*MAT_PARK_ANG_BEAM

This is Material Type 206, available only for beam elements with ELFORM=2. It is not part of the official LS-DYNA release, i.e. not in the LST manual, but is available in the software. A plastic hinge may form at Node 2. The hinge moment-rotation behaviour follows the hysteresis algorithm of Park & Ang.

Card Format

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	E	PR	ALPHA	BETA1	BETA2	GAMMA
Type	I	F	F	F	F	F	F	F
Default	none	none	None	0.0	1.0E8	0.0	0.0	1.0

Card 2	1	2	3	4	5	6	7	8
Variable	BMCPS	BMYPS	BMUPS	BMCNS	BMYNS	BMUNS	RESIDS	LENHS
Type	F	F	F	F	F	F	F	F
Default	none	none	none	-BMCPS	-BMYPS	-BMUPS	0.1	0.0

Card 3	1	2	3	4	5	6	7	8
Variable	KYPS	THUPS	THRPS	THFPS	KYNS	THUNS	THRNS	THFNS
Type	F	F	F	F	F	F	F	F
Default	See notes	none	See notes	See notes	-KYPS	-THUPS	-THRPS	-THFPS

Card 4	1	2	3	4	5	6	7	8
Variable	BMCPT	BMYPT	BMUPT	BMCNT	BMYNT	BMUNT	RESIDT	LENHT
Type	F	F	F	F	F	F	F	F
Default	None	none	none	-BMCPT	-BMYPT	-BMUPT	0.1	0.0

Card 5	1	2	3	4	5	6	7	8
Variable	KYPT	THUPT	THRPT	THFPT	KYNT	THUNT	THRNT	THFNT
Type	F	F	F	F	F	F	F	F
Default	See notes	none	See notes	See notes	-KYPT	-THUPT	-THRPT	-THFPT

Card 6	1	2	3	4	5	6	7	8
Variable	FESP1	FESP2	FESP3	FESP4	FESN1	FESN2	FESN3	FESN4
Type	F	F	F	F	F	F	F	F
Default	See notes	=THUPS	=THRPS	=THFPS	See notes	=THUNS	=THRNS	=THFNS

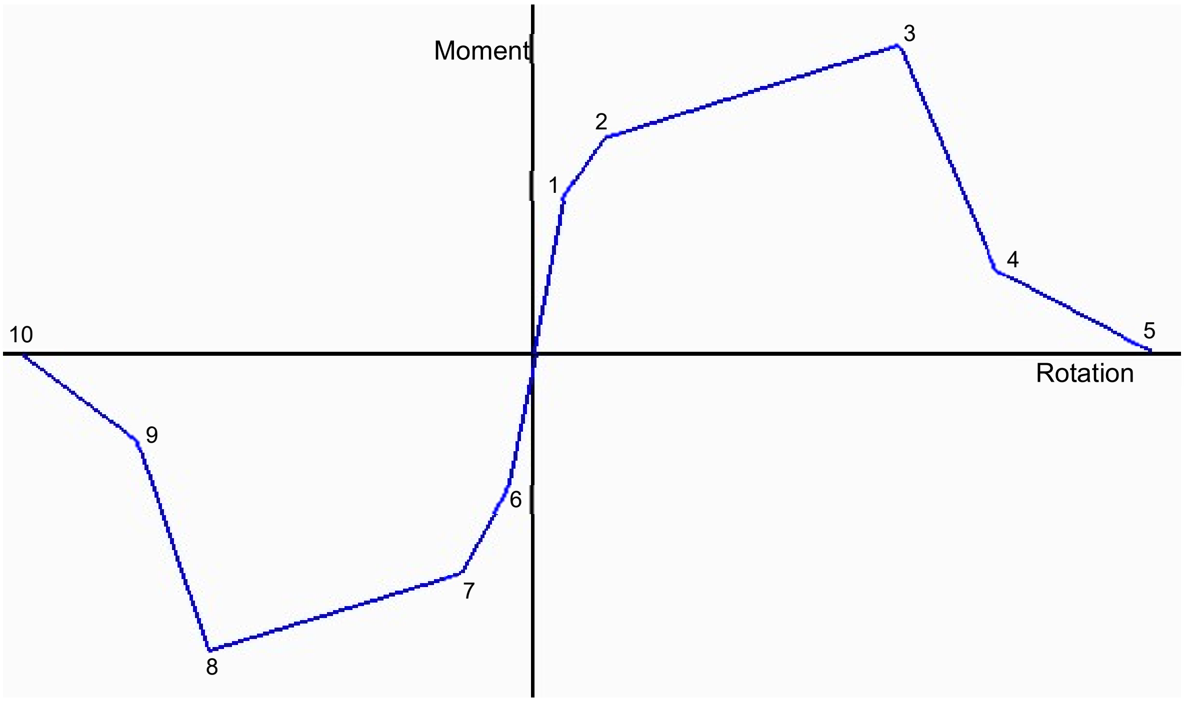
Card 7	1	2	3	4	5	6	7	8
Variable	FETP1	FETP2	FETP3	FETP4	FETN1	FETN2	FETN3	FETN4
Type	F	F	F	F	F	F	F	F
Default	See notes	=THUPT	=THRPT	=THFPT	See notes	=THUNT	=THRNT	=THFNT

