

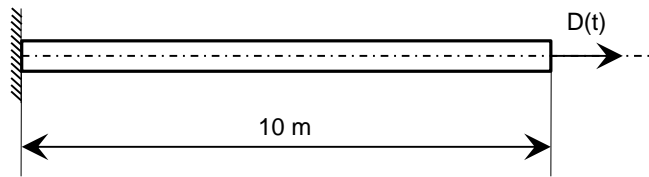


7.1 Multi-linear Model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresis01.gts

Figure 7.1.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of multi-linear model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.1.1
bar element model



Material data	Initial stiffness	$K = 4.0 \times 10^9 \text{ N}$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.1.2
Force-Stiffness reduction factor	1st Yield point	Force : $4.0 \times 10^5 \text{ N}$ Stiffness reduction : 0.1875
	2nd Yield point	Force : $5.5 \times 10^5 \text{ N}$ Stiffness reduction : 0.041667
Hinge location	Lumped plasticity	End node



Figure 7.1.2
Prescribed
displacement at right
end node

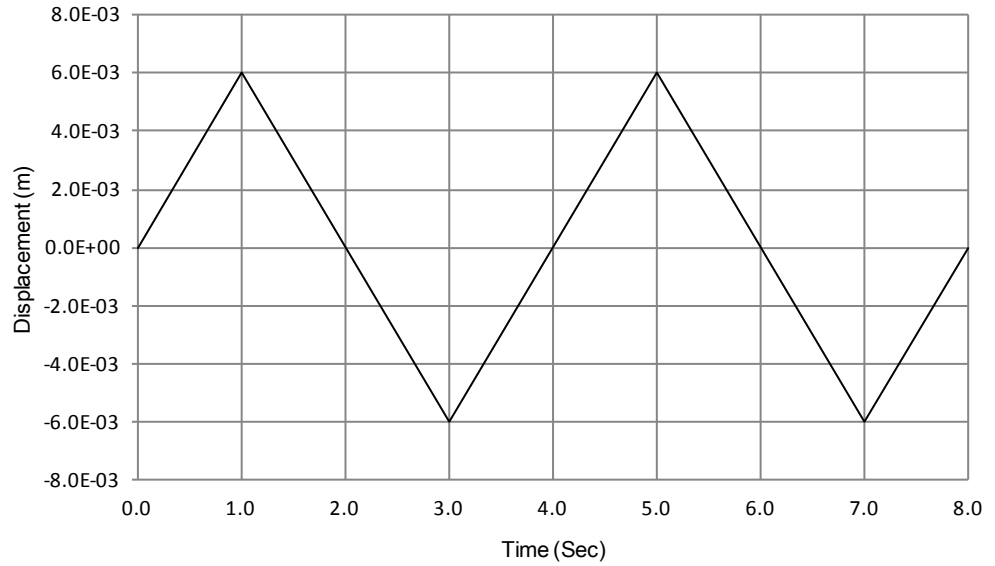


Figure 7.1.3
Force-displacement curve

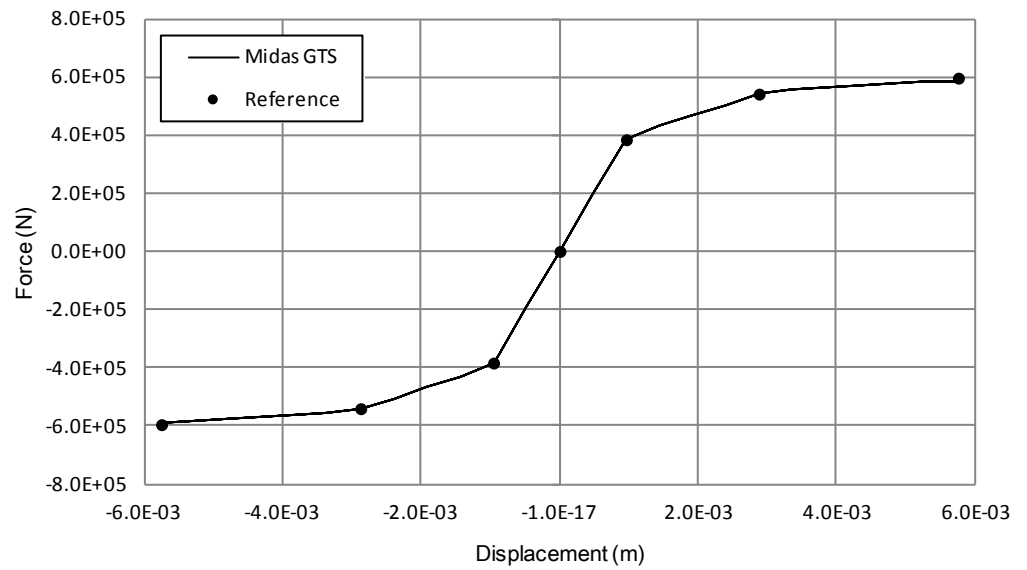




Table 7.1.1 Partial results of force-displacement relationship

Displacement	Force	
	Midas GTS	Reference
-5.76E-03	-5.96E+05	-5.96E+05
-2.88E-03	-5.41E+05	-5.41E+05
-9.60E-04	-3.84E+05	-3.84E+05
0.00E+00	0.00E+00	0.00E+00
9.60E-04	3.84E+05	3.84E+05
2.88E-03	5.41E+05	5.41E+05
5.76E-03	5.96E+05	5.96E+05

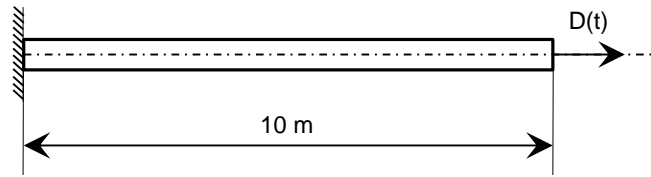


7.2 Kinematic hardening Model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresis02.gts

Figure 7.2.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of kinematic hardening model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.2.1
bar element model



Material data	Initial stiffness	$K = 4.0 \times 10^9 \text{ N}$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.2.2
Skeleton curve data	1st Yield point	Force : $4.0 \times 10^5 \text{ N}$ Stiffness reduction : 0.1875
	2nd Yield point	Force : $5.5 \times 10^5 \text{ N}$ Stiffness reduction : 0.041667
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.2.2
Prescribed
displacement at right
end node

