12.1 Uniaxial load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, secondary creep
MODEL FILENAME	MaterialViscoElastic01.fea

Figure 12.1.1 shows a 2D plane stress model undergoing uniaxial tensile stress. Plane stress elements are incorporated to evaluate the secondary creep response.

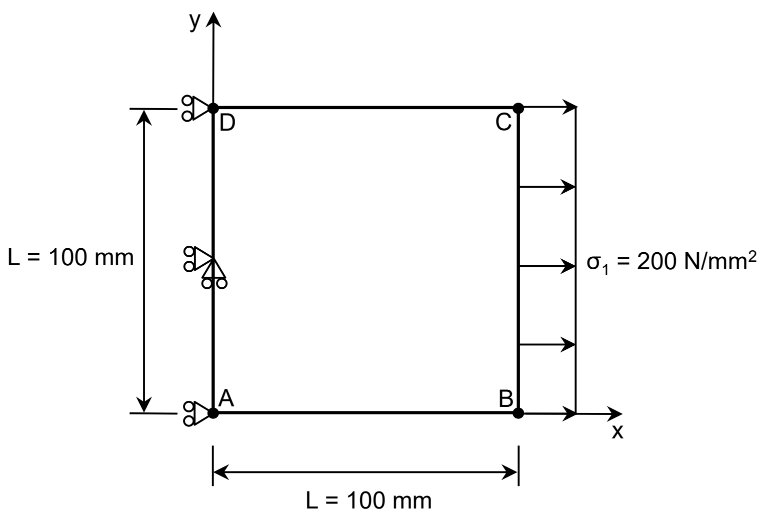


Figure 12.1.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t$, $A=3.125 \times 10^{-14}$, $n=5$ (N/mm^2)
Boundary condition	On line AD At midpoint of line AD	$U_x = 0$ $U_y = 0$
Loading	On line BC	$\sigma_1 = 200$ N/mm^2
Reference creep strain	ε_{xx} ε_{yy}	0.01t -0.005t

Figure 12.1.2
Comparison of reference solution and MaterialViscoElastic01

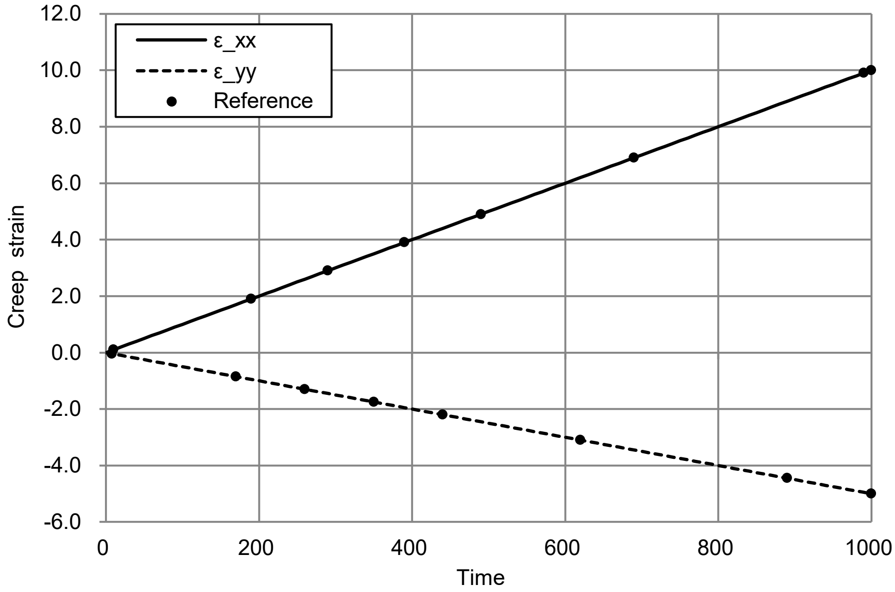


Figure 12.1.3
Result of MaterialViscoElastic01

Time	ε_{xx}	Reference	ε_{yy}	Reference
100	*1.00*	*1.00*	*-0.50*	*-0.50*
200	*2.00*	*2.00*	*-1.00*	*-1.00*
300	*3.00*	*3.00*	*-1.50*	*-1.50*
400	*4.00*	*4.00*	*-2.00*	*-2.00*
500	*5.00*	*5.00*	*-2.50*	*-2.50*
600	*6.00*	*6.00*	*-3.00*	*-3.00*
700	*7.00*	*7.00*	*-3.50*	*-3.50*
800	*8.00*	*8.00*	*-4.00*	*-4.00*
900	*9.00*	*9.00*	*-4.50*	*-4.50*
1000	*10.00*	*10.00*	*-5.00*	*-5.00*

12.2 Uniaxial displacement

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, secondary creep
MODEL FILENAME	MaterialViscoElastic02.fea

Figure 12.2.1 shows a 2D plane stress model undergoing constant uniaxial displacement. Plane stress elements are incorporated to evaluate the secondary creep response.

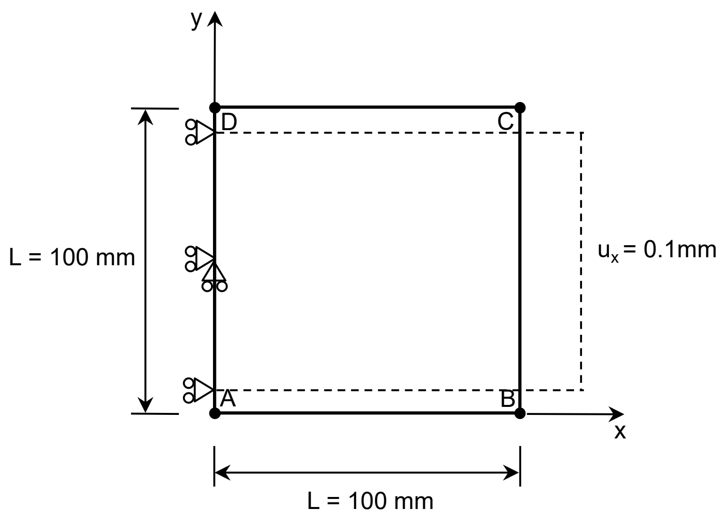


Figure 12.2.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ *N/mm²* $\nu = 0.3$ $\varepsilon = A\sigma^n t$, $A=3.125 \times 10^{-14}$, $n=5$ (N/mm²)
Boundary condition	On line AD At midpoint of line AD On line BC	$U_x = 0$ $U_y = 0$ $U_x = 1$
Reference creep stress	σ_{xx}	$\left[\left(6.25\times10^{-10}\right)+\left(2.5\times10^{-8}\right)t\right]^{-\frac{1}{4}}$ (N/mm2)

Figure 12.2.2
Comparison of reference solution and MaterialViscoElastic02

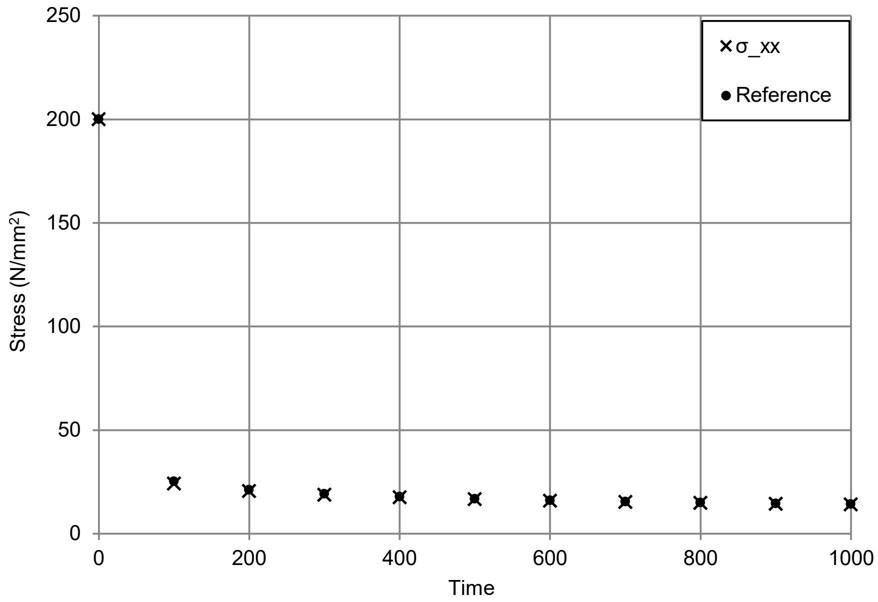


Figure 12.2.3
Result of MaterialViscoElastic02

Time	σ_{xx}	Reference
100	*24.560*	*25.147*
200	*20.884*	*21.147*
300	*18.946*	*19.108*
400	*17.667*	*17.783*
500	*16.729*	*16.818*
600	*15.997*	*16.068*
700	*15.402*	*15.461*
800	*14.903*	*14.953*
900	*14.476*	*14.519*
1000	*14.103*	*14.142*

13.3 Biaxial load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, secondary creep
MODEL FILENAME	MaterialViscoElastic03.fea

Figure 12.3.1 shows a 2D plane stress model undergoing biaxial tensile stress. Plane stress elements are incorporated to evaluate the secondary creep response.

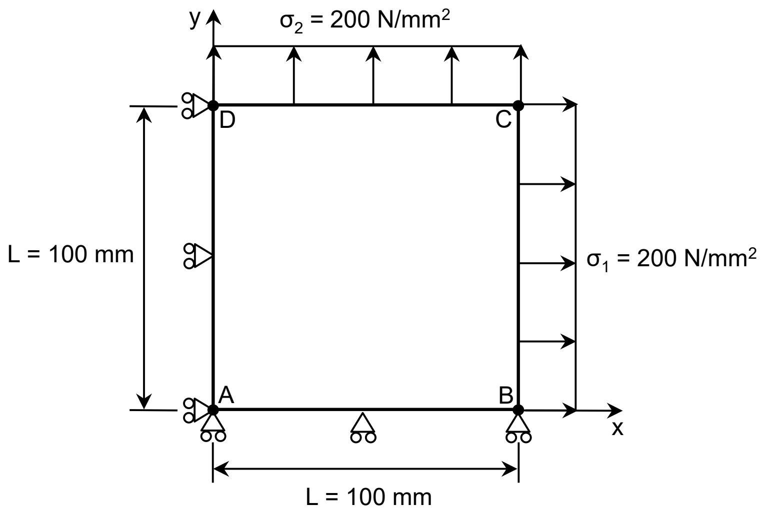


Figure 12.3.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t$, $A = 3.125 \times 10^{-14}$, $n = 5$ (N/mm^2)
Boundary condition	On line AD On line AB	$U_x = 0$ $U_y = 0$
Loading	On line BC On line CD	$\sigma_1 = 200$ N/mm^2 $\sigma_2 = 200$ N/mm^2
Reference creep strain	ε_{xx} ε_{yy}	0.005t 0.005t

