Fig. B-2. Confined ECC Stress-Strain Curve of Example
APPENDIX C: OPENSEES MODELS
C.1. SC-2

```plaintext
# SET UP ---------------------------------------------------------------------
# units: kip, inch, sec
wipe;                     # clear memory of all past model 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;
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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:

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

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

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

# MATERIAL parameters ---------------------------------------------------------------------

```plaintext
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
```

```plaintext
uniaxialMaterial ENT $IDgap 10000;
```

```plaintext
uniaxialMaterial Concrete01 $IDconcU1 -11.55 -0.012 -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 {}
patch circ $IDconcU1 $nfCoreT $nfCoreR 0 0 $ri $rc 0 360
patch circ $IDconccover1 $nfcoverColT $nfcoverColR 0 0 $rc $ro 0 360

# Define the fiber section
set theta [expr 360.0/$numBarsCol ]

section fiberSec $concface {}
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 $numBarsCol $barAreaCol 0 0 $rc $theta 360 }
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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 beamColumn $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 $conface $ColTransfTag;
  element nonlinearBeamColumn 3 4 74 $numIntgrPts $conface $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
$PostTensionBarCompressionPlasticTransition
$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;

recorder Node -file Push/Drift.out -time -iNode 1 -jNode 4 -dof 1 -perpDirn 2;
recorder Node -file Push/Tendon.out -time -node 12 -dof 1 2 3 reaction;

# displacements of support nodes
# support reaction
# lateral drift

# Column section forces, axial and moment, node i
recorder Element -file Push/ForceColSec1.out -time -ele 4 section $PostTensionBarArea force;
recorder Element -file Push/DefoColSec1.out -time -ele 4 section $PostTensionBarArea deformation;

# section deformations, axial and curvature, node j
recorder Element -file Push/ForceColSec$numIntgrPts.out -time -ele 1 section $numIntgrPts force;
```
recorder Element -file Push/DefoColSec$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/seclstrain.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 push/Element1.out -time -ele 331 force;
recorder Element -file push/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 1 section 2 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar9.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
step NormDispInc $Tol 10 ;  # determine if convergence has been achieved at the end of an iteration
algorithm Newton;  # use Newton's solution algorithm: updates tangent stiffness at every iteration
set DGravity [expr 1./$NstepGravity];  # first load increment;
set NstepGravity 10;  # apply gravity in 10 steps
set g 386.4;  # g.
set Mass [expr $PCol/$g];  # nodal mass
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;

puts "Model Built"

C.2. SBR-1

# SET UP ------------------------------------------------------------------
# units: kip, inch, sec
wipe;  # clear memory of all past model definitions
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
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 sqrt 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;  

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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 Unconfinedsseg 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;

# ---------------------------------------------
# Eg=5.6* G*S2
# 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

# STEEL yield stress
set Fy 78.8;
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 -0.007076 -4.3 -0.0847 #28day
uniaxialMaterial Concrete01 $IDconccover1 -7.2 -0.003 -2.8 -0.019667;

# segments
uniaxialMaterial Concrete01 $IDconcU2 -12.3 -0.006213 -4.9 -0.0373 #0.5 0.635 2420 #28day
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

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# 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
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

# 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;                   # displacements of top column
recorder Node -file Push/node3.out -time -node 3 -dof 1 2 3 disp;                         # displacements of top column
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;  
recorder Node -file Push/RBase.out -time -node 1 -dof 1 2 3 reaction;  
recorder Element -file Push/FTendon.out -time -ele 11 axialForce;  
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 Element1.out -time -ele 332 force;  
recorder Element -file Element2.out -time -ele 333 force;  
recorder Element -file Element3.out -time -ele 334 force;  
recorder Element -file Element4.out -time -ele 335 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  

# 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 model 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)]; # Define the model builder, ndm=#dimension, ndf=#dofs
set sec 1.; # define basic units

# define GEOMETRY -----------------------------------------------------------
set LCol 72;    # column length
set Weight 80;  # superstructure weight
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;                        # Bondsip

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

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

node 33 0 20;
nodc 77 0 16.5;

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

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

node 78 0 23.5;
nodc 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.;
set Ec [expr 57*sqrt(-$fc*1000)];
# Concrete Elastic Modulus (the term in sq 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;

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

# MATERIAL parameters ---------------------------------------------------------------------
set IDconcU1 1;
set IDconccoverU1 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 [expr $fc];              # UNCONFINED concrete (todeschini parabolic model), maximum stress
set eps1U -0.003;               # strain at maximum strength of unconfined concrete
set fc2U [expr 0.2*$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
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
uniaxialMaterial Concrete01 $IDconccoverCFRP2 -7.2 -0.002 -9.9 -0.007043; #28day
# CFRP
uniaxialMaterial Concrete01 $IDconcU1 -14.7 -.0052 -5.8 -0.015 #-7.96 -.007838 -4 -0.0327 #28day
# segments
uniaxialMaterial Concrete01 $IDconcU $fc1U $eps1U $fc2U $eps2U $lambda $ftU $Ets;   # build coverCol concrete
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 $IDconcCFRP3 $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 $CFRPface $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/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 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;
recorder Element -file Push/DefoColSec1.out -time -ele 4 section $PostTensionBarArea deformation;
recorder Element -file Push/ForceColSec$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 $Tol 10;  # determine if convergence has been achieved at the end of an iteration
step algorithm Newton;  # use Newton's solution algorithm: updates tangent stiffness at every iteration
set DGravity [expr 1./$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 model 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
set DCol 16;    # Column Depth
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:
ode 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;
nod 76 -11.5 23.5;
nod 5 0 34;
nod 78 0 23.5;
nod 11 0 $LCol;
nod 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

set $Mass 1e-9 0;  # node#, Mx My Mz, Mass=Weight/g, neglect rotational inertia at nodes
# Define ELEMENTS & SECTIONS

