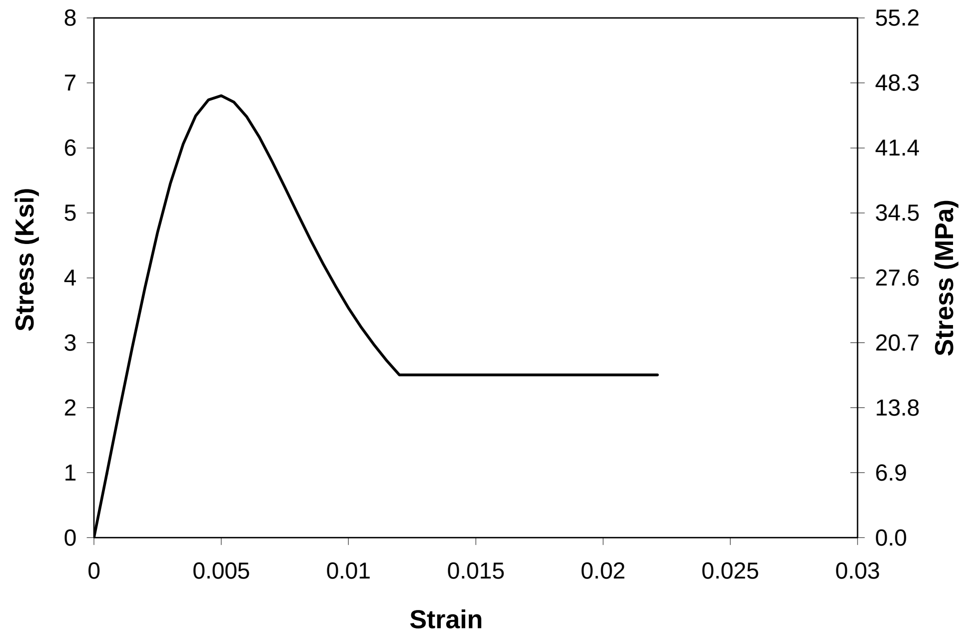

Fig. B-2. Confined ECC Stress-Strain Curve of Example

APPENDIX C: OPENSEES MODELS

C.1. SC-2

```
# SET UP ----------------------------------------------------------------------------
# units: kip, inch, sec
wipe;                                 # clear memory of all past mode0l definitions
file mkdir Push;                             # create data directory
model BasicBuilder -ndm 2 -ndf 3;       # Define the model builder, ndm=#dimension, ndf=#dofs
set PI [expr acos(-1.0)];
set sec 1.; # define basic units

# define GEOMETRY -------------------------------------------------------------
set LCol 72;        # column length
set Weight 80;             # superstructure weight
# define section geometry
set DCol 16;        # Column Depth


# calculated parameters
set PCol $Weight;          # nodal dead-load weight per column
set g 386.4;               # g.
set Mass [expr $PCol/$g];        # nodal mass
# calculated geometry parameters
set ACol [expr 0.25*$PI*pow($DCol,2)];                             # cross-sectional area
set IzCol [expr 0.015625*$PI*pow($DCol,4)];                # Column moment of inertia

# nodal coordinates:
node 1 0 0;                # node#, X, Y
node 2 0 0;  #Define the bond-slip rotation

node 3 0 19;
node 31 -8 19;
node 32 8 19;

node 71 0 15.5;
node 72 11.5 15.5;
node 73 -11.5 15.5;

node 33 0 19;
node 77 0 15.5;

node 4 0 19;
node 41 -8 19;
node 42 8 19;
```

```
node 74 0 22.5;
node 75 11.5 22.5;
node 76 -11.5 22.5;

node 78 0 22.5;

node 5  0 34;

node 11 0 $LCol;

node 12 0 -40;


# Single point constraints -- Boundary Conditions
fix 2 1 1 1;              # node DX DY RZ
fix 12 1 1 1;

#equalDOF $rNodeTag $cNodeTag $dof1 $dof2 ...

equalDOF 71 77 1 3;
equalDOF 3 33 1 3;
equalDOF 74 78 1 3;

equalDOF 3 4 1 3;

set ColTransfTag 1;
geomTransf PDelta $ColTransfTag  ;

# nominal concrete compressive strength
set fc -6.;                     # CONCRETE Compressive Strength (+Tension, -Compression)
set Ec [expr 57*sqrt(-$fc*1000)];             # Concrete Elastic Modulus (the term in sqr root needs to be in
psi
set E1 1000000

# Gap Opening elements
element elasticBeamColumn   1005 71 72 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1006 71 73 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1007 74 75 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1008 74 76 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1001 3 32 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1002 3 31 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1003 4 41 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1004 4 42 $ACol $E1 $IzCol $ColTransfTag;
```

```
 # nodal masses:
 mass 11 $Mass  1e-9 0;          # node#, Mx My Mz, Mass=Weight/g, neglect rotational inertia at nodes


# Define ELEMENTS & SECTIONS -------------------------------------------------------------

set concsec  1;
set Concsecsteel 2;
set concface 3;


# MATERIAL parameters ---------------------------------------------------------------------
set IDconcU1 1;
set IDconccover1 2;
set IDconcU2 3;
set IDconccover2 4;
set IDreinf 5;
set IDgap 6;
set IDconccover3 7;
set IDBondSlip 12;
set IDRigid 13;


# material ID tag -- reinforcement
# unconfined concrete
set fc1U            $fc;              # UNCONFINED concrete (todeschini parabolic model), maximum stress
set eps1U    -0.003;                  # strain at maximum strength of unconfined concrete
set fc2U            [expr 0.2*$fc1U];         # ultimate stress
set eps2U    -0.01;             # strain at ultimate stress
set lambda 0.1;                       # ratio between unloading slope at $eps2 and initial slope $Ec
# tensile-strength properties
set ftU [expr -0.14*$fc1U];                 # tensile strength +tension
set Ets [expr $ftU/0.002];            # tension softening stiffness
# -----------
set Fy 68.6;                    # STEEL yield stress
set Es 29000.;                        # modulus of steel
set Bs 0.005;                   # strain-hardening ratio
set R0 10;                      # control the transition from elastic to plastic branches
set cR1 0.925;                        # control the transition from elastic to plastic branches
set cR2 0.15;                   # control the transition from elastic to plastic branches

uniaxialMaterial ENT $IDgap 10000;


uniaxialMaterial  Concrete01   $IDconcU1      -11.55   -    .012   -4.5  -0.0456;
```

```
uniaxialMaterial Concrete01  $IDconccover1  -8.0   -0.003   -3.2     -0.011;

uniaxialMaterial Concrete01  $IDconcU2    -10.5  -.013   -4.2  -0.052;

uniaxialMaterial Concrete01  $IDconccover2  -7.15   -0.003   -2.8     -0.0113;

uniaxialMaterial Concrete01  $IDconccover3 -7.15   -0.003   -2.8     -0.0113;

# build coverCol concrete (unconfined)
 uniaxialMaterial Steel02 $IDreinf $Fy $Es $Bs $R0 $cR1 $cR2;                    #    build    reinforcement
material


# RC section:
set ri 0
set ro [expr $DCol/2]
set coverCol 1.1875
set numBarsCol 10
set barAreaCol 0.2
set nfCoreR 4
set nfCoreT 20
set nfcoverColR 1
set nfcoverColT 20
set rc [expr $ro-$coverCol]


section fiberSec $Concsecsteel  {;      # Define the fiber section
 patch circ $IDconcU1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/$numBarsCol ]
 # Define the reinforcing layer
 layer circ $IDreinf $numBarsCol $barAreaCol 0 0 $rc $theta 360
}


section fiberSec $concface   {;  # Define the fiber section
 patch circ $IDconccover3 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover3 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.04 0 0 $rc $theta 360
}
```

```
#0.04

section fiberSec $concsec   {;   # Define the fiber section
 patch circ $IDconcU2 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover2 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.01 0 0 $rc $theta 360
}
# define geometric transformation: performs a linear geometric transformation of beam stiffness and resisting
force from the basic system to the global-coordinate system
#set ColTransfTag 1;                    # associate a tag to column transformation
#geomTransf PDelta $ColTransfTag  ;

# element connectivity:
set numIntgrPts 2;
#element beaColumn $eletag $ inode $jnode $ A $E $i $transftag
      # number of integration points for force-based element
element nonlinearBeamColumn  1  1  71   $numIntgrPts $Concsecsteel   $ColTransfTag;
element nonlinearBeamColumn  2  71 3    $numIntgrPts $concface   $ColTransfTag;
element nonlinearBeamColumn  3  4  74   $numIntgrPts $concface        $ColTransfTag;
element nonlinearBeamColumn  4  74 5    $numIntgrPts $concsec        $ColTransfTag;
element nonlinearBeamColumn  5  5  11   5            $concsec        $ColTransfTag;

element zeroLength 332 32 42 -mat $IDgap -dir 2;
element zeroLength 331 31 41 -mat $IDgap -dir 2;



 set PostTensionSteelTag 12;
 set PostTensionSteelElementTag 10;
 set PostTensionBarArea 1.95 ;
 set Dbar 1.625
 set PostTensionForce 115;
 set PostTensionBarStress [expr $PostTensionForce/$PostTensionBarArea];
 set PostTensionBarEValue 26000.0;
 set PostTensionBarTensionPlasticTransition 1E15;
 set PostTensionBarCompressionPlasticTransition -1E15;
 set PostTensionBarInitialStrain [expr -$PostTensionBarStress/$PostTensionBarEValue];
 set PostTensionFy 137
 puts "Post Tension Bar Strain is";
puts $PostTensionBarInitialStrain;
```

```
set Izbar [expr 0.015625*$PI*pow($Dbar,4)];
#                                    matTag                        E                 Fy                         gap
eps0
#uniaxialMaterial      ElasticPPGap           $PostTensionSteelTag      $PostTensionBarEValue      $PostTensionFy
$PostTensionBarInitialStrain
uniaxialMaterial  ElasticPP   $PostTensionSteelTag  $PostTensionBarEValue  $PostTensionBarTensionPlasticTransition
$PostTensionBarCompressionPlasticTransition $PostTensionBarInitialStrain;
element corotTruss 11  12  77  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 12  77  33  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 13  33  78  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 14  78  11  $PostTensionBarArea $PostTensionSteelTag

#Bond-Slip                       tag           M1    R1        M2     R2      -M1    -R1        -M2    -R2
uniaxialMaterial Hysteretic  $IDBondSlip  1716  0.0021  1655  0.0023 -1716  -0.0021  -1655 -0.0023 1 1 0 0 0.32;
uniaxialMaterial Elastic $IDRigid 9e9;

#Bond-Slip
element zeroLength 15 1 2 -mat $IDRigid $IDRigid $IDBondSlip -dir 1 2 6;

# Define RECORDERS -------------------------------------------------------------
recorder Node -file Push/node72.out -time -node 72 -dof 1 2 3 disp;
recorder Node -file Push/node73.out -time -node 73 -dof 1 2 3 disp;
recorder Node -file Push/node75.out -time -node 75 -dof 1 2 3 disp;
recorder Node -file Push/node76.out -time -node 76 -dof 1 2 3 disp;

recorder Element -file Push/F331.out -time -ele 331 force;
recorder Element -file Push/F332.out -time -ele 332 force;


recorder Node -file Push/node33.out -time -node 33 -dof 1 2 3 disp;
recorder Node -file Push/node4.out -time -node 4 -dof 1 2 3 disp;
recorder Node -file Push/node3.out -time -node 3 -dof 1 2 3 disp;
recorder Node -file Push/DFree.out -time -node 11 -dof 1 2 3 disp;
recorder Node -file Push/DBase.out -time -node 1 -dof 1 2 3 disp;        # displacements of support nodes
recorder Node -file Push/RBase.out -time -node 1 -dof 1 2 3 reaction;          # support reaction
recorder Drift -file Push/Drift.out -time -iNode 1 -jNode 4 -dof 1   -perpDirn 2 ;     # lateral drift
recorder Node -file Push/Tendon.out -time -node 12 -dof 1 2 3 reaction;                                  #
element forces -- column
recorder Element -file Push/ForceColSec1.out -time -ele 4 section $PostTensionBarArea force;
      # Column section forces, axial and moment, node i
recorder Element -file Push/DefoColSec1.out -time -ele 4 section $PostTensionBarArea deformation;
      # section deformations, axial and curvature, node i
recorder Element -file Push/ForceColSec$numIntgrPts.out -time -ele 1 section $numIntgrPts force;          #
section forces, axial and moment, node j
```

```
recorder Element -file Push/DefoColSec$numIntgrPts.out -time -ele 1 section 1 deformation;          #     section
deformations, axial and curvature, node j
recorder Element -file push/compressionstrain.out -time -ele 1 section 1 fiber 6.56 0 $IDreinf stressStrain;
recorder Element -file push/tensionstrain.out -time -ele 1 section 1 fiber -6.56 0 $IDreinf stressStrain;
recorder Element -file push/sec1strain.out -time -ele 1 section 1 fiber -6 0 $IDconcU1       stressStrain;
recorder Element -file push/sec2strain.out -time -ele 1 section 1 fiber -8 0 $IDconccover1   stressStrain;
recorder Element -file push/sec3strain.out -time -ele 2 section 2 fiber -6 0 $IDconcU1       stressStrain;
recorder Element -file push/sec4strain.out -time -ele 2 section 2 fiber -8 0 $IDconccover1   stressStrain;
recorder Element -file push/sec5strain.out -time -ele 3 section 1 fiber -6 0 $IDconcU2       stressStrain;
recorder Element -file push/sec6strain.out -time -ele 3 section 1 fiber -8 0 $IDconccover2   stressStrain;
recorder Element -file push/sec7strain.out -time -ele 4 section 2 fiber -6 0 $IDconcU2       stressStrain;
recorder Element -file push/sec8strain.out -time -ele 4 section 2 fiber -8 0 $IDconccover2   stressStrain;
recorder Element -file Element1.out -time -ele 331 force;
recorder Element -file Element2.out -time -ele 332 force;
recorder Element -file push/rebar1.out -time -ele 1 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar2.out -time -ele 2 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar3.out -time -ele 3 section 1 fiber 6.62 0 $IDreinf stressStrain;

recorder Element -file push/rebar4.out -time -ele 1 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar6.out -time -ele 3 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar8.out -time -ele 4 section 1 fiber  6.62 0 $IDreinf stressStrain;

recorder Element -file push/rebar9.out -time -ele 1 section 2 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar10.out -time -ele 1 section 2 fiber 6.62 0 $IDreinf stressStrain;


recorder Node -file Push/gapdisp1.out -time -node 32 -dof 1 2 3 disp
recorder Node -file Push/gapdisp2.out -time -node 42 -dof 1 2 3 disp
recorder Node -file Push/gapdisp3.out -time -node 31 -dof 1 2 3 disp
recorder Node -file Push/gapdisp4.out -time -node 41 -dof 1 2 3 disp




# define GRAVITY -------------------------------------------------------------
pattern Plain 3 Linear {
   load 11 0 -$PCol 0
}


# Gravity-analysis parameters -- load-controlled static analysis
set Tol 1.0e-4;                   # convergence tolerance for test
constraints Plain;                # how it handles boundary conditions
numberer Plain;                   #  renumber  dof's  to   minimize band-width (optimization), if you want to
```

```
system BandGeneral;        # how to store and solve the system of equations in the analysis
test NormDispIncr $Tol 10 ;             # determine if convergence has been achieved at the end of an iteration
step
algorithm Newton;                # use Newton's solution algorithm: updates tangent stiffness at every iteration
set NstepGravity 10;             # apply gravity in 10 steps
set DGravity [expr 1./$NstepGravity];   # first load increment;
integrator LoadControl $DGravity;# determine the next time step for an analysis
analysis Static;                 # define type of analysis static or transient
analyze $NstepGravity;           # apply gravity
# ------------------------------------------------- maintain constant gravity loads and reset time to zero
loadConst -time 0.0

puts "Model Built"
```