Figure 12.3.2
Comparison of reference solution and MaterialViscoElastic03

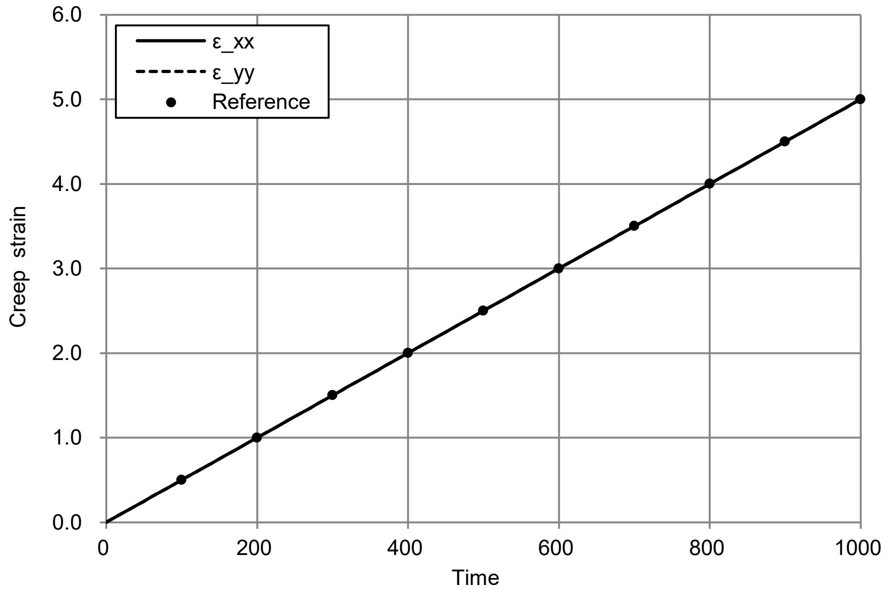


Figure 12.3.3
Result of MaterialViscoElastic03

Time	ε_{xx}	Reference	ε_{yy}	Reference
100	*0.50*	*0.50*	*0.50*	*0.50*
200	*1.00*	*1.00*	*1.00*	*1.00*
300	*1.50*	*1.50*	*1.50*	*1.50*
400	*2.00*	*2.00*	*2.00*	*2.00*
500	*2.50*	*2.50*	*2.50*	*2.50*
600	*3.00*	*3.00*	*3.00*	*3.00*
700	*3.50*	*3.50*	*3.50*	*3.50*
800	*4.00*	*4.00*	*4.00*	*4.00*
900	*4.50*	*4.50*	*4.50*	*4.50*
1000	*5.00*	*5.00*	*5.00*	*5.00*

12.4 Negative biaxial load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, secondary creep
MODEL FILENAME	MaterialViscoElastic04.fea

Figure 12.4.1 shows a 2D plane stress model undergoing biaxial tensile stress. Plane stress elements are incorporated to evaluate the secondary creep response.

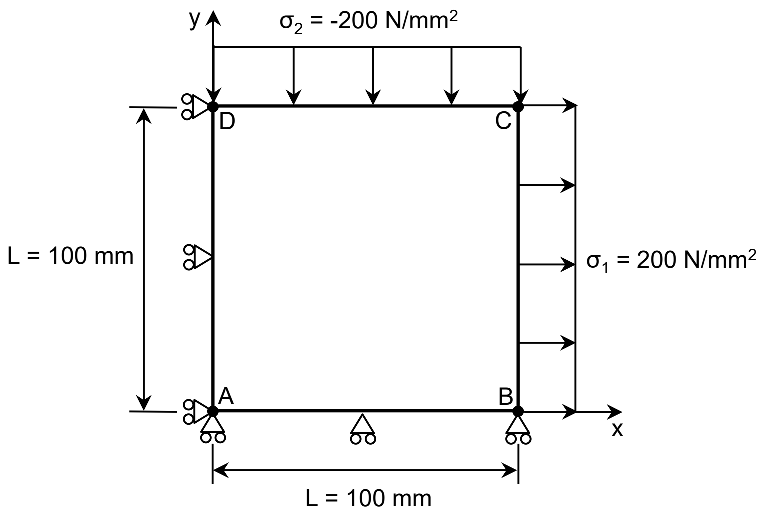


Figure 12.4.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t$, $A=3.125 \times 10^{-14}$, $n=5$ (N/mm^2)
Boundary condition	On line AD On line AB	$U_x = 0$ $U_y = 0$
Loading	On line BC On line CD	$\sigma_1 = 200$ N/mm^2 $\sigma_2 = -200$ N/mm^2

Reference creep strain	ε_{xx} ε_{yy}	0.135t -0.135t

Figure 12.4.2
Comparison of reference solution and MaterialViscoElastic04

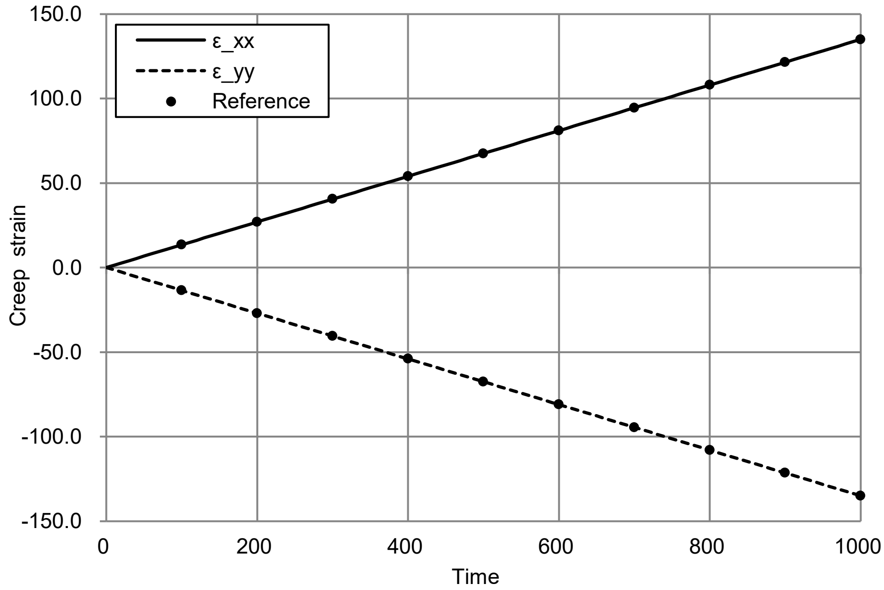


Figure 12.4.3
Result of MaterialViscoElastic04

Time	ε_{xx}	Reference	ε_{yy}	Reference
100	*12.50*	*13.50*	*-13.50*	*-13.50*
200	*27.00*	*27.00*	*-27.00*	*-27.00*
300	*40.50*	*40.50*	*-40.50*	*-40.50*
400	*54.00*	*54.00*	*-54.00*	*-54.00*
500	*67.50*	*67.50*	*-67.50*	*-67.50*
600	*81.00*	*81.00*	*-81.00*	*-81.00*
700	*94.50*	*94.50*	*-94.50*	*-94.50*
800	*108.00*	*108.00*	*-108.00*	*-108.00*

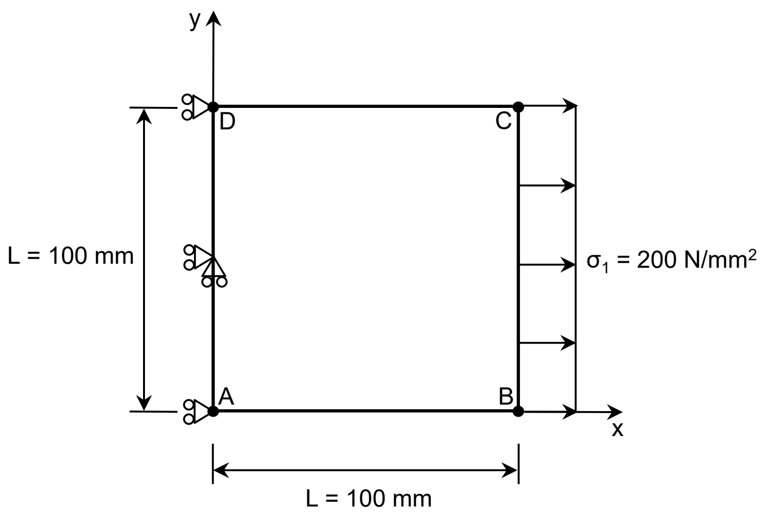
900	*121.50*	*121.50*	*-121.50*	*-121.50*
1000	*135.00*	*135.00*	*-135.00*	*-135.00*

12.5 Uniaxial load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, primary creep
MODEL FILENAME	MaterialViscoElastic05.fea

Figure 12.5.1 shows a 2D plane stress model undergoing biaxial tensile stress. Plane stress elements are incorporated to evaluate the primary creep response.

Figure 12.5.1
2D plane stress model



Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t^m$, $A=3.125 \times 10^{-14}$, $n=5$, $m=5$ (N/mm^2)
Boundary condition	On line AD At midpoint of AD	$U_x = 0$ $U_y = 0$
Loading	On line BC	$\sigma_1 = 200$ N/mm^2
Reference creep strain	ε_{xx} ε_{yy}	$0.01\sqrt{t}$ $-0.005\sqrt{t}$

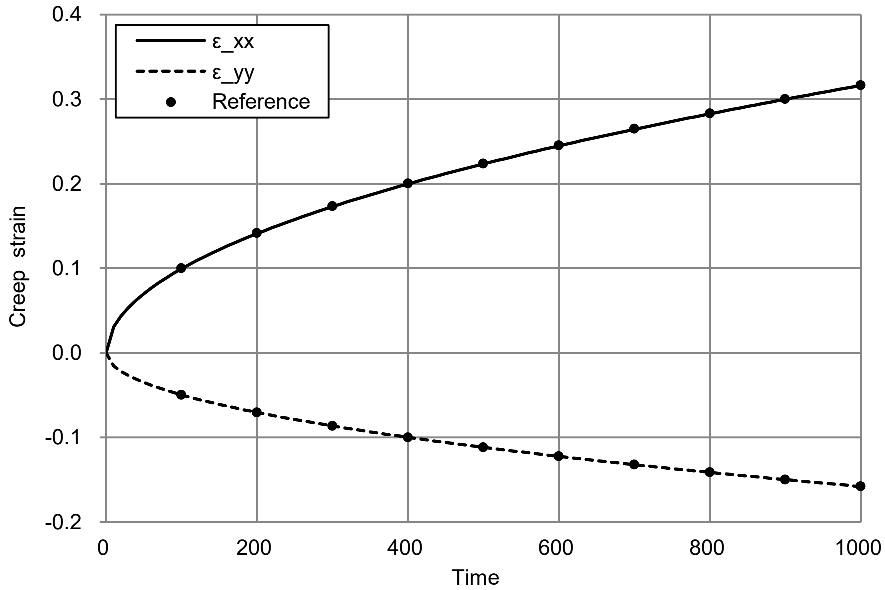


Figure 12.5.2
Comparison of reference solution and MaterialViscoElastic05

Figure 12.5.3
Result of MaterialViscoElastic05

Time	ε_{xx}	Reference	ε_{yy}	Reference
100	*0.099*	*0.100*	*-0.050*	*-0.050*
200	*0.141*	*0.141*	*-0.070*	*-0.071*
300	*0.173*	*0.173*	*-0.086*	*-0.087*
400	*0.200*	*0.200*	*-0.100*	*-0.100*
500	*0.223*	*0.224*	*-0.112*	*-0.112*
600	*0.245*	*0.245*	*-0.122*	*-0.122*
700	*0.264*	*0.265*	*-0.132*	*-0.132*
800	*0.283*	*0.283*	*-0.141*	*-0.141*
900	*0.300*	*0.300*	*-0.150*	*-0.150*
1000	*0.316*	*0.316*	*-0.158*	*-0.158*

12.6 Uniaxial stepped load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, primary creep
MODEL FILENAME	MaterialViscoElastic06.fea

Figure 12.6.1 shows a 2D plane stress model undergoing stepped tensile stress. Plane stress elements are incorporated to evaluate the primary creep response.

