## MAT_HYSTERETIC_BEAM

This is Material Type 209. Lumped plasticity may be developed at both nodes of Belytschko-Schwer resultant beams (ELFORM=2 in Card 1 of *SECTION_BEAM). The yield surfaces at both nodes allow interaction between the bending moments and the axial force. The material also considers yielding in shear and allows development of plastic shear deformation.

### Card Format

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MID | RO | E | PR | IAX | ISURF | IHARD | IFEMA |
| Type | I | F | F | F | I | I | F | I |
| Default | none | none | none | none | 1 | 1 | 2.0 | 0 |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | LCPMS | SFS | LCPMT | SFT | LCAT | SFAT | LCAC | SFAC |
| Type | I | F | I | F | I | F | I | F |
| Default | none | 1.0 | LCPMS | SFS | none | 1.0 | LCAT | SFAT |

| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | ALPHA | BETA | GAMMA | F0 | PINM | PINS | HLOC1 | HLOC2 |
| Type | F | F | F | F | F | F | F | F |
| Default | 2.0 | 2.0 | 2.0 | 0.0 | 1.0 | 1.0 | 0.0 | 0.0 |

| Card 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DELTAS | KAPPAS | DELTAT | KAPPAT | LCSHS | SFSHS | LCSHT | SFSHT |
| Type | F | F | F | F | F | F | F | F |
| Default | 0.0 | 0.0 | 0.0 | 0.0 | none | 1.0 | LCSHS | SFSHS |

| Card 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | HARDMS | GAMMS | HARDMT | GAMMT | HARDAT | GAMAT | HARDAC | GAMAC |
| Type | F | F | F | F | F | F | F | F |
| Default | 0.0 | 0.0 | HARDMS | GAMMS | 0.0 | 0.0 | HARDAT | GAMAT |

| Card 6 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | OMGMS1 | OMGMS2 | OMGMT1 | OMGMT2 | OMGAT1 | OMGAT2 | OMGAC1 | OMGAC2 |
| Type | F | F | F | F | F | F | F | F |
| Default | 0.0 | 0.0 | OMGMS1 | OMGMS2 | 0.0 | 0.0 | OMGAT1 | OMGAT2 |

| Card 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | RUMS | RUMT | DUAT | DUAC | LAM1 | LAM2 | | |
| Type | F | F | F | F | F | F | | |
| Default | 1E20 | RUMS | 1E20 | DUAT | 0.0 | LAM1 | | |

**Define the following card for FEMA limits only if IFEMA > 0**

| Card 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PRS1 | PRS2 | PRS3 | PRS4 | PRT1 | PRT2 | PRT3 | PRT4 |
| Type | F | F | F | F | F | F | F | F |
| Default | 1E20 | 2E20 | 3E20 | 4E20 | 1E20 | 2E20 | 3E20 | 4E20 |

**Define the following card for FEMA limits only if IFEMA = 2**

| Card 9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | TS1 | TS2 | TS3 | TS4 | CS1 | CS2 | CS3 | CS4 |
| Type | F | F | F | F | F | F | F | F |
| Default | 1E20 | 2E20 | 3E20 | 4E20 | TS1 | TS2 | TS3 | TS4 |

A simple input to get started is showed below

*MAT_HYSTERETIC_BEAM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Card1 | 1 | 2400 | 30E9 | 0.2 | 2 | | | |
| Card2 | 1 | 500.0 | 1 | 500.0 | 1 | 1000.0 | 1 | 1000.0 |
| Card3 | 2.0 | 2.0 | 2.0 | 0.0 | | | | |
| Card4 | | | | | | | | |
| Card5 | | | | | | | | |
| Card6 | | | | | | | | |
| Card7 | | | | | | | | |

This is equivalent to
*MAT_SEISMIC_BEAM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Card1 | 1 | 2400 | 30E9 | 0.2 | 3 | 1 | 2 | 0 |
| Card2 | 1 | 500.0 | 1 | 500.0 | 1 | 1000.0 | 1 | 1000.0 |
| Card3 | 2.0 | 2.0 | 2.0 | 2.0 | 1.0 | 0.0 | 0.0 | |

Advanced features can be defined in Card 3 (hinge locations and pinching effect), Card 4 (asymmetry and shear failure), Card 5 (Bauschinger effect), Cards 6 and 7 (stiffness degradation), and Cards 8 and 9 (FEMA flags).

| VARIABLE | DESCRIPTION |
|---|---|
| MID | Material identification. A unique number has to be chosen. |
| RO | Mass density. |
| E | Young's modulus. |
| PR | Poisson's ratio. |
| IAX | Abscissa definition for axial yield force vs. inelastic deformation/strain curves (LCAT and LCAC)<br>EQ.1: plastic deformation (change in length)<br>EQ.2: nominal plastic strain<br>(plastic deformation/undeformed length) |
| ISURF | Yield surface type for interaction |
| IHARD | Isotropic hardening type, yield strength is a function of<br>EQ.1.0: cumulative absolute deformation<br>EQ.2.0: peak deformation<br>EQ.3.0: peak deformation, yield-oriented<br>EQ.4.0: peak deformation, peak-oriented |
| IFEMA | Flag for input of FEMA thresholds<br>EQ.0: No input<br>EQ.1: Input of rotation thresholds only<br>EQ.2: Input of rotation and axial strain thresholds |
| LCPMS | Load curve ID giving normalised yield moment vs. inelastic rotation at hinges about local s-axis. All values are positive. See *DEFINE_CURVE. |
| SFS | Representative yield moment about local s-axis (unsigned). |
| LCPMT | Load curve ID giving normalised yield moment vs. inelastic rotation at hinges about local t-axis. All values are positive. See *DEFINE_CURVE. |
| SFT | Representative yield moment about local t-axis (unsigned). |
| LCAT | Load curve ID giving normalised axial tensile force vs. inelastic deformation/strain. See IAX above. All values are positive. See *DEFINE_CURVE. |
| SFAT | Representative tensile strength (unsigned). |
| LCAC | Load curve ID giving normalized axial compressive force vs. inelastic deformation/strain. See IAX above. All values are positive. See *DEFINE_CURVE. |