C.2. SBR-1

```
# SET UP ----------------------------------------------------------------------------
# units: kip, inch, sec
wipe;                                   # clear memory of all past mode0l definitions
file mkdir Push;                         # create data directory
model BasicBuilder -ndm 2 -ndf 3;# Define the model builder, ndm=#dimension, ndf=#dofs
set PI [expr acos(-1.0)];
set sec 1.;                         # define basic units

# define GEOMETRY -------------------------------------------------------------
set LCol 72;                    # column length
set Weight 80;                         # superstructure weight
# define section geometry
set DCol 16;                    # Column Depth

# calculated parameters
set PCol $Weight;          # nodal dead-load weight per column
set g 386.4;               # g.
set Mass [expr $PCol/$g];  # nodal mass
# calculated geometry parameters
set ACol [expr 0.25*$PI*pow($DCol,2)];                    # cross-sectional area
set IzCol [expr 0.015625*$PI*pow($DCol,4)];               # Column moment of inertia

# nodal coordinates:
node 1   0 0;              # node#, X, Y
node 2   0 8;
node 222 0 0;  #Bond-slip
node 22  0 8;
node 3   0 20;
```

```
node 31 -8 20;
node 32  8 20;

node 71  0 16.5;
node 72  11.5 16.5;
node 73 -11.5 16.5;

node 33  0 20;

node 4   0 20;
node 41 -8 20;
node 42  8 20;

node 74  0 23.5;
node 75  11.5 23.5;
node 76 -11.5 23.5;

node 11  0 $LCol;

node 12  0 -40;
# Single point constraints -- Boundary Conditions
fix 222 1 1 1;                  # node DX DY RZ
fix 12 1 1 1;

#equalDOF $rNodeTag $cNodeTag $dof1 $dof2 ...

equalDOF 2 22 1 3;
equalDOF 3 33 1 3;
equalDOF 3 4 1;

set ColTransfTag 1;
geomTransf PDelta $ColTransfTag  ;

# nominal concrete compressive strength
set fc -6.;                             # CONCRETE Compressive Strength (+Tension, -Compression)
set Ec [expr 57*sqrt(-$fc*1000)];             # Concrete Elastic Modulus (the term in sqr root needs to be in
psi
set E1 1000000

# Gap Opening
element elasticBeamColumn   1005 71 72 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1006 71 73 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1007 74 75 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1008 74 76 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1001 3 32 $ACol $E1 $IzCol   $ColTransfTag;
```

```
element elasticBeamColumn   1002 3 31 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1003 4 41 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1004 4 42 $ACol $E1 $IzCol $ColTransfTag;

# nodal masses:
mass 11 $Mass  1e-9 0;           # node#, Mx My Mz, Mass=Weight/g, neglect rotational inertia at nodes


# Define ELEMENTS & SECTIONS -------------------------------------------------------------
# assign a tag number to the column section
set ColSecTag 1;
set secondcolSectag 2;
set thirdcolSectag 3;
set Unconfinedseg 4;
# MATERIAL parameters -------------------------------------------------------------------
set IDconcU1 1;                     # First Pouring
set IDconccover1 2;                 # First Pouring
set IDconcU2 3;                     # Second Pouring
set IDconccover2 4;             # Second Pouring
set IDreinf 5;
set IDelastomer 6;
set IDgap 7;
set IDelasMat 8;
set IDBondSlip 12;
set IDRigid 13;


#------------------------------------------------------
# Ec=5.6* G*S^2
# G=E0/3, E=modulus of elasticity of rubber
# S=Shape factor of rubber bearing
uniaxialMaterial Elastic $IDelastomer 126;

# material ID tag -- reinforcement
# unconfined concrete
set fc1U           $fc;                # UNCONFINED concrete (todeschini parabolic model), maximum stress
set eps1U    -0.003;                   # strain at maximum strength of unconfined concrete
set fc2U           [expr 0.2*$fc1U];   # ultimate stress
set eps2U    -0.01;              # strain at ultimate stress
set lambda 0.1;                        # ratio between unloading slope at $eps2 and initial slope $Ec
# tensile-strength properties
set ftU [expr -0.14*$fc1U];            # tensile strength +tension
set Ets [expr $ftU/0.002];       # tension softening stiffness
# ----------
set Fy 78.8;                          #   STEEL   yield    stress
```

```
set Es 29000.;                          # modulus of steel
set Bs 0.005;                    # strain-hardening ratio
set R0 18;                             # control the transition from elastic to plastic branches
set cR1 0.925;                          # control the transition from elastic to plastic branches
set cR2 0.15;                    # control the transition from elastic to plastic branches

uniaxialMaterial ENT $IDgap 10000;

# first segment confined core
uniaxialMaterial Concrete01  $IDconcU1    -10.8  -.007076   -4.3  -0.0847  #28day
  # Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccover1  -7.2   -0.003   -2.8    -0.019667 ;
# segments
uniaxialMaterial Concrete01  $IDconcU2     -12.3 -.006213   -4.9    -0.0373  #0.5  0.635 2420 #28day
# Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccover2  -8.6   -0.003   -3.4   -0.00846;
# build reinforcement material
uniaxialMaterial Steel02 $IDreinf $Fy $Es $Bs $R0 $cR1 $cR2;



# RC section:
set ri 0
set ro [expr $DCol/2]
set coverCol 1.1875
set numBarsCol 8
set barAreaCol 0.31
set nfCoreR 8
set nfCoreT 40
set nfcoverColR 2
set nfcoverColT 40


# Define the fiber section
# base Segmentelastomeric bearing
 section fiberSec $ColSecTag   {;
 set rc [expr $ro-$coverCol]
 patch circ $IDelastomer $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDelastomer $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/$numBarsCol ]
 # Define the reinforcing layer
 layer circ $IDreinf $numBarsCol $barAreaCol 0 0 $rc $theta 360
}
```

```
# base segment concrete
 section fiberSec $secondcolSectag   {;
 patch circ $IDconcU1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/$numBarsCol ]
 # Define the reinforcing layer
 layer circ $IDreinf $numBarsCol $barAreaCol 0 0 $rc $theta 360
}


#Typical Segments
section fiberSec $thirdcolSectag   {;
 patch circ $IDconcU2 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover2 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.01 0 0 $rc $theta 360
}

#Typical Segments
section fiberSec $Unconfinedseg   {;
 patch circ $IDconccover2  $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover2 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.04 0 0 $rc $theta 360
}


# element connectivity:
set numIntgrPts 2;
#element beaColumn $eletag $ inode $jnode $ A $E $i $transftag
       # number of integration points for force-based element
element nonlinearBeamColumn  1  1  2    $numIntgrPts $ColSecTag       $ColTransfTag;   #   self-explanatory   when
using variables
element nonlinearBeamColumn  2  2  71   $numIntgrPts $secondcolSectag $ColTransfTag;
element nonlinearBeamColumn  3  71 3    $numIntgrPts $Unconfinedseg $ColTransfTag;
element nonlinearBeamColumn  4  4  74   $numIntgrPts $Unconfinedseg  $ColTransfTag;
element nonlinearBeamColumn  5  74 11   5            $thirdcolSectag  $ColTransfTag;
```

```
element zeroLength 332 32 42 -mat $IDgap -dir 2;
element zeroLength 331 31 41 -mat $IDgap -dir 2;

# Define Post-tensioning unbonded rod material
 set PostTensionSteelTag 9;
 set PostTensionSteelElementTag 4;
 set PostTensionBarArea 1.95 ;
 set PostTensionForce 108;
 set PostTensionBarStress [expr $PostTensionForce/$PostTensionBarArea];
 set PostTensionBarEValue 27000.0;
 set PostTensionBarTensionPlasticTransition 1E15;
 set PostTensionBarCompressionPlasticTransition -1E15;
 set PostTensionBarInitialStrain [expr -$PostTensionBarStress/$PostTensionBarEValue];
 set PostTensionFy 137
 puts "Post Tension Bar Strain is";
 puts $PostTensionBarInitialStrain;


uniaxialMaterial  ElasticPP   $PostTensionSteelTag  $PostTensionBarEValue  $PostTensionBarTensionPlasticTransition
$PostTensionBarCompressionPlasticTransition $PostTensionBarInitialStrain

element corotTruss 11  12  22  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 22  22  33  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 33  33  11  $PostTensionBarArea $PostTensionSteelTag


#Bond-Slip                       tag           M1    R1       M2     R2     -M1    -R1       -M2    -R2
uniaxialMaterial Hysteretic  $IDBondSlip  1320  0.003  1944  0.014 -1320  -0.003  -1944 -0.014 1 1 0 0 0.5;
uniaxialMaterial Elastic $IDRigid 9e9;

#Bond-Slip
element zeroLength 15 1 222 -mat $IDRigid $IDRigid $IDBondSlip -dir 1 2 6;

# Define RECORDERS -------------------------------------------------------------
recorder Node -file Push/node72.out -time -node 72 -dof 1 2 3 disp;
recorder Node -file Push/node73.out -time -node 73 -dof 1 2 3 disp;
recorder Node -file Push/node75.out -time -node 75 -dof 1 2 3 disp;
recorder Node -file Push/node76.out -time -node 76 -dof 1 2 3 disp;

recorder Node -file Push/rotation.out -time -node 2 -dof 1 2 3 disp;
recorder Node -file Push/moment.out -time -node 2 -dof 1 2 3 reaction;

recorder Element -file Push/FTendon33.out -time -ele 33 axialForce;
recorder Element -file Push/FTendon22.out -time -ele 22 axialForce;
recorder  Node  -file  Push/Tendon.out  -time  -node  12  -    dof 1 2 3 reaction;
```

```
recorder Node -file Push/node33.out -time -node 33 -dof 1 2 3 disp;
recorder Node -file Push/node4.out -time -node 4 -dof 1 2 3 disp;
recorder Node -file Push/node3.out -time -node 3 -dof 1 2 3 disp;
recorder Node -file Push/node2.out -time -node 2 -dof 1 2 3 disp;
recorder Node -file Push/DFree.out -time -node 11 -dof 1 2 3 disp;                    # displacements of top
column
recorder Node -file Push/DBase.out -time -node 1 -dof 1 2 3 disp;
recorder Node -file Push/RBase.out -time -node 1 -dof 1 2 3 reaction;                 # support reaction
recorder Element -file Push/FTendon.out -time -ele 11 axialForce;                     #   element   forces   --
column
recorder Element -file push/compressionstrain.out -time -ele 1 section 1 fiber 6.56 0 $IDreinf stressStrain;
recorder Element -file push/tensionstrain.out -time -ele 1 section 1 fiber -6.56 0 $IDreinf stressStrain;
recorder Element -file push/sec1strain.out -time -ele 1 section 1 fiber 6 0 $IDelastomer stressStrain;
recorder Element -file push/sec2strain.out -time -ele 3 section 2 fiber -6 0 $IDconcU1 stressStrain;
recorder Element -file push/sec3strain.out -time -ele 3 section 2 fiber -8 0 $IDconccover1 stressStrain;
recorder Element -file push/sec4strain.out -time -ele 4 section 1 fiber -6 0 $IDconcU2 stressStrain;
recorder Element -file push/sec5strain.out -time -ele 4 section 1 fiber -8 0 $IDconccover2 stressStrain;
recorder Element -file push/sec6strain.out -time -ele 4 section 1 fiber -4 0 $IDconcU2 stressStrain;
recorder Element -file push/sec7strain.out -time -ele 4 section 1 fiber -3 0 $IDconcU2 stressStrain;
recorder Element -file push/sec8strain.out -time -ele 4 section 1 fiber  0 0 $IDconcU2 stressStrain;
recorder Element -file Element1.out -time -ele 331 force;
recorder Element -file Element2.out -time -ele 332 force;
recorder Element -file push/rebar1.out -time -ele 1 section 1 fiber 6.8 0 $IDreinf stressStrain;
recorder Element -file push/rebar2.out -time -ele 2 section 1 fiber 6.8 0 $IDreinf stressStrain;
recorder Element -file push/rebar3.out -time -ele 3 section 1 fiber 6.8 0 $IDreinf stressStrain;

recorder Element -file push/rebar4.out -time -ele 1 section 1 fiber -6.8 0 $IDreinf stressStrain;
recorder Element -file push/rebar5.out -time -ele 2 section 1 fiber -6.8 0 $IDreinf stressStrain;
recorder Element -file push/rebar6.out -time -ele 3 section 1 fiber -6.8 0 $IDreinf stressStrain;

recorder Element -file push/rebar7.out -time -ele 4 section 1 fiber -6.8 0 $IDreinf stressStrain;
recorder Element -file push/rebar8.out -time -ele 4 section 1 fiber  6.8 0 $IDreinf stressStrain;

recorder Element -file push/rebar9.out -time -ele 1 section 2 fiber -6.8 0 $IDreinf stressStrain;
recorder Element -file push/rebar10.out -time -ele 1 section 2 fiber 6.8 0 $IDreinf stressStrain;


recorder Node -file Push/gapdisp1.out -time -node 32 -dof 1 2 3 disp
recorder Node -file Push/gapdisp2.out -time -node 42 -dof 1 2 3 disp
recorder Node -file Push/gapdisp3.out -time -node 31 -dof 1 2 3 disp
recorder Node -file Push/gapdisp4.out -time -node 41 -dof 1 2 3 disp


# define GRAVITY -------------------------------------   -----------------------
```

```
pattern Plain 1 Linear {
   load 11 0 -$PCol 0
}

# Gravity-analysis parameters -- load-controlled static analysis
set Tol 1.0e-4;                                # convergence tolerance for test
constraints Plain;                             # how it handles boundary conditions
numberer Plain;                                # renumber dof's to minimize band-width (optimization), if you want to
system BandGeneral;                     # how to store and solve the system of equations in the analysis
test NormDispIncr $Tol 10 ;                    # determine if convergence has been achieved at the end of an iteration step
algorithm Newton;                              # use Newton's solution algorithm: updates tangent stiffness at every iteration
set NstepGravity 10;                           # apply gravity in 10 steps
set DGravity [expr 1./$NstepGravity];     # first load increment;
integrator LoadControl $DGravity;         # determine the next time step for an analysis
analysis Static;                               # define type of analysis static or transient
analyze $NstepGravity;                         # apply gravity
# ------------------------------------------------- maintain constant gravity loads and reset time to zero
loadConst -time 0.0

puts "Model Built"
```