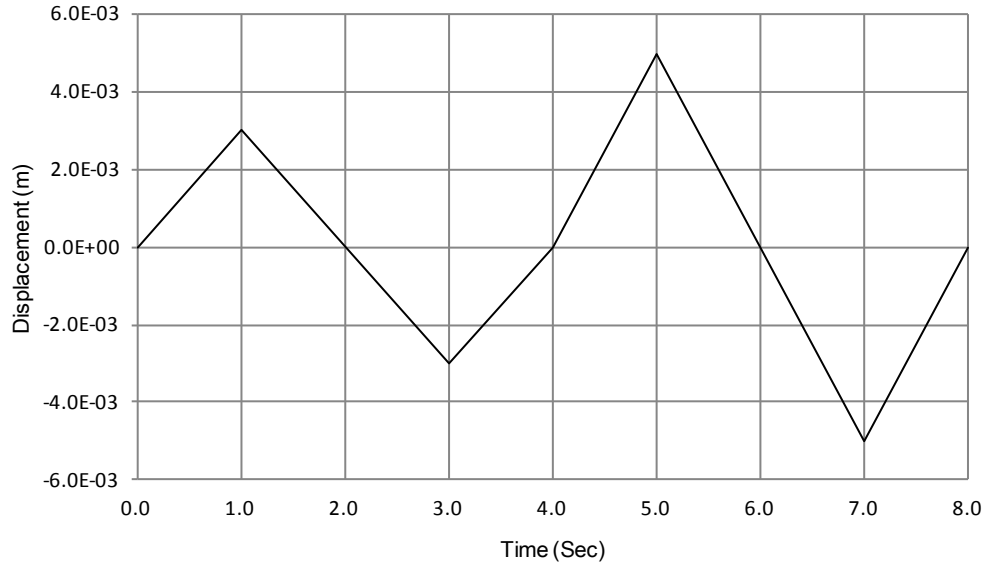


Figure 7.2.3
Force-displacement curve

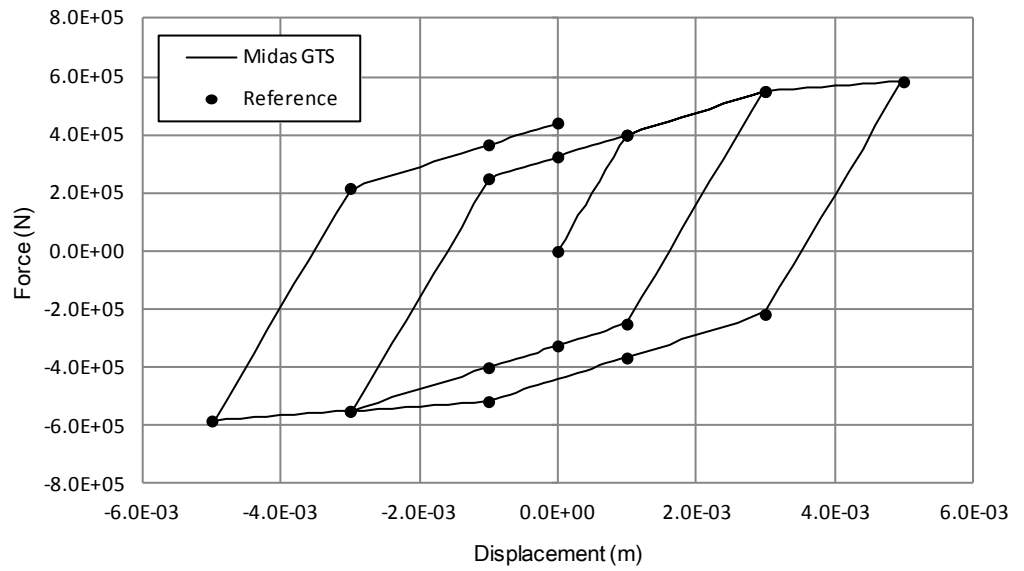




Table 7.2.1 Partial results of force-displacement relationship

Displacement	Force	
	Midas GTS	Reference
0.00E+00	0.00E+00	0.00E+00
1.00E-03	4.00E+05	4.00E+05
3.00E-03	5.50E+05	5.50E+05
1.00E-03	-2.50E+05	-2.50E+05
0.00E+00	-3.25E+05	-3.25E+05
-1.00E-03	-4.00E+05	-4.00E+05
-3.00E-03	-5.50E+05	-5.50E+05
-1.00E-03	2.50E+05	2.50E+05
0.00E+00	3.25E+05	3.25E+05
1.00E-03	4.00E+05	4.00E+05
3.00E-03	5.50E+05	5.50E+05
5.00E-03	5.83E+05	5.83E+05
3.00E-03	-2.17E+05	-2.17E+05
1.00E-03	-3.67E+05	-3.67E+05

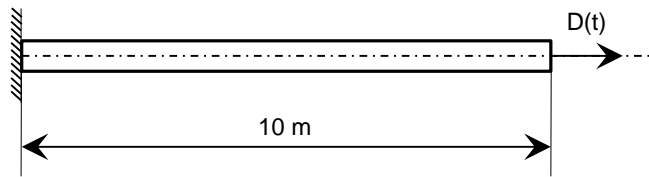


7.3 Peak-Oriented model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresys03.gts

Figure 7.3.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of peak-oriented model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.3.1
bar element model



Material data	Initial stiffness	$K = 4.0 \times 10^9 \text{ N}$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.3.2
Force-Stiffness reduction factor	1st Yield point	Force : $4.0 \times 10^5 \text{ N}$ Stiffness reduction : 0.1875
	2nd Yield point	Force : $5.5 \times 10^5 \text{ N}$ Stiffness reduction : 0.041667
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.3.2
Prescribed
displacement at right
end node

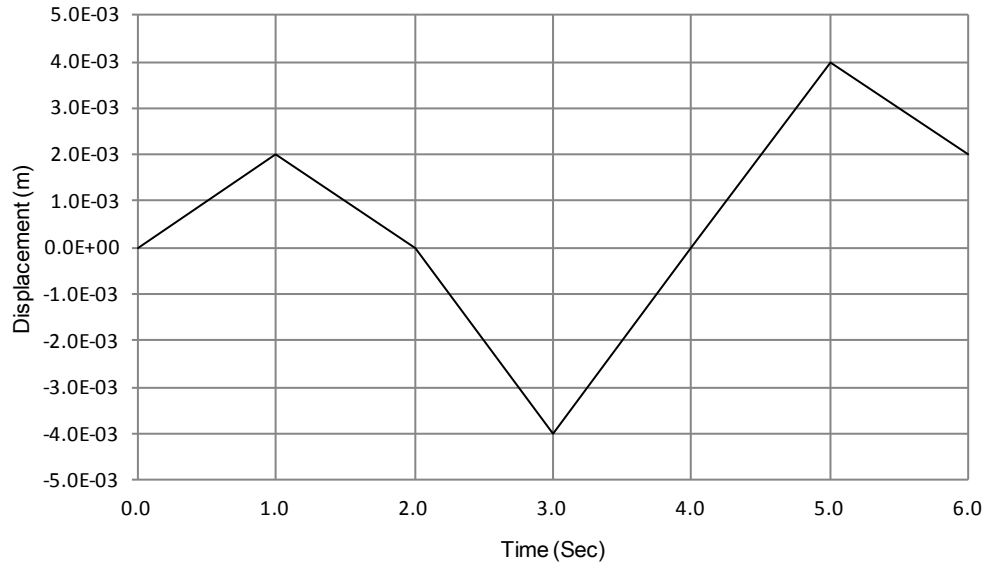
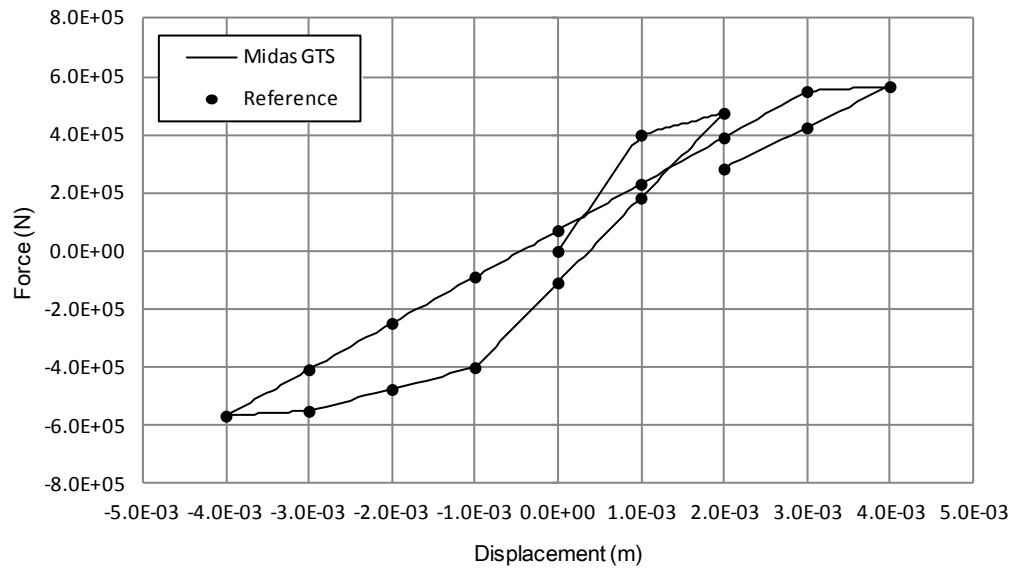


