

FEA NX_線上課程

鋼骨結構
線性挫屈和非線性挫屈

台灣邁達斯

Subject

- MIDAS Design & Simulation
- 基礎觀念介紹
 - 挫曲
 - 後挫曲
 - 線性挫曲&非線性挫曲
- Example1:線性挫曲分析
- Example2:非線性挫曲分析
- Example3:後挫曲分析

挫曲

挫曲(Buckling)

是指細長桿件受到壓力時，發生彎曲變形的一種現象，不穩定造成的結構失效稱為屈曲失效，理想壓桿不穩定後，由原來的直線平衡狀態變為彎曲平衡狀態。

數學家萊昂哈德·歐拉提出了細長理想柱在不挫曲的情形下，可以承受的最大軸向壓縮力。

$$F = \frac{\pi^2 EI}{(KL)^2}$$

F:最大臨界力

E:彈性模數

I:面積慣性矩

L:柱的未支撐長度

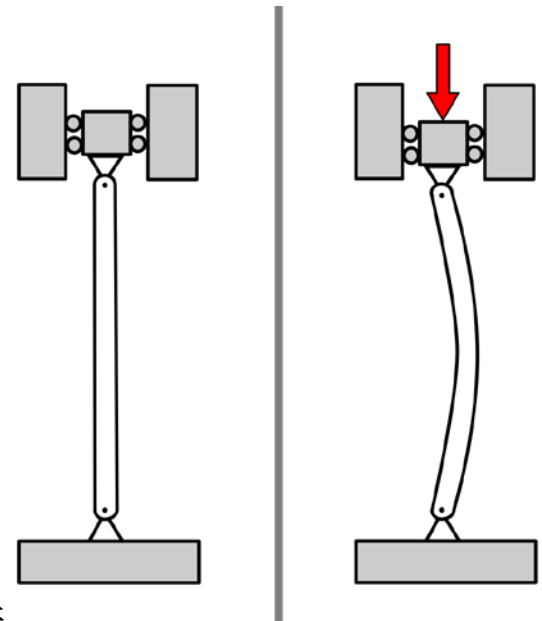
K:視柱子兩側的支撐條件而定

K=1,二端都用插銷連接(可以旋轉)

K=0.5,若二端都固定(無法旋轉)

K≈ 0.699,一端固定一端用插銷連接

K=2,一端固定，另一端可以自由移動



Reference

<https://zh.wikipedia.org/zh-tw/挫曲>

後挫曲

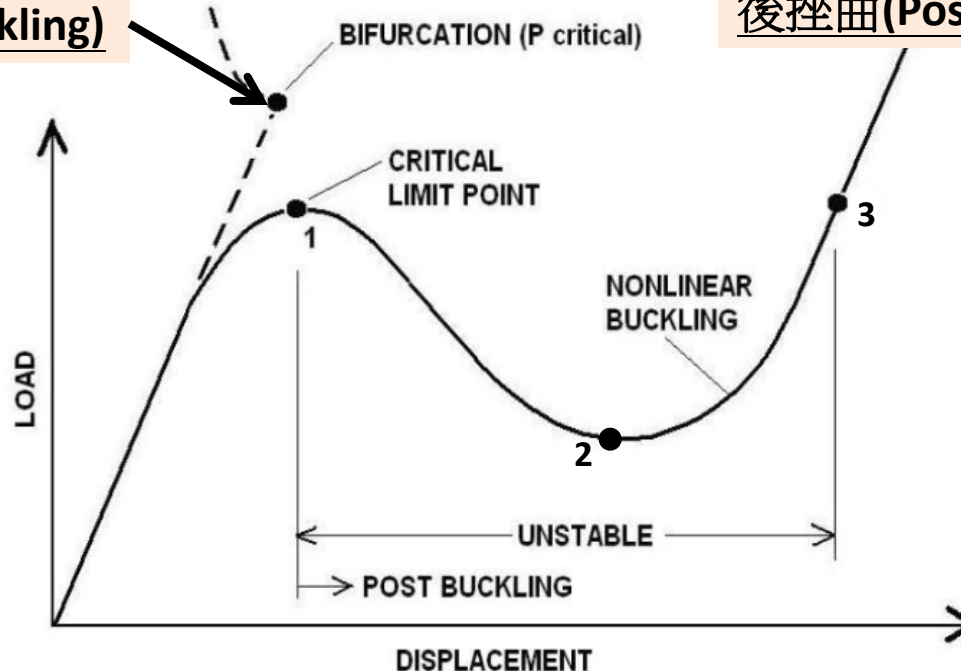
後挫曲(非線性挫曲)分析

載荷較小時分析結果與線性結果一致。當載荷逐步增大，變形逐步增加，結構響應呈現出非線性，力位移曲線開始偏離線性結果，在Point 1點承受外部載荷達到最大。

之後變形繼續變大但是結構能承受的外部載荷變小，結構發生挫曲，變形繼續變大，但是結構承受的載荷繼續變小。達到Point 2位移增加，結構承受的載荷開始增加，Point 3達到之前載荷的極限點。從Point 1到Point 3的過程稱為疾速跳過(snap through)。

線性挫曲(Linear Buckling)

後挫曲(Post Buckling)



Reference

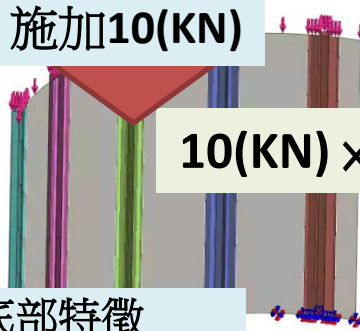
<https://www.linkedin.com/pulse/buckling-post-buckling-abraham-imam-muttaqin>

線性挫曲&非線性挫曲

(Linear & Non-Linear Buckling)

FEA NX-線性挫曲分析(挫曲最大臨界力)

施加10(KN)



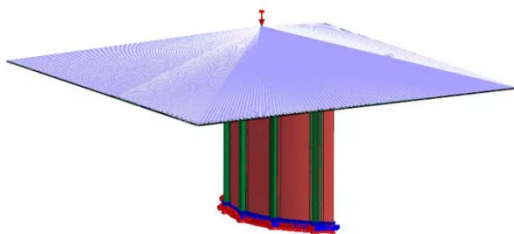
$10(\text{KN}) \times 2902.6(\text{mode 1 (Hz)}) = 29026(\text{KN})$ -挫曲最大臨界力

底部特徵
Tx/Ty/Tz/Rx/Ry/Rz

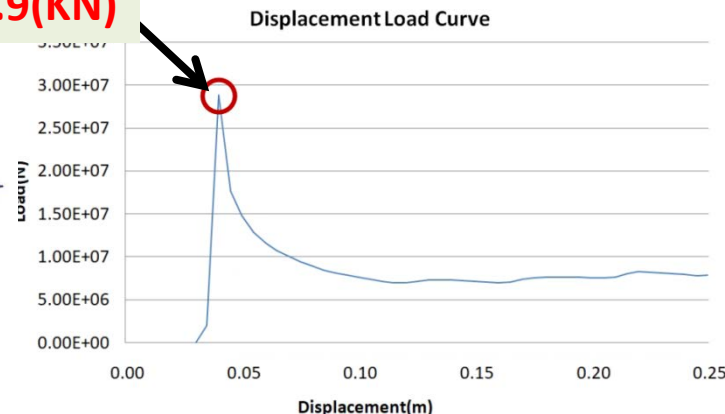
Mode 1-變形

FEA NX-非線性挫曲分析(挫曲過程載荷-位移曲線)

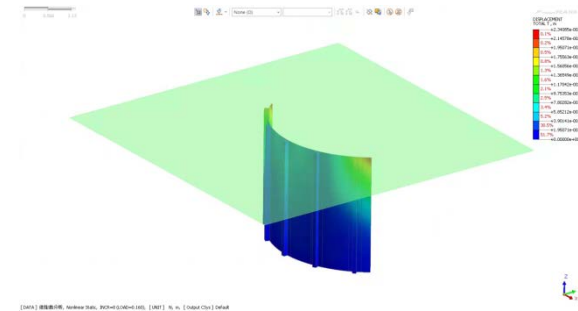
下壓0.25(m)



28832.9(KN)



底部特徵
Tx/Ty/Tz/Rx/Ry/Rz



應變硬化指數

(Strain Hardening Exponent)

應變硬化指數(Strain Hardening Exponent)

通常表示為 n ，常用於與加工硬化中的應力-應變行為相關的計算中的常量。

$$\sigma = K \epsilon^n$$

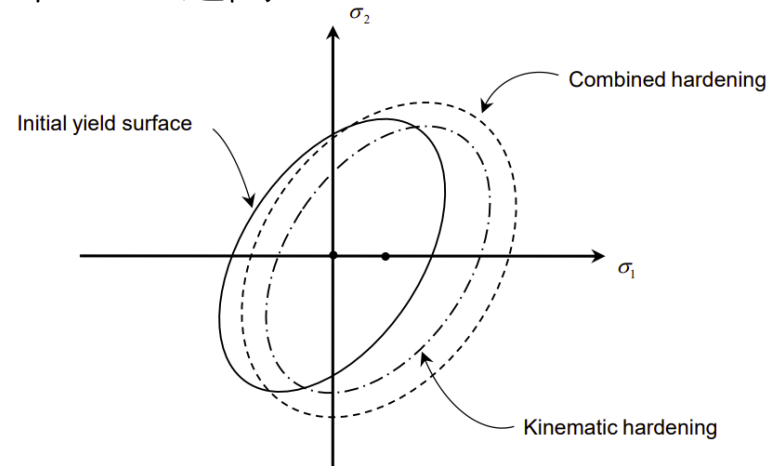
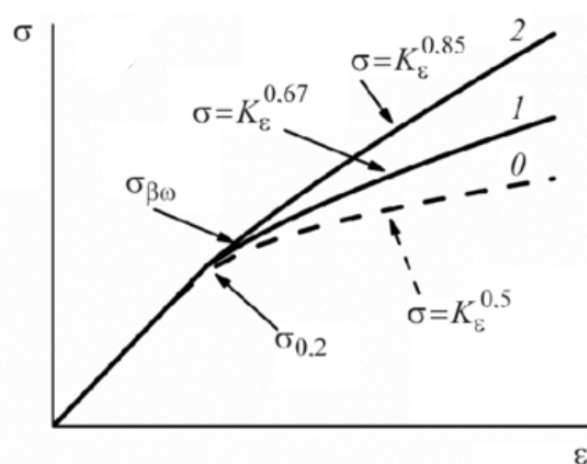
σ 真實應力

ϵ 真實應變

K 強度係數

n 應變硬化指數

應變硬化指數(n), 值介於 0 和 1 之間，0 表示完全塑性，1 表示完全彈性，大多數金屬的 n 值介於 0.10 和 0.50 之間。



硬化模型-屈服面

Reference

GTS NX AND FEA NX Manual

https://en.wikipedia.org/wiki/Strain_hardening_exponent

FEA NX_標準教學系列

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線性挫曲分析

台灣邁達斯

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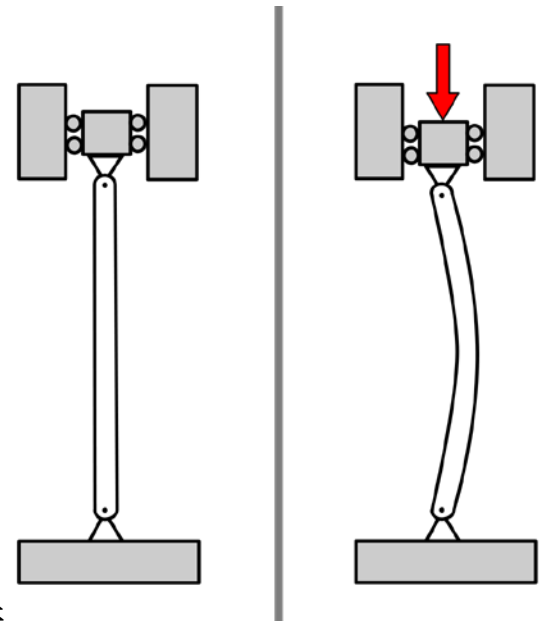
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Reference