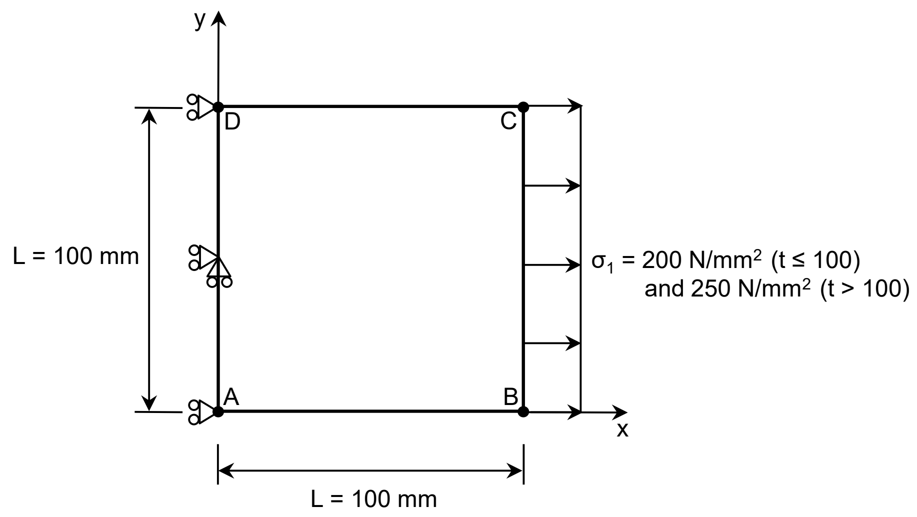


Figure 12.6.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t^m$, $A=3.125 \times 10^{-14}$, $n=5$, $m=5$ (N/mm^2)
Boundary condition	On line AD At midpoint of AD	$U_x = 0$ $U_y = 0$
Loading	On line BC	$\sigma_1 = 200$ N/mm^2 (t≤100) , 250 N/mm^2 (t>100)
Reference creep strain	ε_{xx}	$0.01\sqrt{t}$ (t≤100), $0.03052\sqrt{t-89.262}$ (t>100)

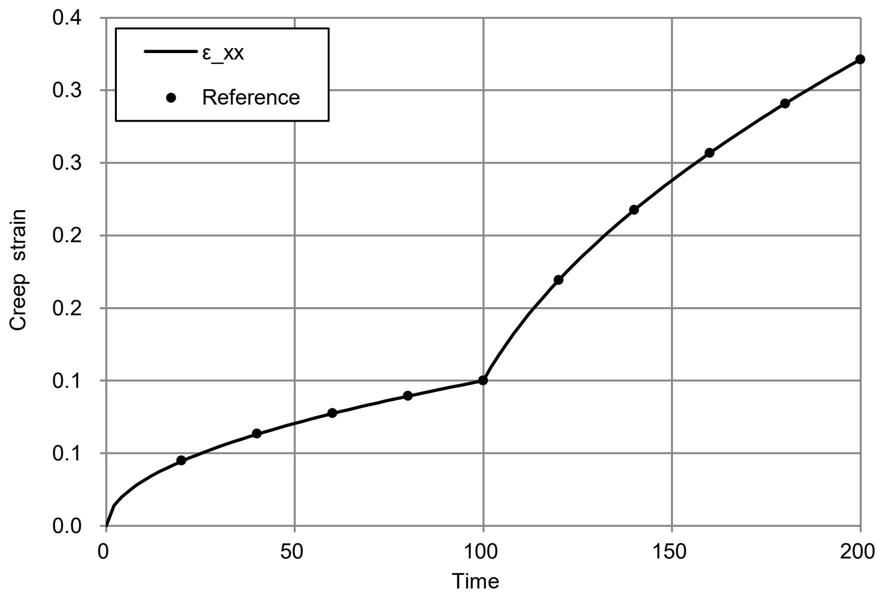


Figure 12.6.2
Comparison of reference solution and MaterialViscoElastic06

Figure 12.6.3
Result of MaterialViscoElastic06

Time	ε_{xx}	Reference
20	*0.044*	*0.045*
40	*0.063*	*0.063*
60	*0.077*	*0.077*
80	*0.089*	*0.089*
100	*0.100*	*0.100*
120	*0.169*	*0.169*
140	*0.218*	*0.217*
160	*0.257*	*0.257*
180	*0.291*	*0.291*
200	*0.321*	*0.321*

12.7 Biaxial load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, primary creep
MODEL FILENAME	MaterialViscoElastic07.fea

Figure 12.7.1 shows a 2D plane stress model undergoing biaxial tensile stress. Plane stress elements are incorporated to evaluate the primary creep response.

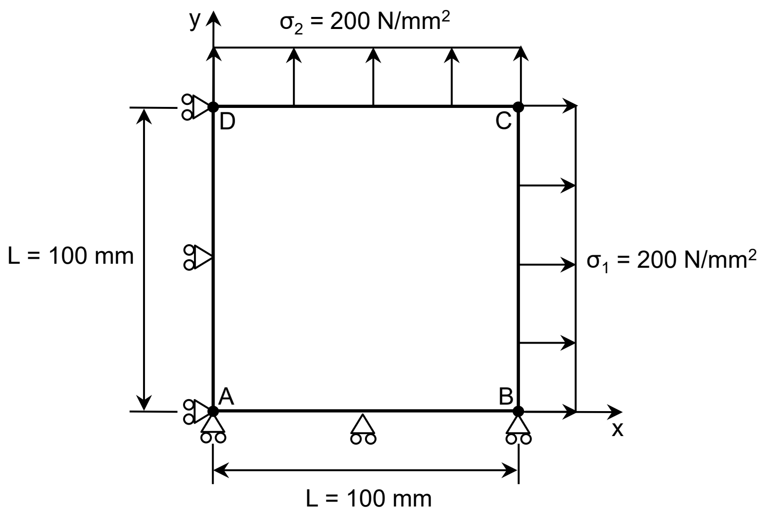


Figure 12.7.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t^m$, $A=3.125 \times 10^{-14}$, $n=5$, $m=5$ (N/mm^2)
Boundary condition	On line AD On line AB	$U_x = 0$ $U_y = 0$
Loading	On line BC On line CD	$\sigma_1 = 200$ N/mm^2 $\sigma_2 = 200$ N/mm^2
Reference creep strain	ε_{xx} ε_{yy}	$0.005\sqrt{t}$ $0.005\sqrt{t}$

Figure 12.7.2
Comparison of
reference solution and
MaterialViscoElastic07

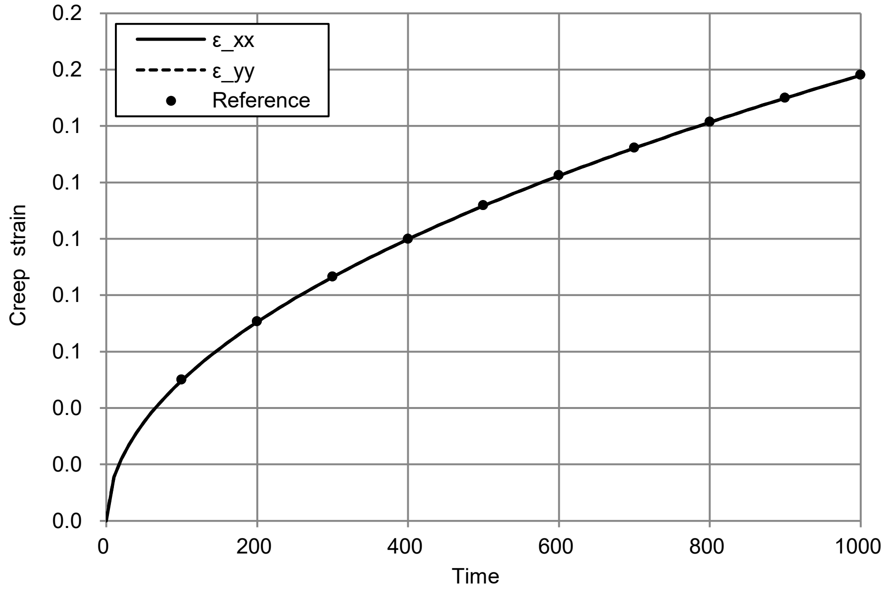


Figure 12.7.3
Result of
MaterialViscoElastic07

Time	ε_{xx}	Reference	ε_{yy}	Reference
100	*0.050*	*0.050*	*-0.050*	*0.050*
200	*0.070*	*0.071*	*-0.070*	*0.071*
300	*0.086*	*0.087*	*-0.086*	*0.087*
400	*0.100*	*0.100*	*-0.100*	*0.100*
500	*0.112*	*0.112*	*-0.112*	*0.112*
600	*0.122*	*0.122*	*-0.122*	*0.122*
700	*0.132*	*0.132*	*-0.132*	*0.132*
800	*0.141*	*0.141*	*-0.141*	*0.141*
900	*0.150*	*0.150*	*-0.150*	*0.150*
1000	*0.158*	*0.158*	*-0.158*	*0.158*

12.8 Biaxial stepped load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, primary creep
MODEL FILENAME	MaterialViscoElastic08.fea

Figure 12.8.1 shows a 2D plane stress model undergoing biaxial stepped tensile stress. Plane stress elements are incorporated to evaluate the primary creep response.

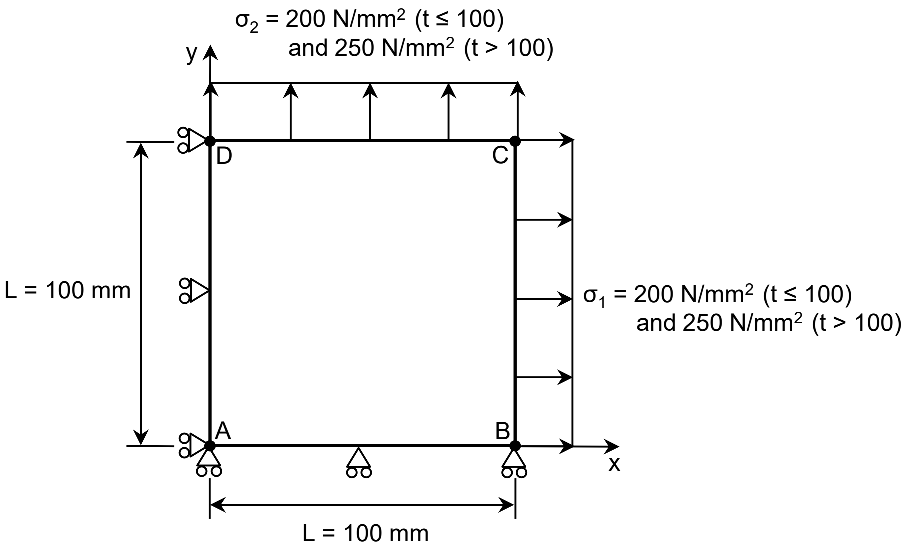


Figure 12.8.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t^m$, $A=3.125 \times 10^{-14}$, $n=5$, $m=5$ (N/mm^2)
Boundary condition	On line AD On line AB	$U_x = 0$ $U_y = 0$
Loading	On line BC On line CD	$\sigma_1 = 200$ N/mm^2 (t≤100) , 250 N/mm^2 (t>100) $\sigma_2 = 200$ N/mm^2 (t≤100) , 250 N/mm^2 (t>100)
Reference creep strain	ε_{xx}	$0.005\sqrt{t}$ (t≤100), $0.01529\sqrt{t-89.262}$ (t>100)