Figure 7.3.3
Force-displacement curve



*Table 7.3.1 Partial results of force-displacement relationship*

Displacement	Force	
	Midas GTS	Reference
0.00E+00	0.00E+00	0.00E+00
1.00E-03	4.00E+05	4.00E+05
2.00E-03	4.75E+05	4.75E+05
1.00E-03	1.83E+05	1.83E+05
0.00E+00	-1.08E+05	-1.08E+05
-1.00E-03	-4.00E+05	-4.00E+05
-2.00E-03	-4.75E+05	-4.75E+05
-3.00E-03	-5.50E+05	-5.50E+05
-4.00E-03	-5.67E+05	-5.67E+05
-3.00E-03	-4.07E+05	-4.07E+05
-2.00E-03	-2.48E+05	-2.48E+05
-1.00E-03	-8.81E+04	-8.81E+04
0.00E+00	7.14E+04	7.14E+04
1.00E-03	2.31E+05	2.31E+05

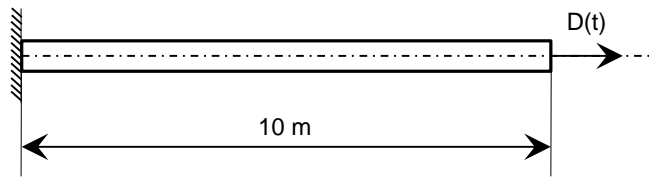


7.4 Origin-Oriented model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresys04.gts

Figure 7.4.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of origin-oriented model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.4.1
bar element model



Material data	Initial stiffness	$K = 4.0 \times 10^9 \text{ N}$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.4.2
Force-Stiffness reduction factor	1st Yield point	Force : $4.0 \times 10^5 \text{ N}$ Stiffness reduction : 0.1875
	2nd Yield point	Force : $5.5 \times 10^5 \text{ N}$ Stiffness reduction : 0.041667
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.4.2
Prescribed
displacement at right
end node

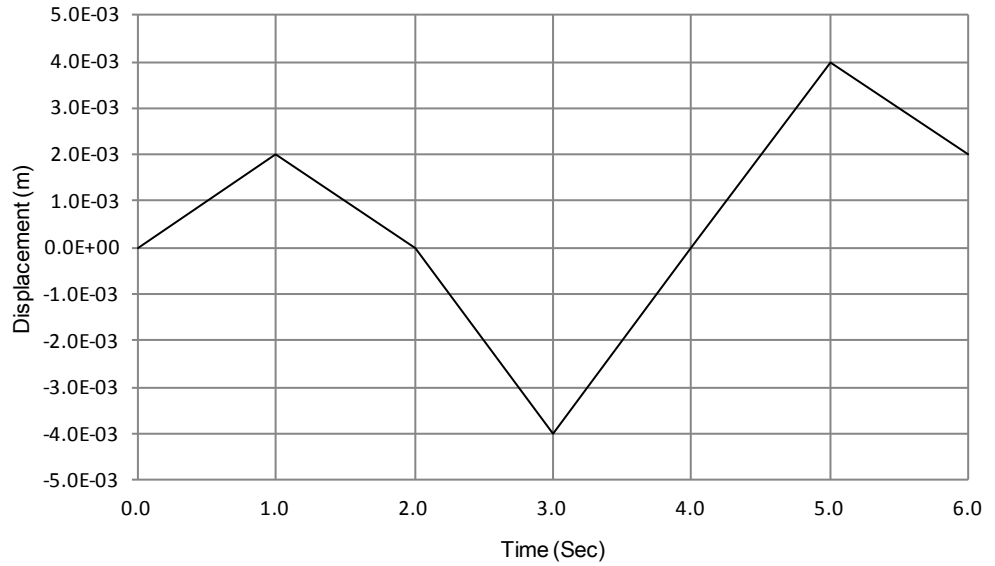


Figure 7.4.3
Force-displacement curve

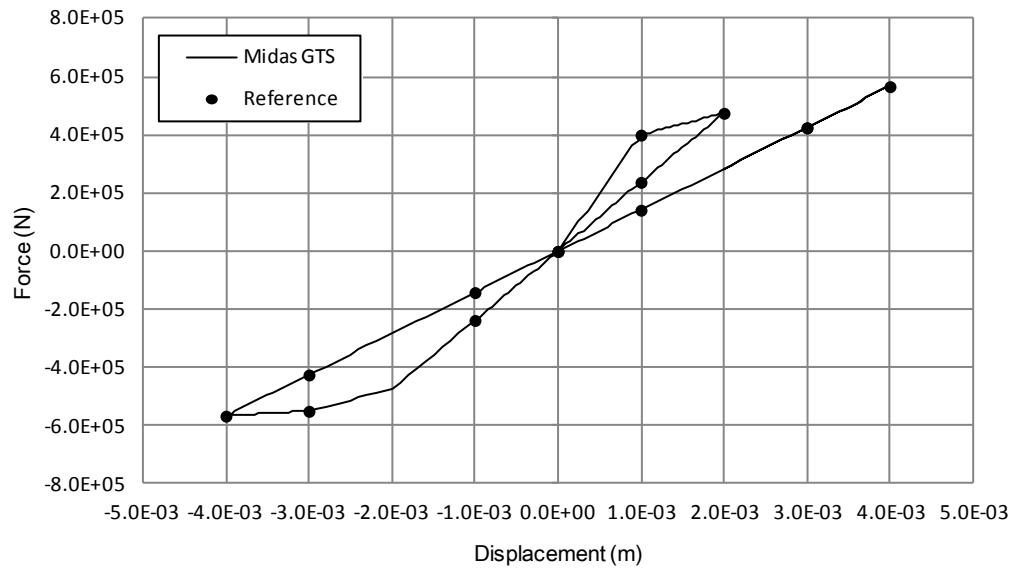




Table 7.4.1 Partial results of force-displacement relationship

Displacement	Force	
	Midas GTS	Reference
0.00E+00	0.00E+00	0.00E+00
1.00E-03	4.00E+05	4.00E+05
2.00E-03	4.75E+05	4.75E+05
1.00E-03	2.38E+05	2.38E+05
0.00E+00	1.65E-09	1.65E-09
-1.00E-03	-2.38E+05	-2.38E+05
-3.00E-03	-5.50E+05	-5.50E+05
-4.00E-03	-5.67E+05	-5.67E+05
-3.00E-03	-4.25E+05	-4.25E+05
-1.00E-03	-1.42E+05	-1.42E+05
0.00E+00	-4.15E-09	-4.15E-09
1.00E-03	1.42E+05	1.42E+05
3.00E-03	4.25E+05	4.25E+05
4.00E-03	5.67E+05	5.67E+05

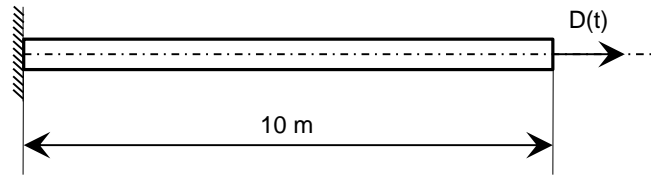


7.5 Clough Model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresys05.gts

Figure 7.5.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of clough model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.5.1
bar element model



Material data	Initial stiffness	$K = 4.0 \times 10^9 \text{ N}$
	Unloading parameter	$\beta = 0.2$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.5.2
Force-Stiffness reduction factor	1st Yield point	Force : $4.0 \times 10^5 \text{ N}$ Stiffness reduction : 0.1875
	2nd Yield point	Force : $5.5 \times 10^5 \text{ N}$ Stiffness reduction : 0.041667
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.5.2
Prescribed
displacement at right
end node