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分析說明

材料

$$E = 70\text{GPa}$$

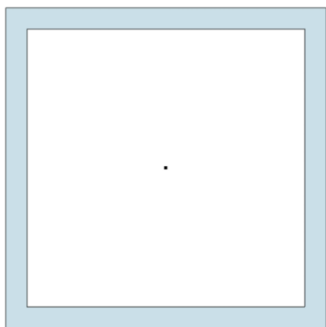
$$\gamma = 0.33$$

$$\rho = 7.850\text{kg} / \text{m}^3$$

截面0.15(m) × 0.15(m)

厚度(t): 0.01(m)

長度(L): 3 (m)



施加160,000(N)
(未固定)

F最大臨界力: 352.86(KN)

$$F = \frac{\pi^2 EI}{(KL)^2}$$

E: 70(GPa)

L: 3(m)

K=2

I: $\frac{1}{12}((0.15 \times 0.15^3) - (0.13 \times 0.13^3))$

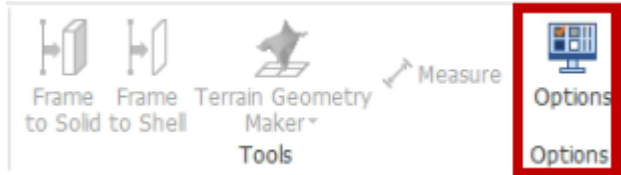


線性挫曲分析
計算最大臨界力

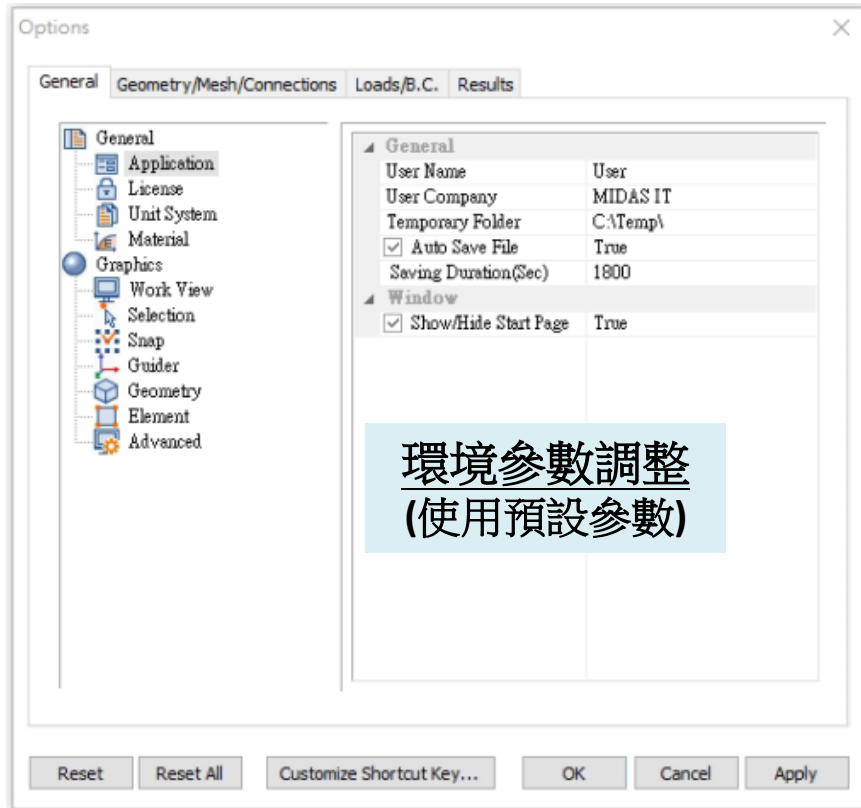
拘束條件

底部面特徵Tx/Ty/Tz/Rx/Ry/Rz

環境

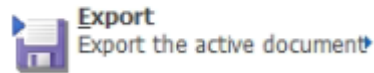


新文件

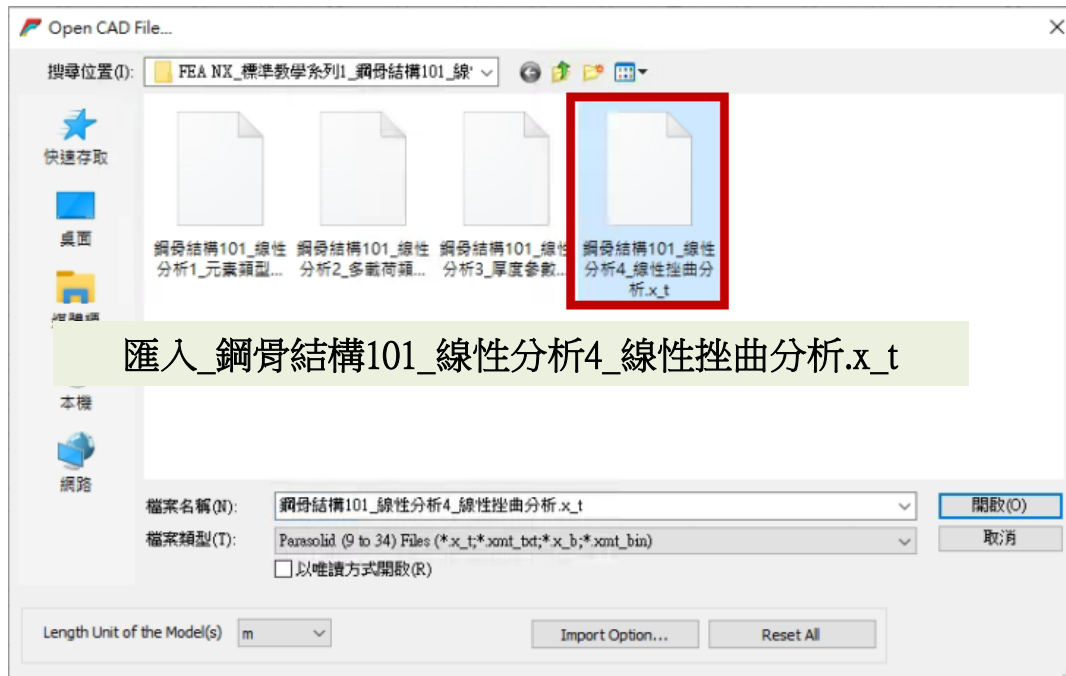
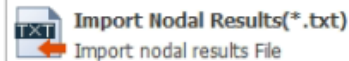
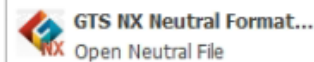
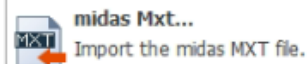
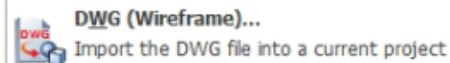
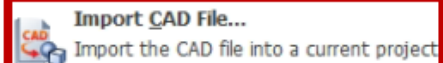


單位使用N/m/J/sec

匯入模型



Import the geometries or FE model in the selected file



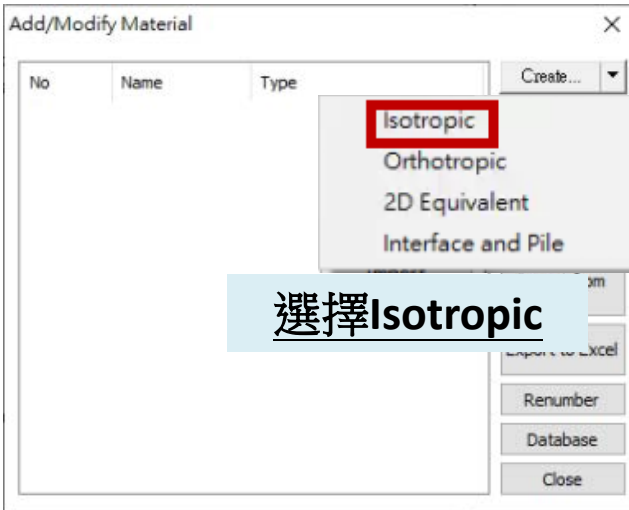
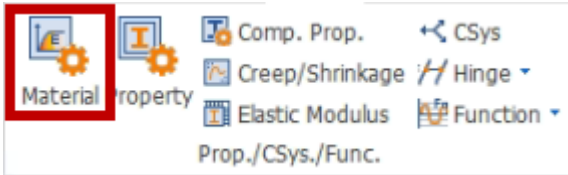
匯入_鋼骨結構101_線性分析4_線性挫曲分析.x_t

鋼構3D模型

材料

自訂材料名稱Test

勾選Structure



選擇Isotropic

Material Properties dialog box for material 'test'.

ID: 1, Name: test, Color: [Pink]

Model Type: Elastic, ☒ Structure

General Tab:

- Elastic Modulus(E): 70e9 N/m²
- Inc. of Elastic Modulus: 0 N/m²
- Inc. of Elastic Modulus Ref. Height: 0 m
- Poisson's Ratio(v): 0.33
- Unit Weight(γ): 7.85*9.81 N/m³

Initial Stress Parameters:

- Ko Determination: 1
- Automatic (selected), Manual, Anisotropy

Thermal Parameter:

- Thermal Coefficient: 1e-006 1/[T]
- Molecular vapor diffusion coefficient: 0 m²/sec
- Thermal diffusion enhancement: 0

Damping Ratio(For Dynamic):

- Damping Ratio: 0.05

Safety Result(Mohr-Coulomb):

- Cohesion(C): 30000 N/m²
- Frictional Angle(φ): 36 [deg]
- Tensile Strength: 0 N/m²

