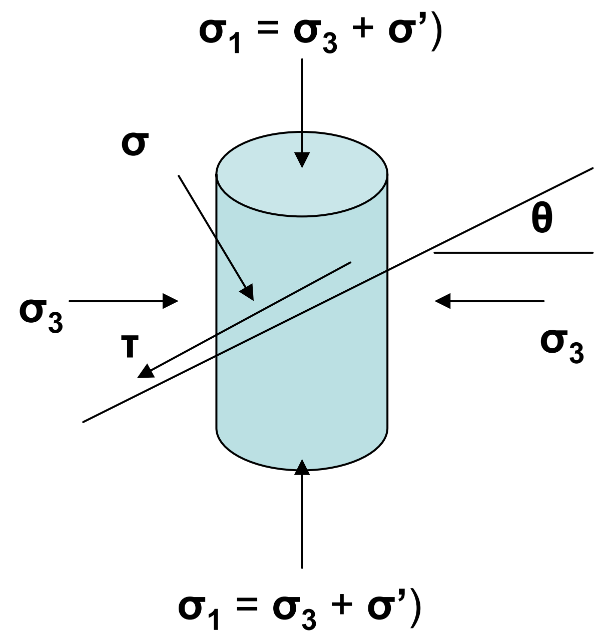
Mohr Circle, Principle Stresses

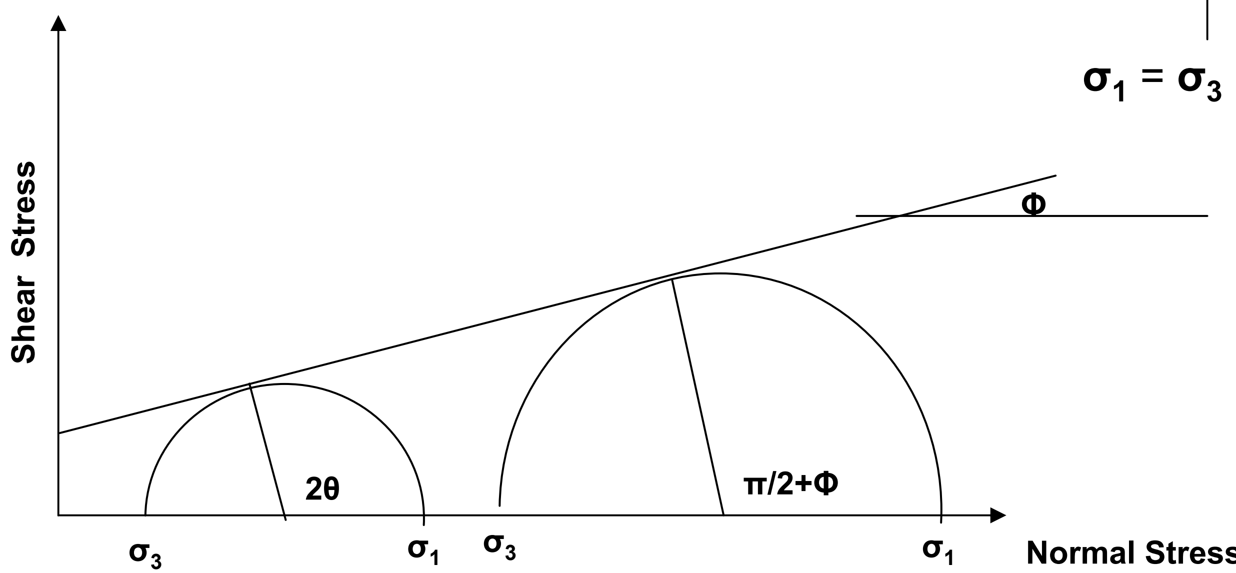
Triaxial Test: Expensive test apparatus used to apply a hydrostatic stress (**σ_3**) around the core, then and total normal stress (**σ_1 = σ_3 + σ'**) applied until failure, and the angle of the failure plane measured (**θ**).

