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;-----
; ---- Excavation and Support for a Shallow Tunnel ----
;-----

; generate primitive components of grid
; concrete liner - upper tunnel
gen zon cshell p0 0 0 0 p1 7 0 0 p2 0 51 0 p3 0 0 5.5 &
    dim 5 5 5 5 size 2 51 10
group 'concrete liner'
;
; upper tunnel
gen zon cyl p0 0 0 0 p1 5 0 0 p2 0 51 0 p3 0 0 5 &
    size 5 51 10
group tunnel range group 'concrete liner' not
;
; lower tunnel & liner
gen zone brick p0 0 0 -4.5 p1 add 7 0 0 p2 add 0 51 0 p3 add 0 0 4.5 &
    size 7 51 3

;
; surrounding rock (10 primitives)
gen zon radcyl p0 0 0 0 p1 27 0 0 p2 0 51 0 p3 0 0 25 &
    dim 7 5.5 7 5.5 size 5 51 10 8 rat 1 1 1 1.3
;
gen zone brick p0 7 0 -4.5 p1 27 0 -15 p2 add 0 51 0 p3 7 0 0 &
    p4 27 51 -15 p5 7 51 0 p6 27 0 0 p7 27 51 0 &
    size 8 51 3 ratio 1.3 1 1
;
gen zone brick p0 0 0 -15 p1 add 27 0 0 p2 add 0 51 0 p3 0 0 -4.5 &
    p4 27 51 -15 p5 0 51 -4.5 p6 7 0 -4.5 p7 7 51 -4.5 &
    size 7 51 8 rat 1 1 0.7692307692307692
;
gen zon brick p0 0 0 25 p1 add 27 0 0 p2 add 0 51 0 p3 add 0 0 10 &
    size 5 51 2
;
gen zon bric p0 27 0 25 p1 add 17 0 0 p2 add 0 51 0 p3 add 0 0 10 &
    size 2 51 2 rat 2 1 1
;
gen zon bric p0 27 0 -15 p1 add 17 0 0 p2 add 0 51 0 p3 add 0 0 40 &
    size 2 51 8 rat 2 1 1
;
gen zon bric p0 27 0 -40 p1 add 17 0 0 p2 add 0 51 0 p3 add 0 0 25 &
    size 2 51 2 rat 2 1 0.5
;
gen zon bric p0 0 0 -40 p1 add 27 0 0 p2 add 0 51 0 p3 add 0 0 25 &

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size 7 51 2 rat 1 1 0.5
;
; assign names to groups of zones
group rock range group 'concrete liner' not group tunnel not
;
; assign Mohr-Coulomb material model
mo mohr
pro bulk 50e6 she 18e6 fric 20 coh 25e3 ten 0 dil 0 range z 25 35
pro bulk 4e8 she 1.5e8 fric 20 coh 50e3 ten 5e3 dil 3 range z -50 25

; assign boundary conditions
fix x range x -.1 .1
fix x range x 43.9 44.1
fix z range z -40.1 -39.9
fix y range y -.1 .1
fix y range y 50.9 51.1

; assign initial stress state
set grav 0 0 -10
ini density 2200
ini szz -770e3 grad 0 0 22000
ini sxx -770e3 grad 0 0 22000
ini syy -385e3 grad 0 0 11000

; monitor variables in model
hist unbal

hist gp zdisp 0 0 5.5
hist gp xdisp 7 0 0
hist gp zdisp 0 0 0
hist gp zdisp 0 0 35

hist gp zdisp 0 30 5.5
hist gp xdisp 7 30 0
hist gp zdisp 0 30 0
hist gp zdisp 0 30 35

hist gp zdisp 0 12 35
hist gp zdisp 0 18 35
hist gp zdisp 0 24 35
hist gp zdisp 0 36 35

hist gp zdisp 5 30 35
hist gp zdisp 10 30 35

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;
;sav geom1.sav
;
def conc_parm
    bmc = 20.7e9
    smc = 12.6e9
end
conc_parm
;
; define the locations of cable patterns 1, 2 and 3
;
def cab_parm
    array x_b(4,3), z_b(4,3)
    y0 = -3

    x_b(1,1) = 0.8
    x_b(2,1) = 2.1
    x_b(3,1) = 3.5
    x_b(4,1) = 5.5
    z_b(1,1) = 5.5
    z_b(2,1) = 2.4
    z_b(3,1) = 4.7
    z_b(4,1) = 1.5

    x_b(1,2) = 0.8
    x_b(2,2) = 0.8
    x_b(3,2) = 3.5
    x_b(4,2) = 5.5
    z_b(1,2) = 0.6
    z_b(2,2) = 4.0
    z_b(3,2) = 2.4
    z_b(4,2) = 0.6

    x_b(1,3) = 0.8
    x_b(2,3) = 2.6
    x_b(3,3) = 5.0
    x_b(4,3) = 3.5
    z_b(1,3) = 2.4
    z_b(2,3) = 4.0
    z_b(3,3) = 3.0
    z_b(4,3) = 0.6
end
def inip
    x1 = x_b(1,iidx)

