Tie-Break Contacts in LS-DYNA

Suri Bala

Livermore Software

Outline

- Introduction

- Need for TIEBREAK

- Basics of Contact Treatment

- Understanding TIEBREAK

- Failure and Damage in TIEBREAK contacts

- Examples

Introduction

- TIEBREAK allows the modeling of connections which transmits both compressive and tensile forces with optional failure criteria

- TIEBREAK contacts are penalty based while TIED contacts are constraint based

- Slave and Master Nodes can belong to other constraint type definitions such as NODAL_RIGID_BODY, SPOTWELD, etc

- There is no sliding allowed between the elements used in the tiebreak definitions

Need for TIEBREAK Contacts

- Traditional contacts transmit only compressive forces. Parts in contact that experience tensile forces undergo separation with no resistance

- Connections such as Glued surfaces transmit both tensile and compressive forces until a failure of the glue. Such connections require the use of TIEBREAK contacts

Glue

Mating Parts
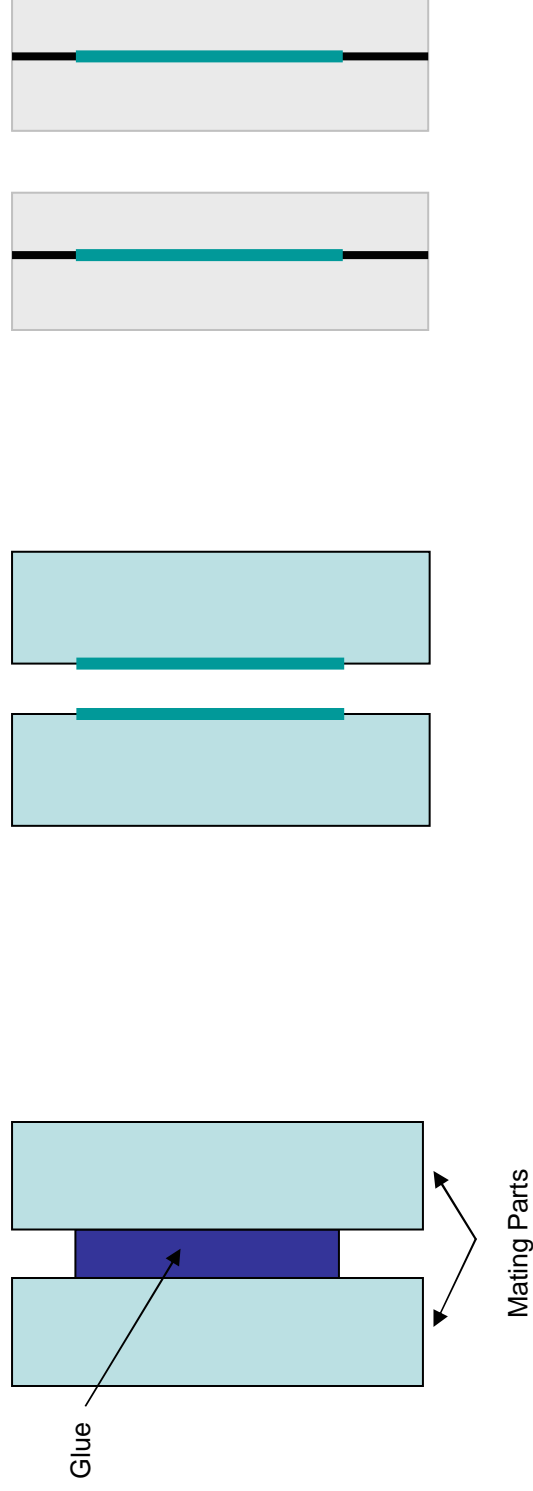
Physical

Solid Representation

Shell Representation

Basics of Contact Treatment

- In any contact treatment, understanding steps involved, once the slave and master information is provided, is important

- Besides segment-to-segment contact, all other contact types at the root level is always working with a node-segment pair in which the node is just a point (with mass) and the segment is either a 3-noded or 4-noded connectivity information referencing a shell element or one of the faces of a solid element

- The node is usually called as "slave" node and the segment is usually called as "master" segment as shown below
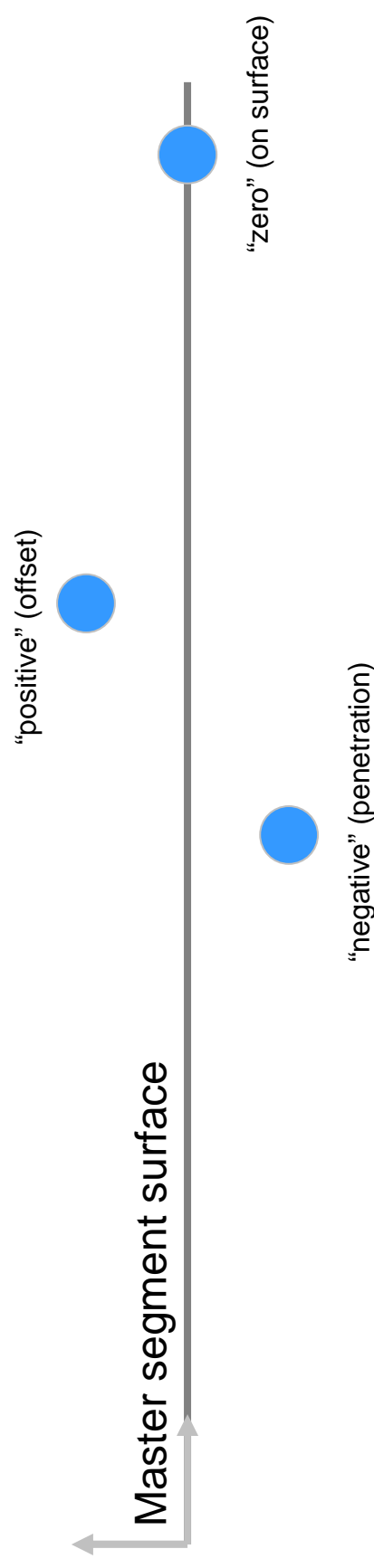
"slave" node
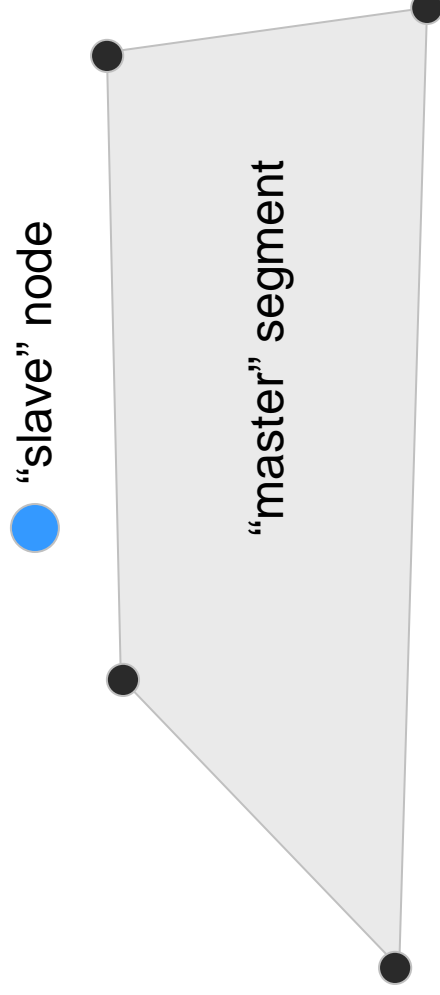
"master" segment

