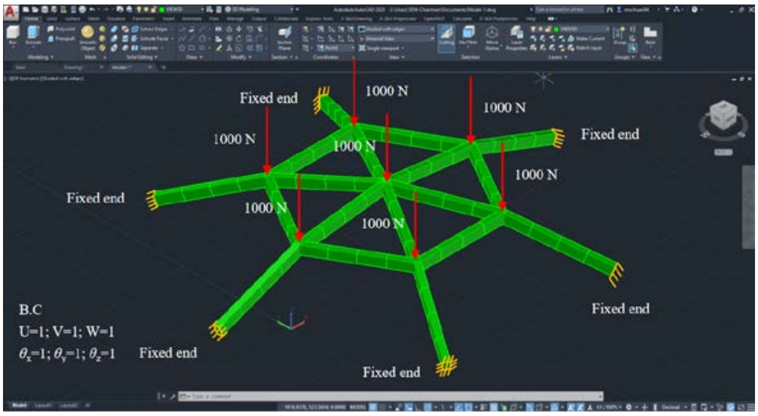
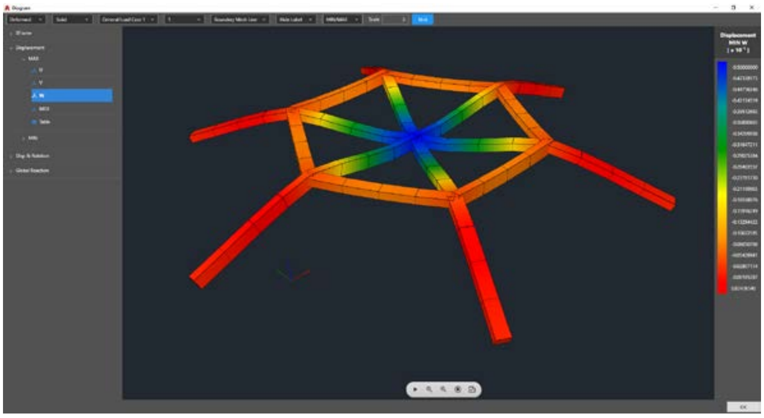
AutoCAD Embedded Finite Element Structural Analysis
Software for Offshore & Onshore Structure

“X-SEA AutoCAD”

Verification Report of 2-node Frame element (Xframe)





KOREA UNIVERSITY

Professor Goangseup Zi
Structural Engineering & Mechanics Lab.
Department of Civil Engineering
Korea University, Seoul, Korea

Verification Example of X-SEA AutoCAD	No: Frame Element 001

Title: Straight Cantilever Beam (Linear Static Analysis)

Problem Description

The beam problem illustrated in Fig.1.1 is analyzed using xframe elements. Four different types of loadings are employed discretely at the free end i.e. extension, in-plane shearing, out-of-plane shearing and twisting moment. The exact displacement for extension, in-plane shear, out-of-plane shear and torsion in the direction of load for the above beam is given below for comparison purpose.

Length L=6.0; Height h=0.2; Thickness t=0.1; E=1.0x10^7; ν=0.3; Load P=unit force at free end.

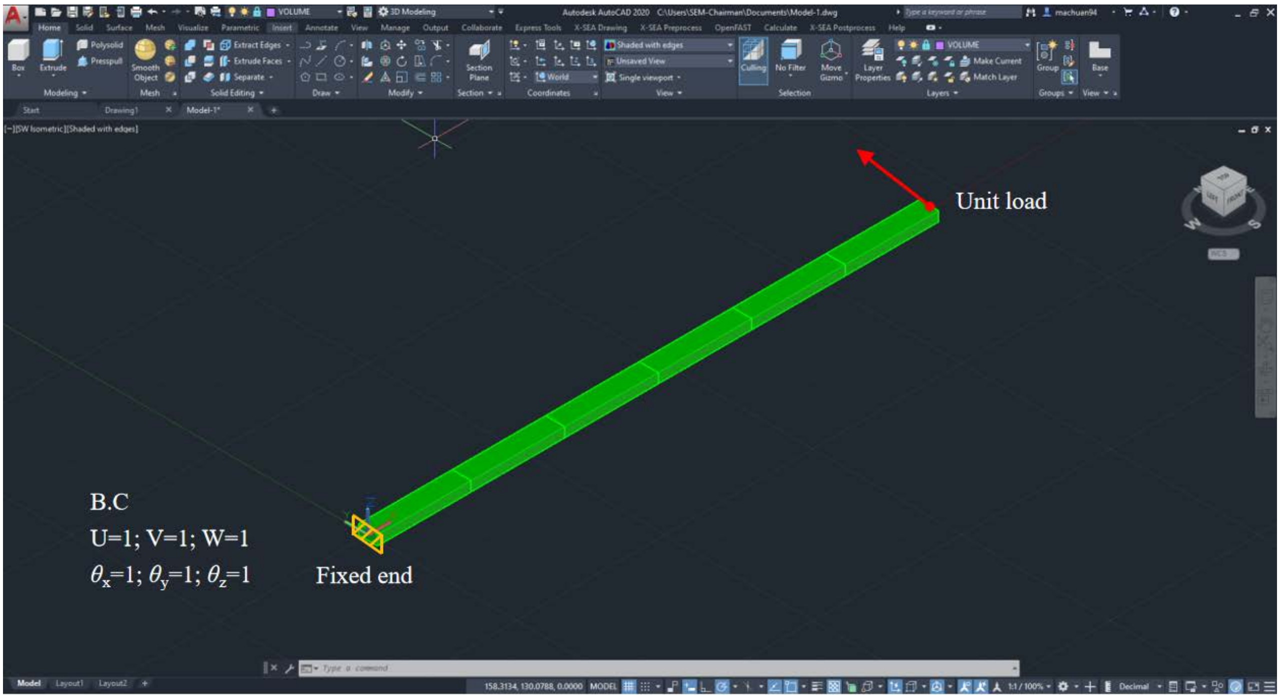


Fig.1.1 Straight cantilever beam model (6 Elements, XFrame)

Results

The results obtained from XFRAME are compared with the above analytical solution in Table 1.1.

Table 1.1 Theoretical and XFrame solutions for beam problems

Problem	Tip load direction	Displacement in direction of load	
		Exact	XFrame
Straight beam	Extension	0.00003	0.000030
	In-plane shear	0.10800	0.108093
	Out-of-plane shear	0.43200	0.432093
	Torsion	0.034243	0.033343
Curved beam	In-plane shear	0.08854	0.087346

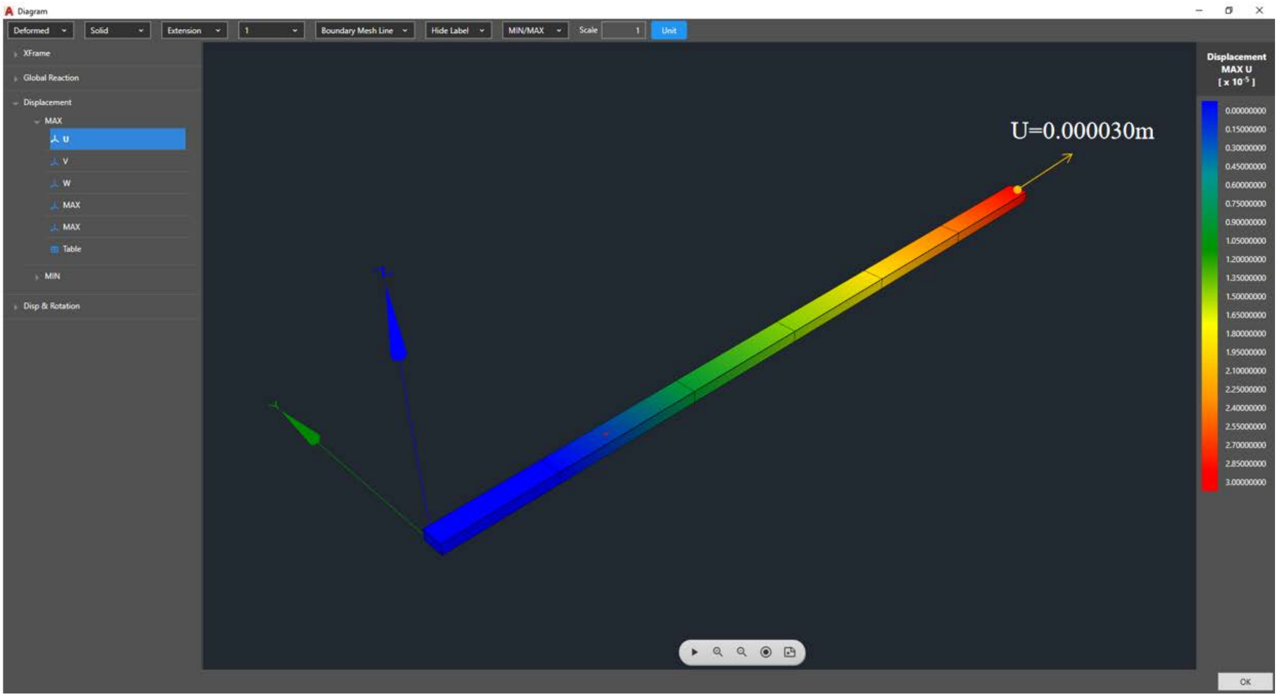


Fig.1.2 Straight cantilever beam's extension (6 Elements, XFrame)

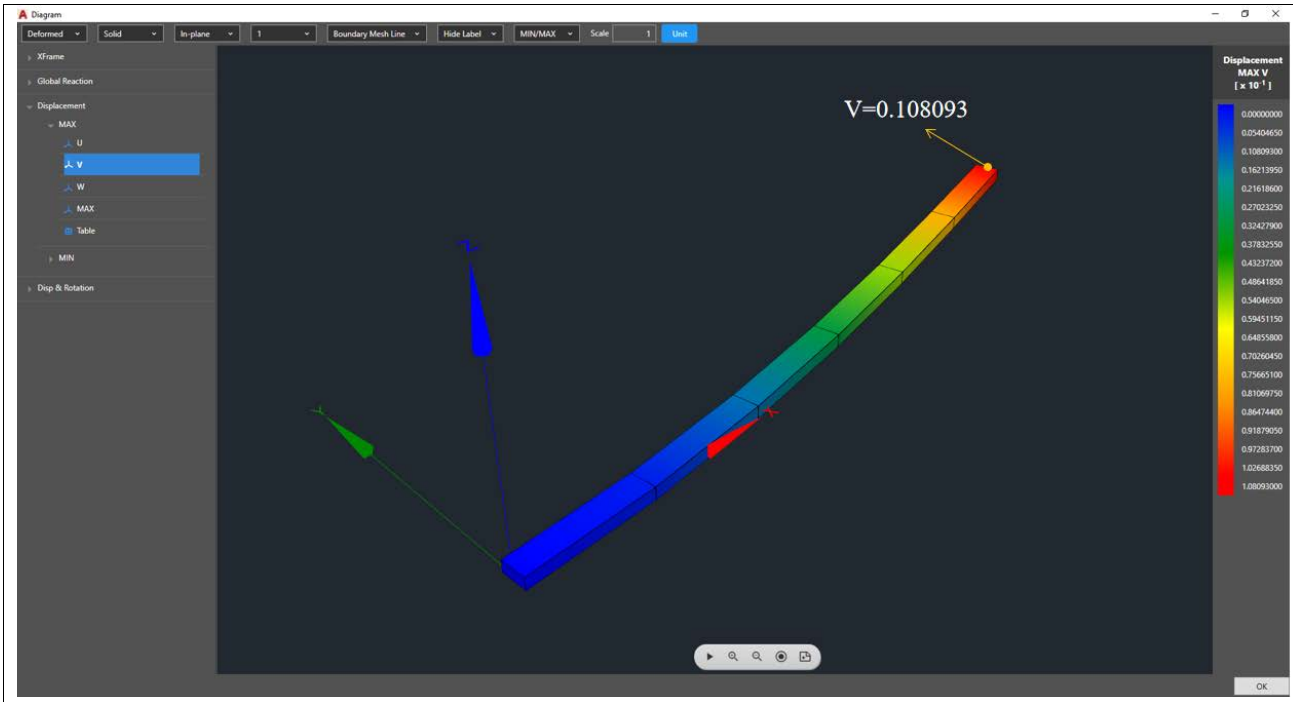


Fig.1.3 Straight cantilever beam’s in-plane shear (6 Elements, XFrame)

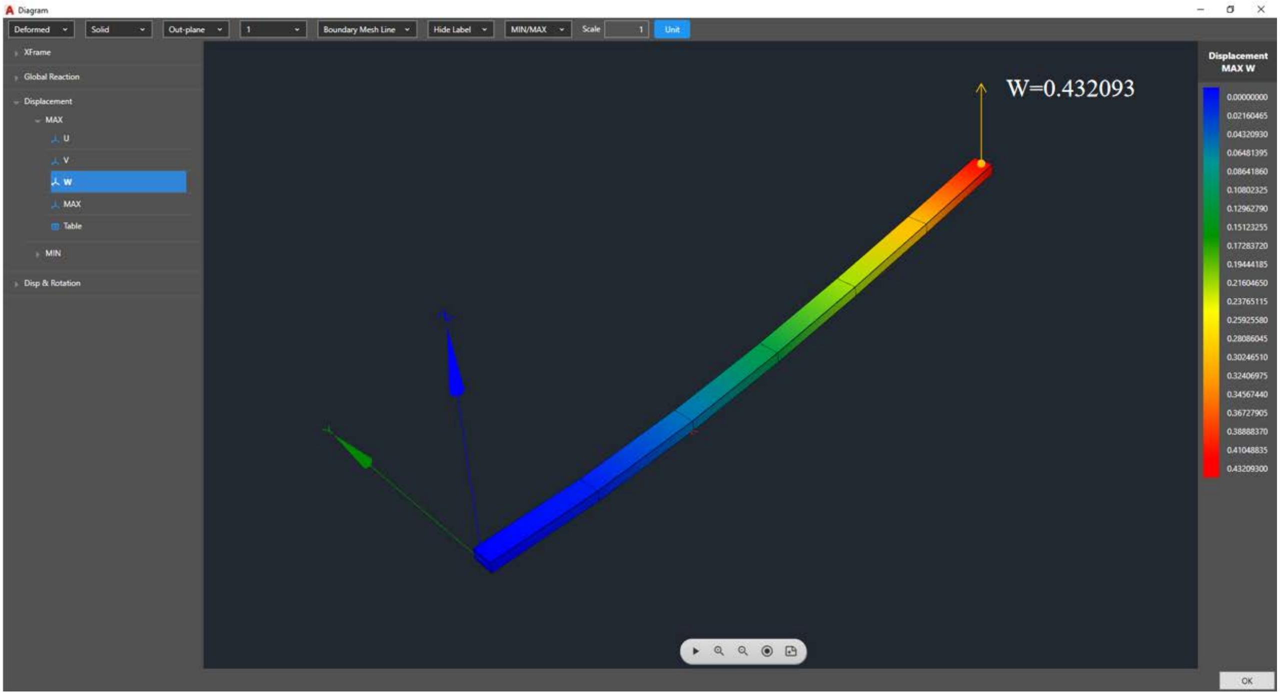


Fig.1.4 Straight cantilever beam’s out-of-plane shear (6 Elements, XFrame)

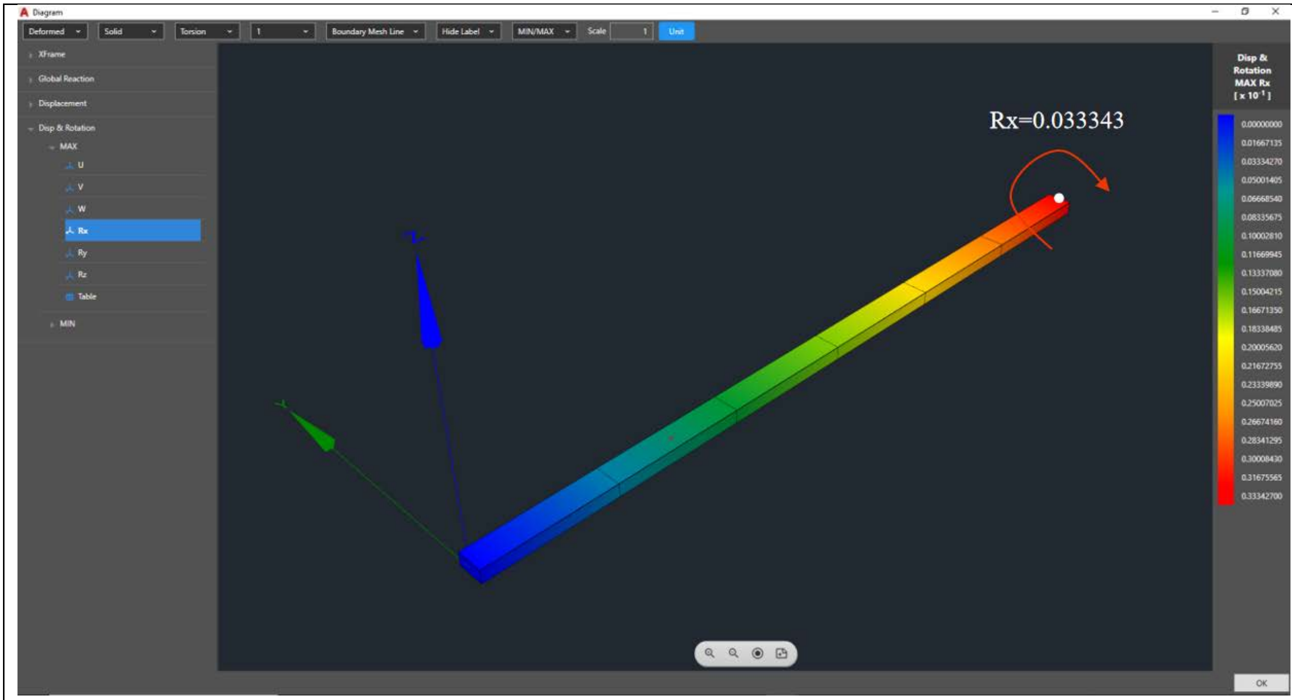


Fig.1.5 Straight cantilever beam's torsion (6 Elements, XFrame)

	XFINASIT Co. LTD
Verification Example of X-SEA AutoCAD	**No: Frame Element 002**
Title: Curved cantilever beam	
Problem Description	

The curved beam is analyzed using the frame elements. A single in-plane shear load at tip suggests various combinations of the principal deformation modes. The results are compared with analytical vertical displacement at tip obtained by Negi and Jangid (1997).

Inner radius=4.12; Outer radius=4.32; Arc=90^0; Thickness=0.1; E=$1.0x10^7$; ν=0.25; Load P=unit in-plane shear force at tip; Mesh size 1x6.

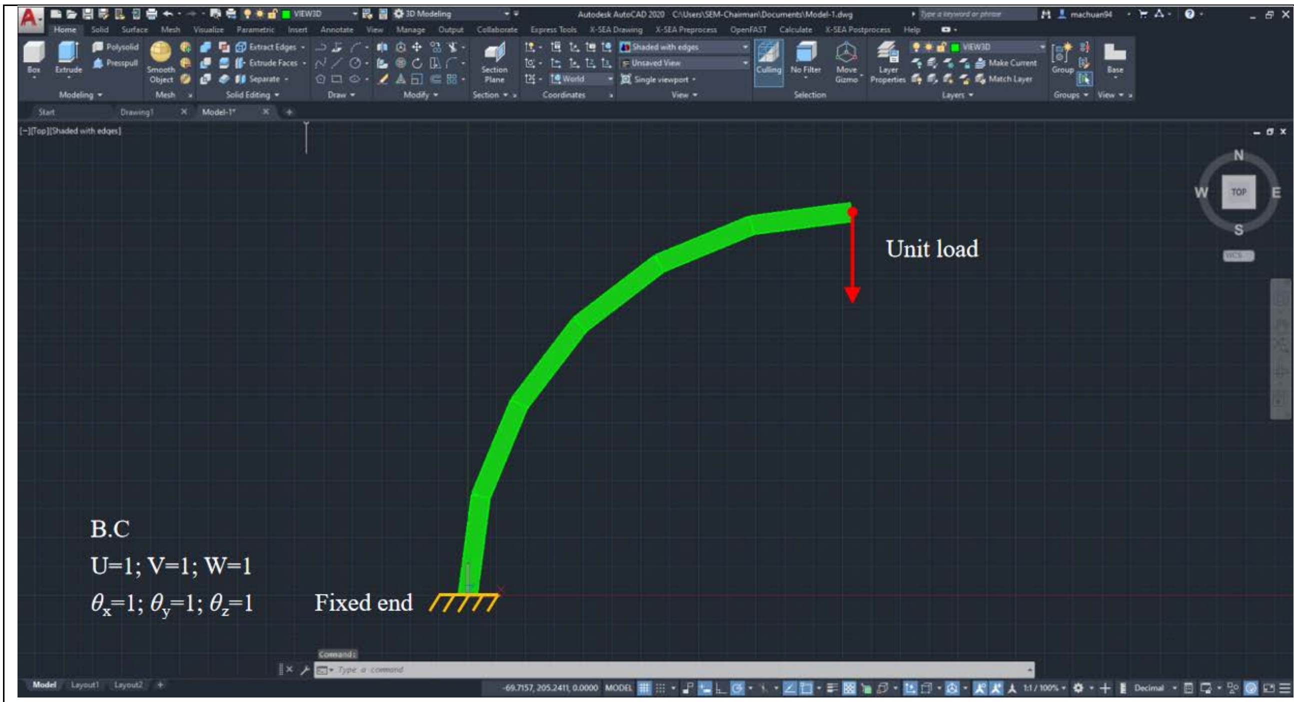


Fig.2.1 Curved cantilever beam model (6 Elements, XFrame)

Results

Table 2.1 Theoretical and XSEA solutions for beam

Problem	Tip load direction	Displacement in direction of load	
		Exact	**XFRAME**
Straight- beam 1	Extension	0.00003	0.000030
	In-plane shear	0.10800	0.108093
	Out-of-plane shear	0.43200	0.432093
	Torsion	0.034243	0.033343
Curved beam	In-plane shear	0.08854	0.087346

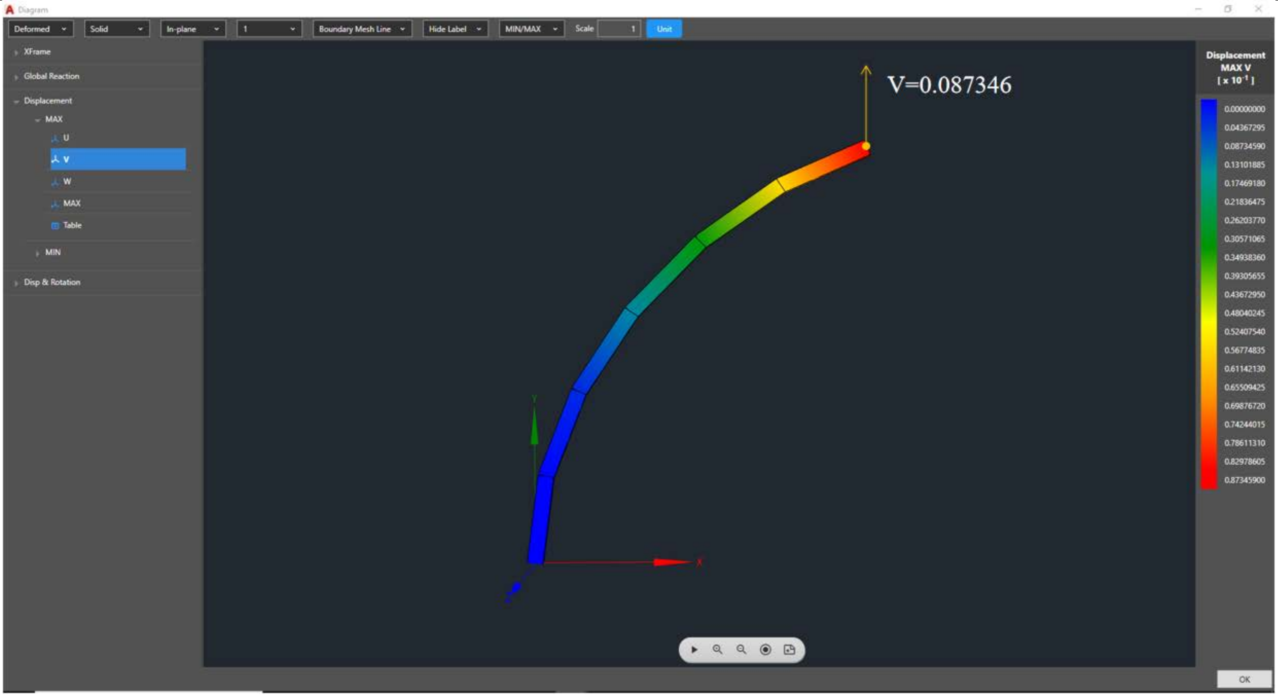


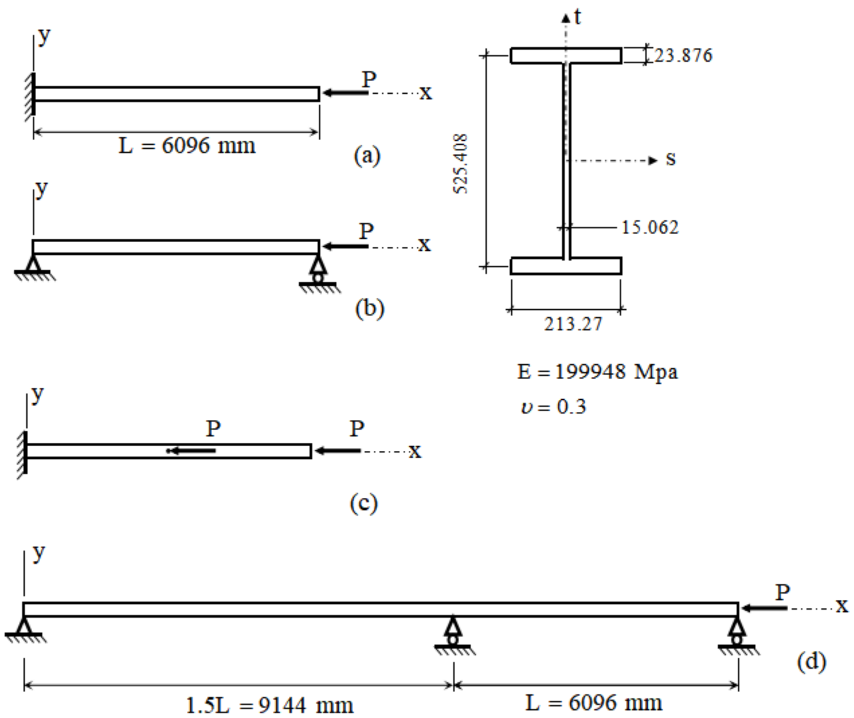
Fig.2.2 Deformation of curved cantilever beam (6 Elements, XFrame)

Verification Example of X-SEA AutoCAD	No: Frame Element 003

Title: Column Buckling

Problem Description

The problems of column buckling are analyzed using the xframe elements and comparing the analytical solutions provided by Chen and Lui (1987).



