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## APPENDIX A.

### Determination of angles between the rupture plane and the soil surface for the centre wedge.

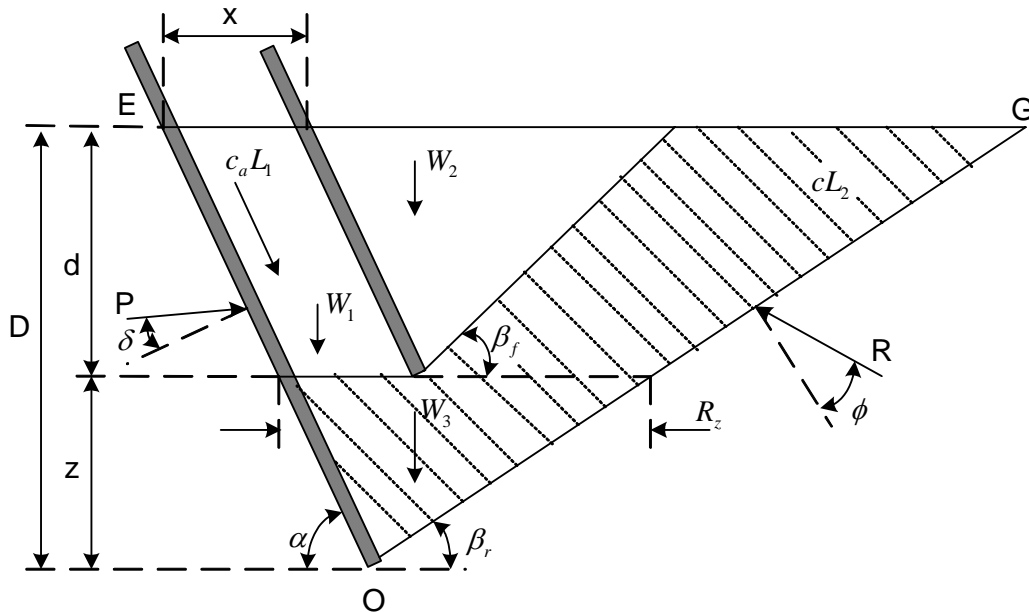


Figure A1: Soil centre wedge failed by the two subsoilers.

To determine  $\beta_f$  and  $\beta_r$  the following situations were considered:

1.  $0 \leq x \leq 150 \text{ mm}$ .

The 150 mm limit was arbitrary chosen as the point when the developed soil-failure pattern for the front subsoiler was likely to be well noted. In this range the two subsoilers are too close to each other that they were regarded as a single unit.

Thus  $\beta_f = \beta_r = \beta$ . Then  $\beta$  is determined by the following expression (McKyes, 1989 p.160):

$$\cot \beta = \left\{ \sqrt{\frac{\sin(\alpha + \delta) \sin(\delta + \phi)}{\sin \alpha \sin \phi}} - \cos(\alpha + \delta + \phi) \right\} \frac{1}{\sin(\alpha + \delta + \phi)} \dots \dots \dots A1.$$

## 2. $150 < x \leq R_z$ .

From figure 1:

$$W_1 = \gamma d.x.w \dots\dots\dots A2.$$

$$W_2 = 0.5 \gamma d w (\cot\alpha + \cot\beta_f) \dots\dots\dots A3.$$

$$W_3 = 0.5 \gamma D w (\cot\alpha + \cot\beta_r) - (W_1 + W_2) \dots\dots\dots A4.$$

Where:

d = Operating depth of the front subsoiler (mm)

D = Operating depth of the rear subsoiler (mm)

z = Effective operating depth of the rear subsoiler in undisturbed soil (mm).

w = Tool width (mm).

$W_1$  = Weight of soil between the subsoilers (N).

$W_2$  = Weight of soil failed by the front subsoilers (N).

$W_3$  = Weight of soil disturbed by the rear subsoilers (N).

x = Projected spacing between the two subsoilers (m).

$\gamma$  = Undisturbed soil unit weight ( $N/m^3$ ).

There is a minimal change in soil volume when it is disturbed but its weight essentially remains the same. The undisturbed soil unit weight was therefore regarded equal to disturbed soil unit weight and the percentage swell was ignored.

If the front subsoiler carries  $W_2$  then the rear subsoiler carries  $W_1$  and  $W_3$ .

$$W_1 + W_3 = P \cos(\alpha + \delta) - c_a L_1 \sin \alpha - c L_2 \sin \beta_r + R \cos(\beta_r + \phi) \dots\dots\dots A5.$$

$$P \sin(\alpha + \delta) = R \sin(\beta_r + \phi) - c_a L_1 \cos \alpha + c L_2 \cos \beta_r \dots\dots\dots A6.$$

Solving for R in equation A5:

$$R = \left[ \frac{W_1 + W_3 - P \cos(\alpha + \delta) + c_a L_1 \sin \alpha + c L_2 \sin \beta_r}{\cos(\beta_r + \phi)} \right]$$

Substituting R into equation A6:



$$P \sin(\alpha + \delta) \cos(\beta_r + \phi) = (W_1 + W_3 - P \cos(\alpha + \delta) + c_a L_1 \sin \alpha + c L_2 \sin \beta_r) + \cos(\beta_r + \phi)(c L_2 \cos \beta_r + c_a L_1 \cos \alpha) \dots \dots \dots A7.$$

Solving for P from equation A7:

$$P = \left\{ \frac{W_1 + W_3}{\cot(\phi + \beta_r) \sin(\alpha + \delta) + \cos(\alpha + \delta)} \right\} + \left\{ \frac{c L_2 [\cot(\phi + \beta_r) \cos \beta_r + \sin \beta_r]}{\cot(\phi + \beta_r) \sin(\alpha + \delta) + \cos(\alpha + \delta)} \right\} + \left\{ \frac{c_a L_1 [\sin \alpha - \cot(\phi + \beta_r) \cos \alpha]}{\cot(\phi + \beta_r) \sin(\alpha + \delta) + \cos(\alpha + \delta)} \right\} \dots \dots \dots A8.$$

Equation A8 can be written as follows:

$$P = P_p + P_{c1} + P_{c2}.$$

The value of  $\beta_r$ , which yields the minimum quantity for  $P_p$ , is the actual value for  $\beta_r$ . It is found by trial and error.

### 3. $x > R_z$

In figure A2, the centre-wedge failed by the front subsoiler is not shown since at this spacing the rear subsoiler has no influence over the front subsoiler. The front subsoiler leaves a loose overburden  $W_4$  of depth  $d$ .

From figure A2:

$$W_4 = 0.5 \gamma d w (R_z + R_r)$$

$$W_5 = 0.5 \gamma z w R_z$$

Where:

$$R_z = z (\cot \alpha + \cot \beta_r).$$

$$z = D - d.$$

In this range, the rear subsoiler carries  $W_4$  and  $W_5$ . Thus:

$$W_4 + W_5 = P \cos(\alpha + \delta) - cL_2 \sin \beta_r - c_a L_1 \sin \alpha + R \cos(\phi + \beta_r) \dots \dots \dots A9.$$

$$P \sin(\alpha + \delta) = R \sin(\phi + \beta_r) + cL_2 \cos \beta_r - c_a L_1 \cos \alpha \dots \dots \dots A10.$$

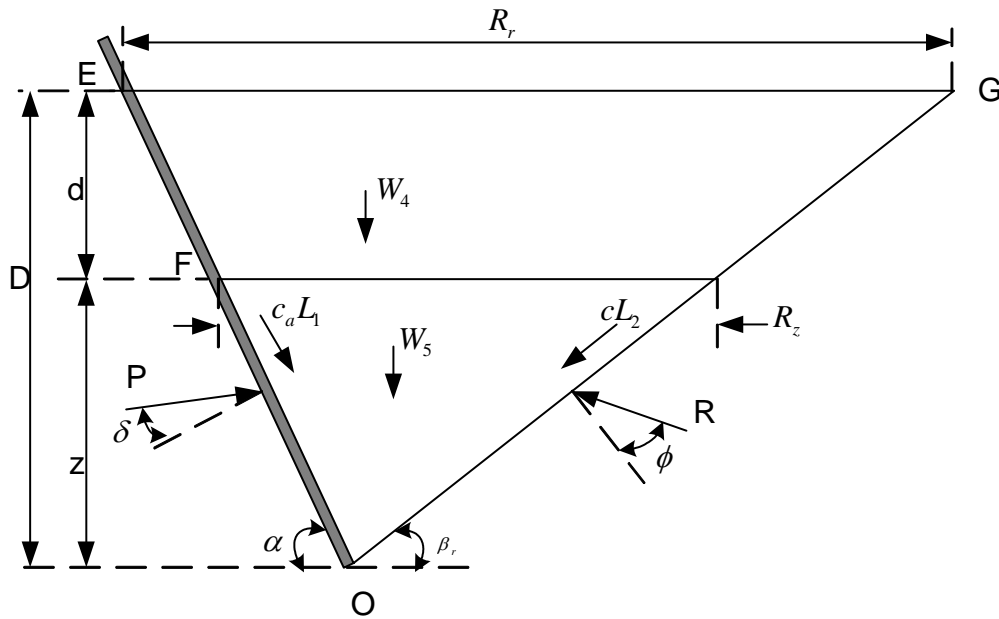


Figure A2: Soil centre-wedge failed by the rear subsoiler.