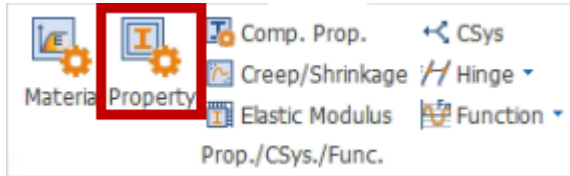
Buttons: OK, Cancel, Apply, DB

$$E = 70\text{GPa}$$
$$\gamma = 0.33$$
$$\rho = 7.850\text{kg} / \text{m}^3$$

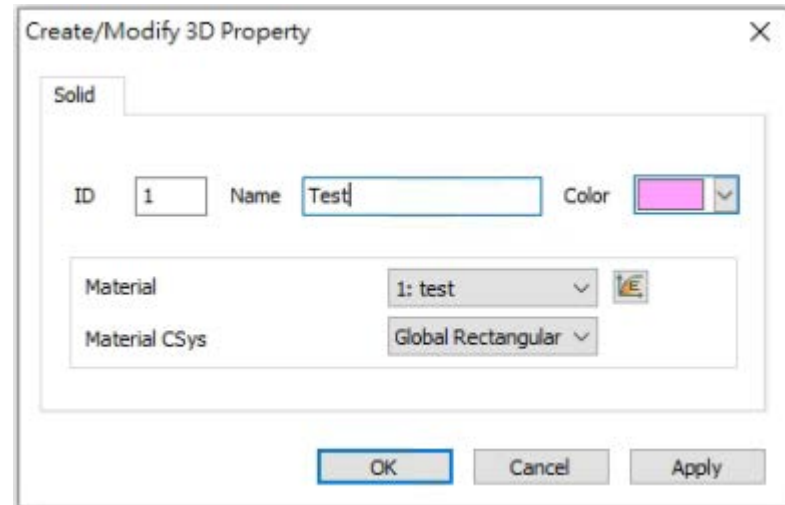
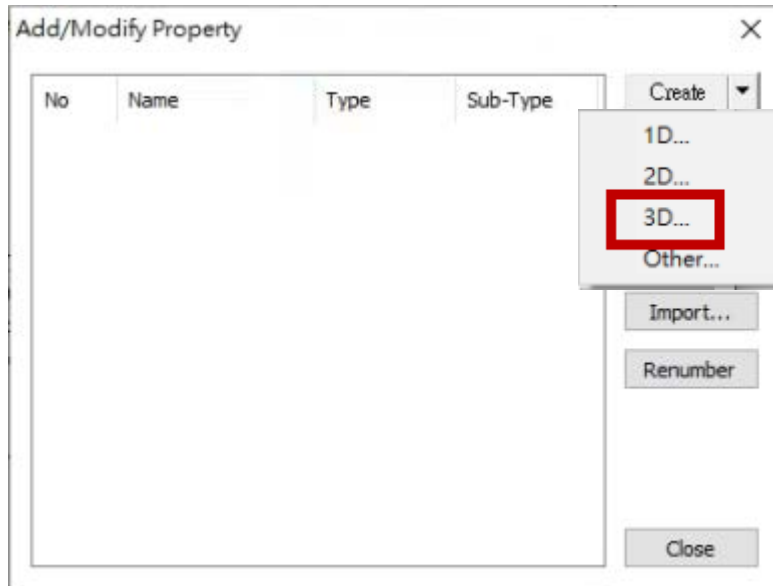
對照輸入材料數據
(密度單位換算)

註:未勾選Structure則視為土壤材料。

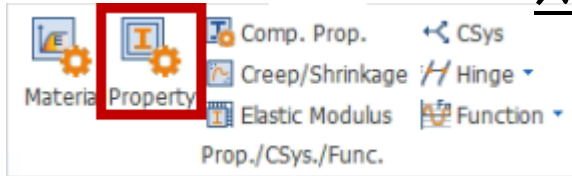
屬性



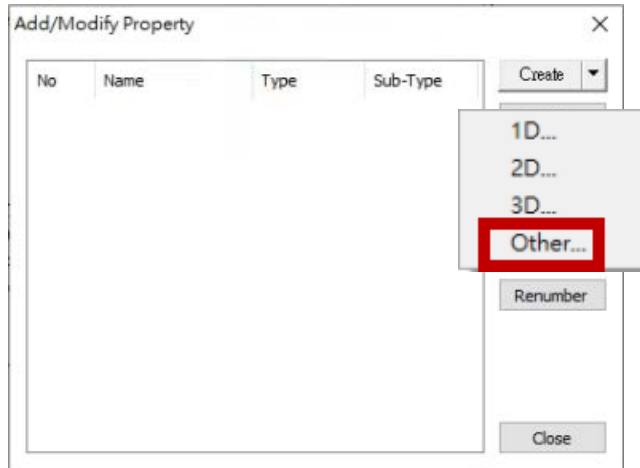
新增Test Property



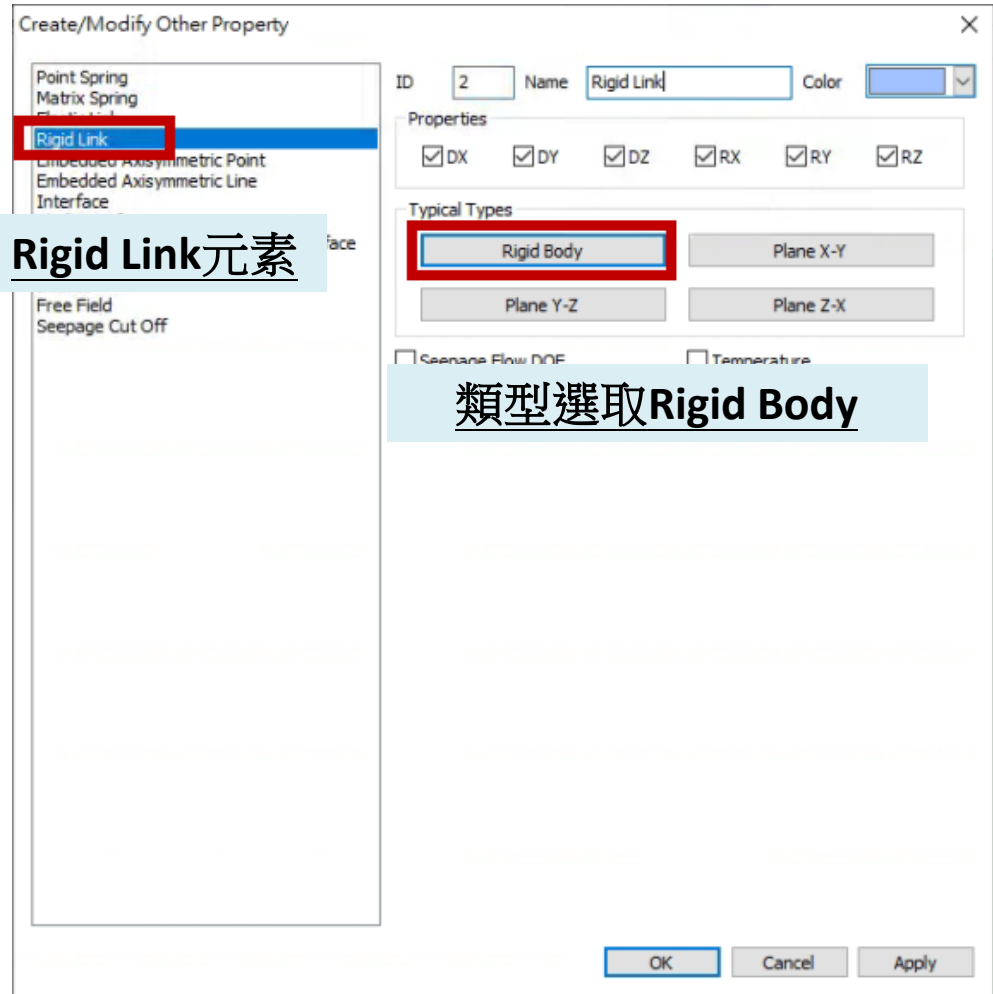
屬性-Rigid Link



新增Rigid Link Property



Rigid Link元素

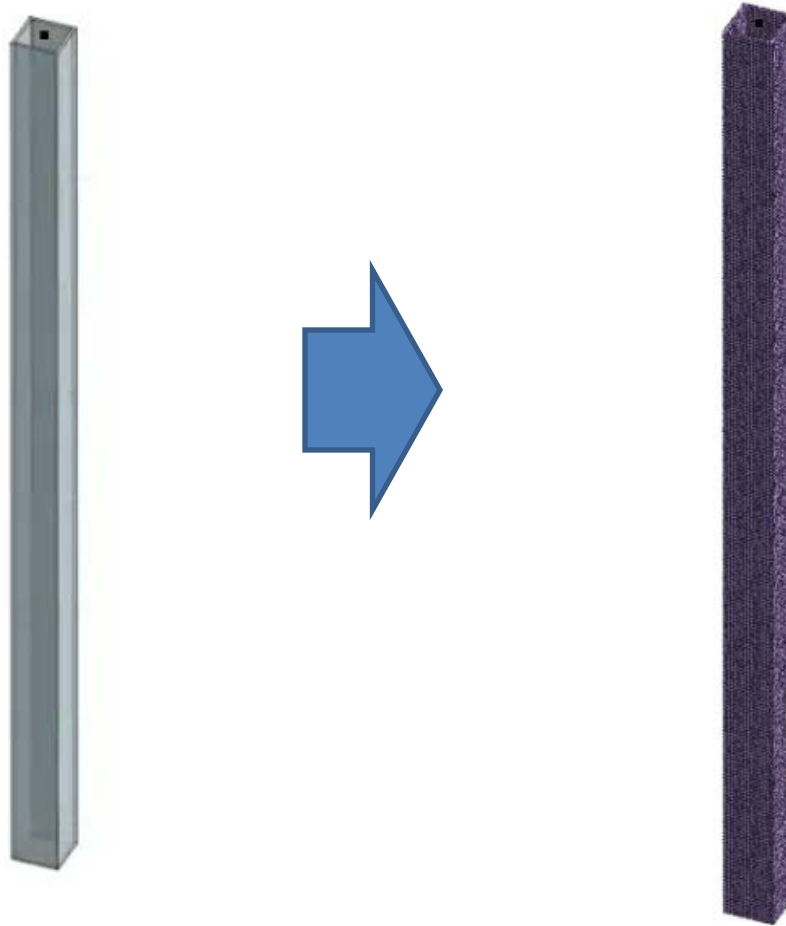


類型選取Rigid Body

3D網格-四面體網格

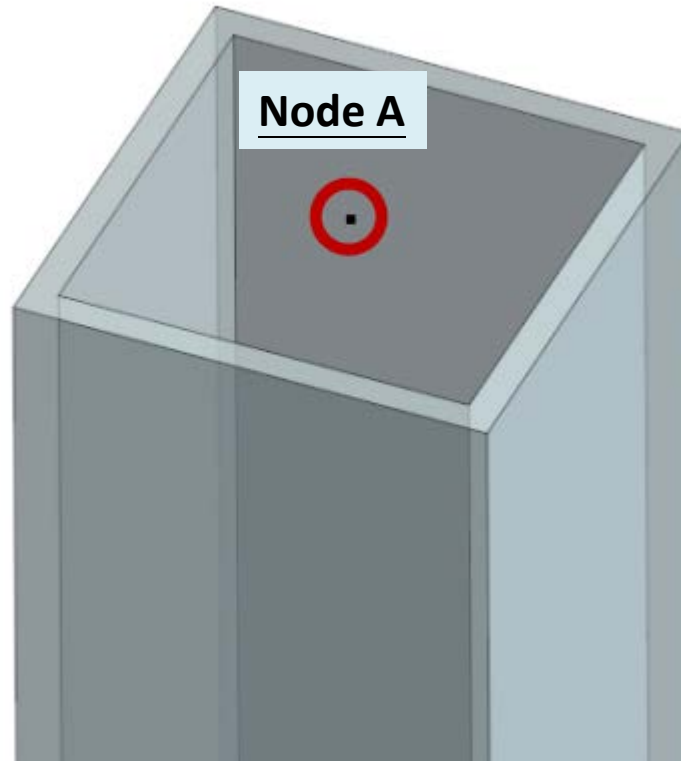
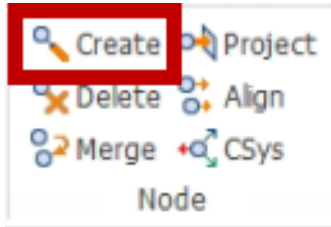