Figure 12.8.2
Comparison of reference solution and MaterialViscoElastic08

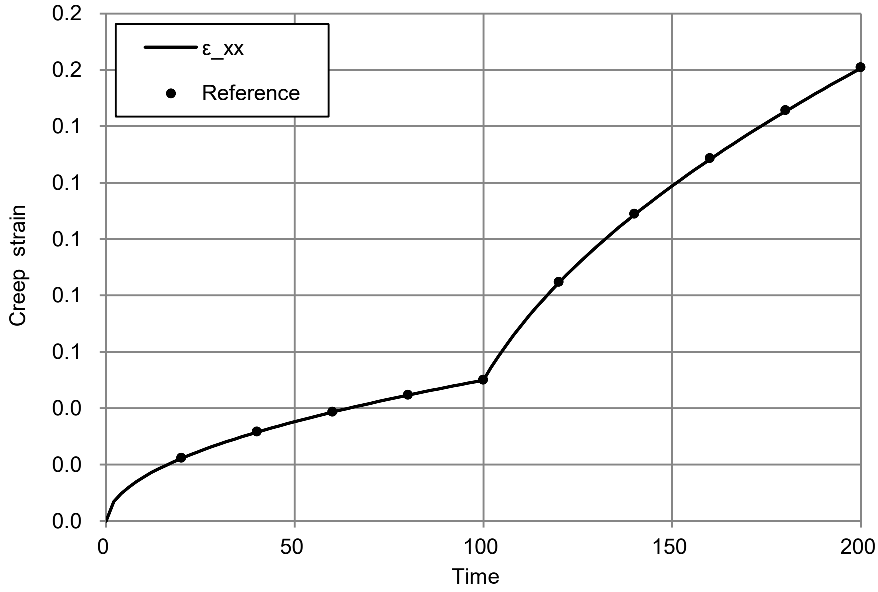


Figure 12.8.3
Result of MaterialViscoElastic08

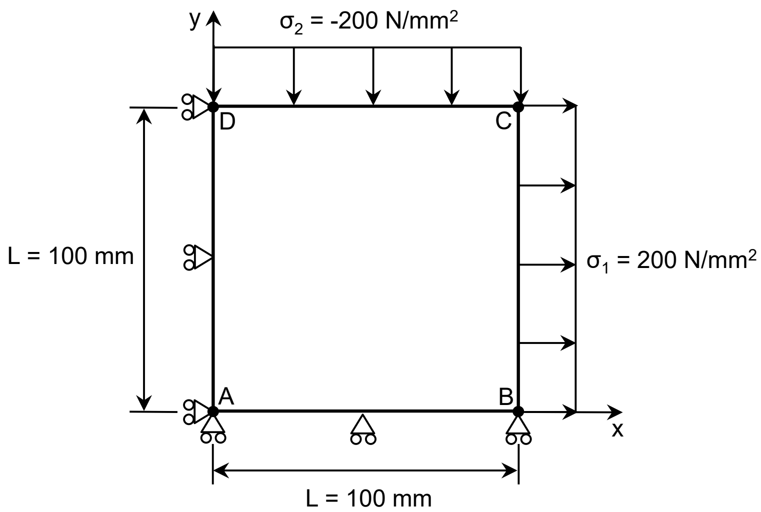
Time	ε_{xx}	Reference
20	*0.022*	*0.022*
40	*0.032*	*0.032*
60	*0.039*	*0.039*
80	*0.045*	*0.045*
100	*0.050*	*0.050*
120	*0.085*	*0.085*
140	*0.109*	*0.109*
160	*0.128*	*0.129*
180	*0.145*	*0.146*
200	*0.161*	*0.161*

12.9 Negative biaxial load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, primary creep
MODEL FILENAME	MaterialViscoElastic09.fea

Figure 12.9.1 shows a 2D plane stress model undergoing biaxial tensile stress. Plane stress elements are incorporated to evaluate the primary creep response.

Figure 12.9.1
2D plane stress model



Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t^m$, $A=3.125 \times 10^{-14}$, $n=5$, $m=5$ (N/mm^2)
Boundary condition	On line AD On line AB	$U_x = 0$ $U_y = 0$
Loading	On line BC On line CD	$\sigma_1 = 200$ N/mm^2 $\sigma_2 = -200$ N/mm^2
Reference creep strain	ε_{xx}	$0.135\sqrt{t}$

Figure 12.9.2
Comparison of reference solution and MaterialViscoElastic09

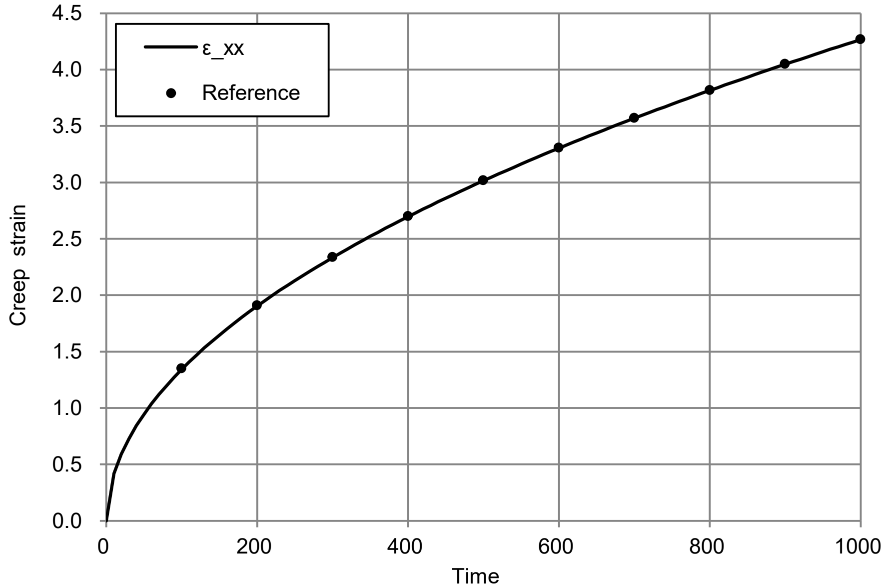


Figure 12.9.3
Result of MaterialViscoElastic09

Time	ε_{xx}	Reference
100	*1.342*	*1.350*
200	*1.904*	*1.909*
300	*2.334*	*2.338*
400	*2.696*	*2.700*
500	*3.015*	*3.019*
600	*3.304*	*3.307*
700	*3.569*	*3.572*
800	*3.816*	*3.818*
900	*4.048*	*4.050*
1000	*4.267*	*4.269*

12.10 Negative biaxial stepped load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, primary creep
MODEL FILENAME	MaterialViscoElastic10.fea

Figure 12.10.1 shows a 2D plane stress model undergoing biaxial stepped tensile stress. Plane stress elements are incorporated to evaluate the primary creep response.

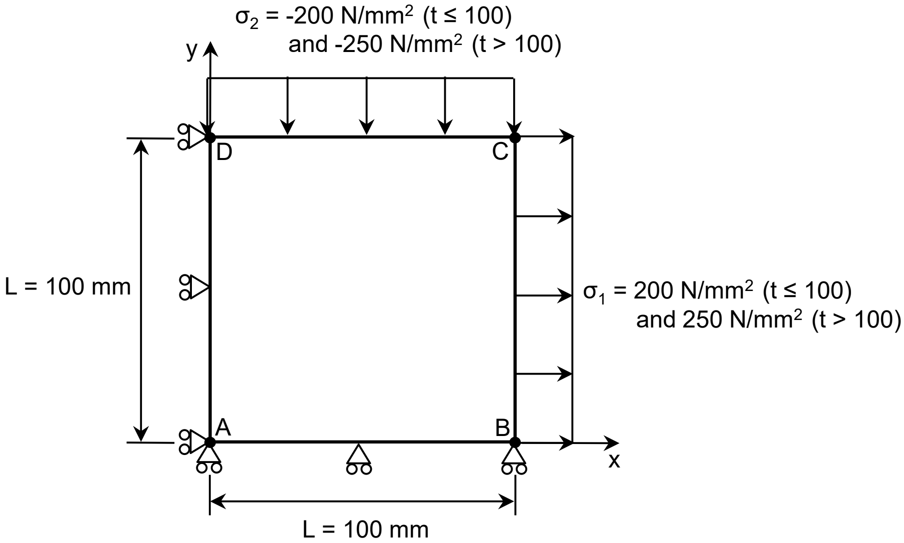


Figure 12.10.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t^m$, $A=3.125 \times 10^{-14}$, $n=5$, $m=5$ (N/mm^2)
Boundary condition	On line AD On line AB	$U_x = 0$ $U_y = 0$
Loading	On line BC On line CD	$\sigma_1 = 200$ N/mm^2 (t≤100) , 250 N/mm^2 (t>100) $\sigma_2 = -200$ N/mm^2 (t≤100) , -250 N/mm^2 (t>100)

Reference creep strain	ε_{xx}	$0.135\sqrt{t}$ *(t≤100),* $0.4120\sqrt{t-89.2605}$ *(t>100)*

Figure 12.10.2
Comparison of reference solution and MaterialViscoElastic10

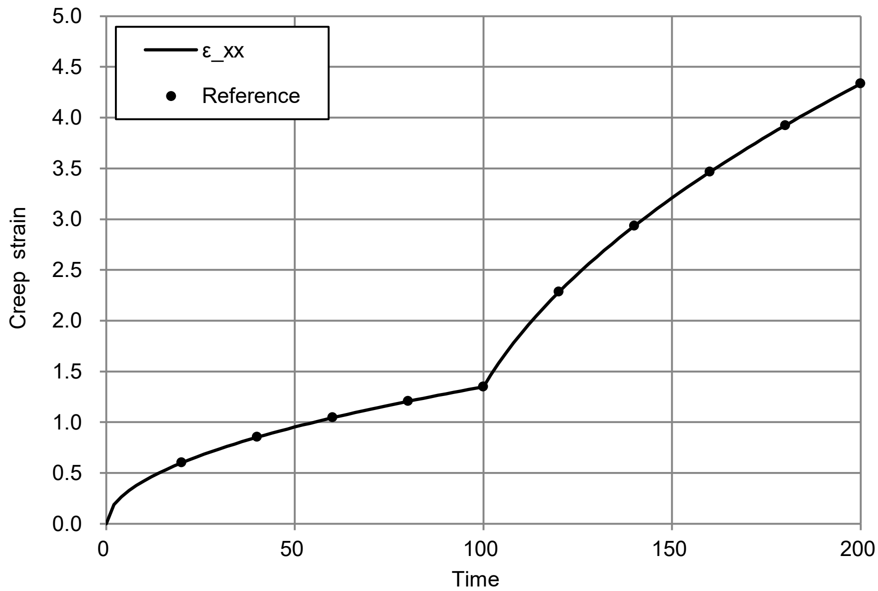


Figure 12.10.3
Result of MaterialViscoElastic10

Time	ε_{xx}	Reference
20	*0.600*	*0.604*
40	*0.851*	*0.854*
60	*1.044*	*1.046*
80	*1.206*	*1.207*
100	*1.348*	*1.350*
120	*2.282*	*2.284*
140	*2.933*	*2.935*
160	*3.464*	*3.465*
180	*3.923*	*3.925*
200	*4.334*	*4.336*

12.11 Uniaxial load

REFERENCE	NAFEM [13-1]
ELEMENT	Plane stress element, Maxwell-kelvin element, primary-secondary creep
MODEL FILENAME	MaterialViscoElastic11.fea

Figure 12.11.1 shows a 2D plane stress model undergoing uniaxial tensile stress. Plane stress elements are incorporated to evaluate the primary and secondary creep response.