Solving for R in equation A9.

$$R = \left[ \frac{W_4 + W_5 - P \cos(\alpha + \delta) + c_a L_1 \sin \alpha + cL_2 \sin \beta_r}{\cos(\beta_r + \phi)} \right]$$

Substituting R into equation A10:

$$P \sin(\alpha + \delta) \cos(\beta_r + \phi) = (W_4 + W_5 - P \cos(\alpha + \delta) + c_a L_1 \sin \alpha + cL_2 \sin \beta_r) + \cos(\beta_r + \phi)(cL_2 \cos \beta_r - c_a L_1 \cos \alpha) \dots \dots \dots A11.$$

Solving for P in equation A11:

$$P = \left\{ \frac{W_4 + W_5}{\cot(\phi + \beta_r) \sin(\alpha + \delta) + \cos(\alpha + \delta)} \right\} + \left\{ \frac{cL_2 [\sin \beta_r + \cos \beta_r \cot(\phi + \beta_r)]}{\cot(\phi + \beta_r) \sin(\alpha + \delta) + \cos(\alpha + \delta)} \right\} + \left\{ \frac{c_a L_1 [\sin \alpha - \cos \alpha \cot(\phi + \beta_r)]}{\cot(\phi + \beta_r) \sin(\alpha + \delta) + \cos(\alpha + \delta)} \right\} \dots \dots \dots A12.$$

Equation A12 can be expressed as:

$$P = P_p + P_{c1} + P_{c2}.$$

$\beta_r$  is equal to the value yielding the minimum quantity for  $P_p$  as above.

A computer program was coded for equation A1 to calculate  $\beta_f$ . Thus  $\beta_f = 31.5^0$ . A similar computer program was coded for portion  $P_p$  of equations A8 and A12 to calculate  $\beta_r$  at the spacing specified in sections 1 and 2 respectively. Table A1 presents the values of  $\beta_r$  at different spacing and operating depths of the front subsoiler while that of the rear subsoiler was equal to 600 mm.

Based on the soil characteristics at the experimental site, the difference between  $\beta_f$  and  $\beta_r$  ranged from  $1.5^0$  to  $5^0$  (Table A1). This resulted in a maximum difference of three percent in predicting  $P$  and was assumed negligible. The two angles were therefore considered equal. Thus  $\beta_f = \beta_r = \beta = 32^0$ . This lead to a difference of three percent in the predicted values for  $P$ .

**Table A1: The values of  $\beta_r$  at different spacing and operating depth of the front subsoiler.**

Spacing= 300 mm		Spacing = 420 mm		Spacing = 540 mm		Spacing = 790 mm	
d mm	$\beta_r$ deg.	d mm	$\beta_r$ deg.	d mm	$\beta_r$ deg.	d mm	$\beta_r$ deg.
410	$35.5^0$	410	$34^0$	410	$33^0$	410	$30^0$
460	$34.3^0$	460	$32^0$	460	$30^0$	460	$28^0$
510	$29^0$	510	$29.5^0$	510	$27^0$	510	$26.6^0$

To derive equations for the side circular failure wedge in terms of  $P_p$ ,  $P_{c1}$  and  $P_{c2}$  will be much more complicated than for the centre wedge. It will probably not cause a difference of much more than four percent to the contribution of  $P$  for the side wedge and it was therefore accepted for the complete profile that  $\beta_r = \beta_f$ .