Contact Point

- Before a node-segment pair is assembled, the following must occur

- The contact (projection) point of the node onto the master segment, along the master segment normal, must lie within the area enclosed by the 3 or 4 nodes of the segment.

- LS-DYNA uses a small increase in the area of the segment in which it scales the master segment area by an additional 2% in an attempt to collect nodes that may lie near the edges

- The contact point is calculated just once (at time zero) for all TIED and TIEBREAK contacts while it is computed at every cycle for all other contacts

- Contact point is computed in the isoparametric coordinates of the master segment

Contact Point

"scaled" segment

"master" segment

segment normal

"slave" node

"contact" point

"projection distance", d
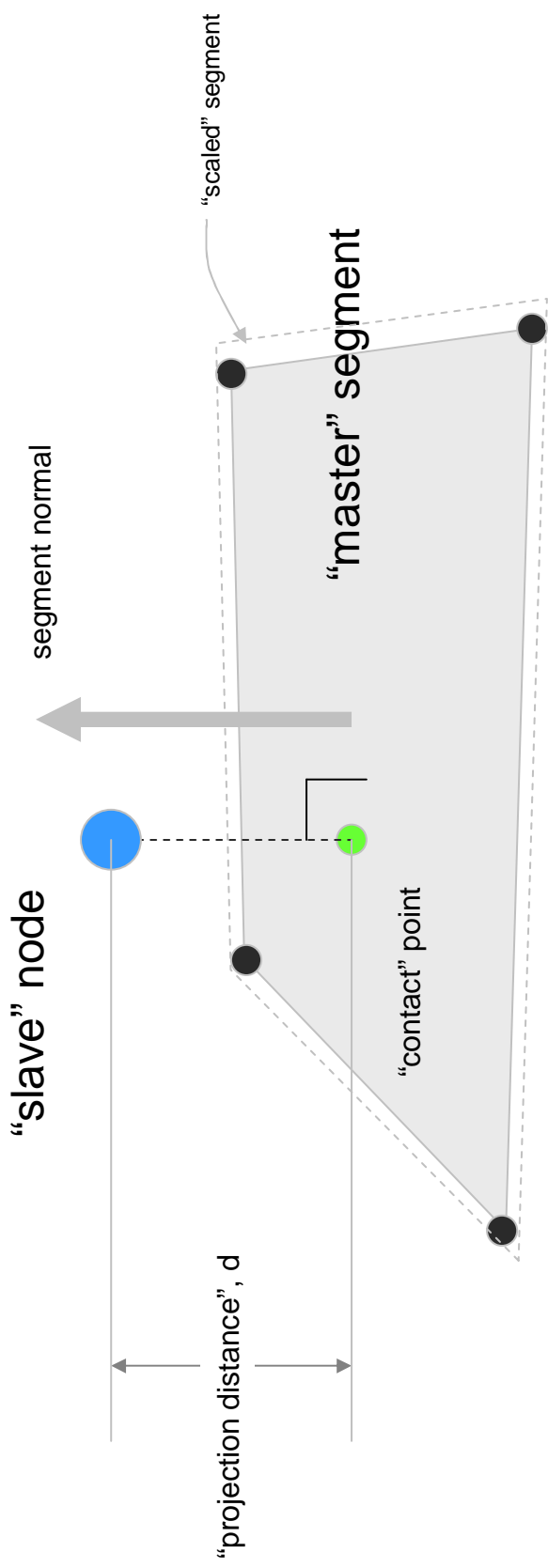
Projection Distance, d

- The projection distance is simply the orthogonal distance of the slave node from the master segment along the master segment normal

- The projection distance is computed in a local coordinate system embedded in the master segment

  – If the projection distance, d, is negative it is often called as "penetration"

  – If the project distance, d, is positive it is often termed as zero penetration or "positive offet"

  – If the projection distance,d, is zero the slave is said to be ON the master segment surface

"zero" (on surface)

"positive" (offset)

"negative" (penetration)

Master segment surface

Force Calculation

- In standard contact treatment if the penetration depth is found to be negative, the absolute value will indicate the depth of the penetration

- A slave nodal force is then calculated proportional to the penetration depth and a internally computed contact stiffness

$$f_s = K_c \delta$$

Contact force

Contact stiffness

Penetration

Force Distribution to the Master Segment Nodes

- After the slave force evaluation, the same force needs to be distributed to the master segment nodes

- The magnitude of the force that each master segment node receives is dependent on its relative location to the contact point