$$\sigma = (\sigma_1+\sigma_3)/2 + (\sigma_1-\sigma_3)/2 * \cos(2\theta)$$

$$\tau = (\sigma_1-\sigma_3)/2 * \sin(2\theta)$$

$$\theta = (\pi/2+\Phi)/2$$

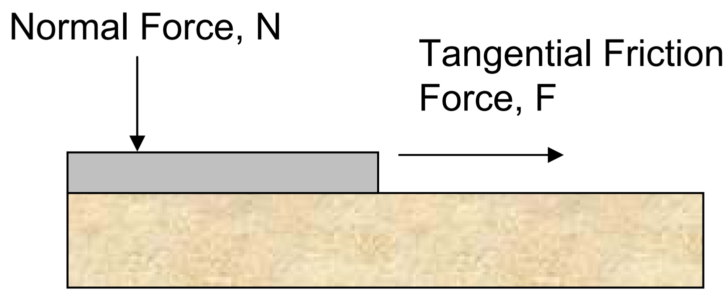




Forces in soil Dynamics: Friction and Adhesion

Types of Friction:

- **Soil-Metal Friction (μ')**
- **Soil-Soil Friction (μ)**
- **Soil Internal Friction tan(Φ)**



<u>Coulomb Friction</u>: The friction coefficient (μ) is defined as tangential friction force (F) divided by the normal force (N). The friction coefficient is also equal to the tangent of the friction angle (ψ)

$$\mu = F/N = \tan(\psi)$$

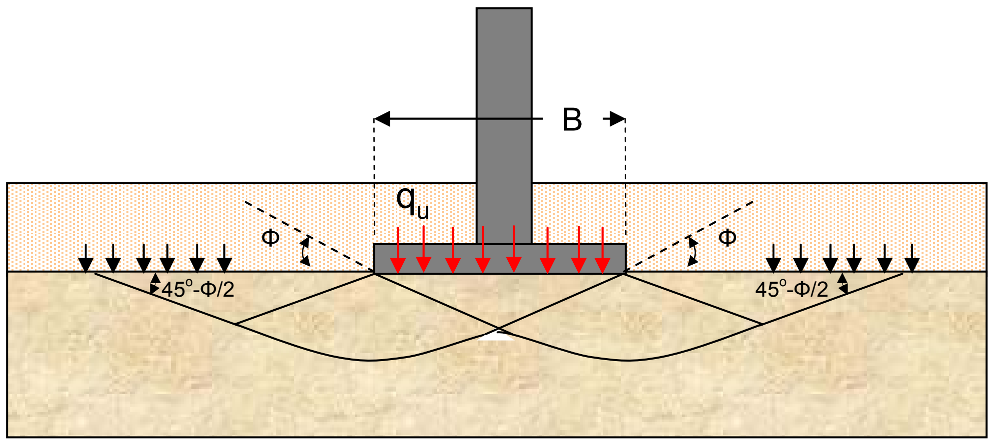
<u>Adhesion</u>: The forces of attraction between two different bodies. In soils a result of surface tension of free and bound water on the soil particles. Cannot be separated from the friction force.

<u>Apparent coefficient of friction</u>:

$$F = a*C_\alpha + N*\tan(\psi)$$

a = area, C_α = Adhesion ψ = friction angle

Bearing Capacity of Soils (Terzaghi, 1943)