## APPENDIX B.

### Computer program: The proposed mathematical force model.

```

%Purpose: To calculate the components required for soil failure by the rear subsoiler and the failed-
%soil volume.
% Section 1: Calculate the draft and vertical force components required to fail the center wedge.
% Section 2: Calculate the draft and vertical force components required to fail the side wedges.
% Section 1.
%=====
% Define the following variables and coefficients.
% x = horizontal spacing between the two subsoilers (m).
% Q1 = surcharge pressure due soil failed by the front subsoiler (N).
% W1 = weight of the soil failed by the rear subsoiler (N).
% C1 = cohesion force at the rupture plane for the rear subsoiler (N).
% c = cohesion coefficients (N/m2).
% F1 = acceleration force exerted by the rear subsoiler (N).
%Ft= total frictional force acting on the sides of a subsoiler (N).
% H = draft force requirement of the rear subsoiler.(N)
%Hd = draft force required the 3-D soil profile (N).
%Hp = part of the draft that accounts for pulverizing the tilled soil (N).
% V1 = vertical force component acting on the rear subsoiler (N).
% Ca = adhesion force at the interface (N).
% ad = adhesion coefficient (N/m2).
% beta = angle between the rupture plane and the soil horizontal plane (degrees).
% alpha = rake angle (degrees).
% delta = interface friction angle (degrees).
% phi = soil internal friction angle (degrees).
% D = operating depth of the rear subsoiler (m)
% d = operating depth of the front subsoiler (m).
% z = effective operating depth of the rear subsoiler (m).
% Rr = rupture radius formed by the rear subsoiler (m).
% Rf = rupture radius formed by the front subsoiler (m).
% Rz = rupture radius formed by the rear subsoiler at depth, d (m).
% w = tool width (m).
% v = operating speed (m/s).
% g = gravitational constsnt , 9.81 m/s2.
% gamma = soil unit weight (N/m3).
% Vct = total soil volume failed by both subsoilers in the center wedge (m3)

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% Prompt the user for the following variables.
clc;
x = input('Enter the spacing variable, x: ');
d = input('Enter the depth variable, d: ');
D = input('Enter the depth variable, D: ');
v = input('Enter the speed variable, v: ');
swc = input('Enter the soil water content, swc: ');
% Define the following variables.
c = 11400;
ad = 7000;
beta = 32;
phi = 36;
delta = 25;
alpha = 37;
gamma = 19890;
w = 0.08;
g = 9.81;
% Calculate the following variables.
Rf = d*(cot(alpha*pi/180)+cot(beta*pi/180));
Rr = D*(cot(alpha*pi/180)+cot(beta*pi/180));
z = D - d;
Rz = z*(cot(alpha*pi/180)+cot(beta*pi/180));
% Determine the forces acting on the center wedge.
if (x>=0)&(x<Rz)
    Q1 = gamma*w*d*z;
    W1 = 0.5*gamma*w*(D*Rr-d*(Rf+2*x));
    C1 = c*w*D/sin(beta*pi/180);
    Ca = ad*w*z/sin(alpha*pi/180);
    F1 = gamma*z*w*v^2*sin(alpha*pi/180)/(g*sin((alpha+beta)*pi/180));
    Vct = 0.5*D*w*Rr;
else
    Q1 = 0.5*gamma*d*w*(Rf+2*Rz);
    W1 = 0.5*gamma*w*(D*Rr-d*(Rf+2*Rz));
    C1 = c*w*z/sin(beta*pi/180);
    F1 = gamma*D*w*v^2*sin(alpha*pi/180)/(g*sin(alpha+beta)*pi/180);
    Vct = 0.5*d*w*(2*x+Rf+z*Rz/d);
end
%Calculate the draft force, H1
J1 = sin(beta*pi/180)+cot((beta+phi)*pi/180)*cos(beta*pi/180);
J2 = cot((alpha+delta)*pi/180)+cot((beta+phi)*pi/180);

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```

H1 = ((Q1+W1+(C1+F1)*J1)-Ca*J1)/J2;
fprintf('The draft force H1 = %2.2f\n',H1)
%Calculate the vertical force component.
J4 = 1+cot((beta+phi)*pi/180)*tan((alpha+delta)*pi/180);
V1 = ((Q1+W1+(C1+F1)*J1)-Ca*J1)/J4;
fprintf('The vertical force component,V1 = %2.2f',V1)
%Compute soil volume,Vt1 failed by both subsoilers in the center wedge.
Vt1 = Vct;

%Section2
%=====
%Define the following variables
%theta = angle between the direction of travel and outer edge edge of the side wedge
(degrees)
%sr = maximum width of the rear side wedge (m).
%rho= angle (degrees).
%rho1 = angle (degrees).
%rho2 = angle (degrees).
%sigma = angle (degrees).
%d1 = distance (m).
%x1 = distance (m).
%Q2 = surcharge force (N)
%W2 = weight of soil disturbed by the rear subsoiler in each side wedge (N)
%C2 = cohesion force at the rapture plane (N).
%F2 = acceleration force (N).
%H2= draft force (N)
%Vst = total soil volume failed by the two subsoilers in the side wedge.
%Determine the variables.
n = -0.1413*swc;
sr = (1146.6*Exp(n))/100;
theta = asin(sr/Rr)*pi/180;
x1 = x-Rz;
h = x1/(cot(alpha*pi/180)+cot(beta*pi/180));
d1 = d - h;
t = sqrt(Rr^2-s^2)-Rr*cos(theta*pi/180);
J3 = J1/J2;
rho = ((theta/(t-Rz))*(x-Rz));
sigma = theta - rho;
L = (Rr^2 - Rr^2 + x^2)/(2*x*Rr);
rho1 = acos(L);

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```

rho2 = theta-(rho1-(180/pi)/(Rr-t)*(x-t));
%Determine the forces acting on the side wedge and volume of soil failed by
%both subsoilers.
if (x>=0)&(x<Rz)
    Q2 = gamma*Rf*d*(Rf+3*x*sin(theta8pi/180))*sin(theta*pi/180)/6;
    W2 = gamma*(D*Rr^2-Rf*d*(Rf+3*x*sin(theta*pi/180)))*sin(theta*pi/180)/6;
    C2 = c*D*Rr*sin(theta*pi/180)/2*sin(beta*pi/180);
    F2 = gamma*v^2*(D*Rr - Rf*d)*sin(beta*pi/180)*sin(theta*pi/180)...
        /(2*g*sin((alpha+beta)*pi/180));
    Vst = D*Rr^2*theta*pi/1080;
elseif (x>=Rz)&(x<t)
    Q2 = gamma*d*Rf*(Rz*sin(theta*pi/180)+x1*sin(theta*pi/180)*(1-n)...
        /(d*cos(beta*pi/180)))+d1*Rr*(Rf^2/Rr*(sigma*pi/180)+rho1*Rr - x...
        *sin(rho1))/(3*d*Rf))*sin(theta*pi/180)/2;
    W2 = gamma*d*Rf*(D*Rr^2/(d*Rf)-3*(Rz*sin(theta*pi/180)*x1*sin(theta*pi/180)...
        *(1-h/(d*cos(beta*pi/180)))+d1*Rr/(3*d*Rf)*(Rf^2*(sigma*pi/180)/Rr+rho1...
        *Rr - x*sin(rho1))))*sin(theta*pi/180)/6;
    C2 = c*z*Rr*sin(theta*pi/180)/(2*sin(beta*pi/180));
    F2 = gamma*Rr*d1*v^2*sin(beta*pi/180)*(D/d1-rho1+sin(rho1)-Rf/Rr)...
        *sin(theta*pi/180)/(2*g*sin((alpha+beta)*pi/180));
    Vst = (Rr^2*(D*theta*pi/180+d1*rho1-d1*x*sin(rho1)/Rr)+Rf^2...
        *(d*theta*pi/180-d1*sigma*pi/180))/6;
else
    Q2 = gamma*Rf*d*(Rz*sin(theta*pi/180)+x1*sin(theta*pi/180)*1/sin(theta*pi/180)...
        -h/(d*cos(beta*pi/180))+d1*Rr / (3*d*Rf)*(Rz*rho2*pi/180-x*sin(rho2*pi/180))...
        *sin(theta*pi/180)/2;
    W2 = gamma*Rf*d*(D*Rr^2/(Rf*d)- 3*(Rz*sin(theta*pi/180)+x1*sin(theta*pi/180)...
        *(1/sin(theta*pi/180)-h/(d*cos(beta*pi/180)))+d1*Rr/(3*d*Rf)...
        *(Rr*rho2*pi/180-x*sin(rho2*pi/180))))*sin(theta*pi/180)/2;
    C2 = c*z*Rz*sin(theta*pi/180)/(2*sin(beta*pi/180));
    F2 = gamma*Rr*d1*v^2*sin(beta*pi/180)*((D/d1)-rho2*pi/180+sin(rho2*pi/180))...
        *sin(theta*pi/180)/(2*g*sin((alpha+beta)*pi/180));
    Vst = (Rr^2*(D*theta*pi/180-d1*rho2*pi/180+x*sin(rho2*pi/180)/Rr)...
        +d*Rf^2*theta*pi/180)/6;
end
%Determine the draft force, H2.
H2 = (Q2+W2)/J2+(C2+F2)*J3;
%Compute the draft force, Hd required to fail a 3-D soil profile.
Hd = H1+2*H2;
%Compute the draft force accounting for soil pulverization.