C.3. SF-2

```
# SET UP ----------------------------------------------------------------------------
# units: kip, inch, sec
wipe;                            # clear memory of all past mode0l definitions
file mkdir Push;                        # create data directory
model BasicBuilder -ndm 2 -ndf 3;       # Define the model builder, ndm=#dimension, ndf=#dofs
set PI [expr acos(-1.0)];
set sec 1.; # define basic units

# define GEOMETRY -------------------------------------------------------------
set LCol 72;        # column length
set Weight 80;            # superstructure weight
# define section geometry
set DCol 16;        # Column Depth


# calculated parameters
set PCol $Weight;         # nodal dead-load weight per column
set g 386.4;              # g.
```

```
set Mass [expr $PCol/$g];        # nodal mass
# calculated geometry parameters
set ACol [expr 0.25*$PI*pow($DCol,2)];                             # cross-sectional area
set IzCol [expr 0.015625*$PI*pow($DCol,4)];                 # Column moment of inertia
# nodal coordinates:

node 1 0 0;               # node#, X, Y
node 2 0 0; # Bondslip

node 3 0 20;
node 31 -8 20;
node 32 8 20;

node 71 0 16.5;
node 72 11.5 16.5;
node 73 -11.5 16.5;

node 33 0 20;
node 77 0 16.5;

node 4 0 20;
node 41 -8 20;
node 42 8 20;

node 74 0 23.5;
node 75 11.5 23.5;
node 76 -11.5 23.5;

node 78 0 23.5;

node 5  0 34;



node 11 0 $LCol;

node 12 0 -50;
# Single point constraints -- Boundary Conditions
fix 2 1 1 1;
                    # node DX DY RZ
fix 12 1 1 1;
#equalDOF $rNodeTag $cNodeTag $dof1 $dof2 ...

equalDOF 71 77 1 3;
equalDOF 3 33 1 3;
```

```
equalDOF 74 78 1 3;

equalDOF 3 4 1 3;

set ColTransfTag 1;
geomTransf PDelta $ColTransfTag  ;

# nominal concrete compressive strength
set fc -6.;                      # CONCRETE Compressive Strength (+Tension, -Compression)
set Ec [expr 57*sqrt(-$fc*1000)];             # Concrete Elastic Modulus (the term in sqr root needs to be in
psi
set E1 1000000

# Gap Opening
element elasticBeamColumn   1005 71 72 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1006 71 73 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1007 74 75 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1008 74 76 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1001 3 32 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1002 3 31 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1003 4 41 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1004 4 42 $ACol $E1 $IzCol $ColTransfTag;

 # nodal masses:
 mass 11 $Mass  1e-9 0;          # node#, Mx My Mz, Mass=Weight/g, neglect rotational inertia at nodes


# Define ELEMENTS & SECTIONS -------------------------------------------------------------
set CFRPsec 1;
set concsec  2;
set CFRPsecsteel 3;
set CFRPface 4;


# MATERIAL parameters -------------------------------------------------------------------
set IDconcU1 1;
set IDconccover1 2;
set IDconcCFRP1 3;
set IDconccoverCFRP1 4;
set IDconcCFRP2 5;
set IDconccoverCFRP2 6;
set IDreinf 7;
set IDgap 8;
set IDconccoverCFRP3 9;
set IDBondSlip 12;
```

```
set IDRigid 13;

# material ID tag -- reinforcement
# unconfined concrete
set fc1U          $fc;                # UNCONFINED concrete (todeschini parabolic model), maximum stress
set eps1U    -0.003;                  # strain at maximum strength of unconfined concrete
set fc2U          [expr 0.2*$fc1U];         # ultimate stress
set eps2U    -0.01;             # strain at ultimate stress
set lambda 0.1;                       # ratio between unloading slope at $eps2 and initial slope $Ec
# tensile-strength properties
set ftU [expr -0.14*$fc1U];                 # tensile strength +tension
set Ets [expr $ftU/0.002];            # tension softening stiffness
# -----------
set Fy 68.5;                    # STEEL yield stress
set Es 29000.;                        # modulus of steel
set Bs 0.005;                   # strain-hardening ratio
set R0 18;                      # control the transition from elastic to plastic branches
set cR1 0.925;                        # control the transition from elastic to plastic branches
set cR2 0.15;                   # control the transition from elastic to plastic branches

uniaxialMaterial ENT $IDgap 100000;


# CFRP spirals are @ 4"
uniaxialMaterial Concrete01  $IDconcCFRP1  -8.24   -0.002   -10.9    -0.006742;  #28day
# CFRP
  # Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccoverCFRP1  -8.24   -0.002   -10.9    -0.006742;   #28day
# CFRP spirals are @ 4"
uniaxialMaterial Concrete01  $IDconcCFRP2  -7.2   -0.002   -9.9    -0.007043;   #28day
# CFRP
  # Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccoverCFRP2  -7.2   -0.002   -9.9    -0.007043;  #28day
# CFRP
  # Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccoverCFRP3  -7.2   -0.002   -9.9    -0.007043;  #28day
# segments
uniaxialMaterial Concrete01  $IDconcU1    -14.7 -.0052   -5.8  -0.015  #-7.96  -.007838   -4  -0.0327 #28day
# Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccover1  -11.18   -0.003   -4.4     -0.006;#-5.0   -0.002   -2.5    -0.00516
#uniaxialMaterial Concrete02 $IDconcU $fc1U $eps1U $fc2U $eps2U $lambda $ftU $Ets;     #  build  coverCol  concrete
(unconfined)
 uniaxialMaterial Steel02 $IDreinf $Fy $Es $Bs $R0 $cR1 $cR2;                          #    build    reinforcement
material
#uniaxialMaterial Steel01 $IDreinf $Fy $Es $Bs
```

```
# RC section:
set ri 0
set ro [expr $DCol/2]
set coverCol 1.375
set numBarsCol 10
set barAreaCol 0.2
set nfCoreR 4
set nfCoreT 20
set nfcoverColR 1
set nfcoverColT 20
set rc [expr $ro-$coverCol]

section fiberSec $CFRPsecsteel  {;      # Define the fiber section
 patch circ $IDconcCFRP1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccoverCFRP1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/$numBarsCol ]
 # Define the reinforcing layer
 layer circ $IDreinf $numBarsCol $barAreaCol 0 0 $rc $theta 360
}

section fiberSec $CFRPface  {;   # Define the fiber section
 patch circ $IDconccoverCFRP3 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccoverCFRP3 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/$numBarsCol ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.04 0 0 $rc $theta 360
}


section fiberSec $concsec   {;   # Define the fiber section
 patch circ $IDconcU1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.01 0 0 $rc $theta 360
}

section fiberSec $CFRPsec   {;   # Define the fiber section
 patch circ $IDconcCFRP2 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch     circ     $IDconccoverCFRP2     $nfcoverColT   $nfcoverColR 0 0 $rc $ro 0 360
```

```
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.01 0 0 $rc $theta 360
}
# define geometric transformation: performs a linear geometric transformation of beam stiffness and resisting
force from the basic system to the global-coordinate system
#set ColTransfTag 1;                    # associate a tag to column transformation
#geomTransf PDelta $ColTransfTag  ;

# element connectivity:
set numIntgrPts 2;
#element beaColumn $eletag $ inode $jnode $ A $E $i $transftag
      # number of integration points for force-based element
element nonlinearBeamColumn  1  1  71   $numIntgrPts $CFRPsecsteel   $ColTransfTag;
element nonlinearBeamColumn  2  71 3    $numIntgrPts $CFRPface   $ColTransfTag;
element nonlinearBeamColumn  3  4  74   $numIntgrPts $CFRPface        $ColTransfTag;
element nonlinearBeamColumn  4  74 5    $numIntgrPts $CFRPsec        $ColTransfTag;
element nonlinearBeamColumn  5  5  11   5            $concsec        $ColTransfTag;


element zeroLength 332 32 42 -mat $IDgap -dir 2;
element zeroLength 331 31 41 -mat $IDgap -dir 2;

 set PostTensionSteelTag 11;
 set PostTensionSteelElementTag 10;
 set Dbar 1.625
 set PostTensionBarArea 1.95 ;
 set PostTensionForce 100;
 set PostTensionBarStress [expr $PostTensionForce/$PostTensionBarArea];
 set PostTensionBarEValue 27000.0;
 set PostTensionBarTensionPlasticTransition 1E15;
 set PostTensionBarCompressionPlasticTransition -1E15;
 set PostTensionBarInitialStrain [expr -$PostTensionBarStress/$PostTensionBarEValue];
 set PostTensionFy 137
 puts "Post Tension Bar Strain is";
 puts $PostTensionBarInitialStrain;

set Izbar [expr 0.015625*$PI*pow($Dbar,4)];

uniaxialMaterial  ElasticPP   $PostTensionSteelTag  $PostTensionBarEValue  $PostTensionBarTensionPlasticTransition
$PostTensionBarCompressionPlasticTransition $PostTensionBarInitialStrain;

element corotTruss 11  12  77  $PostTensionBarArea $PostTensionSteelTag
element  corotTruss  12   77   33   $PostTensionBarArea   $PostTensionSteelTag
```

```
element corotTruss 13  33  78  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 14  78  11  $PostTensionBarArea $PostTensionSteelTag


#Bond-Slip                       tag            M1    R1        M2     R2      -M1    -R1        -M2    -R2
uniaxialMaterial Hysteretic  $IDBondSlip  1883  0.0022  2124  0.0028 -1883  -0.0022  -2124 -0.0028 1 1 0 0 0.24;
uniaxialMaterial Elastic $IDRigid 9e9;

#Bond-Slip
element zeroLength 15 1 2 -mat $IDRigid $IDRigid $IDBondSlip -dir 1 2 6;


# Define RECORDERS -------------------------------------------------------------
recorder Node -file Push/node72.out -time -node 72 -dof 1 2 3 disp;
recorder Node -file Push/node73.out -time -node 73 -dof 1 2 3 disp;
recorder Node -file Push/node75.out -time -node 75 -dof 1 2 3 disp;
recorder Node -file Push/node76.out -time -node 76 -dof 1 2 3 disp;
recorder Element -file Push/F331.out -time -ele 331 force;
recorder Element -file Push/F332.out -time -ele 332 force;
recorder Node -file Push/node33.out -time -node 33 -dof 1 2 3 disp;
recorder Node -file Push/node4.out -time -node 4 -dof 1 2 3 disp;
recorder Node -file Push/node3.out -time -node 3 -dof 1 2 3 disp;
recorder Node -file Push/DFree.out -time -node 11 -dof 1 2 3 disp;
recorder Node -file Push/DBase.out -time -node 1 -dof 1 2 3 disp;        # displacements of support nodes
recorder Node -file Push/RBase.out -time -node 1 -dof 1 2 3 reaction;          # support reaction
recorder Drift -file Push/Drift.out -time -iNode 1 -jNode 4 -dof 1   -perpDirn 2 ;     # lateral drift
recorder Node -file Push/FTendon.out -time -node 12 -dof 1 2 3 reaction;                           #     element
forces -- column
recorder Element -file Push/ForceColSec1.out -time -ele 4 section $PostTensionBarArea force;
       # Column section forces, axial and moment, node i
recorder Element -file Push/DefoColSec1.out -time -ele 4 section $PostTensionBarArea deformation;
       # section deformations, axial and curvature, node i
recorder Element -file Push/ForceColSec$numIntgrPts.out -time -ele 1 section $numIntgrPts force;          #
section forces, axial and moment, node j
recorder Element -file Push/DefoColSec$numIntgrPts.out -time -ele 1 section 1 deformation;          #     section
deformations, axial and curvature, node j
recorder Element -file push/compressionstrain.out -time -ele 1 section 1 fiber 6.56 0 $IDreinf stressStrain;
recorder Element -file push/tensionstrain.out -time -ele 1 section 1 fiber -6.56 0 $IDreinf stressStrain;
recorder Element -file push/sec1strain.out -time -ele 1 section 1 fiber -6 0 $IDconcCFRP1   stressStrain;
recorder Element -file push/sec2strain.out -time -ele 1 section 1 fiber -8 0 $IDconccoverCFRP1   stressStrain;
recorder Element -file push/sec3strain.out -time -ele 2 section 2 fiber -6 0 $IDconcCFRP1   stressStrain;
recorder Element -file push/sec4strain.out -time -ele 2 section 2 fiber -8 0 $IDconccoverCFRP1   stressStrain;
recorder Element -file push/sec5strain.out -time -ele 3 section 1 fiber -6 0 $IDconcCFRP2  stressStrain;
recorder Element -file push/sec6strain.out -time -ele 3 section 1 fiber -8 0 $IDconccoverCFRP2  stressStrain;
recorder  Element  -file  push/sec7strain.out  -time  -ele   4 section 2 fiber -6 0 $IDconcCFRP2 stressStrain;
```

```
recorder Element -file push/sec8strain.out -time -ele 4 section 2 fiber -8 0 $IDconccoverCFRP2  stressStrain;
recorder Element -file Element1.out -time -ele 331 force;
recorder Element -file Element2.out -time -ele 332 force;
recorder Element -file push/rebar1.out -time -ele 1 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar2.out -time -ele 2 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar3.out -time -ele 3 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar4.out -time -ele 1 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar5.out -time -ele 2 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar6.out -time -ele 3 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar7.out -time -ele 4 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar8.out -time -ele 4 section 1 fiber  6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar9.out -time -ele 1 section 2 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar10.out -time -ele 1 section 2 fiber 6.62 0 $IDreinf stressStrain;
recorder Node -file Push/gapdisp1.out -time -node 32 -dof 1 2 3 disp
recorder Node -file Push/gapdisp2.out -time -node 42 -dof 1 2 3 disp
recorder Node -file Push/gapdisp3.out -time -node 31 -dof 1 2 3 disp
recorder Node -file Push/gapdisp4.out -time -node 41 -dof 1 2 3 disp

# define GRAVITY -------------------------------------------------------------
pattern Plain 3 Linear {
   load 11 0 -$PCol 0
}

# Gravity-analysis parameters -- load-controlled static analysis
set Tol 1.0e-4;                  # convergence tolerance for test
constraints Plain;               # how it handles boundary conditions
numberer Plain;                  # renumber dof's to minimize band-width (optimization), if you want to
system BandGeneral;        # how to store and solve the system of equations in the analysis
test NormDispIncr $Tol 10 ;             # determine if convergence has been achieved at the end of an iteration
step
algorithm Newton;                # use Newton's solution algorithm: updates tangent stiffness at every iteration
set NstepGravity 10;             # apply gravity in 10 steps
set DGravity [expr 1./$NstepGravity];   # first load increment;
integrator LoadControl $DGravity;# determine the next time step for an analysis
analysis Static;                 # define type of analysis static or transient
analyze $NstepGravity;           # apply gravity
# ------------------------------------------------ maintain constant gravity loads and reset time to zero
loadConst -time 0.0

puts "Model Built"
```