- To achieve this, the iso-parametric shape functions are used
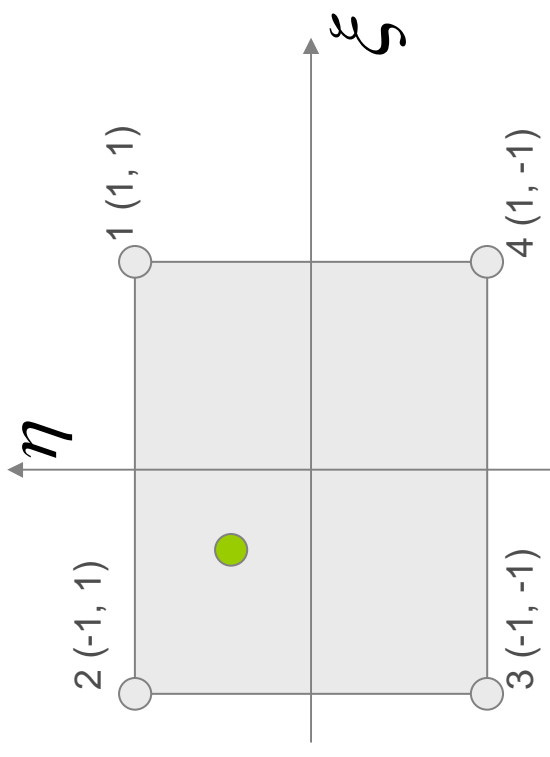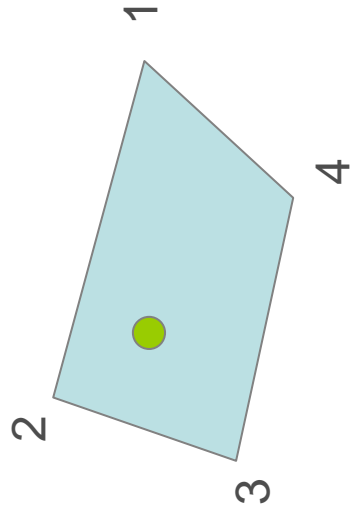
Master Nodal Force

- Each master node gets a fraction of the slave force that is based on contact point location

$$f_m^i = N_i(\xi, \eta) * f_s$$

$$N_1 = \frac{1}{4}(1+\xi)(1+\eta)$$

$$N_2 = \frac{1}{4}(1-\xi)(1+\eta)$$

$$N_3 = \frac{1}{4}(1-\xi)(1-\eta)$$

$$N_4 = \frac{1}{4}(1+\xi)(1-\eta)$$

Quick Summary Of TIEBREAK

- Allows the transmission of both tensile and compressive forces resulting in a TIE. The separation of the slave node from the master is resisted by a linear contact spring for both tensile and compressive forces until failure after which the tensile coupling is removed

- BREAK part of the contact allows the modeling of failure where the spring decouples the tensile forces allowing independent motion of the slave node under tension

- Post failure in all TIEBREAK contacts allows the node to interact with the segment as in traditional compression only contacts

- Failure can be based on
  - Force (One-Way Only)
  - Stress (Two-Way Only)

What contacts model TIE-BREAK type connections ?

- Non-Automatic
  - *CONTACT_TIEBREAK_NODES_TO_SURFACE
  - *CONTACT_TIEBREAK_SURFACE_TO_SURFACE
  - *CONTACT_TIEBREAK_NODES_ONLY

- Automatic
  - *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK
  - *CONTACT_AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE_TIEBREAK

- There are some subtle differences between the two basic types but for most purposes their functionality is identical in all the contact types

Automatic and Non-Automatic Comparison

Features	NON-AUTOMATIC TIEBREAK	AUTOMATIC TIEBREAK
Scope of Slave Nodes that are Tied	All slave nodes, irrespective of their distance from the closest master segment are tied to it at time zero. Care must be taken to ensure that the slave node is roughly 10% of master segment diagonal for stable solutions	Depends on the parameter OPTION. When OPTION = 1,3 all nodes that are initially in contact and that come later into contact will be tied. All other values will only treat nodes that are initially in contact. "Initially in contact" means that node has a projection distance that is either zero, positive offset less than 1% of master diagonal or negative
Force Based Failure	Yes (One-Way Type Only)	No
Stress Based Failure	Yes (Two-Way Type Only)	Yes
Automatic Shell Normal Orientation	No. Shell Normals Must Face Each Other. However, THKOFF can be set to 1(default 0) to invoke this feature only for two-way contacts	Yes
Post Failure Interaction Considered	Yes (Except TIEBREAK_NODES_ONLY)	Yes
Shell Thickness Offsets Considered in Post Failure Interaction	No	Yes
Damage Modeling	No	Yes. Many options available based on OPTION parameter

Why So Many ?

- Simply because they have evolved over time

- Old ones are retained to support backward compatibility

- The basic functionality remains the same in all contacts

How does tying work ?

- Tying is always defined between a node-segment pair

- For every slave node, we first locate a unique master segment based on the smallest projected normal distance

- Once a unique master segment is found, a contact spring is internally created between the slave node and the contact point on the master segment

- For any subsequent incremental change in the projected distance, a force that is proportional to the incremental change in the projected distance is applied to the slave node and is distributed to the master nodes based on the contact point

- The force applied is irrespective of the sign of the incremental projected distance in TIEBREAK contacts while the force is applied only if the projected distance is negative (indicating penetration) in traditional (non-TIEBREAK) contacts

