# Vedlegg C: MATLAB-koder fra beregninger med Borchardts beregningsmetode for sprøytebetong, gitterbuer og «Composite Pile Roofing»

## Kode 1: Implementering av den generaliserte metoden med beregninger fra Yxhugget

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%Yxhugget Stockholm
%Beregninger implementering av beregninger tidligere foretatt av Peter
%Borckhardt
clear all
clc
clf
disp('BEREGNING OG DIMENSJONERING AV SPRØYTEBETONG OG GITTERBUER');
%%
%VARIABLER
%Løsmasse
Ek = 20000;          %Young's modulus til løsmassen
%(elastisitetsmodulus)[kPa]
gamma = 20;          %Tyngdetetthet på løsmasse [kN/m3]
Ko = 0.5;            %Lateral jordtrykkskoeffisient [dimensjonsløs]
phi = 35;            %Friksjonsvinkel på løsmasse[grader]
c = 10;              %cohesjon i løsmassene [kPa]
Po = 15;             %Tilleggslast som ligger på overflaten [kPa]
Fberg = 750;         %Styrke på forankringsmaterialet (eks. forvitret berg)
%[kPa]
Lust= 3;             %Lengde på ustabil sone foran stuff [m]

%Tunnel
r = 7.5;             %Radius av tunnelen [m]
H = 16;              %Overdekning [m]

a1 = 1.5;            %Tunneldrivningsetappe, derav også usikret lengde mot
%stuff etter driving av en etappe [m]
                     %Denne vil som regel være lik c/c gitterbuer (ccgb)

%Gitterbue
Estaal = 210000000; %Young's modulus for stålet i gitterbuen [kPa]
sigmaX = 520000;     %Flytegrensen for stålet i gitterbuen [kPa]
ccgb = 1.5;          %Avstand (c/c) mellom gitterbuer [m]
A = 0.00197;         %Aral for tverrsnitt av stålet i gitterbuen [m2]
Ix = 0.00001264;     %Treghetsmomentet til gitterbuen fra brosjyre. [m4]
SK = 6;              %Gitterbuens knekklengde[m]
Wx = 0.000092;       %Motstandsmoment, notert under Wy i produktbrosjyren
%til PANTEX 130/26/34 [m3]
SK1 = 0.28;          %Knekklengden til en enkelt spindel i gitterbuen [m]
i1 = 0.0085;         %Treghetsradiusen til en enkelt spindel i gitterbuen
%[m]
gammaM = 1.0;        %Partialkoeffisient for stålet i gitterbuen,ifb. med
%bæreevnen til giterbuen
gammaN = 1.2;        %Partialkoeffisient for gjeldende sikkerhetsklasse,
%ifb. med bæreevnen til giterbuen
m = 2;               %Antall identiske elementer som settes sammen for å
%danne gitterbuen (DIN4114)
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```
%Betong
Ebtg = 15000000;    %Young's modulus for sprøytebetongen [kPa]
d = 0.3;            %Tykkelse på sprøytebetong [m]
bm = 1;             %Breddementer sprøytebetong [m]
Bet3t = 3000;       % Holdfastheten til sprøytebetong etter 3 timer [kPa]
Bet6t = 5000;       % Holdfastheten til sprøytebetong etter 6 timer [kPa]
Bet9t = 6000;       % Holdfastheten til sprøytebetong etter 9 timer [kPa]
Bet12t = 8000;      % Holdfastheten til sprøytebetong etter 12 timer [kPa]
Bet15t = 10000;     % Holdfastheten til sprøytebetong etter 15 timer [kPa]
Bet24t = 14500;     % Holdfastheten til sprøytebetong etter 24 timer [kPa]

%Spiling
ccb = 0.4;          %Avstand (c/c) mellom spilingbolter [m]
Py = 525;           %Tillatt strekklast på stålet i spilingen[kN]
Ls = 3;             %Forankringslengde av stålrørene foran ustabil sone [m]
gammaP = 1.6;       %Partialkoeffisient for stålet i spilingstagene.
gamman=1.2;         %Partialkoeffisient, ifb. med heft av spilingbolter
gammam=1.35;        %Partialkoeffisient, ifb. med heft av spilingbolter
dp = 0.09;          %Diameter på pilar dannet av spiling og
%injeksjonsmasse[m]


%%
%DEL 1; Beregning av snittkrefter på tunnelprofil

%Omgjør stivhets-diagrammer til matriser, har på forhånd plottet punkter
%for å få riktig fasong på graf, så lagt på "Shape preserving interpolant,
%for så å få lest av flere punkter langs grafen og lagt dette i matrisene,
%som ligger under.
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0.00200853893000000 0.00200720170666667 0.00200595931000000
0.00200481272000000 0.00200376291666667 0.00200281088000000
0.00200195759000000 0.00200120402666667 0.00200055117000000
0.00200000000000000];

n = length(GrafMF(1,:)); % For å bestemme antall runder forløkken skal
%kjøre ved henting av verdier fra diagrammene.

betaK = [3,6,9,12,15,24
    Bet3t, Bet6t, Bet9t, Bet12t, Bet15t, Bet24t]; % Sprøytebetongens
%holdfasthet etter 3,6,9,12, 15 og 24 timer, satt i matrise [kPa]

%LASTBEREGNINGER PÅ GITTERBUE

Pr0 = 0.5*gamma*(H+((H+r)*Ko))+(0.5*Po*(1+Ko));  %Beregning av overlast
Pr2 = 0.5*gamma*(H-((H+r)*Ko))+(0.5*Po*(1-Ko));  %Beregning av radiell last
Pboyning = (2*Pr2)+Pr2; % Beregning av bøymomenets andel av lasten

%BEREGNING AV NORMALKREFTER, MOMENT OG DEFORMASJON

%Beregning av treghetsmoment (Sprøytebetong+gitterbue)
Ibetong = ((d^3)*bm)/12; %Beregner treghetsmomentet sprøytebetongen
Igbue = Ix*((Estaal/Ebtg)/ccgb); %Beregning av treghetsmomentet til
%gitterbuen..
I = Ibetong + Igbue;  %Beregning av treghetsmoment på sprøytebetong og
%gitterbue samlet.

%Beregning av stivhetsverdien for bruk i diagrammene
Kk = Ek/r;          %Setningsmodul på løsmassen [kN/m3]
beta = round((Kk*(r^4))/(Ebtg*I)); %Beta er stivhetsverdien, brukes i
%diagram.
```

```
%En for-løkke som henter ut verdier fra diagrammer for mF, mU, m90, mS, nF,
%n90, nS og etaF
for i= 2:n
    if beta == GrafMF(1,i)
        mF = GrafMF(2,i);
    end
     if beta == GrafM90(1,i)
        m90 = GrafM90(2,i);
     end
     if beta == GrafMU(1,i)
        mU = GrafMU(2,i);
     end
     if beta == GrafMS(1,i)
        mS = GrafMS(2,i);
     end
    if beta == GrafNF(1,i)
        nF = GrafNF(2,i);
    end
     if beta == GrafN90(1,i)
        n90 = GrafN90(2,i);
     end
     if beta == GrafNS(1,i)
        nS = GrafNS(2,i);
     end
      if beta == GrafWF(1,i)
        etaF = GrafWF(2,i);
     end
end

%Bergning av moment på ulike steder i profilet
MF = mF*Pboyning*(r^2);      %Tak
M90 =m90*Pboyning*(r^2);     %90 grader i vegg
MU =mU*Pboyning*(r^2);       %Ulmen (overgang mellom vegg og heng)
MS =mS*Pboyning*(r^2);       %Sålen

%Beregning av normalkrefter på ulike steder i profilet
NF = (-Pr0+(0.5*Pr2)+(nF*Pboyning))*r;       %Taket
NFabs= abs(NF); %Absoluttverien brukes i diagram over bæreevnen
N90 =(-Pr0-(0.5*Pr2)+(n90*Pboyning))*r;      %90 grader i veggen
N90abs= abs(N90); %Absoluttverien brukes i diagram over bæreevnen
NS =(-Pr0+(0.5*Pr2)+(n90*Pboyning))*r;       %Sålen
NSabs= abs(NS); %Absoluttverien brukes i diagram over bæreevnen

%Beregning av eksentrisitet
e_F = MF/NF;          %Tak
e_90 = M90/N90;       %90 grader i veggen
e_S = MS/NS;          %Sålen

%Finner hvor i profilet eksentisiteten er størst, for bruk i videre
%beregninger.
e_max=max(abs([e_F,e_90,e_S]));

%lager en for-løkke som sier i fra hvor eksentrisiteten er størst, og
%plukker opp verdien til videre bruk.
%Bruker ikke e_max videre for å unngå fortegnsfeil.

if abs(e_F)==e_max
    disp('Størst eksentrisitet oppstår i taket.')
    e_dim=e_F;
```

```
end
if abs(e_90)==e_max
    disp('Størst eksentrisitet oppstår i veggen, 45 grader fra midt i
taktet.')
    e_dim=e_90;
end
if abs(e_S)==e_max
    disp('Størst eksentrisitet oppstår i sålen.')
    e_dim=e_S;
end

%Beregning av deformasjon
WF=(etaF*Pboyning*(r^4))/(Ebtg*I);

%GLOBAL KNEKKNINGSBEREGNING AV GITTERBUE

%Beregning av treghetsradiusen til gitterbuen
ig = sqrt(Ix/A);    %Der Ix er treghetsmomet til stålbue og A er
%tverrsnittsareal til gitterbue

%Beregning av slankhetstallet til gitterbuen
lamdaX = SK/ig;      % SK er gitterbuens knekklengde.