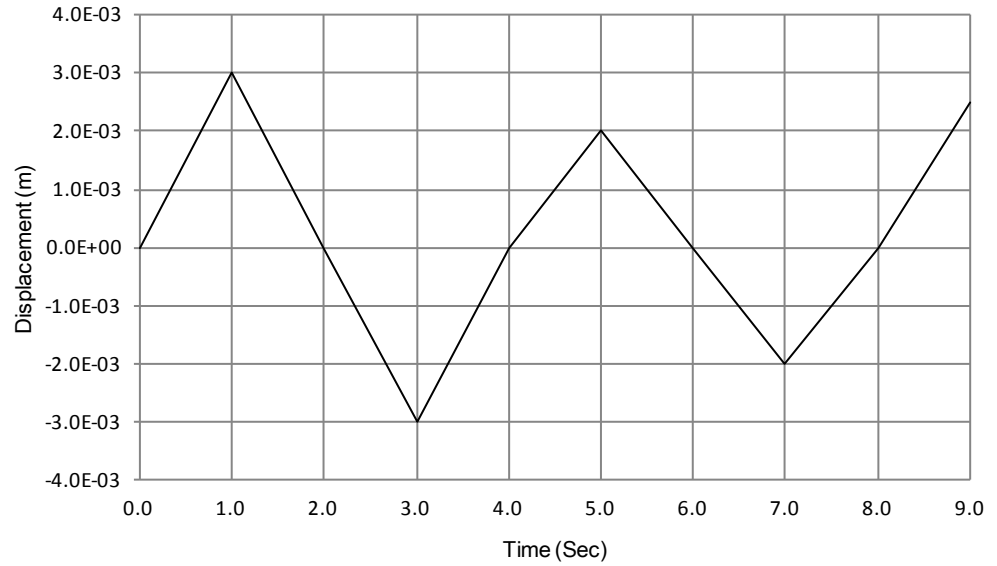
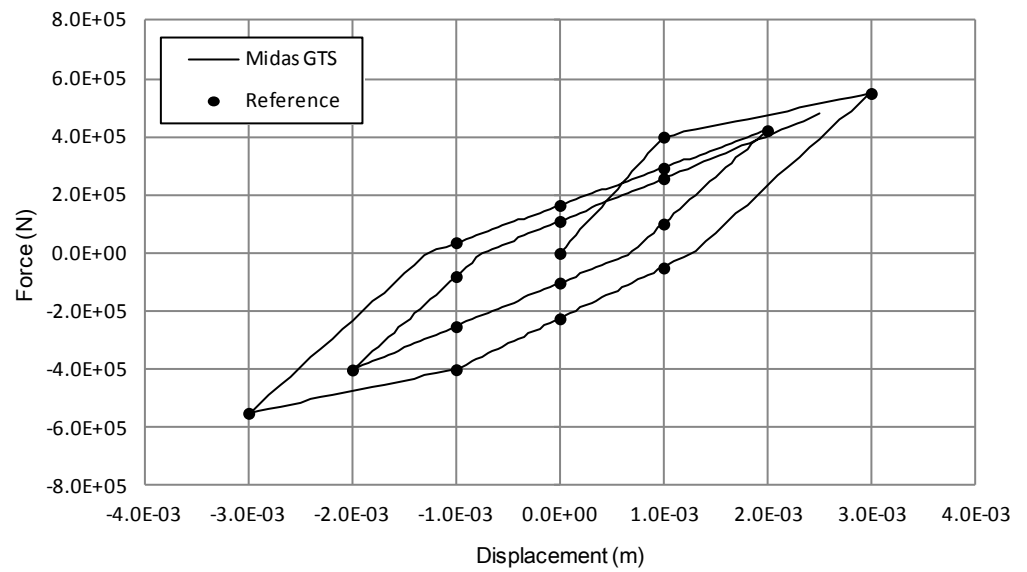


Figure 7.5.3
Force-displacement curve



*Table 7.5.1 Partial results of force-displacement*

Displacement	Force	
	Midas GTS	Reference
0.00E+00	0.00E+00	0.00E+00
1.00E-03	4.00E+05	4.00E+05
3.00E-03	5.50E+05	5.50E+05
1.00E-03	-5.02E+04	-5.02E+04
0.00E+00	-2.25E+05	-2.25E+05
-1.00E-03	-4.00E+05	-4.00E+05
-3.00E-03	-5.50E+05	-5.50E+05
-1.00E-03	3.68E+04	3.68E+04
0.00E+00	1.65E+05	1.65E+05
1.00E-03	2.93E+05	2.93E+05
2.00E-03	4.22E+05	4.22E+05
1.00E-03	1.01E+05	1.01E+05
0.00E+00	-1.02E+05	-1.02E+05
-1.00E-03	-2.52E+05	-2.52E+05

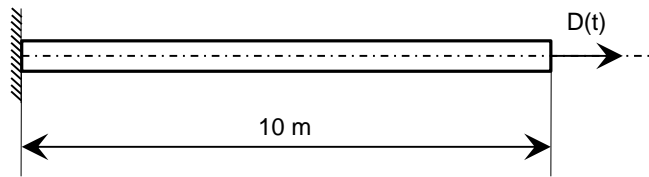


7.6 Degrading Model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresys06.gts

Figure 7.6.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of degrading model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.6.1
bar element model



Material data	Initial stiffness	$K = 4.0 \times 10^9 \text{ N}$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.6.2
Force-Stiffness reduction factor	1st Yield point	Force : $4.0 \times 10^5 \text{ N}$ Stiffness reduction : 0.1875
	2nd Yield point	Force : $5.5 \times 10^5 \text{ N}$ Stiffness reduction : 0.041667
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.6.2
Prescribed
displacement at right
end node