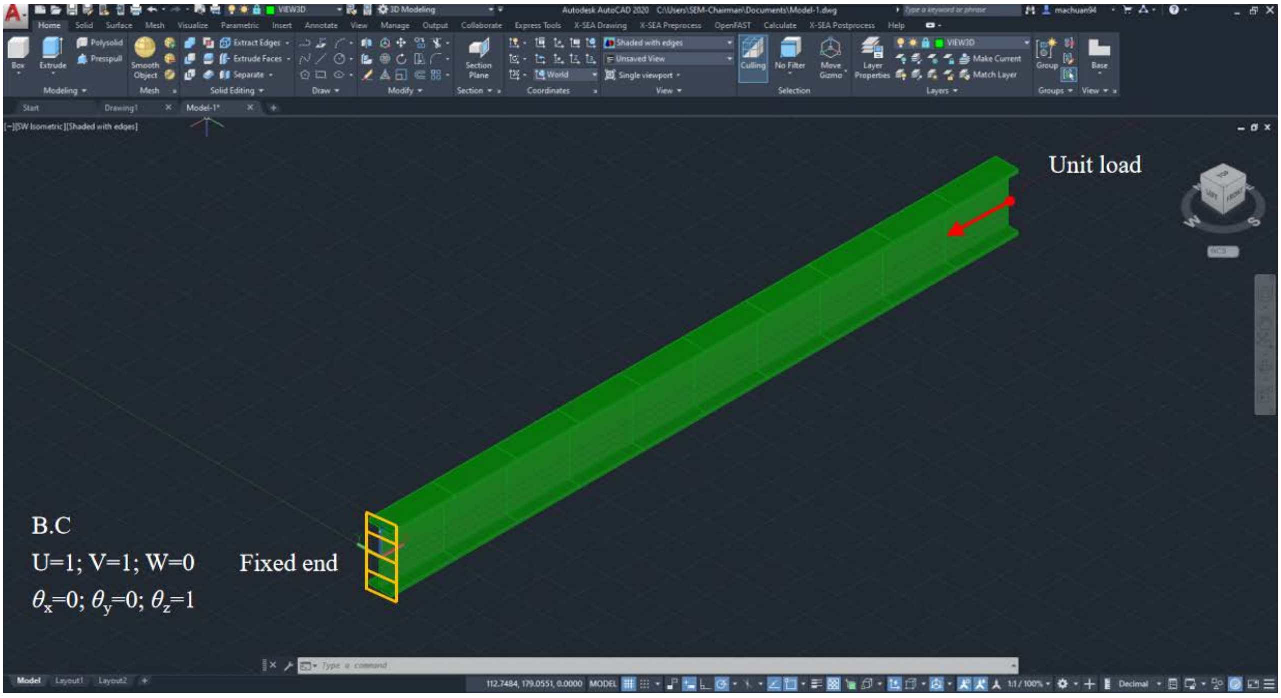


Fig.3.1 Column buckling model (a) Fixed-free column buckling (10 Elements, XFrame)

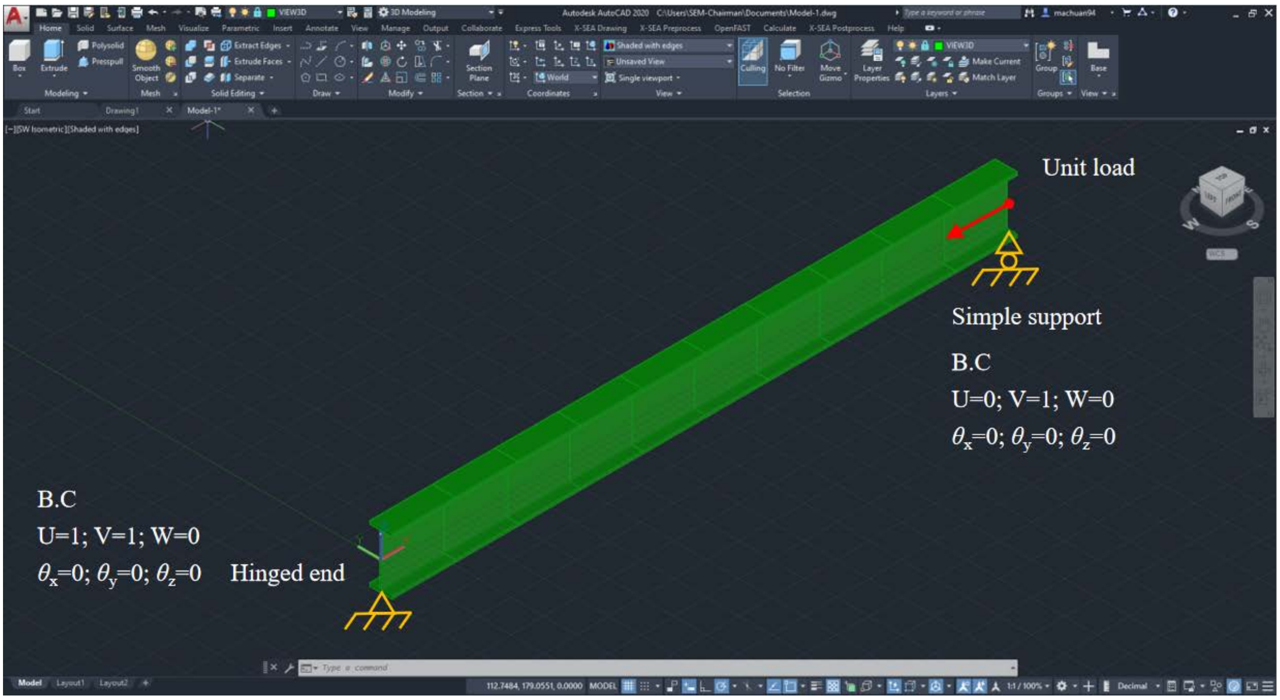


Fig.3.2 Column buckling model (b) Pinned-ended column buckling (10 Elements, XFrame)

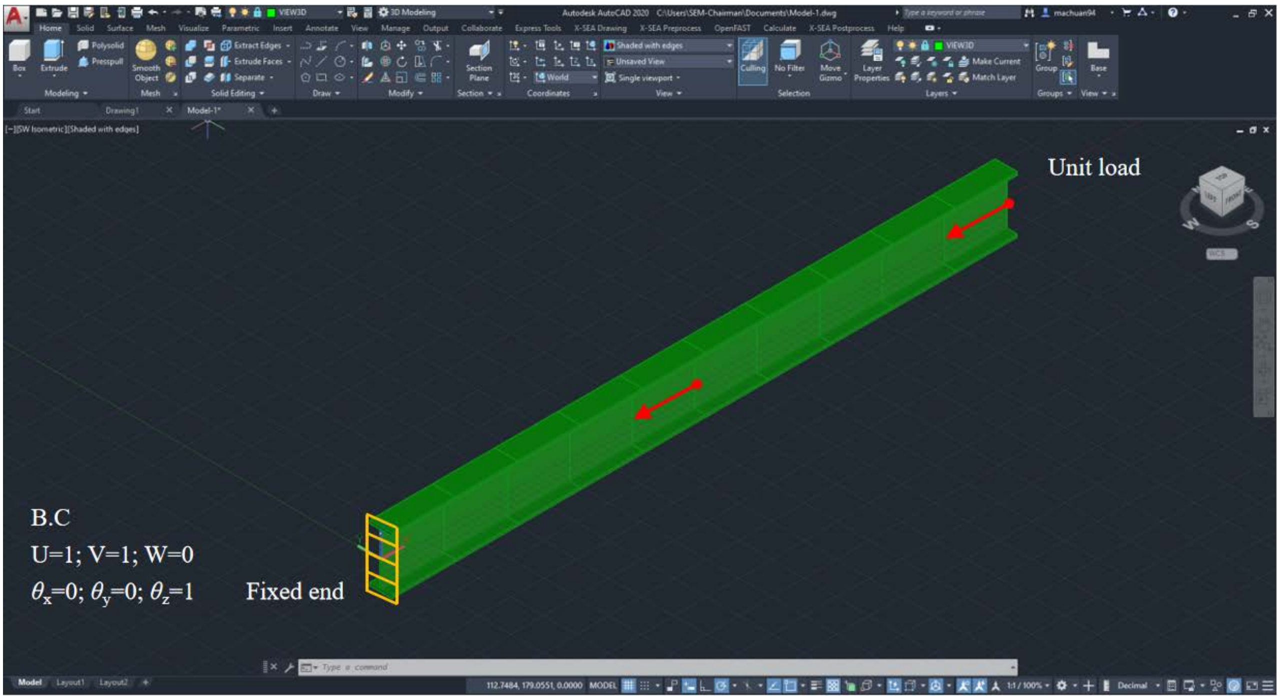


Fig.3.3 Column buckling model (c) Two axial forces cantilever column buckling (10 Elements, XFrame)

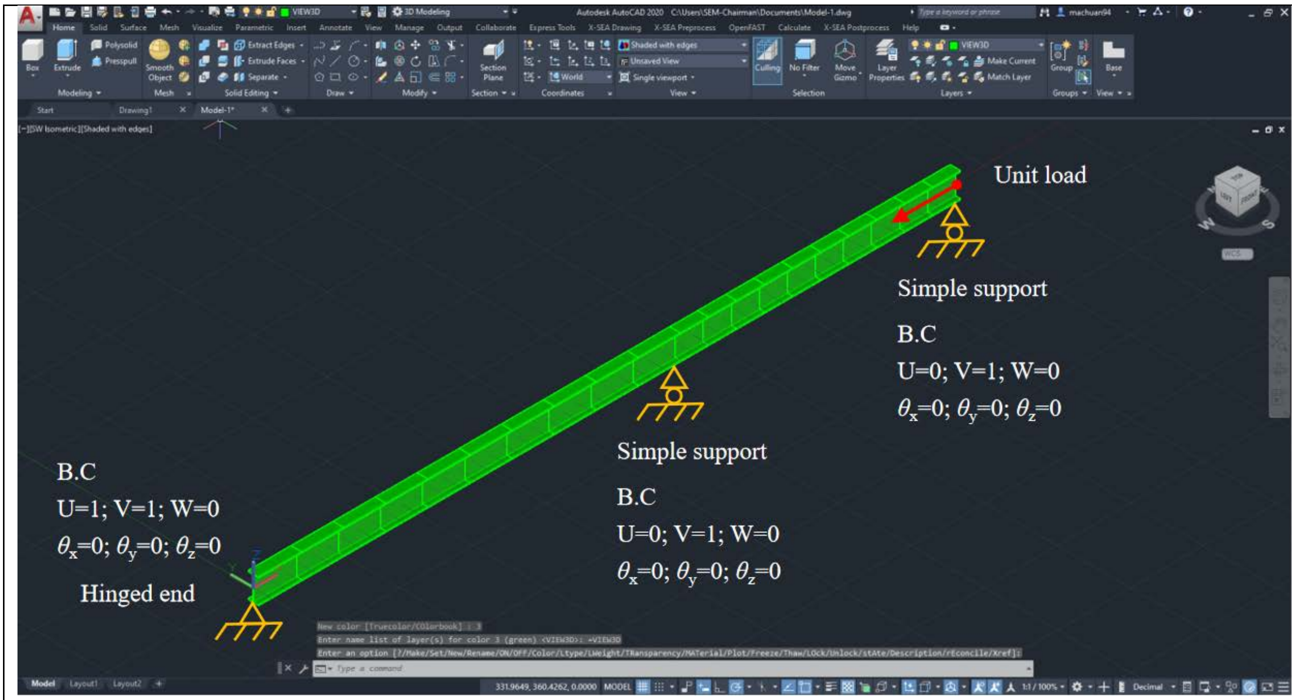


Fig.3.4 Column buckling model (d) Continuous member (20 Elements, XFrame)

Results

The present finite element solutions are compared with the analytical results in Table 3.1. The results calculated by XFRAME give a good agreement with reference.

Table 3.1 Critical loads of column buckling problem ($\times 10^8$N)

Case	Number of elements over length L					
	2	4	6	8	10	Exact
(a)	0.112392	0.112295	0.112283	0.112280	0.112278	0.114394
(b)	0.431049	0.426177	0.425566	0.425376	0.425293	0.457577
(c)	0.094146	0.093895	0.093864	0.093854	0.093850	0.095831
(d)	0.263485	0.260890	0.260599	0.260516	0.260481	0.273074

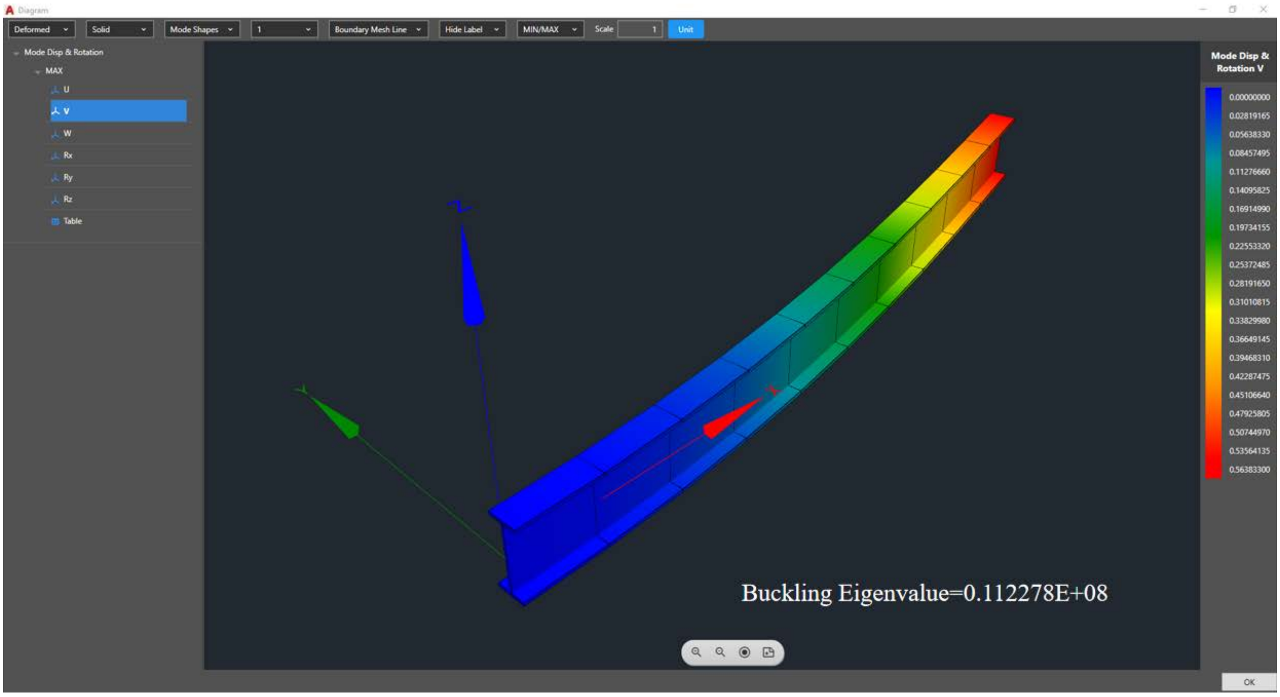


Fig.3.5 Deformation of column buckling (a) Fixed-free column buckling (10 Elements, XFrame)

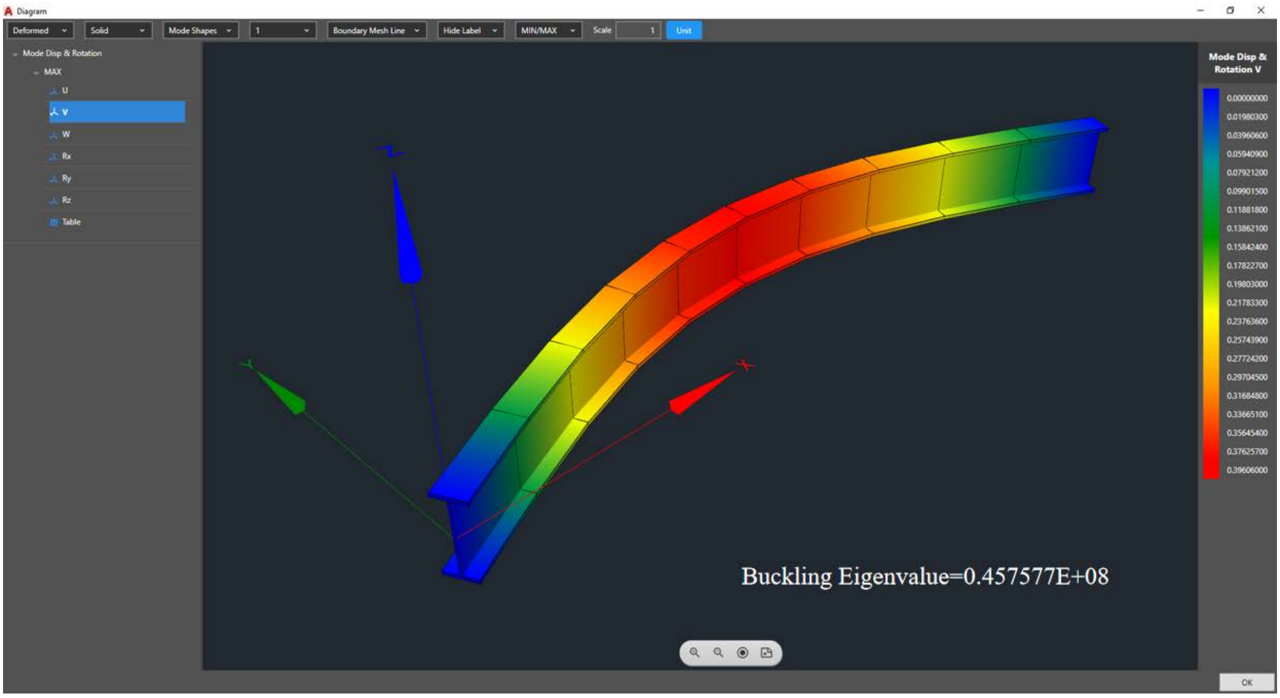


Fig.3.6 Deformation of Column Buckling (b) Pinned-ended column buckling (10 Elements, XFrame)

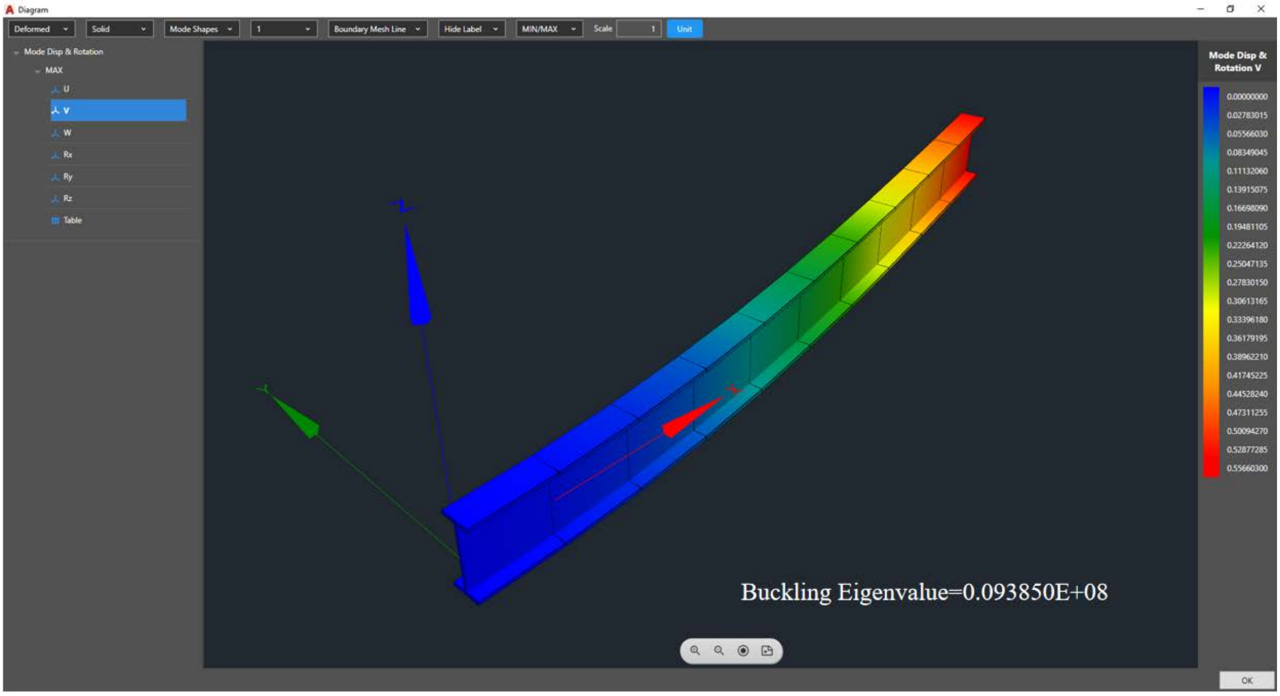


Fig.3.7 Deformation of column buckling (c) Two axial forces cantilever column buckling (10 Elements, XFrame)

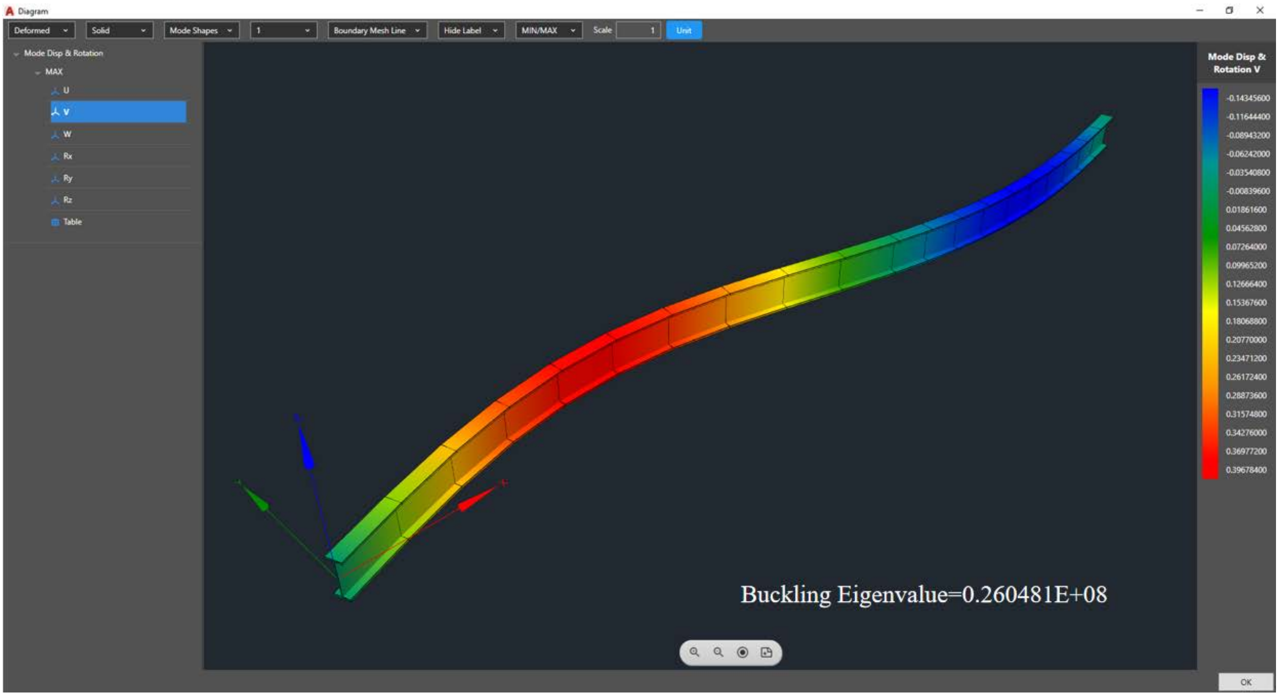


Fig.3.8 Deformation of column buckling (d) Continuous member (20 Elements, XFrame)

Verification Example of X-SEA AutoCAD	No: Frame Element 004
Title : Pin-ended Portal frame	
Problem Description	

The critical loads for the Portal frame given in Fig.4.1 are calculated using XFRAME element. As the critical loads are different depending on whether the frame is unbraced (sway-permitted case) or braced (sway-prevented case).

