Geomechanics Examples

Boris Jeremić

Department of Civil and Environmental Engineering
University of California, Davis

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`http://sokocalo.engr.ucdavis.edu/~jeremic/`

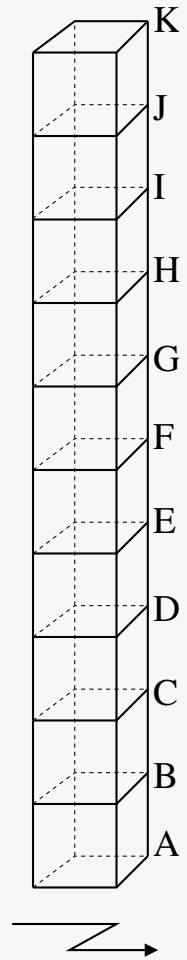
Outline

Liquefaction Modeling Details

- u-p-U solids, bricks
- Fully coupled system
- 7 DOFs per node
- Self weight from the very begining (zero stress) with the soil (model) evolution
- Boundary conditions for solid skeleton and pore fluid
- Follows the
  - displecements of soil skeleton (u)
  - pore fluid pressures (p) and
  - displcements of pore fluid (U)

Liquefaction Model Load Stages

- Phase 1: Soil self weight with pore presure dissipation
- Phase 2: Seismic shaking (coupled, with pore pressure generation and dissipation)
- Phase 3: Pore pressure dissipation after shaking



Model Setup: Nodes

```
wipe all
model BasicBuilder -ndm 3 -ndf 7

set dx 1.0 ; set dy 1.0 ; set dz 1.0
set Num_Elem 10
# Nodal coordinates
for {set i 0} {$i <= $Num_Elem} {incr i} {
  node [expr 4*$i +1] $dx $dy [expr $i*$dz]
  node [expr 4*$i +2] 0.0 $dy [expr $i*$dz]
  node [expr 4*$i +3] 0.0 0.0 [expr $i*$dz]
  node [expr 4*$i +4] $dx 0.0 [expr $i*$dz]
}
```

Model Setup: Boundary Conditions, Bottom and Top Nodes

```
#DOF#-----1--2--3---4---5--6--7
#     N#   ux uy uz    p   Ux Uy Uz
fix    1    1  1  1    0    1  1  1
fix    2    1  1  1    0    1  1  1
fix    3    1  1  1    0    1  1  1
fix    4    1  1  1    0    1  1  1
#                    DOF#----1--2--3---4---5--6--7
#               N#           ux uy uz    p   Ux Uy Uz
fix [expr 4*$Num_Elem +1]   0  1  0    1    0  1  0
fix [expr 4*$Num_Elem +2]   0  1  0    1    0  1  0
fix [expr 4*$Num_Elem +3]   0  1  0    1    0  1  0
fix [expr 4*$Num_Elem +4]   0  1  0    1    0  1  0
```

Model Setup: Boundary Conditions, Intermediate Nodes

```
for {set i 1}{$i<=[expr $Num_Elem -1]}{incr i}{
#DOF#-------------------1---2---3---4---5---6---7
 fix  [expr 4*$i +1]   0   1   0   0   0   1   0
 fix  [expr 4*$i +2]   0   1   0   0   0   1   0
 fix  [expr 4*$i +3]   0   1   0   0   0   1   0
 fix  [expr 4*$i +4]   0   1   0   0   0   1   0
}
for {set i 1} {$i <= $Num_Elem} {incr i} {
#                                    DOFs ux uz Ux Uz
 equalDOF [expr 4*$i +1] [expr 4*$i +2] 1  3  5  7
 equalDOF [expr 4*$i +1] [expr 4*$i +3] 1  3  5  7
 equalDOF [expr 4*$i +1] [expr 4*$i +4] 1  3  5  7
}
```

Model Setup: Dafalias–Manzari Material Model

```
set e0    0.85   ; set G0       125.0
set v     0.05   ; set Pat      100.0
set kc    0.01   ; set M_cal    1.25
set c     0.8    ; set lambda_c 0.019
set xi    0.7    ; set er       0.934
set m_low 0.02   ; set h0       7.05
set ch    0.968  ; set nb       1.1
set A0    0.704  ; set nd       3.5
set z_max 4.0    ; set cz       600.0
set zZ    "0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0"
set p     -1.0
set initS "$p 0.0 0.0 0.0 $p 0.0 0.0 0.0 $p"
set zS    "0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0"
```