Tetra Mesher(四面體網格)/網格尺寸0.01 (m)/2階元素



主控節點建立

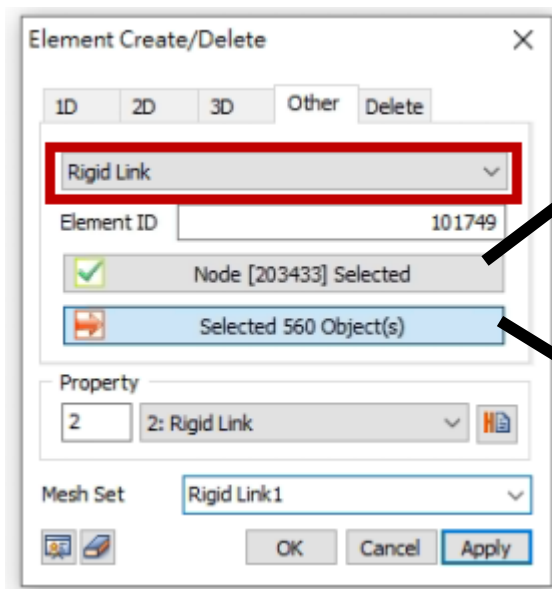
(剛性連接主控點)



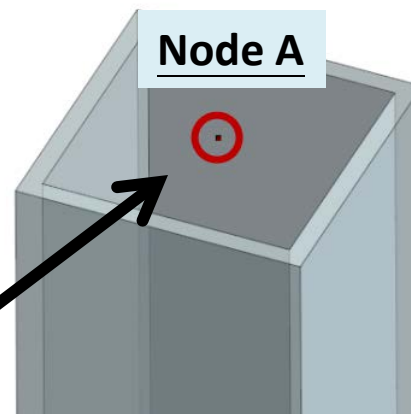
剛性連接



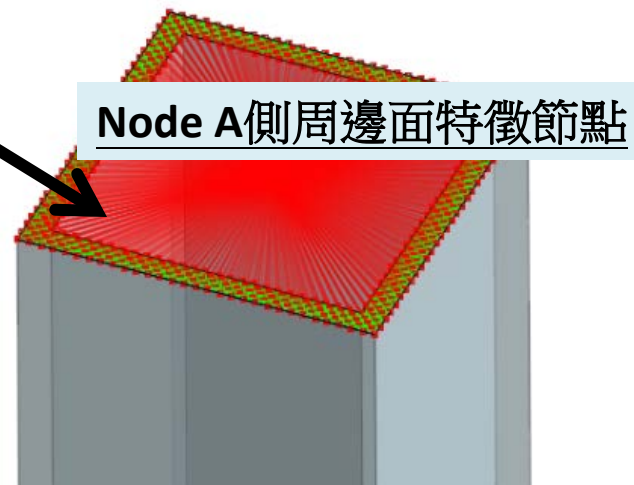
元素類型選取Rigid Link



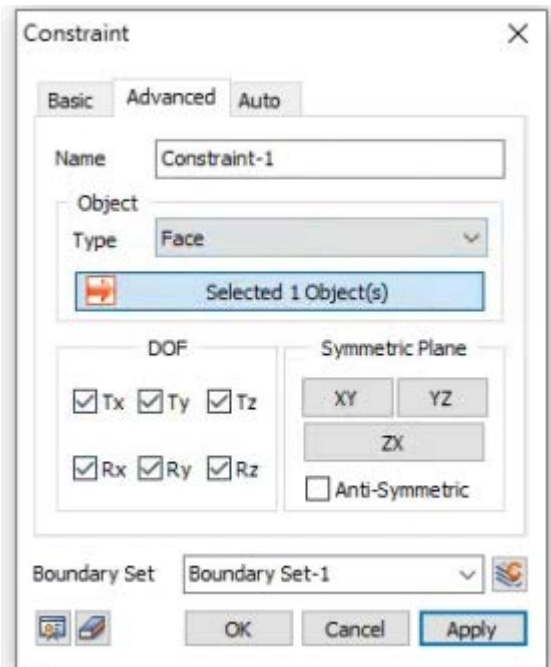
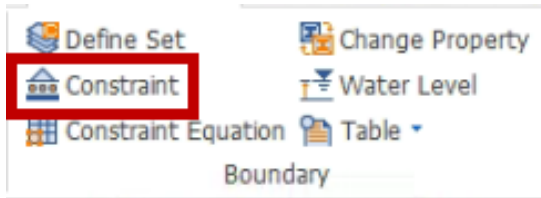
自訂網格集Rigid Link1



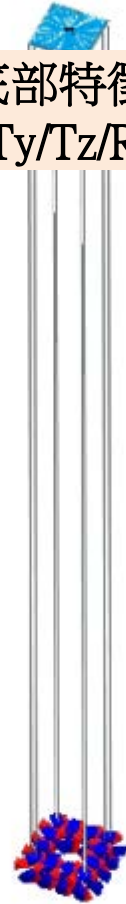
切換使用面特徵選取節點



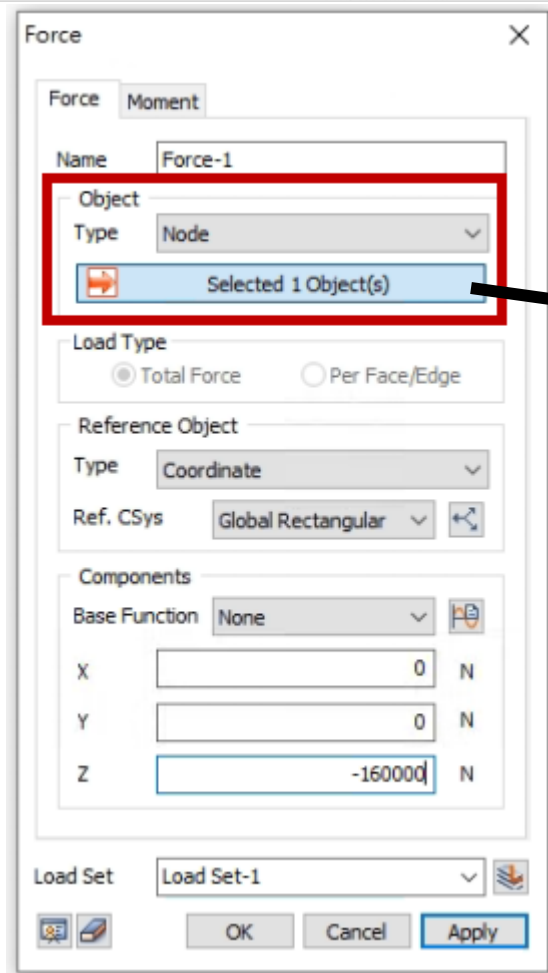
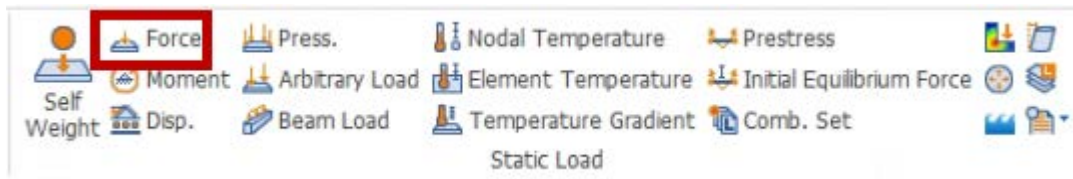
邊界



底部特徵拘束
 $T_x/T_y/T_z/R_x/R_y/R_z$



載荷



$F_z = -160,000 \text{ (Nt)}$

Rigid Link1 主控點

Global 座標判斷方向



線性挫曲分析-1

自訂析名稱



分析類型: Linear Buckling

考慮所有網格集/邊界集/載荷集/接觸對

線性挫曲分析-2

分析控制

Analysis Control

General

Initial Temperature

☐ Initial Temperature By Value [T]

Load Set Control

Load Set	Factor	Load Type
1:Load Set-1	1.0000	Variable

Eigenvectors

☒ Number of Modes

Frequency Range of Interest

☐ Lowest ☐ Highest

Unit: [Cycle]/ sec

☐ Sturm Sequence Check

OK Cancel

輸出10組結果

輸出控制

Output Control

Output Type Output Option

☒ Write Results of All Active Mesh Sets

Nodal Results

☒ Displacement

☒ Applied Load

☒ Reaction Force

☒ Grid Point Force

☐ Contact

Element Results

☒ Force

☒ Stress

☒ Strain

Output Option

☒ Binary ☐ Binary and Text

Element Output Location

☒ Element Corner Results

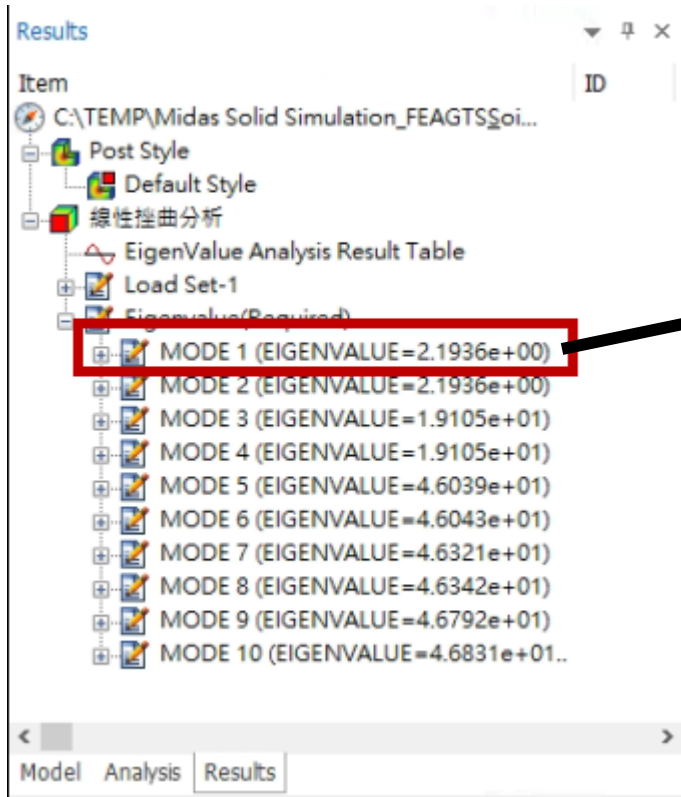
☐ Shell Mid-Plane Results

Number of Beam Output Segments

OK Cancel

自訂輸出項目

挫曲計算



線性挫曲分析

n=1

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E:70(GPa)

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Reference

NFX Analysis Reference



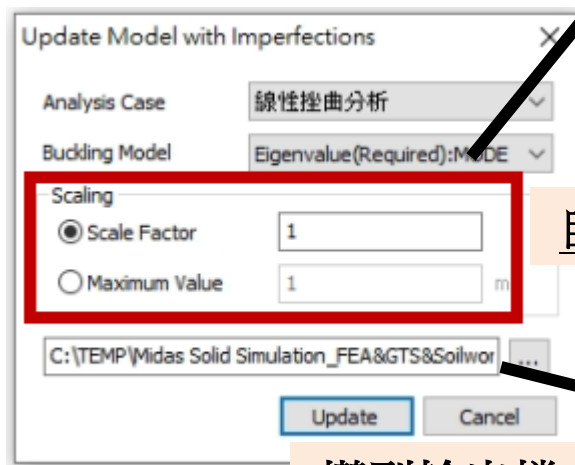
挫曲變形模型

選取結果

Eigenvalue(Required):MODE 1 (EIGENVALUE=2.1936e+00)
Eigenvalue(Required):MODE 2 (EIGENVALUE=2.1936e+00)
Eigenvalue(Required):MODE 3 (EIGENVALUE=1.9105e+01)
Eigenvalue(Required):MODE 4 (EIGENVALUE=1.9105e+01)
Eigenvalue(Required):MODE 5 (EIGENVALUE=4.6039e+01)
Eigenvalue(Required):MODE 6 (EIGENVALUE=4.6043e+01)
Eigenvalue(Required):MODE 7 (EIGENVALUE=4.6321e+01)
Eigenvalue(Required):MODE 8 (EIGENVALUE=4.6342e+01)
Eigenvalue(Required):MODE 9 (EIGENVALUE=4.6792e+01)
Eigenvalue(Required):MODE 10 (EIGENVALUE=4.6831e+01)