C.4. SE-2

```
# SET UP ----------------------------------------------------------------------------
# units: kip, inch, sec
wipe;                                # clear memory of all past mode0l definitions
file mkdir Push;                           # create data directory
model BasicBuilder -ndm 2 -ndf 3;          # Define the model builder, ndm=#dimension, ndf=#dofs
set PI [expr acos(-1.0)];
set sec 1.; # define basic units

# define GEOMETRY -------------------------------------------------------------
set LCol 72;        # column length
set Weight 80;             # superstructure weight
# define section geometry
set DCol 16;        # Column Depth
#set BCol 16;       # Column Width

# calculated parameters
set PCol $Weight;          # nodal dead-load weight per column
set g 386.4;               # g.
set Mass [expr $PCol/$g];        # nodal mass
# calculated geometry parameters
set ACol [expr 0.25*$PI*pow($DCol,2)];                          # cross-sectional area
set IzCol [expr 0.015625*$PI*pow($DCol,4)];                # Column moment of inertia

# nodal coordinates:
node 1 0 0;                # node#, X, Y
node 2 0 0; #bond-slip

node 3 0 20;
node 31 -8 20;
node 32 8 20;

node 71 0 16.5;
node 72 11.5 16.5;
node 73 -11.5 16.5;
node 77 0 16.5;

node 33 0 20;

node 4 0 20;
node 41 -8 20;
node 42 8 20;
```

```
node 74 0 23.5;
node 75 11.5 23.5;
node 76 -11.5 23.5;
node 5  0 34;

node 78 0 23.5;

node 11 0 $LCol;

node 12 0 -40;
# Single point constraints -- Boundary Conditions
fix 2 1 1 1;                # node DX DY RZ
fix 12 1 1 1;

#equalDOF $rNodeTag $cNodeTag $dof1 $dof2 ...
#equalDOF 2 22 1 3;

equalDOF 71 77 1 3;
equalDOF 3 33 1 3;
equalDOF 74 78 1 3;

equalDOF 3 4 1 3;

set ColTransfTag 1;
geomTransf PDelta $ColTransfTag  ;

# nominal concrete compressive strength
set fc -6.;                       # CONCRETE Compressive Strength (+Tension, -Compression)
set Ec [expr 57*sqrt(-$fc*1000)];             # Concrete Elastic Modulus (the term in sqr root needs to be in
psi
set E1 1000000
# Gap Opening
element elasticBeamColumn   1005 71 72 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1006 71 73 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1007 74 75 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1008 74 76 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1001 3 32 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1002 3 31 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1003 4 41 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1004 4 42 $ACol $E1 $IzCol $ColTransfTag;

 # nodal masses:
 mass 11 $Mass  1e-9 0;          # node#, Mx My Mz, Mass=Weight/g, neglect rotational inertia at nodes
```

```
# Define ELEMENTS & SECTIONS -------------------------------------------------------------

set concsec  1;
set ECCsec 2;
set ECCsecsteel 3;
set ECCface 4;

# MATERIAL parameters -------------------------------------------------------------------
set IDconcU1 1;
set IDconccover1 2;
set IDreinf 3;
set IDgap 4;
set ECCcore1  5;
set ECCcover1  6;
set ECCcore2  7;
set ECCcover2  8;
set ECCcover3 9;
set IDBondSlip 12;
set IDRigid 13;

# material ID tag -- reinforcement
# unconfined concrete
set fc1U            $fc;                # UNCONFINED concrete (todeschini parabolic model), maximum stress
set eps1U    -0.003;                    # strain at maximum strength of unconfined concrete
set fc2U            [expr 0.2*$fc1U];         # ultimate stress
set eps2U    -0.01;              # strain at ultimate stress
set lambda 0.1;                         # ratio between unloading slope at $eps2 and initial slope $Ec
# tensile-strength properties
set ftU [expr -0.14*$fc1U];                   # tensile strength +tension
set Ets [expr $ftU/0.002];              # tension softening stiffness
# -----------
set Fy 68;                       # STEEL yield stress
set Es 29000;                    # modulus of steel
set Bs 0.02;                     # strain-hardening ratio
set R0 18;                       # control the transition from elastic to plastic branches
set cR1 0.925;                          # control the transition from elastic to plastic branches
set cR2 0.15;                    # control the transition from elastic to plastic branches

uniaxialMaterial Steel02 $IDreinf $Fy $Es $Bs $R0 $cR1 $cR2;


uniaxialMaterial ENT $IDgap 100000;


# segments
```

```
uniaxialMaterial Concrete01  $IDconcU1    -8.8  -.006   -3.5  -0.052; #-7.96  -.007838   -4  -0.0327 #28day
uniaxialMaterial Concrete01  $IDconccover1  -5.96   -0.003   -2.4     -0.0113; #-5.0   -0.002   -2.5    -0.00516

# ECC, I assumed large compression strain for ECC to count on its flexibility (0.0807)
uniaxialMaterial Concrete01 $ECCcore1 -8.9   -0.0065   -3.5   -0.0334  #0.2 0.8 500;#-11.18   -0.015   -5.6   -
0.0807
uniaxialMaterial Concrete01 $ECCcover1 -7.11   -0.0025   -2.8   -0.005  #0.2 0.8 500;#-8   -0.005   -4   -0.0113
uniaxialMaterial Concrete01 $ECCcover3 -4   -0.005   -1.6   -0.02  #0.2 0.8 500;#-8
uniaxialMaterial Concrete01  $ECCcore2  -9.1   -0.0065   -3.6   -0.0307; #  0.1  0.9  40;# 0.1  0.8  40; 0.5
0.635 2420 #28day
# Cover concrete (unconfined)ECC
uniaxialMaterial Concrete01  $ECCcover2  -7.4   -0.0025   -3   -0.005 ; #0.1  0.9  40;


# tensile strength was assumed 0.06 of compressive strength.
# RC section:
set ri 0
set ro [expr $DCol/2]
set coverCol 1.1875
set numBarsCol 10
set barAreaCol 0.2
set nfCoreR 4
set nfCoreT 20
set nfcoverColR 1
set nfcoverColT 20
set rc [expr $ro-$coverCol]

section fiberSec $ECCsecsteel   {;      # Define the fiber section
 patch circ $ECCcore1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $ECCcover1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/$numBarsCol ]
 # Define the reinforcing layer
 layer circ $IDreinf $numBarsCol $barAreaCol 0 0 $rc $theta 360
}

section fiberSec $ECCface   {;   # Define the fiber section
 patch circ $ECCcover3 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $ECCcover3 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforc62 0.05 0 $rc $theta 360
layer circ $IDreinf 8 0.04 0 0 $rc $theta 360
}
```

```
section fiberSec $ECCsec   {;    # Define the fiber section
 patch circ $ECCcore2 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $ECCcover2 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.01 0 $rc $theta 360
}


section fiberSec $concsec   {;   # Define the fiber section
 patch circ $IDconcU1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.01 0 0 $rc $theta 360
}

# define geometric transformation: performs a linear geometric transformation of beam stiffness and resisting
force from the basic system to the global-coordinate system
#set ColTransfTag 1;                    # associate a tag to column transformation
#geomTransf PDelta $ColTransfTag  ;

# element connectivity:
set numIntgrPts 2;
#element beaColumn $eletag $ inode $jnode $ A $E $i $transftag
      # number of integration points for force-based element
element nonlinearBeamColumn  1  1  71   $numIntgrPts $ECCsecsteel   $ColTransfTag;
element nonlinearBeamColumn  2  71 3    $numIntgrPts $ECCface   $ColTransfTag;
element nonlinearBeamColumn  3  4  74   $numIntgrPts $ECCface       $ColTransfTag;
element nonlinearBeamColumn  4  74 5    $numIntgrPts $ECCsec        $ColTransfTag;
element nonlinearBeamColumn  5  5  11   5            $concsec         $ColTransfTag;


element zeroLength 332 32 42 -mat $IDgap -dir 2;
element zeroLength 331 31 41 -mat $IDgap -dir 2;



 set PostTensionSteelTag 11;
 set PostTensionSteelElementTag 10;
 set Dbar 1.625
```

```
 set PostTensionBarArea 1.95 ;
 set PostTensionForce 110;
 set PostTensionBarStress [expr $PostTensionForce/$PostTensionBarArea];
 set PostTensionBarEValue 26000.0;
 set PostTensionBarTensionPlasticTransition 1E15;
 set PostTensionBarCompressionPlasticTransition -1E15;
 set PostTensionBarInitialStrain [expr -$PostTensionBarStress/$PostTensionBarEValue];
 set PostTensionFy 137
 puts "Post Tension Bar Strain is";
 puts $PostTensionBarInitialStrain;

set Izbar [expr 0.015625*$PI*pow($Dbar,4)];
#                                       matTag                      E                 Fy                        gap
eps0
#uniaxialMaterial      ElasticPPGap           $PostTensionSteelTag      $PostTensionBarEValue      $PostTensionFy
$PostTensionBarInitialStrain
uniaxialMaterial  ElasticPP   $PostTensionSteelTag  $PostTensionBarEValue  $PostTensionBarTensionPlasticTransition
$PostTensionBarCompressionPlasticTransition $PostTensionBarInitialStrain



element corotTruss 11  12  77  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 12  77  33  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 13  33  78  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 14  78  11  $PostTensionBarArea $PostTensionSteelTag


#Bond-Slip                       tag           M1   R1       M2     R2      -M1    -R1       -M2    -R2
uniaxialMaterial Hysteretic  $IDBondSlip  1734  0.0023  1659  0.003 -1734  -0.0023  -1659 -0.003 1 1 0 0 0.24;
uniaxialMaterial Elastic $IDRigid 9e9;

#Bond-Slip
element zeroLength 15 1 2 -mat $IDRigid $IDRigid $IDBondSlip -dir 1 2 6;


# Define RECORDERS -------------------------------------------------------------
recorder Node -file Push/node72.out -time -node 72 -dof 1 2 3 disp;
recorder Node -file Push/node73.out -time -node 73 -dof 1 2 3 disp;
recorder Node -file Push/node75.out -time -node 75 -dof 1 2 3 disp;
recorder Node -file Push/node76.out -time -node 76 -dof 1 2 3 disp;

recorder Element -file Push/F331.out -time -ele 331 force;
recorder Element -file Push/F332.out -time -ele 332 force;
```

```
recorder Node -file Push/node33.out -time -node 33 -dof 1 2 3 disp;
recorder Node -file Push/node4.out -time -node 4 -dof 1 2 3 disp;
recorder Node -file Push/node3.out -time -node 3 -dof 1 2 3 disp;
recorder Node -file Push/DFree.out -time -node 11 -dof 1 2 3 disp;
recorder Node -file Push/DBase.out -time -node 1 -dof 1 2 3 disp;        # displacements of support nodes
recorder Node -file Push/RBase.out -time -node 1 -dof 1 2 3 reaction;          # support reaction
recorder Drift -file Push/Drift.out -time -iNode 1 -jNode 4 -dof 1   -perpDirn 2 ;     # lateral drift
recorder Node -file Push/FTendon.out -time -node 12 -dof 1 2 3 reaction;                            #     element
forces -- column
recorder Element -file Push/ForceColSec1.out -time -ele 4 section $PostTensionBarArea force;
      # Column section forces, axial and moment, node i
recorder Element -file Push/DefoColSec1.out -time -ele 4 section $PostTensionBarArea deformation;
      # section deformations, axial and curvature, node i
recorder Element -file Push/ForceColSec$numIntgrPts.out -time -ele 1 section $numIntgrPts force;          #
section forces, axial and moment, node j
recorder Element -file Push/DefoColSec$numIntgrPts.out -time -ele 1 section 1 deformation;          #     section
deformations, axial and curvature, node j
recorder Element -file push/compressionstrain.out -time -ele 1 section 1 fiber 6.56 0 $IDreinf stressStrain;
recorder Element -file push/tensionstrain.out -time -ele 1 section 1 fiber -6.56 0 $IDreinf stressStrain;
recorder Element -file push/sec1strain.out -time -ele 1 section 1 fiber -6 0 $ECCcore1   stressStrain;
recorder Element -file push/sec2strain.out -time -ele 1 section 1 fiber -8 0 $ECCcover1   stressStrain;
recorder Element -file push/sec3strain.out -time -ele 2 section 2 fiber -6 0 $ECCcore1   stressStrain;
recorder Element -file push/sec4strain.out -time -ele 2 section 2 fiber -8 0 $ECCcover1   stressStrain;
recorder Element -file push/sec5strain.out -time -ele 3 section 1 fiber -6 0 $ECCcore2  stressStrain;
recorder Element -file push/sec6strain.out -time -ele 3 section 1 fiber -8 0 $ECCcover2  stressStrain;
recorder Element -file push/sec7strain.out -time -ele 4 section 2 fiber -6 0 $ECCcore2  stressStrain;
recorder Element -file push/sec8strain.out -time -ele 4 section 2 fiber -8 0 $ECCcover2  stressStrain;
recorder Element -file Element1.out -time -ele 331 force;
recorder Element -file Element2.out -time -ele 332 force;
recorder Element -file push/rebar1.out -time -ele 1 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar2.out -time -ele 2 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar3.out -time -ele 3 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar4.out -time -ele 1 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar5.out -time -ele 2 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar6.out -time -ele 3 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar7.out -time -ele 4 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar8.out -time -ele 4 section 1 fiber  6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar9.out -time -ele 1 section 2 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar10.out -time -ele 1 section 2 fiber 6.62 0 $IDreinf stressStrain;
recorder Node -file Push/gapdisp1.out -time -node 32 -dof 1 2 3 disp
recorder Node -file Push/gapdisp2.out -time -node 42 -dof 1 2 3 disp
recorder Node -file Push/gapdisp3.out -time -node 31 -dof 1 2 3 disp
recorder Node -file Push/gapdisp4.out -time -node 41 -dof 1 2 3 disp
```

```
# define GRAVITY -------------------------------------------------------------
pattern Plain 1 Linear {
 load 11 0 -$PCol 0
}


# Gravity-analysis parameters -- load-controlled static analysis
set Tol 1.0e-8;                  # convergence tolerance for test
constraints Plain;               # how it handles boundary conditions
numberer Plain;                  # renumber dof's to minimize band-width (optimization), if you want to
system BandGeneral;        # how to store and solve the system of equations in the analysis
test NormDispIncr $Tol 10 ;            # determine if convergence has been achieved at the end of an iteration
step
algorithm Newton;                # use Newton's solution algorithm: updates tangent stiffness at every iteration
set NstepGravity 10;             # apply gravity in 10 steps
set DGravity [expr 1./$NstepGravity];   # first load increment;
integrator LoadControl $DGravity;# determine the next time step for an analysis
analysis Static;                 # define type of analysis static or transient
analyze $NstepGravity;           # apply gravity
# ------------------------------------------------- maintain constant gravity loads and reset time to zero
loadConst -time 0.0

puts "Model Built"
```

