

LS-DYNA features:

Reinforced Concrete beams and shells  
with \*MAT\_CONCRETE\_EC2

This presentation is a basic introduction to \*MAT\_CONCRETE\_EC2 (also known as \*MAT\_172). For further details see under Remarks in the Keyword Manual.

## \*MAT\_CONCRETE\_EC2

- Reinforced concrete shells & beams for structural engineering
  - Element sizes typically  $\sim 0.1$  to  $\geq 1$  metre
  - Not modelling the individual rebars
- Applicable to:
  - Quasi-static, basic structural applications
  - Cyclic loading e.g. seismic
  - Fire engineering
- Not applicable to:
  - High strain-rate applications
  - Applications where rebars need to be modelled individually
  - Cracking due to through-thickness shear
  - 3D effects or highly confined concrete
- Defaults taken from Eurocode 2 (“EC2”)

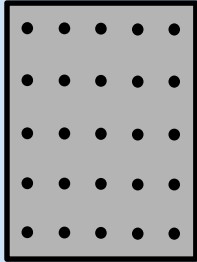
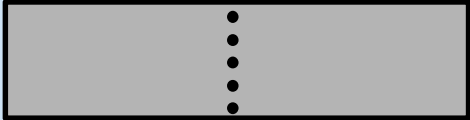
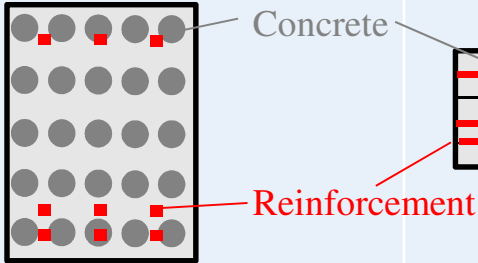
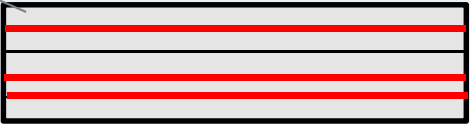
# Concrete and/or reinforcement

- \*MAT\_CONCRETE\_EC2 can model concrete and/or reinforcement, determined by parameter FRACR
  - Plain concrete: FRACR=0
  - Reinforcement: FRACR=1
  - Smearred, e.g. FRACR=0.02

Here, FRACR means the maximum out of FRACRX and FRACRY (reinforcement fractions in local X and Y directions)

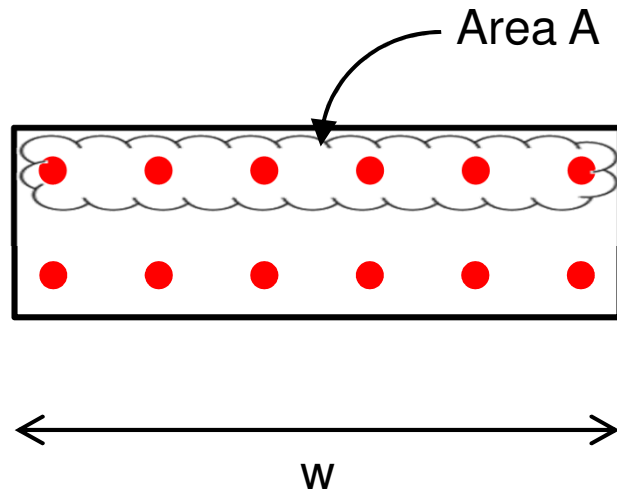
*MAT_CONCRETE_EC2_TITLE									
Smearred 2%									
Concrete – basic inputs	\$:	mid	ro	fc	ft	typec	unitc	ecuten	fcc
		1002	2400.0	4.5E7	3000000.0	0.0	1.0E-6	0.0	0.0
Rebar inputs	\$:	esoft	lchar	mu	taumxf	taumxc	ecragg	aggsz	unitl
		0.0	0.0	0.0	0.0	0.0	0.0	2.0E-2	1000.0
Additional inputs	\$:	ymreinf	prreinf	sureinf	typer	fracrx	fracry	lcrsu	lcalps
		2.0E11	0.3	4.8E8	5.0	2.0E-2	0.0	13	0
	\$:	aopt	et36	prt36	ecut36	lcalpc	degrad	ishchk	unifac
		0.0	0.0	0.0	0.0	0	0.0	0	0.0