VARIABLE	DESCRIPTION
MID	Material identification. A unique number has to be chosen.
RO	Mass density.
E	Young's Modulus
PR	Poisson's Ratio
ALPHA	Stiffness degradation parameter (dimensionless)
BETA1	Strength degradation parameter (ductility-basis) (dimensionless)
BETA2	Strength degradation parameter (hysteretic energy basis) (dimensionless)
GAMMA	Pinching parameter (dimensionless)
BMCPS	Cracking moment for positive hinge rotation about local S axis (All moments have Force x Length units)
BMYPS	Yield moment for positive hinge rotation about local S axis
BMUPS	Ultimate moment for positive hinge rotation about local S axis
BMCNS	Cracking moment for negtive hinge rotation about local S axis
BMYNS	Yield moment for negative hinge rotation about local S axis
BMUNS	Ultimate moment for negative hinge rotation about local S axis
RESIDS	Residual strength factor (fraction of ultimate moment) for local S axis
LENHS	Plastic hinge length for local S axis (Length units)
KYPS	Curvature at yield (positive) about local S axis (units = 1/Length)
THUPS	Ultimate plastic hinge rotation (positive) about local S axis (rotations are in radians - dimensionless)
THRPS	Plastic hinge rotation to residual strength (positive) about local S axis
THFPS	Plastic hinge rotation to failure (positive) about local S axis
KYNS	Curvature at yield (negative) about local S axis
THUNS	Ultimate plastic hinge rotation (negative) about local S axis
THRNS	Plastic hinge rotation to residual strength (negative) about local S axis

THFNS	Plastic hinge rotation to failure (negative) about local S axis
BMCPT	Cracking moment for positive hinge rotation about local T axis
BMYPT	Yield moment for positive hinge rotation about local T axis
BMUPT	Ultimate moment for positive hinge rotation about local T axis
BMCNT	Cracking moment for negative hinge rotation about local T axis
BMYNT	Yield moment for negative hinge rotation about local T axis
BMUNT	Ultimate moment for negative hinge rotation about local T axis
RESIDT	Residual strength factor (fraction of ultimate moment) for local T axis
LENHT	Plastic hinge length for local T axis
KYPT	Curvature at yield (positive) about local T axis
THUPT	Ultimate plastic hinge rotation (positive) about local T axis
THRPT	Plastic hinge rotation to residual strength (positive) about local T axis
THFPT	Plastic hinge rotation to failure (positive) about local T axis
KYNT	Curvature at yield (negative) about local T axis
THUNT	Ultimate plastic hinge rotation (negative) about local T axis
THRNT	Plastic hinge rotation to residual strength (negative) about local T axis
THFNT	Plastic hinge rotation to failure (negative) about local T axis
FESP1-4	Optional FEMA rotation limits for positive rotation about local S axis
FESN1-4	Optional FEMA rotation limits for negative rotation about local S axis
FETP1-4	Optional FEMA rotation limits for positive rotation about local T axis
FETN1-4	Optional FEMA rotation limits for negative rotation about local T axis

Notes:

This material model is elastic, except that a plastic hinge may form at end 2 (similar to *MAT_SEISMIC_BEAM). The backbone moment-rotation curve is calculated from the input parameters as follows:



1 = Cracking (positive rotation). Moment = BMCPS (about s-axis) or BMCPT (about t-axis). Rotation determined by elastic stiffness.

2 = Yield (positive rotation). Moment = BMYPS (about s-axis) or BMYPT (about t-axis). Rotation given for s-axis by THYPS = LENHS*KYPS (hinge length times yield curvature), and for t-axis by THYPT = LENHT*KYPT.

