# 2-D RC Constitutive Relationship Subroutine "RCFER2002"

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## Important Reference Document and Program

- Important Reference Document
  - "Nonlinear FEA for RC Structure", JIANG Jianjing
  - "Principle of Reinforced Concrete" , GUO Zhenhai
  - "FEA of RC and Ultimate analysis for Plate and Shell", J.M. SHEN, C.Z. WANG, J.J. JIANG
  - "FEA for Reinforced Concrete", Q. L. KANG
  - "Finite Element Analysis of Reinforced Concrete", Bazant
  - "Finite Element Method for Nonlinear Problems", Bathe

## Important Reference Document and Program

- Important Reference Program：
  - RCFER, Coded by J.J. JIANG
  - ADINA81 & ADINA84, Coded by Bathe
  - NONSAP, Coded by Bathe
  - RCNFEA, Coded by C.C. LI

## Basic Information of RCFER2002

- Fortran 77+Fortran 90
- Double Precision
- About 3500 Lines
- About 90,000 Characters
- More than 60 subroutine

## Application of RCFER2002

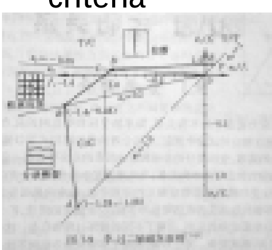
- Courses Education
  - "RC Structure"(for Undergraduate Students)
  - "FEA for RC"(for Graduate Students)
- Research
  - RCPEFG (Code by LU)
  - RCFER (Code by JIANG)
  - RC Element analysis
  - Adjustment for RC Constitutive Relationship

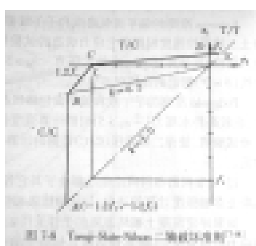
## Basic Request for RCFER2002

- Can simulate the stress and deformation of concrete under planar compression, tension, shear and combined load case
- Can simulate the cracking and cracking surface effect of concrete
- Can be embedded into Msc.MARC with user subroutine function of Msc.MARC
- Can simulate the behavior of concrete under cycle load conditions

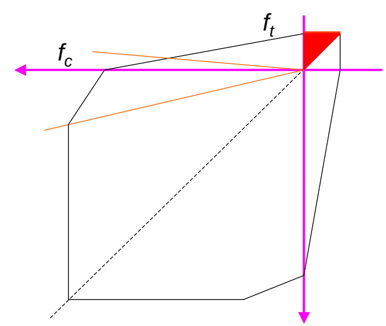
## Strength Criteria

- Using the simplified planar strength criteria based on Li-Guo and Tasuji-Slate-Nilson criteria