# Input methods for defining reinforcement

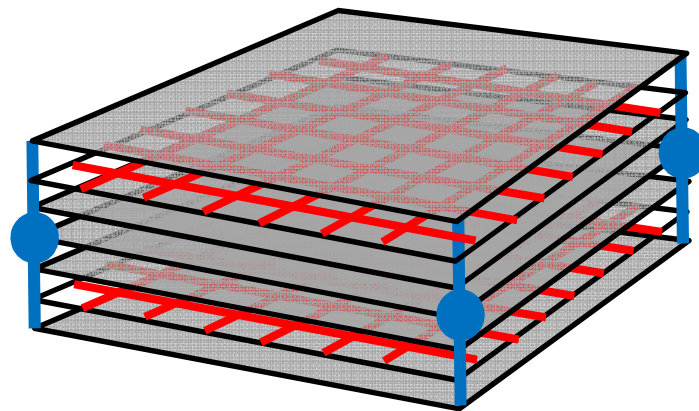
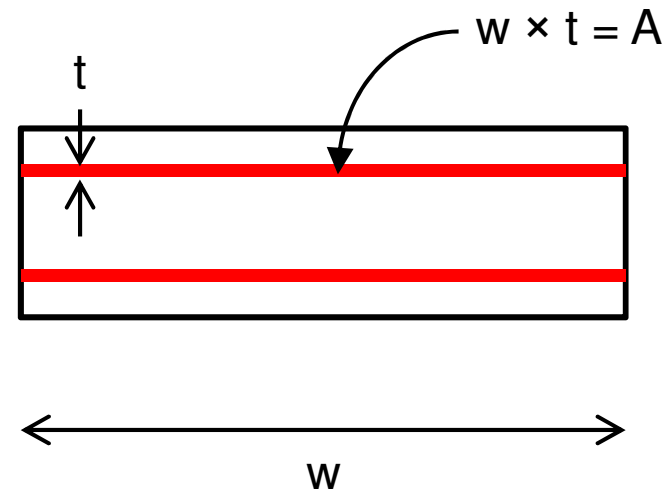
	Beams	Shells
<p>Smearred reinforcement</p> <p>Uniform material properties e.g. 98% concrete, 2% steel</p>	 <p>*SECTION_BEAM, e.g. NIP=5-10 (n x n int points)</p>	 <p>*SECTION_SHELL, e.g. NIP=5-10 (int pts thru thk)</p>
<p>Detailed reinforcement</p> <p>Separate material properties for concrete and steel</p>	 <p>*INTEGRATION_BEAM, Define location, area and material of each int pt.</p>	 <p>*PART_COMPOSITE, Define thickness and material of each layer.</p>

# Layered shell model - reinforcement

Real Section



LS-DYNA



# Concrete properties: basic

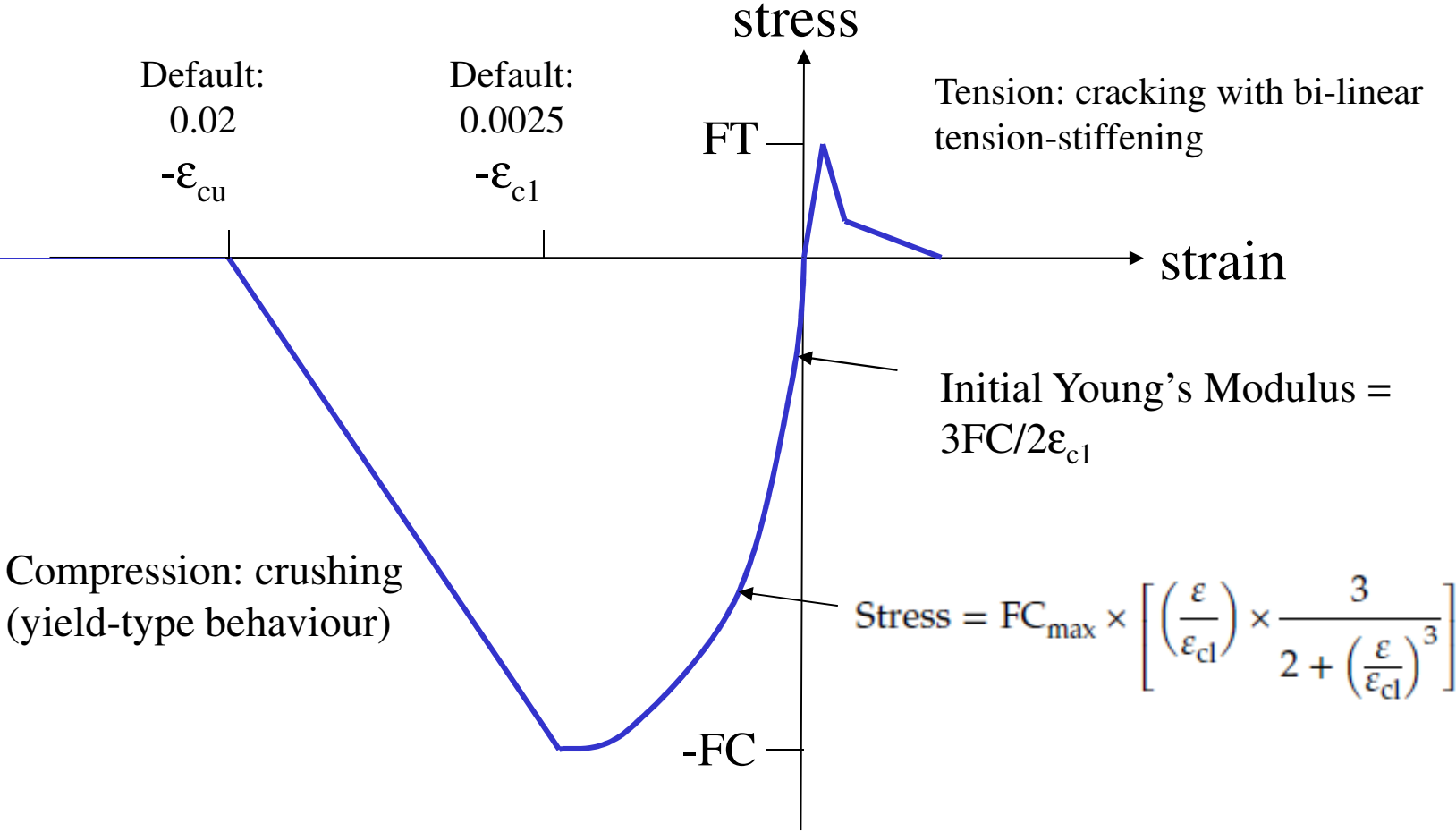
As a minimum, define MID, Density RO, Compressive strength FC, and Tensile strength FT.  
Recommended also to define aggregate size AGGSZ together with length unit factor UNITL.