```



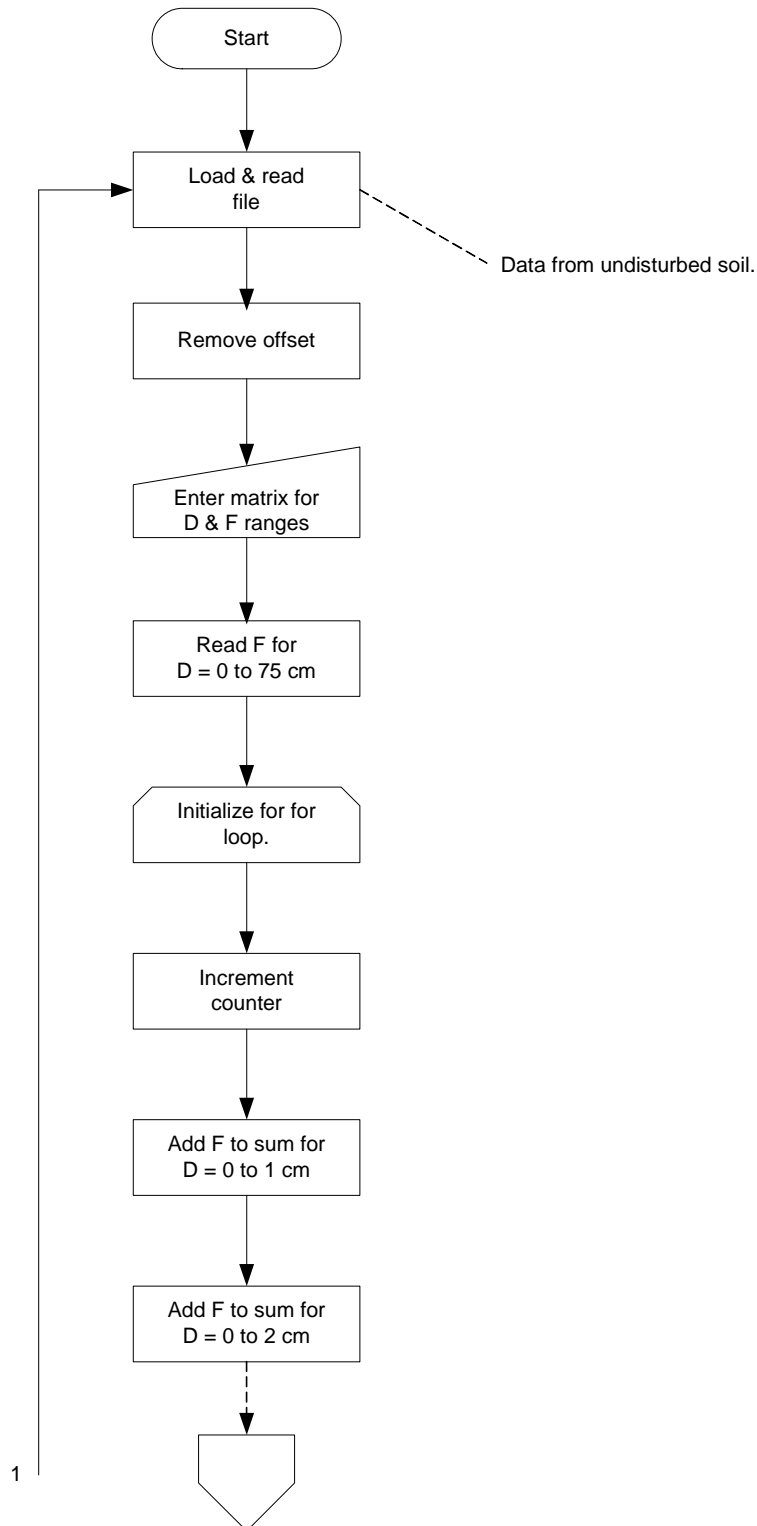
```

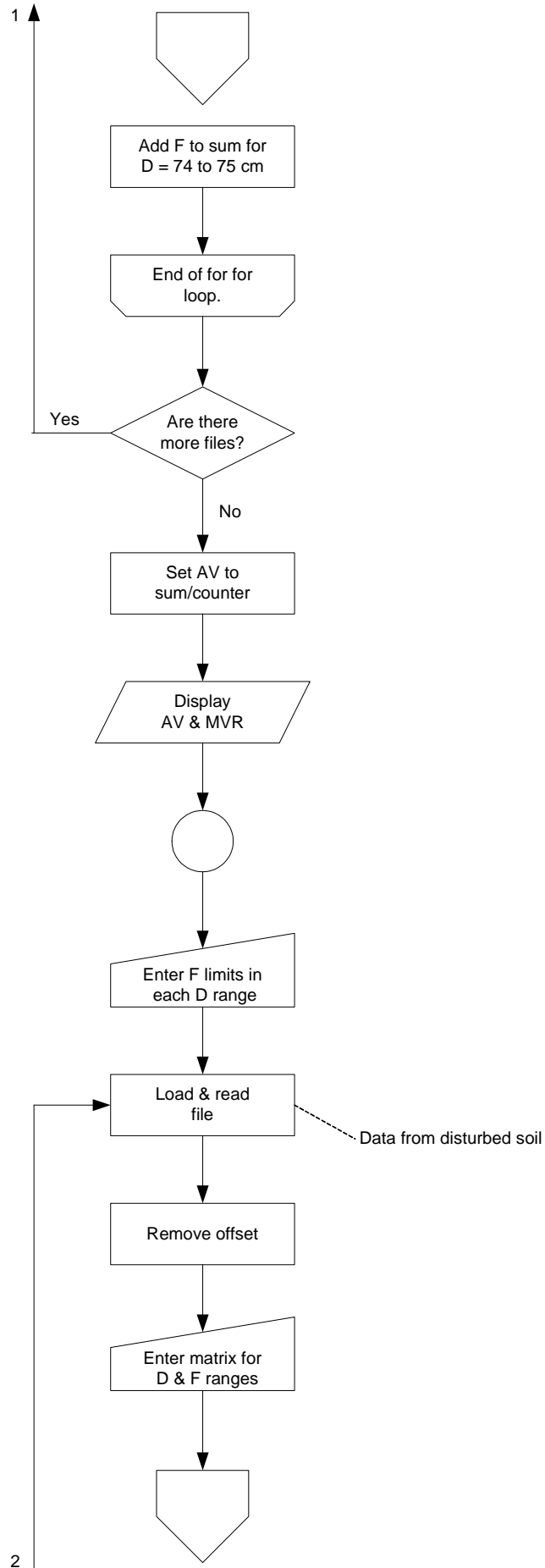
Hp = 0.2*Hd;
%Declare the frictional force (kN).
Ft = 0.62;
%Compute the total draft force required by the rear subsoiler.
H = Hd+Hp+Ft.
fprintf('The total draft force exerted by the rear subsoiler, H= %2.2f\n' ,H)
%Determine the vertical force component,V2
J5 = J1/J4;
V2 = (Q2+W2)/J4+(C2+F2)*J5;
%Compute the vertical force component, V3 due to the failed soil.
V3 = V1+2*V2;
%Compute the total vertical force component, V including the soil pulverization effect.
V = V3 + Hp;
fprintf('The total vertical force component V = %2.2f\n' ,V)
%Compute the total soil volume, Vt2 failed by both subsoilers in each side wedge.
Vt2 = Vst;
%Compute the total soil volume, VT failed by both subsoilers in the entire soil failed wedge.
VT = Vt1+2*Vst;
fprintf('The total soil volume failed, VT = %2.2f\n' VT)
%Compute the maximum cross-sectional area failed by both subsoilers (m2).
Ac = D*(w+sr);
fprintf('The maximum cross-sectional failed, Ac = %2.2f\n' Ac)

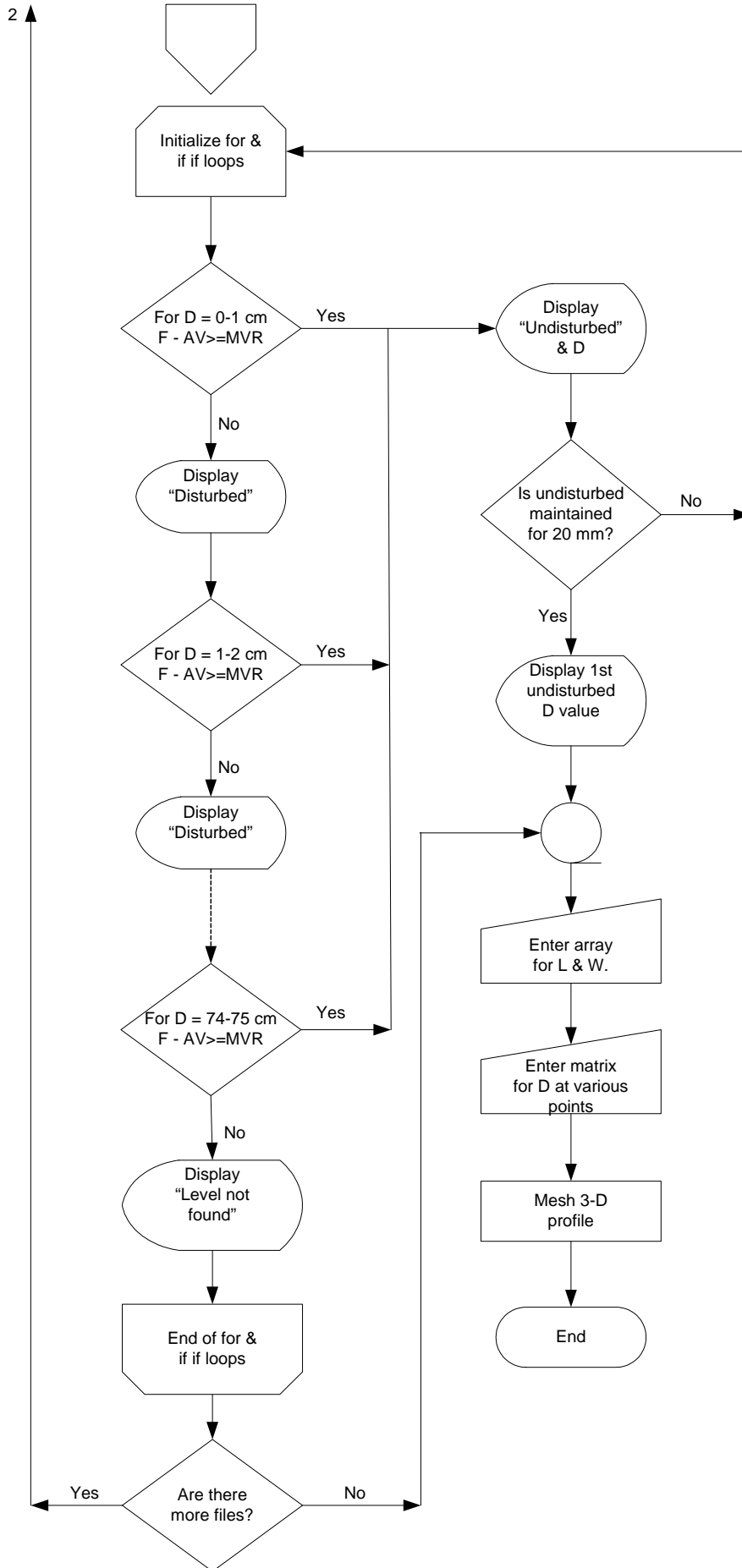
```

## APPENDIX C.

The computer-program flowchart to map a 3-D soil-failed profile measured by the computer-penetrometer technique.