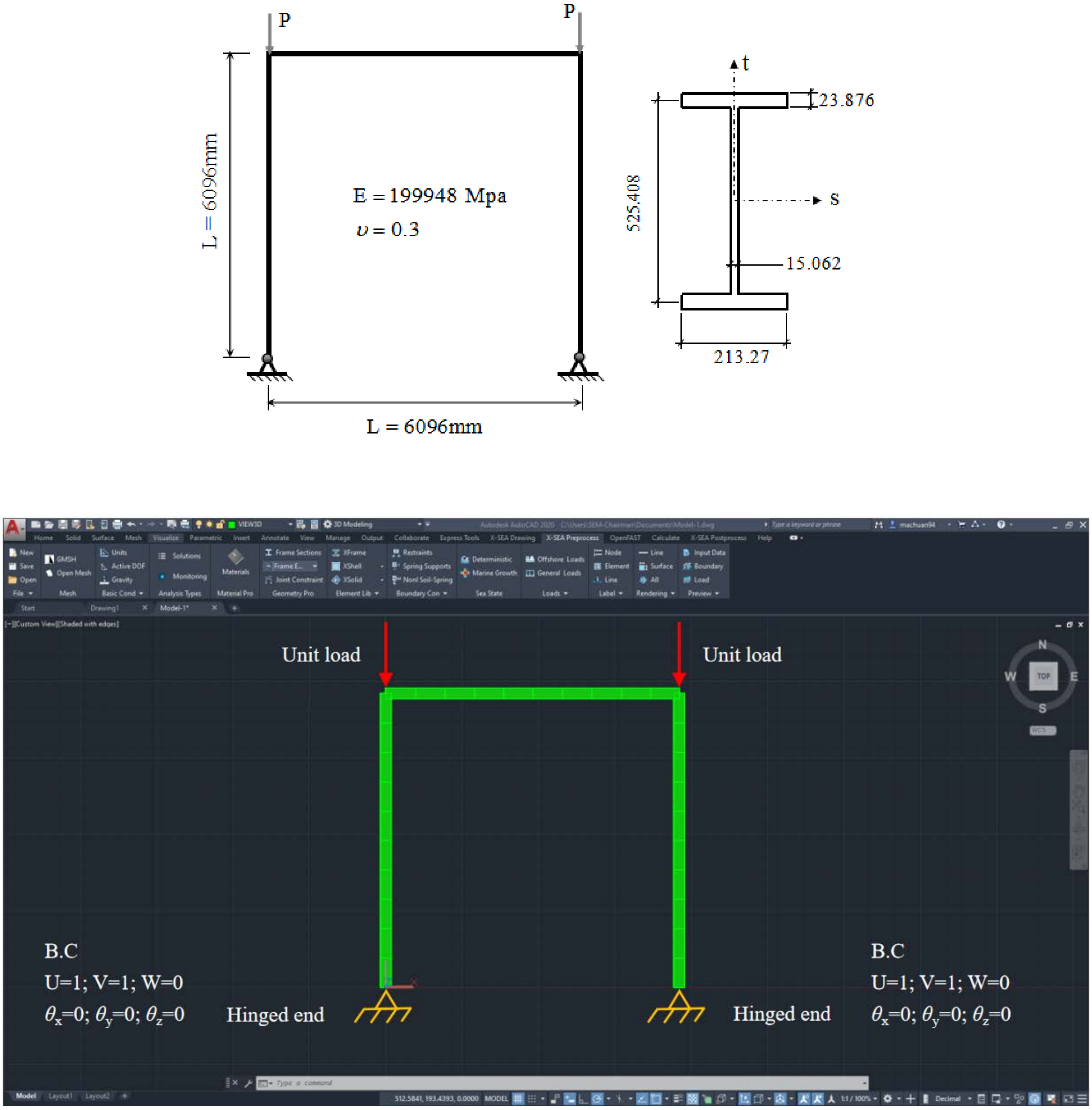


Fig.4.1 Pin-ended portal frame model-Sway permitted (30 Elements, XFrame)

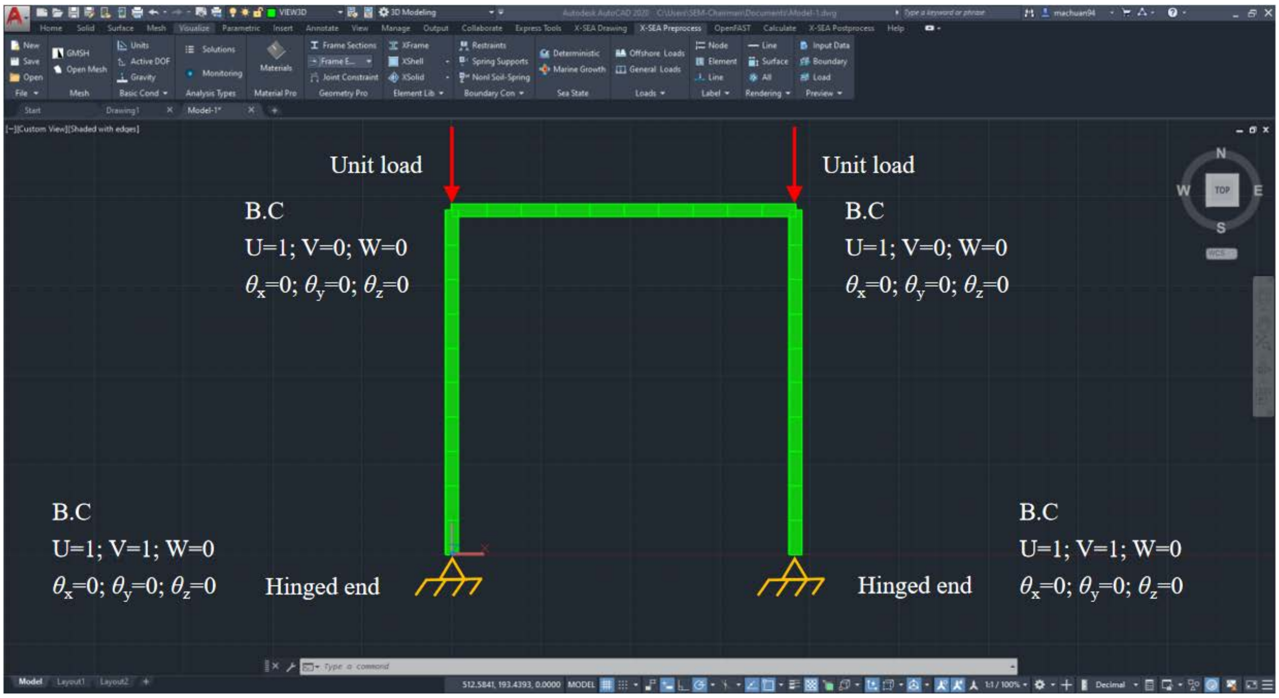
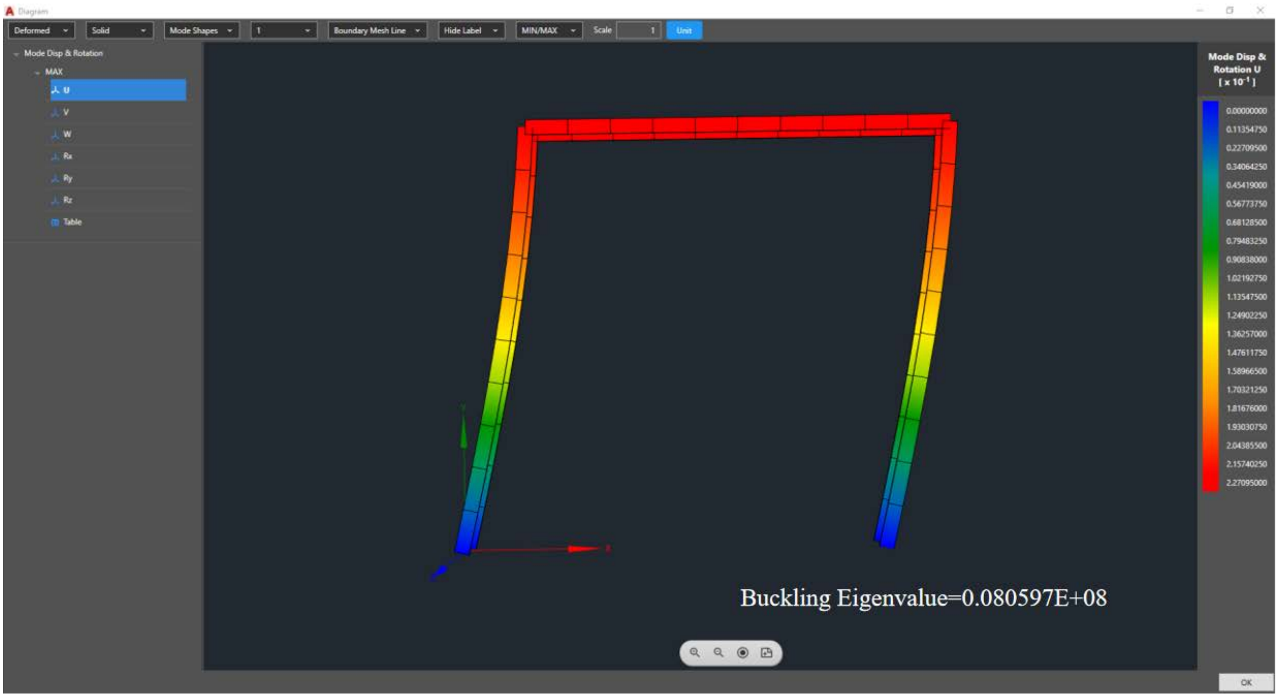


Fig.4.2 Pin-ended portal frame model-Sway prevented (30 Elements, XFrame)

Results

Table 4.1 Comparison of critical loads of pin-ended portal frame (×10^8N)

Case	Analytical solution	XFRAME
Sway-permitted	0.084379	0.080597
Sway-prevented	0.598073	0.542330



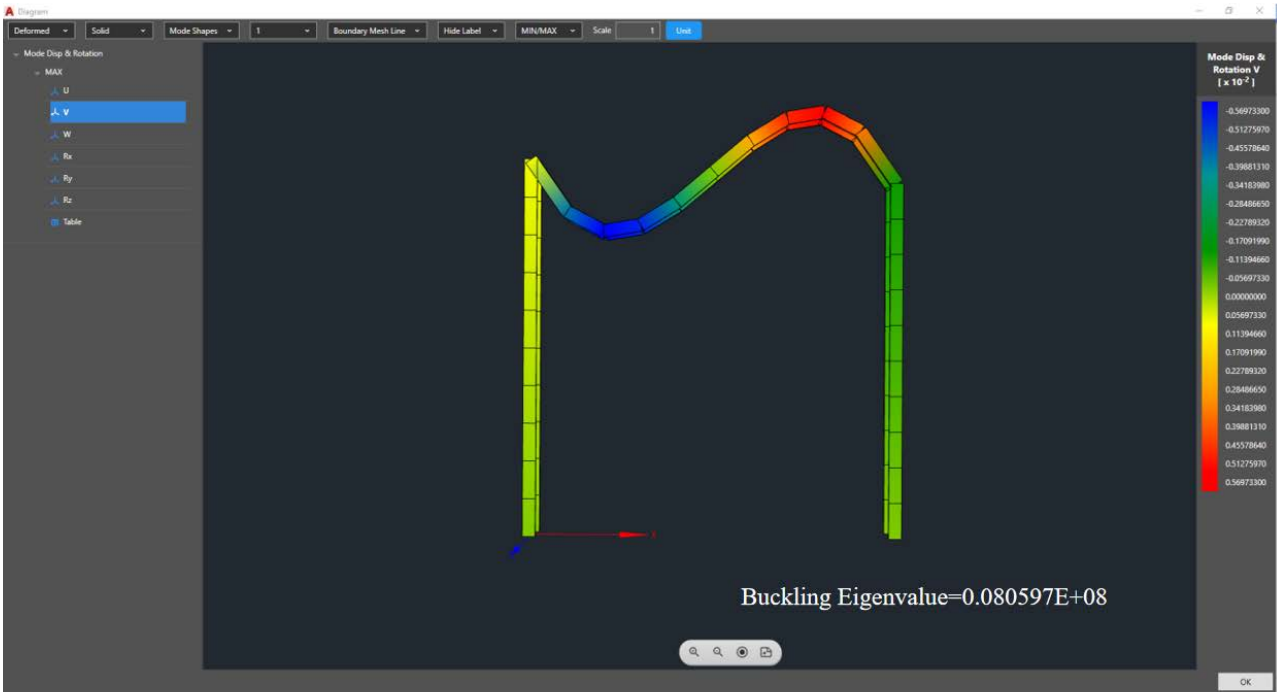
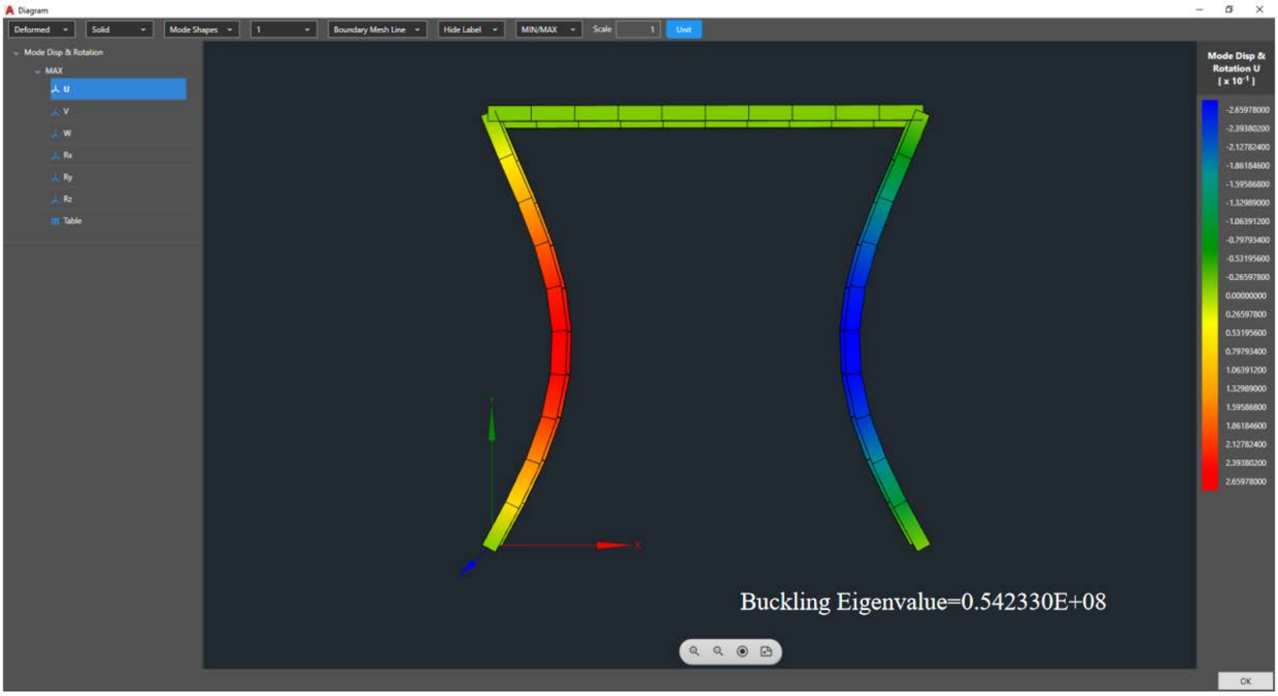


Fig.4.3 Deformation of Pin-ended Portal frame-Sway permitted case (30 Elements, XFrame)



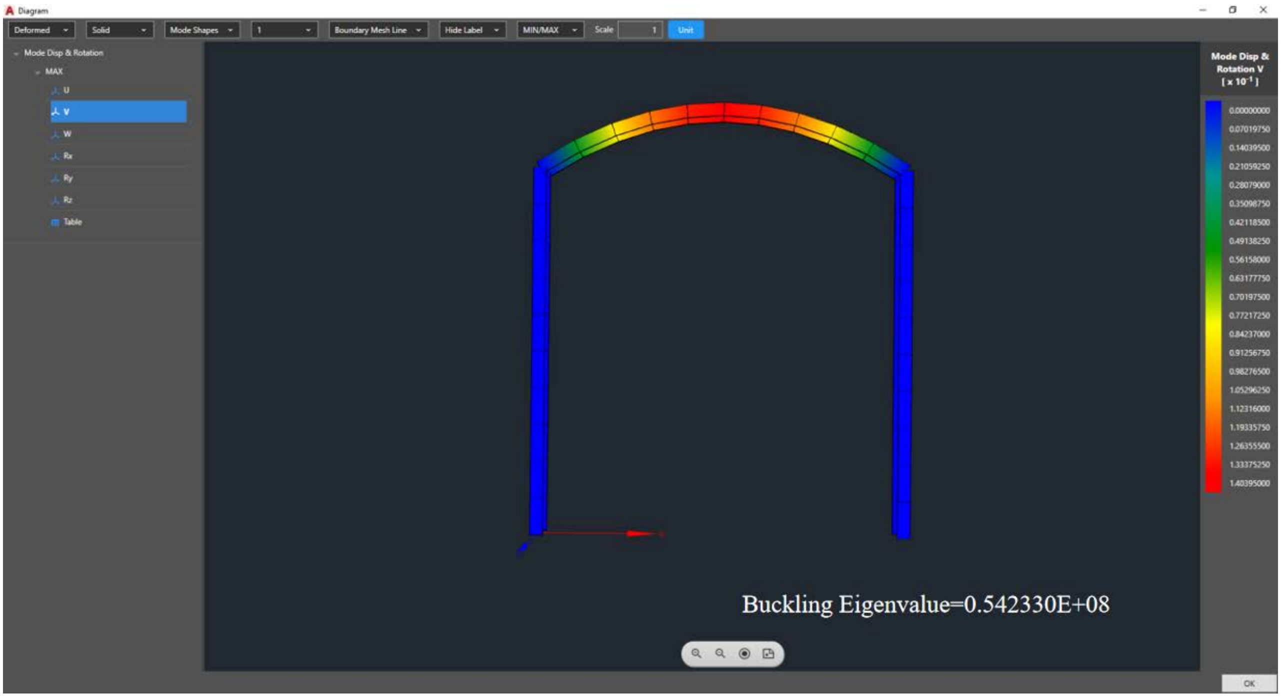


Fig. 4.4 Deformation of pin-ended portal frame-Sway prevented case (30 Elements, XFrame)

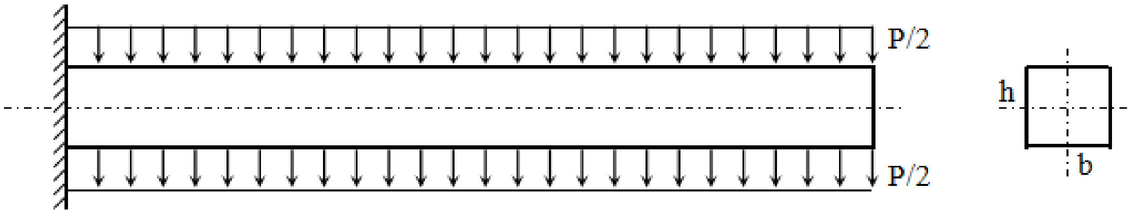
Verification Example of X-SEA AutoCAD	**No: Frame Element 005**

Title : Cantilever beam under uniformly distributed load

Problem Description

The cantilever beam shown in Fig. 5.1 is subjected to uniformly distributed load is modeled using ten beam elements to test for nonlinear analysis. The purpose of this example is to compare the large displacement results of XFRAME with those obtained by NONSAP (Bathe et al., 1974)

Length = 10.0; h = 1.0; b = 1.0; E = $1.2{\times}10^4$; v=0.2;



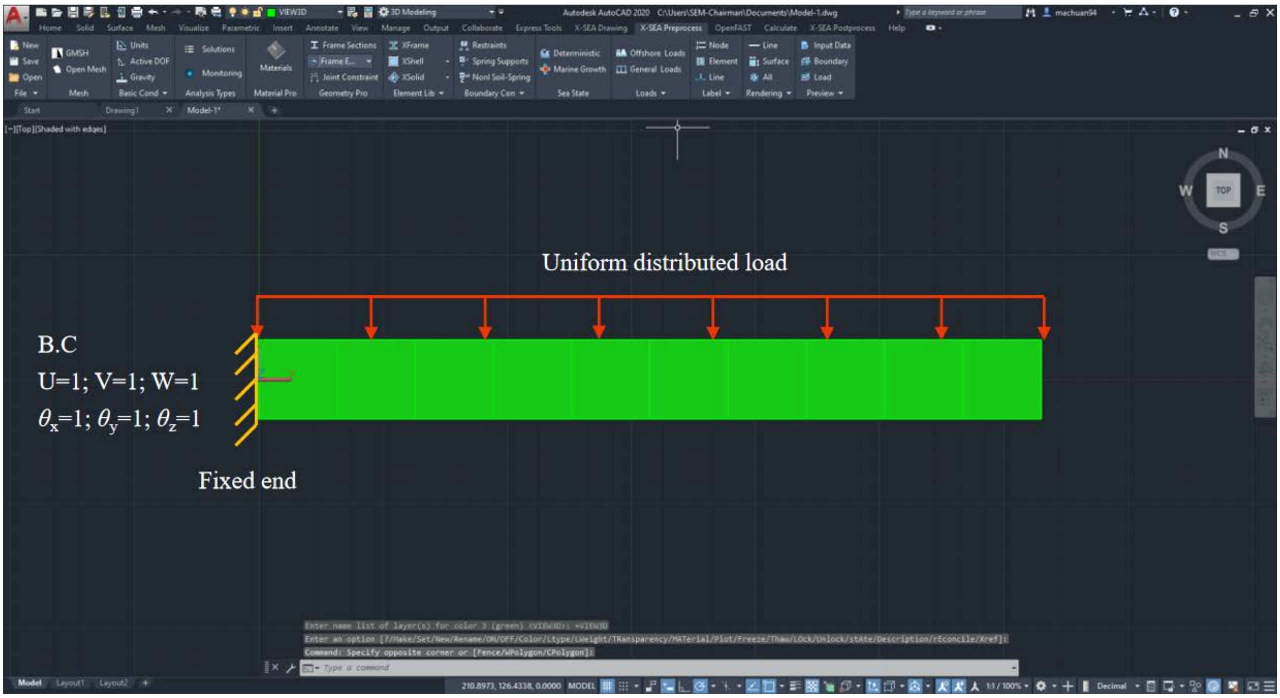


Fig.5.1 Cantilever beam under uniformly distributed load model (10 Elements, XFrame)