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	FC	FT	TYPEC	UNITC	ECUTEN	FCC
Type	A8	F	F	F	F	F	F	F
Default	Basic inputs N.B. elastic modulus not defined...					1.0	0.0025	FC

Card 2	1	2	3	4	5	6	7	8
Variable	ESOFT	LCHAR	MU	TAUMXF	TAUMXC	ECRAGG	AGGSZ	UNITL
Type	F	F	F	F	F	F	F	F
Default	See notes	0.0	0.4	10 <sup>20</sup>	1.161 × FT	0.001	0.0	1.0

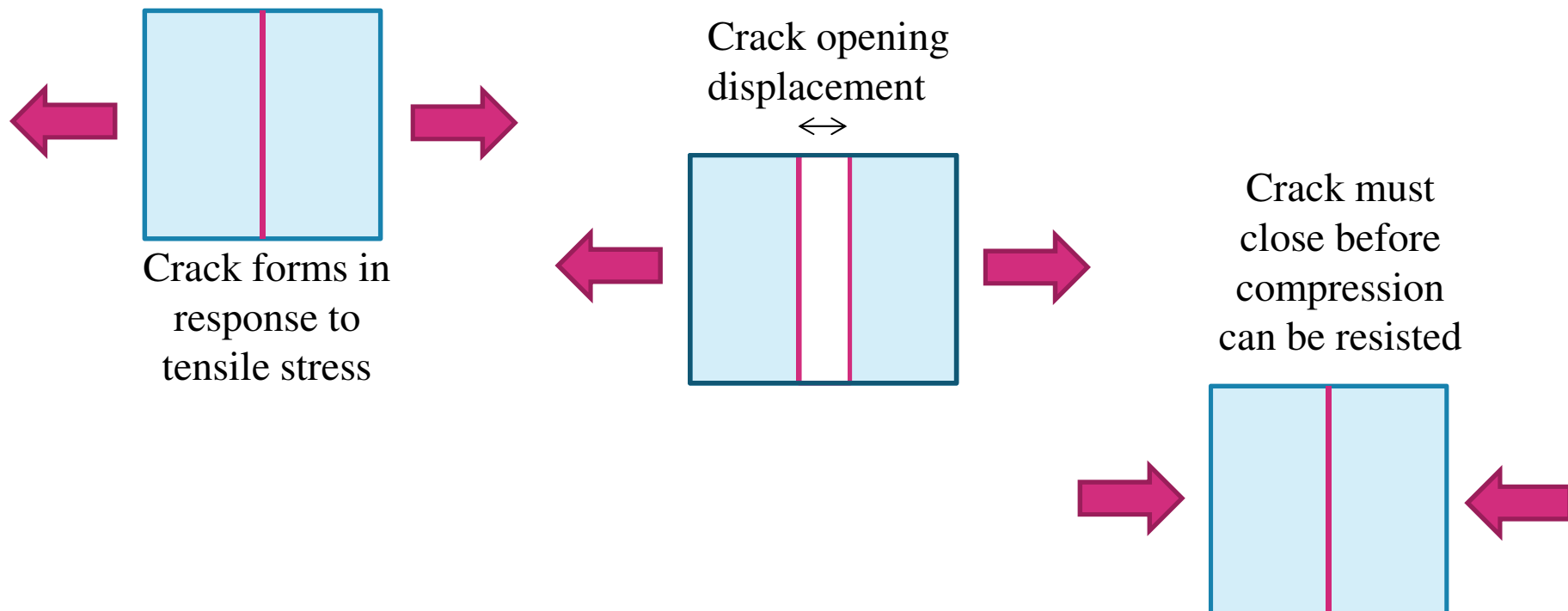
# Concrete properties: basic



At its simplest, the user defines only FT and FC. The above stress-strain relation is generated automatically using data and formulae from Eurocode 2.

# Concrete: cracking behaviour

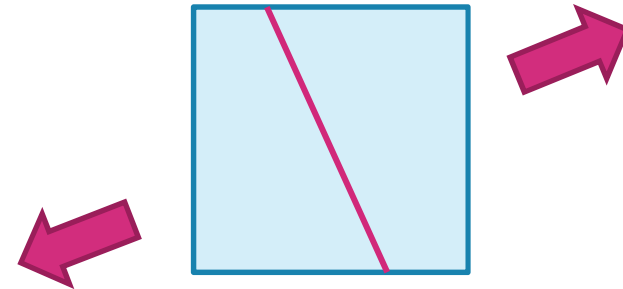
- Smearred crack: mesh does not split apart; the presence of the crack is modelled in the stress-strain behaviour
- Cyclic behaviour: crack opening displacement is tracked



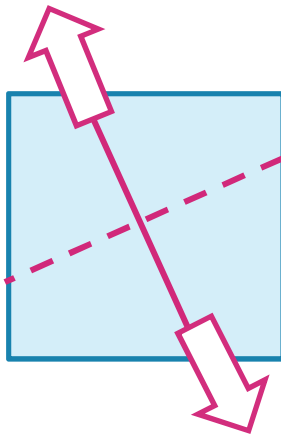
# Concrete: cracking behaviour

- Non-rotating crack
  - The first crack can form at any angle in response to principal tensile stress
  - The crack directions become fixed by creation of the first crack
  - Further cracks can form only at certain angles to the first crack

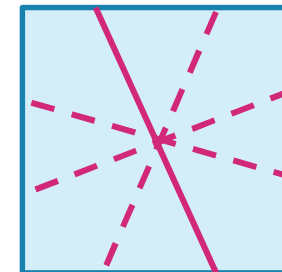
Maximum  
(tensile)  
principal stress



First crack forms when maximum tensile principal stress first reaches  $F_T$ . This sets the angle of cracks in this element for the rest of the analysis.