%Beregning av slankhetstallet til en enkelt stålstang i gitterbuen
lamdaX1 = SK1/i1;

%Beregning av ideelt slankhetstall til gitterbuen
lamdaXi = sqrt((lamdaX^2)+((m/2)*(lamdaX1^2)));
AvrundetlamdaXi = round(round(lamdaXi)*0.1)*10; %Runder av til nærmeste
%hele tier for å bruke til avlesning i tabellen under.

%Tabell fra DIN4114 (Deutche Normen, 1952)
OmegaTabell= [20 1.06 1.06 1.07 1.07 1.08 1.08 1.09 1.09 1.1 1.11
    30 1.11 1.12 1.12 1.13 1.14 1.15 1.15 1.16 1.17 1.18
    40 1.19 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27
    50 1.28 1.30 1.31 1.32 1.33 1.35 1.36 1.37 1.39 1.40
    60 1.41 1.43 1.44 1.46 1.48 1.49 1.51 1.53 1.54 1.56
    70 1.58 1.60 1.62 1.64 1.66 1.68 1.70 1.72 1.74 1.77
    80 1.79 1.81 1.83 1.86 1.88 1.91 1.93 1.95 1.98 2.01
    90 2.05 2.10 2.14 2.19 2.24 2.29 2.33 2.38 2.43 2.48
    100 2.53 2.58 2.64 2.69 2.74 2.79 2.85 2.90 2.95 3.01
    110 3.06 3.12 3.18 3.23 3.29 3.35 3.41 3.47 3.53 3.59
    120 3.65 3.71 3.77 3.83 3.89 3.96 4.02 4.09 4.15 4.22
    130 4.28 4.35 4.41 4.48 4.55 4.62 4.69 4.75 4.82 4.89
    140 4.96 5.04 5.11 5.18 5.25 5.33 5.40 5.47 5.55 5.62
    150 5.70 5.78 5.85 5.93 6.01 6.09 6.16 6.24 6.32 6.40
    160 6.48 6.57 6.65 6.73 6.81 6.90 6.98 7.06 7.15 7.23
    170 7.32 7.41 7.49 7.58 7.67 7.76 7.85 7.94 8.03 8.12
    180 8.21 8.30 8.39 8.48 8.58 8.67 8.76 8.86 8.95 9.05
    190 9.14 9.24 9.34 9.44 9.53 9.63 9.73 9.83 9.93 10.03
    200 10.13 10.23 10.34 10.44 10.54 10.65 10.75 10.85 10.96 11.06
    210 11.17 11.28 11.38 11.49 11.60 11.71 11.82 11.93 12.04 12.15
    220 12.26 12.37 12.48 12.60 12.71 12.82 12.94 13.05 13.17 13.28
    230 13.40 13.52 13.63 13.75 13.87 13.99 14.11 14.23 14.35 14.47
    240 14.59 14.71 14.83 14.96 15.08 15.20 15.33 15.45 15.58 15.71
    250 15.83 0 0 0 0 0 0 0 0 0];

%For-løkke for å plukke ut knekkverdien til gitterbuen.
for i = 1:24
    if OmegaTabell(i,1)== AvrundetlamdaXi
```

```
        Omegaxi= OmegaTabell(i,(2+m));
    end
end

%BEREGNING AV BÆREEVNEN TIL GITTERBUE OG SPRØYTEBETONG

%Bæreevnen med 1m avstand mellom hver gitterbue
Ngcc1 = (sigmaX/((Omegaxi/A)+(0.9*(abs(e_dim)/Wx))))*(1/gammaN*gammaM);
%Her er   det en følgefeil som stammer fra e_tak da denne skal være 0.0570,
%ikke 0.07. Se utregning side 1:6

%Bæreevnen med angitt c/c mellom hver gitterbue
Ngcc15 = Ngcc1/ccgb;

%Bæreevnen til sprøytebetong
Nsp = (d*bm*(1-(2*(abs(e_dim)/d))))*betaK(2,:); % Bæreevnen til
%sprøytebetongen etter 3, 6, 9, 12, 15 og 24 timer [N]

%Bæreevnen til sprøytebetong og gitterbue
Nspcc1 = Nsp + Ngcc1; % Bæreevnen til sprøytebetongen og gitterbue med c/c
%1m etter 3, 6, 9, 12, 15 og 24 timer [N]
Nspcc15 = Nsp + Ngcc15; % Bæreevnen til sprøytebetongen og gitterbue med
%c/c 1.5m etter 3, 6, 9, 12, 15 og 24 timer [N]

%Lager matriser for å plotte normalkreftene som virker på sprøytebetong og
%gitterbue.
NormalkrefterTak = [3,24            %Tak
    NFabs, NFabs];
Normalkrefter90 = [3,24             %Vegg
    N90abs, N90abs];
NormalkrefterS = [3,24              %Såle
    NSabs, NSabs];

figure(1) %Diagram over bæreevnen til sikringen
plot(betaK(1,:),Nsp,'k')            %Plotter bærevne til betong
hold on
plot(betaK(1,:),Nspcc1,'--k');      %Plotter bærevne til betong+gitterbuer
%med c/c 1 meter
plot(betaK(1,:),Nspcc15,':k');      %Plotter bærevne til betong+gitterbuer
%med c/c 1.5 meter
plot(NormalkrefterTak(1,:),NormalkrefterTak(2,:),'-.b'); %Plotter
%normalkreftene i taket
plot(Normalkrefter90(1,:),Normalkrefter90(2,:),'r');   %Plotter
%normalkreftene 90 grader i veggen
plot(NormalkrefterS(1,:),NormalkrefterS(2,:),'--m');     %Plotter
%normalkreftene i sålen
hleg1=legend('Bæreevne s.betong over tid','Bæreevne s.betong og gitterbue,
c/c 1m','Bæreevne s.betong og gitterbue, c/c1.5m','Normalkrefter
tak','Normalkrefter 90° i vegg','Normalkrefter såle');
set(hleg1,'Location','SouthOutside')
xlabel('Tid [t]');
ylabel('Last [kN]');
title('Bæreevnen til sprøytebetong og gitterbuer');
grid on
axis tight
hold off

%%
%Del 2; DIMENSJONERING AV SPILING
```

```
a2 = a1;           %Nylig sikret med sprøytebetong og gitterbue,dvs. uten
%komplett tunnelforsterkning [m]
b = a1+a2+Lust;    %Bredden som krysses av boltene (Ustabil sone) [m]
b0 = b/2;          %Bredden på halvparten av sonen som krysses av boltene
%(for Terzaghi) [m]

%Beregning av silotrykk over åpningen som krysses av spilingbolene (b)
sigmaS_b = ((((b0*gamma)-c)/(Ko*tand(phi)))*(1-exp((-
Ko*H*tand(phi))/b0)))+(Po*exp((-Ko*H*tand(phi))/b0));

%Beregning av silotrykk over a2+Lust (strekning sist sikret og ustabil sone
%foran stuff)
sigmaS_ab = ((((((a2+b0)/2)*gamma)-c)/(Ko*tand(phi)))*(1-exp((-
Ko*H*tand(phi))/((a2+b0)/2))))+(Po*exp((-Ko*H*tand(phi))/((a2+b0)/2)));

%Beregning av pilhøyden
Z=b/8;