## Strength Criteria (T/T)

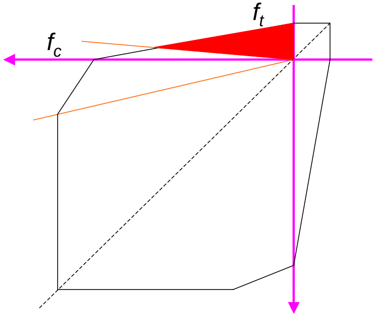



Both Tension

$\sigma_1>0$ & $\sigma_2>0$

Tension Failure

## Strength Criteria (C/T)



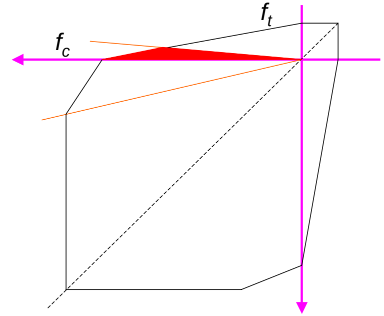

Compression/Tension

$\sigma_1>0$ , $\sigma_2<0$

&, $\sigma_1/\sigma_2<-0.05$

Tension Failure

## Strength Criteria (C/T)



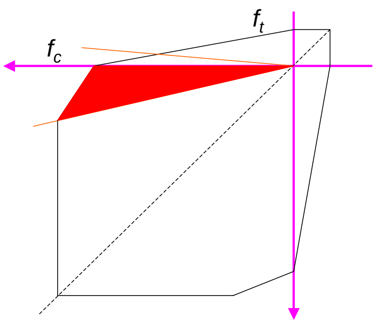

Compression/Tension

$\sigma_1>0$ , $\sigma_2<0$

& $\sigma_1/\sigma_2>-0.05$

Uniaxial Compression Failure

## Strength Criteria (C/C)



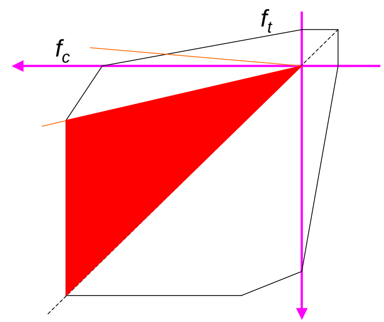

Both Compression

$\sigma_1<0$ , $\sigma_2<0$

& $\sigma_1/\sigma_2<0.2$

Uniaxial Compression Failure

## Strength Criteria (C/C)



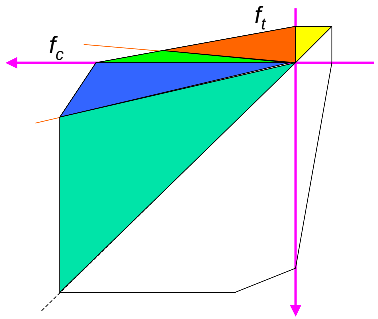

Both Compression

$\sigma_1<0$ , $\sigma_2<0$

& $\sigma_1/\sigma_2>0.2$

Biaxial Compression Failure

## Summary of Strength Criteria

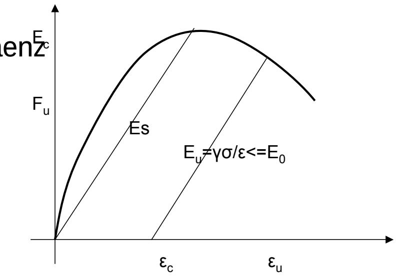



Divide the failure of concrete in planar conditions into 3 failure model, 5 stress combination. Hence, the result has obvious physical meanings.

## Equivalent Uniaxial Stress-Strain Relationship

- Uniaxial Compression Stress-strain Relationship
  - Developed by Saenz

$$E_t = \frac{\left[1-\left(\frac{\varepsilon}{\varepsilon_f}\right)^2\right]E_0}{\left[1+\left(\frac{E_0}{E_s}-2\right)\left(\frac{\varepsilon}{\varepsilon_f}\right)+\left(\frac{\varepsilon}{\varepsilon_f}\right)^2\right]^2}$$



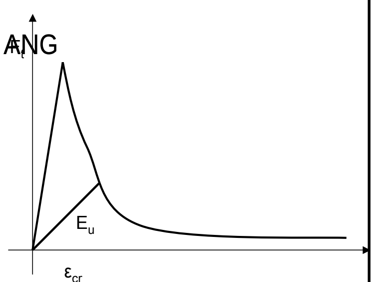

## Equivalent Uniaxial Stress-Strain Relationship

- Uniaxial Compression Stress-strain Relationship
  - Developed by J.J. JIANG

$$\sigma = f_t e^{-a(\varepsilon-\varepsilon_{cr})}$$

- Shear Resist Factor

$$\beta = (\beta_0-\beta_1)e^{-a(\varepsilon-\varepsilon_{cr})}+\beta_1$$




## Loading/Unloading Relationship

- Loading/Unloading is judged in the stress space when the concrete is inside the failure surface
- Loading/Unloading is judged in the strain space when the concrete is outside the failure surface
- 6 nonlinear index is used Evv(1~6)
  - If Evv(I)<=Evmax(I), Unloading/Reloading, Unloading Stiffness is used*
  - If Evv(I)> Evmax(I), Loading along the envelop curve, Current loading stiffness is used.