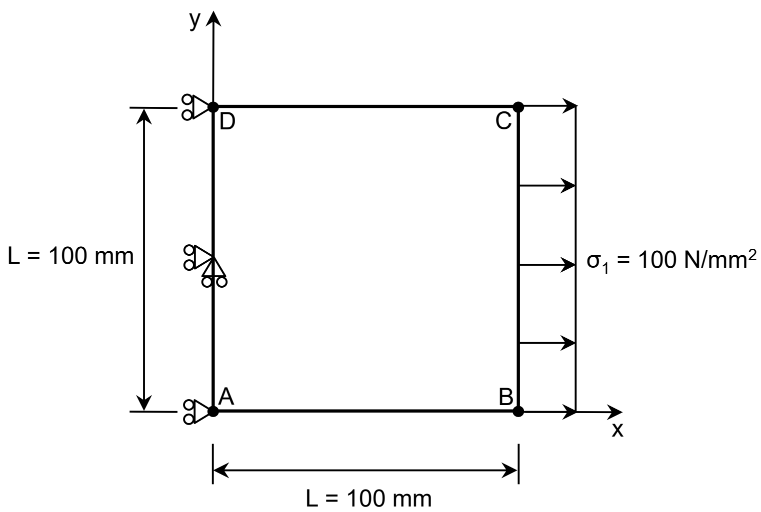


Figure 12.11.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, Primary-secondary	$E = 200.0 \times 10^3$ N/mm^2 $\nu = 0.3$ $\varepsilon = A_1\sigma^n t + A_2\sigma^n t^m$ $A_1=10^{-16}, A_2=10^{-14}, n=5, m=0.5$ (N/mm^2)
Boundary condition	On line AD At midpoint of AD	$U_x = 0$ $U_y = 0$
Loading	On line BC	$\sigma_1 = 100$ N/mm^2

Reference creep strain	ε_{xx} ε_{yy}	$0.0001\left(0.01t+\sqrt{t}\right)$ $-0.5\ \varepsilon_{xx}$

Figure 12.11.2
Comparison of reference solution and MaterialViscoElastic11

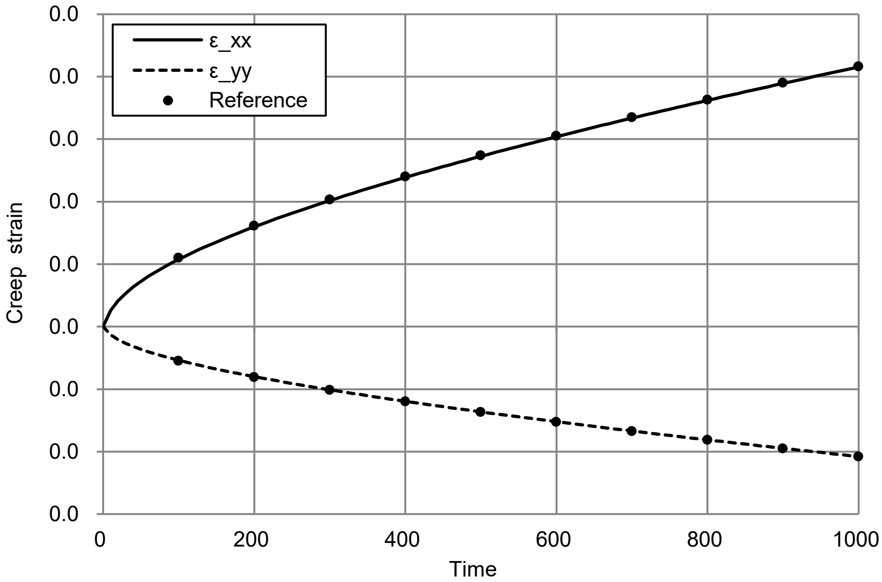


Figure 12.7.3
Result of MaterialViscoElastic11

Time	ε_{xx}	Reference	ε_{yy}	Reference
100	*0.0011*	*0.0011*	*-0.0005*	*-0.0006*
200	*0.0016*	*0.0016*	*-0.0008*	*-0.0008*
300	*0.0020*	*0.0020*	*-0.0010*	*-0.0010*
400	*0.0024*	*0.0024*	*-0.0012*	*-0.0012*
500	*0.0027*	*0.0027*	*-0.0014*	*-0.0014*
600	*0.0030*	*0.0030*	*-0.0015*	*-0.0015*
700	*0.0033*	*0.0033*	*-0.0017*	*-0.0017*
800	*0.0036*	*0.0036*	*-0.0018*	*-0.0018*
900	*0.0039*	*0.0039*	*-0.0019*	*-0.0020*
1000	*0.0042*	*0.0042*	*-0.0021*	*-0.0021*

12.12 Uniaxial load

REFERENCE	Analytical solution
ELEMENT	Plane stress element, generalized kelvin model
MODEL FILENAME	MaterialViscoElastic12.fea

Figure 12.12.1 shows a 2D plane stress model undergoing uniaxial tensile stress. Plane stress elements are incorporated to evaluate the creep response.

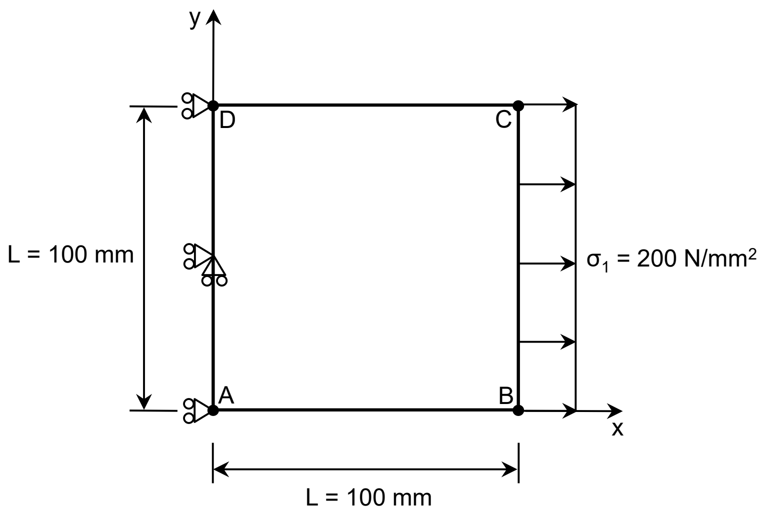


Figure 7.12.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep coefficient	$E = 200.0 \times 10^2$ N/mm^2 $\nu = 0.3$ $\phi(t,t_o) = 1 - e^{-(t-t_o)/50}$
Boundary condition	On line AD At midpoint of AD	$U_x = 0$ $U_y = 0$
Loading	On line BC	$\sigma_1 = 200$ N/mm^2
Reference creep strain	ε_{xx} ε_{yy}	$0.01\phi(t,t_o)$ $-0.003\phi(t,t_o)$

Figure 12.12.1
Comparison of reference solution and MaterialViscoElastic12

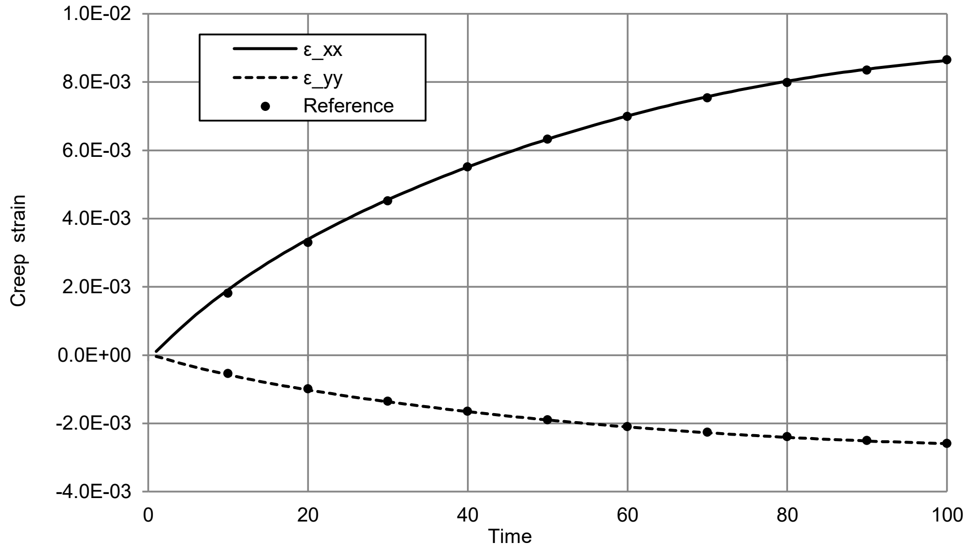


Figure 12.12.1
Result of MaterialViscoElastic12

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*0.0019*	*0.0018*	*-0.0006*	*-0.0005*
20	*0.0034*	*0.0033*	*-0.0010*	*-0.0010*
30	*0.0046*	*0.0045*	*-0.0014*	*-0.0014*
40	*0.0055*	*0.0055*	*-0.0017*	*-0.0017*
50	*0.0063*	*0.0063*	*-0.0019*	*-0.0019*
60	*0.0070*	*0.0070*	*-0.0021*	*-0.0021*
70	*0.0076*	*0.0075*	*-0.0023*	*-0.0023*
80	*0.0080*	*0.0080*	*-0.0024*	*-0.0024*
90	*0.0084*	*0.0083*	*-0.0025*	*-0.0025*
100	*0.0086*	*0.0086*	*-0.0026*	*-0.0026*

12.13 Stepped load

REFERENCE	Analytical solution
ELEMENT	Plane stress element, generalized kelvin model
MODEL FILENAME	MaterialViscoElastic13.fea

Figure 12.13.1 shows a 2D plane stress model undergoing stepped tensile stress. Plane stress elements are incorporated to evaluate the creep response.

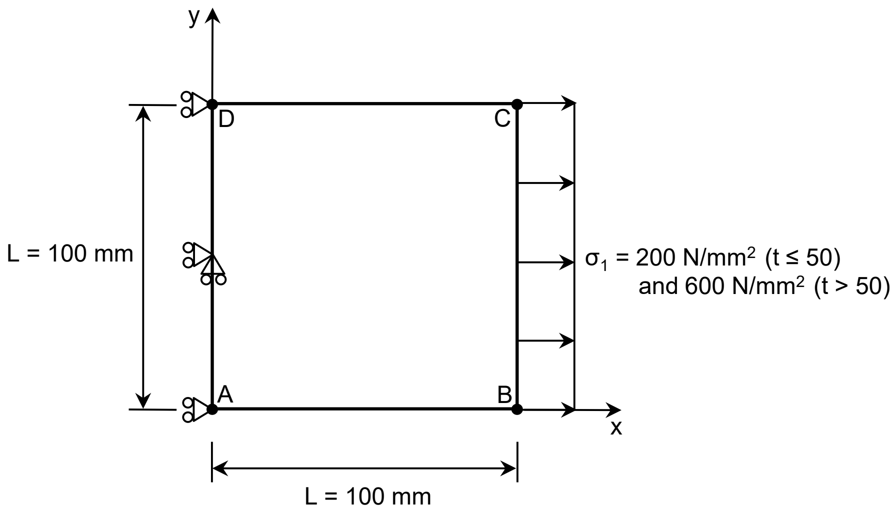


Figure 12.13.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep coefficient	$E = 200.0 \times 10^2$ N/mm² $\nu = 0.3$ $\phi(t,t_o) = 1 - e^{-(t-t_o)/50}$
Boundary condition	On line AD At midpoint of AD	$U_x = 0$ $U_y = 0$
Loading	On line BC	$\sigma_1 = 200$ N/mm² (t≤50) , 600 N/mm² (t>50)
Reference creep strain	ε_{xx} ε_{yy}	$0.01\phi(t,0) + 0.02\phi(t,50)$ $-0.003\phi(t,0) - 0.006\phi(t,50)$