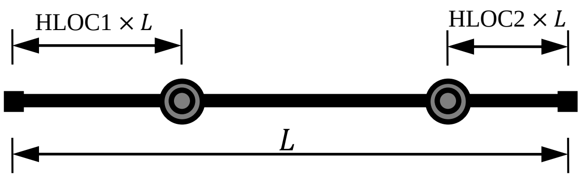
| | |
|---|---|
| SFAC | Representative compressive strength (unsigned). |
| ALPHA | Parameter to define yield surface, value not less than 1.1.<br>GT.0: yield surface parameter ALPHA<br>EQ.-n: where \|n\| is the local curve ID giving yield locus in $M_s$- $F$ plane. Abscissa are moment about local s-axis $M_s$, and ordinates are axial force (tensile positive). |
| BETA | Parameter to define yield surface, value not less than 1.1.<br>GT.0: yield surface parameter BETA<br>EQ.-n: where \|n\| is the local curve ID giving yield locus in $M_t$- $F$ plane. Abscissa are moment about local t-axis $M_t$, and ordinates are axial force (tensile positive). |
| GAMMA | Parameter to define yield surface, value not less than 1.1. |
| F0 | Force at which maximum yield moment is achieved (tensile positive). |
| PINM | Pinching factor for flexural hysteresis (for IHARD = 3 or 4) |
| PINS | Pinching factor for shear hysteresis (for IHARD = 3 or 4) |
| HLOC1 | Location of plastic Hinge 1 from Node 1<br>EQ.-1.0: deactivate Hinge 1<br>GE.0.0: distance of Hinge 1 to Node 1 divided by element length |
| HLOC2 | Location of plastic hinge 2 from node 2<br>EQ.-1.0: deactivate Hinge 2<br>GE.0.0: distance of Hinge 2 to Node 2 divided by element length |
| DELTAS | Parameter $\delta_s$ to define the skew for yield surface Type 3. |
| KAPPAS | Parameter $\kappa_s$ to define the skew for yield surface Type 3. |
| DELTAT | Parameter $\delta_t$ to define the skew for yield surface Type 3. |
| KAPPAT | Parameter $\kappa_t$ to define the skew for yield surface Type 3. |
| LCSHS | Load curve ID giving yield shear force vs. inelastic shear strain (shear angle) in local s-direction. See *DEFINE_CURVE. |
| SFSHS | Scale factor on yield shear force in local s-direction in curve LCSHS.<br>GT.0: constant scale factor<br>EQ.-n: where \|n\| is the local curve ID giving scale factor vs. normalised axial force (tensile positive). See *DEFINE_CURVE. The normalisation uses SFAT for tensile force and SFAC for compressive force. For example, Point (-1.0, 0.5) on the curve defines a scale factor of 0.5 for compressive force of -SFAC. |
| LCSHT | Load curve ID giving yield shear force vs. inelastic shear strain (shear angle) in local t-direction. See *DEFINE_CURVE. |

| | |
|---|---|
| SFSHT | Scale factor on yield shear force in local t-direction in curve LCSHT.<br>GT.0: constant scale factor<br>EQ.-n: where \|n\| is the local curve ID giving scale factor vs. normalised axial force (tensile positive). See *DEFINE_CURVE. The normalisation uses SFAT for tensile force and SFAC for compressive force. For example, Point (-1.0, 0.5) on the curve defines a scale factor of 0.5 for compressive force of -SFAC. |
| HARDMS | Kinematic hardening modulus $K_s$ for moment about local s-axis. |
| GAMMS | Kinematic hardening parameter $C_s$ for moment about local s-axis. |
| HARDMT | Kinematic hardening modulus $K_t$ for moment about local t-axis. |
| GAMMT | Kinematic hardening parameter $C_t$ for moment about local t-axis. |
| HARDAT | Kinematic hardening modulus $K_{at}$ for tensile axial force. |
| GAMAT | Kinematic hardening parameter $C_{at}$ for tensile axial force |
| HARDAC | Kinematic hardening modulus $K_{ac}$ for compressive axial force. |
| GAMAC | Kinematic hardening parameter $C_{ac}$ for compressive axial force |
| OMGMS1 | Damage evolution parameter $\omega_{s1}$ for moment about local s-axis |
| OMGMS2 | Damage evolution parameter $\omega_{s2}$ for moment about local s-axis |
| OMGMT1 | Damage evolution parameter $\omega_{t1}$ for moment about local t-axis |
| OMGMT2 | Damage evolution parameter $\omega_{t2}$ for moment about local t-axis |
| OMGAT1 | Damage evolution parameter $\omega_{at1}$ for tensile force |
| OMGAT2 | Damage evolution parameter $\omega_{at2}$ for tensile force |
| OMGAC1 | Damage evolution parameter $\omega_{ac1}$ for compressive force |
| OMGAC2 | Damage evolution parameter $\omega_{ac2}$ for compressive force |
| RUMS | Ultimate plastic rotation about s-axis for damage calculation |
| RUMT | Ultimate plastic rotation about t-axis for damage calculation |
| DUAT | Ultimate tensile plastic deformation/strain for damage calculation. See IAX above. |
| DUAC | Ultimate compressive plastic deformation/strain for damage calculation. See IAX above. |
| LAM1 and LAM2 | Damage evolution parameter $\lambda_1$ and $\lambda_2$ |
| PRS1-PRS4 | Plastic rotation thresholds 1 to 4 about s-axis |