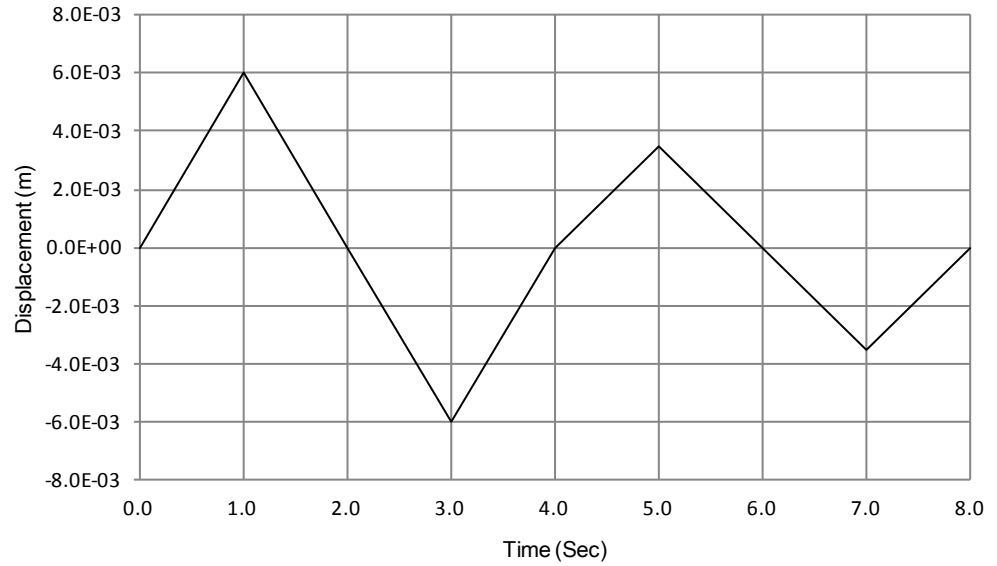


Figure 7.6.3
Force-displacement curve

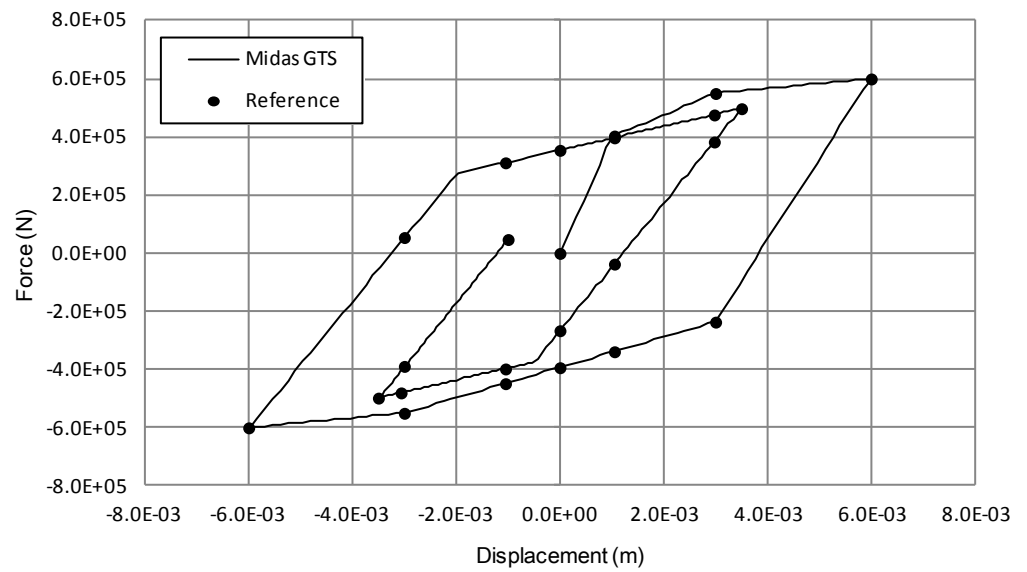




Table 7.6.1 Partial results of force-displacement

Displacement	Force	
	MIDAS GTS	Reference
0.00E+00	0.00E+00	0.00E+00
1.05E-03	4.04E+05	4.04E+05
3.00E-03	5.50E+05	5.50E+05
6.00E-03	6.00E+05	6.00E+05
3.00E-03	-2.36E+05	-2.36E+05
1.05E-03	-3.38E+05	-3.38E+05
0.00E+00	-3.93E+05	-3.93E+05
-1.05E-03	-4.48E+05	-4.48E+05
-3.00E-03	-5.50E+05	-5.50E+05
-6.00E-03	-6.00E+05	-6.00E+05
-3.00E-03	5.45E+04	5.45E+04
-1.05E-03	3.12E+05	3.12E+05
0.00E+00	3.55E+05	3.55E+05
1.05E-03	3.98E+05	3.98E+05

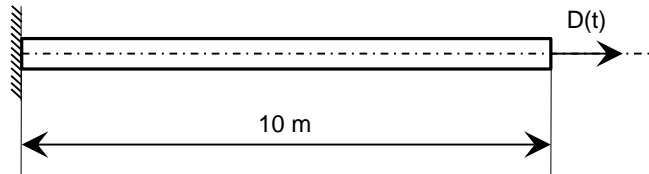


7.7 Takeda Model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresys07A.gts Hysteresys07B.gts

Figure 7.7.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of Takeda model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.7.1
bar element model



Material data	Initial stiffness	$K = 4.0 \times 10^9 \text{ N}$
	Unloading parameter	$\beta = 0.4$
	Inner loop parameter	$\alpha = 0.85$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.7.2 Figure 7.7.3
	Force-Stiffness reduction factor	
	1st Yield point	Force : $4.0 \times 10^5 \text{ N}$ Stiffness reduction : 0.1875
	2nd Yield point	Force : $5.5 \times 10^5 \text{ N}$ Stiffness reduction : 0.041667
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.7.2
Prescribed
displacement at right
end node (case A)

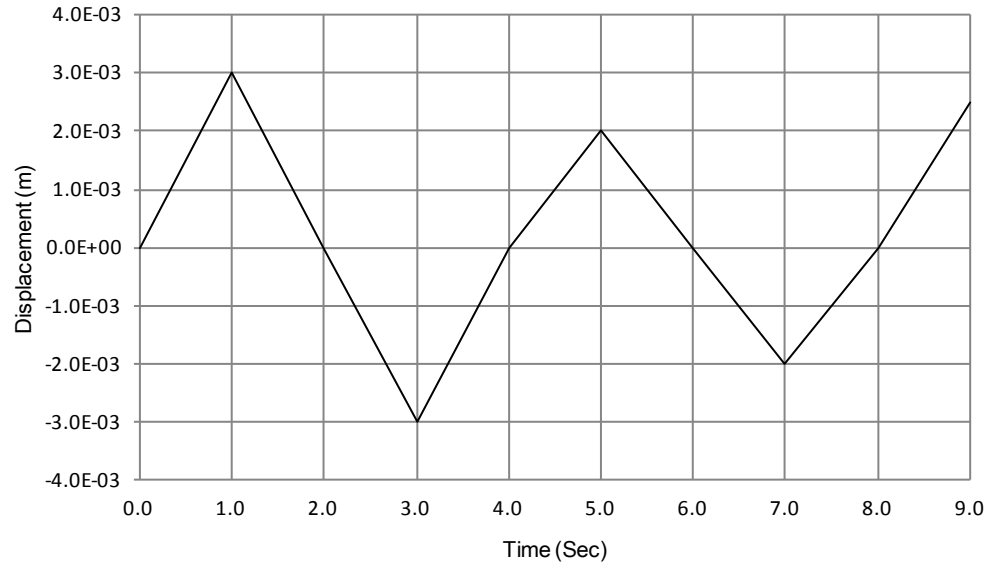


Figure 7.7.3
Prescribed
displacement at right
end node (case B)

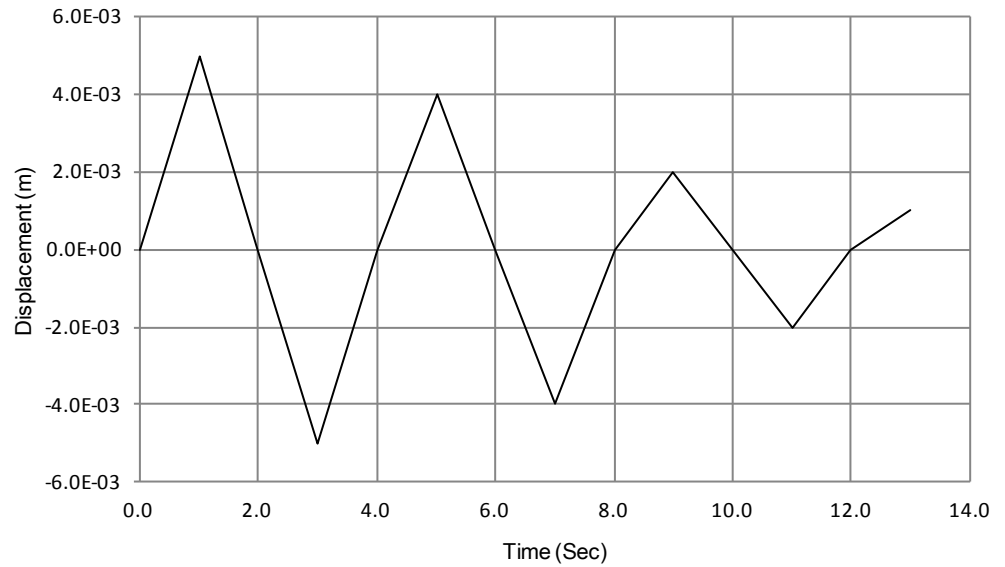




Figure 7.7.4
Force-displacement
curve (case A)