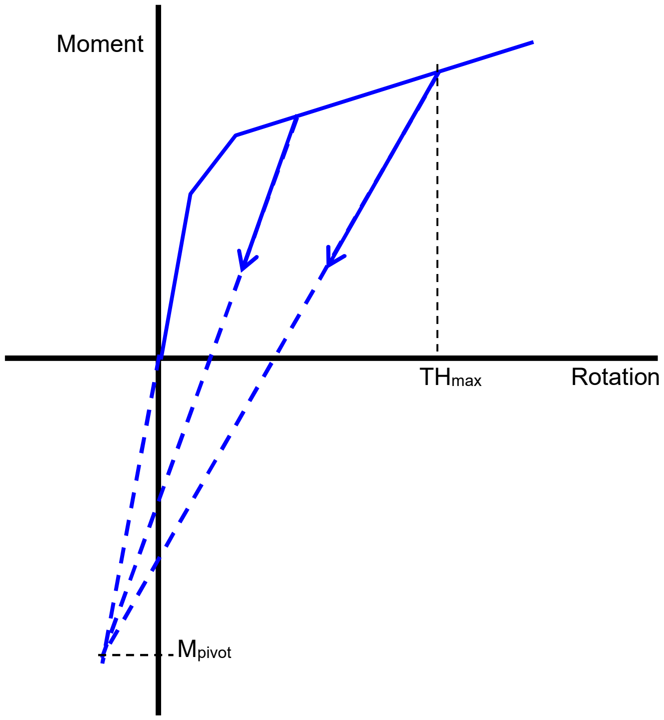
3 = Ultimate (positive rotation). Moment = BMUPS (about s-axis) or BMUPT (about t-axis). Plastic Rotation = THUPS (s-axis) or THUPT (t-axis). Plastic rotation is defined as (Total rotation – Yield rotation), where Yield rotation is THYPS or THYPT for s and t-axes respectively.

4 = Residual (positive rotation). Moment = RESIDS*BMUPS (about s-axis) or RESIDT*BMUPT (t-axis). Plastic rotation = THRPS (s-axis) or THRPT (t-axis). Default for THRPS = 1.5*THUPS, default for THRPT = 1.5*THUPT.

5 = Failure (positive rotation). Moment = zero. Plastic rotation = THFPS (s-axis) or THFPT (t-axis). Defaults are THFPS = 3.0*THUPS and THFPT = 3.0*THUPT.

Points 6, 7, 8, 9 and 10 are the equivalents of 1, 2, 3, 4 and 5 but for negative rotation. By default, the input parameters for negative rotation are equal in magnitude (but of the opposite sign) to those for positive rotation, but separate input values may be given if a different backbone curve is desired for negative rotation. "Positive" s-axis rotation at Node 2 (the end of the element where a hinge may form) is defined as Node 2 rotating positively about the s-axis relative to the line defined by Node1-Node2, and similarly for t-axis rotation.

Stiffness degradation



Degradation of stiffness is controlled by input parameter ALPHA, as shown here. The default ALPHA=1.0E8 implies negligible degradation.

The pivot moment is calculated as Mpivot = ALPHA*My, where My is BMYPS, BMYPT, BMYNS, or BMYNT as appropriate. TH_{max} is the maximum rotation excursion to date. Therefore the stiffness changes only when the previous TH_{max} is exceeded.

Strength degradation

Degradation of strength is applied as a scaling factor F on the backbone curve, controlled by input parameters BETA1 and BETA2. If BETA1 is non-zero, F decreases from 1.0 as the ductility (maximum plastic rotation excursion) increases. If BETA2 is non-zero, F decreases as the energy absorbed in hysteresis increases. Both BETA1 and BETA2 may be defined if desired.