```plaintext
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];   # tension 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 -0.006 -3.5 -0.052; #-7.96 -0.007838 -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 reinforcing layer
  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];
puts "Post Tension Bar Initial Strain is:"
puts $PostTensionBarInitialStrain;

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

```plaintext
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 $Tol 10 ;   # determine if convergence has been achieved at the end of an iteration
algorithm Newton;   # use Newton's solution algorithm: updates tangent stiffness at every iteration
set NstepGravity 10;    # apply gravity in 10 steps
set DGravity [expr 1./$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 model 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 ...
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 sqrt 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;

# 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 IDconccU1 1;
set IDconccover1 2;
set IDconccCFRP1 3;
set IDconccoverCFRP1 4;
set IDconccCFRP2 5;
set IDconccoverCFRP2 6;
set IDreinf 7;
set IDgap 8;
set IDBondSlip 12;
set IDRigid 13;

# material ID tag -- reinforcement
# unconfined concrete
set fc1U $fc;
set eps1U -0.003;  # strain at maximum strength of unconfined concrete
set fc2U [expr 0.2*$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
gemTransf 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
eps0
#uniaxialMaterial ElasticPPGap $PostTensionSteelTag $PostTensionBarEValue $PostTensionPy $PostTensionBarInitialStrain
uniaxialMaterial ElasticPP $PostTensionSteelTag $PostTensionBarEValue $PostTensionBarTensionPlasticTransition $PostTensionBarCompressionPlasticTransition $PostTensionBarInitialStrain

```plaintext
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 1 section 1 fiber 6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar3.out -time -ele 1 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 2 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 4 section 1 fiber -6.62 0 $IDreinf stressStrain;
recorder Element -file push/rebar10.out -time -ele 4 section 1 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 model 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;

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 1 [expr -1*$Span/2] 0;  # node No X Y
node 3 [expr -1*$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 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 [-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 fpco [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;  # build core concrete
uniaxialMaterial Concrete01 $IDconcCover $fc1U $eps1U $fc2U $eps2U;  # 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 0.925 0.15; # Friction
properties
uniaxialMaterial Steel02 $PipeTag $PinCapacity $Stiffness 0 18.5 0.925 0.15;
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
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;

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 $IDFrpIncasConc stressStrain;
recorder Element -file $dataDir/CFFTCorestrain2.out -time -ele 1 section 1 fiber 6.6 0 $IDFrpIncasConc 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
<table>
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CCEER-99-14  Ahmad M. Itani, Jose A. Zepeda, and Elizabeth A. Ware “Cyclic Behavior of Steel Moment Frame Connections for the Moscone Center Expansion,” Department of Civil Engineering, University of Nevada, Reno, Report No. CCEER-99-14, December 1999.


CCEER 00-5  Itani, A., and M. Saiidi, “Seismic Evaluation of Steel Joints for UCLA Center for Health Science Westwood Replacement Hospital,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER-00-5, February 2000.

CCEER 00-6  Will, J. and D. Sanders, “High Performance Concrete Using Nevada Aggregates,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER-00-6, May 2000.

CCEER 00-7  French, C., and M. Saiidi, “A Comparison of Static and Dynamic Performance of Models of Flared Bridge Columns,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER-00-7, October 2000.

CCEER 00-8  Itani, A., H. Sedarat, “Seismic Analysis of the AISI LRFD Design Example of Steel Highway Bridges,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER-00-8, November 2000.

CCEER 00-9  Moore, J., D. Sanders, and M. Saiidi, “Shake Table Testing of 1960’s Two Column Bent with Hinges Bases,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER-00-9, December 2000.