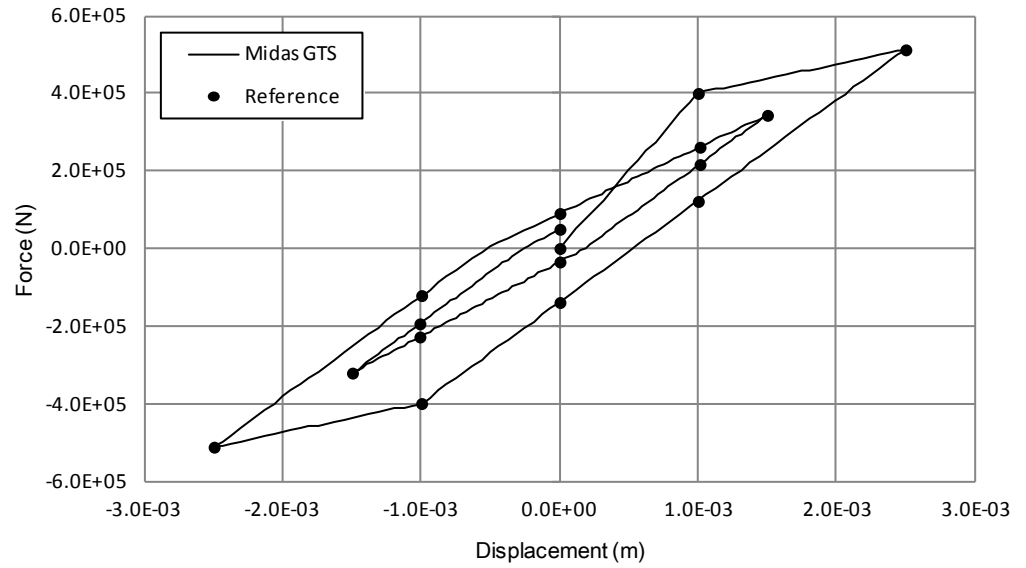
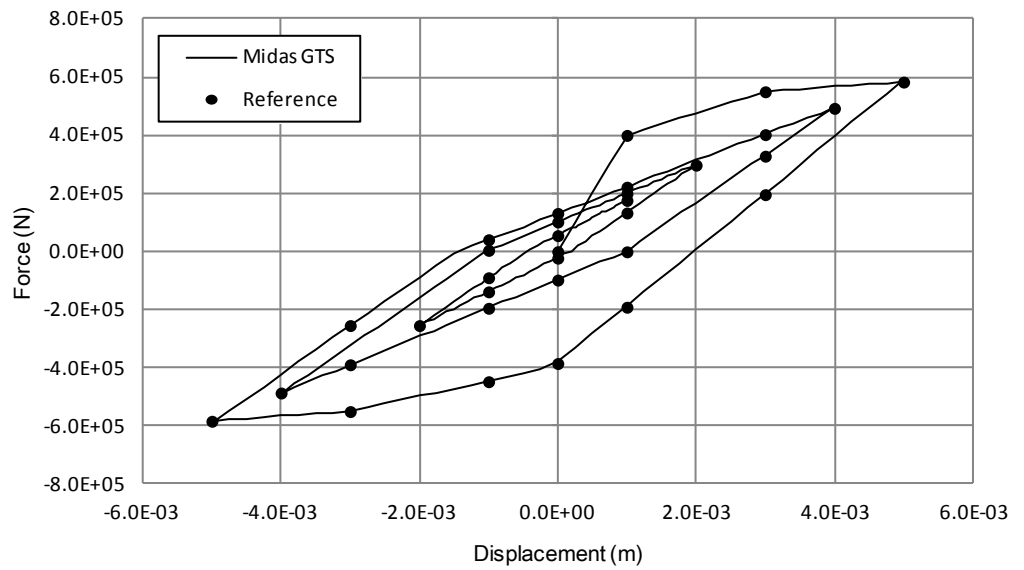


Figure 7.7.5
Force-displacement
curve (case B)



*Table 7.7.1 Partial results of force-displacement (case A)*

Displacement	Force	
	MIDAS GTS	Reference
0.00E+00	0.00E+00	0.00E+00
1.00E-03	4.00E+05	4.00E+05
2.50E-03	5.13E+05	5.13E+05
1.00E-03	1.21E+05	1.21E+05
0.00E+00	-1.39E+05	-1.39E+05
-1.00E-03	-4.00E+05	-4.00E+05
-2.50E-03	-5.13E+05	-5.13E+05
-1.00E-03	-1.21E+05	-1.21E+05
0.00E+00	9.02E+04	9.02E+04
1.01E-03	2.61E+05	2.61E+05
1.50E-03	3.44E+05	3.44E+05
1.01E-03	2.16E+05	2.16E+05
0.00E+00	-3.48E+04	-3.48E+04
-1.01E-03	-2.28E+05	-2.28E+05
-1.50E-03	-3.21E+05	-3.21E+05



Table 7.7.2 Partial results of force-displacement (case B)

Displacement	Force	
	MIDAS GTS	Reference
0.00E+00	0.00E+00	0.00E+00
1.00E-03	4.00E+05	4.00E+05
3.00E-03	5.50E+05	5.50E+05
5.00E-03	5.83E+05	5.83E+05
3.00E-03	1.96E+05	1.96E+05
1.00E-03	-1.91E+05	-1.91E+05
0.00E+00	-3.85E+05	-3.85E+05
-1.00E-03	-4.47E+05	-4.47E+05
-3.00E-03	-5.50E+05	-5.50E+05
-5.00E-03	-5.83E+05	-5.83E+05
-3.00E-03	-2.54E+05	-2.54E+05
-1.00E-03	4.11E+04	4.11E+04
0.00E+00	1.32E+05	1.32E+05
1.00E-03	2.22E+05	2.22E+05
3.00E-03	4.03E+05	4.03E+05

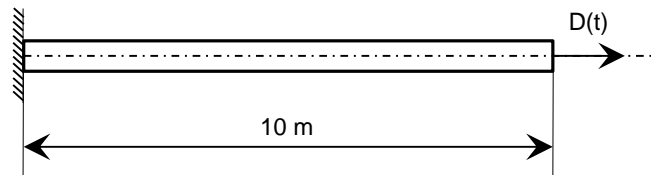


7.8 Modified Takeda Model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresys08.gts

Figure 7.8.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of modified Takeda model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.8.1
bar element model



Material data	Initial stiffness	$K = 4.0 \times 10^9 \text{ N}$
	Unloading parameter	$\beta = 0.4$
	Inner loop parameter	$\alpha = 0.85$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.8.2
Force-Stiffness reduction factor	1st Yield point	Force : $4.0 \times 10^5 \text{ N}$ Stiffness reduction : 0.1875
	2nd Yield point	Force : $5.5 \times 10^5 \text{ N}$ Stiffness reduction : 0.041667
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.8.2
Prescribed
displacement at right
end node