Understanding TIEBREAK

- Following topics are extremely important to understand before using TIEBREAK contacts
  - Criteria for Tying
  - Pre-Tying Behavior
  - Tied Behavior
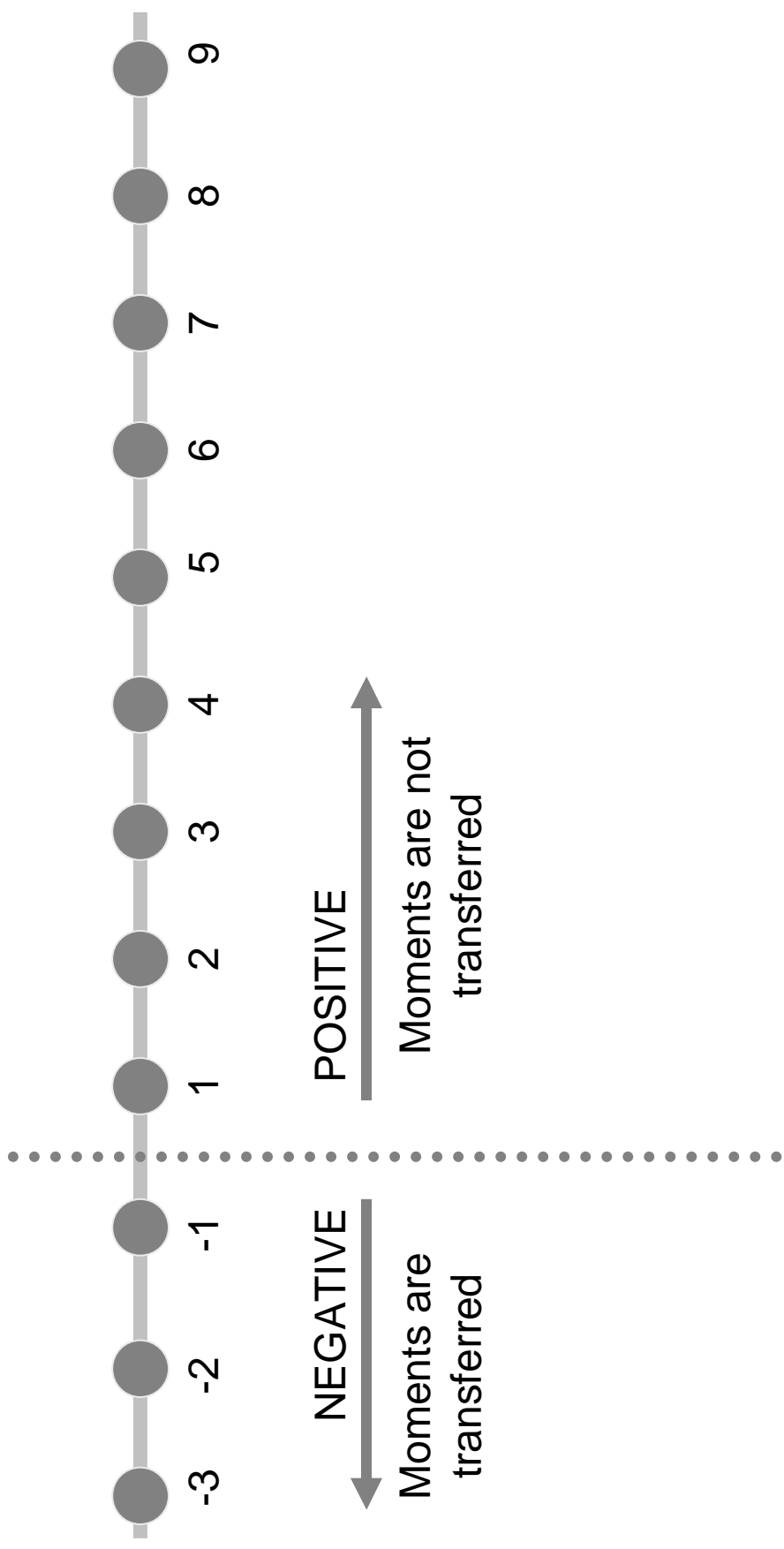 - Post-Break Behavior

Criteria for Tying

- Unlike TIED based contacts, no tolerance is used to determine if a slave node is to be tied or not

- ALL slave nodes are tied to a master segment if a contact point on it can be found

- This can cause difficulties if the projected distance between a slave node and a master segment is extremely large

- In AUTOMATIC TIEBRAK, depending on the value of OPTION, all nodes or nodes that are initially in contact are tied. Values 1,3 will tie all nodes that are initially in contact and that may come in contact.

- A good guideline is to ensure that the projected distance is within a small fraction of the master segment thickness

Pre-Tying Behavior

- Depending on the type of contact, how the surfaces (slave and master) interact before tying conditions are established is important to understand

- All non-AUTOMATIC TIEBREAK contacts establish the contact spring from the start of the simulation (Note: BIRTH is not supported in TIEBREAK contacts as of version 971 R2. Future versions may include them)

- All AUTOMATIC TIEBREAK contacts allow option to determine what nodes are tied initially. This is controlled using the parameter OPTION

- In both types of contact, it is extremely important to understand what nodes are tied initially and later in the simulation
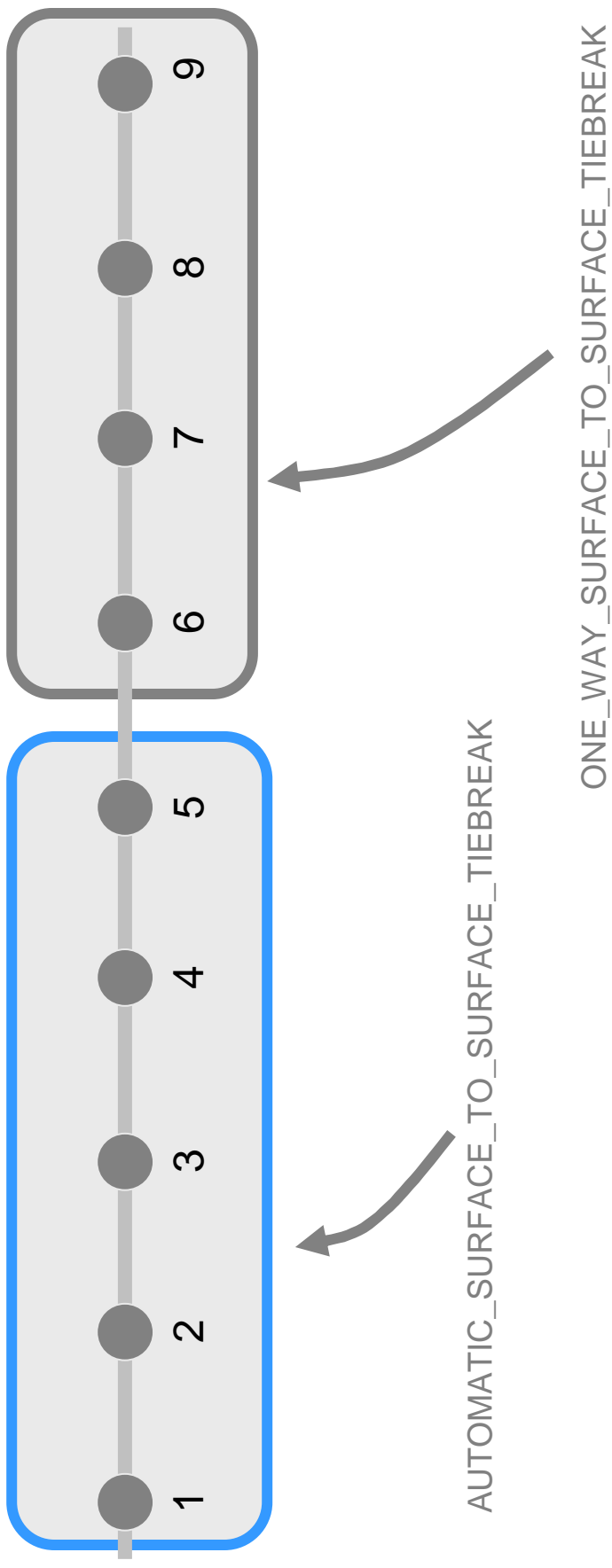
Pre-Tying in AUTOMATIC based TIEBREAK - OPTION