Model Setup: Dafalias–Manzari Material Model

```
set mc  "$rho $e0 $G0 $v $Pat $kc $M_cal $c \
$lambda_c $xi $er $m_low $h0 $ch $nb $A0 \
$nd $z_max $cz"
set it "$zS $zZ"
set mp "MaterialConstant 19 $mc \
          InternalTensor 2 $it"
set el "Dafalias-Manzari  3 4 5 6 2 $initS"
set yf "Dafalias-Manzari  0 12 2 1"
set pf "Dafalias-Manzari  0 2 0 11 0 9 0 10 0 5 \
                0 12 0 7 0 8 0 16 0 17 2 1 2 2"
set te1 "Dafalias-Manzari  2 11 9 10 5 12 7 8 15 \
                           13 14 3 1 2"
set te2 "Dafalias-Manzari-fabric  12 19 18 1 2"
set te  "$te1 $te2"
```

Model Setup: Dafalias–Manzari Material Model

```
nDMaterial \
   NewTemplate3Dep 1 -MaterialParameter $mp \
                     -ElasticState $el \
                     -YieldFunction $yf \
                     -PlasticFlow $pf \
                     -TensorEvolution $te
```

Model Setup: Liquefaction Model, Additional Constants

```
set grvt    10.0  ; set Gr [expr -$grvt];
set porosity    [expr $e0/(1.0+$e0)]
set bulk_f  2.2e6
set alpha   1.0     ; set rho_s   2.8
set rho_f   1.0     ; set bulk_s  1.0e12
set kx      [expr 5.0e-4/$grvt/$rho_f]
set ky      [expr 5.0e-4/$grvt/$rho_f]
set kz      [expr 5.0e-4/$grvt/$rho_f]
set rho     [expr (1.0-$porosity)*$rho_s +\
              $porosity*$rho_f ]
```

Model Setup: u-p-U Elements

```
for {set i 1} {$i <= $Num_Elem} {incr i} {
  set N1 [expr 4*$i+1] ; set N2 [expr 4*$i+2]
  set N3 [expr 4*$i+3] ; set N4 [expr 4*$i+4]
  set N5 [expr 4*$i-3] ; set N6 [expr 4*$i-2]
  set N7 [expr 4*$i-1] ; set N8 [expr 4*$i-0]
  element  \
    Brick8N_u_p_U \
        $i $N1 $N2 $N3 $N4 $N5 $N6 $N7 $N8 \
        1  0.0 0.0 $Gr $porosity $alpha  \
        $rho_s $rho_f \
        $kx $ky $kz $bulk_s $bulk_f 0.0
}
```

Loading: Soil Self Weight

```
pattern Plain 1 "Constant" {
  for {set i 1} {$i <= $Num_Elem} {incr i} {
        eleLoad -ele $i -type -BrickW } }
set gamma 1.5  ; numberer RCM
integrator Newmark  $gamma \
[expr pow($gamma+0.5, 2)/4]
constraints Penalty 1.0e15 1.0e15
test NormDispIncr 1.0e-3 50 1
algorithm KrylovNewton ; system UmfPack
analysis VariableTransient
for {set isw 0} {$isw < 2000} {incr isw} {
   analyze  1  0.2  0.1  0.2  30
    puts "Self Weight step -->> $isw " }
```

Loading: Seismic Shaking

```
wipeAnalysis ; loadConst -time 0.0
recorder Node -file ZD.out  -time -node 1 5  9 \
                    25 29 33 37 41 -dof  3  disp
recorder Node -file UzD.out -time -node 1 5  9 \
                    25 29 33 37 41 -dof  7  disp
recorder Node -file PP.out  -time -node 1 5  9  \
                    25 29 33 37 41 -dof  4  disp
recorder Element  -file  stress10.out  -time \
                                -ele 10 stress
set dt 0.016625
set Gaccel "Series -dt $dt -filePath \
            M1T2AH.txt -factor [expr $grvt]"
pattern UniformExcitation  2  1  -accel $Gaccel
```