Where:

D = depth of soil-failed profile/penetrometer-displacement (mm).

L = length of the soil-failed profile (mm).

W = width of the soil-failed profile (mm).

AV = average force value (N)

F = measured force exerted on the penetrometer (N).

MVR = minimum force value in each depth range of 10 mm (N).

## APPENDIX D.

### Computer program: Determining the volume of soil-failure profile.

```

%Program for determining the volume of a pin-profile meter measure soil-failure profile.
%=====
%Purpose: To calculate the total volume of a soil-failure profile
%from depth measurements taken by the pin-profile meter.
% Declare the width and length of each element within the profile.
xi = 50; %width (mm) of the ith element.
yi = 100; %length (mm) of the ith element.
% Determine the base area (mm^2) for ith element.
A = xi*yi;
% Declare the heights, hij (mm) of all the elements where i = 1,2,3.....j.
% Height of elements in the first row.
z1a = h11; z1b = h12; z1c = h13; .....z1j = h1j;
% height of the elements in the 2nd row.
z2a = h21; z2b = h22; z2c = h23;.....z2j = h2j;
% height of elements in the nth row.
zna = hn1; znb = hn2; znc = hn3;.....z nj = hnj;
%Declare an array for all the height values in each row.
% Declared array for the 1st row.
z1 = [z1a z1b z1c .....z1j];
% Declared array for the 2nd row.
z2 = [z2a z2b z2c.....z2j];
% Declared array for the nth row.
zn = [zna znb znc.....z nj];
%Determine the volume for individual elements.
%Determine the volume for each element in the 1st and 2nd rows.
v11 = A*(z1(1)+z1(2)+z2(1)+z2(2))/4;
v12 = A*(z1(2)+z1(3)+z2(2)+z2(3))/4;
v1j-1 = A*(z1(j-i)+z1(j)+z2(j-1)+z2(j))/4;
%summation of the element volumes in the 1st and 2nd rows.
V1 = v11+v12+.....v1j-1;
%Determine the volume for each element in the 2nd and 3rd rows.

v21 = A*(z2(1)+z2(2)+z3(1)+z3(2))/4;
v22 = A*(z2(2)+z2(3)+z3(2)+z3(3))/4;
v2j-1 = A*(z2(j-1)+z2(j)+z3(j-1)+z3(j))/4;

```

%Summation of the element volumes in the 2nd and 3rd rows.

$V_2 = v_{21} + v_{22} + \dots + v_{2j-1}$ ;

%Determine the volume of each element in the n-1 and nth rows.

$v_{(n-1)1} = A * (z_{n-1}(1) + z_{n-1}(2) + z_n(1) + z_n(2)) / 4$ ;

$v_{(n-1)2} = A * (z_{n-1}(2) + z_{n-1}(3) + z_n(2) + z_n(3)) / 4$ ;

$v_{(n-1)(j-1)} = A * (z_{n-1}(j-1) + z_{n-1}(j) + z_n(j-1) + z_n(j)) / 4$ ;

% summation of the element volumes in n-1 and nth rows.

$V_{n-1} = v_{(n-1)1} + v_{(n-1)2} + \dots + v_{(n-1)(j-1)}$ ;

%Determine the total volume in  $\text{cm}^3$ .

$V = [V_1 \ V_2 \ \dots \ V_{n-1}]$ ;

$\text{sum}(V) / 1000$

## APPENDIX E.

### Computer program: Solving Swick-Perumpral (1988) mathematical force model.

% Purpose: To calculate soil force components acting on the front subsoiler in a tandem configuration based on Swick-model.  
 % Section 1: Calculates force components required to fail the center wedge.  
 % Section 2: Calculates force components required to fail the side circular wedges.

%Section 1.

%-----

%Define the following variables:

%gamma = Soil unit weight (Nm<sup>-3</sup>).

%g = Gravitational constant, 9.81 (ms<sup>-2</sup>).

%d = Front subsoiler operating depth (m).

%alpha = Rake angle (degrees).

%beta = Angle between the soil rupture plain and the horizontal soil surface (degrees).

%phi = Soil internal friction angle (degrees).

%delta = Interface friction angle (degrees).

%F<sub>1</sub> = Acceleration force (N).

%q = Surcharge pressure (Pa).

%Q<sub>1</sub> = Surcharge force at the center wedge (N).

%R<sub>f</sub> = Soil rupture radius due to the front subsoiler (m).

%C<sub>1</sub> = Cohesion force at the rupture plain (N).

%c<sub>c</sub> = Cohesion coefficient (Nm<sup>-2</sup>).

%C<sub>a</sub> = Adhesion force at the interface (N).

%ad = Adhesion factor (Nm<sup>-2</sup>)

%W<sub>1</sub> = Soil weight failed in the center wedge (N).

%Declare the values the following constants

g = 9.81;

gamma = 19890;

beta = 32;

alpha =36;

delta = 25;

c<sub>c</sub> = 11400;

ad = 7000;

phi = 36;

w = 0.08;

q = 0;

%Prompt the user to enter the operating depth and speed.

d = input('Enter the depth, d: ');

s = input('Enter the speed, s: ');

%Determine the following variables.

R<sub>f</sub> = d\*(cot(alpha\*pi/180)+cot(beta\*pi/180));

F<sub>1</sub> = gamma\*w\*d\*v^2\*sin(alpha\*pi/180)/(g\*sin((alpha+beta)\*pi/180));

Q<sub>1</sub> = q\*w\*R<sub>f</sub>;

C<sub>1</sub> =c<sub>c</sub>\*w\*d/sin(beta\*pi/180);

C<sub>a</sub> = ad\*w\*d/sin(alpha\*pi/180);

W<sub>1</sub> = gamma\*w\*d\*R<sub>f</sub>\*0.5;

%Determine the force, P<sub>1</sub> to fail the center wedge.

P<sub>1</sub> = ((Q<sub>1</sub>+ W<sub>1</sub> )\*sin((phi+beta)\*pi/180)-C<sub>a</sub>\*cos((alpha+phi+beta)\*pi/180)...



$$+(C_1 + F_1) \cdot \cos(\phi \cdot \pi / 180) / \sin((\alpha + \phi + \beta + \delta) \cdot \pi / 180);$$

%Determine the horizontal force,  $H_1$  to fail the center wedge.

$$H_1 = P_1 \cdot \sin((\alpha + \delta) \cdot \pi / 180);$$

%Determine the vertical force,  $V_1$  to fail the center wedge.

$$V_1 = P_1 \cdot \cos((\alpha + \delta) \cdot \pi / 180);$$

%Section 2.

%-----

%Define the following variables:

% $s_f$  = Maximum width of the circular side wedge (m).

% $\theta$  = Angle (degrees)

% $W_2$  = Weight of failed soil in the side circular wedge (N)

% $C_2$  = Cohesion force (N)

% $F_2$  = Acceleration force (N).

% $Q_2$  = Surcharge force at the side wedge (N).