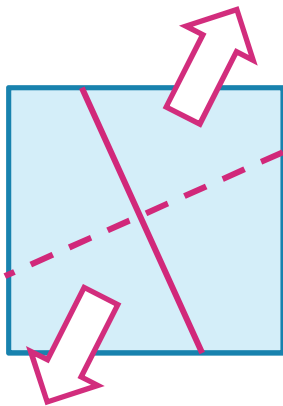
LS-DYNA R9 and below: one further crack can form at 90 degrees to first crack



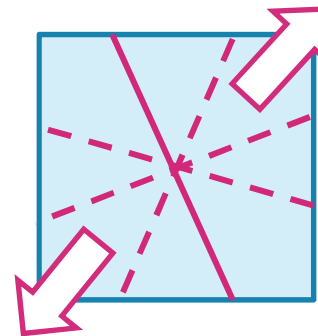
LS-DYNA R10 and above: three further cracks can form (90, 45, 135 degrees)

# Concrete: limitations

- Non-rotating crack
  - The tensile strength limit  $FT$  applies only in directions perpendicular to a potential crack
  - After the first crack is formed, tensile stresses can exceed  $FT$  in directions that are not perpendicular to a potential crack, e.g. at 45 degrees to the first crack in LS-DYNA R9, or at 22.5 degrees to the first crack in LS-DYNA R10.
  - The “error” (amount by which the tensile stress exceeds  $FT$ ) is usually less in R10 than in R9 – this is why the extra potential cracks were added in R10.
- Cracks form due to in-plane tension only, not through-thickness shear



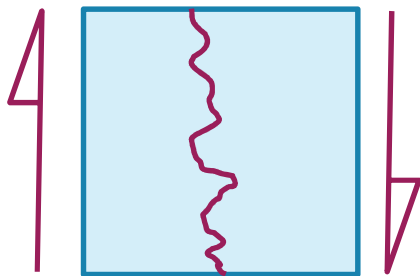
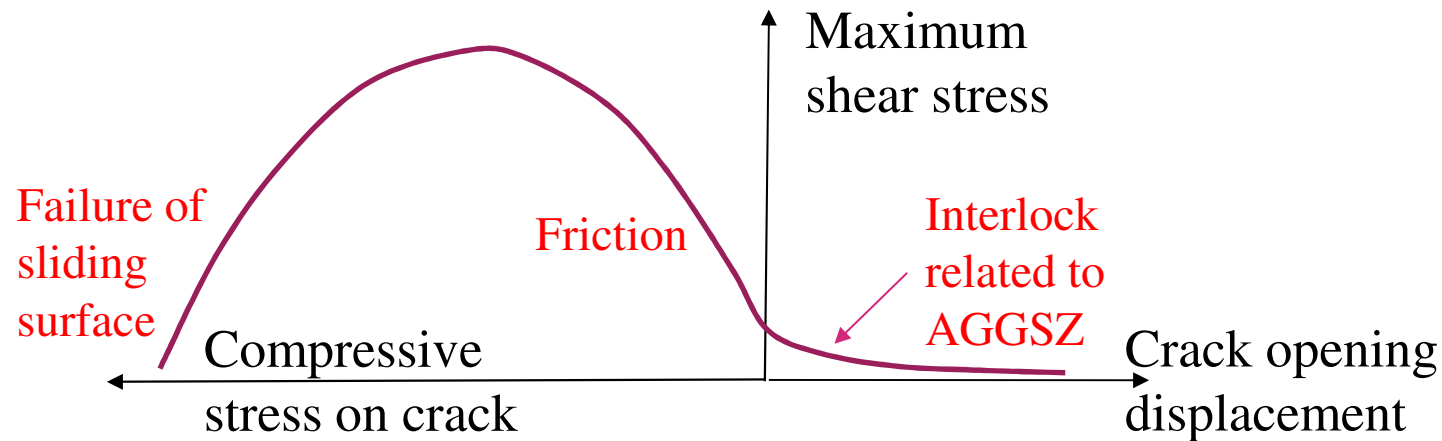
LS-DYNA R9 and below: tensile stress at 45 degrees to first crack could exceed  $FT$ .



LS-DYNA R10 and above: tensile stress at 22.5 degrees to first crack could exceed  $FT$ .