Results

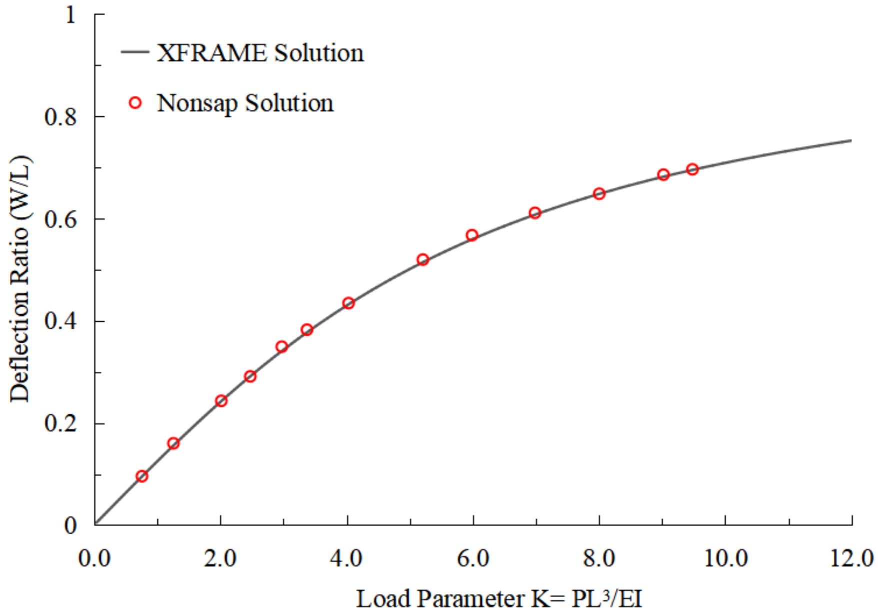


Fig.5.2 Load-displacement relationship of cantilever beam under uniformly distributed load

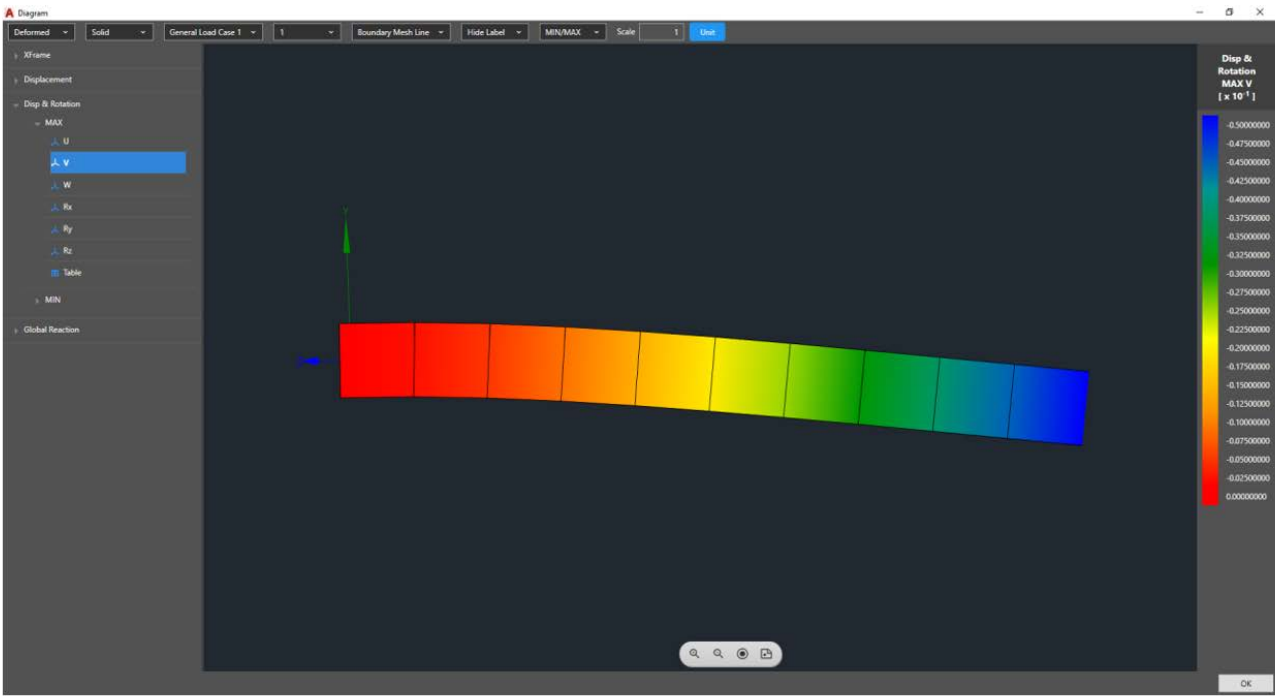


Fig.5.3 Deformation of cantilever beam under uniformly distributed load (10 Elements, XFrame)

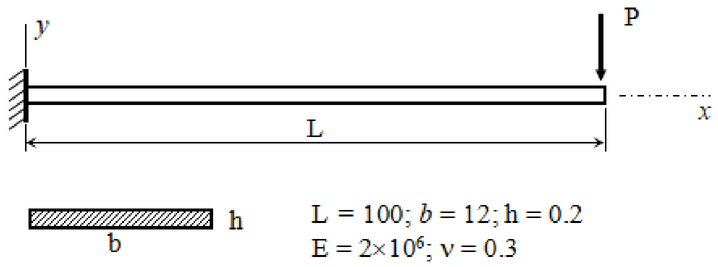
Verification Example of X-SEA AutoCAD	No: Frame Element 006

Title : Cantilever beam under end load

Problem Description

In this cantilever analysis subjected to the concentrated tip load, the objective was to demonstrate the effects of aspect ratio in the geometrically nonlinear range for beam and frame analysis.

Length = 100; h = 0.2; b = 12; E = 2×10^{6}; ν=0.3;



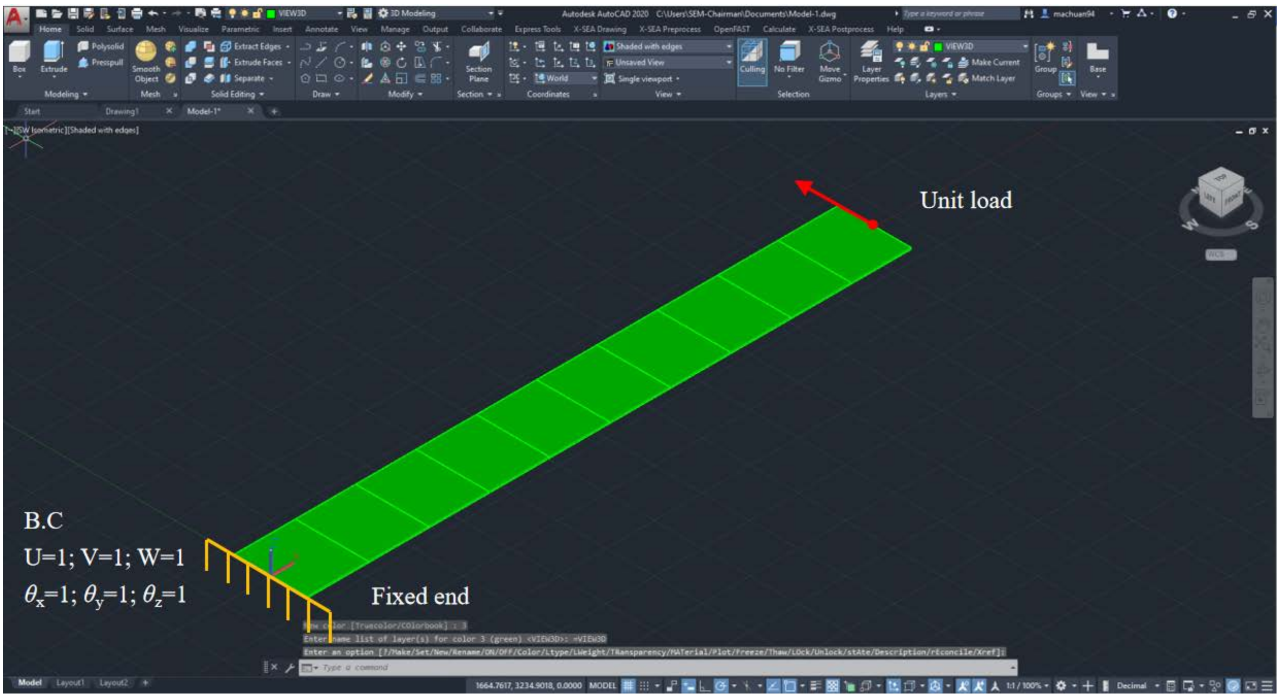


Fig.6.1 Cantilever beam under end load model (10 Elements, XFrame)

Results

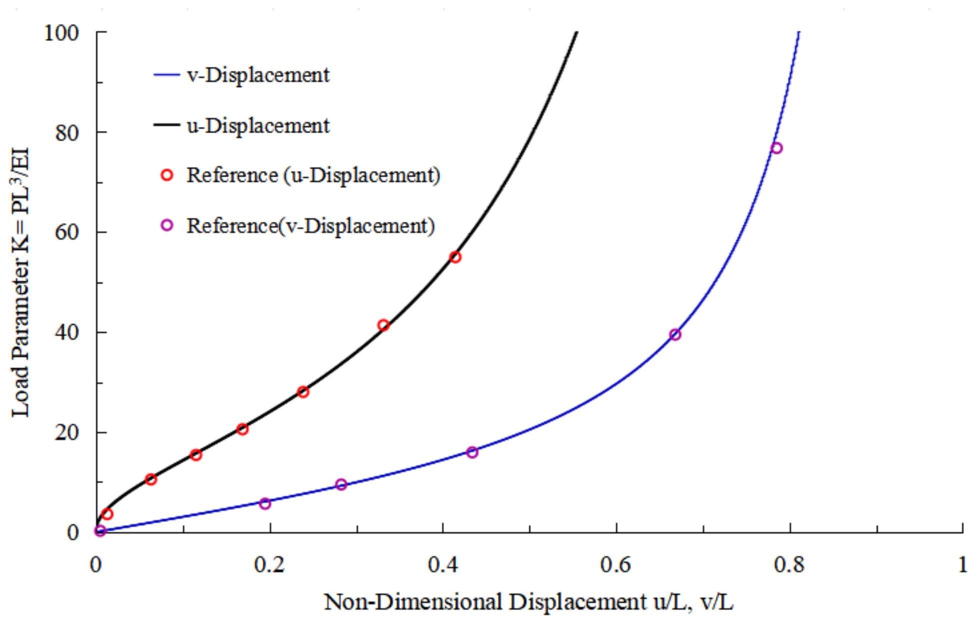


Fig.6.2 Load-displacement relationship of cantilever beam under end load (10 Elements, XFrame)

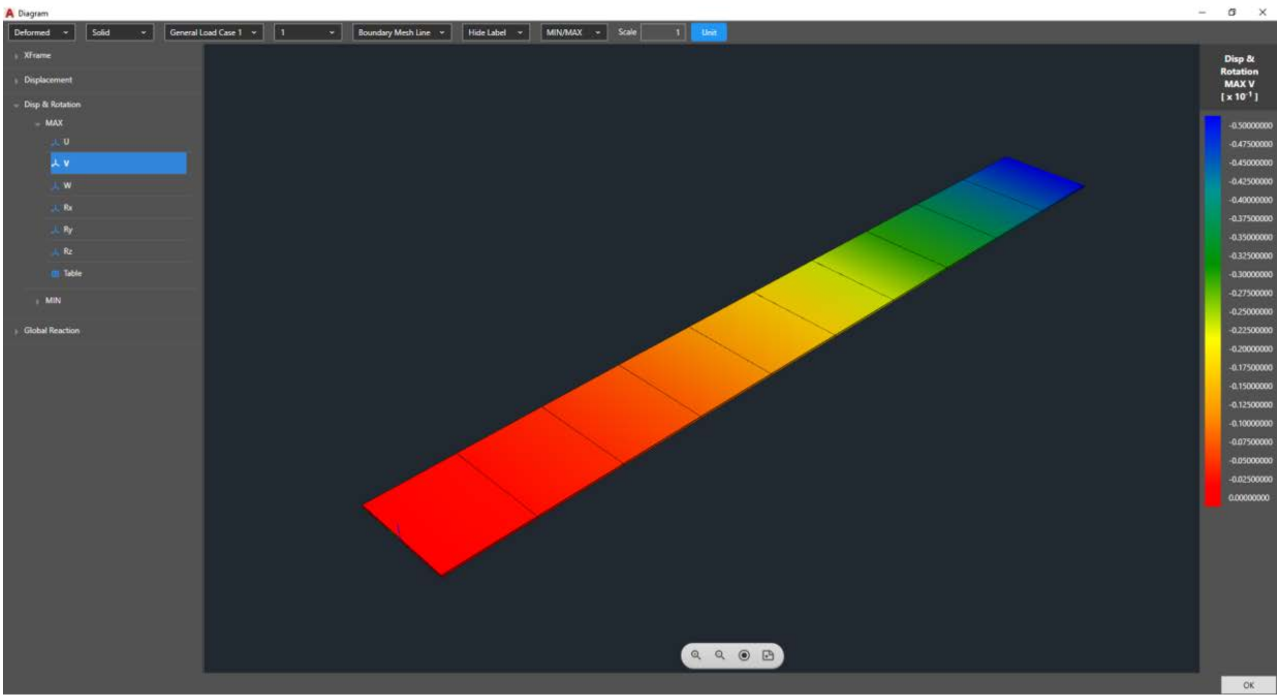


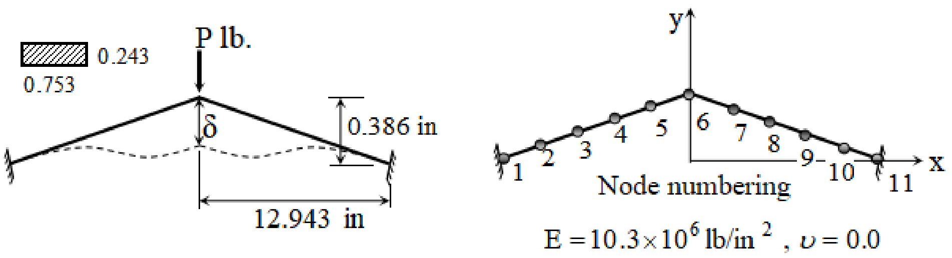
Fig.6.3 Deformation of cantilever beam under end load (10 Elements, XFrame)

Verification Example of X-SEA AutoCAD	No: Frame Element 007

Title: Williams toggle frame

Problem Description

Williams solved the frame problem shown in Fig.7.1 analytically and compared the results with experimental observations. Wood and Zienkiewicz (1977) also idealized this frame using total Lagrangian formulation.



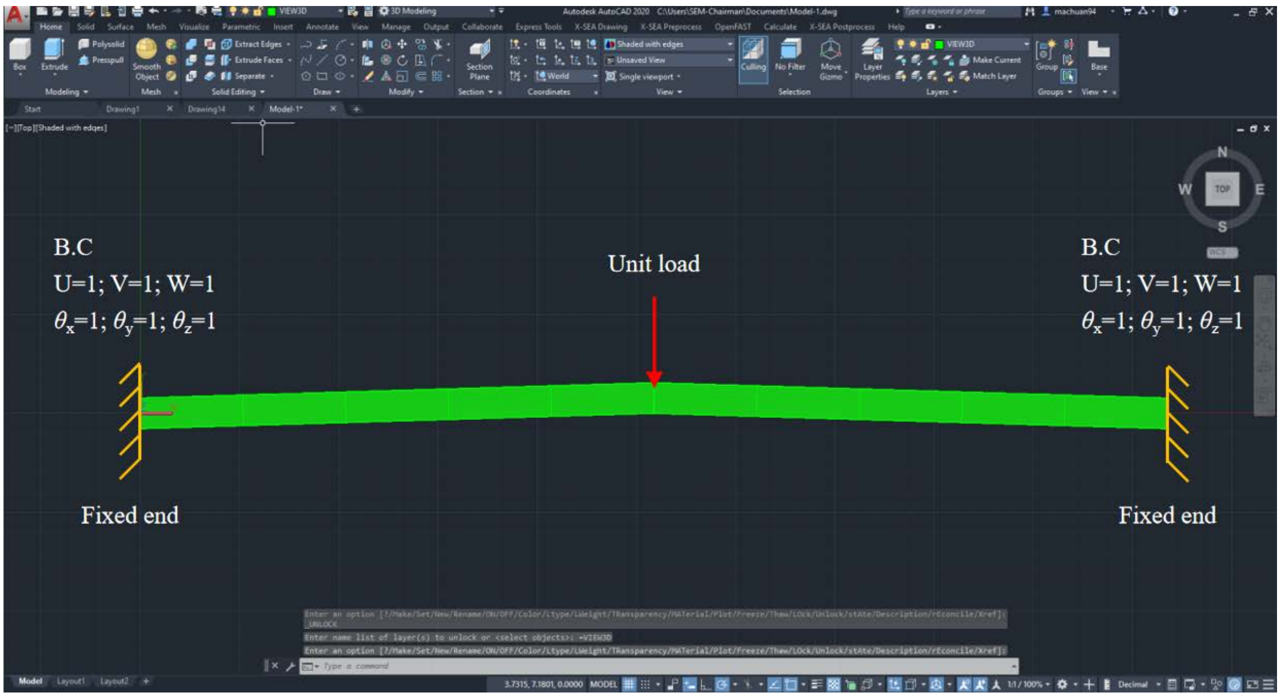


Fig.7.1 Williams Toggle Frame Model (10 Elements, XFrame)

Results

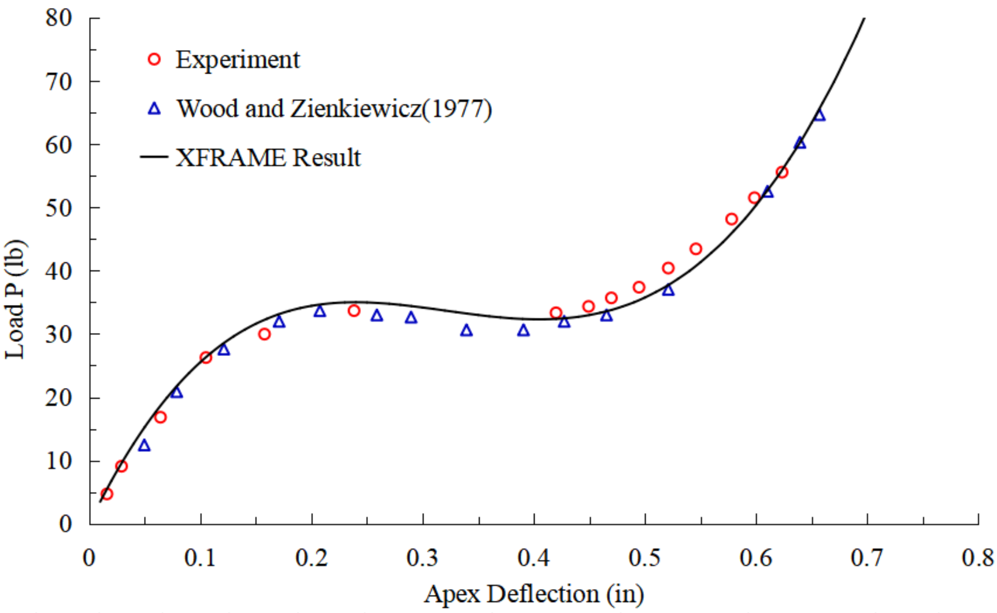


Fig.7.2 Load-Deflection curve of Williams Toggle problem

Fig.7.3 Deformation of Williams Toggle frame (10 Elements, XFrame)

Verification Example of X-SEA AutoCAD	No: Frame Element 008

Title: Lee's elastic frame

Problem Description

Lee's frame along with its geometrical and material properties is shown in Fig.8.1. The frame was modeled with twenty elements. For the loaded node two equilibrium paths are plotted, showing the relationship between load P and vertical and horizontal displacements.