- OPTION must be specified

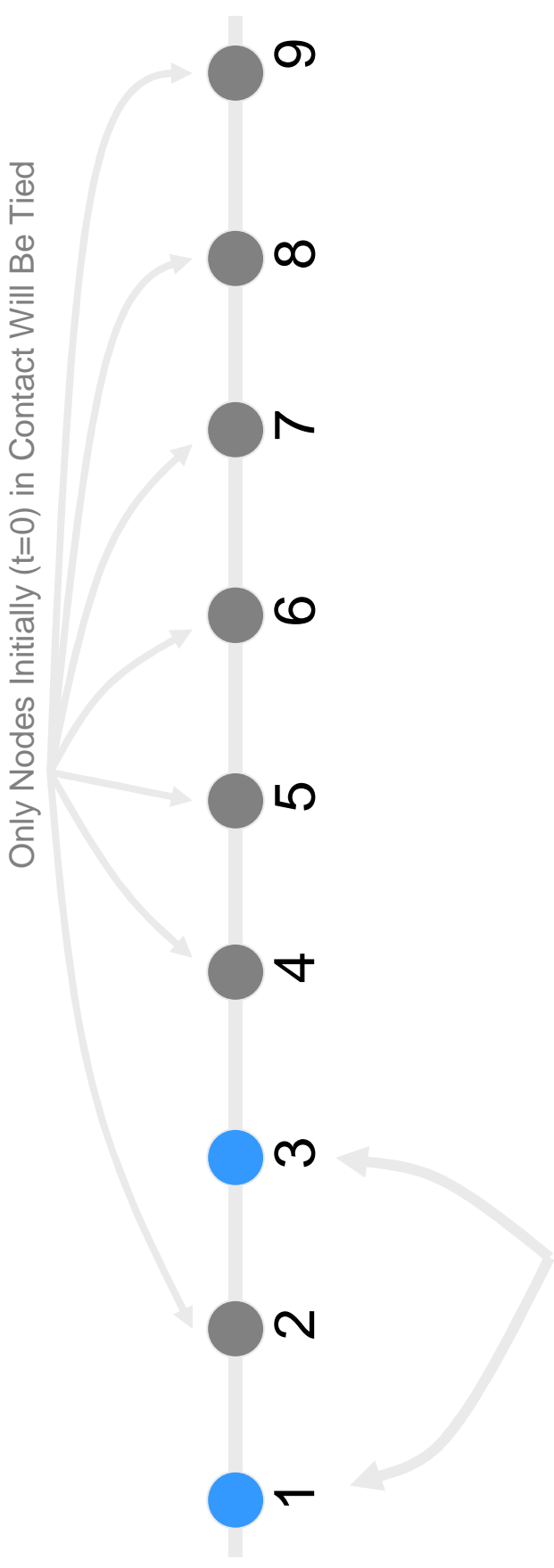- Acceptable values for OPTION are the following