% Beregning trekkraften som virker på spilingen i de to situasjonene
F_b = (sigmaS_b*(b^2))/(8*Z); %Beregning av strekklast på spilingen ved
%åpningen b som krysses av spilingbolene (b)
FA_b = F_b*ccb; % Beregner strekklasten pr. bolt

F_ab = (sigmaS_ab*((a1+b0)^2))/(8*Z);%Beregning av strekklast ved åpning
%a2+Lust
FA_ab = F_ab*ccb; % Beregner strekklasten pr. bolt

if FA_b >= FA_ab   %Finner ut det alternativet hvor strekklasten er størst,
%for videre bruk
    FA = FA_b;
else
    FA = FA_ab;
end

disp('BEREGNING OG DIMENSJONERING AV "COMPOSITE PILE ROOFING"')
%%
%Sammenligner strekklasten med størst tillatt strekklast på stålet i
%stålrøret, og gir output med resultatet.
Ftill = Py/gammaP;  %Tillat last på stålrøret inkl. sikkerhetsfaktor[kN]
if FA <= Ftill
    fprintf('Strekklast på stålrør er %0.0f kN og er lavere enn tillatt
strekklast på stålet, som er %0.0f kN (inkl. sikkerhetsfaktor.)',FA,Ftill);
else
    fprintf('Strekklast på stålrør er %0.0f kN og er høyere enn tillatt
last på stålet, som er %0.0f kN (inkl. sikkerhetsfaktor.)',FA,Ftill);
end

%Beregning av heft mellom sement og omliggende masse, dvs. hvor mye
%forankringen tåler.
qs = (FA*gamman*gammam)/(pi*dp*Ls);  %Beregner grensemantelfriksjonen.
%%
%Sammenligner grensemantelfriksjonen med styrken til forankringsmaterialet
if qs <= Fberg
    fprintf('Forankringslengden er tilstrekkelig. Grensemantelfriksjon
mellom sement og forankringsmaterialet er %0.0f kPa og er mindre enn
styrken til forankringsmaterialet på %0.0f kPa.',qs,Fberg)
else
    fprintf('Forankringslengden er ikke tilstrekkelig. Grensemantelfriksjon
mellom sement og forankringsmaterialet er %0.0f kPa og er større enn
styrken til forankringsmaterialet på %0.0f kPa.',qs,Fberg)
```

```
end
%%
%Lager tabeller over alle variablene

f = figure(2);
set(f,'Position',[200 100 413 610]);
dat =  {'  Overlast',round(Pr0), '        kPa';...
        '  Radiell last',round(Pr2), '        kPa';...
        '  Bøyemoment',round(Pboyning), '        kN';...
        '  Treghetsmoment:bue+betong',I, '        m4';...
        '  Beta-verdi',beta, '        ';...
        '  Avlest Tabell: mF',mF, '        ';...
        '  Avlest Tabell: mU',mU, '        ';...
        '  Avlest Tabell: m90',m90, '        ';...
        '  Avlest Tabell: mS',mS, '        ';...
        '  Avlest Tabell: nF',nF, '        ';...
        '  Avlest Tabell: n90',n90, '        ';...
        '  Avlest Tabell: nS',nS, '        ';...
        '  Moment Tak',round(MF), '        kN';...
        '  Moment 45° i vegg',round(MU), '        kN';...
        '  Moment 90° i vegg',round(M90), '        kN';...
        '  Moment såle',round(MS), '        kN';...
        '  Normalspenning tak',round(NF), '        kPa';...
        '  Normalspenning 90° i vegg',round(N90), '        kPa';...
        '  Normalspenning såle',round(NS), '        kPa';...
        '  Eksentrisitet tak',e_F, '        Meter';...
        '  Eksentrisitet 90° i vegg',e_90, '        Meter';...
        '  Eksentrisitet såle',e_S, '        Meter';...
        '  Slanketstall gitterbue',lamdaX, '        ';...
        '  Slanketstall enkelt spindel',lamdaX1, '        ';...
        '  Ideelt slanketstall gitterbue',lamdaXi, '        ';...
        '  Knekkverdi for gitterbue',Omegaxi, '        ';...
        '  Bæreevne gitterbue, c/c 1m',round(Ngcc1), '        kN';...
        '  Bæreevne gitterbue, c/c 1.5m',round(Ngcc15), '        kN';};
columnname =   {'   Parametere primærsikring   ', 'Verdi', 'Enhet'};
columnformat = {'char', 'numeric', 'char'};
t = uitable('Units','normalized','Position',...
            [0.05 0.05 0.755 0.87], 'Data', dat,...
            'ColumnName', columnname,...
            'ColumnFormat', columnformat,...
            'RowName',[]);

figure(3)
f = figure(3);
set(f,'Position',[600 300 507 135]);
dat =  {'  Silotrykk, lengde b',round(sigmaS_b), '        kPa';...
        '  Silotrykk, lengde a1+b0',round(sigmaS_ab), '        kPa';...
        '  Strekklast på hvert stålrør, lengde b',round(FA_b), '
kN';...
        '  Strekklast på hvert stålrør, lengde a1+b0', round(FA_ab), '
kN';...
        '  Grensemantelfriksjon',round(qs), '        kPa';};
columnname =   {'                       Parametere rørskjerm
', 'Verdi', 'Enhet'};
columnformat = {'char', 'numeric', 'char'};
t = uitable('Units','normalized','Position',...
            [0.05 0.05 0.755 0.87], 'Data', dat,...
            'ColumnName', columnname,...
            'ColumnFormat', columnformat,...
            'RowName',[]);
```

**Kode 2: Parameterstudie 1, på sprøytebetong og gitterbuer.**

```
%Parameterstudie på sprøytebetong og gitterbuer, variabel cc mellom
%gitterbuer

clear all
clc
clf
disp('BEREGNINGER OG DIMENSJONERING AV SIKRING UNDER DRIVING');
%%
%VARIABLER
%Løsmasse
Ek = 20000;          %Young's modulus til løsmassen
%(elastisitetsmodulus)[kPa]
gamma = 20;          %Tyngdetetthet på løsmasse [kN/m3]
Ko = 0.5;            %Lateral jordtrykkskoeffisient [dimensjonsløs]
phi = 35;            %Friksjonsvinkel på løsmasse[grader]
c = 10;              %Cohesjon i løsmassene [kPa]
Po = 15;             %Tilleggslast som ligger på overflaten [kPa]
Fberg = 750;         %Styrke på forankringsmaterialet (eks. oppknust berg)
%[kPa]
Lust= 3;             %Lengde på ustabil sone foran stuff [m]

%Tunnel
r = 7.5;             %Radius av tunnelen [m]
H = 16;              %Overdekning [m]

a1 = 1.5;            %Tunneldrivningsetappe, derav også usikret lengde mot
%stuff etter driving av en etappe [m]
                     %Denne vil som regel være lik c/c gitterbuer (ccgb)

%Gitterbue%
ccgb= linspace(1,3,5);  %VARIABEL VED PARAMETERSTUDIE:Beregner for c/c på
%1, 1.5, 2, 2.5 og 3 meter

Estaal = 210000000; %Young's modulus for stålet i gitterbuen [kPa]
sigmaX = 520000;     %Flytegrensen for stålet i gitterbuen [kPa]
A = 0.00197;         %Aral for tverrsnitt av stålet i gitterbuen [m2]
Ix = 0.00001264;     %Treghetsmomentet til gitterbuen fra brosjyre. [m4]
SK = 6;              %Gitterbuens knekklengde[m]
Wx = 0.000092;       %Motstandsmoment, notert under Wy i produktbrosjyren
%til PANTEX 130/26/34 [m3]
SK1 = 0.28;          %Knekklengden til en enkelt spindel i gitterbuen [m]
i1 = 0.0085;         %Treghetsradiusen til en enkelt spindel i gitterbuen
%[m]
gammaM = 1.0;        %Partialkoeffisient for stålet i gitterbuen,ifb. med
%bæreevnen til giterbuen
gammaN = 1.2;        %Partialkoeffisient for gjeldende sikkerhetsklasse,
%ifb. med bæreevnen til giterbuen
m = 2;               %Antall identiske elementer som settes sammen for å
%danne gitterbuen (DIN4114)