## Nonlinear Index

- Evv(1): Nonlinear index for biaxial failure
- Evv(2): Nonlinear index for uniaxial failure
- Evv(3): Nonlinear index when no failure happens
- Evv(4): Nonlinear index for crack, only one crack
- Evv(5): Nonlinear index for the 1st crack, two crack conditions
- Evv(6): Nonlinear index for the 2nd crack, two crack conditions

## Unify for Nonlinear Index

- Evv(1):

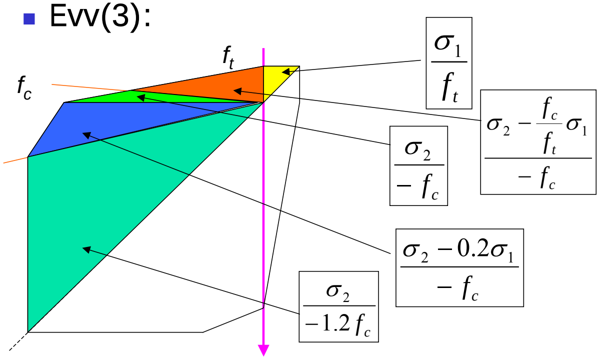
$$(1.2\varepsilon_c + d\varepsilon_2^*)/\varepsilon_c$$

$$d\varepsilon_2^* = (d\varepsilon_2 - 0.2d\varepsilon_1)/0.96$$

- Evv(2) $(\varepsilon_c + d\varepsilon_2)/\varepsilon_c$

## Unify for Nonlinear Index

- Evv(3):




## Unify for Nonlinear Index

- Evv(4): $1 + d\varepsilon_1^* E_0 / f_t$
- Evv(5) $1 + d\varepsilon_1^* E_0 / f_t$
- Evv(6) $1 + d\varepsilon_2^* E_0 / f_t$

## Crack Opening and Closing

- Once the stress in crack direction σ<0, we consider the crack is closed
- Once the crack has closed, the crack can not bearing any tensional force=>CrRelease(i)=1

## Independent Variable List (1)

- SIG(3),EPS(3),dEPS(3),dSIG(3): ${}^{t}\sigma_{ij}$, ${}^{t}\varepsilon_{ij}$, $d\sigma_{ij}$, $d\varepsilon_{ij}$
- Stress(3),Strain(3) ${}^{t+dt}\sigma_{ij}$, ${}^{t+dt}\varepsilon_{ij}$
- E0,MU0,Fc,Ft,SIGMAU,EPSC,EPSU
  - $E$, $\mu$, $f_c$, $f_t$, $\sigma_u$, $\varepsilon_c$, $\varepsilon_u$
- N(3,3), T(3,3) Coordination transform matrix
- D(3,3) constitutive matrix
- SIGP(3), EPSP(3) ${}^{t}\sigma_{i}$, ${}^{t}\varepsilon_{i}$ principle stress/strain

## Independent Variable List (2)

- dSIGP(3), dEPSP(3) $d\sigma_i$, $d\varepsilon_i$ Principle stress/strain increment
- dEPSP1(3),equivalent principle strain increment
- Evv(6), Evmax(6) nonlinear index
- Epstate, AddLoad load condition index
- Crack =-2 Biaxial Compression Failure, -1 Uniaxial Tension Failure, 0 No Failure, 1 One Crack 2 Two Crack, 100 Entire Failure

## Independent Variable List (3)

- ANGLE Cracking Angle
- ANG, Alpha， Principle stress angle, principle stress ratio
- A1,A2,Beta0,Beta1, cracking surface parameter
- Inc, Ncycle, increment, sub-increment
- ITEM, State index

## Subroutine List (1)

- Con_GetD(Lxz_Con): General Control Subroutine
- Con_Crack1(C) when Crack==-2 biaxial compression failure
- Con_Crack2(C) when Crack==-1 uniaxial compression failure
- Con_Crack3(C) when Crack==0 no failure
- Con_Crack4(C) when Crack==1 one crack
- Con_Crack5(C) when Crack==2 two crack
- Con_Crack100(C) when Crack==100 entire failure

## Subroutine List (2)

- Con_N2Crack01(C) biaxial compression failure, under tensile stress, entire failure
- Con_N2Crack02(C) biaxial compression failure, loading
- Con_N2UnLoad(C) biaxial compression failure, Unloading