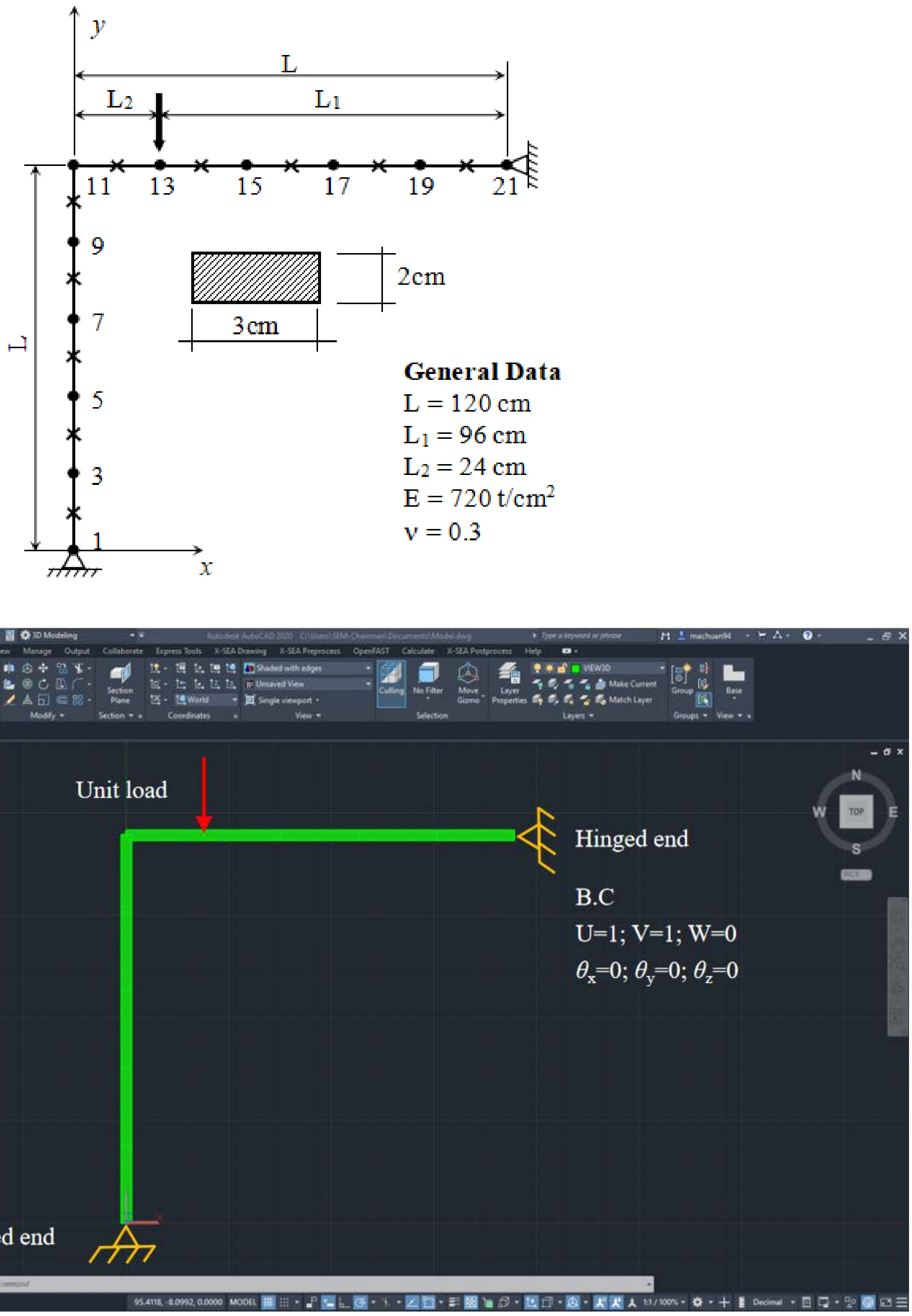


Fig.8.1 Lee's elastic frame model (10 Elements, XFrame)

Results

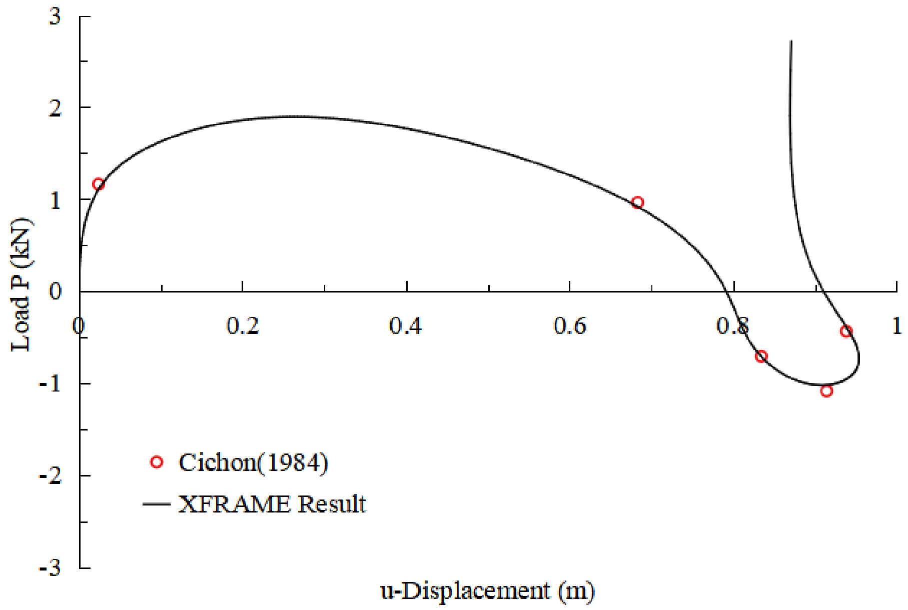


Fig.8.2 Nonlinear load and X-displacement relationship of Lee's frame

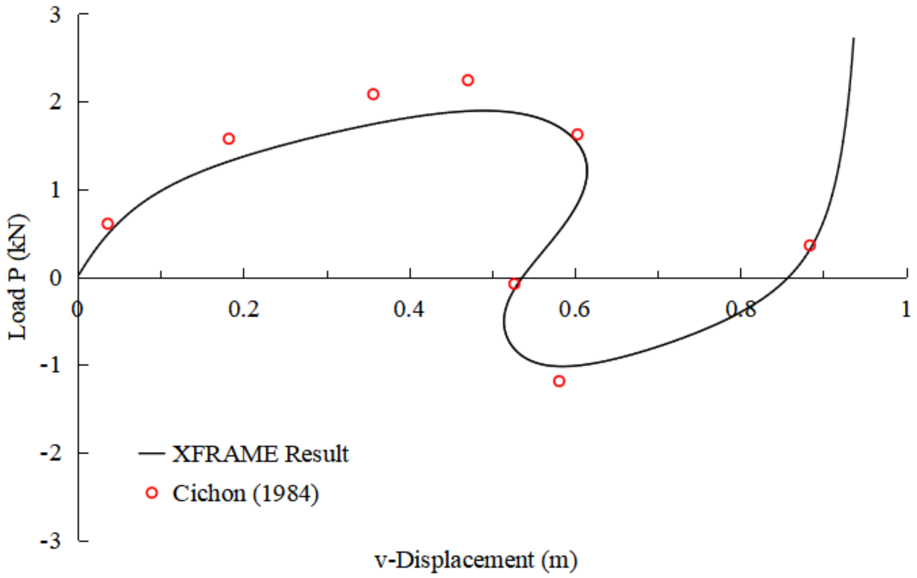


Fig.8.3 Nonlinear load and Y-displacement relationship of Lee's frame

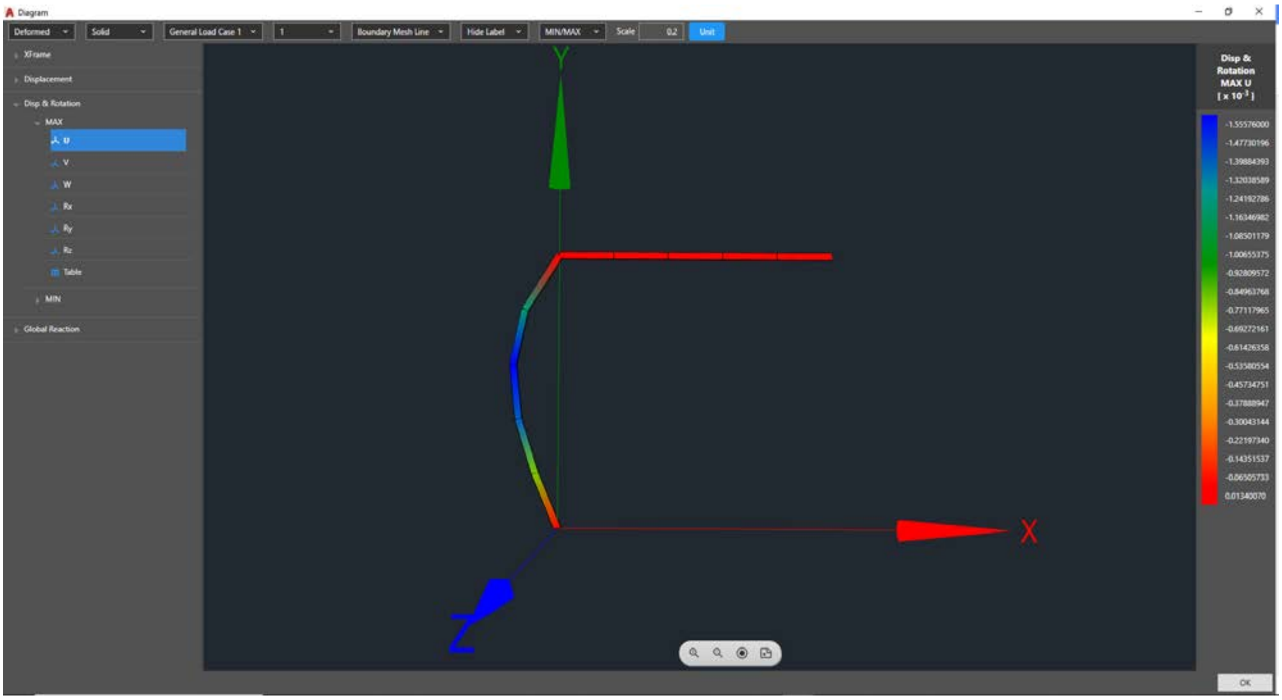


Fig.8.4 Vertical deformation of Lee's elastic frame model result (10 Elements, XFrame)

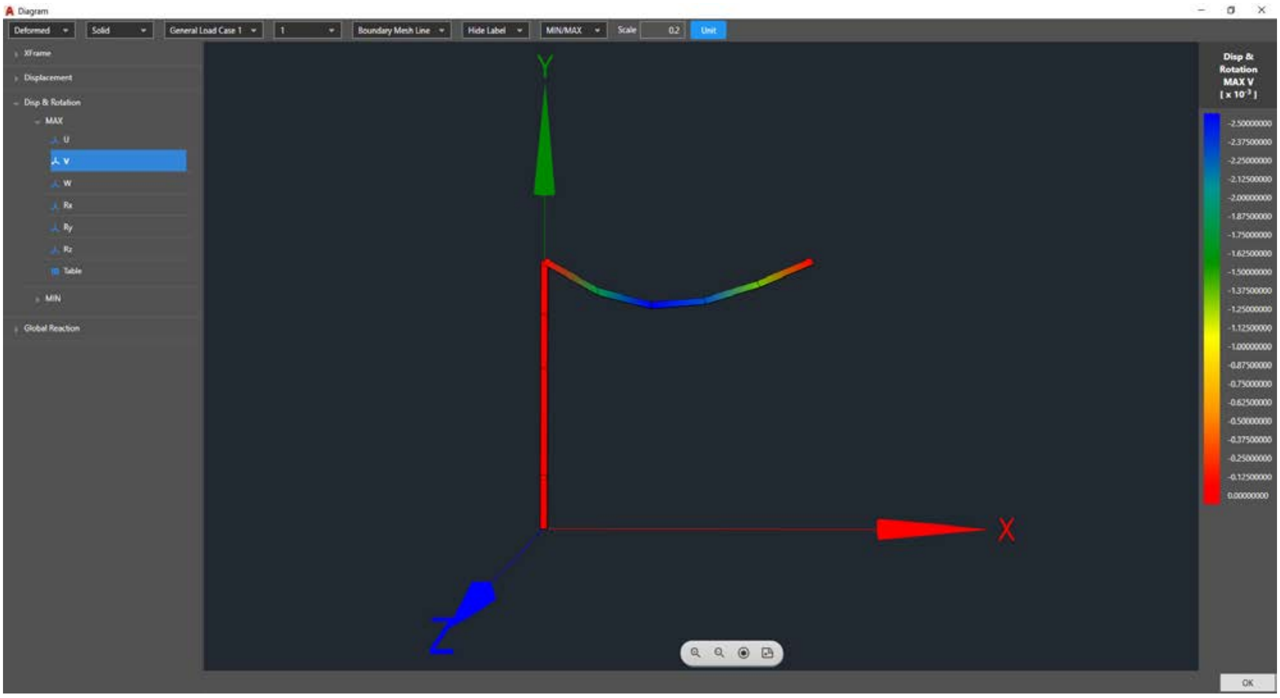


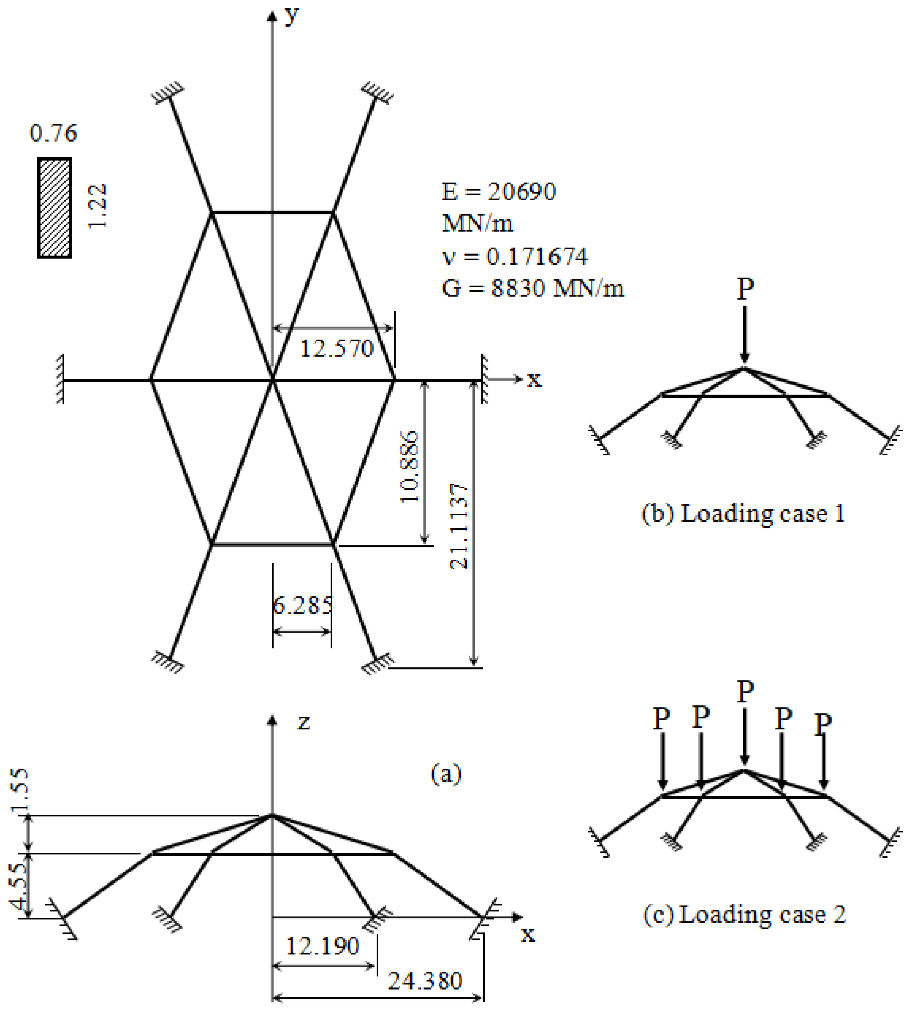
Fig.8.5 Horizontal deformation of Lee's elastic frame model result (10 Elements, XFrame)

Verification Example of X-SEA AutoCAD	No: Frame Element 009

Title: Static instability analysis of Framed Dome

Problem Description

The framed dome problem illustrates the nonlinear static analysis of space frames under two different loading conditions. The first loading case considered is that of a single concentrated load at the crown point. The loading second system consists of concentrated vertical loads of equal magnitude P at the crown pointand also at the end points of the horizontal members.



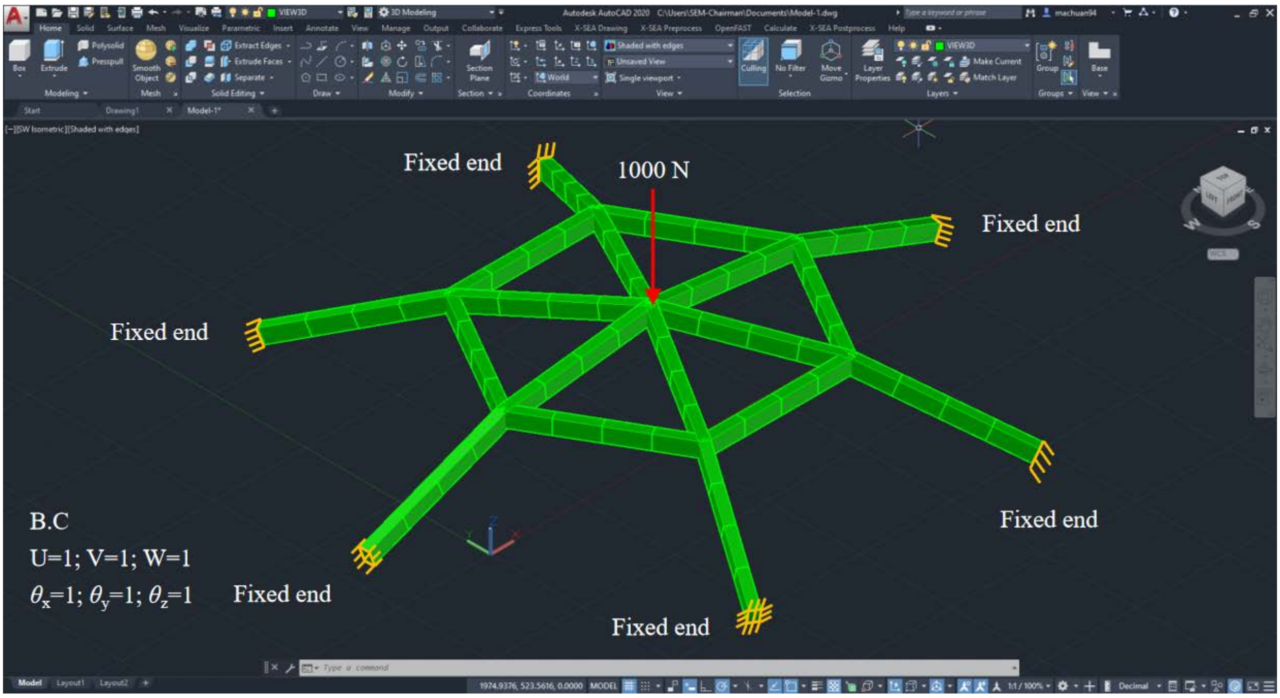


Fig.9.1 Framed dome model under load case 1 (72 Elements, XFrame)

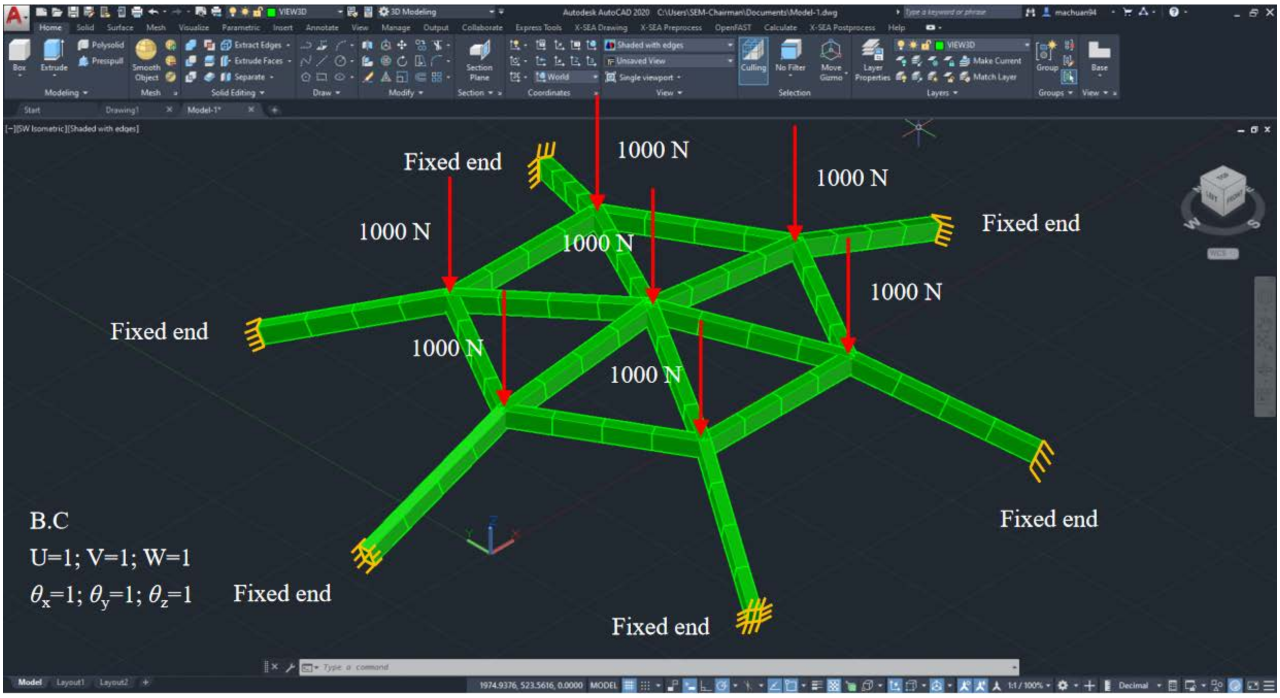


Fig. 9.2 Framed dome model under load case 2 (72 Elements, XFrame)

Results

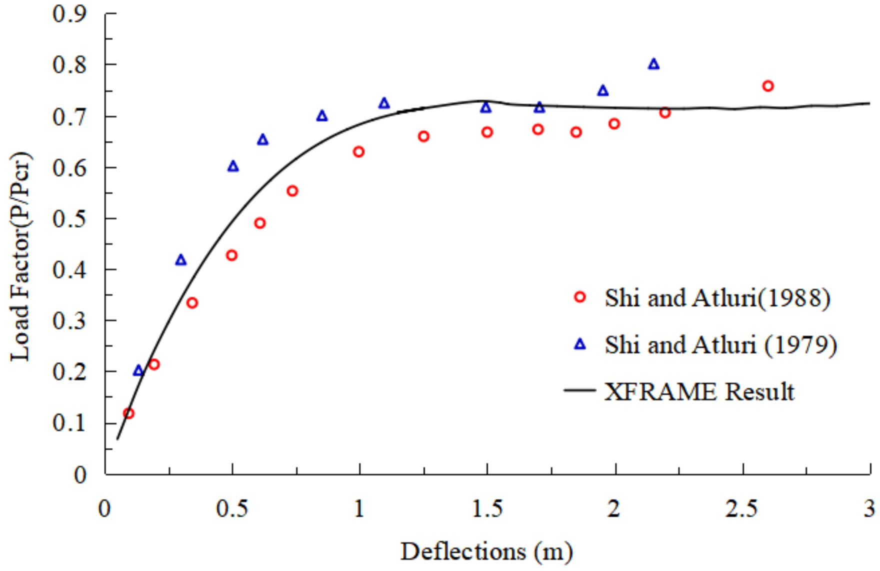


Fig.9.3 Load-Deflection curves for vertical displacement under load case 1

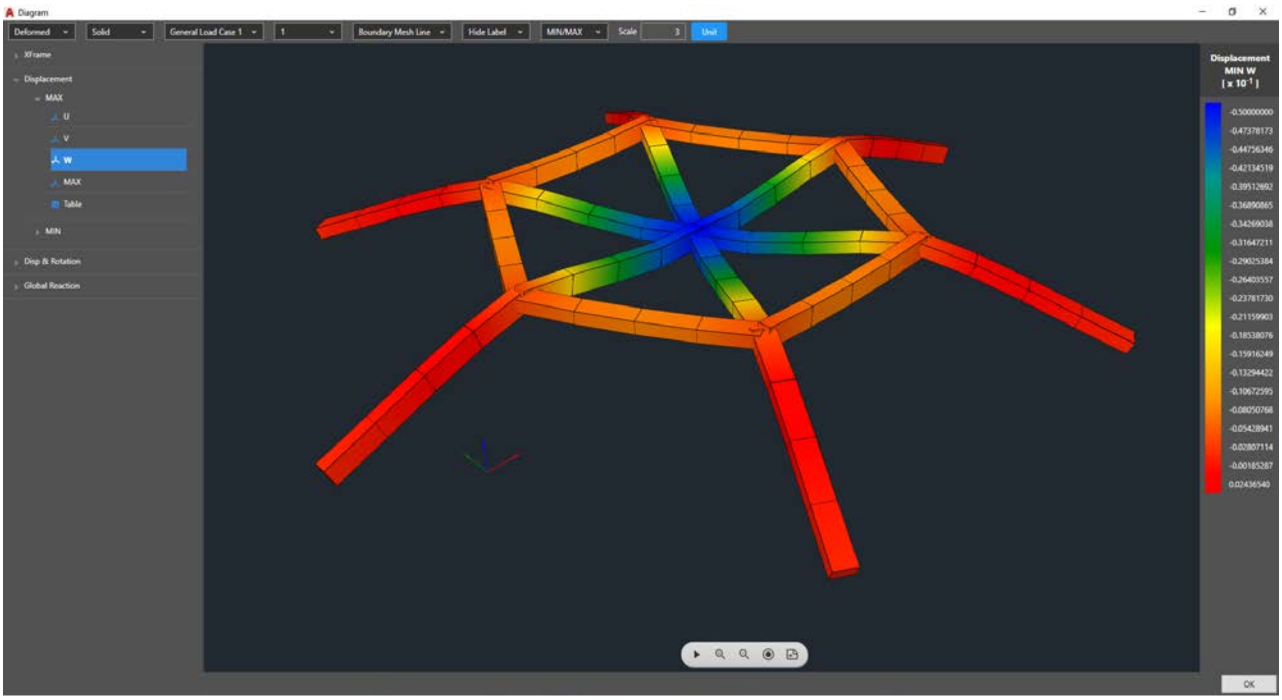


Fig.9.4 Deformation of framed dome model under load case 1 (72 Elements, XFrame)