# Concrete: shear across cracks

- Aggregate interlock model from Norwegian Standard NS3473 (recommended; used if  $AGGSZ > 0$ )



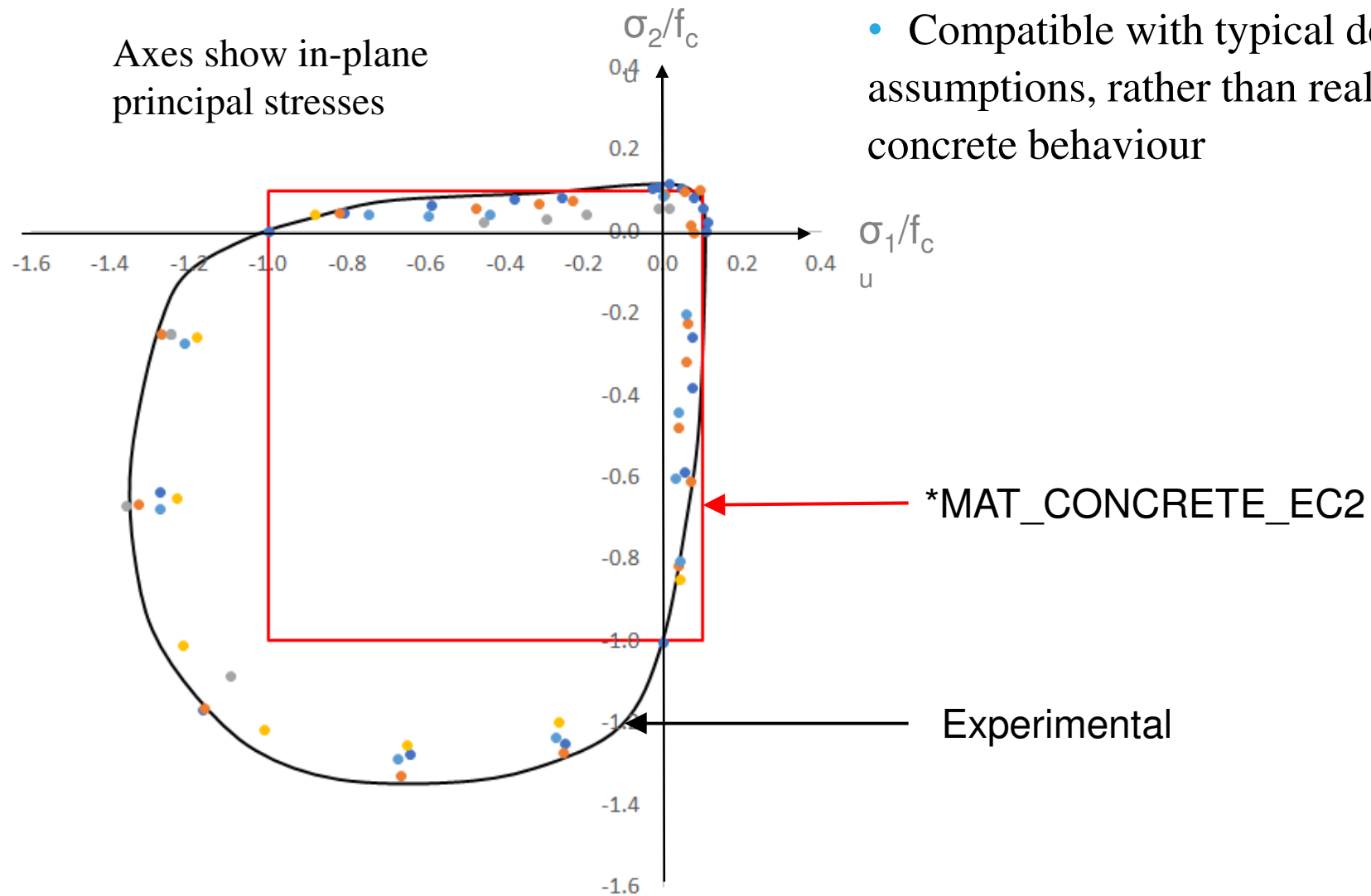
This applies to resultant shear stress (through-thickness and in-plane), on the crack plane.

Through thickness shear stress cannot cause cracking, and is unlimited before cracking occurs, but its magnitude becomes limited (as described in this slide) after cracking occurs.

- Simple friction model also available (less realistic)