%Determination of the following variables

$$s_f = (46 \cdot R_f + 0.904 \cdot \alpha - 6.03) / 100;$$

$$\theta = \arcsin(s_f / F_f) \cdot 180 / \pi;$$

$$Q_2 = q \cdot R_f^2 / 2;$$

$$F_2 = \gamma \cdot d \cdot R_f \cdot v^2 \cdot \sin(\alpha \cdot \pi / 180) / (2 \cdot g \cdot \sin((\alpha + \beta) \cdot \pi / 180));$$

$$C_2 = c_c \cdot d \cdot R_f / (2 \cdot \sin(\beta \cdot \pi / 180));$$

$$W_2 = \gamma \cdot d \cdot F_f^2 / 6;$$

%Determine the force,  $P_2$  to fail the side wedge.

$$P_2 = ((Q_2 + W_2) \cdot \sin((\phi + \beta) \cdot \pi / 180) + F_2 \cdot \cos(\phi \cdot \pi / 180) \cdot (\theta \cdot \pi / 180 \dots \\ + \sin(2 \cdot \theta \cdot \pi / 720)) + C_2 \cdot \cos(\phi \cdot \pi / 180) \cdot \sin(\theta \cdot \pi / 180)) \dots \\ / \sin((\alpha + \phi + \beta + \delta) \cdot \pi / 180);$$

%Determine the horizontal force component  $H_2$

$$H_2 = P_2 \cdot \sin((\alpha + \delta) \cdot \pi / 180);$$

%Determine the vertical force component  $V_2$

$$V_2 = P_2 \cdot \cos((\alpha + \delta) \cdot \pi / 180);$$

%Determine the total horizontal force component  $H$

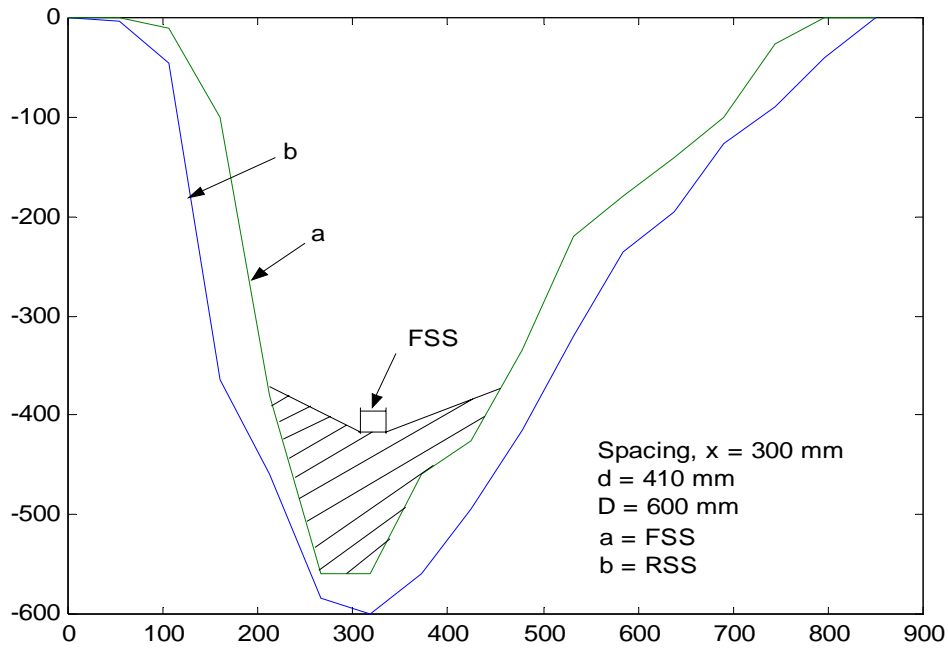
$$H = H_1 + 2 \cdot H_2$$

%Determine the total vertical force component  $V$

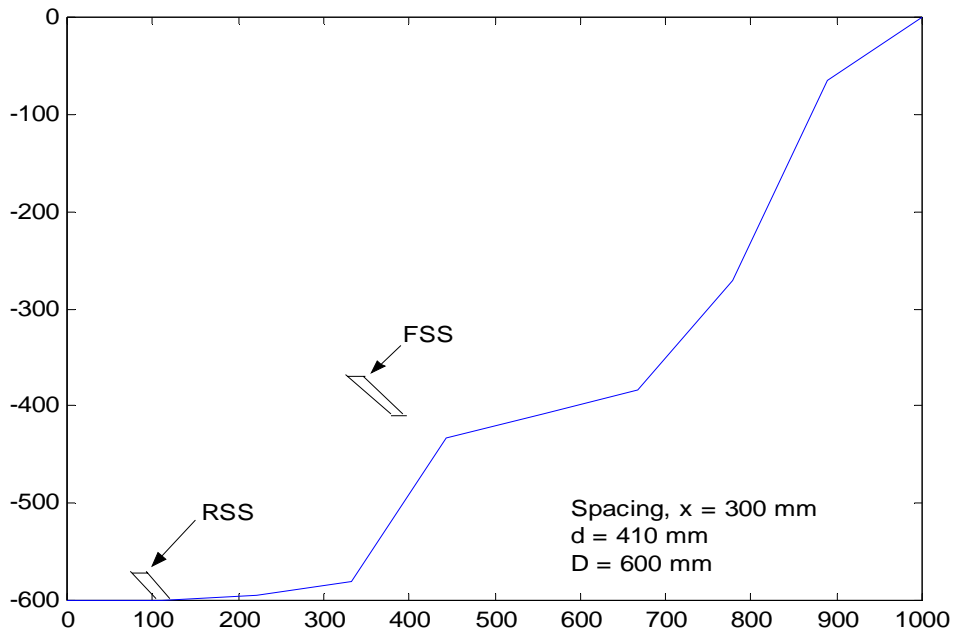
$$V = V_1 + 2 \cdot V_2$$

## APPENDIX F.

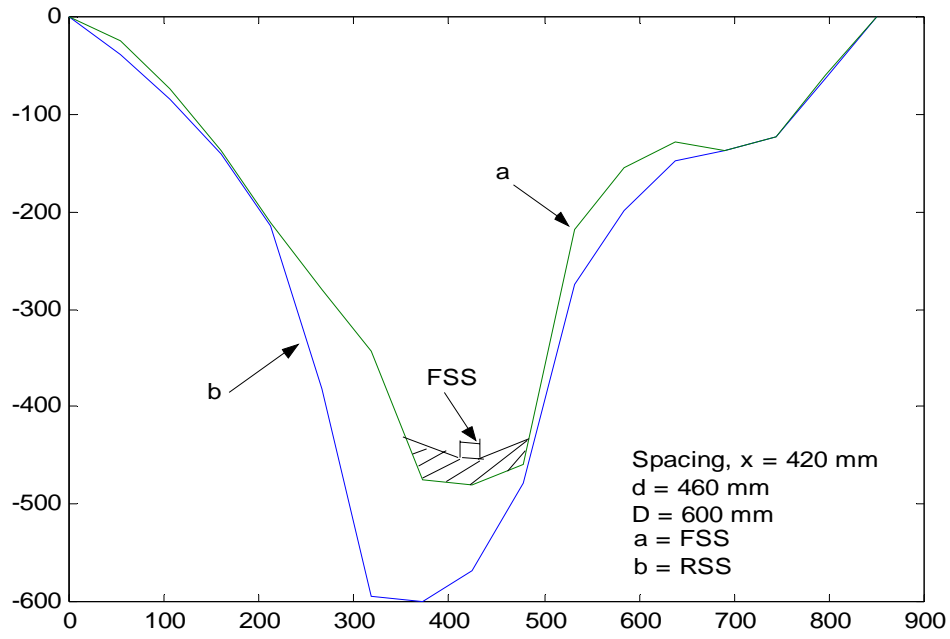
### Soil-failure profiles.