C.5. SC-2R

```
# SET UP ----------------------------------------------------------------------
# units: kip, inch, sec
wipe;                            # clear memory of all past mode0l definitions
file mkdir Push;                        # create data directory
model BasicBuilder -ndm 2 -ndf 3;       # Define the model builder, ndm=#dimension, ndf=#dofs
set PI [expr acos(-1.0)];
set sec 1.; # define basic units

# define GEOMETRY -------------------------------------------------------------
set LCol 72;        # column length
set Weight 80;            # superstructure weight
# define section geometry
set DCol 16;        # Column Depth


# calculated parameters
```

```
set PCol $Weight;          # nodal dead-load weight per column
set g 386.4;               # g.
set Mass [expr $PCol/$g];        # nodal mass
# calculated geometry parameters
set ACol [expr 0.25*$PI*pow($DCol,2)];                              # cross-sectional area
set IzCol [expr 0.015625*$PI*pow($DCol,4)];                 # Column moment of inertia

# nodal coordinates:
node 1 0 0;                # node#, X, Y
node 2 0 8; #bond-slip

node 3 0 19;
node 31 -8 19;
node 32 8 19;

node 71 0 15.5;
node 72 11.5 15.5;
node 73 -11.5 15.5;

node 33 0 19;
node 77 0 15.5;

node 4 0 19;
node 41 -8 19;
node 42 8 19;

node 74 0 22.5;
node 75 11.5 22.5;
node 76 -11.5 22.5;

node 78 0 22.5;


node 5  0 34;


node 11 0 $LCol;

node 12 0 -40;
# Single point constraints -- Boundary Conditions
fix 2 1 1 1;               # node DX DY RZ
fix 12 1 1 1;

#equalDOF $rNodeTag $cNodeTag $dof1 $dof2 ...
```

```
equalDOF 3 33 1 3;
equalDOF 71 77 1 3;
equalDOF 74 78 1 3;

equalDOF 3 4 1;

set ColTransfTag 1;
geomTransf PDelta $ColTransfTag  ;

# nominal concrete compressive strength
set fc -6.;                      # CONCRETE Compressive Strength (+Tension, -Compression)
set Ec [expr 57*sqrt(-$fc*1000)];             # Concrete Elastic Modulus (the term in sqr root needs to be in
psi
set E1 1000000

# Gap Opening Elements
element elasticBeamColumn   1005 71 72 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1006 71 73 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1007 74 75 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1008 74 76 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1001 3 32 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1002 3 31 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1003 4 41 $ACol $E1 $IzCol $ColTransfTag;
element elasticBeamColumn   1004 4 42 $ACol $E1 $IzCol $ColTransfTag;

 # nodal masses:
 mass 11 $Mass  1e-9 0;          # node#, Mx My Mz, Mass=Weight/g, neglect rotational inertia at nodes


# Define ELEMENTS & SECTIONS -------------------------------------------------------------
set CFRPsec 1;
set concsec  2;
set CFRPsecsteel 3;
set Concsecsteel 4;
set CFRPface 5;
# MATERIAL parameters -------------------------------------------------------------------
set IDconcU1 1;
set IDconccover1 2;
set IDconcCFRP1 3;
set IDconccoverCFRP1 4;
set IDconcCFRP2 5;
set IDconccoverCFRP2 6;
set IDreinf 7;
set IDgap 8;
set IDBondSlip 12;
```

```
set IDRigid 13;

# material ID tag -- reinforcement
# unconfined concrete
set fc1U            $fc;                # UNCONFINED concrete (todeschini parabolic model), maximum stress
set eps1U    -0.003;                    # strain at maximum strength of unconfined concrete
set fc2U            [expr 0.2*$fc1U];          # ultimate stress
set eps2U    -0.01;              # strain at ultimate stress
set lambda 0.1;                         # ratio between unloading slope at $eps2 and initial slope $Ec
# tensile-strength properties
set ftU [expr -0.14*$fc1U];                    # tensile strength +tension
set Ets [expr $ftU/0.002];              # tension softening stiffness
# -----------
set Fy 69;                       # STEEL yield stress
set Es 29000.;                          # modulus of steel
set Bs 0.005;                    # strain-hardening ratio
set R0 18;                       # control the transition from elastic to plastic branches
set cR1 0.925;                          # control the transition from elastic to plastic branches
set cR2 0.15;                    # control the transition from elastic to plastic branches

uniaxialMaterial ENT $IDgap 10000;

# Note: since the concrete was repaired, the strength of 4 ksi was considered for concrete and the strain of
0.002 was replaced by 0.004 to show the softer behavior

# CFRP spirals are @ 4" base segment
uniaxialMaterial Concrete01  $IDconcCFRP1  -4   -0.004   -6.8    -0.017;   #28day
# CFRP
  # Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccoverCFRP1   -4   -0.004   -6.8    -0.017; #28day
# CFRP spirals are @ 4"
uniaxialMaterial Concrete01  $IDconcCFRP2  -3.6   -0.004   -6.4    -0.018;  #28day
# CFRP
  # Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccoverCFRP2  -3.6   -0.004   -6.4    -0.018;  #28day
# segments
uniaxialMaterial Concrete01  $IDconcU1    -13.9  -.00547   -5.5  -0.027;
  # Cover concrete (unconfined)
uniaxialMaterial Concrete01  $IDconccover1  -10.3   -0.003   -4     -0.0137;
```

```
 uniaxialMaterial Steel02 $IDreinf $Fy $Es $Bs $R0 $cR1 $cR2;                          #    build    reinforcement
material
#uniaxialMaterial Steel01 $IDreinf $Fy $Es $Bs
#$R0 $cR1 $cR2;
#
# RC section:
set ri 0
set ro [expr $DCol/2]
set coverCol 1.1875
set numBarsCol 10
set barAreaCol 0.2
set nfCoreR 4
set nfCoreT 20
set nfcoverColR 1
set nfcoverColT 20
set rc [expr $ro-$coverCol]

section fiberSec $CFRPsecsteel  {;      # Define the fiber section
 patch circ $IDconcCFRP1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccoverCFRP1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/$numBarsCol ]
 # Define the reinforcing layer
 layer circ $IDreinf $numBarsCol $barAreaCol 0 0 $rc $theta 360
}

section fiberSec $concsec   {;    # Define the fiber section
 patch circ $IDconcU1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccover1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.01 0 0 $rc $theta 360
}

section fiberSec $CFRPsec   {;    # Define the fiber section
 patch circ $IDconcCFRP2 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccoverCFRP2 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.01 0 0 $rc $theta 360
}

section fiberSec $CFRPface   {;   #  Define   the   fiber    section
```

```
 patch circ $IDconccoverCFRP2 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
 patch circ $IDconccoverCFRP2 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360
 # Determine angle increment between bars
 set theta [expr 360.0/8 ]
 # Define the reinforcing layer
 layer circ $IDreinf 8 0.04 0 0 $rc $theta 360
}

# define geometric transformation: performs a linear geometric transformation of beam stiffness and resisting
force from the basic system to the global-coordinate system
#set ColTransfTag 1;                    # associate a tag to column transformation
#geomTransf PDelta $ColTransfTag  ;

# element connectivity:
set numIntgrPts 2;

element nonlinearBeamColumn  1  1  71   $numIntgrPts $CFRPsecsteel   $ColTransfTag;
element nonlinearBeamColumn  2  71 3    $numIntgrPts $CFRPface   $ColTransfTag;
element nonlinearBeamColumn  3  4  74   $numIntgrPts $CFRPface       $ColTransfTag;
element nonlinearBeamColumn  4  74 5    $numIntgrPts $CFRPsec        $ColTransfTag;
element nonlinearBeamColumn  5  5  11   3            $concsec         $ColTransfTag;



element zeroLength 332 32 42 -mat $IDgap -dir 2;
element zeroLength 331 31 41 -mat $IDgap -dir 2;



 set PostTensionSteelTag 11;
 set PostTensionSteelElementTag 10;
 set PostTensionBarArea 1.95 ;
 set PostTensionForce 88;
 set PostTensionBarStress [expr $PostTensionForce/$PostTensionBarArea];
 set PostTensionBarEValue 26000.0;
 set PostTensionBarTensionPlasticTransition 1E15;
 set PostTensionBarCompressionPlasticTransition -1E15;
 set PostTensionBarInitialStrain [expr -$PostTensionBarStress/$PostTensionBarEValue];
 set PostTensionFy 137
 puts "Post Tension Bar Strain is";
 puts $PostTensionBarInitialStrain;
# n

#                                       matTag                      E                Fy                       gap
eps0
```

```
#uniaxialMaterial      ElasticPPGap           $PostTensionSteelTag      $PostTensionBarEValue      $PostTensionFy
$PostTensionBarInitialStrain
uniaxialMaterial  ElasticPP   $PostTensionSteelTag  $PostTensionBarEValue  $PostTensionBarTensionPlasticTransition
$PostTensionBarCompressionPlasticTransition $PostTensionBarInitialStrain


element corotTruss 11  12  77  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 12  77  33  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 13  33  78  $PostTensionBarArea $PostTensionSteelTag
element corotTruss 14  78  11  $PostTensionBarArea $PostTensionSteelTag


#Bond-Slip                       tag           M1   R1       M2     R2     -M1   -R1       -M2   -R2
uniaxialMaterial Hysteretic  $IDBondSlip  1646  0.0023  1889  0.003 -1646  -0.0023  -1889 -0.003 1 1 0 0 0.25;
uniaxialMaterial Elastic $IDRigid 9e9;

#Bond-Slip
element zeroLength 15 1 2 -mat $IDRigid $IDRigid $IDBondSlip -dir 1 2 6;

# Define RECORDERS -------------------------------------------------------------
recorder Node -file Push/node72.out -time -node 72 -dof 1 2 3 disp;
recorder Node -file Push/node73.out -time -node 73 -dof 1 2 3 disp;
recorder Node -file Push/node75.out -time -node 75 -dof 1 2 3 disp;
recorder Node -file Push/node76.out -time -node 76 -dof 1 2 3 disp;
recorder Element -file Push/F331.out -time -ele 331 force;
recorder Element -file Push/F332.out -time -ele 332 force;
recorder Node -file Push/node33.out -time -node 33 -dof 1 2 3 disp;
recorder Node -file Push/node4.out -time -node 4 -dof 1 2 3 disp;
recorder Node -file Push/node3.out -time -node 3 -dof 1 2 3 disp;
recorder Node -file Push/DFree.out -time -node 11 -dof 1 2 3 disp;
recorder Node -file Push/DBase.out -time -node 1 -dof 1 2 3 disp;        # displacements of support nodes
recorder Node -file Push/RBase.out -time -node 1 -dof 1 2 3 reaction;          # support reaction
recorder Drift -file Push/Drift.out -time -iNode 1 -jNode 4 -dof 1   -perpDirn 2 ;     # lateral drift
recorder Node -file Push/FTendon.out -time -node 12 -dof 1 2 3 reaction;                                  #
element forces -- column
recorder Element -file Push/ForceColSec1.out -time -ele 4 section $PostTensionBarArea force;
       # Column section forces, axial and moment, node i
recorder Element -file Push/DefoColSec1.out -time -ele 4 section $PostTensionBarArea deformation;
       # section deformations, axial and curvature, node i
recorder Element -file Push/ForceColSec$numIntgrPts.out -time -ele 1 section $numIntgrPts force;          #
section forces, axial and moment, node j
recorder Element -file Push/DefoColSec$numIntgrPts.out -time -ele 1 section 1 deformation;          #     section
deformations, axial and curvature, node j
recorder Element -file push/compressionstrain.out -time -ele 1 section 1 fiber 6.56 0 $IDreinf stressStrain;
recorder  Element  -file  push/tensionstrain.out  -time  -    ele 1 section 1 fiber -6.56 0 $IDreinf stressStrain;
```

```
recorder Element -file push/sec1strain.out -time -ele 1 section 1 fiber -6 0 $IDconcCFRP1   stressStrain;
recorder Element -file push/sec2strain.out -time -ele 1 section 1 fiber -8 0 $IDconccoverCFRP1   stressStrain;
recorder Element -file push/sec3strain.out -time -ele 2 section 2 fiber -6 0 $IDconcCFRP1   stressStrain;
recorder Element -file push/sec4strain.out -time -ele 2 section 2 fiber -8 0 $IDconccoverCFRP1   stressStrain;
recorder Element -file push/sec5strain.out -time -ele 3 section 1 fiber -6 0 $IDconcCFRP2  stressStrain;
recorder Element -file push/sec6strain.out -time -ele 3 section 1 fiber -8 0 $IDconccoverCFRP2  stressStrain;
recorder Element -file push/sec7strain.out -time -ele 4 section 2 fiber -6 0 $IDconcCFRP2  stressStrain;
recorder Element -file push/sec8strain.out -time -ele 4 section 2 fiber -8 0 $IDconccoverCFRP2  stressStrain;
recorder Element -file Element1.out -time -ele 331 force;
recorder Element -file Element2.out -time -ele 332 force;
recorder Element -file push/rebar1.out -time -ele 1 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar2.out -time -ele 2 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar3.out -time -ele 3 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar4.out -time -ele 1 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar5.out -time -ele 2 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar6.out -time -ele 3 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar7.out -time -ele 4 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar8.out -time -ele 4 section 1 fiber  6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar9.out -time -ele 1 section 2 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar10.out -time -ele 1 section 2 fiber 6.62 0 $IDreinf stressStrain;
recorder Node -file Push/gapdisp1.out -time -node 32 -dof 1 2 3 disp
recorder Node -file Push/gapdisp2.out -time -node 42 -dof 1 2 3 disp
recorder Node -file Push/gapdisp3.out -time -node 31 -dof 1 2 3 disp
recorder Node -file Push/gapdisp4.out -time -node 41 -dof 1 2 3 disp

# Gravity-analysis parameters -- load-controlled static analysis
set Tol 1.0e-4;                  # convergence tolerance for test
constraints Plain;               # how it handles boundary conditions
numberer Plain;                  # renumber dof's to minimize band-width (optimization), if you want to
system BandGeneral;        # how to store and solve the system of equations in the analysis
test NormDispIncr $Tol 10 ;             # determine if convergence has been achieved at the end of an iteration
step
algorithm Newton;                # use Newton's solution algorithm: updates tangent stiffness at every iteration
set NstepGravity 10;             # apply gravity in 10 steps
set DGravity [expr 1./$NstepGravity];   # first load increment;
integrator LoadControl $DGravity;# determine the next time step for an analysis
analysis Static;                 # define type of analysis static or transient
analyze $NstepGravity;           # apply gravity
# ------------------------------------------------- maintain constant gravity loads and reset time to zero
loadConst -time 0.0

puts "Model Built"
```