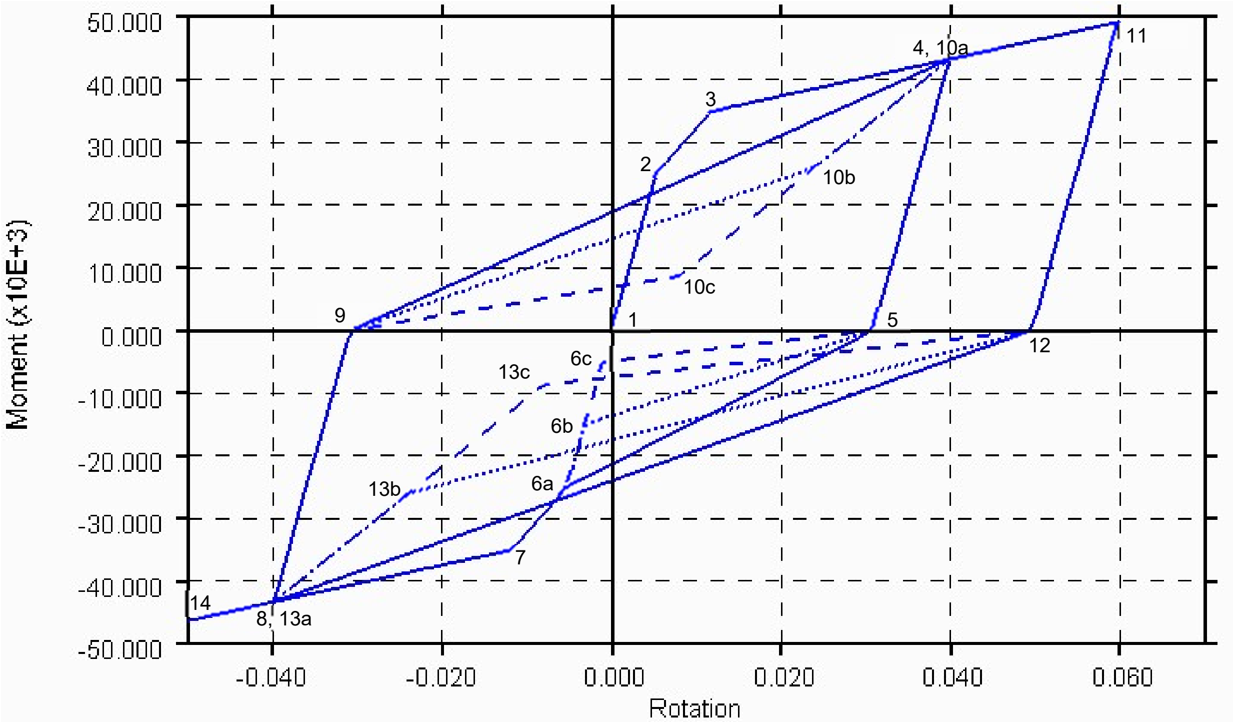
$F = (1 – BETA1*THP_{max}/THP_u)*(1 – BETA2*H/(1-BETA2)*H_u)$

Where THP_{max} = maximum plastic rotation excursion (with plastic rotation defined as above), THPu= ultimate plastic rotation (e.g. THUPS), H = Energy absorbed by hinge, H_u =Area under backbone curve between cracking and ultimate points.

Hysteresis Law and Pinching

The hysteresis law may be seen in the diagram below (solid line). Unloading (e.g. between points 11 and 12) follows the elastic stiffness, which may be degraded if parameter ALPHA has been defined, until Moment = 0. Thereafter, a straight line is drawn to the previous maximum excursion on the backbone curve (for example, point 13a is identical to point 8).

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 obtained in the model using input parameter GAMMA, as shown below. The default, GAMMA=1, gives no pinching. The “pinch points” (e.g. 10b, 13b) are given by Moment = GAMMA*M_{max}, Rotation = GAMMA*TH_{max}, where M_{max}, TH_{max} = the moment and rotation at the previous maximum excursion on the backbone curve; for example, when calculating pinch point 10b, the moment and rotation at Point 4 would be used.



Output

For this material model, special output parameters are written to the d3plot and d3thdt files. Some post-processors may interpret this data as if the elements were integrated beams. Depending on the post-processor used, the data may be accessed as follows:

Integration point	1	2	3	4	
Extra (history) variable	1	6	11	16	XX(RR) axial stress
	2	7	12	17	XY(RS) shear stress
	3	8	13	18	ZX(TR) shear stress
	4	9	14	19	Equivalent plastic strain
	5	10	15	20	XX(RR) axial strain

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

Extra variable 4: Total rotation about s-axis at node 2
Extra variable 5: Plastic rotation about s-axis at node 2
Extra variable 6: Total rotation about s-axis at node 2
Extra variable 7: Plastic rotation about s-axis at node 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 16: FEMA rotation flag

The FEMA output flag for hinge rotation is given the value 0, 1, 2, 3, or 4:

0 means that the rotation has not exceeded yield;
1 means that the rotation has exceeded yield but not ultimate;
2 means that the rotation has exceeded ultimate but has not reached the residual;
3 means than the rotation has exceeded the residual but the element has not failed;
4 means that the element has failed.

The plastic rotation values that trigger the FEMA flag to take the values 0, 1, 2, 3 or 4 correspond by default to points 2,3,4,5 on the backbone curve for positive rotation, and to points 7,8,9,10 on the backbone curve for negative rotation. These rotation values may be overridden on Cards 6 and 7.