## Subroutine List (3)

- Con_N1Crack01(C) uniaxial compression failure, under tensile stress, entire failure
- Con_N1Crack02(C) uniaxial compression failure, loading
- Con_N1UnLoad(C) uniaxial compression failure, Unloading

## Subroutine List (4)

- Con_NoCrack01(C) no crack, C/C, $\alpha > 0.2$ ,Loading/Loading
- Con_NoCrack02(C) no crack, C/C, $\alpha < 0.2$ ,Loading/Loading
- Con_NoCrack03(C) no crack, C/T, $\alpha < -0.05$ ,Loading/Loading
- Con_NoCrack04(C) no crack, C/T, $\alpha > -0.05$, Loading/Loading
- Con_NoCrack05(C) no crack, T/T, Loading/Loading

# Subroutine List (5)

- Con_NoUnLoad01(C) no crack,
  C/C, α >0.2 ,UnLoading/UnLoading
- Con_NoUnLoad02(C) no crack, C/C, α <0.2 , UnLoading/UnLoading Con_NoUnLoad03(C) no crack, C/T, α <-0.05 , UnLoading/UnLoading
- Con_NoUnLoad04(C) no crack, C/T, α >-0.05, UnLoading/UnLoading
- Con_NoUnLoad05(C) no crack, T/T, UnLoading/UnLoading

# Subroutine List (6)

- One crack, closed, just like no crack
- Con_P1Crack01(C) no crack, C/C, α >0.2 ,Loading/Loading
- Con_P1Crack02(C) no crack, C/C, α <0.2 ,Loading/Loading
- Con_P1Crack03(C) no crack, C/T, α <-0.05 ,Loading/Loading
- Con_P1Crack04(C) no crack, C/T, α >-0.05, Loading/Loading
- Con_P1Crack05(C) no crack, T/T, Loading/Loading
- Con_P1UnLoad01(C) no crack, C/C, α >0.2 ,UnLoading/UnLoading
- Con_P1UnLoad02(C) no crack, C/C, α <0.2 , UnLoading/UnLoading Con_P1UnLoad03(C) no crack, C/T, α <-0.05 , UnLoading/UnLoading
- Con_P1UnLoad04(C) no crack, C/T, α >-0.05, UnLoading/UnLoading
- Con_P1UnLoad05(C) no crack, T/T, UnLoading/UnLoading

# Subroutine List (7)

- One crack,opened, if there is crush in the vertical direction, concrete is entire failed, if there is crack in the vertical direction, change to 2 cracks condition
- Con_P1Crack06(C): 1 Crack, Open, T/C, L/L(L: Loading, U: UnLoading)
- Con_P1Crack07(C) : 1 Crack, Open, T/C, L/U
- Con_P1Crack08(C) : 1 Crack, Open, T/C, U/L
- Con_P1Crack09(C) : 1 Crack, Open, T/C, U/U
- Con_P1Crack10(C) : 1 Crack, Open, T/T, L/L
- Con_P1Crack11(C) : 1 Crack, Open, T/T, L/U
- Con_P1Crack12(C) : 1 Crack, Open, T/T, U/L
- Con_P1Crack13(C) : 1 Crack, Open, T/T, U/U

# Subroutine List (8)

- Both cracks are closed ,treated as no crack condtions
- Con_P2Crack01(C): 2 Cracks, Both Closed, C/C, >0.2, L/L
- Con_P2Crack02(C) : 2 Cracks, Both Closed, C/C, <0.2, L/L
- Con_P2Crack03(C) : 2 Cracks, Both Closed, C/C, <-0.05, L/L
- Con_P2Crack04(C) : 2 Cracks, Both Closed, C/C, >-0.05, L/L
- Con_P2Crack05(C) : 2 Cracks, Both Closed, T/T, L/L

## Subroutine List (9)

- 1 of 2 Cracks is closed, treat as 1 crack conditions
- Con_P2Crack06(C) 2 cracks, 1 close, 2 open, C, T, U, U
- Con_P2Crack07(C) 2 cracks, 1 close, 2 open, C, T, U, L
- Con_P2Crack08(C) 2 cracks, 1 close, 2 open, C, T, L, U
- Con_P2Crack09(C) 2 cracks, 1 close, 2 open, C, T, L, L
- Con_P2Crack10(C) 2 cracks, 1 open, 2 close, C, T, U, U