%Betong
Ebtg = 15000000;     %Young's modulus for sprøytebetongen [kPa]
d = 0.3;             %Tykkelse på sprøytebetong [m]
bm = 1;              %Breddementer sprøytebetong [m]
Bet3t = 3000;        % Holdfastheten til sprøytebetong etter 3 timer [kPa]
Bet6t = 5000;        % Holdfastheten til sprøytebetong etter 6 timer [kPa]
Bet9t = 6000;        % Holdfastheten til sprøytebetong etter 9 timer [kPa]
Bet12t = 8000;       % Holdfastheten til sprøytebetong etter 12 timer [kPa]
```

```
Bet15t = 10000;     % Holdfastheten til sprøytebetong etter 15 timer [kPa]
Bet24t = 14500;     % Holdfastheten til sprøytebetong etter 24 timer [kPa]

%Spiling
ccb = 0.4;          %Avstand (c/c) mellom spilingbolter [m]
Py = 525;           %Tillat last på stålet i spilingen[kN]
Ls = 3;             %Forankringslengde av stålrørene foran ustabil sone [m]
gammaP = 1.6;       %Sikkerhetsfaktor for stålet i spilingstagene.
gamman=1.2;         %Partialkoeffisient, ifb. med heft av spilingbolter
gammam=1.35;        %Partialkoeffisient, ifb. med heft av spilingbolter
dp = 0.09;          %Diameter på pilar (spiling+injeksjonsmasse)[m]

%%
%DEL 1; Beregning av snittkrefter på tunnelprofil

% Omgjør stivhets-diagrammer til matriser, har på forhånd plottet punkter
%for å få riktig fasong på graf, så lagt på "Shape preserving interpolant,
%for så å få lest av flere punkter langs grafen og lagt dette i matriser.
%Disse matrisene ligger i den første koden og gjentas ikke.

%LASTBEREGNINGER PÅ GITTERBUE

Pr0 = 0.5*gamma*(H+((H+r)*Ko))+(0.5*Po*(1+Ko));  %Beregning av overlast
Pr2 = 0.5*gamma*(H-((H+r)*Ko))+(0.5*Po*(1-Ko));  %Beregning av radiell last
Pboyning = (2*Pr2)+Pr2; % Beregning av bøymomenets andel av lasten

%BEREGNING AV NORMALKREFTER, MOMENT OG DEFORMASJON
%Beregning av treghetsmoment (Sprøytebetong+gitterbue)
Ibetong = ((d^3)*bm)/12; %Treghetsmoment sprøytebetong
Igbue = Ix.*((Estaal./Ebtg)./ccgb); %Treghetsmoment gitterbue
I = Ibetong + Igbue;  %Treghetsmoment sprøytebetong og gitterbue

%Beregning av stivhetsverdien
Kk = Ek/r;          %Setningsmodul på løsmassen [kN/m3]
beta = round((Kk*(r^4))./(Ebtg.*I)); %Beta er stivhetsverdien, brukes i
%diagram over verdier for bøyemoment

%En for-løkke som henter ut verdier fra diagrammer for mF, mU, m90, mS, nF,
%n90, nS og etaF
for i= 2:n
    if beta(1) == GrafMF(1,i);
        mF(1) = GrafMF(2,i);
    end
    if  beta(2) == GrafMF(1,i);
        mF(2) = GrafMF(2,i);
    end
    if  beta(3) == GrafMF(1,i);
        mF(3) = GrafMF(2,i);
    end
    if  beta(4) == GrafMF(1,i);
        mF(4) = GrafMF(2,i);
    end
    if  beta(5) == GrafMF(1,i);
        mF(5) = GrafMF(2,i);
    end
     if beta(1) == GrafM90(1,i);
        m90(1) = GrafM90(2,i);
     end
     if beta(2) == GrafM90(1,i);
        m90(2) = GrafM90(2,i);
```

```
 end
 if beta(3) == GrafM90(1,i);
    m90(3) = GrafM90(2,i);
 end
 if beta(4) == GrafM90(1,i);
    m90(4) = GrafM90(2,i);
 end
 if beta(5) == GrafM90(1,i);
    m90(5) = GrafM90(2,i);
 end
 if beta(1) == GrafMU(1,i);
    mU(1) = GrafMU(2,i);
 end
 if beta(2) == GrafMU(1,i);
    mU(2) = GrafMU(2,i);
 end
 if beta(3) == GrafMU(1,i);
    mU(3) = GrafMU(2,i);
 end
 if beta(4) == GrafMU(1,i);
    mU(4) = GrafMU(2,i);
 end
 if beta(5) == GrafMU(1,i);
    mU(5) = GrafMU(2,i);
 end
 if beta(1) == GrafMS(1,i);
    mS(1) = GrafMS(2,i);
 end
 if beta(2) == GrafMS(1,i);
    mS(2) = GrafMS(2,i);
 end
 if beta(3) == GrafMS(1,i);
    mS(3) = GrafMS(2,i);
 end
 if beta(4) == GrafMS(1,i);
    mS(4) = GrafMS(2,i);
 end
 if beta(5) == GrafMS(1,i);
    mS(5) = GrafMS(2,i);
 end
if beta(1) == GrafNF(1,i);
    nF(1) = GrafNF(2,i);
end
if  beta(2) == GrafNF(1,i);
    nF(2) = GrafNF(2,i);
end
if  beta(3) == GrafNF(1,i);
    nF(3) = GrafNF(2,i);
end
if  beta(4) == GrafNF(1,i);
    nF(4) = GrafNF(2,i);
end
if  beta(5) == GrafNF(1,i);
    nF(5) = GrafNF(2,i);
end
 if beta(1) == GrafN90(1,i);
    n90(1) = GrafN90(2,i);
 end
 if beta(2) == GrafN90(1,i);
    n90(2) = GrafN90(2,i);
 end
```

```
      if beta(3) == GrafN90(1,i);
         n90(3) = GrafN90(2,i);
      end
      if beta(4) == GrafN90(1,i);
         n90(4) = GrafN90(2,i);
      end
      if beta(5) == GrafN90(1,i);
         n90(5) = GrafN90(2,i);
      end
      if beta(1) == GrafNS(1,i);
         nS(1) = GrafNS(2,i);
      end
      if beta(2) == GrafNS(1,i);
         nS(2) = GrafNS(2,i);
      end
      if beta(3) == GrafNS(1,i);
         nS(3) = GrafNS(2,i);
      end
      if beta(4) == GrafNS(1,i);
         nS(4) = GrafNS(2,i);
      end
      if beta(5) == GrafNS(1,i);
         nS(5) = GrafNS(2,i);
      end
       if beta(1) == GrafWF(1,i);
         etaF(1) = GrafWF(2,i);
       end
       if beta(2) == GrafWF(1,i);
         etaF(2) = GrafWF(2,i);
       end
       if beta(3) == GrafWF(1,i);
         etaF(3) = GrafWF(2,i);
       end
       if beta(4) == GrafWF(1,i);
         etaF(4) = GrafWF(2,i);
       end
       if beta(5) == GrafWF(1,i);
         etaF(5) = GrafWF(2,i);
       end
end

%Moment
MF = mF.*Pboyning*(r^2);
M90 =m90.*Pboyning*(r^2);
MU =mU.*Pboyning*(r^2);
MS =mS.*Pboyning*(r^2);

%Normalkrefter
NF =  (-Pr0+(0.5*Pr2)+(nF.*Pboyning)).*r;
NFabs= abs(NF); %Absoluttverien brukes i plot
N90 =(-Pr0-(0.5*Pr2)+(n90.*Pboyning)).*r;
N90abs= abs(N90); %Absoluttverien brukes i plot
NS =(-Pr0+(0.5*Pr2)+(n90.*Pboyning)).*r;
NSabs= abs(NS); %Absoluttverien brukes i plot

%Beregning av eksentrisitet
e_F = MF./NF;
e_90 = M90./N90;
e_S = MS./NS;

%Finner hvor i profilet eksentisiteten er størst
```

```
e_max(1)=max(abs([e_F(1),e_90(1),e_S(1)]));
e_max(2)=max(abs([e_F(2),e_90(2),e_S(2)]));
e_max(3)=max(abs([e_F(3),e_90(3),e_S(3)]));
e_max(4)=max(abs([e_F(4),e_90(4),e_S(4)]));
e_max(5)=max(abs([e_F(5),e_90(5),e_S(5)]));

%GLOBAL KNEKKNINGSBEREGNING AV GITTERBUE
%Beregning av treghetsradiusen til gitterbuen
ig = sqrt(Ix/A);    %Der Ix er treghetsmomet til stålbue og A er
tverrsnittareal til bue

%Beregning av slankhetstallet til gitterbuen
lamdaX = SK/ig;      % SK er gitterbuens knekklengde.