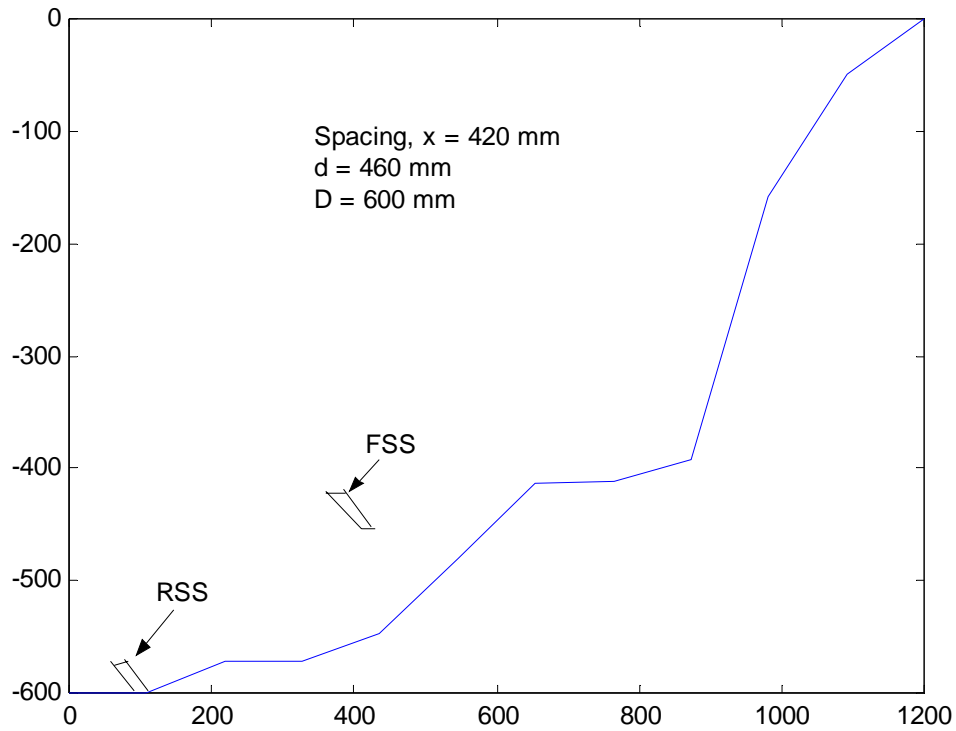
**Figure F1: Measured cross-section areas of failed soil-profile at the FSS and RSS. ( $x = 300$  mm).**



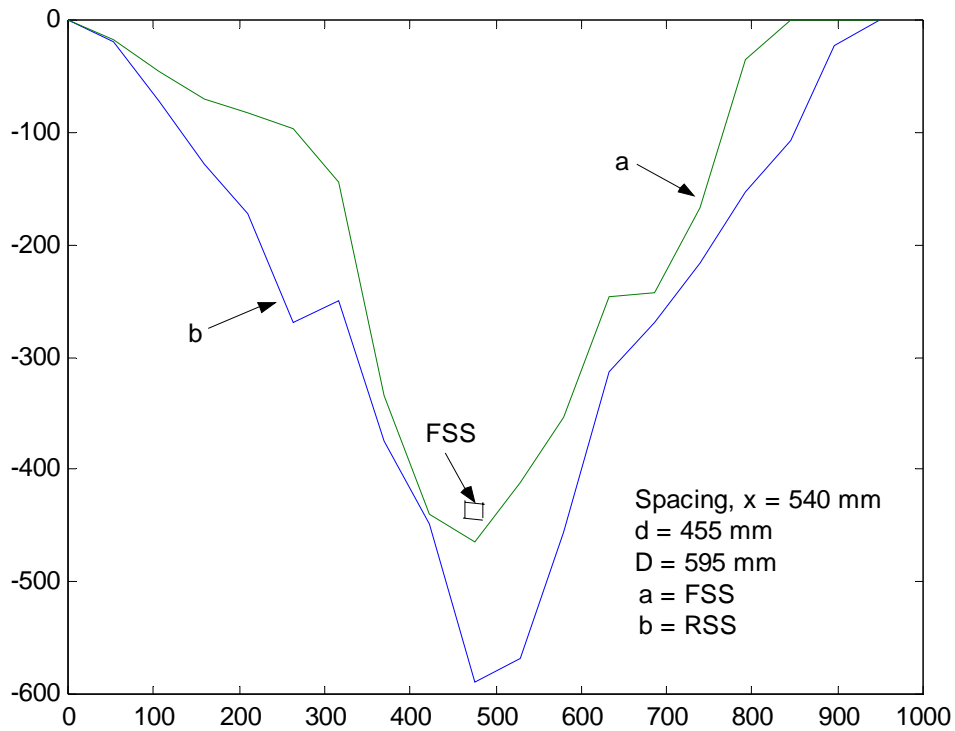
**Figure F2: Measured longitudinal section of failed soil-profile at the FSS and RSS. ( $x = 300$  mm).**



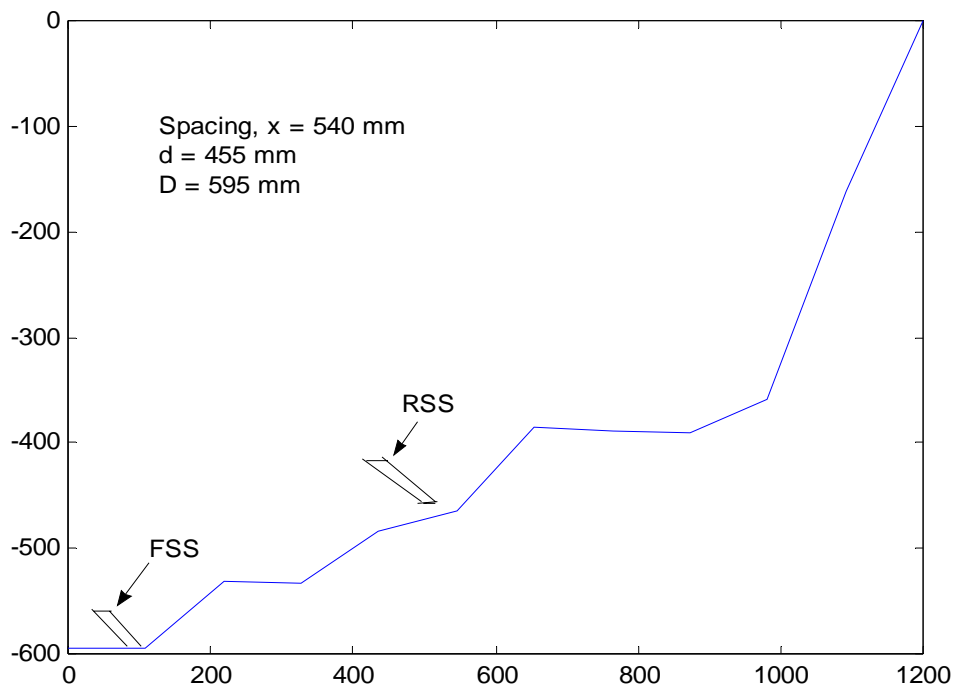
**Figure F3: Measured cross-section areas of failed soil-profile at the FSS and RSS. ( $x = 420$  mm).**



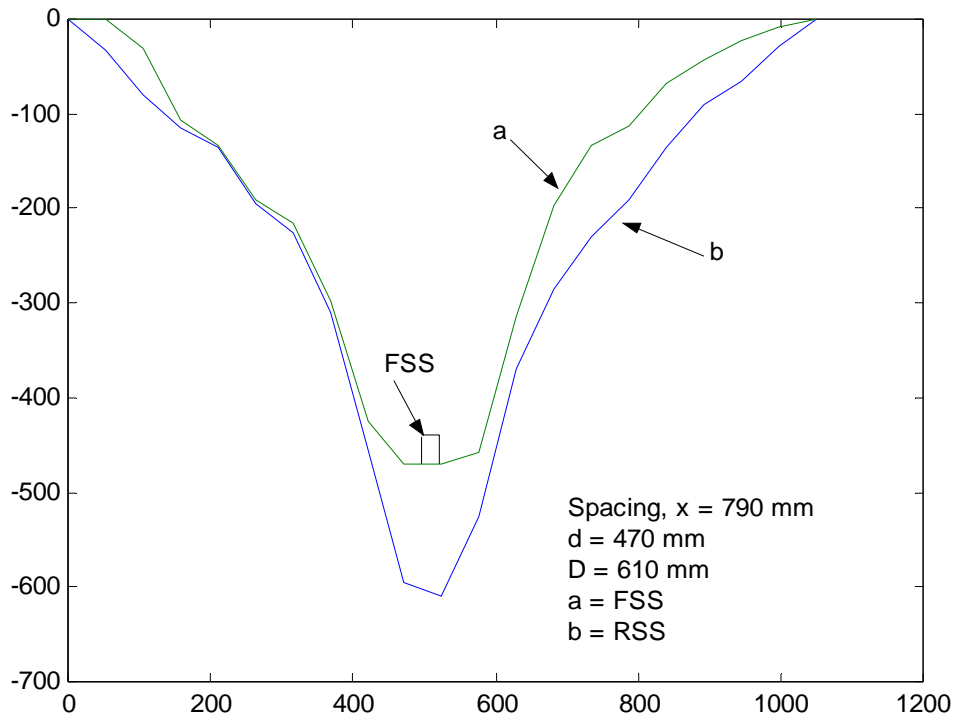
**Figure F4: Measured longitudinal section of failed soil-profile at the FSS and RSS. ( $x = 420$  mm).**