C.6. PEFB

```
# SET UP ----------------------------------------------------------------------------
# units: kip, inch, sec
wipe;                                              # clear memory of all past mode0l definitions
set dataDir TimeHistory;
file mkdir $dataDir;                               # create data directory
model BasicBuilder -ndm 2 -ndf 3;       # Define the model builder, ndm=#dimension, ndf=#dofs
set PI [expr acos(-1.0)];
set sec 1.;                                        # define basic units

# define GEOMETRY -------------------------------------------------------------
set LCol 63;                            # column length
set DCol 14;
set ODtubeCol 14.567;                              # Outer diameter of the FRP tube
set DepthOfBent 18;                     # Depth of Bent cap section
set WidthOfBent 18;                     # Width of Bent cap section
set Span 84;

# calculated parameters
set Weight 50;                                     # superstructure weight
set PCol $Weight;                       # nodal dead-load weight per column
set g 386.4;                            # g.
set Mass [expr (2*$PCol+5)/$g];                    # nodal mass

# calculated geometry parameters
set ABent [expr $DepthOfBent*$WidthOfBent];                # cross-sectional area of bent cap
set IzBent [expr pow($DepthOfBent,3)*$WidthOfBent/12];     # Bent cap moment of inertia
set ACol [expr 0.25*$PI*pow($DCol,2)];                           # cross-sectional area
set IzCol [expr 0.015625*$PI*pow($DCol,4)];                # Column moment of inertia


# nodal coordinates:
# node No X Y
node 1 [expr -1*$Span/2] 0;
node 3 [expr -1*$Span/2] 0;
node 2 [expr +1*$Span/2] 0;
node 4 [expr +1*$Span/2] 0;
node 10 [expr -1*$Span/2] $LCol;
node 20 [expr +1*$Span/2] $LCol;
node 11 [expr -1*$Span/2+1] $LCol;
node 22 [expr +1*$Span/2-1] $LCol;
node 100 0 $LCol;
node 111 0 [expr 6+$LCol];
```

```
node 12  [expr +1*$Span/2] 21;  # End of SMA-ECC Zone
# Single point constraints -- Boundary Conditions
# node DX DY RZ
fix 3 1 1 1;
fix 4 1 1 1;

mass 111 [expr 0.947*$Mass]  1e-9 0;          #  node#,  Mx  My  Mz,  Mass=Weight/g,  neglect  rotational  inertia  at
nodes
mass 10 [expr 0.0015*$Mass]  1e-9 0;
mass 20 [expr 0.0015*$Mass]  1e-9 0;
mass 11 [expr 0.025*$Mass]  1e-9 0;
mass 22 [expr 0.025*$Mass]  1e-9 0;


#equalDOF $rNodeTag $cNodeTag $dof1 $dof2 ...
equalDOF 100 111 3;
equalDOF 100 11 3;
equalDOF 100 22 3;

equalDOF 11 10 2;
equalDOF 22 20 2;


# MATERIAL parameters -------------------------------------------------------------------
set IDconcCore 1;                 # material ID tag -- confined core concrete
set IDconcCover 2;
set ECCcore 3;
set ECCcover 4;                   # material ID tag -- unconfined cover concrete
set IDreinf3 5;
set IDreinf5 6;
             # material ID tag -- reinforcement
set IDFrpIncasesConc 7;                 # material ID tag -- FRP confined Concrete
set IDFrpTube 8;
set IDBondSlipRC 10;
set IDBondSlipFRP 11;
set IDRigid 12;
set Elastic 13;


             # material ID tag -- FRP tube

# nominal concrete compressive strength
set fc              -5.68;            # CONCRETE Compressive Strength, ksi   (+Tension, -Compression)
set Ec             [expr 57*sqrt(-$fc*1000)]; # Concrete Elastic Modulus
# confined concrete
```

```
set fc1C            -8.99;       # CONFINED concrete (mander model), maximum stress
set eps1C           -7.83e-3;          # strain at maximum stress
set fc2C            -7.69;       # ultimate stress
set eps2C           -22.37e-3;         # strain at ultimate stress
# unconfined concrete
set fc1U            $fc;               # UNCONFINED concrete (todeschini parabolic model), maximum stress
set eps1U           -0.002;            # strain at maximum strength of unconfined concrete
set fc2U            [expr 0.85*$fc1U];  # ultimate stress
set eps2U           -0.006;            # strain at ultimate stress
set lambda           0.1;  # tensile-strength properties

set ftC             [expr 0.007*sqrt(-$fc*1000)];           # tensile strength +tension
set ftU             [expr 0.007*sqrt(-$fc*1000)];           # tensile strength +tension
set Ets             [expr $ftU/0.002];               # tension softening stiffness
# FRP confined concrete
# Modified stress-strain relationship for concrete confined by FRP
# Simple Model of Saiidi, M., K. Sureshkumar, and C. Pulido (2005)
set Efiber          [expr 1850.0];            # tension modulus of FRP fabric
set ffrp          [expr 34.0];          # tensile strength of FRP fabric
set t        0.269;                    # FRP tube thickness

set fpc             [expr -$fc];                     # CONCRETE Compressive Strength, ksi
set tj            [expr $t];                       # Thickness of FRP fabric
set ej            [expr 0.5*$ffrp/$Efiber];          # ultimate cfrp strain
set pcf             [expr 4*$tj/($ODtubeCol-2*$t)];  # cfrp volumetric ratio
set fpco            [expr $fpc+0.003*$pcf*$Efiber];  # concrete stress at start of post yielding branch
set fr       [expr 2.0*$Efiber*$ej*$tj/($ODtubeCol-2*$t)];  # confining pressure (stress) at fibers
set eccu            [expr $ej/(0.1-0.25*log($fr/$fpc))];    # radial ultimate strain eccu
set fpcu            [expr $fpc+3.5*pow($fr,0.7)];           # ultimate concrete stress

# Steel bars #3
set Fy3             74;                # STEEL yield stress
set Es3             29000;       # modulus of steel
set Bs3             0.005;             # strain-hardening ratio
set 3R0 18.5;                    # control the transition from elastic to plastic branches
set cR1 0.925;                         # control the transition from elastic to plastic branches
set cR2 0.15;
set Fu3 139.53;                        # control the transition from elastic to plastic branches

set lsr3  26;
set beta3  0.5;
set r3  1;
set gama3  0.5;

# Steel bars #5
```

```
set Fy5             86.8;              # STEEL yield stress
set Es5             29000;       # modulus of steel
set Bs5             0.01;
                    # strain-hardening ratio
set 5R0  18.5;                         # control the transition from elastic to plastic branches
set cR1  0.925;                        # control the transition from elastic to plastic branches
set cR2  0.15;                         # control the transition from elastic to plastic branches
set Fu5  105;

set lsr5  3.2;
set beta5  1;
set r5  0.6;
set gama5  0.5;
uniaxialMaterial Concrete01 $IDconcCore $fc1C $eps1C $fc2C $eps2C; #$lambda $ftC $Ets; #   build   core   concrete
(confined)
uniaxialMaterial Concrete01 $IDconcCover $fc1U $eps1U $fc2U $eps2U; #$lambda $ftU $Ets;      #    build    cover
concrete (unconfined)
uniaxialMaterial Steel02 $IDreinf3 $Fy3 $Es3 $Bs3 $3R0 $cR1 $cR2;
uniaxialMaterial Steel02 $IDreinf5 $Fy5 $Es5 $Bs5 $5R0 $cR1 $cR2;                           #             build
reinforcement material
uniaxialMaterial Concrete01 $IDFrpIncasesConc [expr -$fpco] [expr 1*2*$fc/$Ec] [expr -$fpcu] -$eccu;      #
build FRP confined Concrete
uniaxialMaterial Hysteretic $IDFrpTube 9  0.0025  23  0.015  23  0.05  -9  -0.0025  -23  -0.015  -23  -0.05 1 1 0
0 0.3;



# ECC core
uniaxialMaterial Concrete02 $ECCcore -8.087   -0.0055   -3.2   -0.0207 0.2 .8 500;# -0.0207

uniaxialMaterial Concrete02 $ECCcover -5.6   -0.0025   -2.24   -0.006 0.2 .6 500;# 0.006


# section1 GEOMETRY SMA-ECC
set SecTag1  1;          # set tag for symmetric section of conventional Column
set DSec            14;          # Column Diameter
set coverSec 1.125;      # Column cover to reinforcing steel NA.
set numBarsSec1     8;          #   number   of   uniformly-distributed   longitudinal-reinforcement   bars   in
conventional column
set numBarsSec3     7;          # number of uniformly-distributed longitudinal-reinforcement bars in FRP column
set barAreaSec1     0.31;       # area of longitudinal-reinforcement bars
set barAreaSec3     0.11;       # area of longitudinal-reinforcement bars


# Generate a circular reinforced concrete section
```

```
# with one layer of steel evenly distributed around the perimeter and a confined core.
# confined core.
# Notes
#    The center of the reinforcing bars are placed at the inner radius
#    The core concrete ends at the inner radius (same as reinforcing bars)
#    The reinforcing bars are all the same size
#    The center of the section is at (0,0) in the local axis system
#    Zero degrees is along section y-axis
#
set ri1             0.0;                # inner radius of the section, only for hollow sections
set ro              [expr $DSec/2];     # overall (outer) radius of the section
set nfCoreR  18;                  # number of radial divisions in the core (number of "rings")