%Beregning av slankhetstallet til en enkelt stålstang i gitterbuen
lamdaX1 = SK1/i1;

%Beregning av ideelt slankhetstall til gitterbuen
lamdaXi = sqrt((lamdaX^2)+((m/2)*(lamdaX1^2)));
AvrundetlamdaXi = round(round(lamdaXi)*0.1)*10; %Runder av til nærmeste
%hele tier for å bruke i tabell under.

%Tabell fra DIN4114 (Deutche Normen, 1952)
OmegaTabell= [20 1.06 1.06 1.07 1.07 1.08 1.08 1.09 1.09 1.1 1.11
    30 1.11 1.12 1.12 1.13 1.14 1.15 1.15 1.16 1.17 1.18
    40 1.19 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27
    50 1.28 1.30 1.31 1.32 1.33 1.35 1.36 1.37 1.39 1.40
    60 1.41 1.43 1.44 1.46 1.48 1.49 1.51 1.53 1.54 1.56
    70 1.58 1.60 1.62 1.64 1.66 1.68 1.70 1.72 1.74 1.77
    80 1.79 1.81 1.83 1.86 1.88 1.91 1.93 1.95 1.98 2.01
    90 2.05 2.10 2.14 2.19 2.24 2.29 2.33 2.38 2.43 2.48
    100 2.53 2.58 2.64 2.69 2.74 2.79 2.85 2.90 2.95 3.01
    110 3.06 3.12 3.18 3.23 3.29 3.35 3.41 3.47 3.53 3.59
    120 3.65 3.71 3.77 3.83 3.89 3.96 4.02 4.09 4.15 4.22
    130 4.28 4.35 4.41 4.48 4.55 4.62 4.69 4.75 4.82 4.89
    140 4.96 5.04 5.11 5.18 5.25 5.33 5.40 5.47 5.55 5.62
    150 5.70 5.78 5.85 5.93 6.01 6.09 6.16 6.24 6.32 6.40
    160 6.48 6.57 6.65 6.73 6.81 6.90 6.98 7.06 7.15 7.23
    170 7.32 7.41 7.49 7.58 7.67 7.76 7.85 7.94 8.03 8.12
    180 8.21 8.30 8.39 8.48 8.58 8.67 8.76 8.86 8.95 9.05
    190 9.14 9.24 9.34 9.44 9.53 9.63 9.73 9.83 9.93 10.03
    200 10.13 10.23 10.34 10.44 10.54 10.65 10.75 10.85 10.96 11.06
    210 11.17 11.28 11.38 11.49 11.60 11.71 11.82 11.93 12.04 12.15
    220 12.26 12.37 12.48 12.60 12.71 12.82 12.94 13.05 13.17 13.28
    230 13.40 13.52 13.63 13.75 13.87 13.99 14.11 14.23 14.35 14.47
    240 14.59 14.71 14.83 14.96 15.08 15.20 15.33 15.45 15.58 15.71
    250 15.83 0 0 0 0 0 0 0 0 0];

%For-løkke for å plukke ut knekkverdien til gitterbuen.
for i = 1:24
    if OmegaTabell(i,1)== AvrundetlamdaXi
        Omegaxi= OmegaTabell(i,(2+m));
    end
end

%BEREGNING AV BÆREEVNEN TIL GITTERBUE OG SPRØYTEBETONG
%Bæreevnen med 1m avstand mellom hver gitterbue
Ngcc1(1)  =
(sigmaX./((Omegaxi./A)+(0.9*(abs(e_max(1))/Wx))))*(1./gammaN*gammaM);
```

```
Ngcc1(2) =
(sigmaX./((Omegaxi./A)+(0.9*(abs(e_max(2))/Wx))))*(1./gammaN*gammaM);
Ngcc1(3) =
(sigmaX./((Omegaxi./A)+(0.9*(abs(e_max(3))/Wx))))*(1./gammaN*gammaM);
Ngcc1(4) =
(sigmaX./((Omegaxi./A)+(0.9*(abs(e_max(4))/Wx))))*(1./gammaN*gammaM);
Ngcc1(5) =
(sigmaX./((Omegaxi./A)+(0.9*(abs(e_max(5))/Wx))))*(1./gammaN*gammaM);

%Bæreevnen med angitt c/c mellom hver gitterbue
Ngcc = (Ngcc1./ccgb)'; % under denne beregnes gjøres også rekken om til en
%kolonne ved bruk av '

%Bæreevnen til sprøytebetong
Nsp(1,:) = (d*bm*(1-(2.*(abs(e_max(1))/d))))*betaK(2,:); % Bærekraften til
%sprøytebetongen etter 3, 6, 9, 12, 15 og 24 timer [N]
Nsp(2,:) = (d.*bm.*(1-(2.*(abs(e_max(2))./d)))).*betaK(2,:);
Nsp(3,:) = (d.*bm.*(1-(2.*(abs(e_max(3))./d)))).*betaK(2,:);
Nsp(4,:) = (d.*bm.*(1-(2.*(abs(e_max(4))./d)))).*betaK(2,:);
Nsp(5,:) = (d.*bm.*(1-(2.*(abs(e_max(5))./d)))).*betaK(2,:);

%Bæreevnen til sprøytebetong og gitterbue etter 3, 6, 9, 12, 15 og 24 timer
%[N]
Nspcc(:,1)= Nsp(:,1)+Ngcc;
Nspcc(:,2)= Nsp(:,2)+Ngcc;
Nspcc(:,3)= Nsp(:,3)+Ngcc;
Nspcc(:,4)= Nsp(:,4)+Ngcc;
Nspcc(:,5)= Nsp(:,5)+Ngcc;
Nspcc(:,6)= Nsp(:,6)+Ngcc;

%Lager matriser for å plotte normalkreftene som virker på sprøytebetong og
%gitterbue.
Normalkrefter1 = [3,24             %Vegg
    N90abs(1), N90abs(1)];
Normalkrefter15 = [3,24
    N90abs(2), N90abs(2)];
Normalkrefter2 = [3,24
    N90abs(3), N90abs(3)];
Normalkrefter25 = [3,24
    N90abs(4), N90abs(4)];
Normalkrefter3 = [3,24
    N90abs(5), N90abs(5)];

figure(1)
plot(betaK(1,:),Nspcc(1,:),'r')
hold on
plot(betaK(1,:),Nspcc(2,:),'--b');
plot(betaK(1,:),Nspcc(3,:),'--m');
plot(betaK(1,:),Nspcc(4,:),'--g');
plot(betaK(1,:),Nspcc(5,:),'k');

plot(Normalkrefter1(1,:),Normalkrefter1(2,:),'--k');

hleg1=legend('Bæreevne med c/c gitterbuer: 1 meter','Bæreevne med c/c
gitterbuer: 1.5 meter','Bæreevne med c/c gitterbuer: 2 meter','Bæreevne med
c/c gitterbuer: 2.5 meter','Bæreevne med c/c gitterbuer: 3
meter','Normalkrefter 90° vegg i alle tilfeller');
set(hleg1,'Location','SouthOutside')
xlabel('Tid [t]');
ylabel('Last [kN]');
```

```
title('Bæreevne PARAMETERSTUDIE c/c gitterbuer, betongtykkelse 0.3 meter');
grid
axis tight
hold off
```

### Kode 3: Parameterstudie 2, på sprøytebetong og gitterbuer.