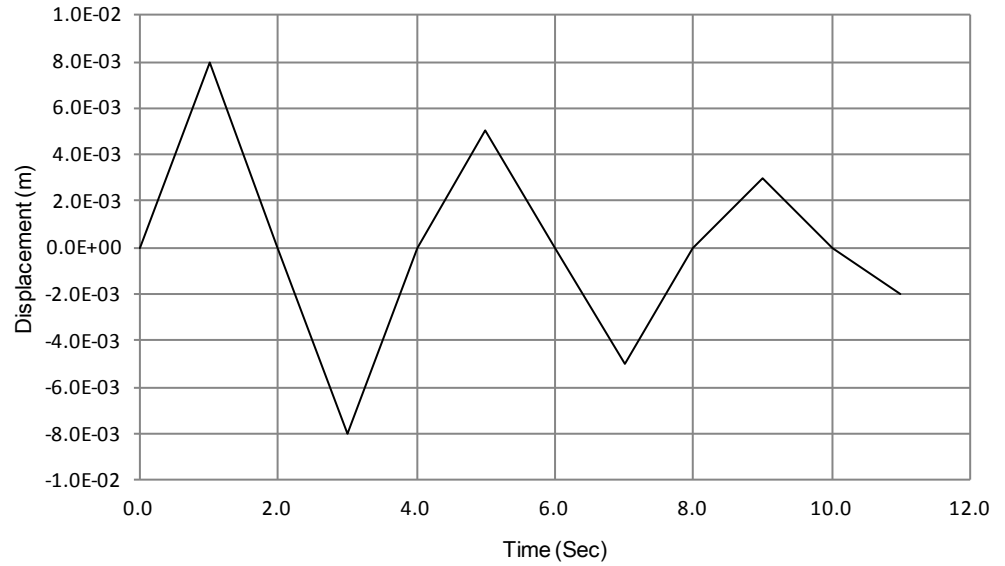


Figure 7.8.3
Force-displacement curve

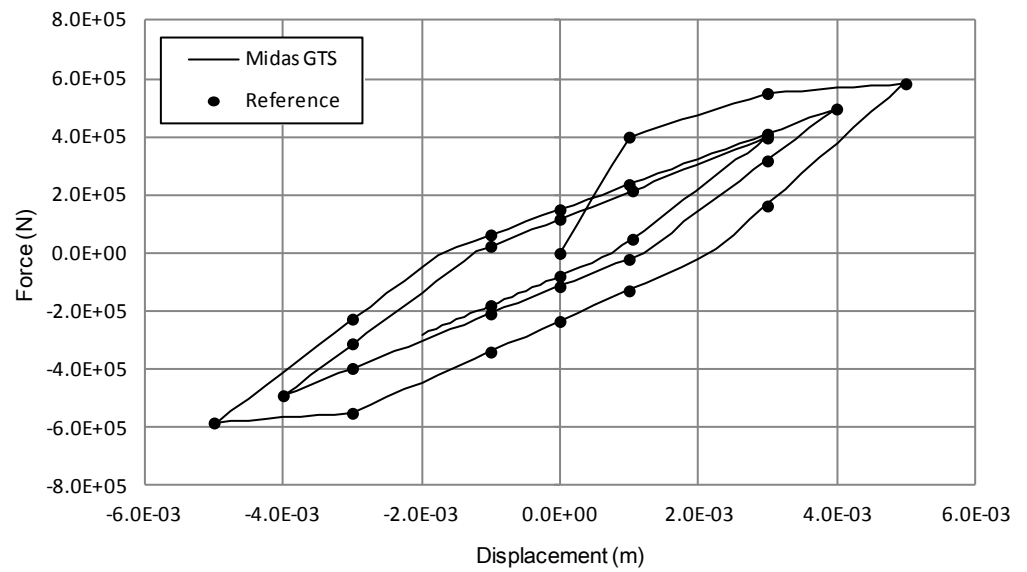




Table 7.8.1 Partial results of force-displacement

Displacement	Force	
	Midas GTS	Reference
0.00E+00	0.00E+00	0.00E+00
1.00E-03	4.00E+05	4.00E+05
3.00E-03	5.50E+05	5.50E+05
5.00E-03	5.83E+05	5.83E+05
3.00E-03	1.63E+05	1.63E+05
1.00E-03	-1.29E+05	-1.29E+05
0.00E+00	-2.34E+05	-2.34E+05
-1.00E-03	-3.39E+05	-3.39E+05
-3.00E-03	-5.50E+05	-5.50E+05
-5.00E-03	-5.83E+05	-5.83E+05
-3.00E-03	-2.26E+05	-2.26E+05
-1.00E-03	6.36E+04	6.36E+04
0.00E+00	1.50E+05	1.50E+05
1.00E-03	2.37E+05	2.37E+05
3.00E-03	4.10E+05	4.10E+05

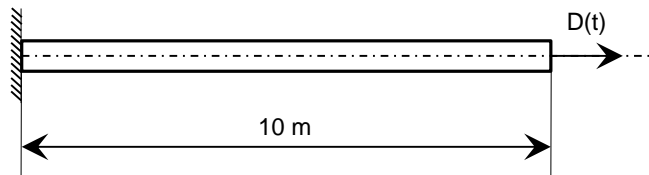


7.9 Ramberg Osgood Model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresys09.gts

Figure 7.9.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of Ramberg Osgood model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.9.1
bar element model



Material data	Elastic modulus	$E = 210.0 \times 10^9 \text{ N/m}^2$
	Critical displacement	$\delta_r = 1.90476 \times 10^{-8} \text{ m}$
	Maximum damping	$h_{max} = 0.12732$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.9.2
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.8.2
Prescribed
displacement at right
end node