-3 -2 -1 1 2 3 4 5 6 7 8 9

NEGATIVE

Moments are transferred

POSITIVE

Moments are not transferred

Pre-Tying in AUTOMATIC based TIEBREAK - OPTION

- One-Way and Two-Way

1 2 3 4 5   6 7 8 9

AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK

ONE_WAY_SURFACE_TO_SURFACE_TIEBREAK

Pre-Tying in AUTOMATIC based TIEBREAK - OPTION

- Scope of nodes that will be tied

Only Nodes Initially (t=0) in Contact Will Be Tied

Nodes in Contact and All Nodes That Come In Contact Will Be Tied

Pre-Tying in AUTOMATIC based TIEBREAK - OPTION

- Elements types that can be tied

1   2   3   4   5   6   7   8   9
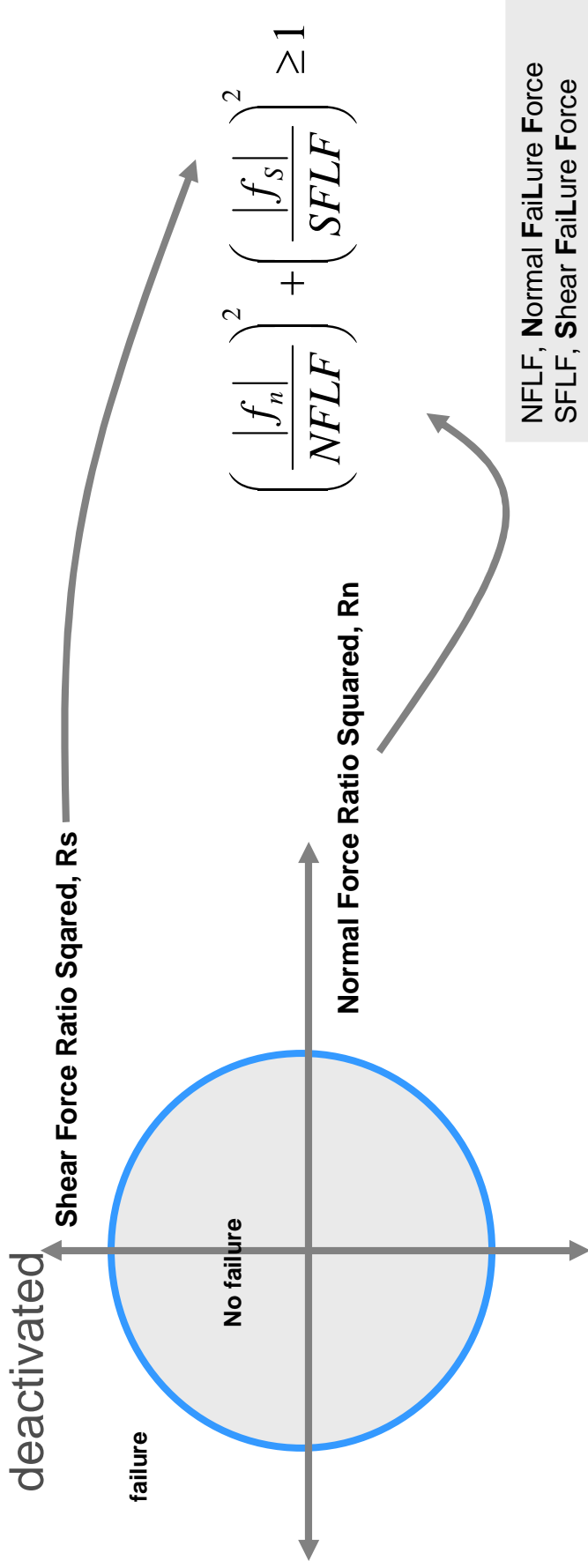
Solids Only
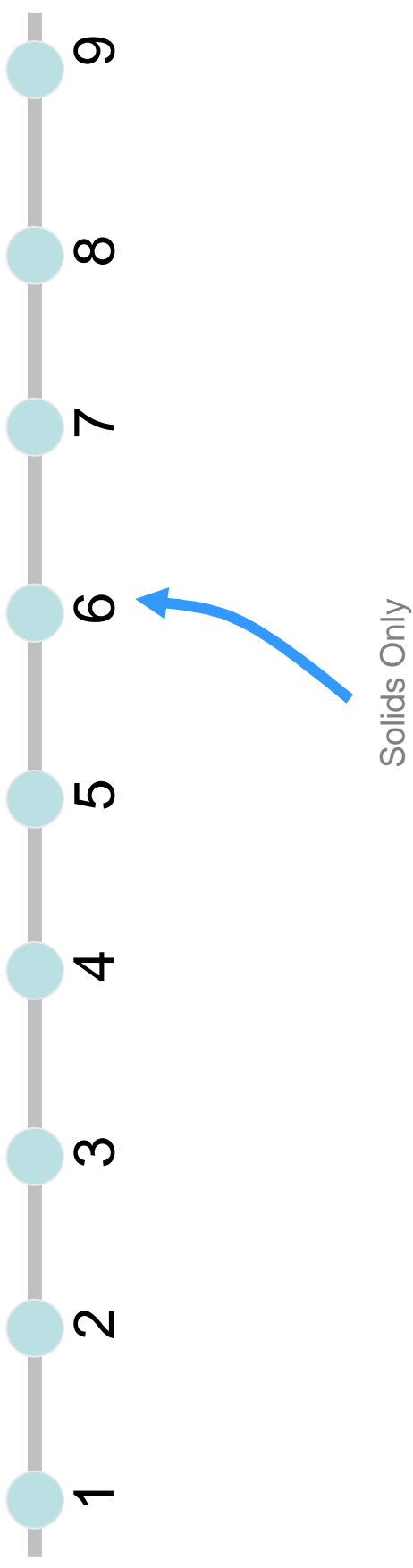
Failure

- All TIEBREAK contacts allow the modeling of failure

- One-Way failure is based on Forces Only

- Two-Way failure is based on Stresses Only

- Except for TIEBREAK_NODES_ONLY, post-failure, the interface acts as traditional contacts which resist compressive forces only
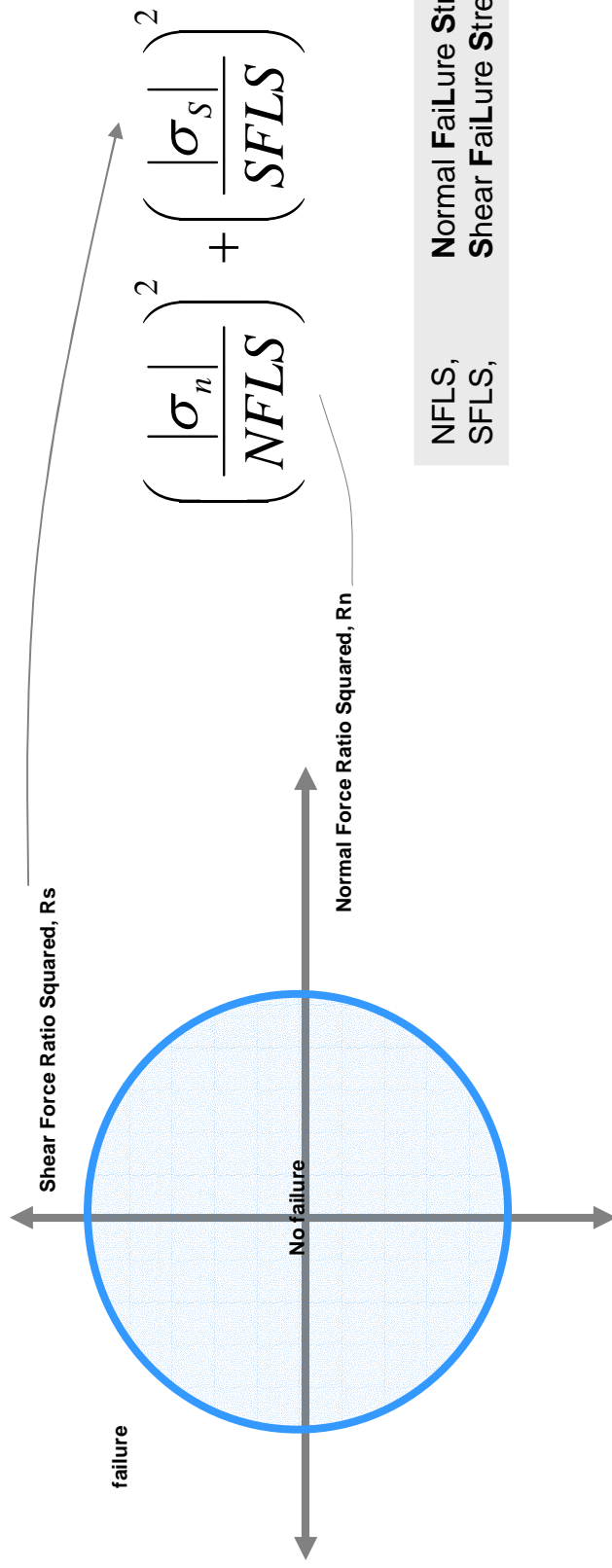
Force Based Failure