set nfCoreT  32;                  # number of theta divisions in the core (number of "wedges")
set nfCoverR 2;                   # number of radial divisions in the cover
set nfCoverT 32;                  # number of theta divisions in the cover

# Define the fiber section SMA- ECC Down segment
section fiberSec $SecTag1  {
      set rc [expr $ro-$coverSec+.5];                             # Core radius
      set rb [expr $ro-$coverSec];                                       # Bars radius
      patch circ $ECCcore $nfCoreT $nfCoreR 0 0 $ri1 $rc 0 360;          # Define the core patch
      patch circ $ECCcover $nfCoverT $nfCoverR 0 0 $rc $ro 0 360; # Define the cover patch
      set theta [expr 360.0/$numBarsSec1];          # Determine angle increment between bars
      layer circ $IDreinf5 $numBarsSec1 $barAreaSec1 0 0 $rb $theta 360; # Define the reinforcing layer
}

set SecTag2  2;
# Define the fiber section SMA- ECC Up segment

section fiberSec $SecTag2  {
      set rc [expr $ro-$coverSec+.5];                             # Core radius
      set rb [expr $ro-$coverSec];                                       # Bars radius
      patch circ $IDconcCore $nfCoreT $nfCoreR 0 0 $ri1 $rc 0 360;             # Define the core patch
      patch circ $IDconcCover $nfCoverT $nfCoverR 0 0 $rc $ro 0 360;     # Define the cover patch
      set theta [expr 360.0/$numBarsSec1];          # Determine angle increment between bars
      layer circ $IDreinf5 $numBarsSec1 $barAreaSec1 0 0 $rb $theta 360; # Define the reinforcing layer
}

set SecTag3          3;                 # set tag for symmetric section of FRP Column
set ri2             0.0;
set ro2             [expr $ODtubeCol/2];
set nfCoreR2 18;                  # number of radial divisions in the core (number of "rings")
set nfCoreT2 28;                  # number of theta divisions in the core (number of "wedges")
set nfFRPR          2;                  # number of radial divisions in the cover
set nfFRPT          28;                 #   number   of   theta divisions in the cover
```

```
set coverSec2     1.2065;

# Define the fiber section2
section fiberSec $SecTag3  {
       set rc2 [expr $ro2-$t];                                        # Core radius
       set rb [expr $ro2-$coverSec2];                                 # Bars radius
       patch circ $IDFrpIncasesConc $nfCoreT2 $nfCoreR2 0 0 $ri2 $rc2 0 360;          # Define the core patch
       patch circ $IDFrpTube $nfFRPT $nfFRPR 0 0 $rc2 $ro2 0 360;                     # Define the cover patch
       set theta [expr 360.0/$numBarsSec3];          # Determine angle increment between bars
       layer circ $IDreinf3 $numBarsSec3 $barAreaSec3 0 0 $rb $theta 360; # Define the reinforcing layer
}


# Gap parameters ------------------------------------------------------------------
set TGapMatTag 101
set CGapMatTag 102
set FrictionMatTag 103
set PipeTag 104
set GapParallelTag 105
set GapComplete 106

set TGap 0.05
set CGap -0.05
set FrictionForce 65
set Stiffness 4000
set GStiffness 4000
set PinCapacity 150
set PinPure [expr $PinCapacity-$FrictionForce]


uniaxialMaterial ElasticPPGap $TGapMatTag $GStiffness 500 $TGap;                             #     Tension     Gap
properties
uniaxialMaterial ElasticPPGap $CGapMatTag $GStiffness -500 $CGap;                            #   Compression   Gap
properties
uniaxialMaterial Steel02 $FrictionMatTag $FrictionForce $Stiffness 0 30 .925 .15;            #           Friction
properties
uniaxialMaterial Steel02 $PipeTag $PinCapacity $Stiffness 0 18.5 .925 .15;
uniaxialMaterial Parallel $GapParallelTag $TGapMatTag $CGapMatTag $FrictionMatTag;           # Parallel mat
uniaxialMaterial Series $GapComplete $GapParallelTag $PipeTag;


#Bond-Slip                      tag           M1    R1       M2     R2     -M1    -R1       -M2    -R2
uniaxialMaterial Hysteretic  $IDBondSlipRC  1187  0.004622  1317  0.011368 -1187  -0.004622  -1317 -0.011368 1 1
0 0 0.5;
```

```
uniaxialMaterial Hysteretic  $IDBondSlipFRP  1694.87  0.004861  2091.9  0.024 -1694.87  -0.004861  -2091.9 -0.024
1 1 0 0 0.5;
uniaxialMaterial Elastic $IDRigid 9e9;


# Element parameters ------------------------------------------------------------------

# define geometric transformation: performs a linear geometric transformation of beam stiffness and resisting
force from the basic system to the global-coordinate system
set ColTransfTag 1;                     # associate a tag to column transformation
geomTransf PDelta $ColTransfTag  ;

set E1 1000000;
 set numIntgrPts 7;
#Columns
element nonlinearBeamColumn 1 1  10 5 $SecTag3 $ColTransfTag;
element nonlinearBeamColumn 2 2  12 3            $SecTag1 $ColTransfTag;
element nonlinearBeamColumn 3 12 20 $numIntgrPts $SecTag2 $ColTransfTag;
#Bent
element elasticBeamColumn  4 11 100 $ABent $E1 $IzBent $ColTransfTag;
element elasticBeamColumn  5 100 22 $ABent $E1 $IzBent $ColTransfTag;
element elasticBeamColumn  34 100 111 $ABent $E1 $IzBent $ColTransfTag;

#Gap
uniaxialMaterial Elastic $Elastic 1000;
#element truss 6 10 11 1.0 $GapComplete;
#element truss 7 20 22 1.0 $GapComplete;

element truss 6 10 11 1.0 $Elastic;
element truss 7 20 22 1.0 $Elastic;



#Bond-Slip
element zeroLength 10 1 3 -mat $IDRigid $IDRigid $IDBondSlipRC -dir 1 2 6;
element zeroLength 11 2 4 -mat $IDRigid $IDRigid $IDBondSlipFRP -dir 1 2 6;


# Define RECORDERS -------------------------------------------------------------
recorder Node -file $dataDir/node111.out -time -node 111 -dof 1 disp;
recorder Node -file $dataDir/RBaseFRP.out -time -node 3  -dof 1 2 3 reaction;         # support reaction
recorder Node -file $dataDir/RBaseRCECC.out -time -node  4 -dof 1 2 3 reaction;
recorder Node -file $dataDir/Disps.out -time -node 10 20 -dof 1 disp;          # support reaction
recorder Element -file $dataDir/FRPtubestrain1.out  -time -ele 1 section 1 fiber -7 0   $IDFrpTube  stressStrain;
```

```
recorder Element -file $dataDir/FRPtubestrain2.out  -time -ele 1 section 1 fiber  7 0   $IDFrpTube  stressStrain;
recorder  Element  -file  $dataDir/CFFTCorestrain1.out  -time  -ele  1  section  1  fiber  -6.6  0  $IDFrpIncasesConc
stressStrain;
recorder  Element  -file  $dataDir/CFFTCorestrain2.out  -time  -ele  1  section  1  fiber   6.6  0  $IDFrpIncasesConc
stressStrain;
recorder Element -file $dataDir/ECCcoverstrain1.out  -time -ele 2 section 1 fiber -7 0   $ECCcover  stressStrain;
recorder Element -file $dataDir/ECCcoverstrain2.out  -time -ele 2 section 1 fiber  7 0   $ECCcover  stressStrain;
recorder Element -file $dataDir/ECCCorestrain1.out   -time -ele 2 section 1 fiber -5.5 0 $ECCcore  stressStrain;
recorder Element -file $dataDir/ECCCorestrain2.out   -time -ele 2 section 1 fiber  5.5 0 $ECCcore  stressStrain;
recorder Element -file $dataDir/rebar1.out  -time -ele 1 section 1 fiber -6.077 0     $IDreinf3 stressStrain;
recorder Element -file $dataDir/rebar12.out -time -ele 1 section 1 fiber 5.475  2.637 $IDreinf3 stressStrain;
recorder Element -file $dataDir/rebar2.out  -time -ele 2 section 1 fiber -5.871  0    $IDreinf5  stressStrain;
recorder Element -file $dataDir/rebar22.out -time -ele 2 section 1 fiber 5.871  0     $IDreinf5   stressStrain;
recorder Element -file $dataDir/Gap1F.out -time -ele 5 axialForce;       # element forces -Gap
recorder Element -file $dataDir/Gap1D.out -time -ele 5 deformation;
recorder Element -file $dataDir/Gap2F.out -time -ele 6 axialForce;       # element forces -Gap
recorder Element -file $dataDir/Gap2D.out -time -ele 6 deformation;

# Gravity-analysis parameters -- load-controlled static analysis
set Tol 1.0e-8;                   # convergence tolerance for test
constraints Plain;                # how it handles boundary conditions
numberer Plain;                   # renumber dof's to minimize band-width (optimization), if you want to
system BandGeneral;        # how to store and solve the system of equations in the analysis
test NormDispIncr $Tol 8 ;              # determine if convergence has been achieved at the end of an iteration
step
algorithm Newton;                 # use Newton's solution algorithm: updates tangent stiffness at every iteration
set NstepGravity 10;              # apply gravity in 10 steps
set DGravity [expr 1./$NstepGravity];   # first load increment;
integrator LoadControl $DGravity;# determine the next time step for an analysis
analysis Static;                  # define type of analysis static or transient
analyze $NstepGravity;            # apply gravity
# ------------------------------------------------- maintain constant gravity loads and reset time to zero
loadConst -time 0.0

puts "Model Built"
```