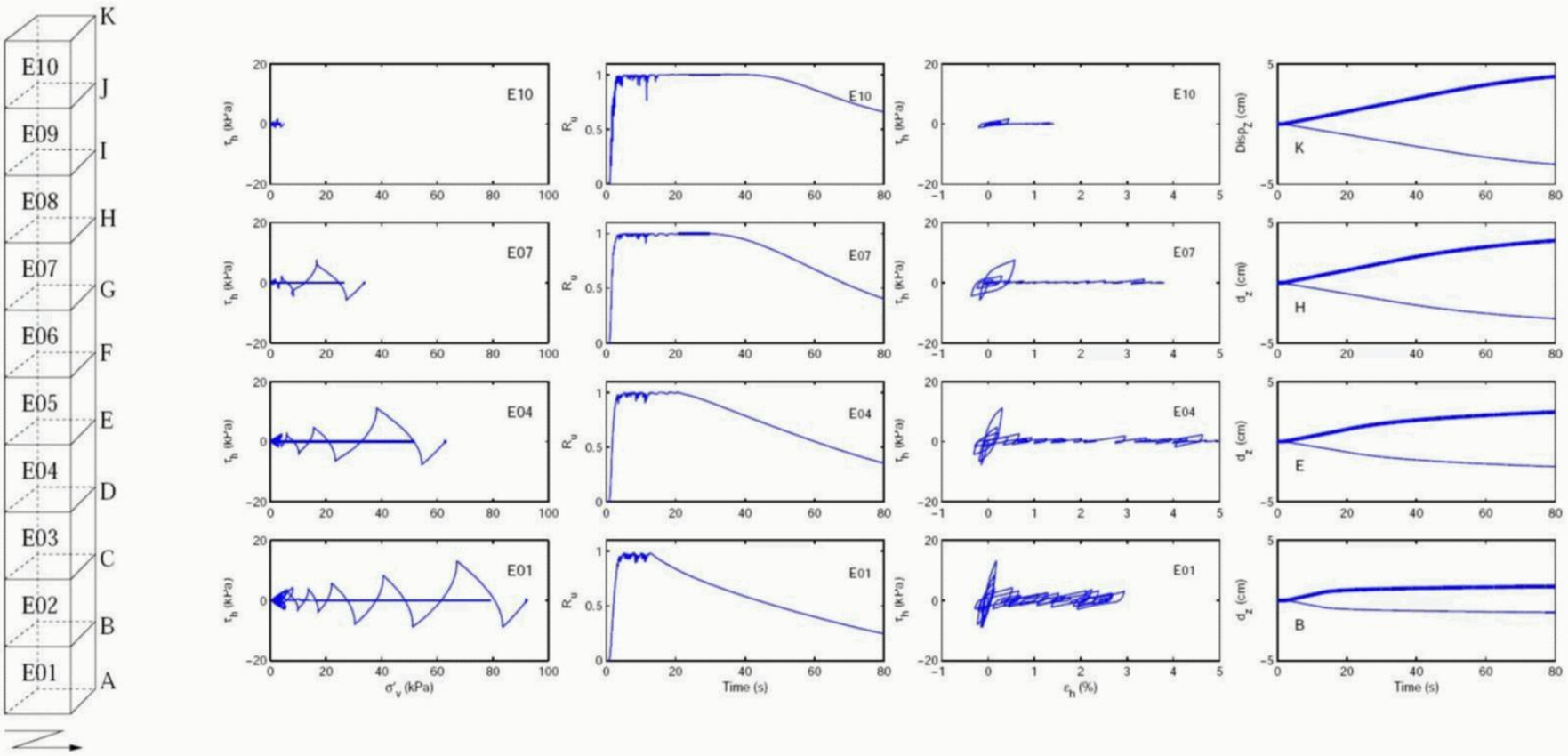
Loading: Seismic Shaking

```
integrator HHT  0.8
numberer RCM
constraints Penalty 1.0e15 1.0e15
test NormDispIncr 1e-3 30 1
algorithm KrylovNewton
system UmfPack
analysis VariableTransient

set dt1 0.002
for {set isw 0} {$isw < 10000} {incr isw} {
    analyze 1 $dt1 [expr $dt1/16] $dt1 40
    puts "Seismic excitation step -->> $isw "
}
```

Pore Pressure Dissipation After Shaking

```
set dt2 0.01
for {set isw 0} {$isw < 8000} {incr isw} {
    analyze 1 $dt1 [expr $dt1/16] $dt1 40
    puts "Pore pressure dissipation step -->> $isw
}

wipe
```