# Concrete: yield surface (shells)

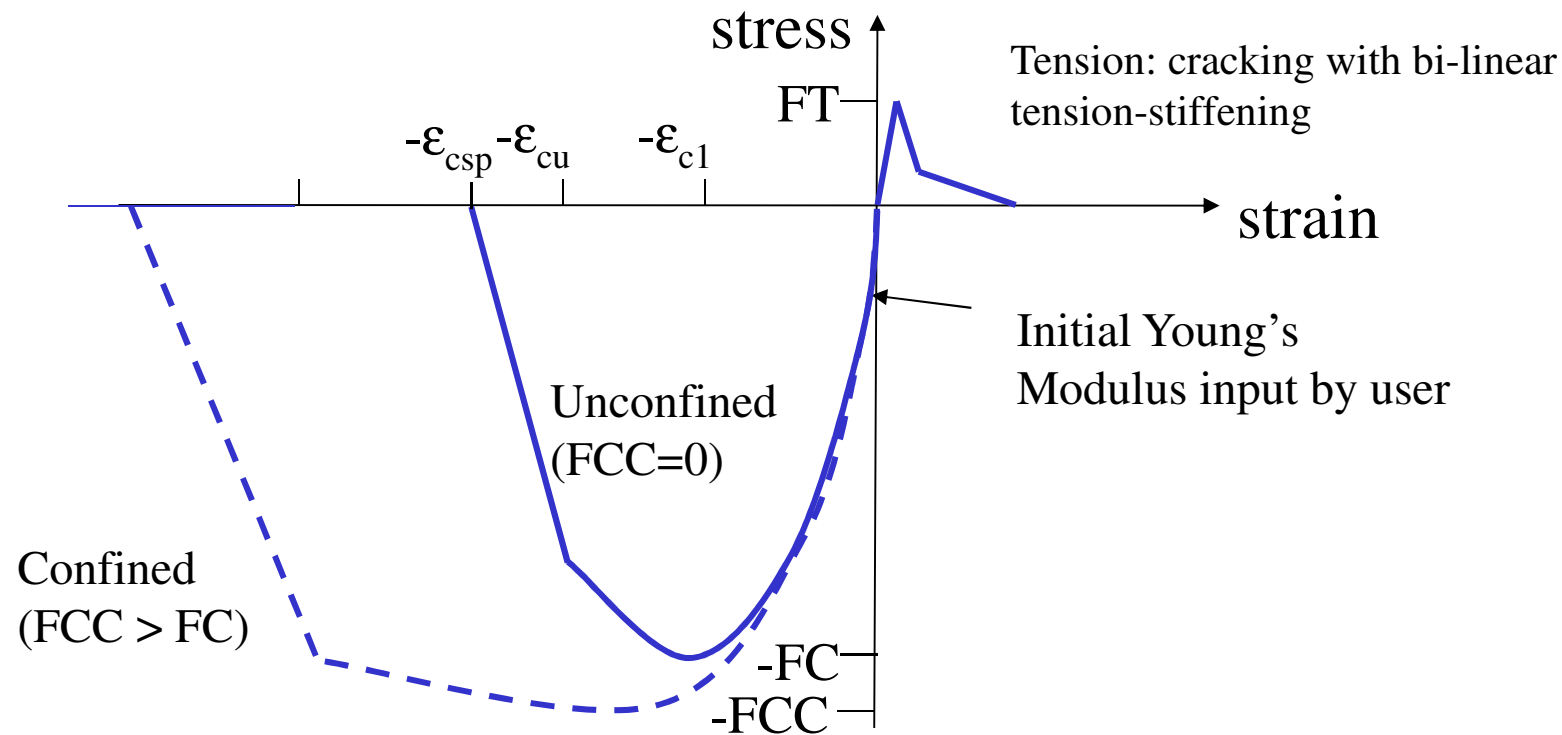
Axes show in-plane principal stresses



- Compatible with typical design assumptions, rather than realistic concrete behaviour

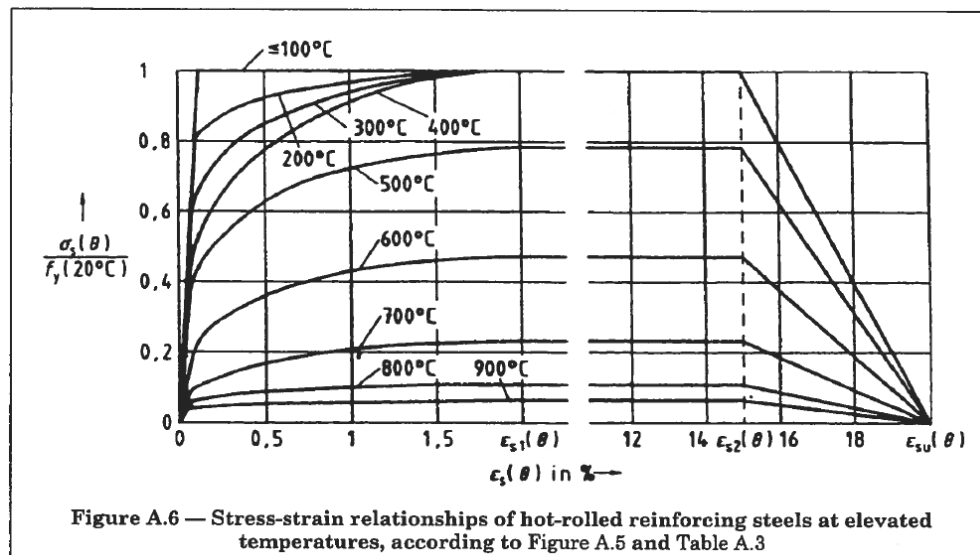
# Concrete properties: for seismic analysis

- “Mander” compression curve (TYPEC=6). Fewer defaults, more user input. Mander, J.B., M.J.N. Priestley, and R. Park 1984. *Theoretical Stress-Strain Model for Confined Concrete*. Journal of Structural Engineering. ASCE. 114(3). 1804-1826.
- Use different \*MAT card properties for unconfined cover concrete versus confined concrete within the rebar cage



# Concrete properties: for thermal/fire analysis

- TYPEC = 7,8
  - Thermal expansion coefficients automatically generated (do not use \*MAT\_ADD\_THERMAL\_EXPANSION)
  - Material properties soften with increasing temperature
  - Softening factors hard-wired to tabulated values in EC2-2 Annex
  - Some user-input options also available



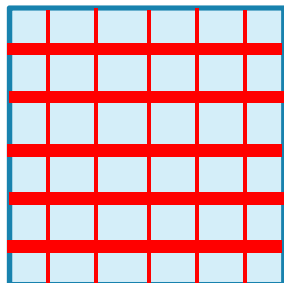
Example: stress/strain relations for hot-rolled reinforcing steel at elevated temperatures, from EC2 (ENV 1992-1-2 1995)