Figure 12.13.1
Comparison of
reference solution and
MaterialViscoElastic13

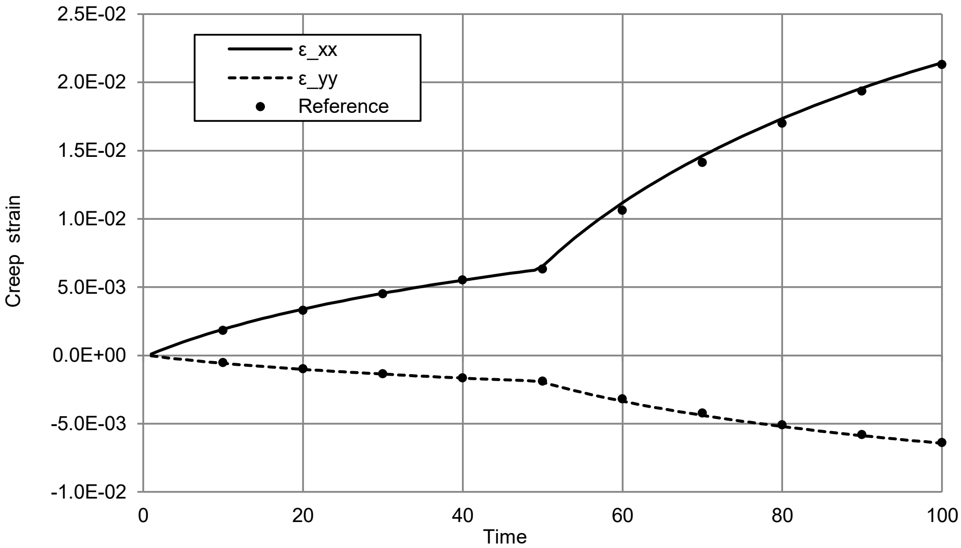


Figure 12.13.1
Result of
MaterialViscoElastic13

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*0.0019*	*0.0018*	*-0.0006*	*-0.0005*
20	*0.0034*	*0.0033*	*-0.0010*	*-0.0010*
30	*0.0046*	*0.0045*	*-0.0014*	*-0.0014*
40	*0.0055*	*0.0055*	*-0.0017*	*-0.0017*
50	*0.0065*	*0.0063*	*-0.0020*	*-0.0019*
60	*0.0112*	*0.0106*	*-0.0034*	*-0.0032*
70	*0.0146*	*0.0141*	*-0.0044*	*-0.0042*
80	*0.0173*	*0.0170*	*-0.0052*	*-0.0051*
90	*0.0196*	*0.0194*	*-0.0059*	*-0.0058*
100	*0.0214*	*0.0213*	*-0.0064*	*-0.0064*

12.14 Biaxial load

REFERENCE	Analytical solution
ELEMENT	Plane stress element, generalized kelvin model
MODEL FILENAME	MaterialViscoElastic14.fea

Figure 12.14.1 shows a 2D plane stress model undergoing biaxial tensile stress. Plane stress elements are incorporated to evaluate the creep response.

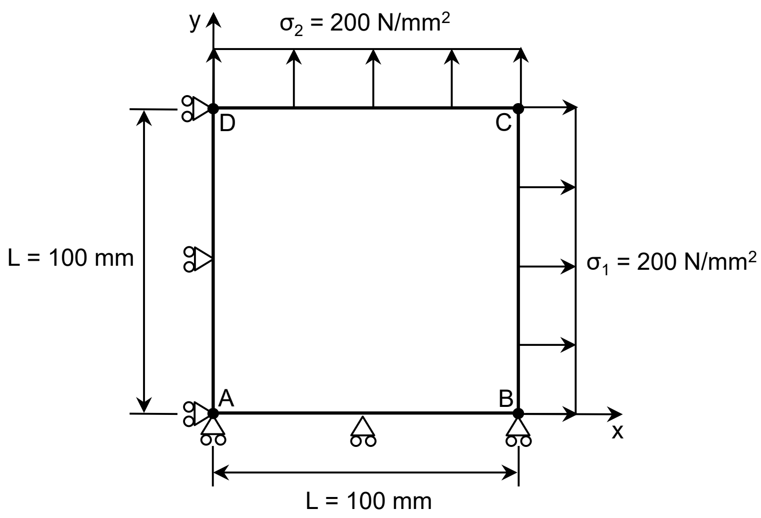


Figure 12.14.1
2D plane stress model

Material data	Young's modulus	$E = 200.0 \times 10^2$ N/mm^2
	Poisson's ratio	$\nu = 0.3$
	Creep coefficient	$\phi(t,t_o) = 1 - e^{-(t-t_o)/50}$
Boundary condition	On line AD	$U_x = 0$
	On line AB	$U_y = 0$
Loading	On line BC	$\sigma_1 = 200$ N/mm^2
	On line CD	$\sigma_2 = 200$ N/mm^2
Reference creep strain	ε_{xx}	$0.007\phi(t,0)$
	ε_{yy}	$0.007\phi(t,0)$

Figure 12.14.1
Comparison of reference solution and MaterialViscoElastic14

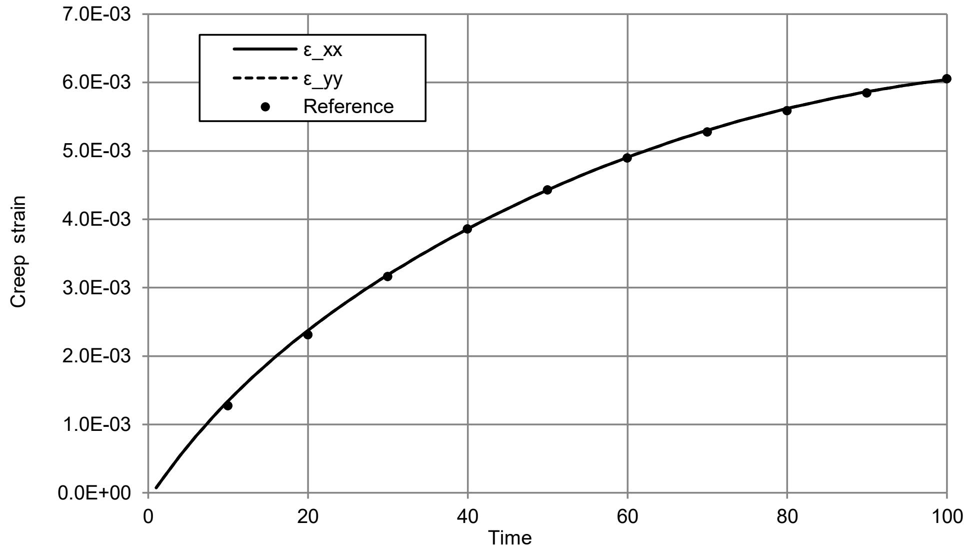


Figure 12.14.1
Result of MaterialViscoElastic14

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*0.0013*	*0.0013*	*0.0013*	*0.0013*
20	*0.0022*	*0.0023*	*0.0022*	*0.0023*
30	*0.0032*	*0.0032*	*0.0032*	*0.0032*
40	*0.0037*	*0.0039*	*0.0037*	*0.0039*
50	*0.0044*	*0.0044*	*0.0044*	*0.0044*
60	*0.0049*	*0.0049*	*0.0049*	*0.0049*
70	*0.0053*	*0.0053*	*0.0053*	*0.0053*
80	*0.0056*	*0.0056*	*0.0056*	*0.0056*
90	*0.0059*	*0.0058*	*0.0059*	*0.0058*
100	*0.0060*	*0.0061*	*0.0060*	*0.0061*

12.15 Biaxial stepped load

REFERENCE	Analytical solution
ELEMENT	Plane stress element, generalized kelvin model
MODEL FILENAME	MaterialViscoElastic15.fea

Figure 12.15.1 shows a 2D plane stress model undergoing biaxial stepped tensile stress. Plane stress elements are incorporated to evaluate the creep response.

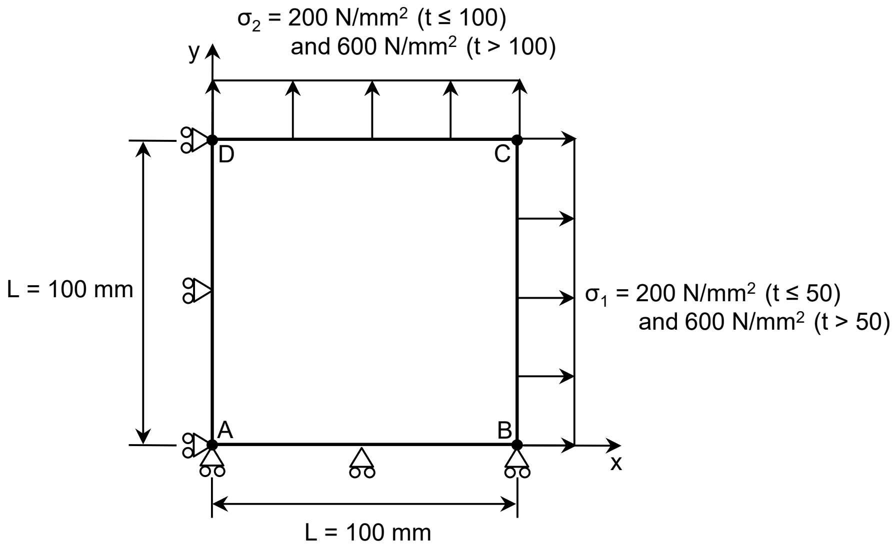


Figure 12.15.1
2D plane stress model

Material data	Young's modulus	$E = 200.0 \times 10^2$ N/mm^2
	Poisson's ratio	$\nu = 0.3$
	Creep coefficient	$\phi(t,t_o) = 1 - e^{-(t-t_o)/50}$
Boundary condition	On line AD	$U_x = 0$
	On line AB	$U_y = 0$
Loading	On line BC	$\sigma_1 = 200$ N/mm^2 (t≤50) , 600 N/mm^2 (t>50)
	On line CD	$\sigma_2 = 200$ N/mm^2 (t≤50) , 600 N/mm^2 (t>50)
Reference creep strain	ε_{xx}	$0.007\phi(t,0) + 0.014\phi(t,50)$
	ε_{yy}	$0.007\phi(t,0) + 0.014\phi(t,50)$