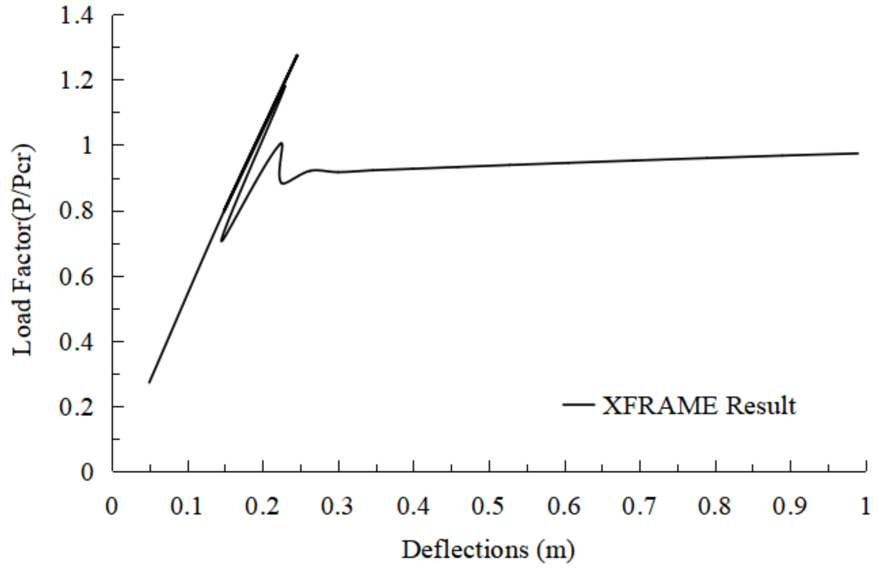


Fig.9.5 Load-Deflection curves for vertical displacement under load case 2

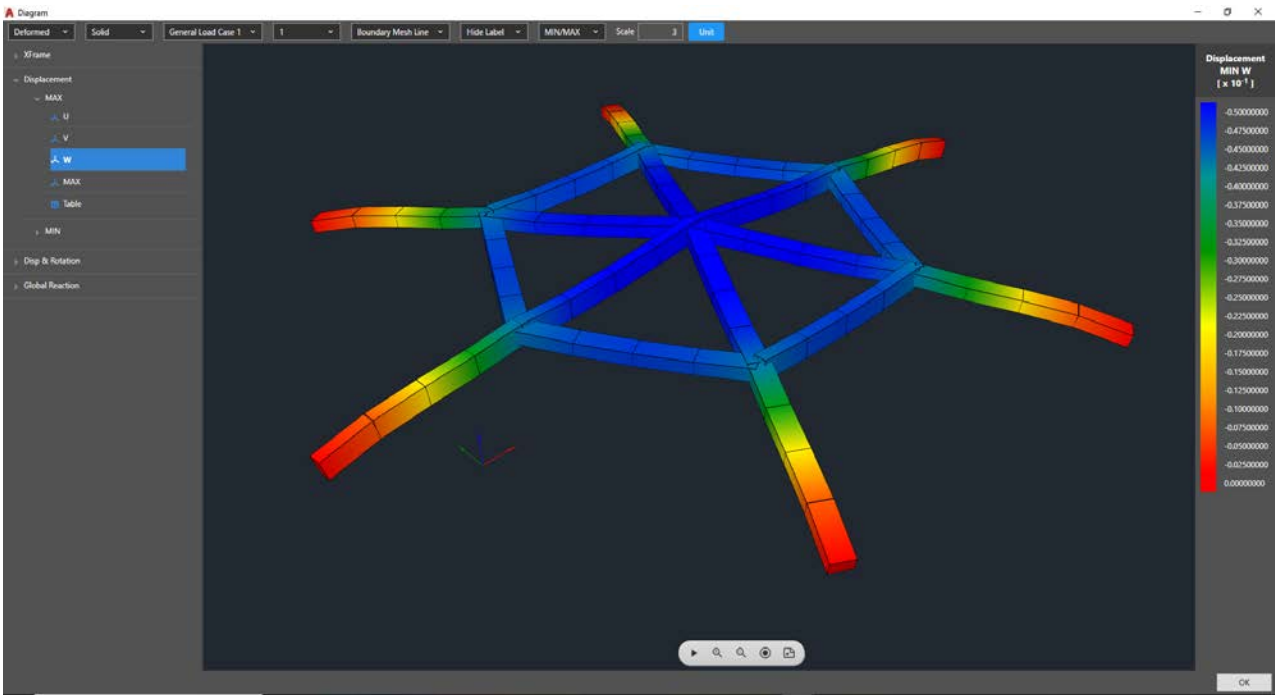


Fig.9.6 Deformation of framed dome model under load case 2 (72 Elements, XFrame)

Verification Example of X-SEA AutoCAD	**No: Frame Element 010**
Title: Lee's elasto-plastic frame	
Problem Description	

The final example deals with the elasto-plastic behavior of Lee's frame subjected to point load at node 1SHELL ELEMENT15 Dr. KiDu Kim3. This problem was previously analyzed by Park and Lee (1996).The geometrical and material data for themembers, which are identical, is given in Fig. 10.1.

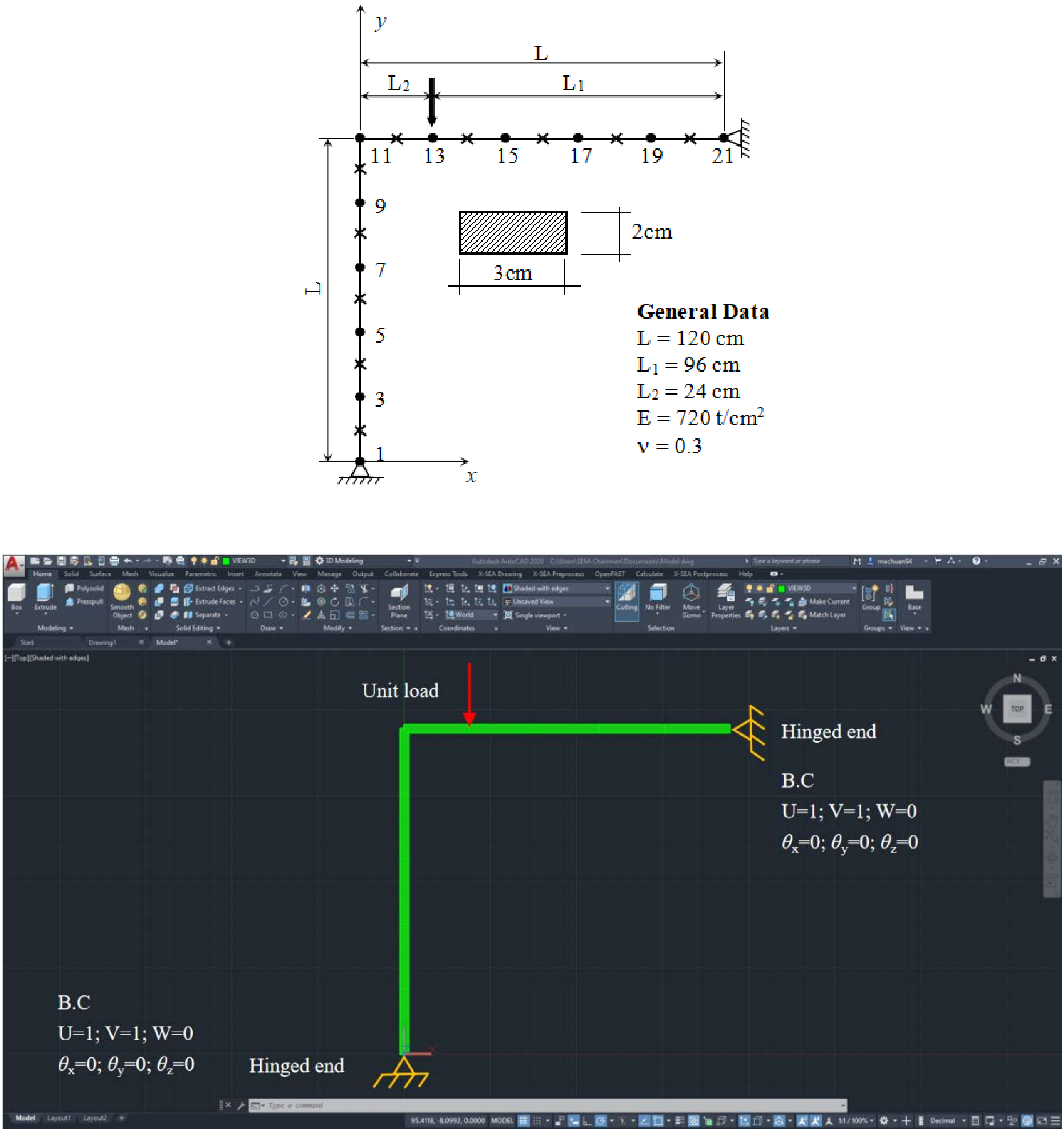


Fig.10.1 Lee's elastic frame model (10 Elements, XFrame)

Results

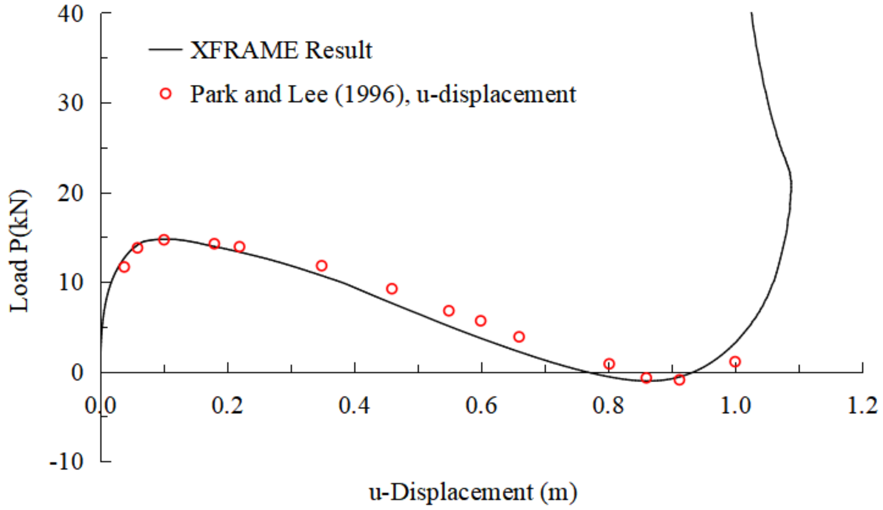


Fig. 10.2 Nonlinear load and X-displacement relationship of Lee's elasto-plastic frame

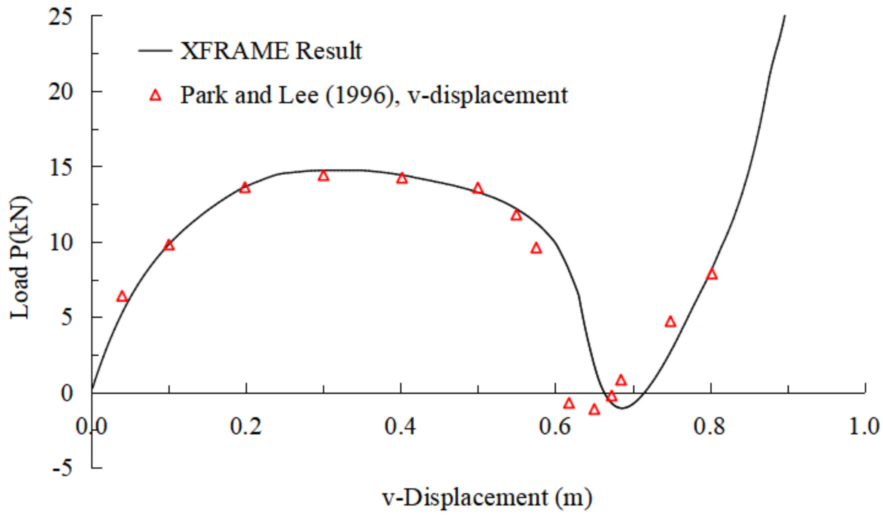


Fig. 10.3 Nonlinear load and Y-displacement relationship of Lee's elasto-plastic frame

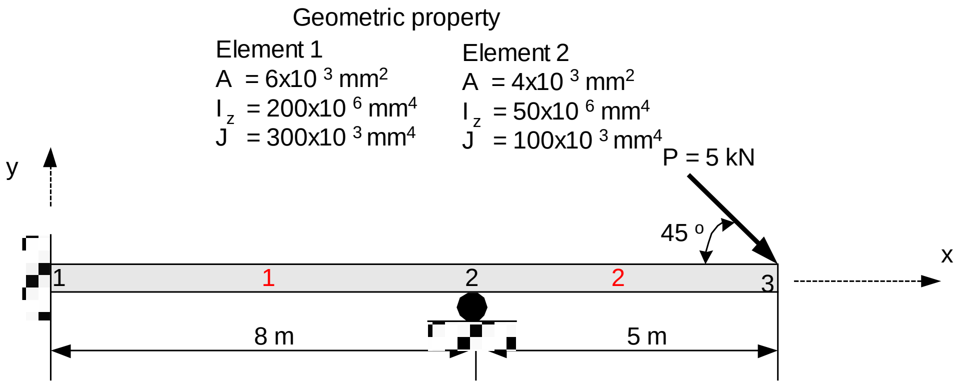
Verification Example of X-SEA AutoCAD	No: Frame Element 011

Title: Frame Element Numerical Examples-1

Problem Description

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



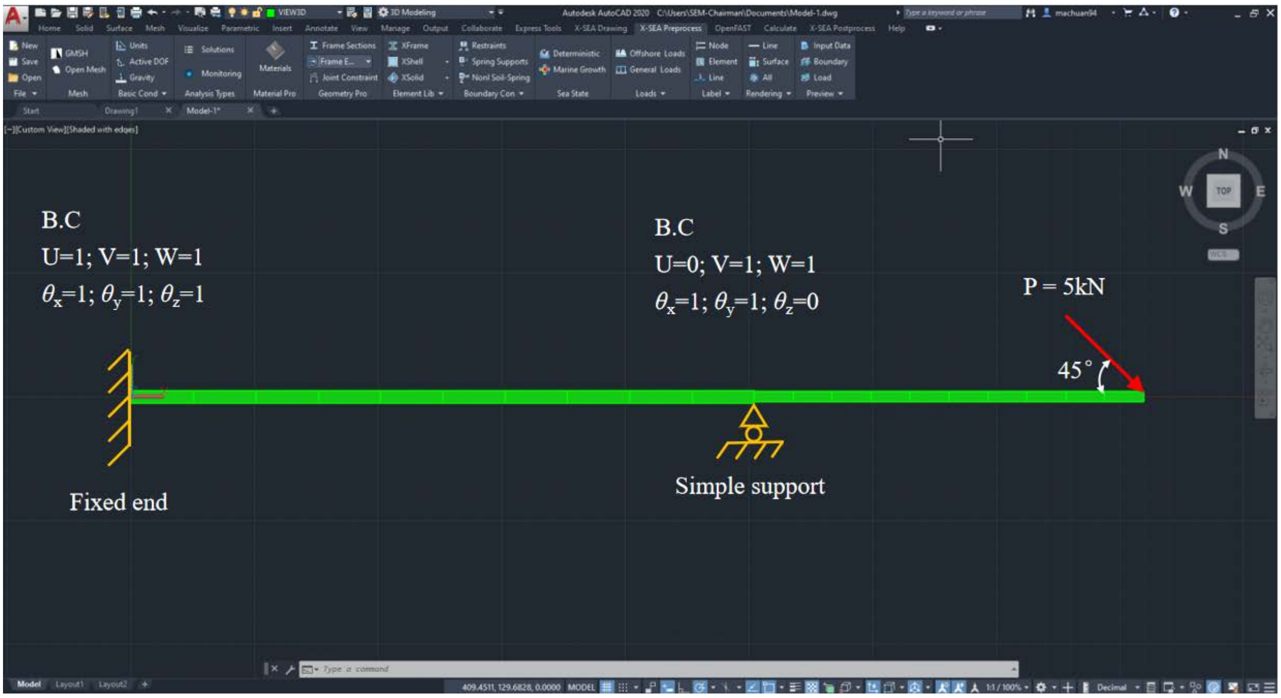


Fig.11.1 Frame model-1 (20 Elements, XFrame)

Results

Fig.11.2 Displacement of beam in y direction (20 Elements, XFrame)

Table 11.1 Displacement at node 2 and 3

Element type	Node 2		Node 3		
	U (mm)	R_z (rad)	U (mm)	V (mm)	R_z (rad)

Reference	0.24E-01	-0.88E-03	0.46E-01	-0.1915E+02	-0.53E-02
XSEA	0.2358E-01	-0.8841E-03	0.4568E-01	-0.1916E+02	-0.5304E-02

Table 11.2 Reaction at node 1

Element type	**F_x (N)**	**F_y (N)**	**M_z (N·mm)**
Reference	-0.36E+04	-0.33E+04	-0.88E+07
XSEA	-0.3536E+04	-0.3315E+04	-0.8839E+07

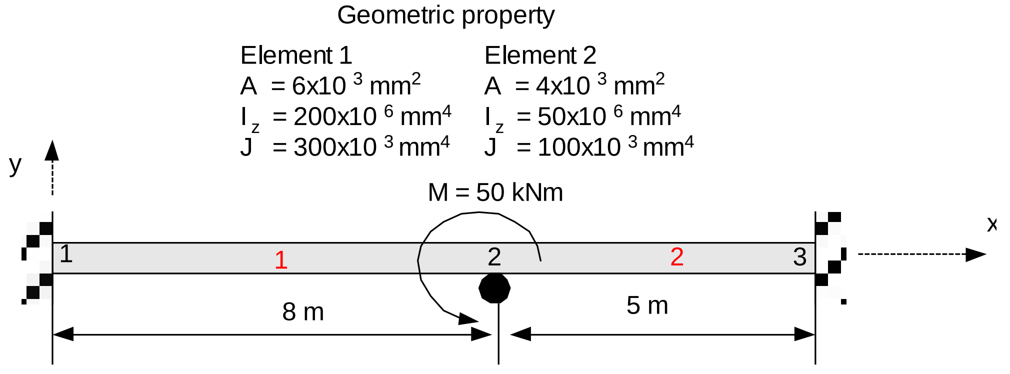
	XFINASIT Co. LTD
Verification Example of X-SEA AutoCAD	**No: Frame Element 012**

Title: Frame Element Numerical Examples-2

Problem Description

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



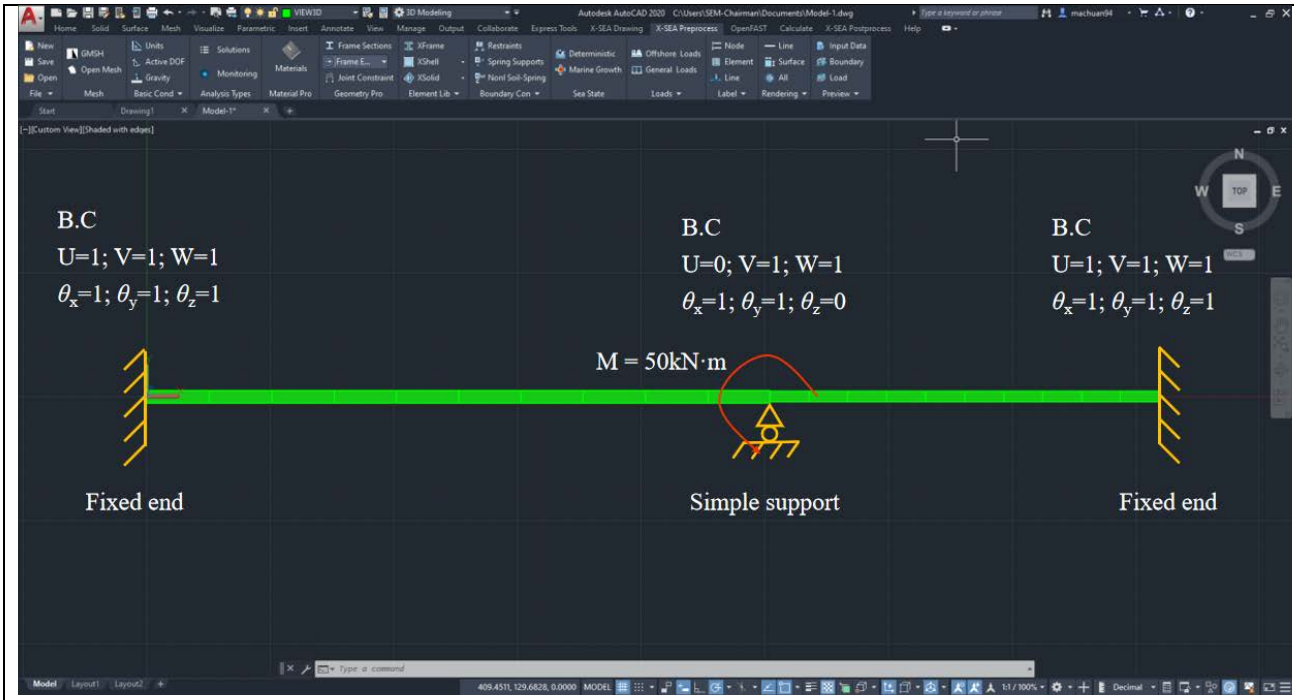


Fig.12.1 Frame model-2 (20 Elements, XFrame)

Results

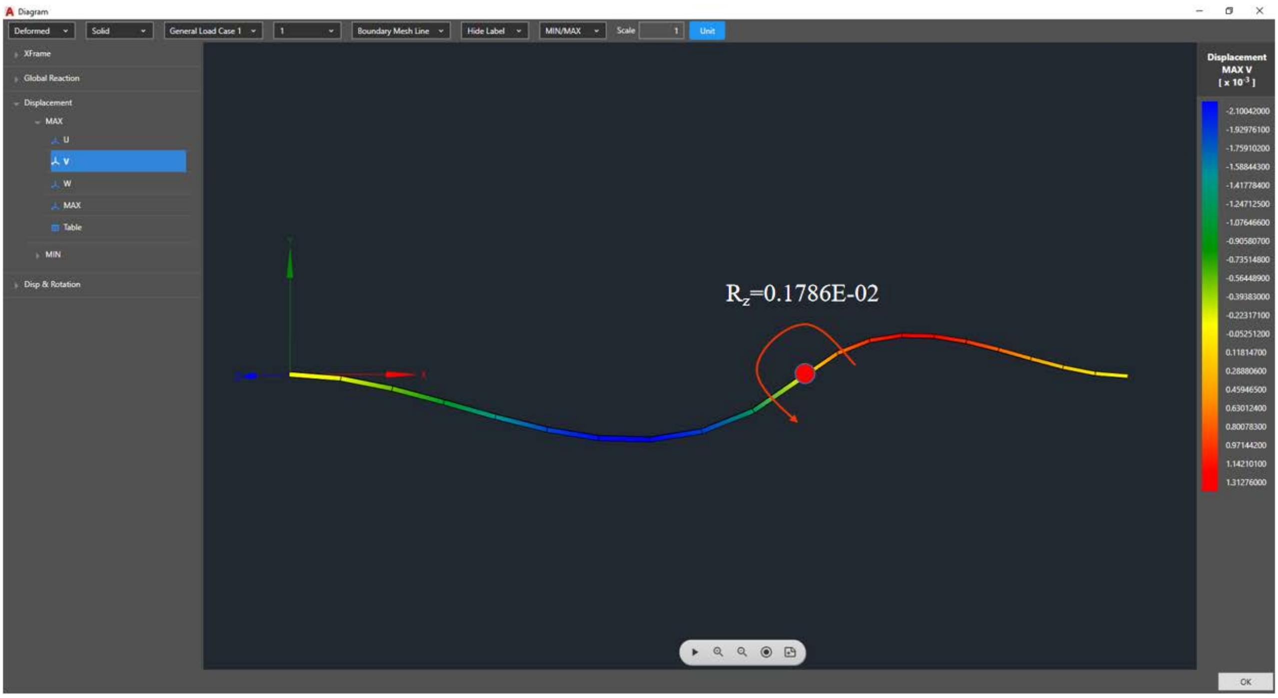


Fig.12.2 Displacement of beam in y direction (20 Elements, XFrame)

Table 12.1 Displacement at node 2

Element type	R_z (rad)
Reference	0.1786E-02
XSEA	0.1786E-02

Table 12.2 Reaction at node 1

Element type	Node 1		Node 3	
	F_y (N)	M_z (N·mm)	F_y (N)	M_z (N·mm)
Reference	0.67E+04	0.1786E+08	-0.429E+04	0.714E+07
XSEA	0.6696E+04	0.1786E+08	-0.4286E+04	0.7143E+07