# Concrete: meanings of TYPEC

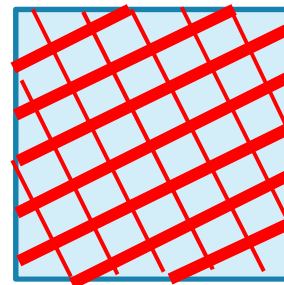
TYPEC	Source of defaults	Thermal softening & expansion	Notes/recommendation
0 1 2 4 5	Draft EC2 Annex (Fire engineering) ENV 1992-1-2:1995	Y	Basic option
3	Simple non-thermally-sensitive	N	
6	Mander	N	Seismic analysis; input FCC>FC for confined concrete
7 8	EC2-1-2:2004 (fire)	Y	Fire analysis
9	EC2 general struct. Engrg. EC2 1-1:2004	N	Use when close adherence to Eurocode is important. Can input the concrete strength class (e.g. 30 for C30 concrete) and let the other properties be taken automatically from EC2 1-1:2004 Table 3.1

# Reinforcement: basic

- Reinforcement option within \*MAT\_CONCRETE\_EC2
- Bars act uniaxially (no shear stress)
- Beams: bars act only in the beam's axial direction
- Shells: separate area fractions are input for local X and Y directions;  
shear stress is zero in-plane and through-thickness.
  - Use AOPT to define bar directions. Default: same as element local axes, i.e. Node 1 to Node 2 is local X



Default:  
Rebars aligned in  
element X, Y axes

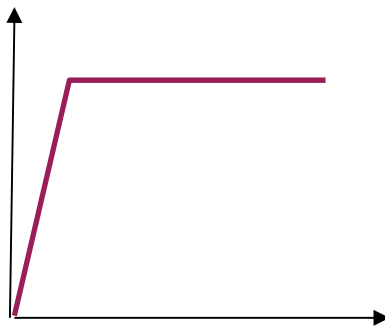


With AOPT:  
Rebars at user-  
controlled angle

# Reinforcement: basic

Card 3	1	2	3	4	5	6	7	8
Variable	YMREINF	PRREINF	SUREINF	TYPER	FRACRX	FRACY	LCRSU	LCALPS
Type	F	F	F	F	F	F	I	I
Default	none	0.0	0.0	2.0	0.0	0.0	none	none

Simple elastic/perfectly plastic stress/strain relation



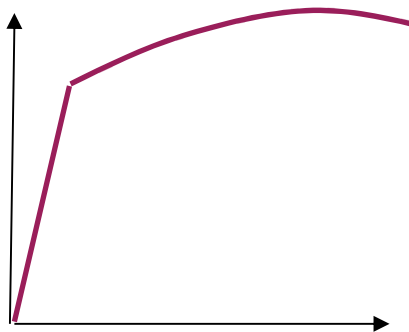
To model smeared reinforcement: input FRACRX and/or FRACY = fraction of reinforcement across whole section, e.g. 0.02

To model detailed reinforcement, i.e. an integration point representing pure reinforcement: input FRACRX = 1.0 and/or FRACY = 1.0

# Reinforcement: basic

Card 3	1	2	3	4	5	6	7	8
Variable	YMREINF	PRREINF	SUREINF	TYPER	FRACRX	FRACY	LCRSU	LCALPS
Type	F	F	F	F	F	F	I	I
Default	none	0.0	0.0	2.0	0.0	0.0	none	none

Add a curve if required

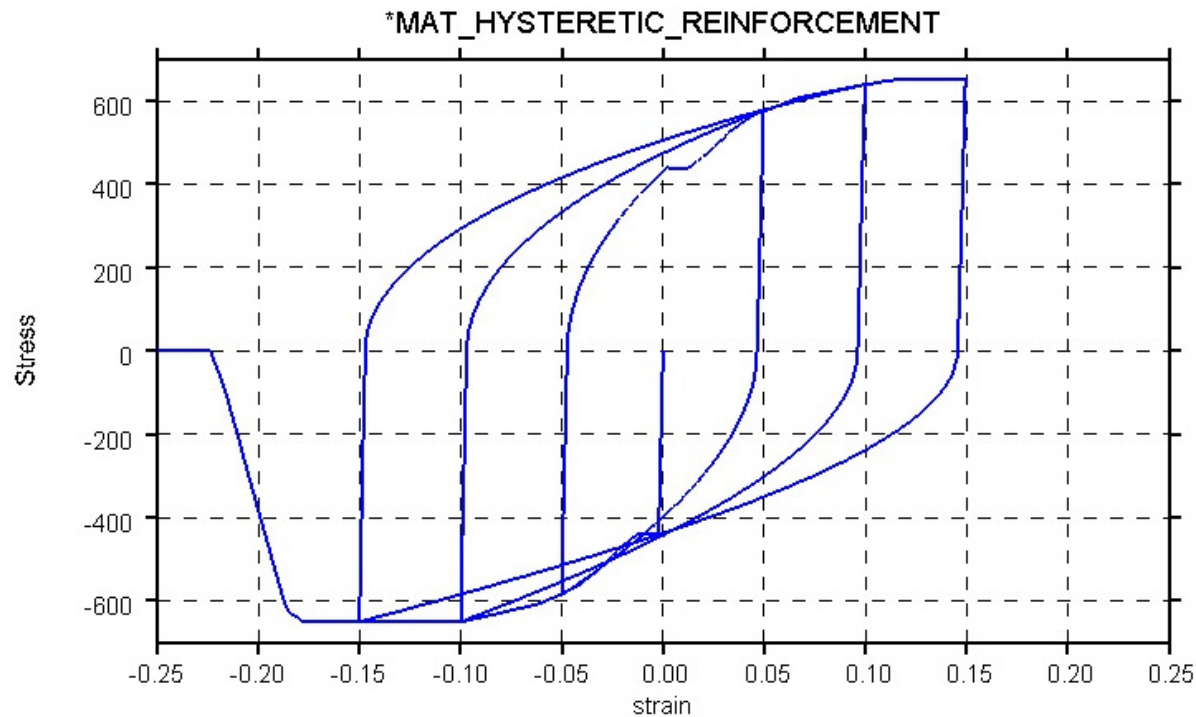


To model smeared reinforcement: input FRACRX and/or FRACY = fraction of reinforcement across whole section, e.g. 0.02