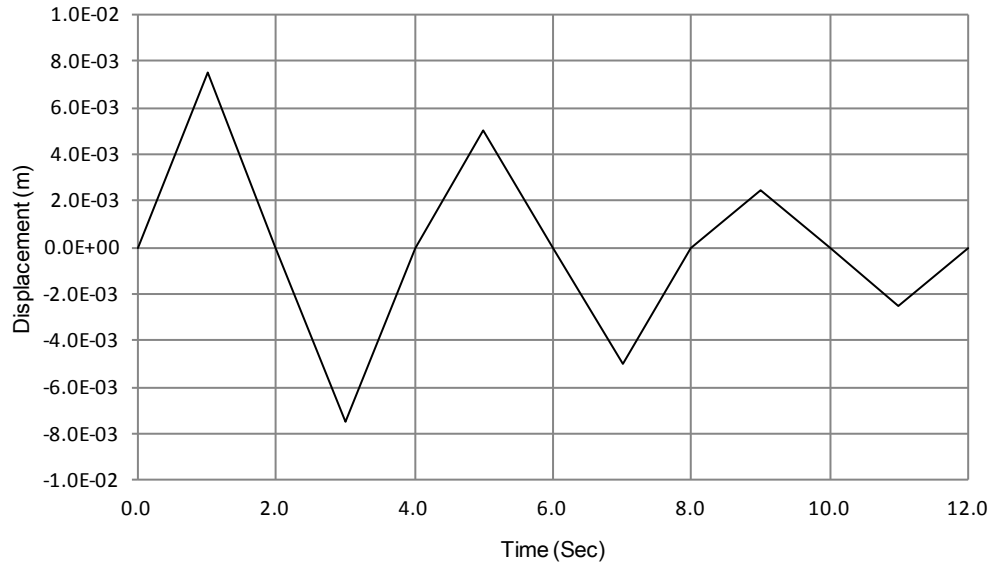


Figure 7.8.3
Force-displacement curve

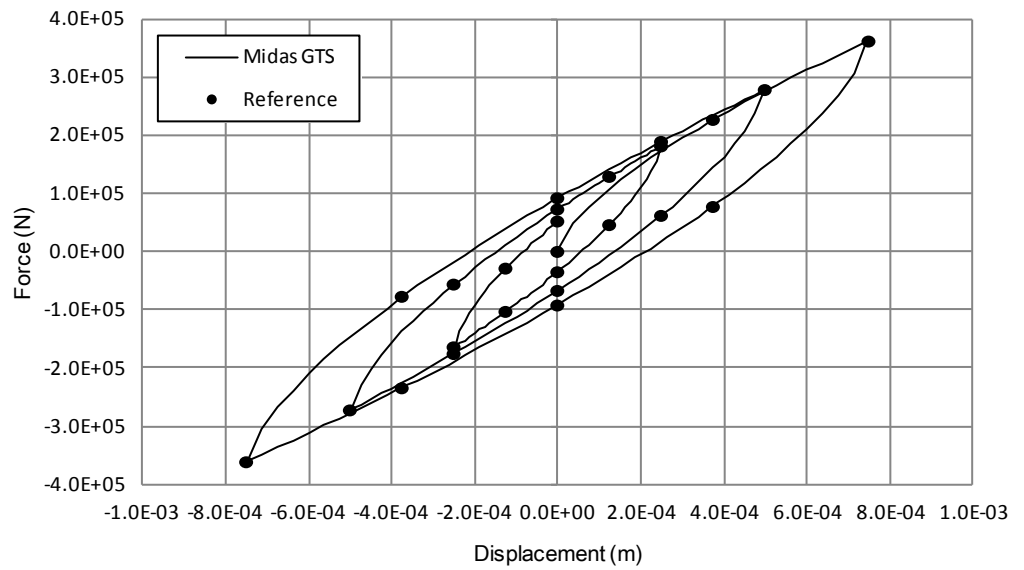




Table 7.9.1 Partial results of force-displacement

Displacement	Force	
	MIDAS GTS	Reference
0.00E+00	0.00E+00	0.00E+00
3.75E-04	2.27E+05	2.27E+05
7.50E-04	3.62E+05	3.62E+05
3.75E-04	7.72E+04	7.72E+04
0.00E+00	-9.22E+04	-9.22E+04
-3.75E-04	-2.35E+05	-2.35E+05
-7.50E-04	-3.62E+05	-3.62E+05
-3.75E-04	-7.72E+04	-7.72E+04
0.00E+00	9.22E+04	9.22E+04
2.50E-04	1.89E+05	1.89E+05
5.00E-04	2.78E+05	2.78E+05
2.50E-04	6.20E+04	6.20E+04
0.00E+00	-6.71E+04	-6.71E+04
-2.50E-04	-1.76E+05	-1.76E+05
-5.00E-04	-2.73E+05	-2.73E+05

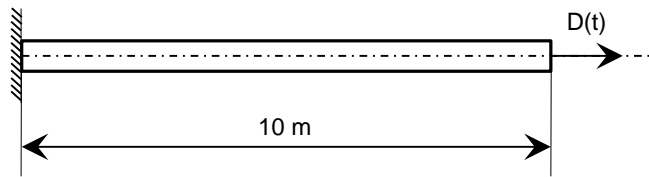


7.10 Hardin Drnevich Model

REFERENCE	Analytical solution
ELEMENT	Bar element
MODEL FILENAME	Hysteresys10.gts

Figure 7.10.1 shows a various Bar element model subjected to axial displacement dependent on time. The fixed boundary condition is assigned to the left end. In case of Hardin Drnevich model, hinge is considered in order to evaluate relationship between force and stiffness reduction factor at the hinge location.

Figure 7.10.1
bar element model



Material data	Elastic modulus	$E = 210.0 \times 10^9 \text{ N/m}^2$
	Critical displacement	$\delta_r = 9.5238 \times 10^{-4} \text{ m}$
Section property	Cross-sectional area	$A = 1 \text{ m}^2$
Loading	Prescribed displacement	Figure 7.10.2
Hinge location	Distributed plasticity	Gauss-Lobatto integration point



Figure 7.10.2
Prescribed
displacement at right
end node

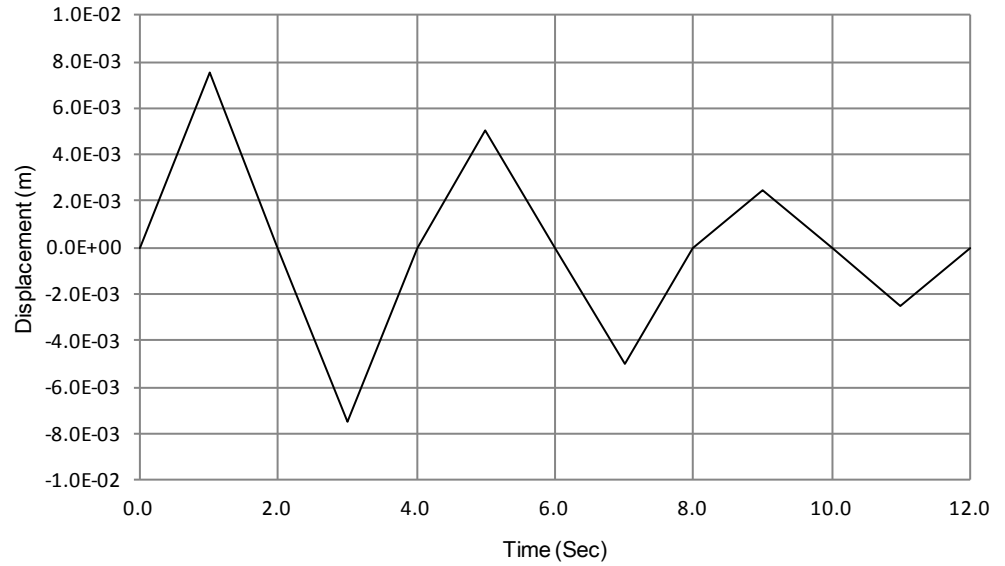


Figure 7.10.3
Force-displacement curve

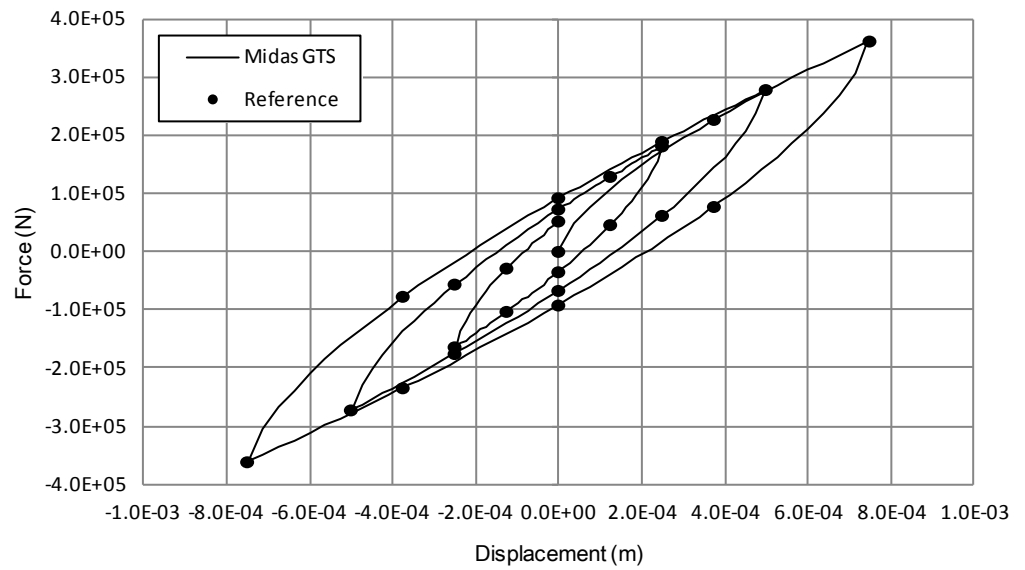




Table 7.10.1 Partial results of force-displacement

Displacement	Force	
	MIDAS GTS	Reference
0.00E+00	0.00E+00	0.00E+00
3.75E-04	5.65E+06	5.65E+06
7.50E-04	8.81E+06	8.81E+06
3.75E-04	2.23E+06	2.23E+06
0.00E+00	-2.49E+06	-2.49E+06
-3.75E-04	-6.04E+06	-6.04E+06
-7.50E-04	-8.81E+06	-8.81E+06
-3.75E-04	-2.23E+06	-2.23E+06
0.00E+00	2.49E+06	2.49E+06
2.50E-04	4.96E+06	4.96E+06
5.00E-04	7.04E+06	7.04E+06
2.50E-04	2.40E+06	2.40E+06
0.00E+00	-1.28E+06	-1.28E+06
-2.50E-04	-4.26E+06	-4.26E+06
-5.00E-04	-6.73E+06	-6.73E+06