自訂變形比例

模型輸出檔名



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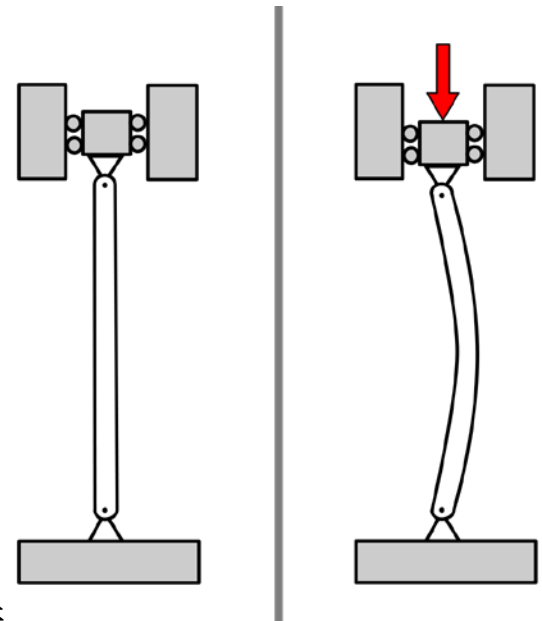
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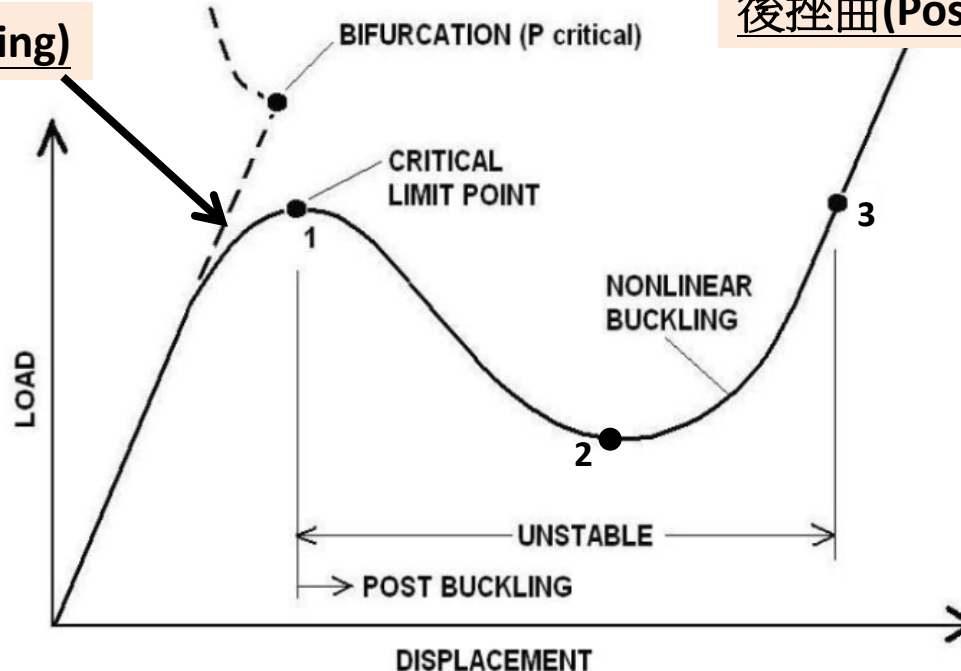
範例探討內容

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之後變形繼續變大但是結構能承受的外部載荷變小，結構發生挫曲，變形繼續變大，但是結構承受的載荷繼續變小。達到Point 2位移增加，結構承受的載荷開始增加，Point 3達到之前載荷的極限點。從Point 1到Point 3的過程稱為疾速跳過(snap through)。

挫曲(Buckling)



後挫曲(Post Buckling)

Reference

<https://www.linkedin.com/pulse/buckling-post-buckling-abraham-imam-muttaqin>

分析說明

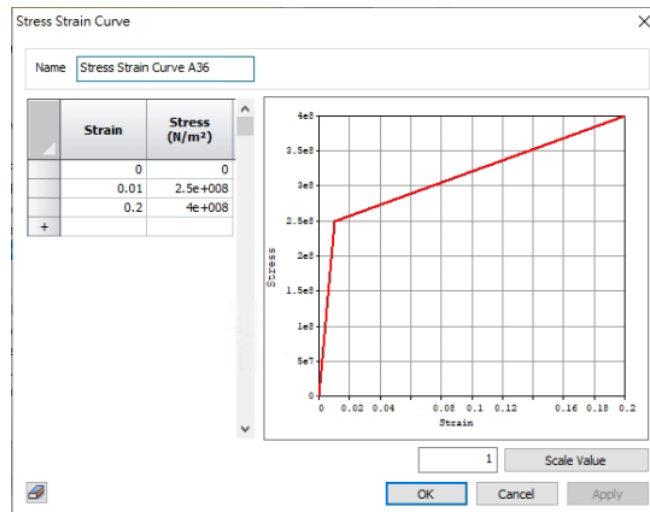
計算立柱下壓過程位移過程所需載荷!!

材料Steel/ASTM A36

下壓1(m)



立柱底部面特徵
 $T_x/T_y/T_z/R_x/R_y/R_z$



ASTM A36 Steel, plate

Categories: Metal, Ferrous Metal, ASTM Steel, Carbon Steel, Low Carbon Steel

Material Notes: Steel for general structural purposes including bridges and buildings.

Minimum Cu content when copper steel is specified.

Tests performed in transverse direction for plates wider than 550 mm.

Key Words: UNS K02600

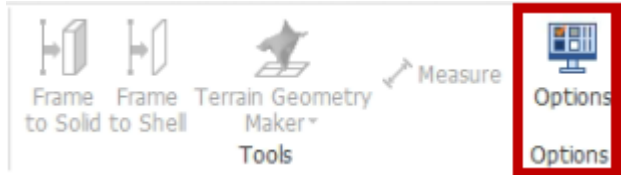
Vendors: No vendors are listed for this material. Please [click here](#) if you are a supplier and would like information on how to add your listing to this material.

[Print friendly version](#) [Download as PDF](#) [Download to Excel \(requires Excel and Windows\)](#)

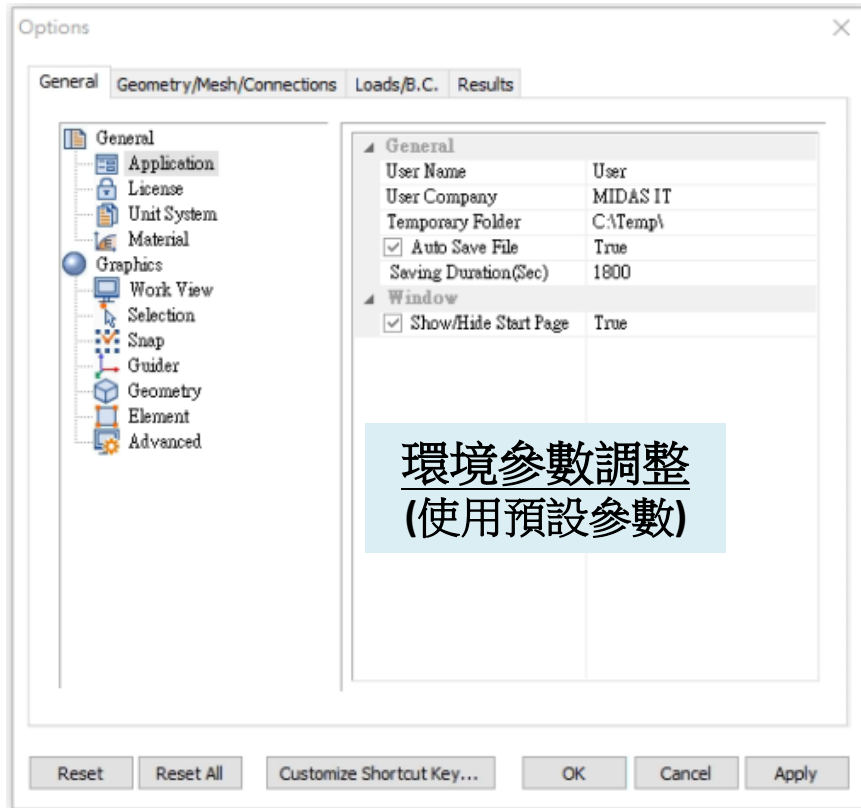
[Export data to your CAD/CAM program](#)

Physical Properties		
	Metric	English
Density	7.80 g/cc	0.282 lb/in³
Mechanical Properties		
	Metric	English
Tensile Strength, Ultimate	400 - 550 MPa	58000 - 79000 psi
Tensile Strength, Yield	250 MPa	36300 psi
Elongation at Break	20 %	20 %
	23 %	23 %
Modulus of Elasticity	200 GPa	29000 ksi
Bulk Modulus	160 GPa	23200 ksi
Poisson's Ratio	0.26	0.26
Shear Modulus	79.3 GPa	11500 ksi
Component Elements Properties		
	Metric	English
Carbon, C	0.25 - 0.29 %	0.25 - 0.29 %
Copper, Cu	0.20 %	0.20 %
Iron, Fe	98 %	98 %
Manganese, Mn	1.03 %	1.03 %
Phosphorus, P	<= 0.040 %	<= 0.040 %
Silicon, Si	0.28 %	0.28 %
Sulfur, S	<= 0.050 %	<= 0.050 %