- This option applies for one-way contact types only
  - CONTACT_TIEBREAK_NODES_TO_SURFACE
  - CONTACT_TIEBREAK_NODES_ONLY

- The failure force can be based on normal or shear or both

- When the squared normalized radius of the circle is greater than 1, then failure is assumed and the tensile spring is immediately deactivated

$$\left(\frac{|f_n|}{NFLF}\right)^2 + \left(\frac{|f_s|}{SFLF}\right)^2 \geq 1$$

Shear Force Ratio Sqared, Rs

Normal Force Ratio Squared, Rn

No failure

failure

NFLF, **N**ormal **F**ai**L**ure **F**orce
SFLF, **S**hear **F**ai**L**ure Force
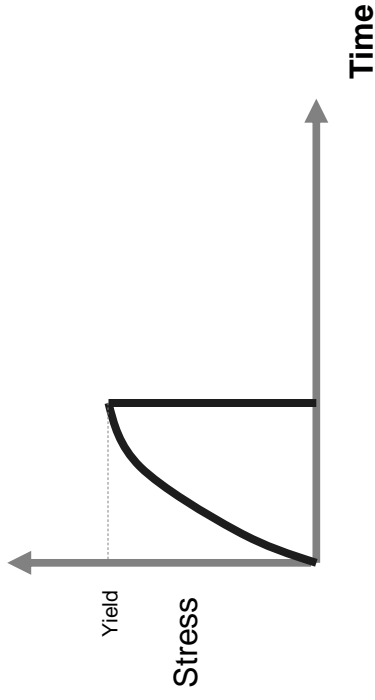
Stress Based Failure

- This option applies for two-way contact types only

  - CONTACT_TIEBREAK_SURFACE_TO_SURFACE
  - CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBRAK (OPTION=2,3,6)
  - CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK
  - CONTACT_AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE_TIEBREAK (OPTION=2,3,6)

- When the squared normalized radius of the circle is equal to or greater than 1, then failure is assumed and the tensile spring is deactivated

$$\left(\frac{|\sigma_n|}{NFLS}\right)^2 + \left(\frac{|\sigma_s|}{SFLS}\right)^2$$

Shear Force Ratio Squared, Rs

Normal Force Ratio Squared, Rn

No failure

failure

NFLS, **N**ormal **F**ai**L**ure **S**tress
SFLS, **S**hear **F**ai**L**ure **S**tress

Damage Modeling

- **OPTION = 7**
  - allows crack initiation using Dycos Discrete Crack Model as shown below

$$\left(\frac{\max(\sigma_n,0)}{NFLS}\right)^2 + \left(\frac{\sigma_s}{SFLS(1-\sin(PARAM)\min(0,\sigma_n))}\right) = 1$$

Stress Profile

Some notes on Failure

- Each node-segment pair is independently evaluated allowing the modeling of "peeling"

- The stress due to contact forces, "contact" stresses, is computed based on the spring force and the area of the segment

- The components are then decomposed into normal and shear components in the local coordinate system of the master segment

- Significant noise can be present in the forces so some percentage of viscous damping should be used to avoid pre-mature failure
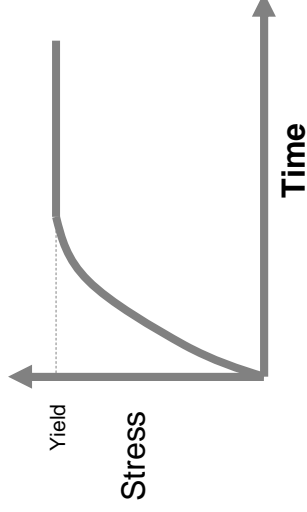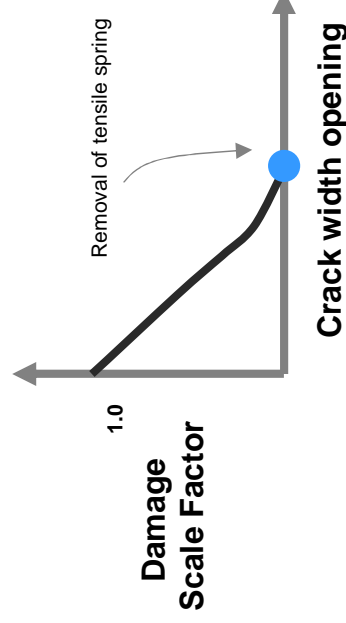
Damage Modeling

OPTION = 5 (shells and solids)

– allows damage by scaling the stress components after the failure is met

– Stress is limited by a perfectly plastic yield condition

– In tension the yield condition is

$$\frac{\sqrt{\sigma_n^2 + 3|\sigma_s|^2}}{NLFS} \leq 1$$

– In compression, the yield condition is

$$\frac{\sqrt{3|\sigma_s|^2}}{NLFS} \leq 1$$

– In addition, the stress is scaled by a factor that is user-defined as a function of the crack width opening using SFLS which becomes the load curve id