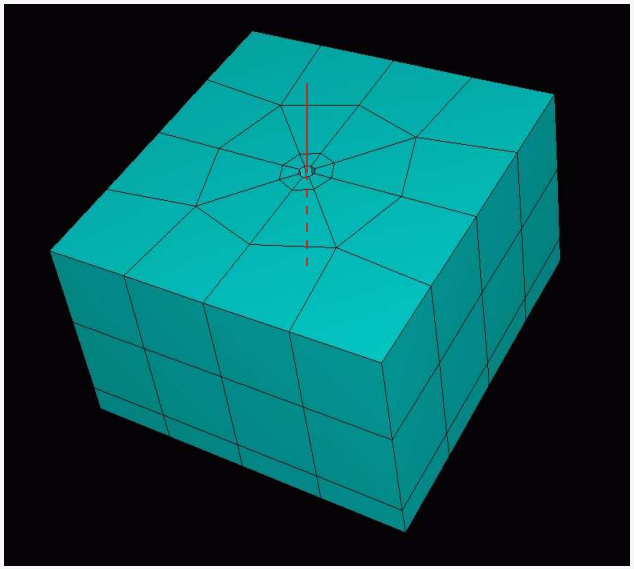
Liquefaction of a Soil Column

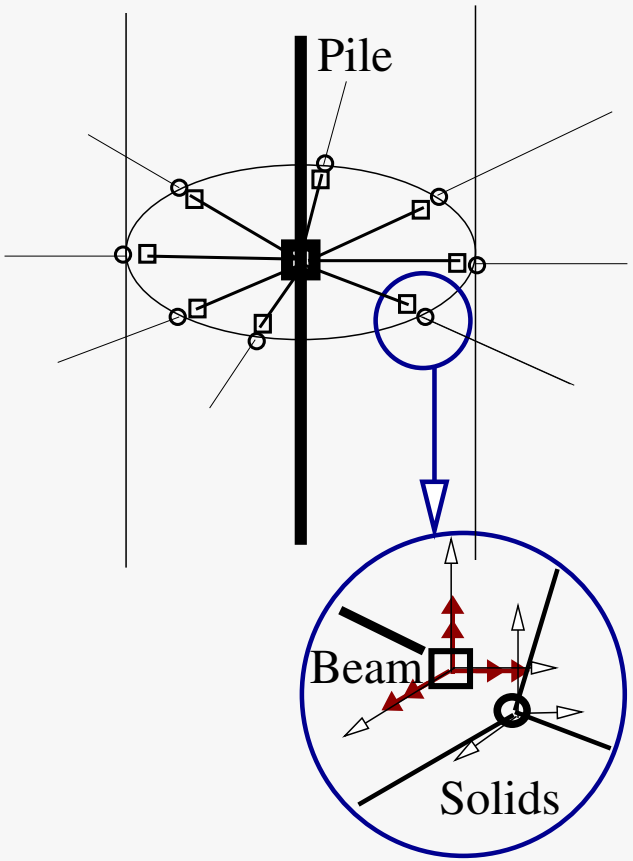


$(e_0 = 0.85)$

SFSI Model Setup

- Solids for soil
- Nonlinear beam for pile and structure
- Connection of solids and structural elements
- Excavation
- Boundary conditions





SFSI Model Loads

- Phase 1: Soil self weight
- Phase 2: Soil excavation (for pile installation)
- Phase 3: pile and structure construction
- Phase 3: pile and structure self weight
- Phase 4: static pushover
- Phase 4: dynamic (seismic) shaking

Soil Self Weight

```
model BasicBuilder -ndm 3 -ndf 3

source Units.tcl;

source InputSoilNodes.tcl
source CreateMaterial_Soil.tcl
source InputSoilElements.tcl
source Apply_SoilBC.tcl

source Apply_SoilSelfWeight.tcl
source SelfWeight_Analysis_Soil.tcl
```

Create Piles, Excavate Soil

```
setTime 0.0
loadConst
wipeAnalysis
model BasicBuilder -ndm 3 -ndf 6

source CreateMaterial_Pile.tcl
source CreatePileSection.tcl

source Remove_HoleElements.tcl
source Remove_HoleNodes.tcl
```

Install Pile

```
source InputPileNodes.tcl
source InputPileElements.tcl
source SetUpConnection.tcl
source Apply_PileBC.tcl
source Apply_PileSelfWeight.tcl

source Recorder_Iso.tcl
source SelfWeight_Analysis_Pile.tcl
```

Shake (or do Pushover of) the SFS System

```
wipeAnalysis
setTime 0.0
loadConst

remove recorders
source Recorder_Pile.tcl

source GroundMotion_Analysis.tcl
```

Summary

- A number of simplistic and advanced models, elements and procedures are available for use in simulations
- Targeting both
  - advanced geomechanics problems
  - practical geotechanicsl problems
- Theories, formulations, implementation details, as well as verification, validation and application examples are available at: `http://sokocalo.engr.ucdavis.edu/~jeremic/`