Documentation for Nonlocal Element and Material Models

Code developed by: Maha Kenawy, University of Nevada, Reno

The following text provides documentation on using the nonlocal element, fiber and material models on Opensees. These objects are used to enforce interactions between multiple elements in numerical models to overcome the mesh sensitivity associated with distributed plasticity beam-column elements. The nonlocal element must be used with the nonlocal fiber section and nonlocal material models (three are available). Otherwise, the nonlocal nature is deactivated and the element will yield results identical to the conventional fiber-section beam column element. At the time of writing this document, the element is only capable of modeling a single structural component (a column or a beam). Using the element for an entire frame is currently under development.

Nonlocal Displacement Beam-Column Element

The following command is used to construct a nonlocal displacement beam element object, which is based on the displacement formulation, and is capable of simulating the spread of plasticity along the element without mesh sensitivity. To activate the nonlocal characteristics, this element must be used with a nonlocal fiber section, and nonlocal material models (NLConcrete, NLConcretewTension, NLConcrete01). Other standard materials (steel02, for example) can be used and will not cause issues as long as they do not have a softening branch.

element NLDispBeamColumn2d $eleTag $iNode $jNode $numIntgrPts $secTag $transfTag $memID -nllength $nllength <-mass $massDens> <-cMass> <-integration $intType>

$eleTag	unique element object tag
$iNode $jNode	end nodes
$numIntgrPts	number of integration points along the element.
$secTag	identifier for previously-defined section object
$transfTag	identifier for previously-defined coordinate-transformation (CrdTransf) object
$memID	unique tag for a 'structural member' that includes a number of elements which will incorporate nonlocal interactions between elements of the same member.
$nllength	length of nonlocal interaction zone between the elements of a structural member. This length should be larger than the length of a single element and smaller than the size of the entire member. Default value = 0.0. See guidance in reference papers on determining the nonlocal length. Note

	that not specifying nllength will deactivate the nonlocal interactions in the model, and lead to identical results to dispBeamColumn.
$massDens	element mass density (per unit length), from which a lumped-mass matrix is formed (optional, default = 0.0)
-cMass	to form consistent mass matrix (optional, default = lumped mass matrix)
$intType	numerical integration type, options are Lobotto, Legendre, Radau, NewtonCotes, Trapezoidal (optional, default = Legendre)

NOTE:

- The default integration along the element is based on Gauss-Legendre quadrature rule.
- The valid queries to a displacement-based beam-column element when creating an ElementRecorder object are 'force,' and 'section $secNum secArg1 secArg2...' Where $secNum refers to the integration point whose data is to be output valid entries being 1 through $numIntgrPts.

EXAMPLE:

element NLDispBeamColumn2d 3 6 7 2 8 1 5 -nllength 400.0;

nonlocal displacement-based beam column element added with tag 3 between nodes 6 and 7 that has 2 integration points, each using section 8, and the element uses geometric transformation 1, belongs to structural member 5 and has a nonlocal interaction length of 400.0.

REFERENCES:

Kenawy, M., Kunnath, S., Kolwankar, S., & Kanvinde, A. (2018). Fiber-based nonlocal formulation for simulating softening in reinforced concrete beam-columns. Journal of Structural Engineering, 144(12), 04018217.

Nonlocal Fiber Section

This command allows the user to construct a nonlocal fiber section object. Each NLFiber section object is composed of fibers, with each fiber containing a UniaxialMaterial, an area and a location (y,z). The command to generate NLFiber section object must contain the commands needed to generate all the fibers in the object inside the curly braces { }. To construct a NLFiber section and populate it, the following command is used:

section NLFiber $secTag {
fiber...
patch...
layer...
...
}

$secTag	unique tag among sections
fiber...	command to generate a single fiber
patch...	command to generate a number of fibers over a geometric cross-section
layer...	command to generate a row of fibers along a geometric-arc

NOTES:

- The command to generate a NLFiber section must contain the commands needed to generate all the fibers in the section inside the curly braces { }.
- The patch and layer commands can be used to generate multiple fibers in a single command.
- In an element recorder you can ask a NLFiber Section for its 'deformations', 'forces', 'forceAndDeformation', 'fiber $fiberNum $matArg1 ..', 'fiber $yLoc $zLoc $matTag $matArg1'.