Figure 12.15.1
Comparison of
reference solution and
MaterialViscoElastic15

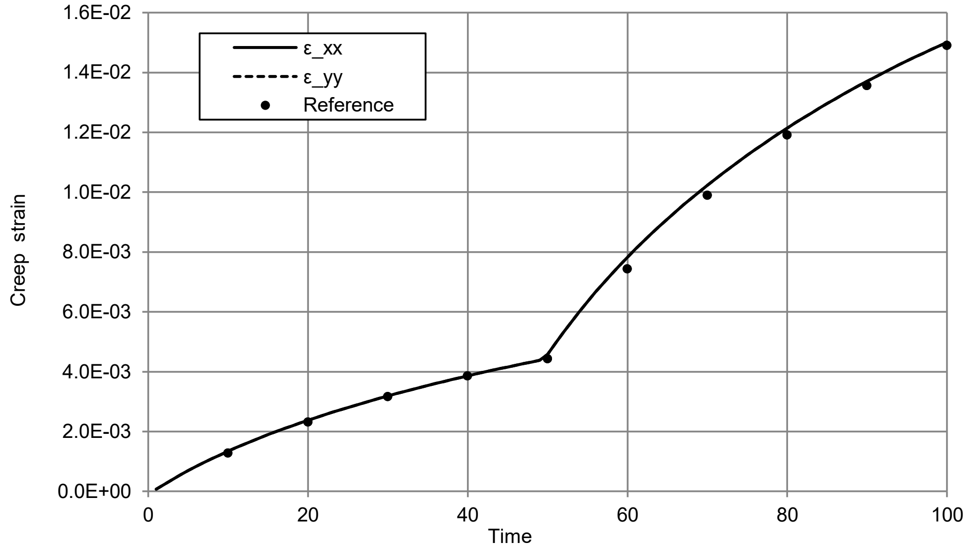


Figure 12.15.1
Result of
MaterialViscoElastic15

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*0.0013*	*0.0013*	*0.0013*	*0.0013*
20	*0.0024*	*0.0023*	*0.0024*	*0.0023*
30	*0.0032*	*0.0032*	*0.0032*	*0.0032*
40	*0.0039*	*0.0039*	*0.0039*	*0.0039*
50	*0.0046*	*0.0044*	*0.0046*	*0.0044*
60	*0.0078*	*0.0074*	*0.0078*	*0.0074*
70	*0.0102*	*0.0099*	*0.0102*	*0.0099*
80	*0.0121*	*0.0119*	*0.0121*	*0.0119*
90	*0.0137*	*0.0136*	*0.0137*	*0.0136*
100	*0.0150*	*0.0149*	*0.0150*	*0.0149*

12.16 Negative biaxial load

REFERENCE	Analytical solution
ELEMENT	Plane stress element, generalized kelvin model
MODEL FILENAME	MaterialViscoElastic16.fea

Figure 12.16.1 shows a 2D plane stress model undergoing biaxial tensile stress. Plane stress elements are incorporated to evaluate the creep response.

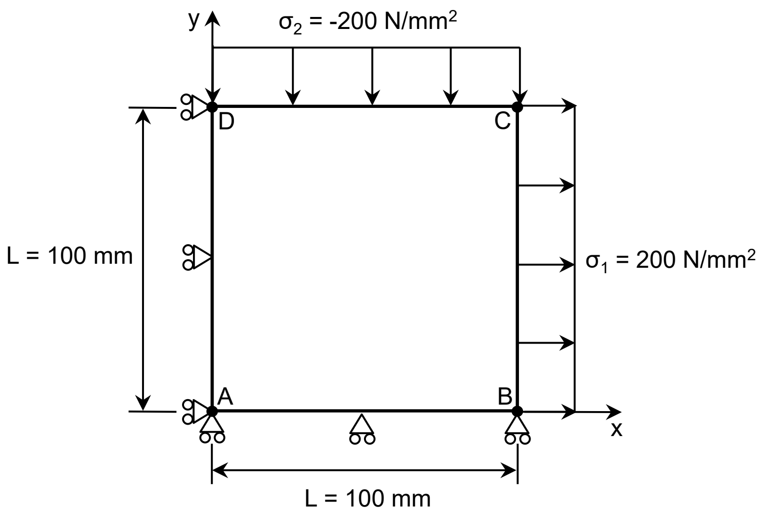


Figure 12.16.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep law, secondary	$E = 200.0 \times 10^2$ N/mm^2 $\nu = 0.3$ $\varepsilon = A\sigma^n t$, $A = 3.125 \times 10^{-14}$, $n = 5$ (N/mm^2)
Boundary condition	On line AD On line AB	$U_x = 0$ $U_y = 0$
Loading	On line BC On line CD	$\sigma_1 = 200$ N/mm^2 $\sigma_2 = -200$ N/mm^2
Reference creep strain	ε_{xx} ε_{yy}	$0.013\phi(t,0)$ $-0.013\phi(t,0)$

Figure 12.16.2
Comparison of reference solution and MaterialViscoElastic16

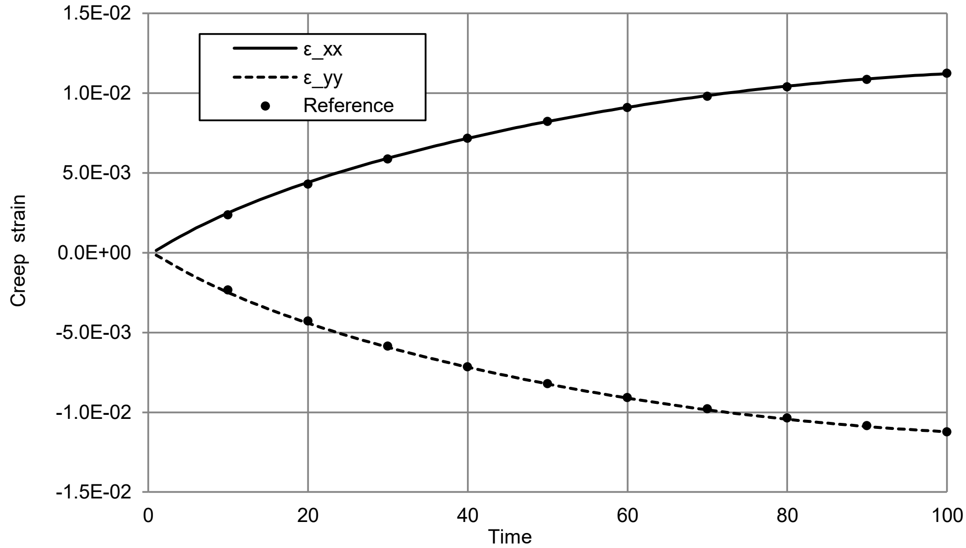


Figure 12.16.3
Result of MaterialViscoElastic16

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*0.0025*	*0.0024*	*-0.0025*	*-0.0024*
20	*0.0044*	*0.0043*	*-0.0044*	*-0.0043*
30	*0.0059*	*0.0059*	*-0.0059*	*-0.0059*
40	*0.0072*	*0.0072*	*-0.0072*	*-0.0072*
50	*0.0082*	*0.0082*	*-0.0082*	*-0.0082*
60	*0.0089*	*0.0091*	*-0.0089*	*-0.0091*
70	*0.0098*	*0.0098*	*-0.0098*	*-0.0098*
80	*0.0104*	*0.0104*	*-0.0104*	*-0.0104*
90	*0.0109*	*0.0109*	*-0.0109*	*-0.0109*
100	*0.0112*	*0.0112*	*-0.0112*	*-0.0112*

12.17 Negative biaxial stepped load

REFERENCE	Analytical solution
ELEMENT	Plane stress element, generalized kelvin model
MODEL FILENAME	MaterialViscoElastic17.fea

Figure 12.17.1 shows a 2D plane stress model undergoing biaxial stepped tensile stress. Plane stress elements are incorporated to evaluate the creep response.

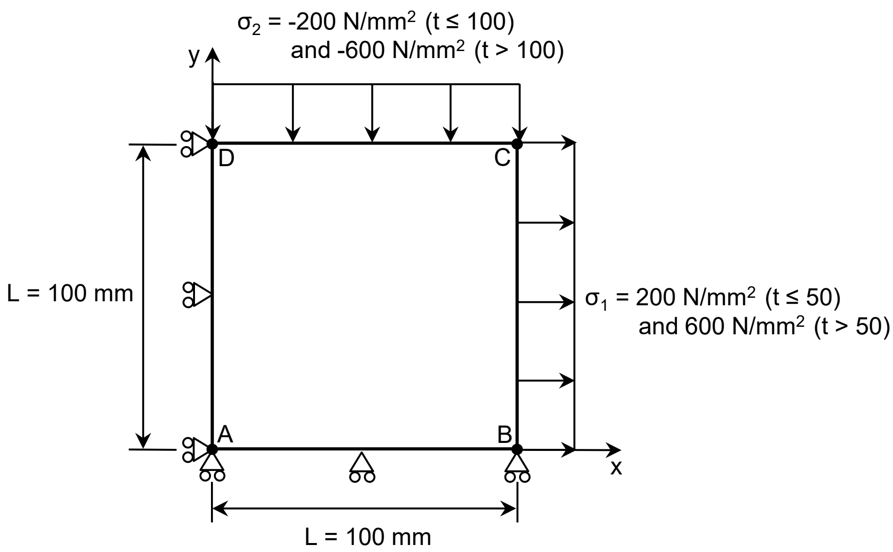


Figure 12.17.1
2D plane stress model

Material data	Young's modulus Poisson's ratio Creep coefficient	$E = 200.0 \times 10^2$ N/mm^2 $\nu = 0.3$ $\phi(t,t_o) = 1 - e^{-(t-t_o)/50}$
Boundary condition	On line AD On line AB	$U_x = 0$ $U_y = 0$
Loading	On line BC On line CD	$\sigma_1 = 200$ N/mm^2 (t≤50) , 600 N/mm^2 (t>50) $\sigma_2 = -200$ N/mm^2 (t≤50) , -600 N/mm^2 (t>50)
Reference creep strain	ε_{xx} ε_{yy}	$0.013\phi(t,0) + 0.026\phi(t,50)$ $-0.013\phi(t,0) - 0.026\phi(t,50)$

Figure 12.17.2
Comparison of reference solution and MaterialViscoelastic17

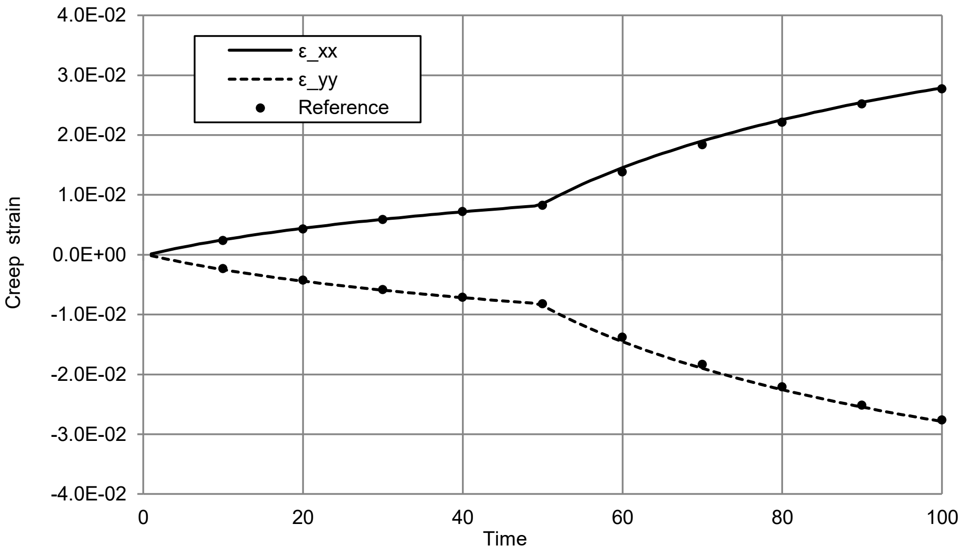


Figure 12.17.3
Result of MaterialViscoElastic17

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*0.0025*	*0.0024*	*-0.0025*	*-0.0024*
20	*0.0044*	*0.0043*	*-0.0044*	*-0.0043*
30	*0.0059*	*0.0059*	*-0.0059*	*-0.0059*
40	*0.0072*	*0.0072*	*-0.0072*	*-0.0072*
50	*0.0085*	*0.0082*	*-0.0085*	*-0.0082*
60	*0.0145*	*0.0138*	*-0.0145*	*-0.0138*
70	*0.0190*	*0.0184*	*-0.0190*	*-0.0184*
80	*0.0225*	*0.0221*	*-0.0225*	*-0.0221*
90	*0.0255*	*0.0252*	*-0.0255*	*-0.0252*
100	*0.0279*	*0.0277*	*-0.0279*	*-0.0277*

12.18 Time dependent negative biaxial stepped load

REFERENCE	Analytical solution
ELEMENT	Plane stress element, generalized kelvin model
MODEL FILENAME	MaterialViscoElastic18.fea

Figure 12.17.1 shows a 2D plane stress model undergoing biaxial stepped tensile stress. Plane stress elements are incorporated to evaluate the creep, shrinkage and time dependent elastic modulus response.