| | |
|---|---|
| PRT1-PRT4 | Plastic rotation thresholds 1 to 4 about t-axis |
| TS1-TS4 | Tensile plastic axial deformation/strain thresholds 1 to 4 |
| CS1-CS4 | Compressive plastic axial deformation/strain thresholds 1 to 4 |

Remarks:

Two plastic hinges can be developed at user-specified locations. The default plastic hinge locations are at the ends of the beam element.




Three types of yield surface are available. Yield surface type 1 is of the form:

$$\psi = \left|\frac{M_s - m_s}{M_{ys}}\right|^{\alpha} + \left|\frac{M_t - m_t}{M_{yt}}\right|^{\beta} + \left|\frac{F - f - F_0}{F_y - F_0}\right|^{\gamma} - 1$$

Yield surface type 2 is of the form:

$$\psi = \left[\left(\frac{M_s - m_s}{M_{ys}}\right)^2 + \left(\frac{M_t - m_t}{M_{yt}}\right)^2\right]^{\frac{\alpha}{2}} + \left|\frac{F - f - F_0}{F_y - F_0}\right|^{\gamma} - 1$$

Yield surface type 3 is of the form:

$$\psi = \left\{\left[\frac{(M_s - m_s) + \delta_s(F - f - F_0)}{(1 - \delta_s\kappa_s)M_{ys}}\right]^2 + \left[\frac{(M_t - m_t) + \delta_t(F - f - F_0)}{(1 - \delta_t\kappa_t)M_{yt}}\right]^2\right\}^{\frac{\alpha}{2}} + \left|\frac{(F - f - F_0) + \kappa_s(M_s - m_s) + \kappa_t(M_t - m_t)}{(1 - \delta_s\kappa_s - \delta_t\kappa_t)(F_y - F_0)}\right|^{\gamma} - 1$$

where: $M_s$, $M_t$ and $F$ are the moments about s- and t-axes and axial force

$M_{ys}$, $M_{yt}$ and $F_y$ are the current yield moments and forces;

$$F_y = \begin{cases} F_{yt} & (F - f \geq F_0) \\ -F_{yc} & (F - f < F_0) \end{cases}$$

$F_{yt}$ and $F_{yc}$ are current tensile and compressive strengths.

$m_s$, $m_t$ and $f$ are the current moments and forces that determine the centre of the yield surface; They are closely related to the Bauschinger effect or kinematic hardening discussed below.

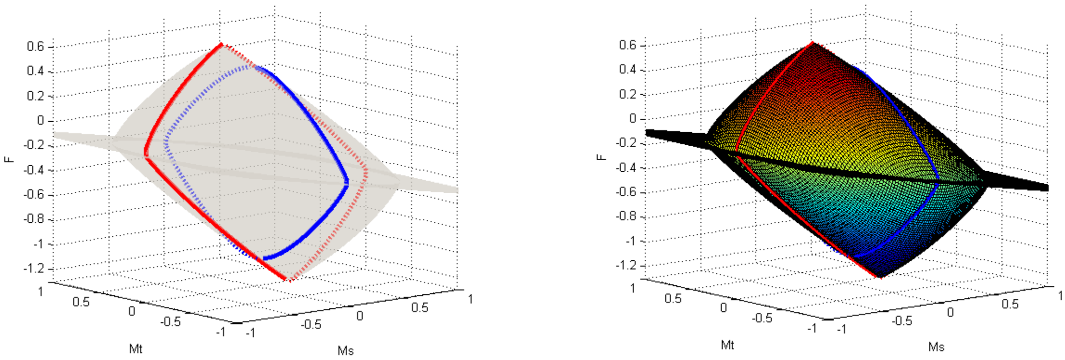
$\alpha$, $\beta$ and $\gamma$ are real numbers greater than or equal to 1.1.

$\delta_s$ and $\delta_t$ are properties of length unit, for skew of yield surface.

$\kappa_s$ and $\kappa_t$ are properties of 1/length unit, for skew of yield surface.