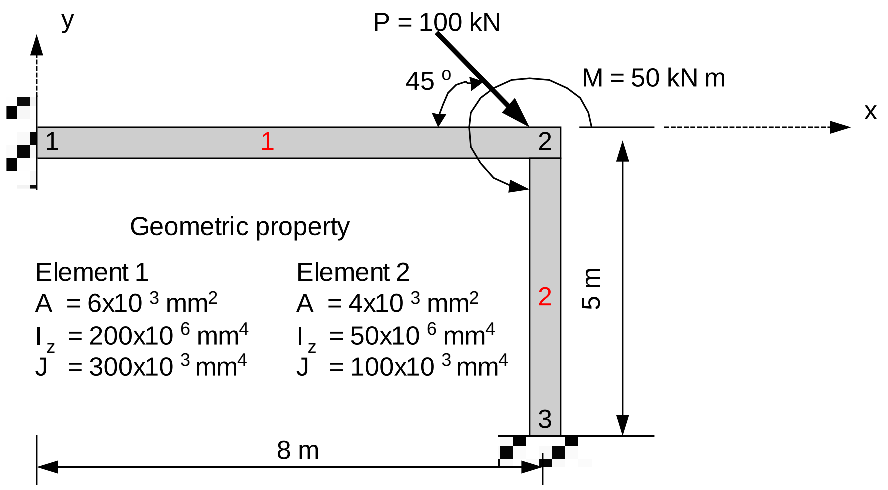
Verification Example of X-SEA AutoCAD	No: Frame Element 013

Title: Frame Element Numerical Examples-3

Problem Description

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



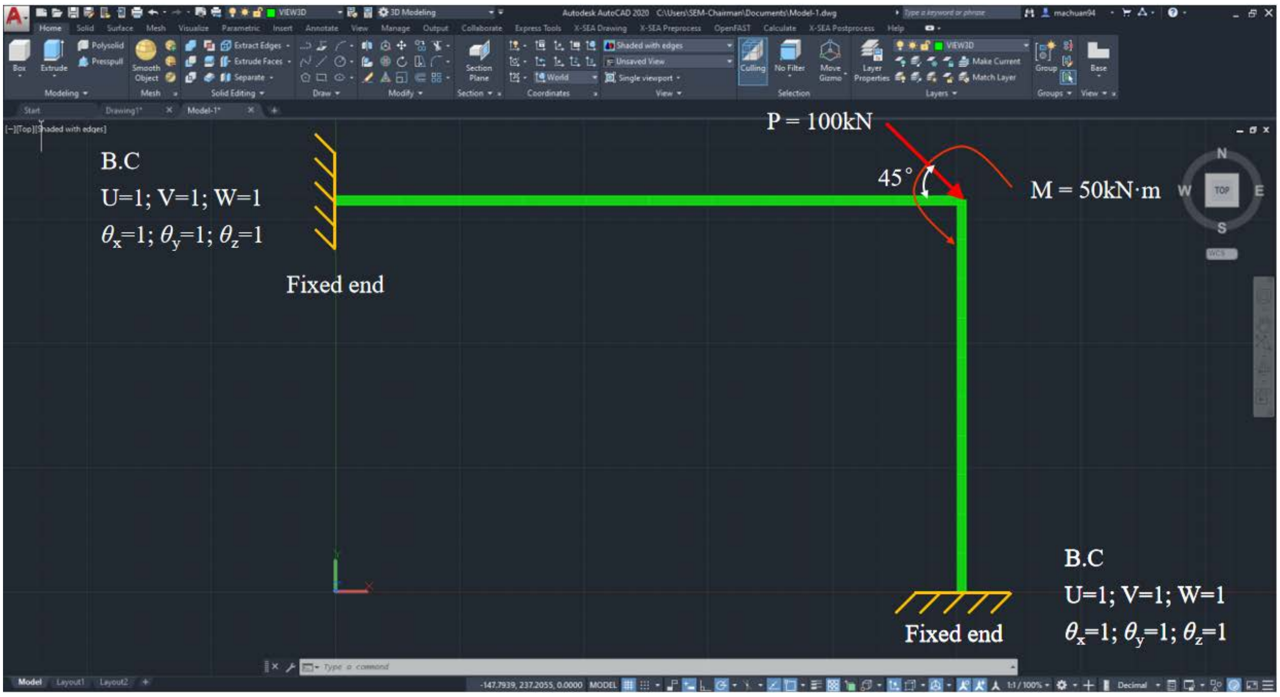


Fig.13.1 Frame model-3 (20 Elements, XFrame)

Results

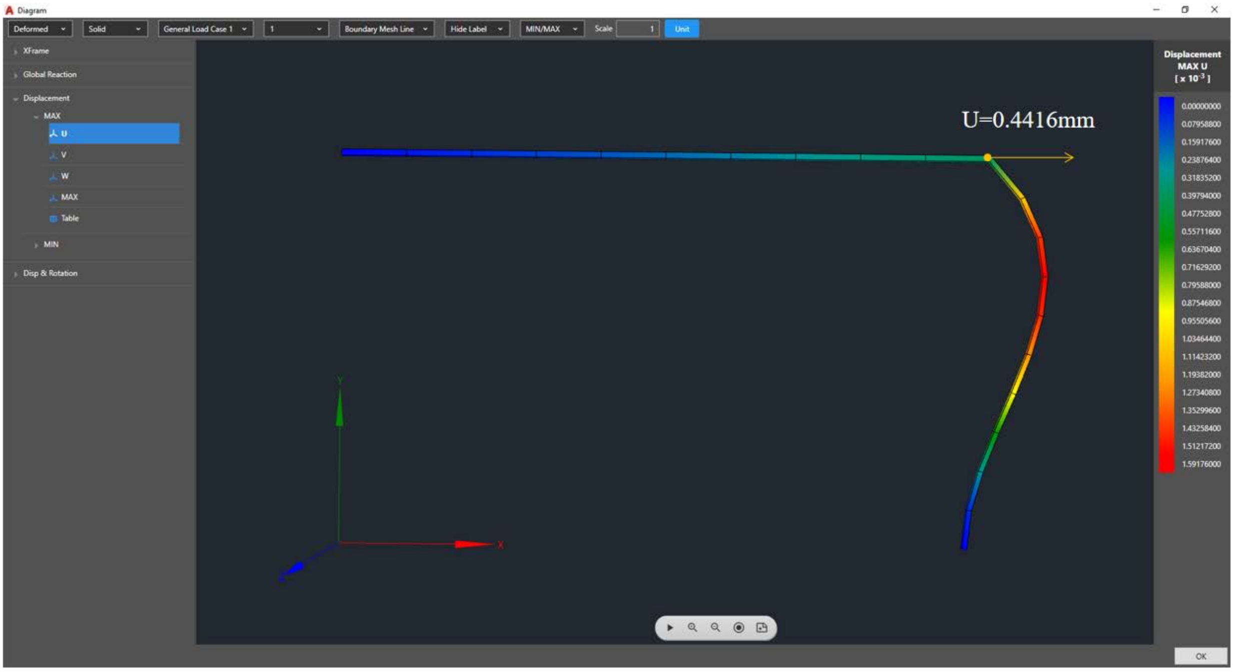


Fig.13.2 Displacement of beam in X direction (20 Elements, XFrame)

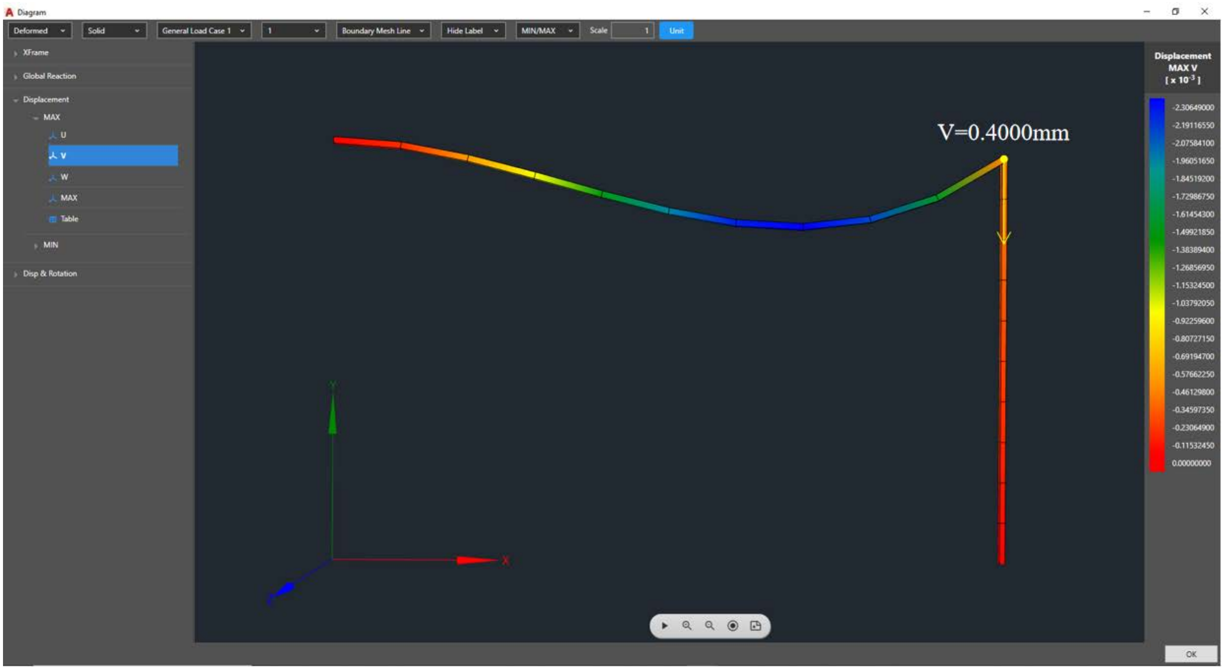


Fig.13.3 Displacement of beam in Y direction (20 Elements, XFrame)

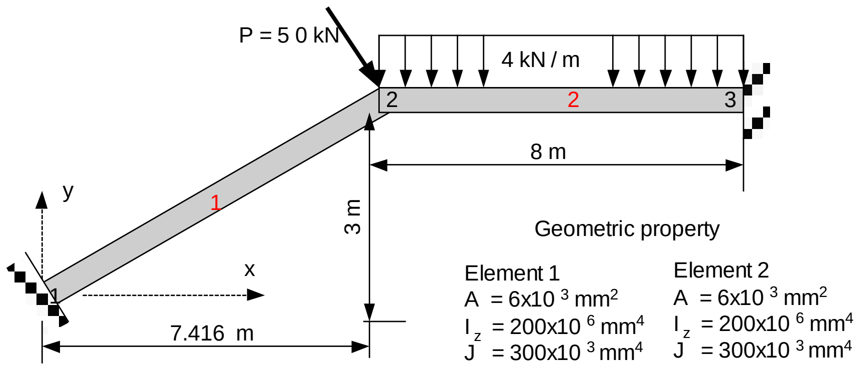
Table 13.1 Displacement at node 2

Element type	**U (mm)**	**V (mm)**	$\mathbf{R_z}$ (rad)
Reference	0.4414	-0.3998	0.1690E-02
XSEA	0.4416	-0.4000	0.1695E-02

	XFINASIT Co. LTD
Verification Example of X-SEA AutoCAD	**No: Frame Element 014**
Title: Frame Element Numerical Examples-4	
Problem Description	

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



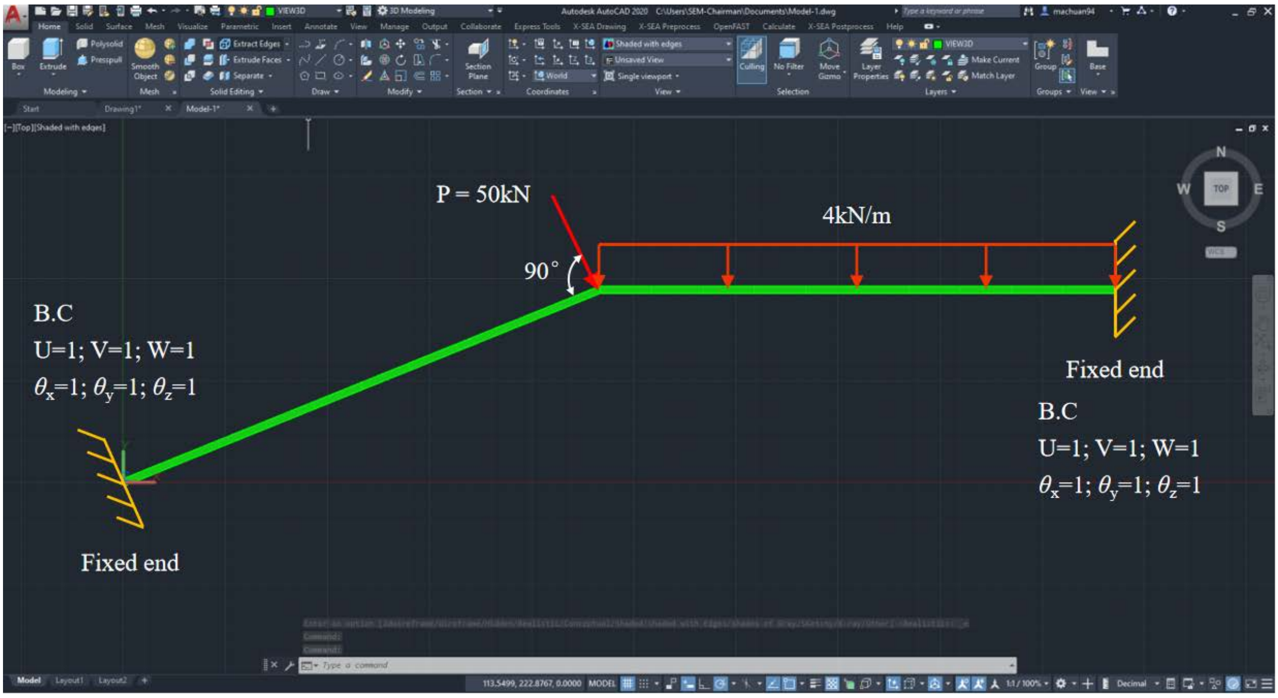


Fig.14.1 Frame model-4 (20 Elements, XFrame

Results

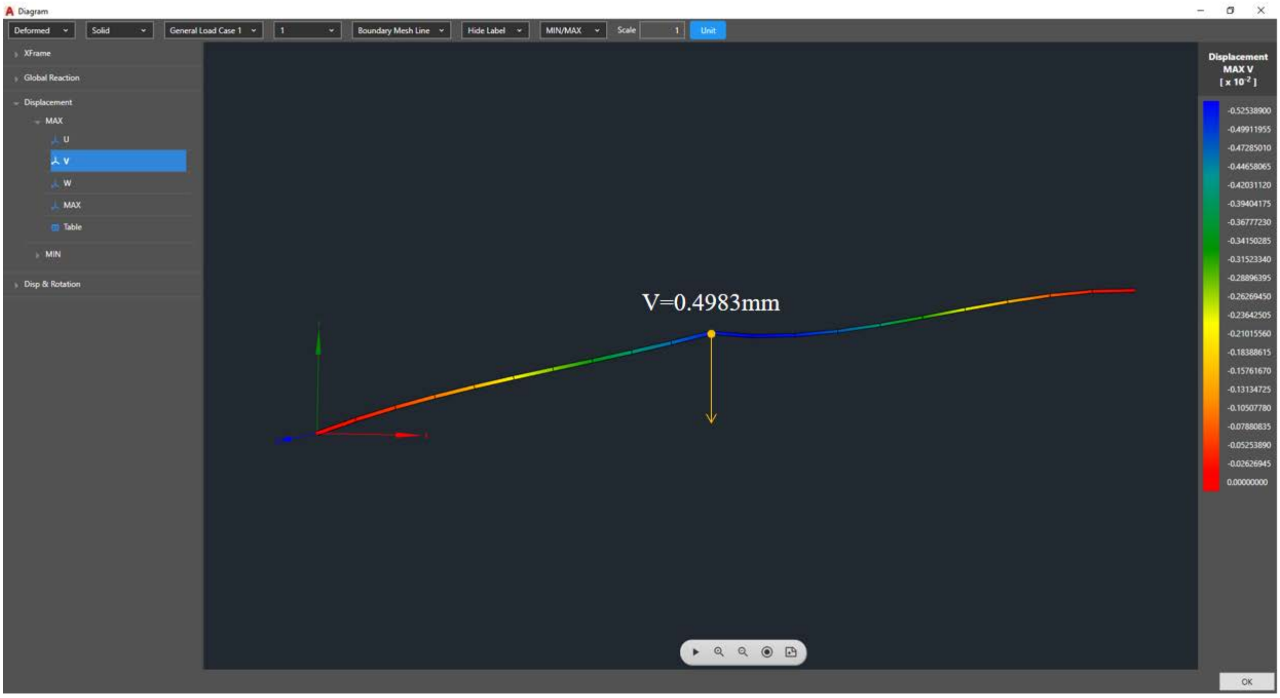


Fig.14.2 Displacement of beam in y direction (20 Elements, XFrame)

Table 14.1 Displacement at node 2

Element type	U (mm)	V (mm)	R_z (rad)
Reference	0.9982	-0.4996E+01	-0.5340E-03
XSEA	0.9953	-0.4983E+01	-0.5344E-03

Table 14.2 Reaction at node 1 and 3

Element type	Node 1			Node 3		
	F_x (N)	F_y (N)	M_z (N·mm)	F_x (N)	F_y (N)	M_z (N·mm)
Reference	0.1310E+06	0.5540E+05	0.1343E+08	-0.1497E+06	0.2270E+05	-0.4541E+08
XSEA	0.1305E+06	0.5568E+05	0.1337E+08	-0.1493E+06	0.2267E+05	-0.4536E+08

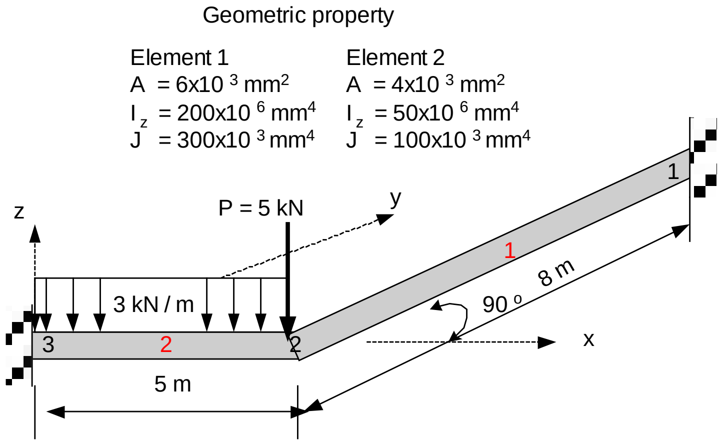
	XFINASIT Co. LTD
Verification Example of X-SEA AutoCAD	**No: Frame Element 015**

Title: Frame Element Numerical Examples-5

Problem Description

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



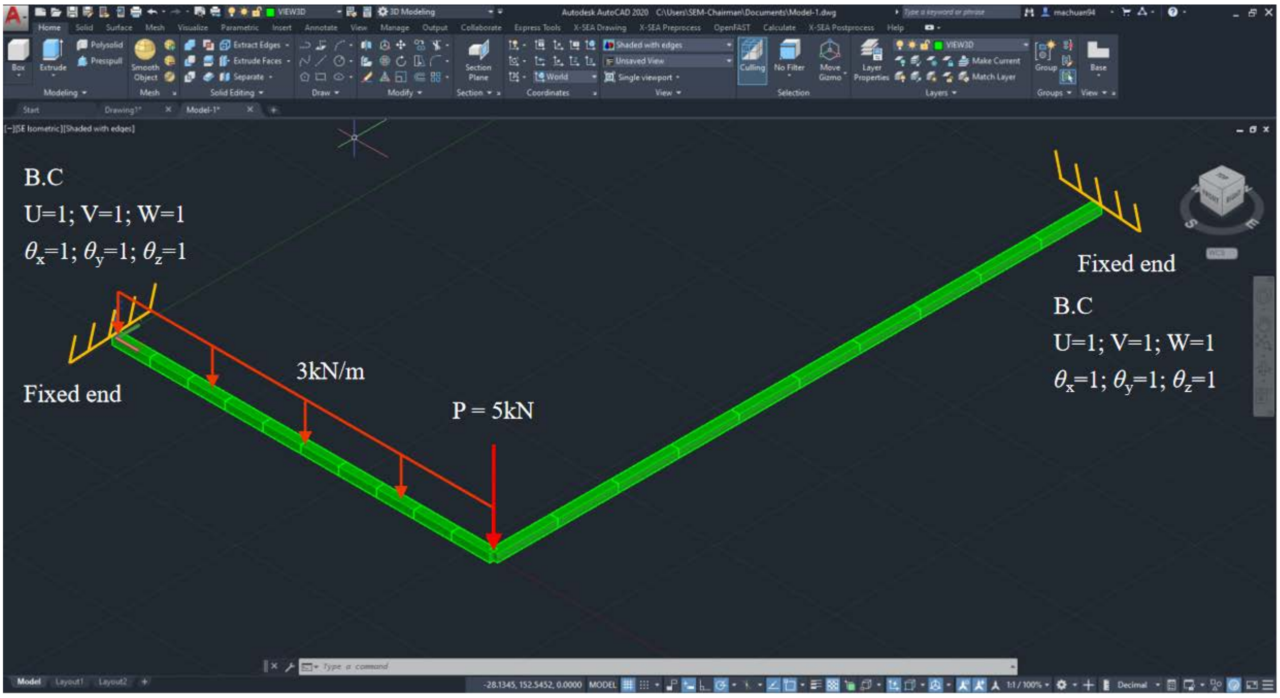


Fig.15.1 Frame model-5 (20 Elements, XFrame)

Results

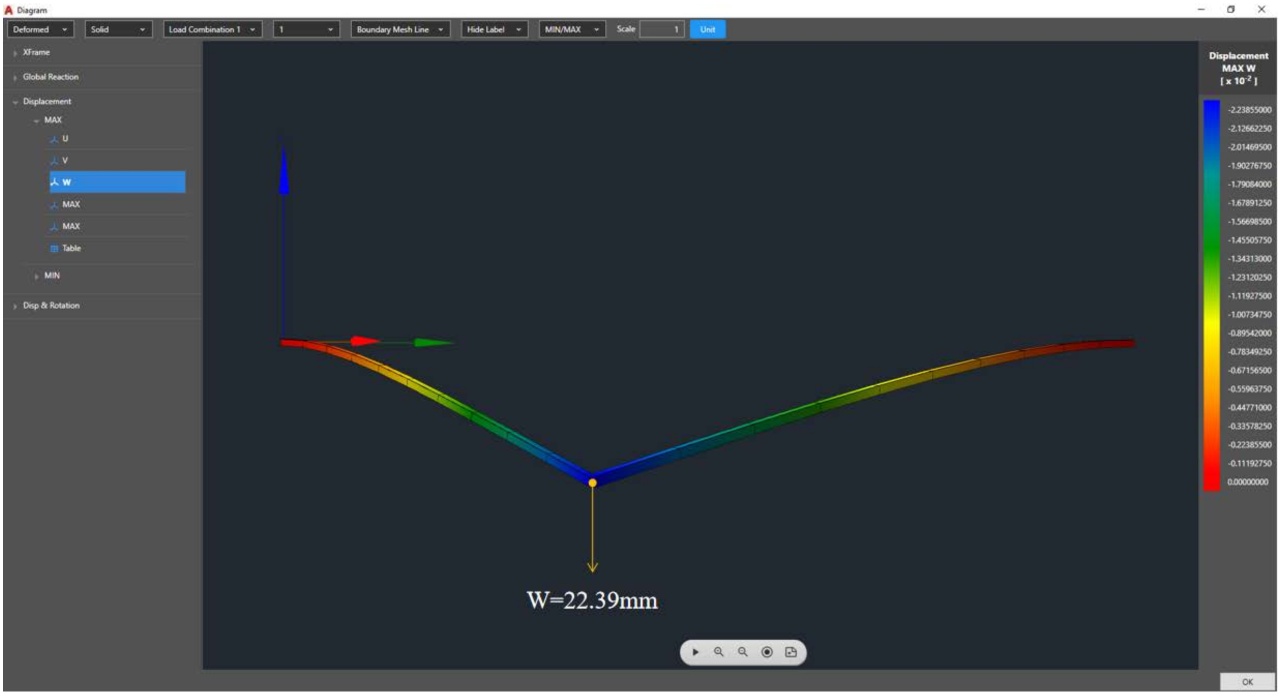


Fig.15.2 Displacement of beam in Z direction (20 Elements, XFrame)