```
%Yxhugget Stockholm
%Parameterstudie over tykkelse på sprøytebetong
clear all
clc
clf
disp('BEREGNINGER OG DIMENSJONERING AV SIKRING UNDER DRIVING');
%%
%VARIABLER
%Løsmasse
Ek = 20000;          %Young's modulus til løsmassen
%(elastisitetsmodulus)[kPa]
gamma = 20;          %Tyngdetetthet på løsmasse [kN/m3]
Ko = 0.5;            %Lateral jordtrykkskoeffisient [dimensjonsløs]
phi = 35;            %Friksjonsvinkel på løsmasse[grader]
c = 10;              %cohesjon i løsmassene [kPa]
Po = 15;             %Tilleggslast som ligger på overflaten [kPa]

%Tunnel
r = 7.5;             %Radius av tunnelen [m]
H = 16;              %Overdekning [m]

%Gitterbue
Estaal = 210000000; %Young's modulus for stålet i gitterbuen [kPa]
sigmaX = 520000;     %Flytegrensen for stålet i gitterbuen [kPa]
ccgb = 1.5;          %Avstand (c/c) mellom gitterbuer [m]
A = 0.00197;         %Aral for tverrsnitt av stålet i gitterbuen [m2]
Ix = 0.00001264;     %Treghetsmomentet til gitterbuen fra brosjyre [m4]
SK = 6;              %Gitterbuens knekklengde[m]
Wx = 0.000092;       %Motstandsmoment, notert under Wy i produktbrosjyren
%til PANTEX 130/26/34 [m3]
SK1 = 0.28;          %Knekklengden til en enkelt spindel i gitterbuen [m]
i1 = 0.0085;         %Treghetsradiusen til en enkelt spindel i gitterbuen
%[m]
gammaM = 1.0;        %Partialkoeffisient for stålet i gitterbuen,ifb. med
%bæreevnen til giterbuen
gammaN = 1.2;        %Partialkoeffisient for gjeldende sikkerhetsklasse,
%ifb. med bæreevnen til giterbuen
m = 2;               %Antall identiske elementer som settes sammen for å
%danne gitterbuen (DIN4114)

%Betong
Ebtg = 15000000;         %Young's modulus for sprøytebetongen [kPa]
d = [0.25 0.30 0.35];     %VARIABEL I PARAMETERSTUDIE Tykkelse på
%sprøytebetong [m]
bm = 1;                  %Breddementer sprøytebetong [m]
Bet3t = 3000;            % Holdfastheten til sprøytebetong etter 3 timer
%[kPa]
Bet6t = 5000;            % Holdfastheten til sprøytebetong etter 6 timer
%[kPa]
Bet9t = 6000;            % Holdfastheten til sprøytebetong etter 9 timer
%[kPa]
Bet12t = 8000;           % Holdfastheten til sprøytebetong etter 12 timer
%[kPa]
```

```
Bet15t = 10000;         % Holdfastheten til sprøytebetong etter 15 timer
%[kPa]
Bet24t = 14500;         % Holdfastheten til sprøytebetong etter 24 timer
%[kPa]


%%
%DEL 1; Beregning av snittkrefter på tunnelprofil

% Omgjør stivhets-diagrammer til matriser, har på forhånd plottet punkter
%for å få riktig fasong på graf, så lagt på "Shape preserving interpolant,
%for så å få lest av flere punkter langs grafen og lagt dette i matriser.
%Disse matrisene ligger i den første koden og gjentas ikke.

%LASTBEREGNINGER PÅ GITTERBUE

Pr0 = 0.5*gamma*(H+((H+r)*Ko))+(0.5*Po*(1+Ko));  %Beregning av overlast
Pr2 = 0.5*gamma*(H-((H+r)*Ko))+(0.5*Po*(1-Ko));  %Beregning av radiell last
Pboyning = (2*Pr2)+Pr2; % Beregning av bøymomenets andel av lasten

%BEREGNING AV NORMALKREFTER, MOMENT OG DEFORMASJON

for i=1:3       %For-løkke for å beregne for ulik tykkelse av sprøytebetong
    %Beregning av treghetsmoment (Sprøytebetong+gitterbue)
    Ibetong(i) = ((d(i)^3)*bm)/12 %Treghetsmoment sprøytebetong
    Igbue = Ix*((Estaal/Ebtg)/ccgb); %Treghetsmoment gitterbue verdier i
%formelen har ukjent opphav.
    I(i) = Ibetong(i) + Igbue;  %Treghetsmoment sprøytebetong og gitterbue

    %Beregning av stivhetsverdien
    Kk = Ek/r;          %Setningsmodul på løsmassen [kN/m3]
    beta(i) = round((Kk*(r^4))/(Ebtg*I(i))) %Beta er stivhetsverdien,
%brukes i  diagram over verdier for bøyemoment

    %En for-løkke som henter ut verdier fra diagrammer for mF, mU, m90, mS,
%nF, n90, nS og etaF
    for j= 2:n
        if beta(i) == GrafMF(1,j)
            mF(i) = GrafMF(2,j);
        end
        if beta(i) == GrafM90(1,j)
            m90(i) = GrafM90(2,j);
        end
        if beta(i) == GrafMU(1,j)
            mU(i) = GrafMU(2,j);
        end
        if beta(i) == GrafMS(1,j)
            mS(i) = GrafMS(2,j);
        end
        if beta(i) == GrafNF(1,j)
            nF(i) = GrafNF(2,j);
        end
        if beta(i) == GrafN90(1,j)
            n90(i) = GrafN90(2,j);
        end
        if beta(i) == GrafNS(1,j)
            nS = GrafNS(2,j);
        end
        if beta(i) == GrafWF(1,j)
            etaF(i) = GrafWF(2,j);
```

```
        end
    end

    %Moment
    MF(i) = mF(i)*Pboyning*(r^2);
    M90(i) =m90(i)*Pboyning*(r^2);
    MU(i) =mU(i)*Pboyning*(r^2);
    MS(i) =mS(i)*Pboyning*(r^2);

    %Normalkrefter
    NF(i) = (-Pr0+(0.5*Pr2)+(nF(i)*Pboyning))*r;
    NFabs(i)= abs(NF(i)); %Absoluttverien brukes i diagram over bæreevne
    N90(i) =(-Pr0-(0.5*Pr2)+(n90(i)*Pboyning))*r;
    N90abs(i)= abs(N90(i)); %Absoluttverien brukes i diagram over bæreevne
    NS(i) =(-Pr0+(0.5*Pr2)+(n90(i)*Pboyning))*r;
    NSabs(i)= abs(NS(i)); %Absoluttverien brukes i diagram over bæreevne

    %Beregning av eksentrisitet
    e_F(i) = MF(i)/NF(i);
    e_90(i) = M90(i)/N90(i);
    e_S(i) = MS(i)/NS(i);

    %Finner hvor i profilet eksentisiteten er størst
    e_max(i)=max(abs([e_F(i),e_90(i),e_S(i)]))

    %Sier i fra hvor eksentrisiteten er størst og plukker opp verdien til
%videre bruk.
    %Bruker ikke e_max videre for å unngå fortegnsfeil.

    if abs(e_F(i))==e_max(i)
        e_dim(i)=e_F(i);
    end
    if abs(e_90(i))==e_max(i)
        e_dim(i)=e_90(i);
    end
    if abs(e_S(i))==e_max(i)
        e_dim(i)=e_S(i);
    end

    %GLOBAL KNEKKNINGSBEREGNING AV GITTERBUE

    %Beregning av treghetsradiusen til gitterbuen
    ig = sqrt(Ix/A);     %Der Ix er treghetsmomet til stålbue og A er
%tverrsnittareal til bue

    %Beregning av slankhetstallet til gitterbuen
    lamdaX = SK/ig;        % SK er gitterbuens knekklengde.

    %Beregning av slankhetstallet til en enkelt stålstang i gitterbuen
    lamdaX1 = SK1/i1;

    %Beregning av ideelt slankhetstall til gitterbuen
    lamdaXi = sqrt((lamdaX^2)+((m/2)*(lamdaX1^2)));
    AvrundetlamdaXi = round(round(lamdaXi)*0.1)*10; %Runder av til nærmeste
%hele tier for å bruke i tabell under.