$$\mathbf{q_u = c^*N_c + q^*N_q + 0.5^*\gamma^*B^*N_\gamma}$$

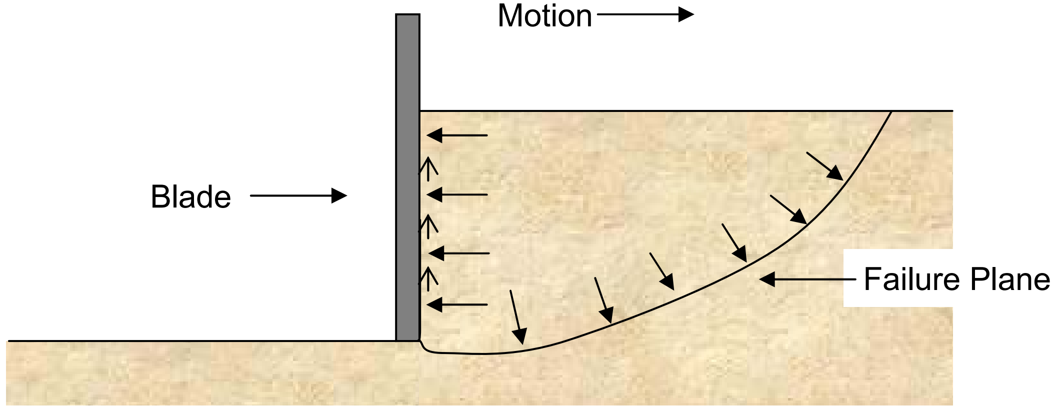
q_u = Ultimate bearing capacity
c = soil cohesion
q = surcharge pressure ($q = \gamma^*D$)
γ = Bulk density
D = Depth to footing base
B = Width of footing

Possible Dimensionless Factors (Vesic, 1973)

$N_c = \exp[\pi^*\tan(\Phi)]^*\tan[(90-\Phi)/2]$
$N_q = (N_c - 1)^*\cot(\Phi)$
$N_\gamma = 2(N_c - 1)^*\tan(\Phi)$

N_c , N_q , N_γ = Dimensionless Bearing Factors

Earthmoving Equation (Reece, 1965)