Table 15.1 Displacement at node 2

Element type	W (mm)	R_x (rad)	R_y (rad)
Reference	-0.2237E+02	0.4195E-03	0.5931E-03
XSEA	-0.2239E+02	0.4197E-02	0.5932E-02

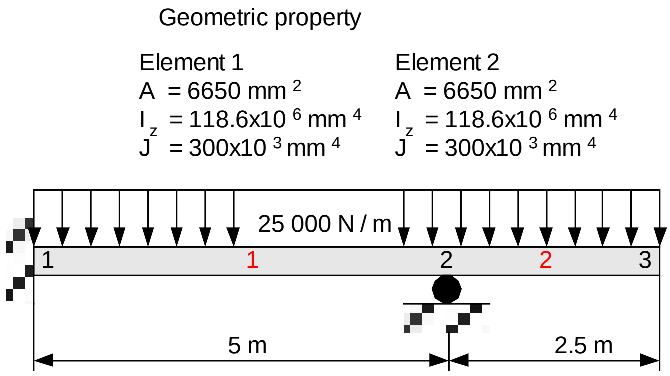
Table 15.2 Reaction at node 1 and 3

Element type	Node 1			Node 3		
	F_z (N)	M_x (N)	M_y (N·mm)	F_z (N)	M_x (N)	M_y (N·mm)
Reference	0.5250E+04	-0.4194E+08	-0.1711E+05	0.1474E+05	-0.6450E+04	-0.3621E+08
XSEA	0.5247E+04	-0.4197E+08	-0.2159E+05	0.1474E+05	-0.8148E+04	-0.3624E+08

Verification Example of X-SEA AutoCAD	No: Frame Element 016
Title: Frame Element Numerical Examples-6	
Problem Description	

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



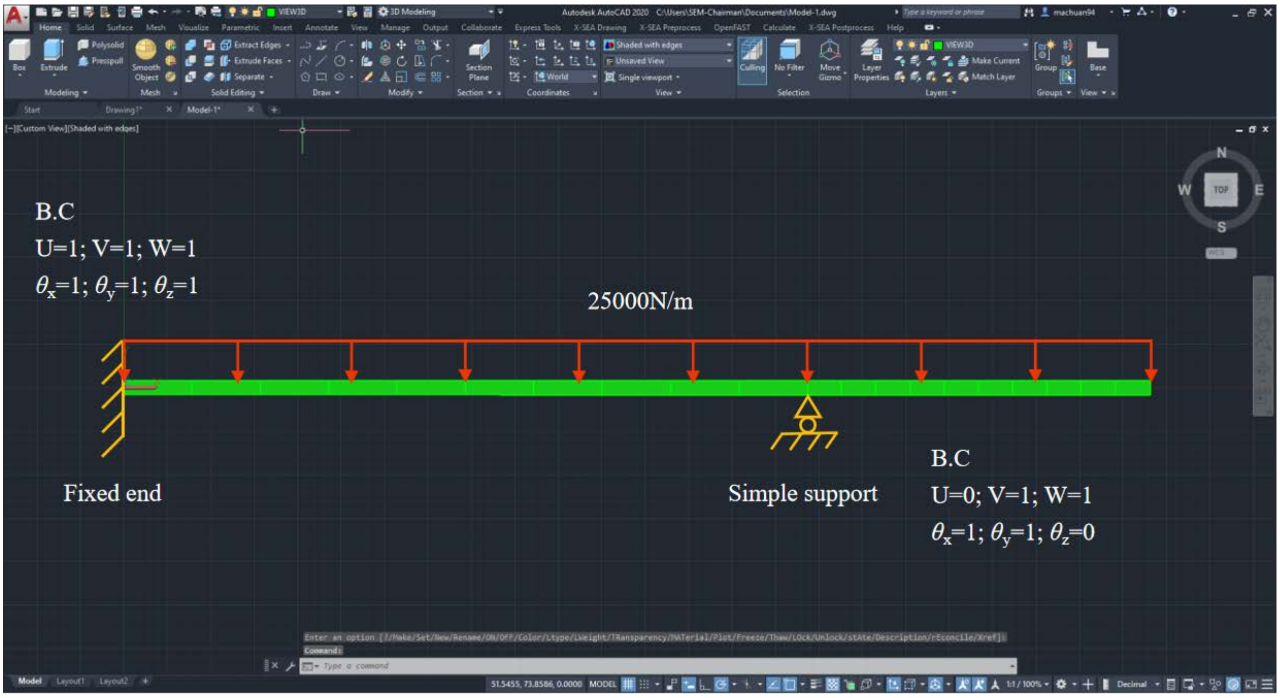


Fig.16.1 Frame model-6 (20Elements, XFrame)

Results

Fig.16.2 Displacement of beam in Y direction (20Elements, XFrame)

Table 16.1 Displacement at node 2 and 3

Element type	Node 2	Node 3	
	R_z (rad)	V (mm)	R_z (rad)
Reference	-0.1372E-02	-0.8577E+01	-0.4117E-02
XSEA	-0.1372E-02	-0.8579E+01	-0.4118E-02

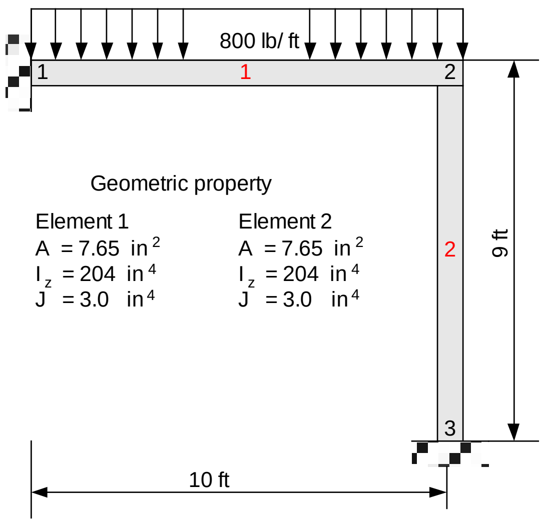
Table 16.2 Reaction at node 1

Element type	Node 1	
	F_y (N)	M_x (N)
Reference	0.54687E+05	0.39062E+08
XSEA	0.54688E+05	0.39063E+08

	XFINASIT Co. LTD
Verification Example of X-SEA AutoCAD	**No: Frame Element 017**
Title: Frame Element Numerical Examples-7	
Problem Description	

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



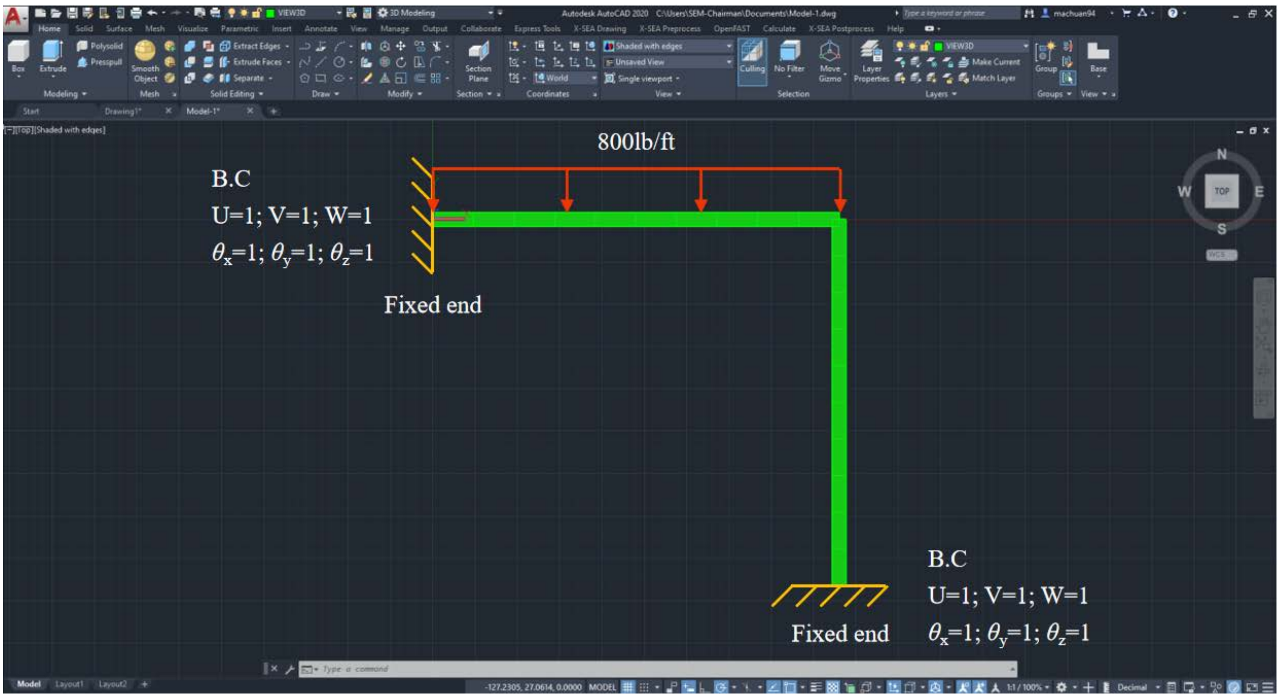


Fig.17.1 Frame model-7 (20Elements, XFrame)

Results

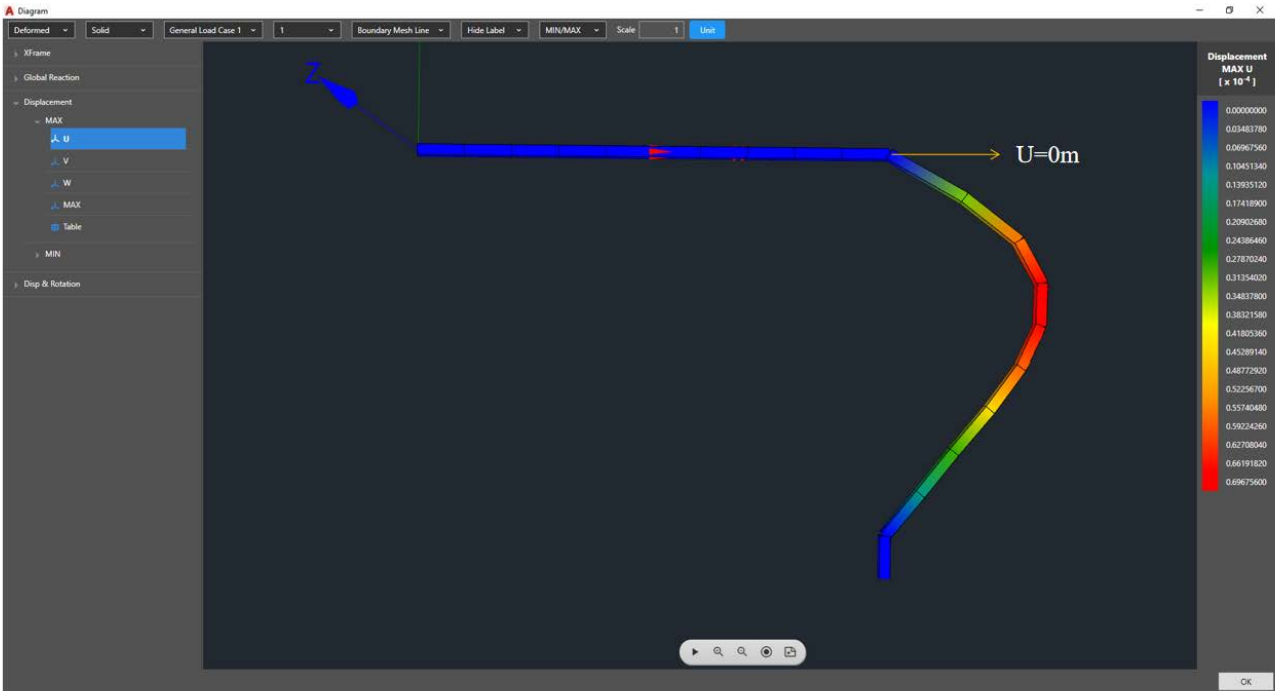


Fig.17.2 Displacement of beam in X direction (20Elements, XFrame)

Fig.17.3 Displacement of beam in Y direction (20Elements, XFrame)

Table 17.1 Displacement at node 2

Element type	U (in (m))	V (in (m))	R_Z (rad)
Reference	-0.2845E-03	-0.16359E-02	0.17815E-03
XSEA	0	-0.1722E-02 (-4.3750E-05)	0.18758E-03

Table 17.2 Reaction at node 1 and 3

Element type	Node 1			Node 3		
	F_x (lbf) (N)	F_y (lbf) (N)	M_z (lbf·in) (N·m)	F_x (lbf) (N)	F_y (lbf) (N)	M_z (lbf·in) (N·m)
Reference	0.5443E+03	0.4524E+04	0.1024E+06	-0.5443E+03	0.3476E+04	0.1930E+05
XSEA	0.5540E+03 (2.4643E+03)	0.4605E+04 (2.0483E+04)	0.1042E+06 (1.1770E+04)	-0.5540E+03 (-2.4643E+03)	0.3538E+04 (1.5740E+04)	0.1964E+05 (2.2190E+03)

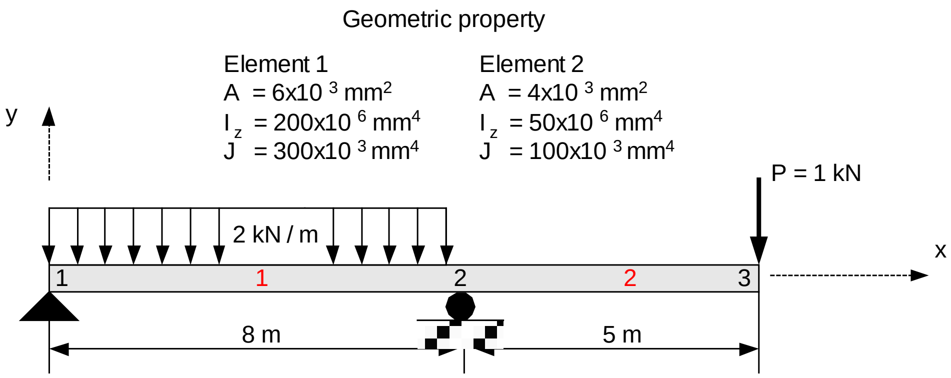
Verification Example of X-SEA AutoCAD	No: Frame Element 018

Title: Frame Element Numerical Examples-8

Problem Description

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



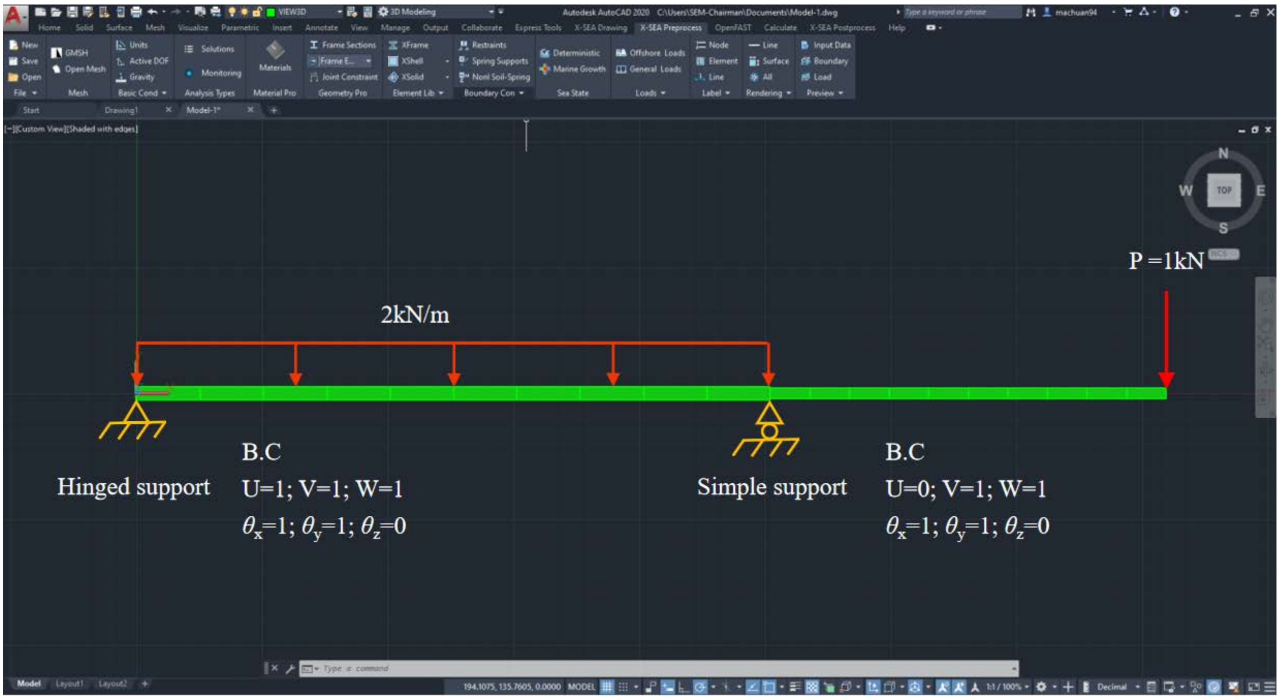


Fig.18.1 Frame model-8 (20Elements, XFrame)

Results

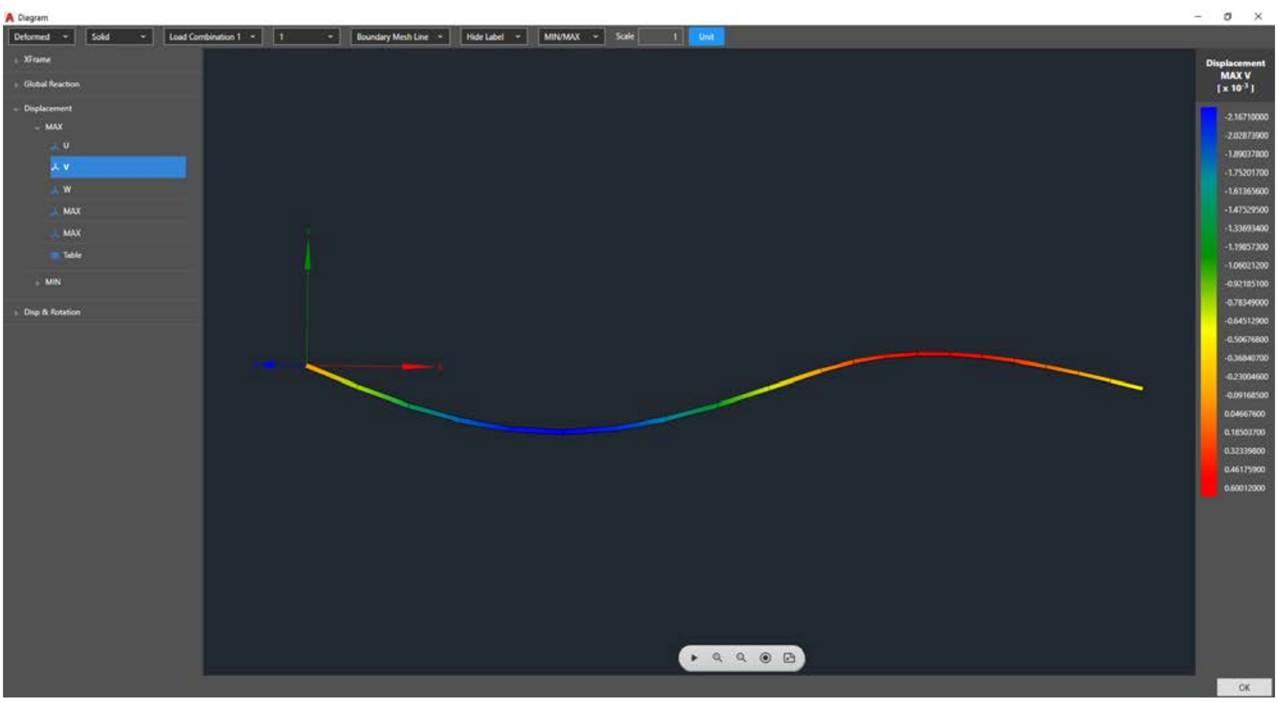


Fig.18.2 Displacement of beam in Y direction (20Elements, XFrame)

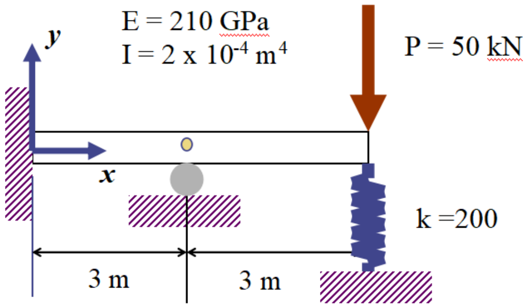
Table 18.1 Reaction at node 1, 2

Element type	Reaction F_y (N)	
	Node1	Node 2
Reference	0.7375E+04	0.9625E+04
XSEA	0.7375E+04	0.9625E+04

Verification Example of X-SEA AutoCAD	No: Frame Element 019
Title: Validation of the proposed spring supported boundary element	
Problem Description	

Beam is supported and loaded as follows.

E=199.96GPa; v=0.03.



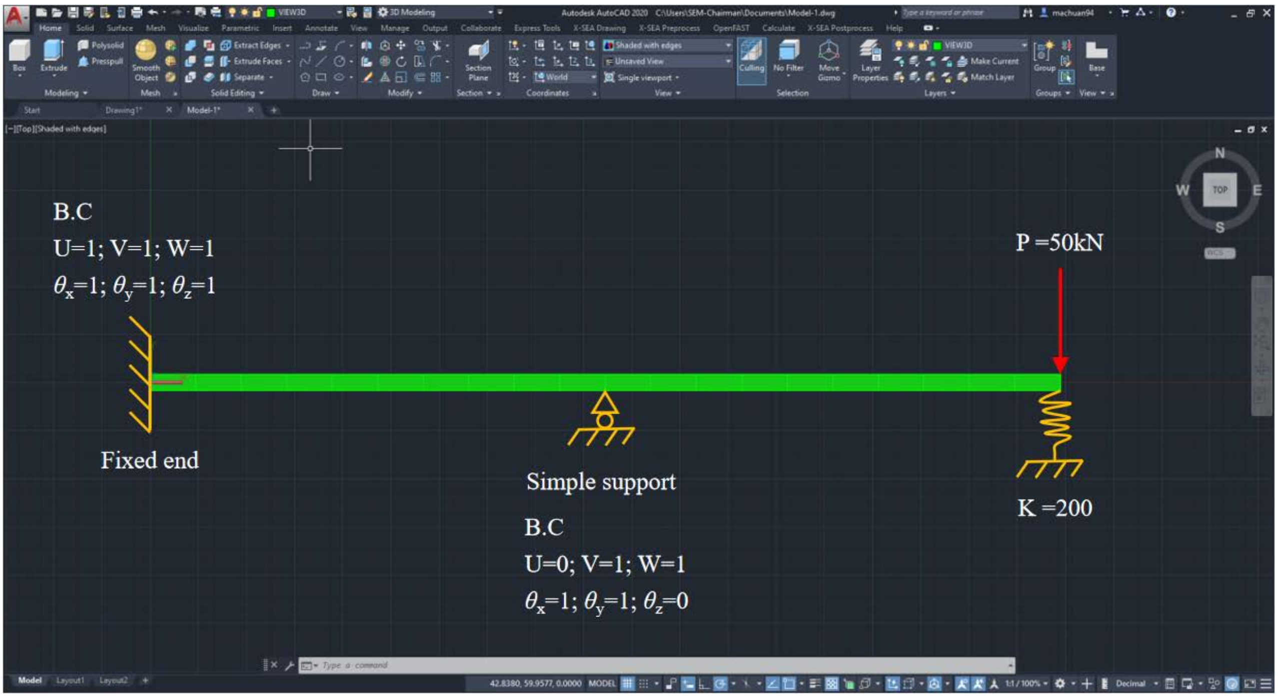


Fig.19.1 Frame model-8 (20Elements, XFrame)

Results

Fig.19.2 Displacement of beam in Y direction (20Elements, XFrame)

Table 19.1 Reaction at end node

Element type	Displacement (m)	Rotation (rad)
Reference	-0.01740	-0.00747
XSEA	-0.01875	-0.00803