APPENDIX D: LIST OF CCEER PUBLICATIONS

Report No.	Publication
CCEER-84-1	Saiidi, M., and R. Lawver, "User's Manual for LZAK-C64, A Computer Program to Implement the Q-Model on Commodore 64," Civil Engineering Department, Report No. CCEER-84-1, University of Nevada, Reno, January 1984.
CCEER-84-1 Reprint	Douglas, B., Norris, G., Saiidi, M., Dodd, L., Richardson, J. and Reid, W., "Simple Bridge Models for Earthquakes and Test Data," Civil Engineering Department, Report No. CCEER-84-1 Reprint, University of Nevada, Reno, January 1984.
CCEER-84-2	Douglas, B. and T. Iwasaki, "Proceedings of the First USA-Japan Bridge Engineering Workshop," held at the Public Works Research Institute, Tsukuba, Japan, Civil Engineering Department, Report No. CCEER-84-2, University of Nevada, Reno, April 1984.
CCEER-84-3	Saiidi, M., J. Hart, and B. Douglas, "Inelastic Static and Dynamic Analysis of Short R/C Bridges Subjected to Lateral Loads," Civil Engineering Department, Report No. CCEER-84-3, University of Nevada, Reno, July 1984.
CCEER-84-4	Douglas, B., "A Proposed Plan for a National Bridge Engineering Laboratory," Civil Engineering Department, Report No. CCEER-84-4, University of Nevada, Reno, December 1984.
CCEER-85-1	Norris, G. and P. Abdollaholiaee, "Laterally Loaded Pile Response: Studies with the Strain Wedge Model," Civil Engineering Department, Report No. CCEER-85-1, University of Nevada, Reno, April 1985.
CCEER-86-1	Ghusn, G. and M. Saiidi, "A Simple Hysteretic Element for Biaxial Bending of R/C in NEABS-86," Civil Engineering Department, Report No. CCEER-86-1, University of Nevada, Reno, July 1986.
CCEER-86-2	Saiidi, M., R. Lawver, and J. Hart, "User's Manual of ISADAB and SIBA, Computer Programs for Nonlinear Transverse Analysis of Highway Bridges Subjected to Static and Dynamic Lateral Loads," Civil Engineering Department, Report No. CCEER-86-2, University of Nevada, Reno, September 1986.
CCEER-87-1	Siddharthan, R., "Dynamic Effective Stress Response of Surface and Embedded Footings in Sand," Civil Engineering Department, Report No. CCEER-86-2, University of Nevada, Reno, June 1987.
CCEER-87-2	Norris, G. and R. Sack, "Lateral and Rotational Stiffness of Pile Groups for Seismic Analysis of Highway Bridges," Civil Engineering Department, Report No. CCEER-87-2, University of Nevada, Reno, June 1987.
CCEER-88-1	Orie, J. and M. Saiidi, "A Preliminary Study of One-Way Reinforced Concrete Pier Hinges Subjected to Shear and Flexure," Civil Engineering Department, Report No. CCEER-88-1, University of Nevada, Reno, January 1988.
CCEER-88-2	Orie, D., M. Saiidi, and B. Douglas, "A Micro-CAD System for Seismic Design of Regular Highway Bridges," Civil Engineering Department, Report No. CCEER-88-2, University of Nevada, Reno, June 1988.
CCEER-88-3	Orie, D. and M. Saiidi, "User's Manual for Micro-SARB, a Microcomputer Program for Seismic Analysis of Regular Highway Bridges," Civil Engineering Department, Report No. CCEER-88-3, University of Nevada, Reno, October 1988.

CCEER-89-1 Douglas, B., M. Saiidi, R. Hayes, and G. Holcomb, “A Comprehensive Study of the Loads and Pressures Exerted on Wall Forms by the Placement of Concrete,” Civil Engineering Department, Report No. CCEER-89-1, University of Nevada, Reno, February 1989.

CCEER-89-2 Richardson, J. and B. Douglas, “Dynamic Response Analysis of the Dominion Road Bridge Test Data,” Civil Engineering Department, Report No. CCEER-89-2, University of Nevada, Reno, March 1989.

CCEER-89-2 Vrontinos, S., M. Saiidi, and B. Douglas, “A Simple Model to Predict the Ultimate Response of R/C Beams with Concrete Overlays,” Civil Engineering Department, Report NO. CCEER-89-2, University of Nevada, Reno, June 1989.

CCEER-89-3 Ebrahimpour, A. and P. Jagadish, “Statistical Modeling of Bridge Traffic Loads - A Case Study,” Civil Engineering Department, Report No. CCEER-89-3, University of Nevada, Reno, December 1989.

CCEER-89-4 Shields, J. and M. Saiidi, “Direct Field Measurement of Prestress Losses in Box Girder Bridges,” Civil Engineering Department, Report No. CCEER-89-4, University of Nevada, Reno, December 1989.

CCEER-90-1 Saiidi, M., E. Maragakis, G. Ghusn, Y. Jiang, and D. Schwartz, “Survey and Evaluation of Nevada's Transportation Infrastructure, Task 7.2 - Highway Bridges, Final Report,” Civil Engineering Department, Report No. CCEER 90-1, University of Nevada, Reno, October 1990.

CCEER-90-2 Abdel-Ghaffar, S., E. Maragakis, and M. Saiidi, “Analysis of the Response of Reinforced Concrete Structures During the Whittier Earthquake 1987,” Civil Engineering Department, Report No. CCEER 90-2, University of Nevada, Reno, October 1990.

CCEER-91-1 Saiidi, M., E. Hwang, E. Maragakis, and B. Douglas, “Dynamic Testing and the Analysis of the Flamingo Road Interchange,” Civil Engineering Department, Report No. CCEER-91-1, University of Nevada, Reno, February 1991.

CCEER-91-2 Norris, G., R. Siddharthan, Z. Zafir, S. Abdel-Ghaffar, and P. Gowda, “Soil-Foundation-Structure Behavior at the Oakland Outer Harbor Wharf,” Civil Engineering Department, Report No. CCEER-91-2, University of Nevada, Reno, July 1991.

CCEER-91-3 Norris, G., “Seismic Lateral and Rotational Pile Foundation Stiffnesses at Cypress,” Civil Engineering Department, Report No. CCEER-91-3, University of Nevada, Reno, August 1991.

CCEER-91-4 O'Connor, D. and M. Saiidi, “A Study of Protective Overlays for Highway Bridge Decks in Nevada, with Emphasis on Polyester-Styrene Polymer Concrete,” Civil Engineering Department, Report No. CCEER-91-4, University of Nevada, Reno, October 1991.

CCEER-91-5 O'Connor, D.N. and M. Saiidi, “Laboratory Studies of Polyester-Styrene Polymer Concrete Engineering Properties,” Civil Engineering Department, Report No. CCEER-91-5, University of Nevada, Reno, November 1991.

CCEER-92-1 Straw, D.L. and M. Saiidi, “Scale Model Testing of One-Way Reinforced Concrete Pier Hinges Subject to Combined Axial Force, Shear and Flexure,” edited by D.N. O'Connor, Civil Engineering Department, Report No. CCEER-92-1, University of Nevada, Reno, March 1992.

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