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x2 = x_b(2, iidx)
x3 = x_b(3, iidx)
x4 = x_b(4, iidx)
z1 = z_b(1, iidx)
z2 = z_b(2, iidx)
z3 = z_b(3, iidx)
z4 = z_b(4, iidx)
end
cab_parm
;
; install initial cables
;
def ins_cab
  loop iidx (1,3)
    inip
    cab_seg = cab_seg_m-3*(3-iidx)
    y1      = 0.
    y2      = float(cab_seg)
    command
      sel cable id iidx begin x1 y1 z1 end x1 y2 z1 nseg cab_seg
      sel cable id iidx begin x2 y1 z2 end x2 y2 z2 nseg cab_seg
      sel cable id iidx begin x3 y1 z3 end x3 y2 z3 nseg cab_seg
      sel cable id iidx begin x4 y1 z4 end x4 y2 z4 nseg cab_seg
      sel cable pro emod 45e9 xcarea 1.57e-3 gr_per 1. &
        yten 25e4 gr_k 17.5e6 gr_c 20e4 ran id iidx
    end_command
  end_loop
end
set cab_seg_m 15
ins_cab
; install pre-support concrete
;
sel shell id 10 group rock range cyl end1 0 0 -1.5 end2 0 1 -1.5 rad 7.4 &
      cyl end1 0 0 -1.5 end2 0 1 -1.5 rad 6.7 not &
      z -0.1 6

sel shell prop isotropic 10.5e9,0.25 thickness 0.3 density 2500
def monit
  ipt_surf   = gp_near(0,30,35)
  ipt_crown  = gp_near(0,30,5.5)
  ipt_spring = gp_near(7,30,0)
end
monit

save m_ini.sav

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ca inshell.fis
;
; FISH function to control excavation and support sequence
def excav
  y0 = y0+3
  cut_i = y0/3+1
  loop cut (cut_i,16)
    cut_cur = cut
    step_name = ' EXCAVATION STEP ' + string(cut)
    ii = out(step_name)
    y0 = 3*(cut-1)
    y1 = y0+3
    yp0 = y0+1
    yp1 = y1+1
    ys0 = yp0-3
    ys1 = yp1-3
    yc0 = y0-3
    yc1 = y1-3
    id_ = 10*(cut+1)
    command
      ; install pre support concrete
      sel shell id id_ group rock &
        range cyl end1 0 yp0 -1.5 end2 0 yp1 -1.5 rad 7.4 &
          cyl end1 0 yp0 -1.5 end2 0 yp1 -1.5 rad 6.7 not &
            z -0.1 6
    end_command
  in_shell
  command
    sel shell prop isotropic 10.5e9,0.25 thickness 0.3 density 2500 &
      ran y yp0 yp1
    ; excavate next cut
    mo null range reg tunnel y y0 y1
    mo null range reg 'concrete liner' y y0 y1
    ; delete-cables in the excavated area
    sel delete cable 1 range y y0 y1
    sel delete cable 2 range y y0 y1
    sel delete cable 3 range y y0 y1
  end_command
  cut_1 = cut-1
  iidx=int(cut_1-3*(cut_1/3))+1
  y2=min(y1+15,51)
  inip
  ii = out(' CABLE BOLT PATTERN '+string(iidx))

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command
  sel delete cable iidx
  ; install new cables
  sel cable id iidx begin x1 y1 z1 end x1 y2 z1 nseg cab_seg_m
  sel cable id iidx begin x2 y1 z2 end x2 y2 z2 nseg cab_seg_m
  sel cable id iidx begin x3 y1 z3 end x3 y2 z3 nseg cab_seg_m
  sel cable id iidx begin x4 y1 z4 end x4 y2 z4 nseg cab_seg_m
  sel cable pro emod 45e9 xcarea 1.57e-3 gr_per 1. &
      yten 25e4 gr_k 17.5e6 gr_c 20e4 ran id iidx
  ; shotcrete
  sel shell prop isotropic 10.5e9,0.25 thickness 0.5 density 2500 &
      ran y ys0 ys1
end_command
if cut > 1 then
  command
    ; concrete liner
    mo el range group 'concrete liner' y yc0 yc1
    pro bulk bmc sh smc range group 'concrete liner' y yc0 yc1
  end_command
end_if
command
  step 3000
end_command
; store displacements in tables
xtable(1,cut) = 3.0 * cut
ytable(1,cut) = zdisp(ipt_surf)
xtable(2,cut) = 3.0 * cut
ytable(2,cut) = zdisp(ipt_crown)
xtable(3,cut) = 3.0 * cut
ytable(3,cut) = zdisp(ipt_spring)
command
  save m1.sav
end_command
if cut=10 then
  command
    save m1_30.sav
  end_command
end_if
end_loop
end
excav
ret

```