$$P = c*z*b*K_c + q*z*b*K_q - \gamma*z^2*b*K_\gamma + c_a*z*b*K_a$$

P = Total force on bladeUltimate bearing capacity

c = soil cohesion

q = surcharge pressure on failure surface

γ = Bulk density

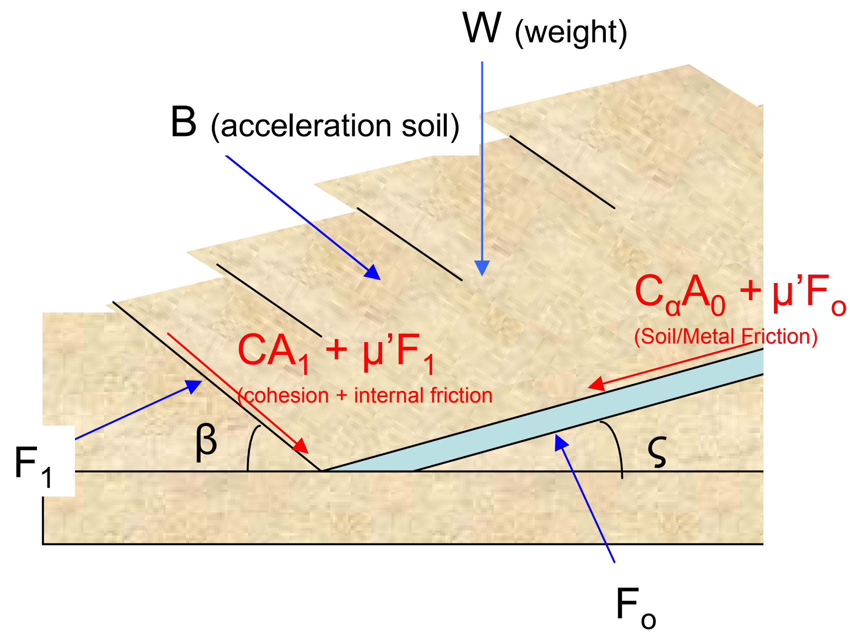
c_a = adhesion of soil to metal blade

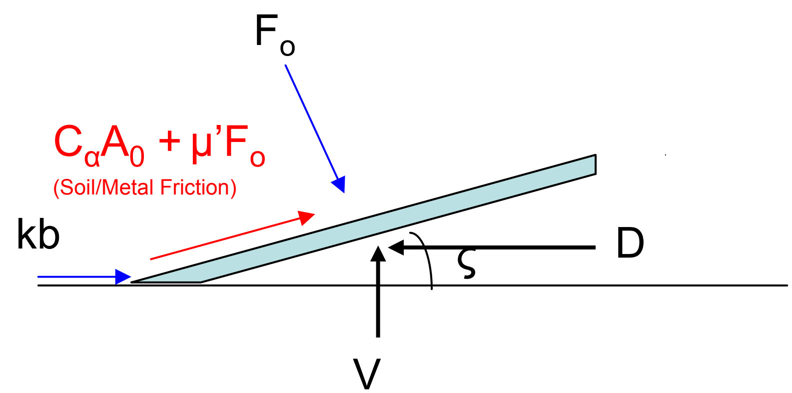
z = Depth cutting blade

b = Width of blade

K_c , K_q , K_γ K_a = Dimensionless Earthmoving Factors

Forces in acting on a simple tool

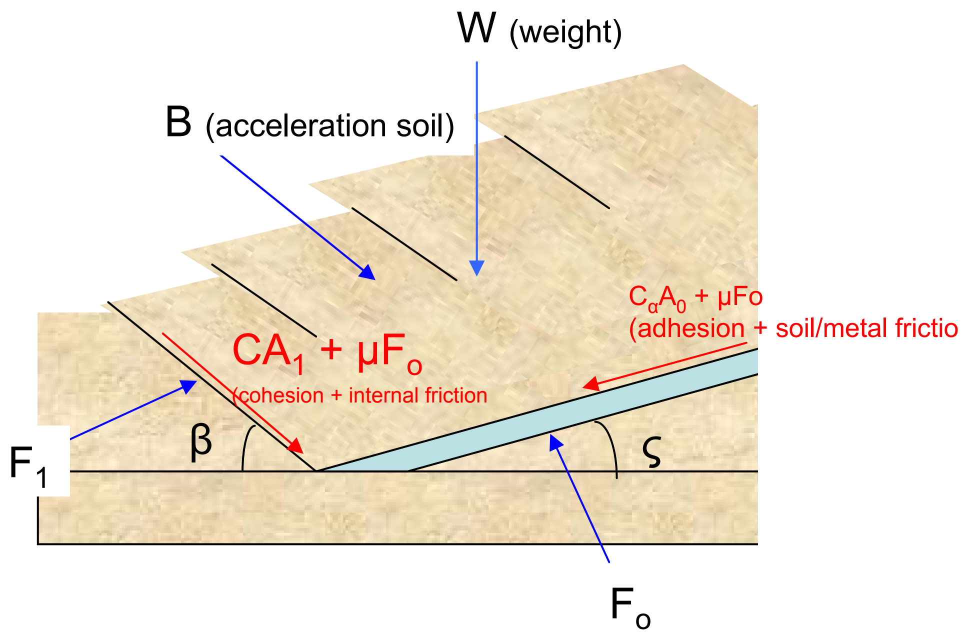


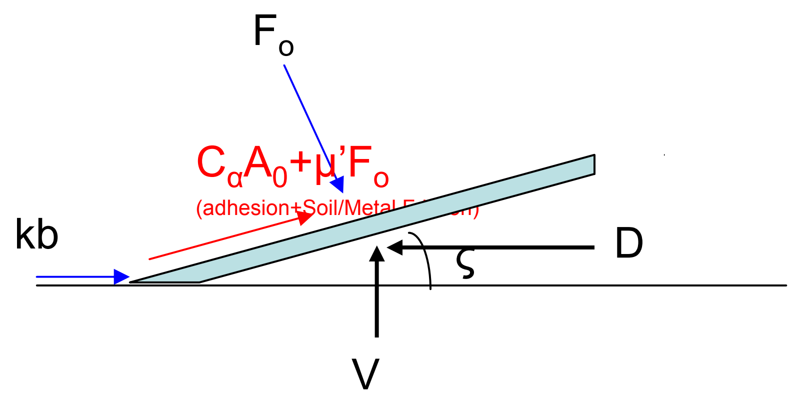


Forces acting on a simple Tool

1. Soil Shear and Cohesion, $CA_1 + \mu F_1$
2. Soil Metal Friction and adhesion, $C_\alpha A_0 + \mu' F_0$
3. Soil cutting Force, kb
4. Soil Acceleration Forces, B