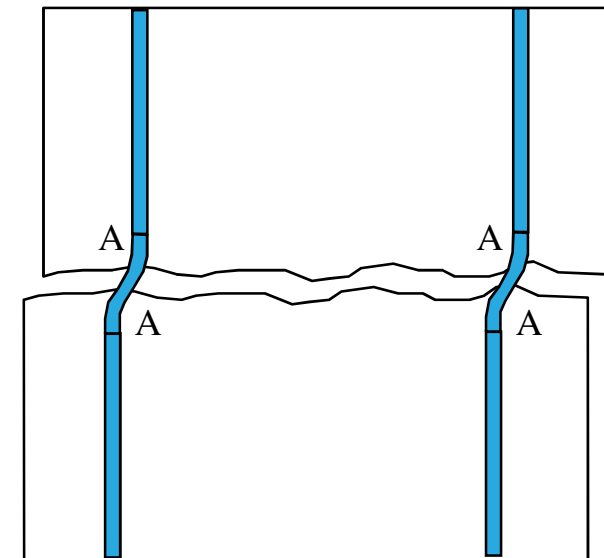
To model detailed reinforcement, i.e. an integration point representing pure reinforcement: input FRACRX = 1.0 and/or FRACY = 1.0

# Reinforcement: improved cyclic behaviour

- \*MAT\_HYSTERETIC\_REINFORCEMENT (\*MAT\_203)
- Use within reinforced concrete section defined by \*PART\_COMPOSITE or \*INTEGRATION\_BEAM: Concrete = MAT\_172, Reinforcement = MAT\_203



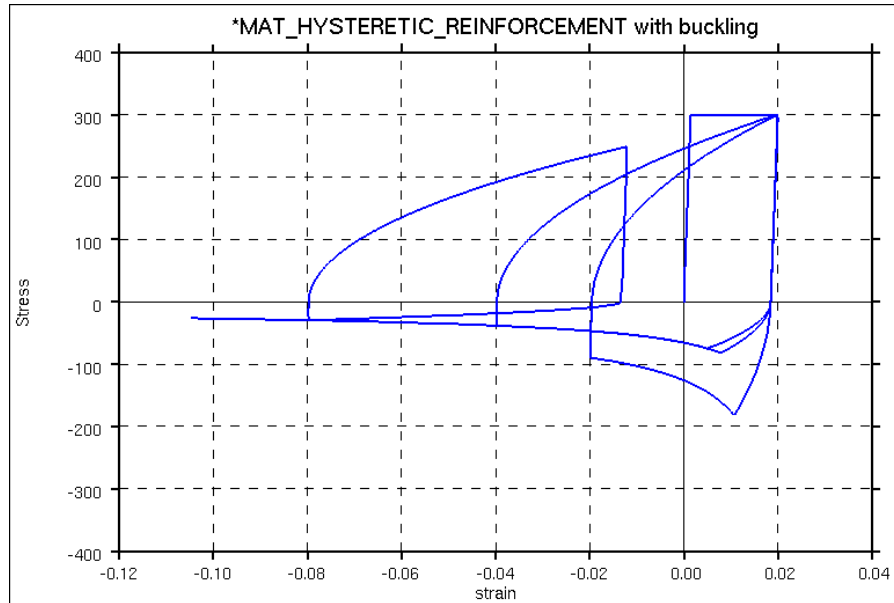
Axial response with Bauschinger effect  
(Example without bar buckling)



Shear – dowel action  
(optional)

# Reinforcement: improved cyclic behaviour

- \*MAT\_HYSTERETIC\_REINFORCEMENT (\*MAT\_203)



Axial response with Bauschinger effect (Example with bar buckling, invoked by inputting the slenderness ratio LAMDA)

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	YM	PR	SIGY	LAMDA	SBUCK	POWER
Type	I	F	F	F	F	F	F	F
Default	none	0.0	0.0	0.0	0.0	0.0	SIGY	0.5

# \*MAT\_HYSTERETIC\_REINFORCEMENT

Card 1	1	2	3	4	5	6	7	8
Variable	MID	R0	YM	PR	SIGY	LAMDA	SBUCK	POWER
Type	I	F	F	F	F	F	F	F
Default	Basic inputs				0.0	0.0	Bar buckling	

Card 2	1	2	3	4	5	6	7
Variable	FRACX	FRACY	LCTEN	LCCOMP	AOPT	EBU	DOWNSL
Type	F	F	F	F	F	F	F
Default	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Card 3	1	2	3	4	5	6	7
Variable	DBAR	FCDOW	LCHARD	UNITC	UNITL	Dowel action	
Type	F	F	F	F	F		
Default	0.0	0.0	0.0	1.0	1.0		