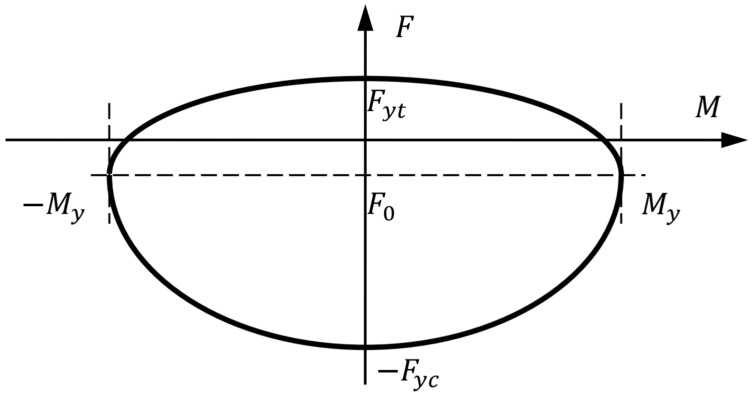
$F_0$ offsets the yield surface parallel to the axial force axis. It is the axial force at which the maximum bending moment capacity about the local s-axis (determined by LCPMS and SFS), and that about the local t-axis (determined by LCPMT and SFT), occur. For steel components, the value of $F_0$ is usually zero. For reinforced concrete components, the maximum bending moment capacity occurs corresponding to a certain compressive axial force, $F_0$. For compressive offset, the value of $F_0$ must be input as negative.

When $\alpha$ and $\beta$ are less than 0.0 and $\gamma$ is equal to 0.0, the negated $\alpha$ and $\beta$ are the load curves that define the yield loci in $M_s$- $F$ and $M_t$- $F$ planes. The program will automatically find the set of parameters ALPHA, BETA, GAMMA, SFS, SFT, SFAT, SFAC, F0, DELTAS, KAPPAS, DELTAT and KAPPAT that best fits the yield loci and the yield surface type ISURF.

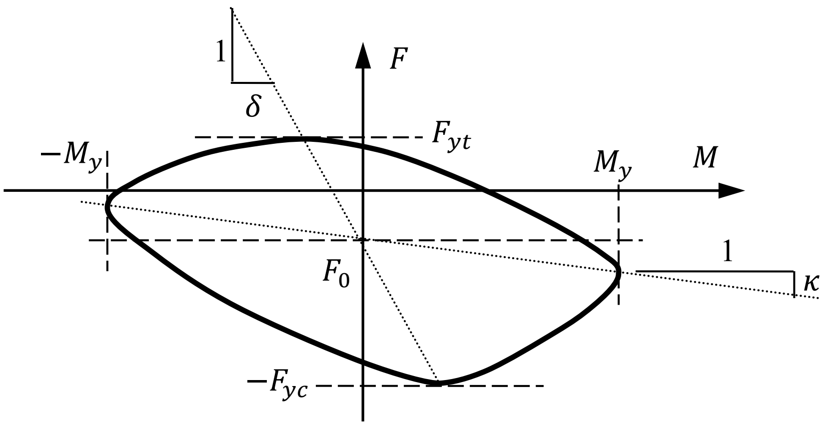



Automatic conversion of yield loci in $M_s$- $F$ (red) and $M_t$- $F$ (blue) planes to yield surface

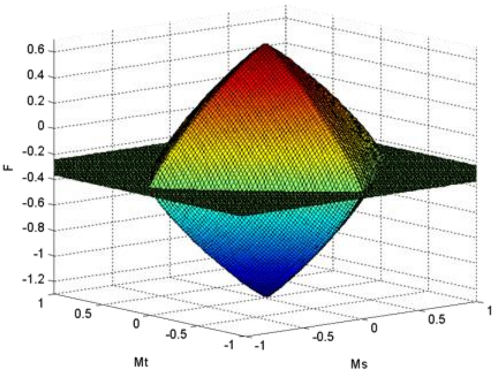
Reinforced concrete section that has asymmetric reinforcement has a skew yield surface. The bending moment capacities at zero axial force are different in positive and negative bending. The maximum axial capacity occurs at a nonzero bending moments. And the maximum biaxial bending moment capacity occurs at varying axial force. This can be modelled with yield surface Type 3, where $\delta_s$ and $\delta_t$ control the slope of the line connecting peak tensile and compressive strength vertexes, and $\kappa_s$ and $\kappa_t$ control the gradient of the balance plane.




Schematics of strength parameters

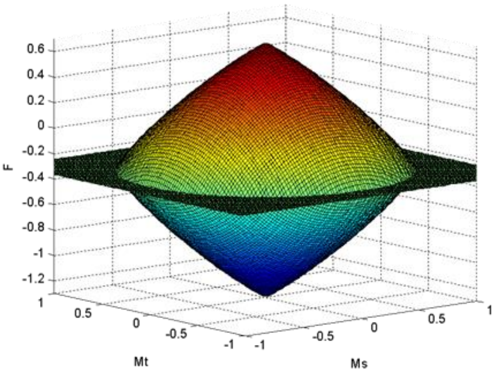


Schematics of skew parameters for surface Type 3



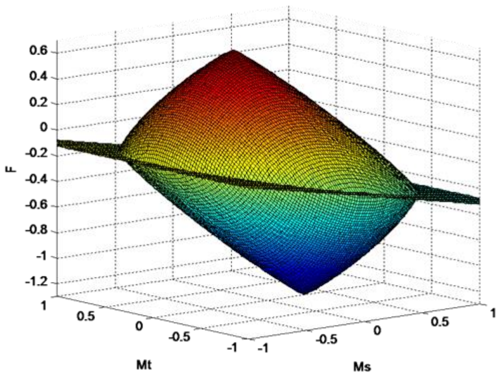

$\alpha = \beta = 1.1$
$\gamma = 1.2$
$M_{ys} = M_{yt} = 1$
$F_y = 1$, $F_0 = -0.3$