環境

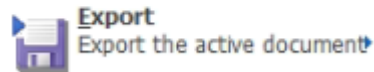


新文件

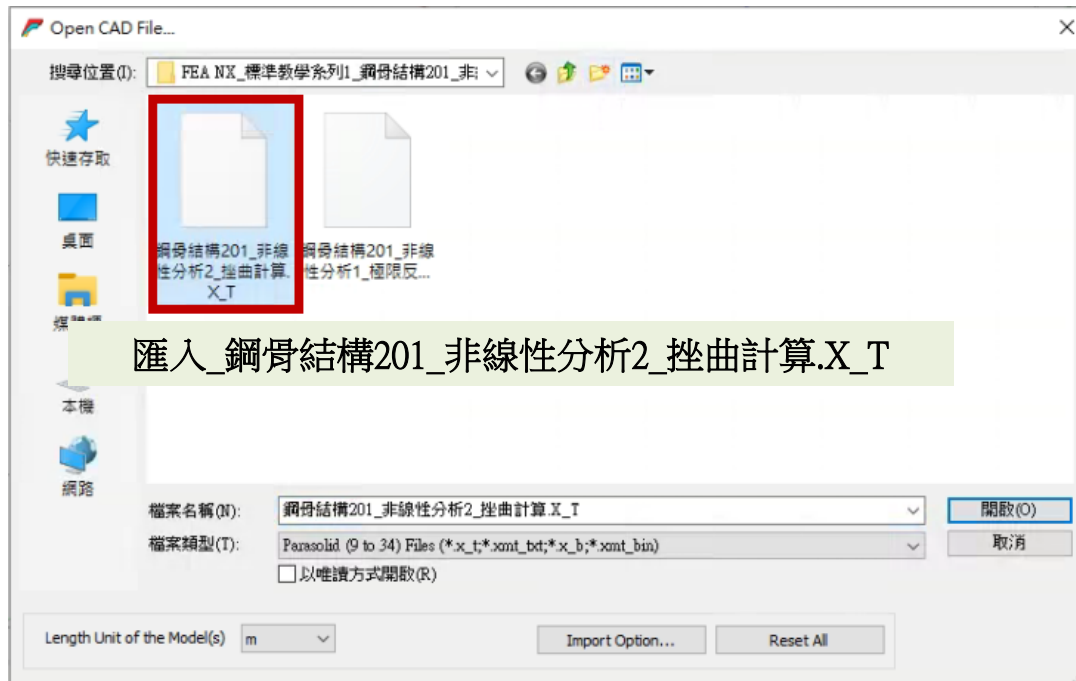
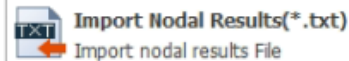
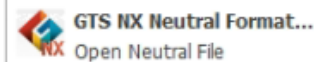
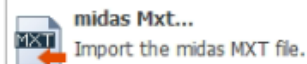
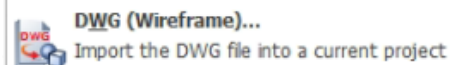
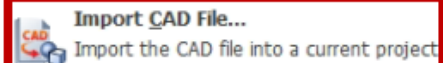


單位使用N/m/J/sec

匯入模型



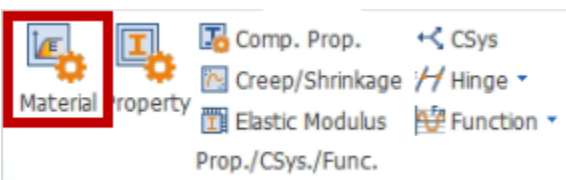
Import the geometries or FE model in the selected file



匯入_鋼骨結構201_非線性分析2_挫曲計算.X_T

鋼構立柱3D模型



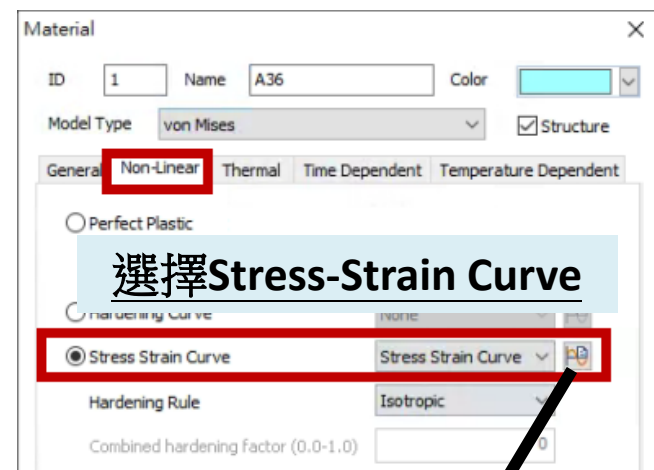


材料

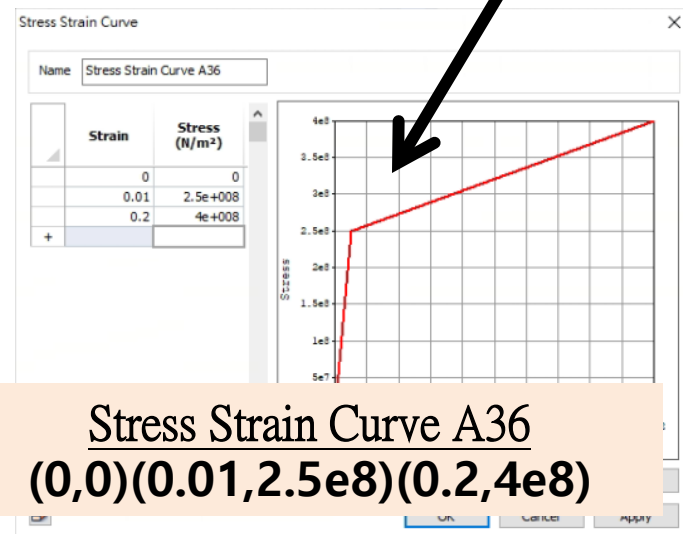
自訂材料名稱A36

材料模型: Von Mises

勾選Structure



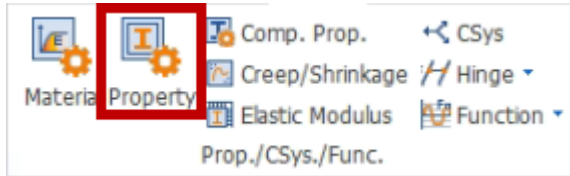
選擇Stress-Strain Curve



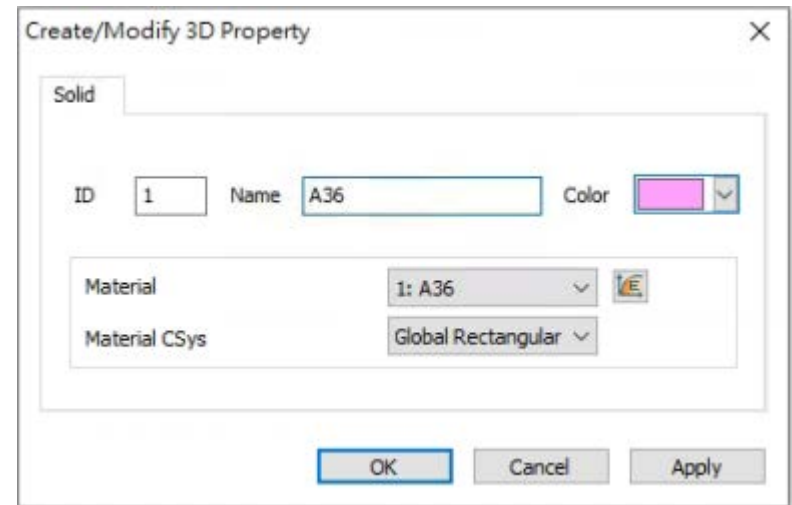
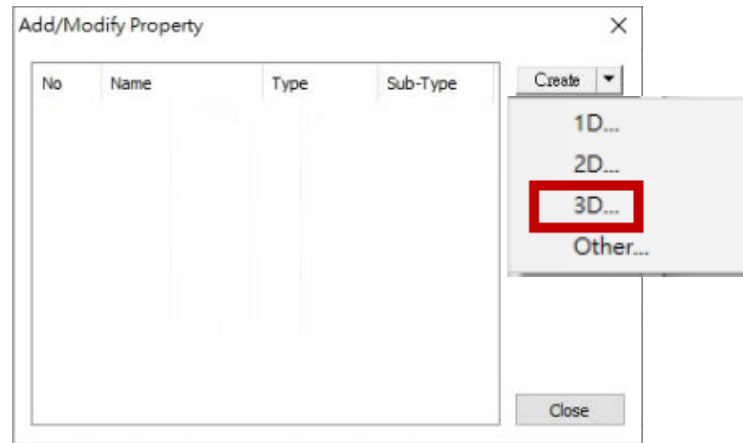
Stress Strain Curve A36
(0,0)(0.01,2.5e8)(0.2,4e8)