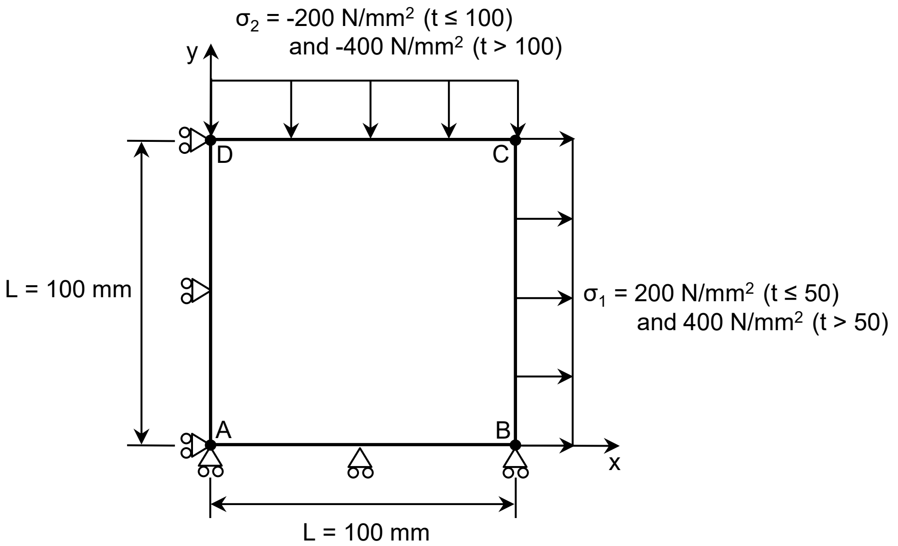


Figure 12.18.1
2D plane stress model

Material data	Young's modulus	*E = 200.0 × 10^2 N/mm^2 (t≤50)* *100.0 × 10^2 N/mm^2 (t>50)*
	Poisson's ratio	ν = 0.3
	Creep coefficient	$\phi(t,t_o) = 1 - e^{-(t-t_o)/50}$
	Shrinkage	$\varepsilon_{sh}(t) = -0.05\left(1 - e^{-t/50}\right)$
Boundary condition	On line AD	$U_x = 0$
	On line AB	$U_y = 0$
Loading	On line BC	$\sigma_1 = 200$ N/mm^2 (t≤50) , 400 N/mm^2 (t>50)
	On line CD	$\sigma_2 = -200$ N/mm^2 (t≤50) , -400 N/mm^2 (t>50)

Reference creep strain	ε_{xx}	$0.013\phi(t,0)+0.026\phi(t,50)$
	ε_{yy}	$-0.013\phi(t,0)-0.026\phi(t,50)$

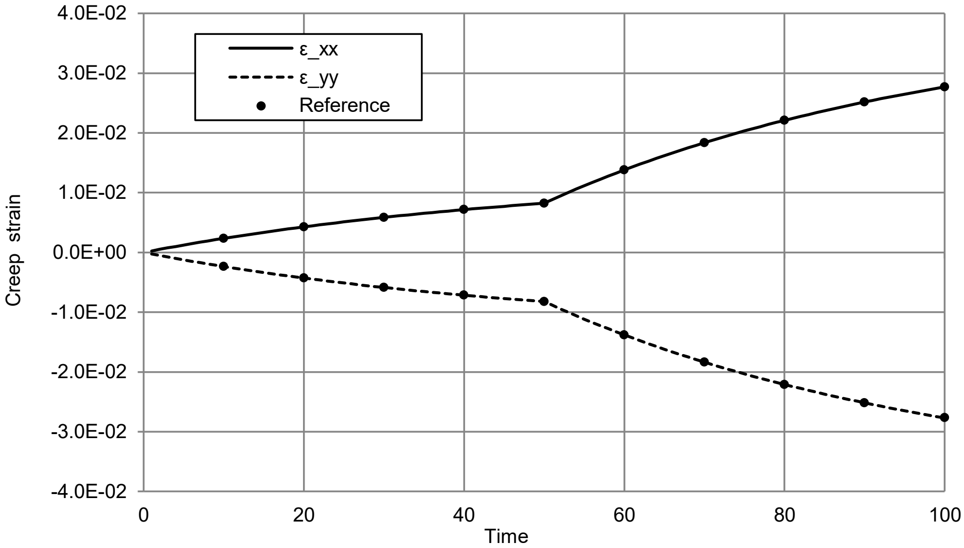


Figure 12.18.2
Comparison of reference creep solution and MaterialViscoelastic18

Figure 12.18.3
Creep strain of MaterialViscoElastic18

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*0.0024*	*0.0024*	*-0.0024*	*-0.0024*
20	*0.0043*	*0.0043*	*-0.0043*	*-0.0043*
30	*0.0059*	*0.0059*	*-0.0059*	*-0.0059*
40	*0.0072*	*0.0072*	*-0.0072*	*-0.0072*
50	*0.0082*	*0.0082*	*-0.0082*	*-0.0082*
60	*0.0138*	*0.0138*	*-0.0138*	*-0.0138*
70	*0.0184*	*0.0184*	*-0.0184*	*-0.0184*
80	*0.0221*	*0.0221*	*-0.0221*	*-0.0221*
90	*0.0252*	*0.0252*	*-0.0252*	*-0.0252*
100	*0.0277*	*0.0277*	*-0.0277*	*-0.0277*

Figure 12.18.4
Comparison of reference shrinkage solution and MaterialViscoelastic18

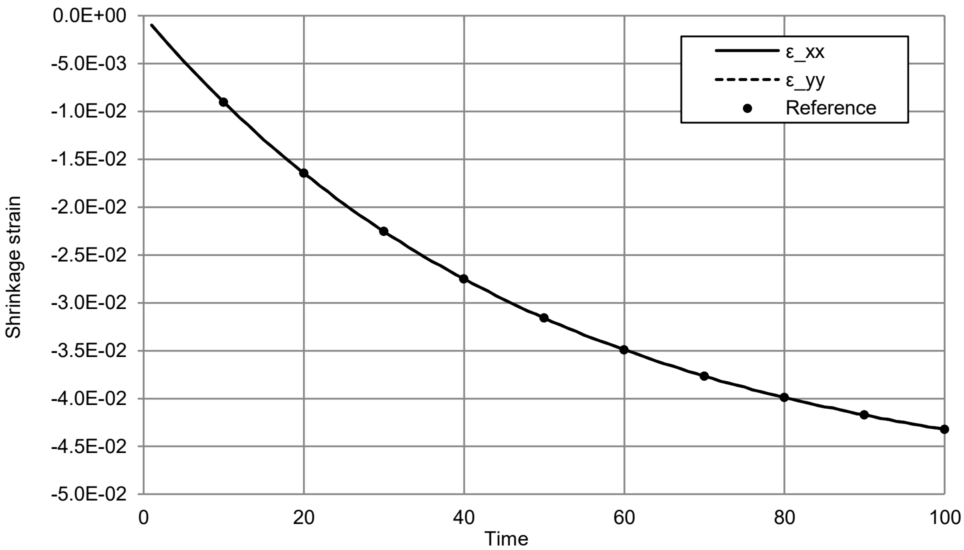


Figure 12.18.5
shrinkage strain of MaterialViscoElastic18

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*-0.0090*	*-0.0091*	*-0.0090*	*-0.0091*
20	*-0.0165*	*-0.0165*	*-0.0165*	*-0.0165*
30	*-0.0226*	*-0.0226*	*-0.0226*	*-0.0226*
40	*-0.0275*	*-0.0275*	*-0.0275*	*-0.0275*
50	*-0.0316*	*-0.0316*	*-0.0316*	*-0.0316*
60	*-0.0349*	*-0.0349*	*-0.0349*	*-0.0349*
70	*-0.0377*	*-0.0377*	*-0.0377*	*-0.0377*
80	*-0.0399*	*-0.0399*	*-0.0399*	*-0.0399*
90	*-0.0414*	*-0.0417*	*-0.0414*	*-0.0417*
100	*-0.0432*	*-0.0432*	*-0.0432*	*-0.0432*

Figure 12.18.6
Comparison of reference elastic solution and MaterialViscoelastic18

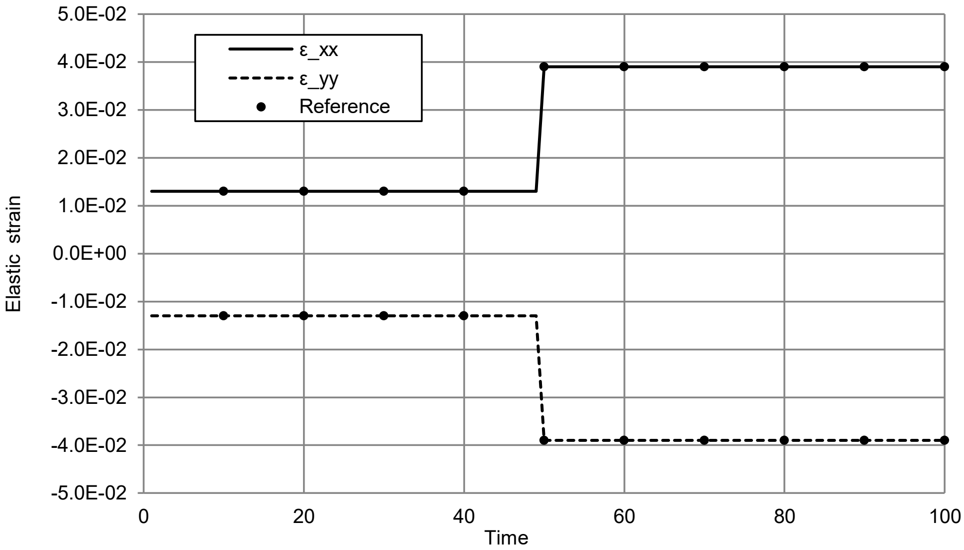


Figure 12.18.7
Elastic strain of MaterialViscoElastic18

Time	ε_{xx}	Reference	ε_{yy}	Reference
10	*0.0130*	*0.0130*	*-0.0130*	*-0.0130*
20	*0.0130*	*0.0130*	*-0.0130*	*-0.0130*
30	*0.0130*	*0.0130*	*-0.0130*	*-0.0130*
40	*0.0130*	*0.0130*	*-0.0130*	*-0.0130*
50	*0.0390*	*0.0390*	*-0.0390*	*-0.0390*
60	*0.0390*	*0.0390*	*-0.0390*	*-0.0390*
70	*0.0390*	*0.0390*	*-0.0390*	*-0.0390*
80	*0.0390*	*0.0390*	*-0.0390*	*-0.0390*
90	*0.0390*	*0.0390*	*-0.0390*	*-0.0390*
100	*0.0390*	*0.0390*	*-0.0390*	*-0.0390*