Schematics of yield surface Type 1 and its balance plane




$\alpha = 1.1$
$\gamma = 1.2$
$M_{ys} = M_{yt} = 1$
$F_y = 1$, $F_0 = -0.3$

Schematics of yield surface Type 2 and its balance plane



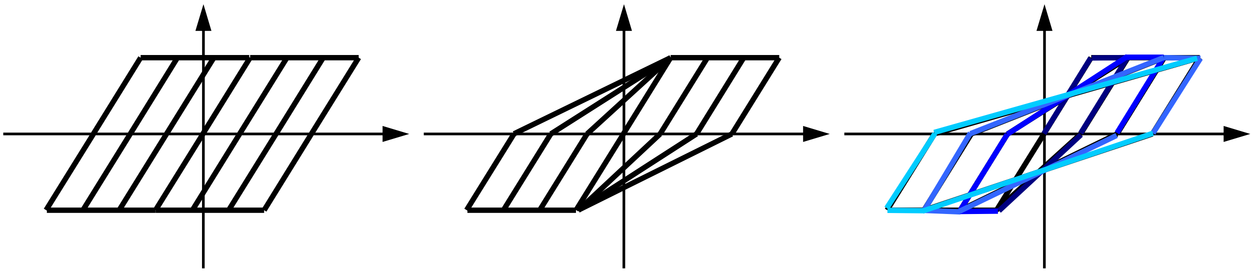

$\alpha = \beta = 1.1$
$\gamma = 1.2$
$M_{ys} = M_{yt} = 1$
$F_y = 1$, $F_0 = -0.3$
$\delta_s = 0.3$, $\kappa_s = 0.2$

Schematics of yield surface Type 3 and its balance plane

Isotropic hardening controls the size of yield surface as functions of plastic deformation. The option for isotropic hardening, IHARD, determines the definition of the abscissa of a yield force-plastic deformation or moment-plastic rotation curve as follows.

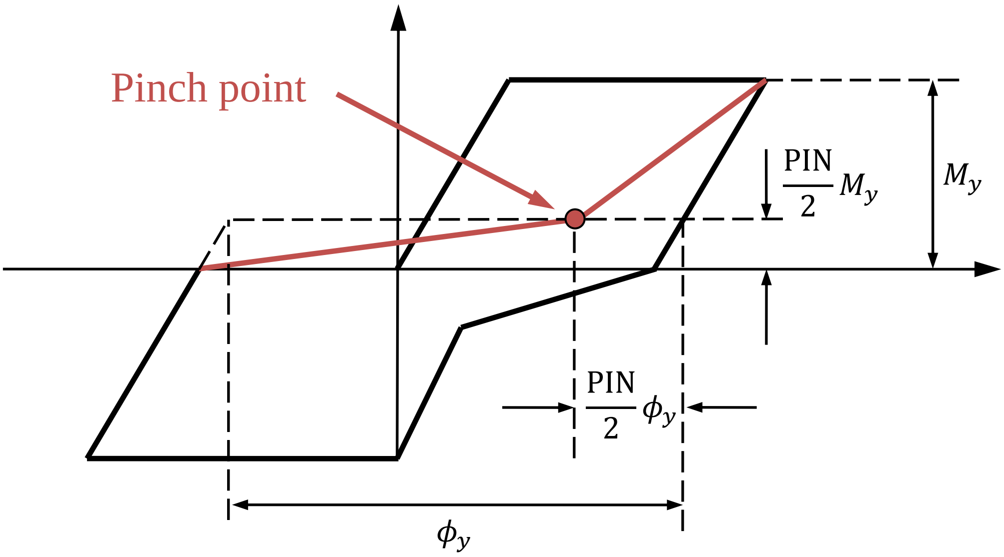
If IHARD = 1.0, the abscissa represent cumulative absolute plastic deformation. This quantity is always positive, and increases whenever there is plastic rotation in either direction. Thus, during hysteresis, the yield moments are taken from points in the input curve with increasingly positive rotation. If the curve shows a degrading behaviour (reducing strength with deformation), then, once degraded by plastic rotation, the yield moment can never recover to its initial value. This option can be thought of as having 'fatigue-type' hysteretic behaviour, where

all plastic cycles contribute to the degradation. In axial direction, plastic deformation is cumulated individually for incremental tensile and compressive excursion.
If IHARD = 2.0 to 4.0 the abscissa represent the peak value (always positive) of the plastic deformation. This quantity increases only when the absolute value of plastic deformation exceeds the previously recorded maximum. This option can be thought of as showing peak-deformation-controlled strength degradation, and follows the FEMA approach. In particular, IHARD of 3.0 and 4.0 reproduce the yield-oriented and peak-oriented hysteresis, respectively, as showed below.