Steel/ASTM(S)/A36

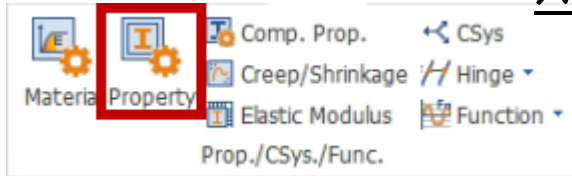
屬性



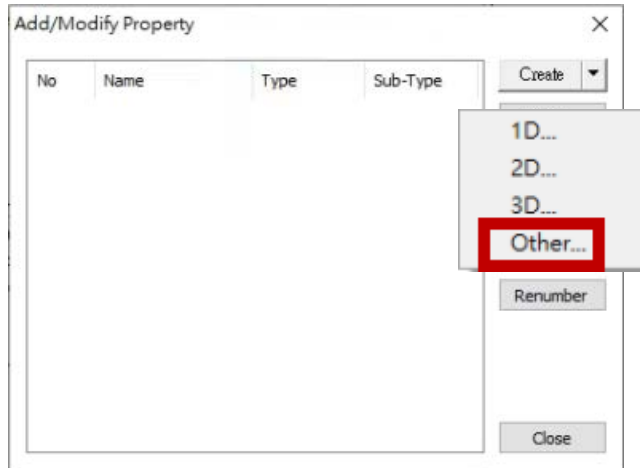
新增A36 Property



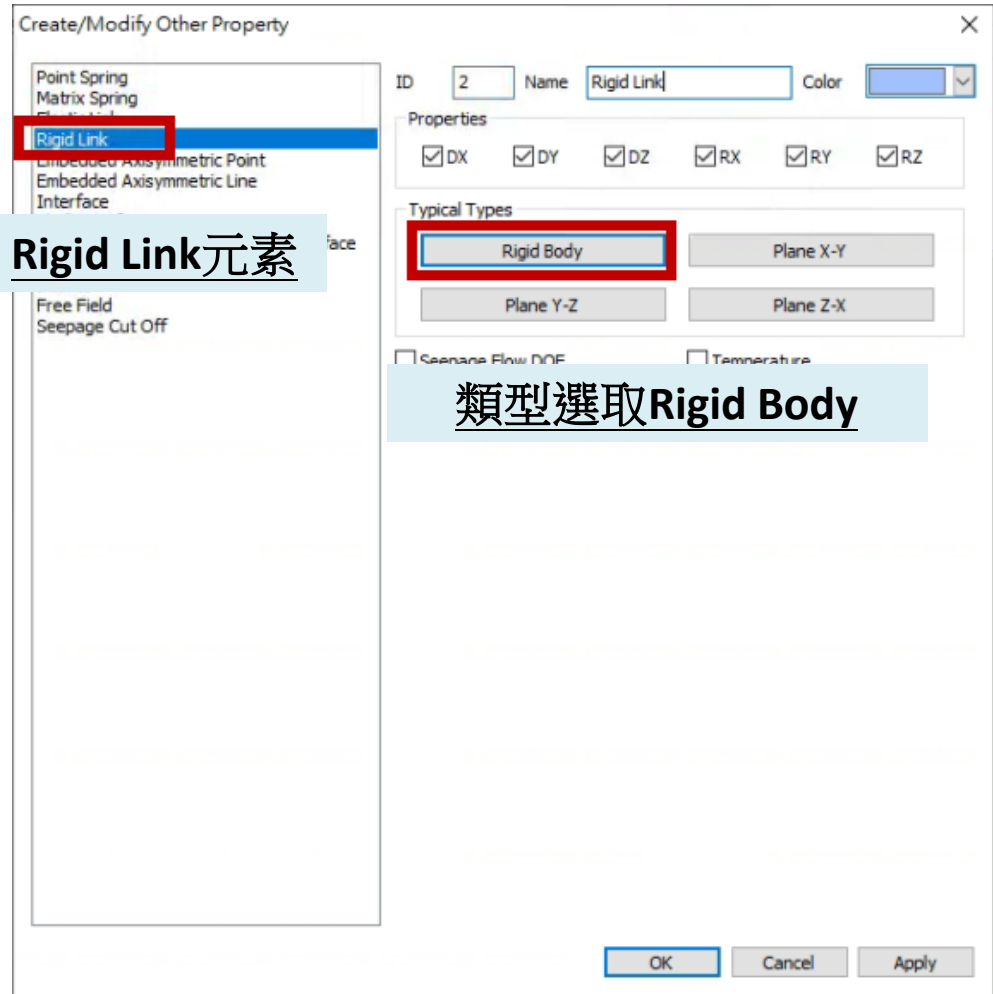
屬性-Rigid Link



新增Rigid Link Property



Rigid Link元素

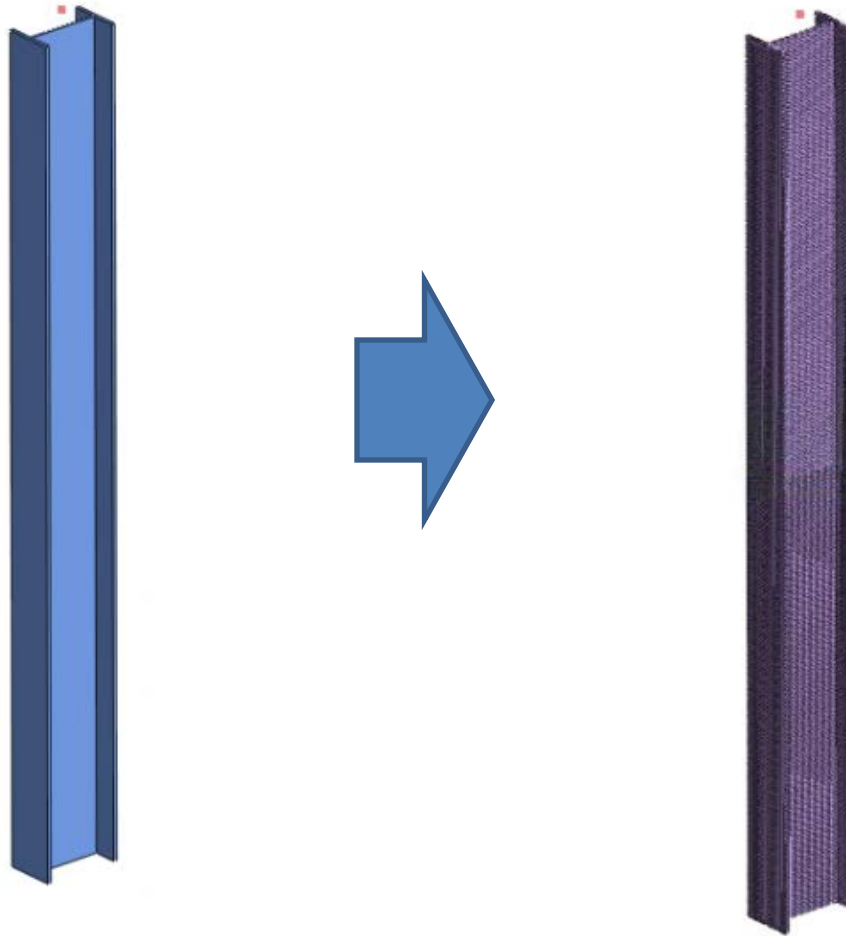


類型選取Rigid Body

3D網格-混合網格

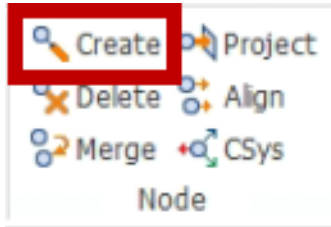


Hybrid Mesher(混合網格)/網格尺寸0.015 (m)

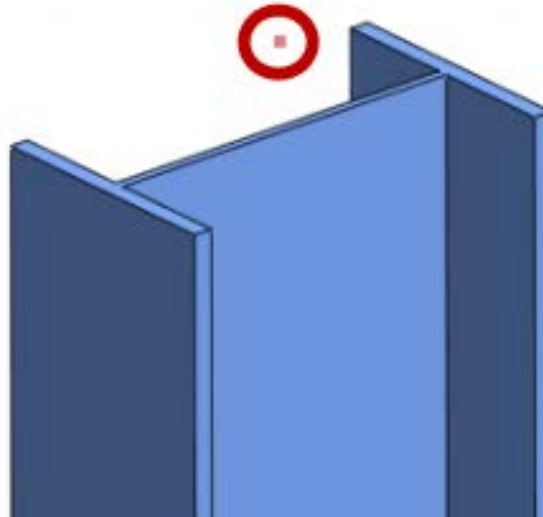


主控節點建立

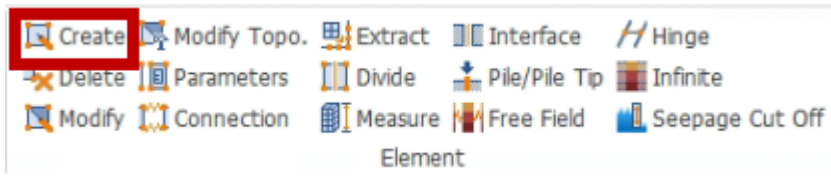
(剛性連接主控點)



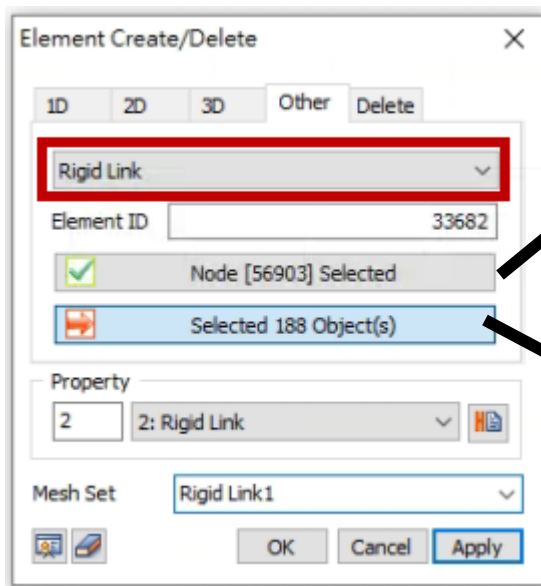
Node A



剛性連接

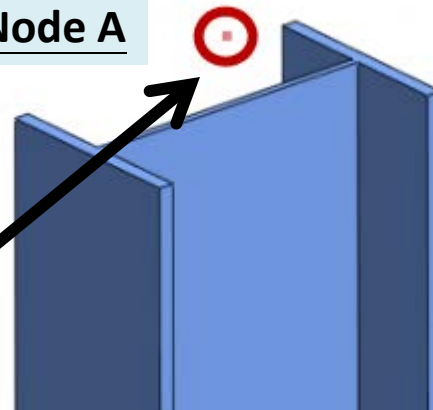


元素類型選取Rigid Link



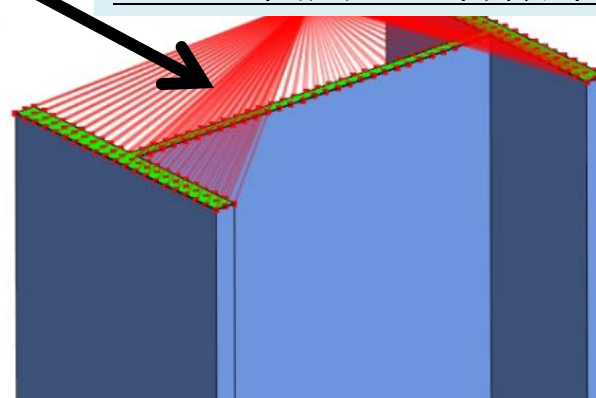
自訂網格集Rigid Link1

Node A

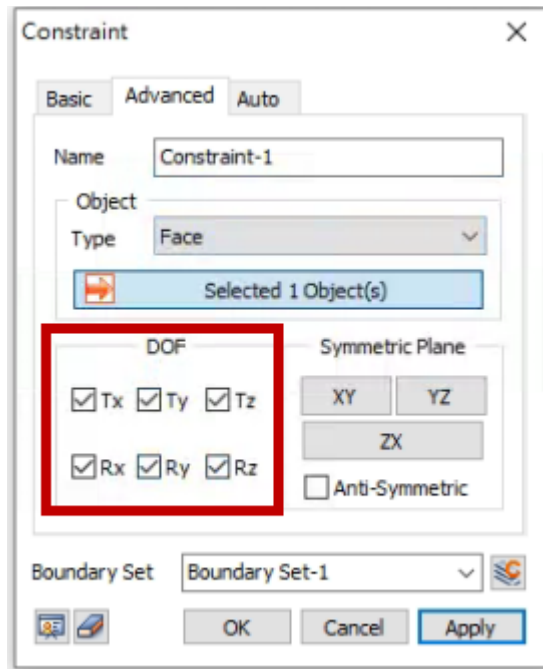
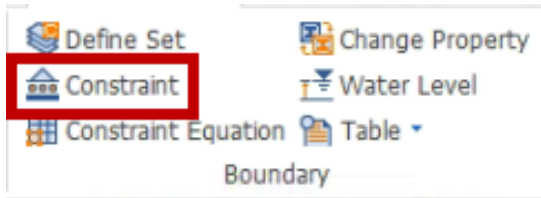


切換使用面特徵選取節點

Node A側周邊面特徵節點



邊界



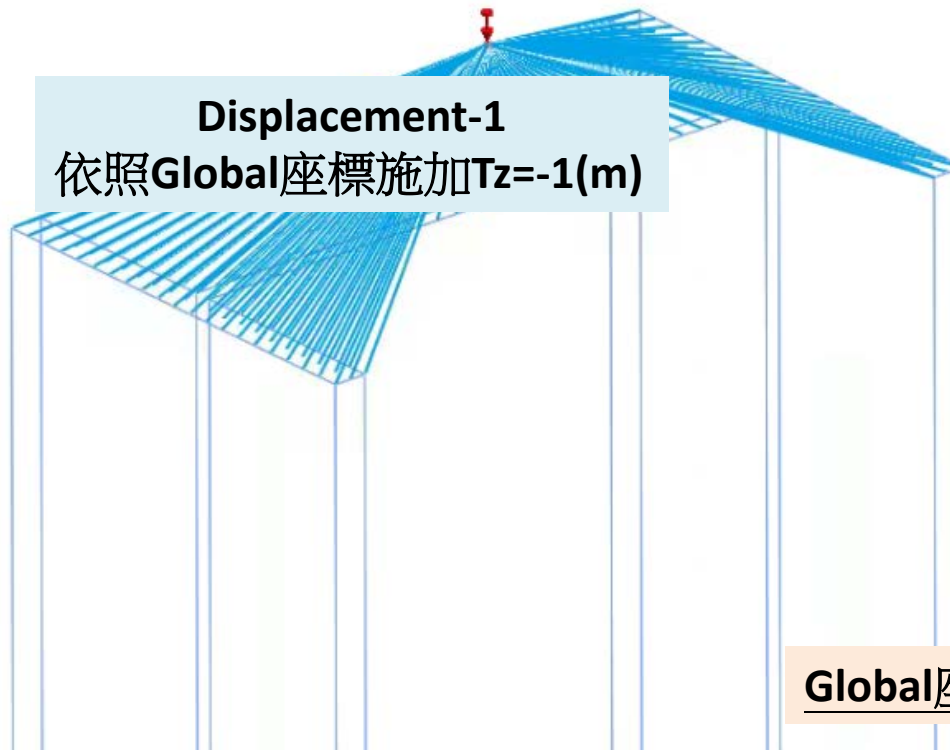
立柱底部面特徵
 $T_x/T_y/T_z/R_x/R_y/R_z$



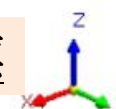
位移



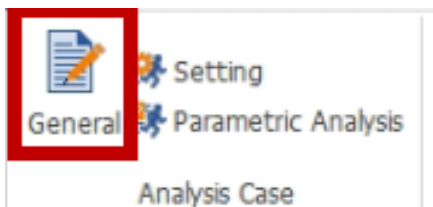
Displacement-1
依照Global座標施加Tz=-1(m)