REFERENCES:

Kenawy, M., Kunnath, S., Kolwankar, S., & Kanvinde, A. (2018). Fiber-based nonlocal formulation for simulating softening in reinforced concrete beam-columns. Journal of Structural Engineering, 144(12), 04018217.

Nonlocal Material Model: NLConcrete

This command is used to construct a uniaxial nonlocal concrete material based on a damage-plasticity framework for compressive behavior only. Tensile strength is neglected. This material must be used with a nonlocal element (such as NLDispBeamColumn2d).

uniaxialMaterial NLConcrete $matTag $Ec $fc $ec0 $Ed;

$matTag	integer tag identifying material
$Ec	concrete elastic modulus
$fc	concrete compressive strength
$ec0	concrete strain at compressive strength
$Ed	concrete softening slope (negative value)

NOTE:

Compressive concrete parameters must be input as positive values, except for the softening slope.

EXAMPLE:

uniaxialMaterial NLConcrete 1 30000.0 40.0 0.002 -2000.0; # concrete material with tag 1 with elastic modulus of 30000, reaches a compressive strength of 40.0 at strain of 0.002, and has a softening slope of -2000.0.

REFERENCES:

Kenawy, M., Kunnath, S., Kolwankar, S., & Kanvinde, A. (2020). Concrete Uniaxial Nonlocal Damage-Plasticity Model for Simulating Post-Peak Response of Reinforced Concrete Beam-Columns under Cyclic Loading. Journal of Structural Engineering, 146(5), 04020052.

Nonlocal Material Model: NLConcretewTension

This command is used to construct a uniaxial nonlocal concrete material based on a damage-plasticity framework. This model incorporates compressive plasticity and damage, tensile plasticity and damage, and crack-closing behavior as the material transitions from tension to compression. This material must be used with a nonlocal element (such as NLDispBeamColumn2d).

uniaxialMaterial NLConcretewTension $matTag $Ec $fc $ec0 $Ed $ft $eft;

$matTag	integer tag identifying material
$Ec	concrete elastic modulus
$fc	concrete compressive strength
$ec0	concrete strain at compressive strength
$Ed	concrete softening slope (negative value)
$ft	concrete tensile strength
$eft	tensile strain at zero tensile stress

NOTE:

Compressive and tensile concrete parameters should be input as positive values, except for the softening slope.

EXAMPLE:

uniaxialMaterial NLConcrete 1 30000.0 40.0 0.002 -2000.0 4.0 0.003; # concrete material with tag 1 with elastic modulus of 30000, reaches a compressive strength of 40.0 at a strain of 0.002, and has a softening slope of -2000.0. Under tensile stress, the material has a tensile strength of 4.0 and reaches zero stress at a strain of 0.003.

REFERENCES:

Kenawy, M., Kunnath, S., Kolwankar, S., & Kanvinde, A. (2020). Concrete Uniaxial Nonlocal Damage-Plasticity Model for Simulating Post-Peak Response of Reinforced Concrete Beam-Columns under Cyclic Loading. Journal of Structural Engineering, 146(5), 04020052.

Nonlocal Material Model: NLConcrete01

This command is used to construct a nonlocal uniaxial Kent-Scott-Park concrete material object with mesh-insensitive softening behavior, degraded linear unloading/reloading stiffness according to the work of Karsan-Jirsa and no tensile strength. This material must be used with a nonlocal element (such as NLDispBeamColumn2d). This material is based on Concrete01 (REF: FEDEAS).

uniaxialMaterial NLConcrete01 $matTag $fpc $epsc0 $fpcu $epsU

$matTag	integer tag identifying material
$fpc	concrete compressive strength (negative)
$epsc0	concrete strain at compressive strength (negative)
$fpcu	concrete ultimate strength (negative)
$epsU	concrete strain at ultimate strength (negative)

NOTE:

- Compressive concrete parameters should be input as negative values (if input as positive, they will be converted to negative internally).
- The initial slope for this model is (2*$fpc/$epsc0)

EXAMPLE:

uniaxialMaterial NLConcrete01 1 -40.0 -0.002 0.0 -0.005; # concrete material with tag 1 reaches compressive strength of 40.0 at strain of 0.002 and reaches ultimate strength of 0.0 at strain of 0.005.