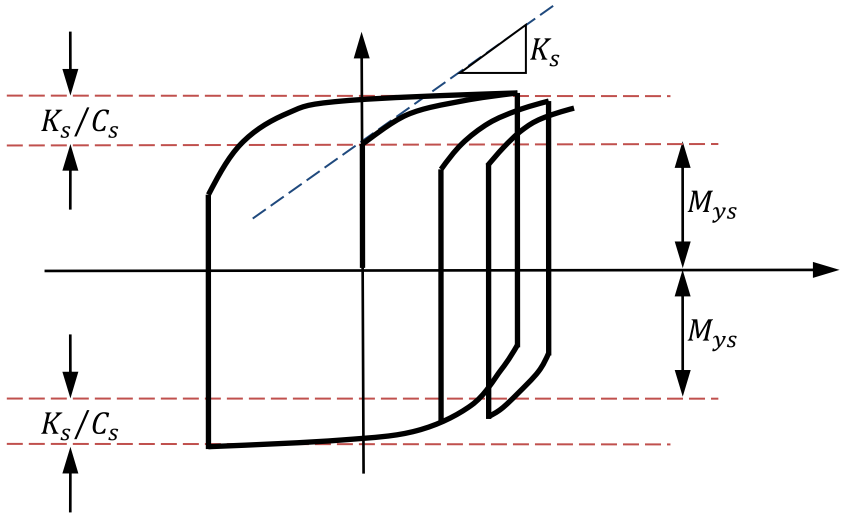
Schematic of hysteresis types

Pinched-shape hysteresis loops are seen in experiments on reinforced concrete, and are caused by stiffness changes due to cracks opening and closing. This effect may be simulated in the model using input parameter PIN (PINM and PINS). The default, PIN = 1.0, gives no pinching. The “pinch points” are given by moments and rotations illustrated in the schematic below.



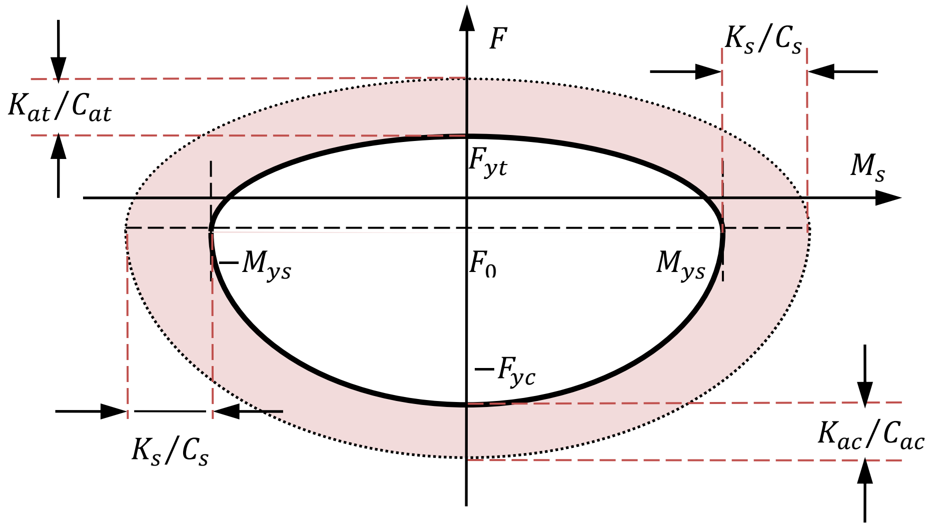
Schematic of pinching factor PIN

Kinematic hardening is known as Bauschinger effect: an increase in tensile yield strength occurs at the expense of compressive yield strength. This is modelled as the shift of the centre of the yield surface. The hardening modulus $K$ controls the speed of shift. And the hardening parameters $C$ control the maximum increase that can occur in tensile yield strength at the expense of compressive yield strength. The following figure shows how the shift affects a moment-plastic rotation hysteresis.




Schematics of kinematic hardening

The yield surface can shift but it is bounded. The size of bounding surface is showed in the following figure. If the kinematic hardening parameters $C$ are zero, then the bounding surface size becomes infinitely large and thus the yield surface is effectively unbounded.




Schematics of kinematic hardening bounding surface (dotted curve)

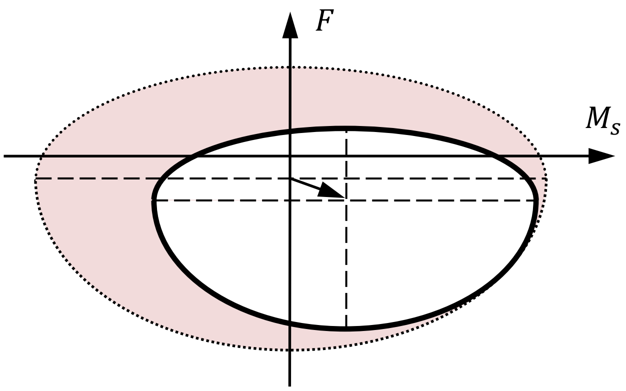



Illustration of the shift of the yield surface constrained by the bounding surface

Stiffness degradation is modelled using damage index. The damaged part of the material does not contribute to the forces/moments or the stiffness. If the ratio of damaged part to the whole is defined as the damage index $D$, then the physical forces/moments can be calculated as nominal or undamaged forces/moments multiplied by $(1-D)$. The damage indexes are defined individually for tensile and compressive axial forces and bending moment about s- and t-axis at two plastic hinges, with the following formulae:

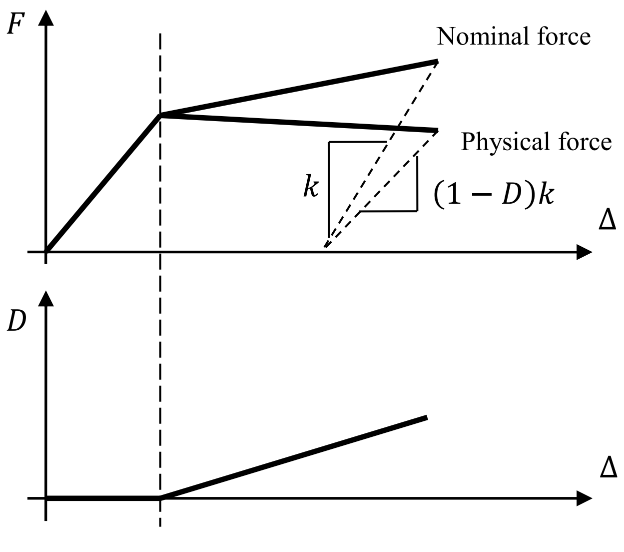
$$D_{at}(t) = 1 - \left[1 - \omega_{1at}\frac{\Delta^p_{t,\mathrm{peak}}(t)}{\Delta^u_t}\right]^{\lambda_1}\left[1 - \omega_{2at}\frac{\overline{\Delta}^p_t(t)}{\Delta^u_t}\right]^{\lambda_2}$$

$$D_{ac}(t) = 1 - \left[1 - \omega_{1ac}\frac{\Delta^p_{c,\mathrm{peak}}(t)}{\Delta^u_c}\right]^{\lambda_1}\left[1 - \omega_{2ac}\frac{\overline{\Delta}^p_t(t)}{\Delta^u_c}\right]^{\lambda_2}$$

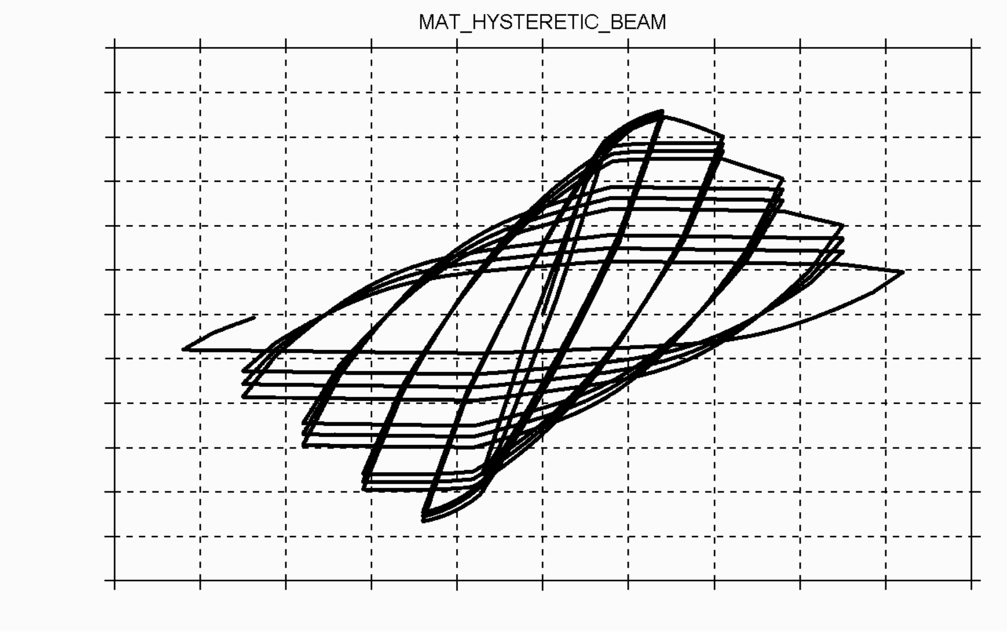
$$D_{ms}(t) = 1 - \left[1 - \omega_{1s}\frac{\theta^p_{s,\mathrm{peak}}(t)}{\theta^u_s}\right]^{\lambda_1}\left[1 - \omega_{2s}\frac{\bar{\theta}^p_s(t)}{\theta^u_s}\right]^{\lambda_2}$$

$$D_{mt}(t) = 1 - \left[1 - \omega_{1t}\frac{\theta^p_{t,\mathrm{peak}}(t)}{\theta^u_t}\right]^{\lambda_1}\left[1 - \omega_{2t}\frac{\bar{\theta}^p_t(t)}{\theta^u_t}\right]^{\lambda_2}$$

where $\omega$'s are damage evolution parameters, the superscript $u$ represents the ultimate plastic deformation or rotation (e.g., $\Delta^u_t$), the 'bar' represents the cumulative plastic deformation or rotation (e.g., $\overline{\Delta}^p_t$), and the subscript 'peak' represents the peak plastic deformation or rotation (e.g., $\Delta^p_{t,\mathrm{peak}}$). If $\lambda_1 = 1$ and $\lambda_2 = 0$, then $\omega_1$ represents the stiffness degradation ratio caused by peak plastic deformation or rotation. Similarly, if $\lambda_1 = 0$ and $\lambda_2 = 1$, then $\omega_2$ represents the stiffness degradation ratio caused by cumulative plastic deformation or rotation. The following figure shows the effect of damage variable on forces and elastic (unloading) stiffness.