Removal of tensile spring

1.0

**Damage
Scale Factor**

Crack width opening
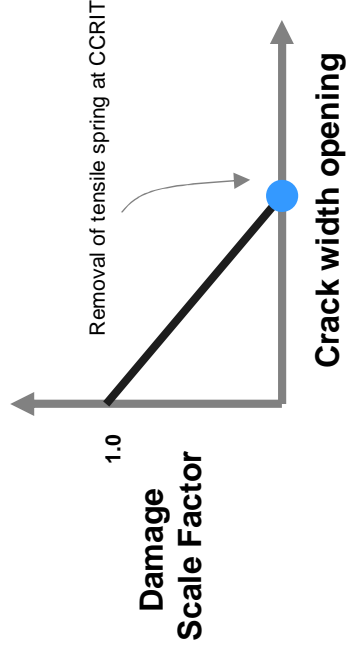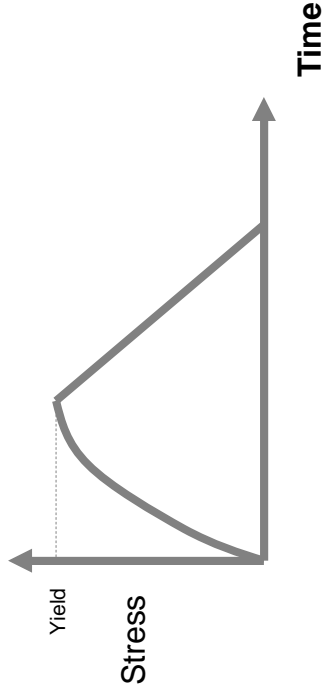
Damage Profile

Yield

Stress

Time

Stress Profile

Damage Modeling

- OPTION = 6 (Solids Only)
  - allows damage by scaling the stress components after the failure is met
  - Damage is initiated when the stress reaches the failure criteria specified by

$$\left(\frac{|\sigma_n|}{NFLS}\right)^2 + \left(\frac{|\sigma_S|}{SFLS}\right)^2$$

  - After the damage is initiated, a the stress is linearly scaled down until the crack depth reaches PARAM which is CCRIT

Stress Profile

Damage Profile

Damage Modeling

- **OPTION = 8 (Offset Shells Only)**

  – To be used only with ONE_WAY AUTOMATIC TIEBREAK

  – Allows damage by scaling the stress components after the failure is met

  – Damage is initiated when the stress reaches the failure criteria specified by

$$\left(\frac{|\sigma_n|}{NFLS}\right)^2 + \left(\frac{|\sigma_S|}{SFLS}\right)^2$$

  – After the damage is initiated, a the stress is linearly scaled down until the crack depth reaches PARAM which is CCRIT
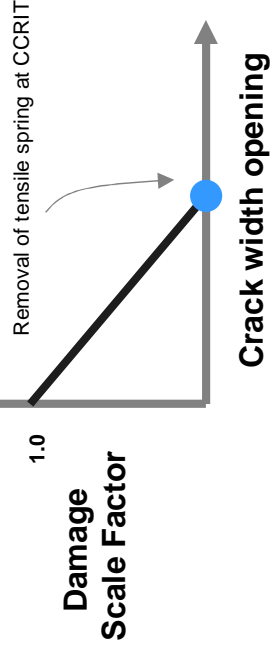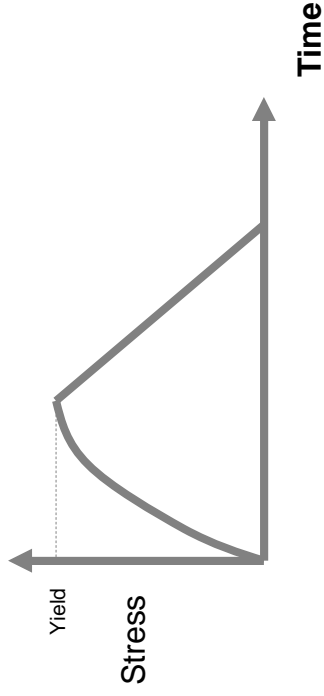

Stress Profile

Damage Profile

OPTION comparison

Values	Initiation of Failure	Damage Evolution	Significance of PARAM
1	NONE. Nodes will stick permanently	NONE. Nodes will stick permanantly	NONE
2	$\left(\frac{\lvert\sigma_n\rvert}{NFLS}\right)^2 + \left(\frac{\lvert\sigma_s\rvert}{SFLS}\right)^2$	NONE	When PARAM=1, shell offsets are ignored after failure
3	$\left(\frac{\lvert\sigma_n\rvert}{NFLS}\right)^2 + \left(\frac{\lvert\sigma_s\rvert}{SFLS}\right)^2$	NONE	NONE
4	$\frac{\lvert\sigma_N\rvert}{nfls} \geq 1$	NONE	Causes SFLS to be a frictional stress limit
5	**T** $\dfrac{\sqrt{\sigma_n^2+3\lvert\sigma_s\rvert^2}}{NLFS} \leq 1$ **C** $\dfrac{\sqrt{3\lvert\sigma_s\rvert^2}}{NLFS} \leq 1$	Yes. Using a LoadCurve so Nonlinearity is allowed.	Causes SFLS to become a loadcurve id that defines stress reduction scale factor vs crack opening
6	$\left(\frac{\lvert\sigma_n\rvert}{NFLS}\right)^2 + \left(\frac{\lvert\sigma_s\rvert}{SFLS}\right)^2$	Yes. Linear	Causes PARAM to become a CCRIT which is the critical crack opening for complete failure
7	$\left(\frac{\max(\sigma_n,0)}{NFLS}\right)^2 + \left(\frac{\sigma_s}{SFLS\ (1-\sin(PARAM\ )\ \min(\,0,\sigma_n))}\right) = 1$	NONE	Causes SFLS to become frictional angle
8	$\left(\frac{\lvert\sigma_n\rvert}{NFLS}\right)^2 + \left(\frac{\lvert\sigma_s\rvert}{SFLS}\right)^2$		
9	Cohesive Model	See MAT_COHESIVE_MIXED_MOD	See MAT_COHESIVE_MIXED_MOD

Examples

- "Initially in contact"

- "Peeling"

- "Post-Failure" Interaction

- "Linear-Damage Modeling"

- "Nonlinear-Damage Modeling"