Analysis of Forces (1)





Horizontal Forces on Soil

$F_o*[\sin(\varsigma)+\mu'\cos(\varsigma)] - F_1*[\sin(\beta)+\mu\cos(\beta)] -$
$[CA_1+B]\cos(\beta) + [C_\alpha A_0]\cos(\delta) = 0$ ....(Eqn. 1)

Vertical Forces on Soil

$W - F_o*[\cos(\varsigma)-\mu'\sin(\varsigma)] - F_1*[\cos(\beta)-\mu\sin(\beta)] +$
$[CA_1+B]\sin(\beta) + [C_\alpha A_0]\sin(\delta) = 0$ ....(Eqn. 2)

Horizontal Draft Forces

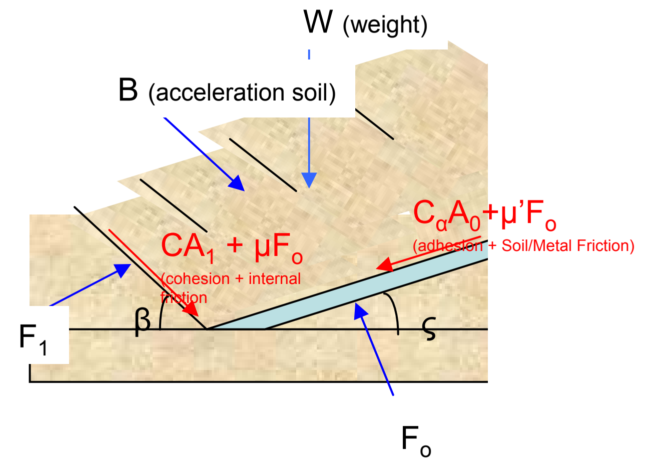
$D = F_o*[\sin(\varsigma)+\mu'\cos(\varsigma)] +$
$[C_\alpha A_0]\cos(\delta) + kb$

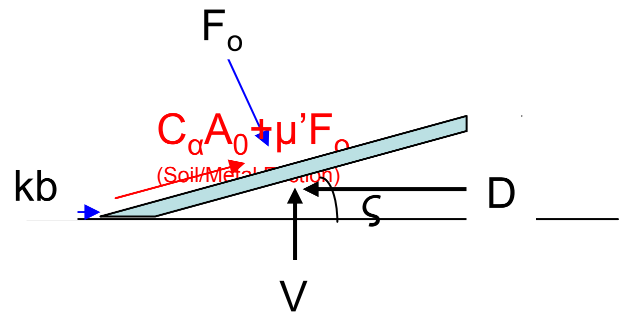
$D^{\ddagger} = F_o*[\sin(\varsigma)+\mu'\cos(\varsigma)] +$
$[C_\alpha A_0]\cos(\delta)$ ....(Eqn. 3)

Vertical Forces on Tool

$V = F_o*[\cos(\varsigma)+\mu'\sin(\varsigma)] +$
$[C_\alpha A_0]\sin(\delta)$ ......(Eqn. 4)

Analysis of Forces (2)





Solve for F_o using eqn.3

$$\mathbf{F_o = [D^{\ddagger}+C_\alpha A_0\cos(\delta)] / [\sin(\varsigma)+\mu'\cos(\varsigma)]}$$

Substitute F_o in eqn 1 to find F_1

$$F_1*[\sin(\beta)+\mu\cos(\beta)] = F_o*[\sin(\varsigma)+\mu'\cos(\varsigma)] – [CA_1+B]\cos(\beta) - [C_\alpha A_0]\cos(\delta)$$

$$F_1*[\sin(\beta)+\mu\cos(\beta)] = \{[D^{\ddagger}+C_\alpha A_0\cos(\delta)] /[\sin(\varsigma)+\mu'\cos(\varsigma)] \} * \{[\sin(\varsigma)+\mu'\cos(\varsigma)]\} – [CA_1+B]\cos(\beta) - [C_\alpha A_0]\cos(\delta)$$

$$F_1*[\sin(\beta)+\mu\cos(\beta)] = D^{\ddagger} – [CA_1+B]\cos(\beta)$$

$$\underline{\mathbf{F_1= \{D^{\ddagger} – [CA_1+B]\cos(\beta)\}/ \{\sin(\beta)+\mu\cos(\beta)\}}}$$