    %Tabell fra DIN4114 (Deutche Normen, 1952)
    OmegaTabell= [20 1.06 1.06 1.07 1.07 1.08 1.08 1.09 1.09 1.1 1.11
        30 1.11 1.12 1.12 1.13 1.14 1.15 1.15 1.16 1.17 1.18
```

```
        40 1.19 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27
        50 1.28 1.30 1.31 1.32 1.33 1.35 1.36 1.37 1.39 1.40
        60 1.41 1.43 1.44 1.46 1.48 1.49 1.51 1.53 1.54 1.56
        70 1.58 1.60 1.62 1.64 1.66 1.68 1.70 1.72 1.74 1.77
        80 1.79 1.81 1.83 1.86 1.88 1.91 1.93 1.95 1.98 2.01
        90 2.05 2.10 2.14 2.19 2.24 2.29 2.33 2.38 2.43 2.48
        100 2.53 2.58 2.64 2.69 2.74 2.79 2.85 2.90 2.95 3.01
        110 3.06 3.12 3.18 3.23 3.29 3.35 3.41 3.47 3.53 3.59
        120 3.65 3.71 3.77 3.83 3.89 3.96 4.02 4.09 4.15 4.22
        130 4.28 4.35 4.41 4.48 4.55 4.62 4.69 4.75 4.82 4.89
        140 4.96 5.04 5.11 5.18 5.25 5.33 5.40 5.47 5.55 5.62
        150 5.70 5.78 5.85 5.93 6.01 6.09 6.16 6.24 6.32 6.40
        160 6.48 6.57 6.65 6.73 6.81 6.90 6.98 7.06 7.15 7.23
        170 7.32 7.41 7.49 7.58 7.67 7.76 7.85 7.94 8.03 8.12
        180 8.21 8.30 8.39 8.48 8.58 8.67 8.76 8.86 8.95 9.05
        190 9.14 9.24 9.34 9.44 9.53 9.63 9.73 9.83 9.93 10.03
        200 10.13 10.23 10.34 10.44 10.54 10.65 10.75 10.85 10.96 11.06
        210 11.17 11.28 11.38 11.49 11.60 11.71 11.82 11.93 12.04 12.15
        220 12.26 12.37 12.48 12.60 12.71 12.82 12.94 13.05 13.17 13.28
        230 13.40 13.52 13.63 13.75 13.87 13.99 14.11 14.23 14.35 14.47
        240 14.59 14.71 14.83 14.96 15.08 15.20 15.33 15.45 15.58 15.71
        250 15.83 0 0 0 0 0 0 0 0 0];

    %For-løkke for å plukke ut knekkverdien til gitterbuen.
    for k = 1:24
        if OmegaTabell(k,1)== AvrundetlamdaXi
            Omegaxi= OmegaTabell(k,(2+m));
        end
    end

    %BEREGNING AV BÆREEVNEN TIL GITTERBUE OG SPRØYTEBETONG

    %Bæreevnen med 1m avstand mellom hver gitterbue
    Ngcc1(i) =
((sigmaX/((Omegaxi/A)+(0.9*(abs(e_dim(i))/Wx))))*(1/gammaN*gammaM))' %Her
%er  det en følgefeil som stammer fra e_tak da denne skal være 0.0570,
%ikke 0.07. Se utregning side 1:6

    %Bæreevnen med angitt c/c mellom hver gitterbue
    Ngcc15(i) = (Ngcc1(i)/ccgb)' ;

    %Bæreevnen til sprøytebetong
    NspTEST(i,:) = d(i)*bm*(1-(2*(abs(e_dim(i))/d(i))))
    Nsp(i,:) = d(i)*bm*betaK(2,:)*(1-(2*(abs(e_dim(i))/d(i)))) %
%Bærekraften til sprøytebetongen etter 3, 6, 9, 12, 15 og 24 timer [N]

    %Bæreevnen til sprøytebetong og gitterbue
    Nspcc1(i,:) = Nsp(i,:) + Ngcc1(i); % Bæreevnen til sprøytebetongen og
%gitterbue med c/c 1m etter 3, 6, 9, 12, 15 og 24 timer [N]
    Nspcc15(i,:) = Nsp(i,:) + Ngcc15(i); % Bæreevnen til sprøytebetongen og
%gitterbue med c/c 1.5m etter 3, 6, 9, 12, 15 og 24 timer [N]
end

%Lager matriser for å plotte normalkreftene som virker på sprøytebetong og
%gitterbue.
NormalkrefterTak1 = [3,24                   %Tak
   NFabs(1), NFabs(1)];
Normalkrefter901 = [3,24                    %Vegg
   N90abs(1), N90abs(1)];
NormalkrefterS1 = [3,24                     %Såle
```

```
   NSabs(1), NSabs(1)];

NormalkrefterTak2 = [3,24             %Tak
   NFabs(2), NFabs(2)];
Normalkrefter902 = [3,24              %Vegg
   N90abs(2), N90abs(2)];
NormalkrefterS2 = [3,24               %Såle
   NSabs(2), NSabs(2)];

NormalkrefterTak3 = [3,24             %Tak
   NFabs(3), NFabs(3)];
Normalkrefter903 = [3,24              %Vegg
   N90abs(3), N90abs(3)];
NormalkrefterS3 = [3,24               %Såle
   NSabs(3), NSabs(3)];

figure(1)
hold on

plot(betaK(1,:),Nspcc15(1,:),'k');
plot(betaK(1,:),Nspcc15(2,:),'b');
plot(betaK(1,:),Nspcc15(3,:),'r');
plot(Normalkrefter903(1,:),Normalkrefter903(2,:),'--k');

hleg1=legend('Bæreevne med 0.25 meter tykk sprøytebetong','Bæreevne med 0.3
meter tykk sprøytebetong','Bæreevne med 0.4 meter tykk
sprøytebetong','Normalkrefter 90° vegg i alle tilfeller');
set(hleg1,'Location','SouthOutside')
xlabel('Tid [t]');
ylabel('Last [kN]');
title('Sikring av tunnelprofil: PARAMETERSTUDIE tykkelse sprøytebetong, med
c/c gitterbuer på 1.5 meter');
grid on
axis tight
hold off
```

### Kode 4: Parameterstudie 1, “Composite Pile Roofing”

```
%Parameterstudie av avstand mellom hver rørskjerm
clear all
clc
clf
disp('BEREGNINGER OG DIMENSJONERING AV SIKRING UNDER DRIVING');
%%
%VARIABLER
%Løsmasse
gamma = 20;          %Tyngdetetthet på løsmasse [kN/m3]
Ko = 0.5;            %Lateral jordtrykkskoeffisient [dimensjonsløs]
phi = 35;            %Friksjonsvinkel på løsmasse[grader]
c = 10;              %cohesjon i løsmassene [kPa]
Po = 15;             %Tilleggslast som ligger på overflaten [kPa]
qsberg = 750;        %Styrke på forankringsmaterialet (eks. oppknust berg)
[kPa]
Lust= 3;             %Lengde på ustabil sone foran stuff [m]

%Tunnel
h = 16;              %Overdekning [m]
a = 1;               %Inndrift [m]Denne vil som regel være lik c/c
%gitterbuer
```

```
%Spiling
ccb = 0.4;          %Avstand (c/c) mellom spilingbolter [m]
Ftill = 325;        %Tillat strekklast på stålet i spilingen[kN]
Ls = 3;             %Forankringslengde av stålrørene foran ustabil sone [m]
gammaP = 1.6;       %Sikkerhetsfaktor for stålet i spilingboltene.
gamman=1.2;         %Partialkoeffisient, ifb. med heft av spilingbolter
gammam=1.35;        %Partialkoeffisient, ifb. med heft av spilingbolter
dp = 0.09;          %Diameter på pilar (spiling+injeksjonsmasse)[m]


%%
%PARAMETERSTUDIE SPILING
a=linspace(0,3,4);              %Ved parameterstudiet settes inndrift til 1
%for å kunne skyve spilingskjermen
a2 = 1;             %Nylig sikret med sprøytebetong og gitterbue,dvs. uten
%komplett tunnelforsterkning [m]
b = a2+Lust+a;      %Bredden som krysses av boltene (Ustabil sone) [m]
b0 = b/2;           %Bredden på halvparten av sonen som krysses av boltene
%(for Terzaghi) [m]
interv=a2+a;        %Installasjonsintervall mellom hver rørskjerm

%Beregning av silotrykk over åpningen som krysses av spilingbolene (b)
sigmaS = ((((b0.*gamma)-c)/(Ko*tand(phi))).*(1-exp((-
Ko*h*tand(phi))./b0)))+(Po.*exp((-Ko*h*tand(phi))./b0));

%Beregning av pilhøyden
Z=b/8;

% Beregning trekkraften som virker på spilingen
F = (sigmaS.*(b.^2))./(8.*Z); %Beregning av trekkraft på silingen ved
%åpningen b som krysses av spilingbolene (b)
FA = F.*ccb;
Ftill2= [Ftill Ftill Ftill Ftill];
%Beregning av heft mellom sement og omliggende masse
qs = (FA.*gamman.*gammam)./(pi.*dp.*Ls);
qstill= [qsberg qsberg qsberg qsberg];

figure(1)
subplot(2,2,1)
plot(interv,sigmaS)
title('Silotrykk på ustabil sone')
xlabel('c/c mellom hver rørskjerm [m]')
ylabel('Silotrykk [kPa]')
grid on
axis tight

subplot(2,2,2)
plot(interv,FA)
hold on
plot(interv,Ftill2,'--r')
leg=legend('Beregnet strekklast[kN]','Tillatt strekklast på TITAN
40/16[kN]');
set(leg,'Location','SouthOutside')
grid on
axis tight
title('Beregnet strekklast på ett stålrør vs. tillatt strekklast på TITAN
40/16')
xlabel('c/c mellom hver rørskjerm [m]')
ylabel('Strekklast [kN]')
```