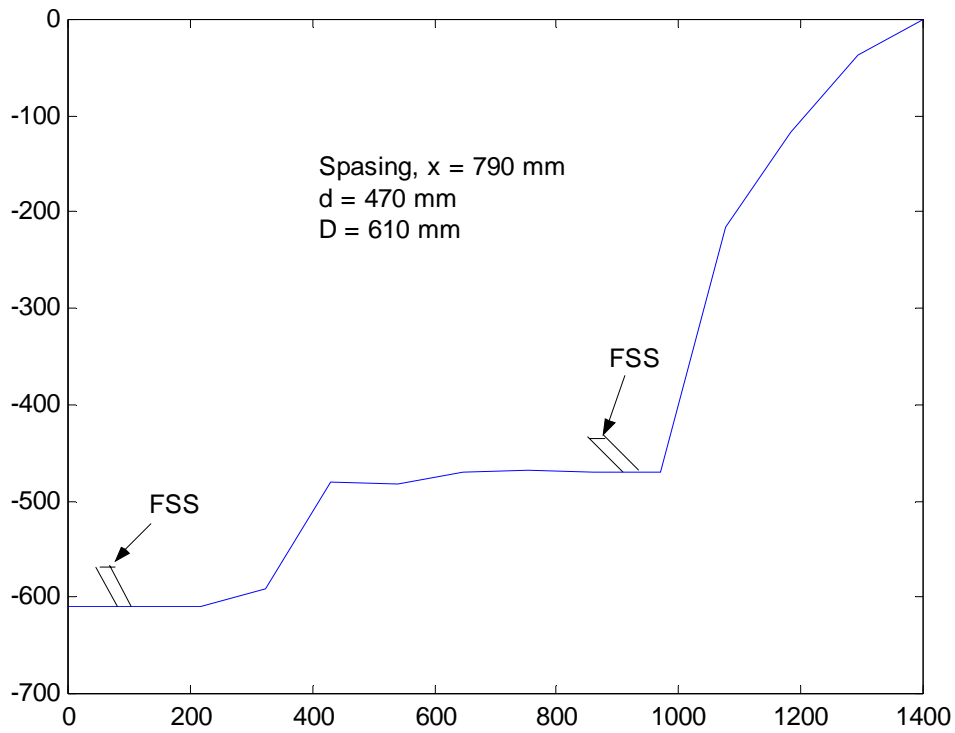
**Figure F5: Measured cross-section areas of failed soil-profile at the FSS and RSS. ( $x = 540$  mm).**



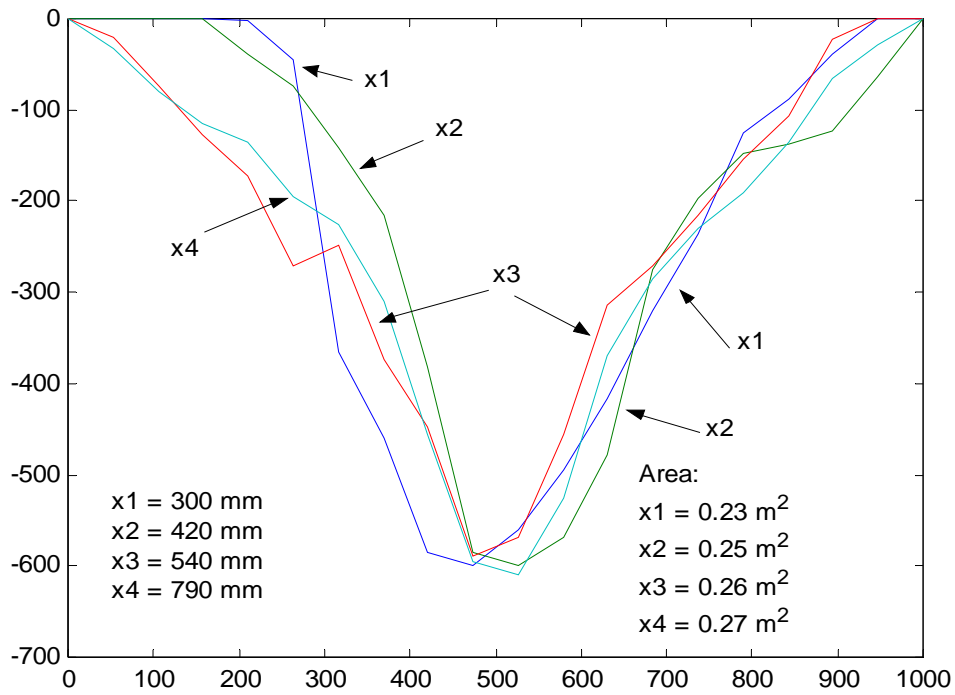
**Figure F6: Measured longitudinal section of failed soil-profile at the FSS and RSS. ( $x = 540$  mm).**



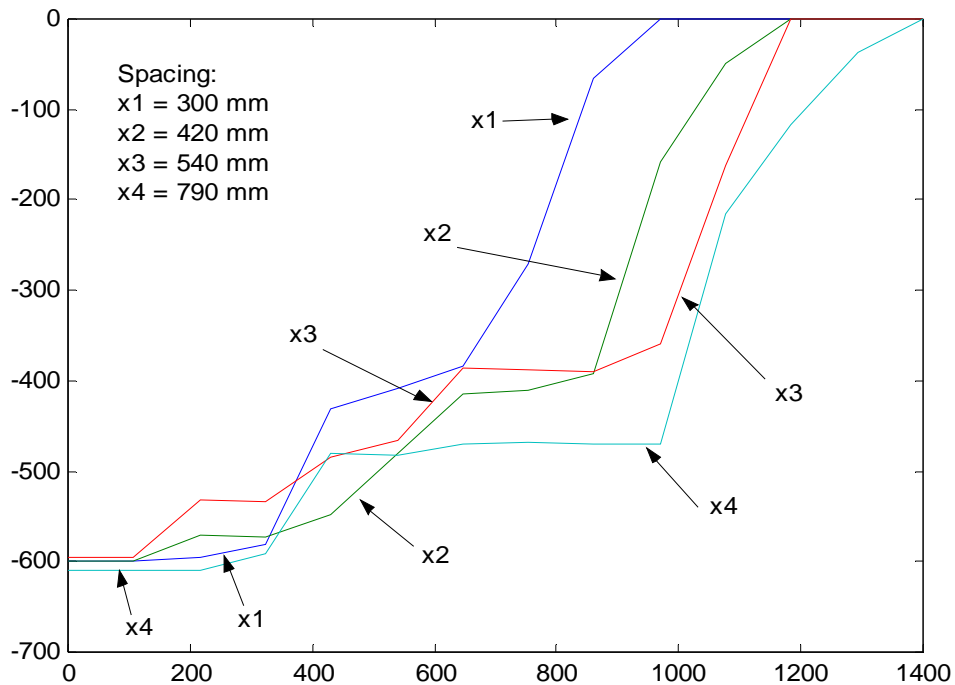
**Figure F7: Measured cross-section areas of failed soil-profile at the FSS and RSS. (x = 790 mm).**



**Figure F8: Measured longitudinal section of failed soil-profile at the FSS and RSS. (x = 790 mm).**



**Figure F9: Comparison of measured cross-section areas of failed soil-profiles at the RSS. (x = 300, 420, 540, 790 mm).**



**Figure F10: Comparison of measured longitudinal section of failed soil-profiles. (x = 300, 420, 540, 790 mm).**