By combining the isotropic and kinematic hardening, and the damage evolution, the hysteresis of structural components can be modelled realistically. An example of the simulated hysteresis is showed below.




Simulated hysteresis for a steel beam component

FEMA thresholds are the plastic rotations at which the element is deemed to have passed from one category to the next, e.g. "Elastic", "Immediate Occupancy", "Life Safe", etc. The high-tide plastic rotation (maximum of Y and Z) is checked against the user-defined limits FEMA1, FEMA2, etc. The output flag is then set to 0, 1, 2, 3, or 4: 0 means that the rotation is less than FEMA1; 1 means that the rotation is between FEMA1 and FEMA2, and so on. By contouring this flag, it is possible to see quickly which joints have passed critical thresholds.

Yielding and failure in shear can be considered with interaction between shear forces in local s- and t-directions. Yield surface for shear is of the form:

$$\psi_s = \left(\frac{V_s}{V_{ys}}\right)^2 + \left(\frac{V_t}{V_{yt}}\right)^2 - 1$$

where: $V_s$ and $V_t$ are the current shear forces in local s- and t-directions, respectively.

$V_{ys}$ and $V_{yt}$ are the current yield shear forces in local s- and t-directions, respectively. They are functions of plastic shear strain (shear angle), specified in Curves LCSHS and LCSHT, respectively. In addition, their scale factors can be functions of axial force $F$, specified in Curves [-SFSHS] and [-SFSHT], respectively.

The shear strengths are functions of plastic shear strains in s- and t-directions. The plastic strain can be either peak or cumulative, depending on IHARD. This might be used to simulate the cyclic degradation of shear links in a steel structure. The shear strengths are also function of the axial forces, which might be helpful to modelling shear failure of reinforced concrete column.

For this material model, special output parameters are written to the d3plot and d3thdt files. The number of output parameters for beam elements is automatically increased to 45 (in addition to the 6 standard resultants) when parts of this material type are present. Some post-processors may interpret this data as if the elements were integrated beams with 9 integration points. Depending on the post-processor used, the data may be accessed as follows:

| Integration point | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Extra (history) variable | 1 | 6 | 11 | 16 | 21 | 26 | 31 | 36 | 41 | XX(RR) axial stress |
| | 2 | 7 | 12 | 17 | 22 | 27 | 32 | 37 | 42 | XY(RS) shear stress |
| | 3 | 8 | 13 | 18 | 23 | 28 | 33 | 38 | 43 | ZX(TR) shear stress |
| | 4 | 9 | 14 | 19 | 24 | 29 | 34 | 39 | 44 | Equivalent plastic strain |
| | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | XX(RR) axial strain |

e.g. XX(RR) axial stress at integration point 4 is Extra variable 16

Extra variable 1: Total axial deformation/strain
Extra variable 2: Hysteretic bending energy at plastic hinge 1
Extra variable 3: Hysteretic bending energy at plastic hinge 2
Extra variable 4: Plastic rotation about s-axis at hinge 1
Extra variable 5: Plastic rotation about s-axis at hinge 2
Extra variable 6: Plastic rotation about t-axis at hinge 1
Extra variable 7: Plastic rotation about t-axis at hinge 2
Extra variable 8: Bending moment about s-axis at node 1
Extra variable 9: Bending moment about s-axis at node 2
Extra variable 10: Bending moment about t-axis at node 1
Extra variable 11: Bending moment about t-axis at node 2
Extra variable 12: Hysteretic axial deformation energy
Extra variable 13: Internal energy
Extra variable 14: Plastic torsional rotation (always zero)
Extra variable 15: Axial plastic deformation
Extra variable 16: FEMA rotation flag
Extra variable 17: Current utilization
Extra variable 18: Peak utilization
Extra variable 20: FEMA axial flag
Extra variable 21: Peak plastic tensile axial deformation
Extra variable 22: Peak plastic compressive axial deformation
Extra variable 23: Peak plastic rotation about s-axis at hinge 1
Extra variable 24: Peak plastic rotation about s-axis at hinge 2
Extra variable 25: Peak plastic rotation about t-axis at hinge 1
Extra variable 26: Peak plastic rotation about t-axis at hinge 2
Extra variable 27: Cumulative plastic tensile axial deformation
Extra variable 28: Cumulative plastic compressive axial deformation
Extra variable 29: Cumulative plastic rotation about s-axis at hinge 1
Extra variable 30: Cumulative plastic rotation about s-axis at hinge 2
Extra variable 31: Cumulative plastic rotation about t-axis at hinge 1
Extra variable 32: Cumulative plastic rotation about t-axis at hinge 2
Extra variable 33: Axial tensile damage
Extra variable 34: Axial compressive damage
Extra variable 35: Flexural damage about s-axis at hinge 1
Extra variable 36: Flexural damage about s-axis at hinge 2
Extra variable 37: Flexural damage about t-axis at hinge 1

| | |
|---|---|
| Extra variable 38: | Flexural damage about t-axis at hinge 2 |
| Extra variable 39: | Plastic shear strain in s-direction |
| Extra variable 40: | Plastic shear strain in t-direction |
| Extra variable 41: | Peak plastic shear strain in s-direction |
| Extra variable 42: | Peak Plastic shear strain in t-direction |
| Extra variable 43: | Cumulative plastic shear strain in s-direction |
| Extra variable 44: | Cumulative plastic shear strain in t-direction |