```
hold off

subplot(2,2,4)
plot(interv,qs)
hold on
plot(interv,qstill,'--r')
leg2=legend('Grensemantelfriksjon [kPa]','Styrke på forvitret berg[kPa]');
set(leg2,'Location','SouthOutside')
grid on
title('Grensemantelfriksjon med forankringslengde på 3 meter')
xlabel('c/c mellom hver rørskjerm [m]')
ylabel('Friksjon [kPa]')
hold off
```

### Kode 5: Parameterstudie 2, “Composite Pile Roofing”

```
%Parameterstudie av avstand mellom hvert rør i rørskjermen
clear all
clc
clf
disp('BEREGNINGER OG DIMENSJONERING AV SIKRING UNDER DRIVING');
%%
%VARIABLER
%Løsmasse
Ek = 20000;           %Young's modulus til løsmassen
%(elastisitetsmodulus)[kPa]
gamma = 20;           %Tyngdetetthet på løsmasse [kN/m3]
Ko = 0.5;             %Lateral jordtrykkskoeffisient [dimensjonsløs]
phi = 35;             %Friksjonsvinkel på løsmasse[grader]
c = 10;               %cohesjon i løsmassene [kPa]
Po = 15;              %Tilleggslast som ligger på overflaten [kPa]
Fberg = 750;          %Styrke på forankringsmaterialet (eks. oppknust berg)
%[kPa]
Lust= 3;              %Lengde på ustabil sone foran stuff [m]

%Tunnel
H = 16;               %Overdekning [m]
a1 = 1.5;             %Tunneldrivningsetappe, derav også usikret lengde mot
%stuff etter driving av en etappe [m]
                      %Denne vil som regel være lik c/c gitterbuer (ccgb)

%Spiling
ccb=linspace(0.2,0.7,6);% VARIABEL PARAMETERSTUDIE:Lager en rekke med ulike
%monteringasavstander
Py = 525;             %Tillat last på stålet i spilingen[kN]
Ls = 3;               %Forankringslengde av stålrørene foran ustabil sone [m]
gammaP = 1.6;         %Sikkerhetsfaktor for stålet i spilingstagene.
gamman=1.2;           %Partialkoeffisient, ifb. med heft av spilingbolter
gammam=1.35;          %Partialkoeffisient, ifb. med heft av spilingbolter
dp = 0.09;            %Diameter på pilar (spiling+injeksjonsmasse)[m]



%%
%PARAMETERSTUDIE SPILING
a2 = a1;              %Nylig sikret med sprøytebetong og gitterbue,dvs. uten
%komplett tunnelforsterkning [m]
b = a2+Lust+a1;       %Bredden som krysses av boltene (Ustabil sone) [m]
b0 = b/2;             %Bredden på halvparten av sonen som krysses av boltene
%(for Terzaghi) [m]
interv=a2+a1;         %Installasjonsintervall mellom hver rørskjerm
```

```
%Beregning av silotrykk over åpningen som krysses av spilingbolene (b)
sigmaS = ((((b0.*gamma)-c)/(Ko*tand(phi))).*(1-exp((-
Ko*H*tand(phi))./b0)))+(Po.*exp((-Ko*H*tand(phi))./b0));

%Beregning av pilhøyden
Z=b/8;

% Beregning av strekklast som virker på spilingen
F = (sigmaS.*(b.^2))./(8.*Z); %Beregning av strekklast på spilingen ved
%åpningen b som krysses av spilingbolene (b)
FA = ccb.*F;
Ftill= [325 325];
%Beregning av heft mellom injeksjonsmasse og omliggende masse
qs = (FA*gamman*gammam)/(pi*dp*Ls)
qstill= [750 750];

figure(1)
subplot(1,2,1)
plot(ccb,FA)
hold on
plot([0.2 0.7],Ftill,'r--')
leg=legend('Beregnet strekklast på ett stålrør [kN]','Tillatt strekklast på
TITAN 40/16 [kN]');
set(leg,'Location','SouthOutside')
grid on
axis tight
title('Beregnet strekklast vs. tillatt strekklast på TITAN 40/16')
xlabel('c/c mellom hvert stålrør [m]')
ylabel('Strekklast [kN]')
hold off

subplot(1,2,2)
plot(ccb,qs)
hold on
plot([0.2 0.7],qstill,'r--')
leg2=legend('Grensemantelfriksjon [kPa]','Styrke på forvitret berg[kPa]');
set(leg2,'Location','SouthOutside')
grid on
axis tight
title('Grensemantelfriksjon med fast forankringslengde på 3 meter')
xlabel('c/c mellom hvert stålrør [m]')
ylabel('Friksjon [kPa]')
hold off
```

### Kode 5: Parameterstudie 3, “Composite Pile Roofing”

```
%Parameterstudie av forankringslengde/lengde på rørene
clear all
clc
clf
disp('BEREGNINGER OG DIMENSJONERING AV SIKRING UNDER DRIVING');
%%
%VARIABLER
%Løsmasse
Ek = 20000;          %Young's modulus til løsmassen
%(elastisitetsmodulus)[kPa]
gamma = 20;          %Tyngdetetthet på løsmasse [kN/m3]
Ko = 0.5;            %Lateral jordtrykkskoeffisient [dimensjonsløs]
```

```
phi = 35;            %Friksjonsvinkel på løsmasse[grader]
c = 10;              %cohesjon i løsmassene [kPa]
Po = 15;             %Tilleggslast som ligger på overflaten [kPa]
Fberg = 750;         %Styrke på forankringsmaterialet (eks. oppknust berg)
%[kPa]
Lust= 3;             %Lengde på ustabil sone foran stuff [m]

%Tunnel
H = 16;              %Overdekning [m]
a1 = 1.5;            %Tunneldrivningsetappe, derav også usikret lengde mot
%stuff etter driving av en etappe [m]
                     %Denne vil som regel være lik c/c gitterbuer (ccgb)

%Spiling
ccb = 0.4;           %Avstand (c/c) mellom spilingbolter [m]
Py = 525;            %Tillat last på stålet i spilingen[kN]
Ls=linspace(1,9,9); %VARIABLEL PARAMETERSTUDIE:Ulik forankringslengde på
rør
gammaP = 1.6;        %Sikkerhetsfaktor for stålet i spilingstagene.
gamman=1.2;          %Partialkoeffisient, ifb. med heft av spilingbolter
gammam=1.35;         %Partialkoeffisient, ifb. med heft av spilingbolter
dp = 0.09;           %Diameter på pilar (spiling+injeksjonsmasse)[m]

%%
%PARAMETERSTUDIE SPILING
a2 = a1;             %Nylig sikret med sprøytebetong og gitterbue,dvs. uten
%komplett tunnelforsterkning [m]
b = a2+Lust+a1;      %Bredden som krysses av boltene (Ustabil sone) [m]
b0 = b/2;            %Bredden på halvparten av sonen som krysses av boltene
%(for Terzaghi) [m]
interv=a2+a1;        %Insallasjonsintervall mellom hver rørskjerm

%Beregning av silotrykk over åpningen som krysses av spilingbolene (b)
sigmaS = ((((b0.*gamma)-c)/(Ko*tand(phi))).*(1-exp((-
Ko*H*tand(phi))./b0)))+(Po.*exp((-Ko*H*tand(phi))./b0));

%Beregning av pilhøyden
Z=b/8;

% Beregning strekklast som virker på spilingen
F = (sigmaS.*(b.^2))./(8.*Z); %Beregning av strekklast på spilingen ved
%åpningen b som krysses av spilingbolene (b)
FA = F.*ccb;

%Beregning av heft(grensemantelfriksjon) mellom injeksjonsmasse og
%forvitret berg
qs = (FA.*gamman.*gammam)./(pi.*dp.*Ls);
qstill= [750 750];

figure(1)
plot(Ls,qs)
hold on
plot([1 9],qstill,'--r')
leg2=legend('Grensemantelfriksjon [kPa]','Styrke på forvitret berg[kPa]');
set(leg2,'Location','SouthOutside')
grid on
title('Grensemantelfriksjon, avhengig av forankringslengde på stålrør')
xlabel('Forankringslengde på stålrør [m]')
ylabel('Friksjon [kPa]')
hold off
```