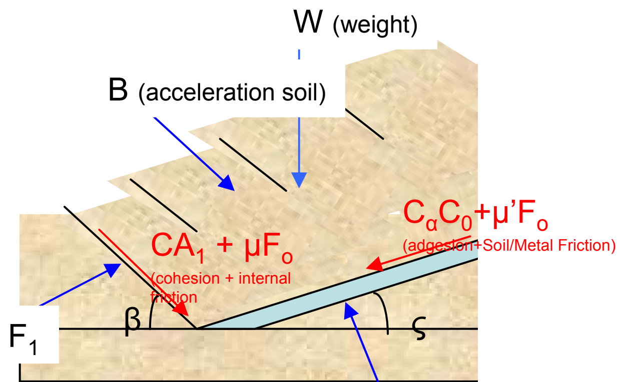
Substitute F_o & F_1 in Vertical Forces (eqn2)

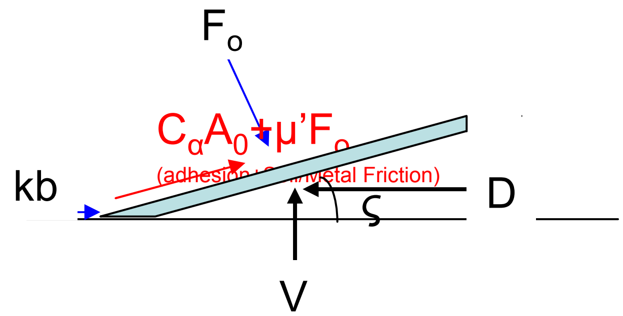
$$W - F_o*[\cos(\varsigma)-\mu'\sin(\varsigma)] – F_1*[\cos(\beta)-\mu\sin(\beta)] + [CA_1+B]\sin(\beta) + [C_\alpha A_0]\sin(\delta) = 0$$

$$\{D^{\ddagger}/[\sin(\varsigma)-\mu'\cos(\varsigma)] \} *[\cos(\varsigma)+\mu'\sin(\varsigma)] –$$
$$\{D^{\ddagger}–[CA1+B]\cos(\beta)\}/ \{\sin(\beta)+\mu\cos(\beta)\} *[\cos(\beta)-\mu\sin(\beta)] = W + [CA_1+B]\sin(\beta) + [C_\alpha A_0]\sin(\delta)$$

$$D^{\ddagger}*\{[\cos(\varsigma)-\mu'\sin(\varsigma)]/[\sin(\varsigma)+\mu'\cos(\varsigma)] + [\cos(\beta)-\mu\sin(\beta)]/[\sin(\beta)+\mu\cos(\beta)] = W + [CA_1+B]/[\sin(\beta)+ \mu\cos(\beta)] + [C_\alpha A_0]/[\sin(\delta)+ \mu\cos(\delta)]$$

Analysis of Forces (3)





$$D^{\ddagger}*\{[\cos(\varsigma)-\mu'\sin(\varsigma)]/[\sin(\varsigma)+\mu'\cos(\varsigma)] + [\cos(\beta)-\mu\sin(\beta)]/[\sin(\beta)+\mu\cos(\beta)] = W + [CA_1+B]/[\sin(\beta)+ \mu\cos(\beta)] + [C_\alpha A_0]/[\sin(\delta)+ \mu\cos(\delta)]$$

Let $Z = [\cos(\varsigma)-\mu'\sin(\varsigma)]/[\sin(\varsigma)+\mu'\cos(\varsigma)] + [\cos(\beta)-\mu\sin(\beta)]/[\sin(\beta)+\mu\cos(\beta)]$

$$D^{\ddagger *}Z = W + [CA_1+B]/[\sin(\beta)+ \mu\cos(\beta)] + [C_\alpha A_0]/[\sin(\delta)+ \mu\cos(\delta)]$$

$$\mathbf{D^{\ddagger} = W/Z + [CA_1+B]/\{Z*[\sin(\beta)+ \mu\cos(\beta)]\} + [C_\alpha A_0]/\{Z*[\sin(\delta)+ \mu'\cos(\delta)]\}}$$