CCEER 01-1  Ah Sha, H., D. Sanders, M. Saiidi, “Early Age Shrinkage and Cracking of Nevada Concrete Bridge Decks,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER 01-01, May 2001.


CCEER 01-5  Not Published
CCEER 01-6 Laplace, P., D. Sanders, and M. Saiidi, “Experimental Study and Analysis of Retrofitted Flexure and Shear Dominated Circular Reinforced Concrete Bridge Columns Subjected to Shake Table Excitation,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER 01-6, June 2001.

CCEER 01-7 Reppi, F., and D. Sanders, “Removal and Replacement of Cast-in-Place, Post-tensioned, Box Girder Bridge,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER 01-7, December 2001.


CCEER 02-3 M. Saiidi, B. Gopalakrishnan, E. Reinhardt, and R. Siddharthan, “A Preliminary Study of Shake Table Response of A Two-Column Bridge Bent on Flexible Footings,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER 02-3, June 2002.

CCEER 02-4 Not Published

CCEER 02-5 Banghart, A., Sanders, D., Saiidi, M., “Evaluation of Concrete Mixes for Filling the Steel Arches in the Galena Creek Bridge,” Civil Engineering Department, University of Nevada, Reno, Report No. CCEER 02-5, June 2002.


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<th>Report No.</th>
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<th>Department and University</th>
<th>Date</th>
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<tbody>
<tr>
<td>CCEER 04-8</td>
<td>Built-up Shear Links as Energy Dissipaters for Seismic Protection of Bridges</td>
<td>Dusicka, P., Itani, A. and Buckle, I.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>November 2004</td>
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<tr>
<td>CCEER 04-9</td>
<td>Seismic Retrofit of Two-Column Bents with Diamond Shape Columns</td>
<td>Sureshkumar, K., Saiidi, S., Itani, A. and Ladkany, S.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>November 2004</td>
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<tr>
<td>CCEER 05-1</td>
<td>A Study of RC Columns with Shape Memory Alloy and Engineered Cementitious Composites</td>
<td>Wang, H. and Saiidi, S.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>January 2005</td>
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<tr>
<td>CCEER 05-2</td>
<td>A Study of Fiber Reinforced Plastics for Seismic Bridge Restrainers</td>
<td>Johnson, R., Saiidi, S. and Maragakis, E.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>January 2005</td>
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<td>CCEER 05-3</td>
<td>Seismic Load Path in Steel Girder Bridge Superstructures</td>
<td>Carden, L.P., Itani, A.M., Buckle, I.G.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>January 2005</td>
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<td>CCEER 05-4</td>
<td>Seismic Performance of Steel Girder Bridge Superstructures with Ductile End Cross Frames and Seismic Isolation</td>
<td>Carden, L.P., Itani, A.M., Buckle, I.G.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
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<td>CCEER 05-5</td>
<td>Experimental Evaluation of the Seismic Performance of Hospital Piping Subassemblies</td>
<td>Goodwin, E., Maragakis, M., Itani, A. and Luo, S.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>February 2005</td>
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<td>CCEER 05-6</td>
<td>Seismic Vulnerability Evaluation and Retrofit Design of Las Vegas Downtown Viaduct</td>
<td>Zadeh M. S., Saiidi, S, Itani, A. and Ladkany, S.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>February 2005</td>
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<td>CCEER 05-7</td>
<td>Near Fault (Near Field) Ground Motion Effects on Reinforced Concrete Bridge Columns</td>
<td>Phan, V., Saiidi, S. and Anderson, J.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>August 2005</td>
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<tr>
<td>CCEER 05-8</td>
<td>Performance of Steel Props at the UNR Fire Science Academy subjected to Repeated Fire</td>
<td>Carden, L., Itani, A. and Laplace, P.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>August 2005</td>
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<tr>
<td>CCEER 05-9</td>
<td>Shake Table Testing and an Analytical Study of Unbonded Prestressed Hollow Concrete Column Constructed with Precast Segments</td>
<td>Yamashita, R. and Sanders, D.</td>
<td>Center for Civil Engineering Earthquake Research, Department of Civil Engineering, University of Nevada, Reno, Nevada</td>
<td>August 2005</td>
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<td>CCEER 05-10</td>
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CCEER 10-06 Ayoub, M., Sanders, D., “Testing of Pile Extension Connections to Slab Bridges,” Center for Civil Engineering Earthquake Research, Department of Civil and Environmental Engineering, University of Nevada, Reno, Nevada, Report No. CCEER-10-06, October 2010.


CCEER 10-08 Monzon, E. V., “Seismic Performance of Steel Plate Girder Bridges with Integral Abutments,” Center for Civil Engineering Earthquake Research, Department of Civil and Environmental Engineering, University of Nevada, Reno, Nevada, Report No. CCEER-10-08, November 2010.