## 函数列表(10)

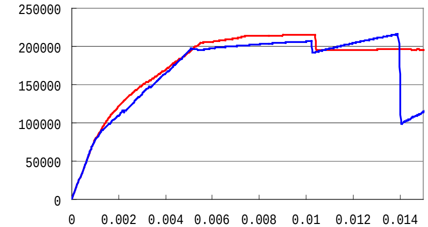
- Both Cracks are open, it is assumed that the concrete can go on bearing shear force, that is $\beta = \min(\beta_{crack1}\ \beta_{crack2})$
- Con_P2Crack14(C) 2 Cracks, Both opend, T, T, L, L
- Con_P2Crack15(C) 2 Cracks, Both opend, T, T, U, L
- Con_P2Crack16(C) 2 Cracks, Both opend, T, T, L, U
- Con_P2Crack17(C) 2 Cracks, Both opend, T, T, U, U

## Connection with Msc.Marc

- Use the user subroutine for Hyperelastic material of Msc.Marc
- SUBROUTINE HYPELA (D,G,E,DE,S,TEMP,DTEMP,NGENS,N,NN,KC, MATS,NDI,NSHEAR)
- Post Process: Crack, Load conditions
- Use the user subroutine of PLOTV

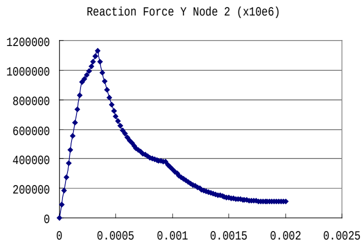
## Example 1

- Balance reinforced cantilever beam
- Compare of Msc.Marc and RCFER2002 (Red: Msc.Marc, Blue: RCFER2002)



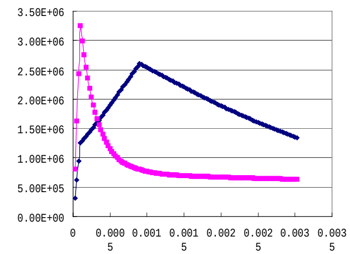
## Example 2

- 4 nodes element under pure shear force



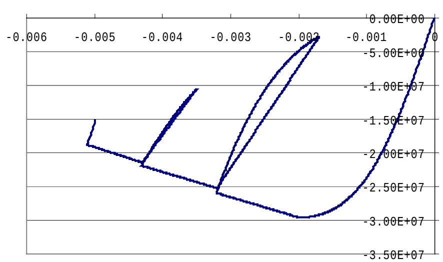

## Example 3

- Tension-shear combination force



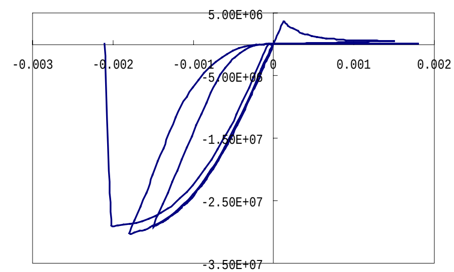

## Example 4

- Uniaxial compression cycle load



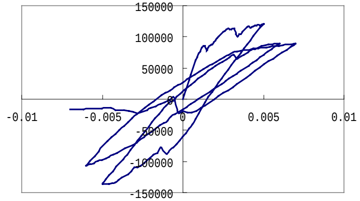

## Example 5

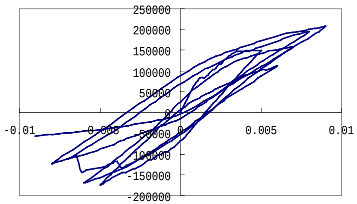
- Uniaxial compression-tension cycle load

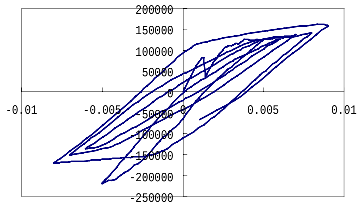


## Example 6

- Cantilever beam under cycle load




## Example 7

- Shear test for FRP sheet