Where: $\mu = \tan(\Phi)$, **and** $\beta = (90- \Phi)/2$

<u>Now to find W and A_1</u>

$$\mathbf{W = g*\gamma*b*d^{\ddagger} * [L_o+(L_1+L_2)/2]}$$

g = gravity

γ = Bulk density (kg/m^3)

b = tool width (m)

d = depth (m)

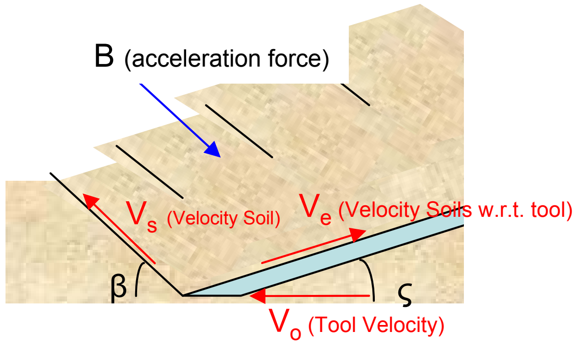
$d^{\ddagger} = d*[\sin(\varsigma+\beta)]/ \{\sin(\beta)\}$

$L_1 = d*[\cos(\varsigma+\beta)]/ \{\sin(\beta)\}$

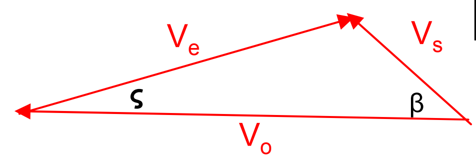
$L_1 = d^{\ddagger} *\tan(\beta)$

$$\mathbf{A_1 = d*b/\{\sin(\beta)\}}$$

Analysis of Forces (4): Acceleration Force



Vector addition of Velocity
($V_s = V_o + V_e$)



Velocity Defined as
V_s Velocity soil w.r.t ground
V_o Velocity of tool w.r.t ground
V_e Velocity of soil w.r.t tool
(i.e. soil sliding along tool surface)

Newton's second Law

$$\mathbf{B = m*dV_s/dt}$$

Finding mass of soil

$$\mathbf{m = \gamma*d*b*t_0*V_0}$$

m=mass soil, γ=Bulk Density,
d=depth, d=width,
g=gravity
t_0 = average time soil engaged by tool,
V_0 = tool velocity

$B = \gamma*d*b*(V_0)^2*[\sin(\varsigma)]/[\sin(\varsigma + \beta)]$

Using Vector Addition of velocity

$V_o = V_s \cos(\beta) + V_e \cos(\varsigma)$ …………..Eqn 1

$V_s \sin(\beta) = V_e \sin(\varsigma)$ …………………Eqn 2

Solving for V_s

$$V_s = V_o \sin(\varsigma)/\sin(\varsigma + \beta)$$

Now assuming

$$dV_s/dt = \Delta V_s / \Delta t = (V_s-0)/(t_o-0) = (V_s)/(t_o)$$

Solving for dV_s/dt

$$dV_s/dt = [V_o \sin(\varsigma)]/[t_o*\sin(\varsigma + \beta)]$$

ASAE D497.4 FEB03
Agricultural Machinery Management Data

$$D = F_i[A + B(S) + C(S)^2]WT$$

where:

D is implement draft, N (lbf);

F_i is a dimensionless soil texture adjustment parameter (table1);

i = 1 for fine, 2 for medium and 3 for coarse textured soils;

A, B and **C** are machine-specific parameters (table1);

S is field speed, km/h (mile/h).

W is machine width, m (ft) or number of rows or tools (table1);

T is tillage depth, cm (in.) for major tools,

1 (dimensionless) for minor tillage tools and seeding implements.