Global座標



非線性分析-1



Add/Modify Analysis Case

Analysis Case Setting

Title: 挫曲計算 **自訂析名稱**

Description:

Solution Type: Nonlinear Static

Construction Stage Set:

Analysis Control: [Icon]

Output Control: [Icon]

Analysis Case

分析類型: Nonlinear Static

Mesh

- Auto-Mesh(3D)
- Default Mesh Set
- Node A
- Rigid Link1

Boundary Condition

- Boundary Set-1

Static Load

- Displacement-1

考慮所有網格集/邊界集/載荷集

☐ Solve Each Load Set Independently

Sorting: Name

OK Cancel Apply

非線性控制

非線性分析-2

Analysis Control

General Nonlinear

Geometry Nonlinearity

☒ Consider Geometric Nonlinear Effects

☐ Update Pore Pressure with Deformation

Basic Nonlinear Parameters

☒ Load Steps

☒ Number of Increments

Intermediate Output Request

☐ Manual with User-Defined Steps

☐ Time Steps

☒ Time(Duration) sec

Number of Increments

Intermediate Output Request

☐ Manual with User-Defined Steps

Iterative Scheme

☒ General ☐ Enhanced Init Stress

Convergence Criteria / Error Tolerance

☒ Displacement(U)

☐ Load(P)

☒ Work(W)

☐ Use Iteration Method

☒ Arc-Length Method ☐ Displacement-Control Method

Min. Arc-Length Adjustment Ratio

Max. Arc-Length Adjustment Ratio

Max Arc-Length Increments

預設計算材料非線性,勾選才計算幾何&邊界(接觸)非線性

增量數分成50等份/輸出每次增量結果
每一增量增加變形量 $1(\text{m})/50=0.02(\text{m})$

收斂判斷採Displacement/Work

非線性分析-3

輸出控制

Output Control

Output Type Output Option

☒ Write Results of All Active Mesh Sets

Nodal Results

☒ Displacement Mesh Set...

☒ Applied Load Mesh Set...

☒ Reaction Force Mesh Set...

☒ Grid Point Force Mesh Set...

☐ Contact Mesh Set...

Element Results

☒ Force Mesh Set...

☒ Stress Mesh Set...

☒ Strain Mesh Set...

☒ Status Mesh Set...

☐ Ductility Mesh Set...

☐ Multi-layered Grid Mesh Set...

Element Output Location

☒ Element Corner Results

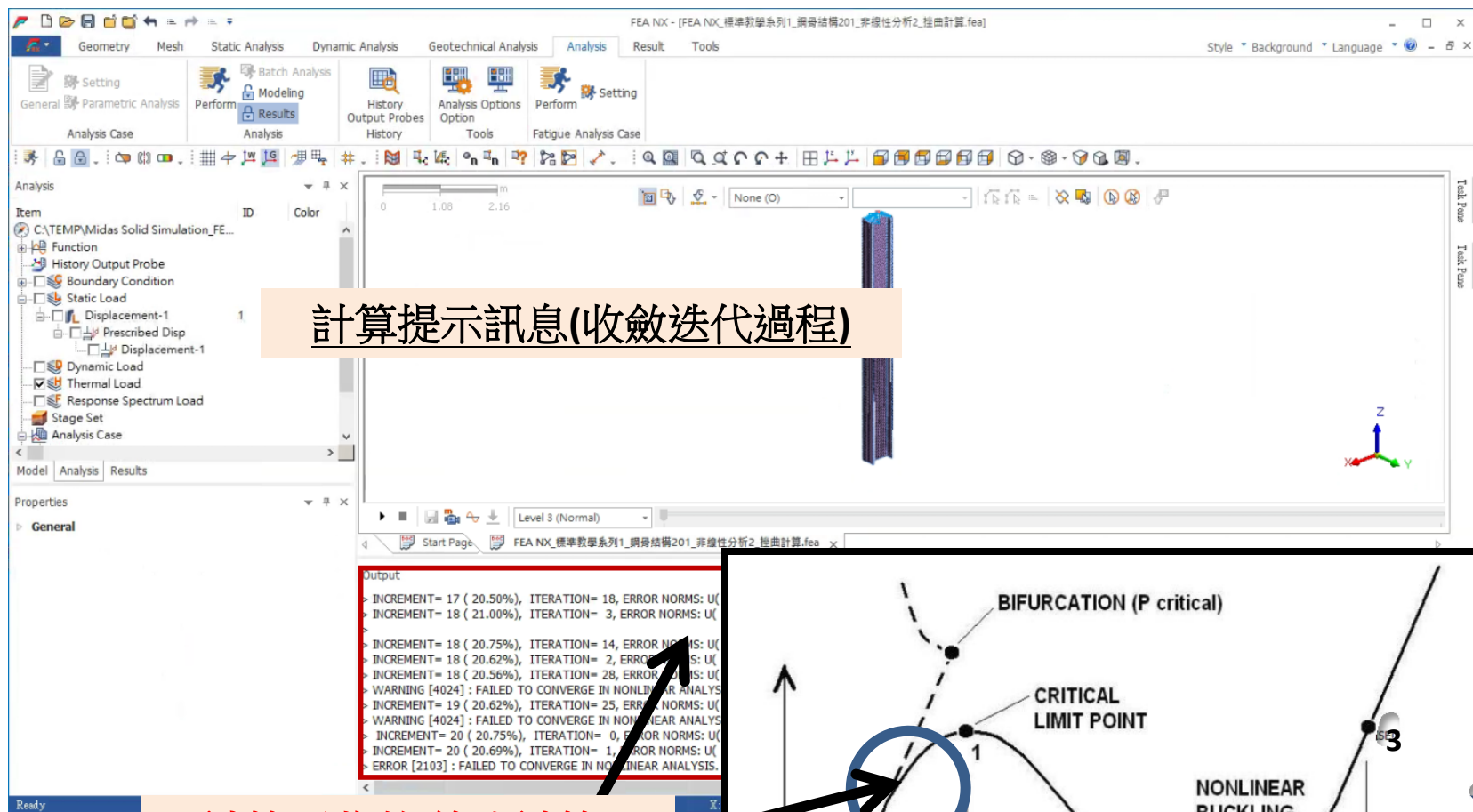
☐ Shell Mid-Plane Results

Number of Beam Output Segments 4 ▾

OK Cancel

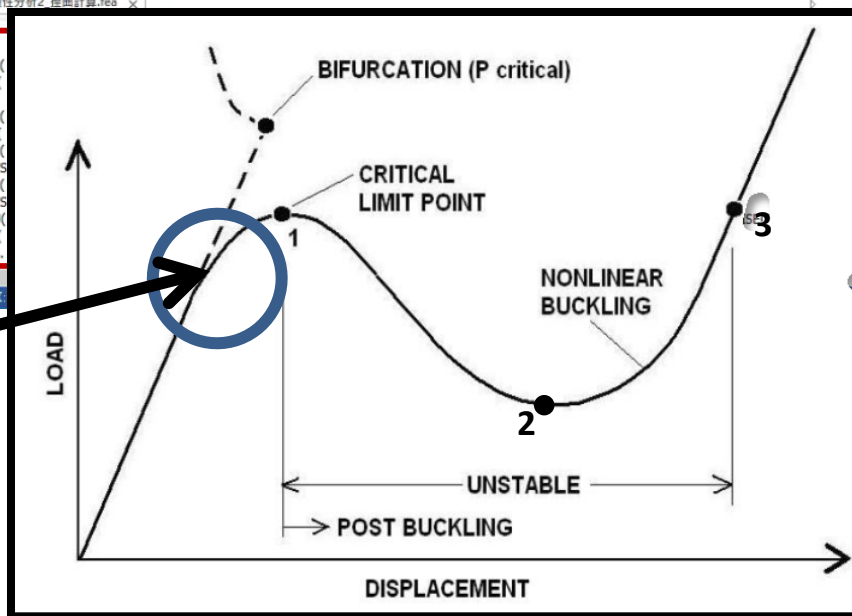
內力/反力結果輸出

執行分析



計算提示訊息(收斂迭代過程)

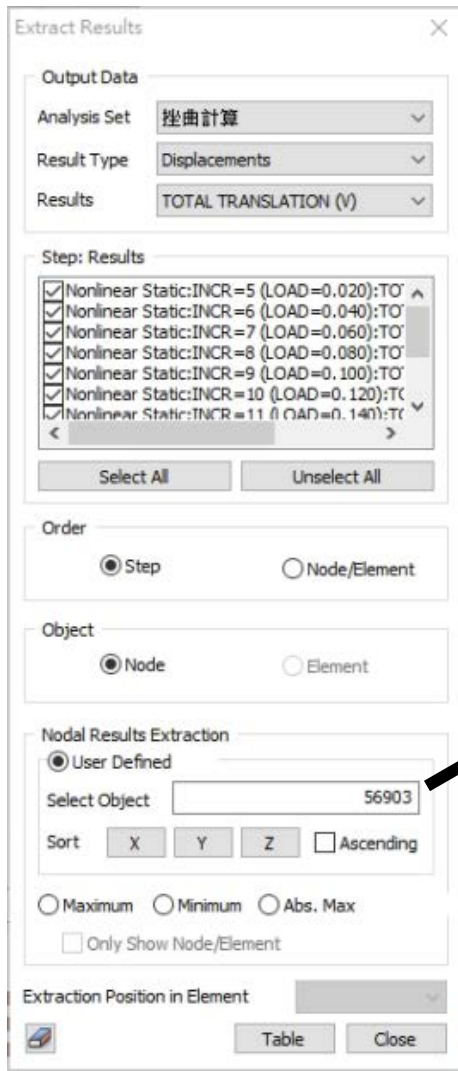
計算不收斂(終止計算)
對照挫曲位移-載荷曲線



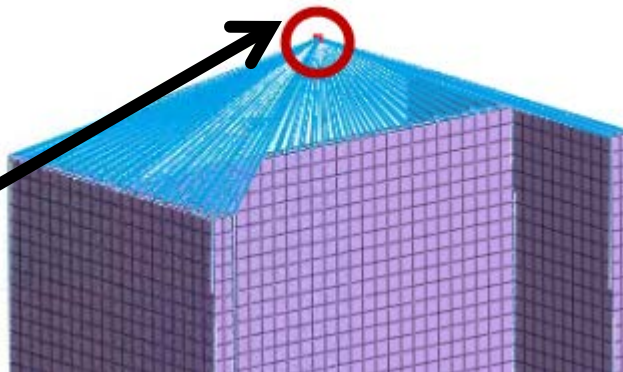
提取-迭代過程結果

分析結果-1

迭代過程剛性中心點位移結果



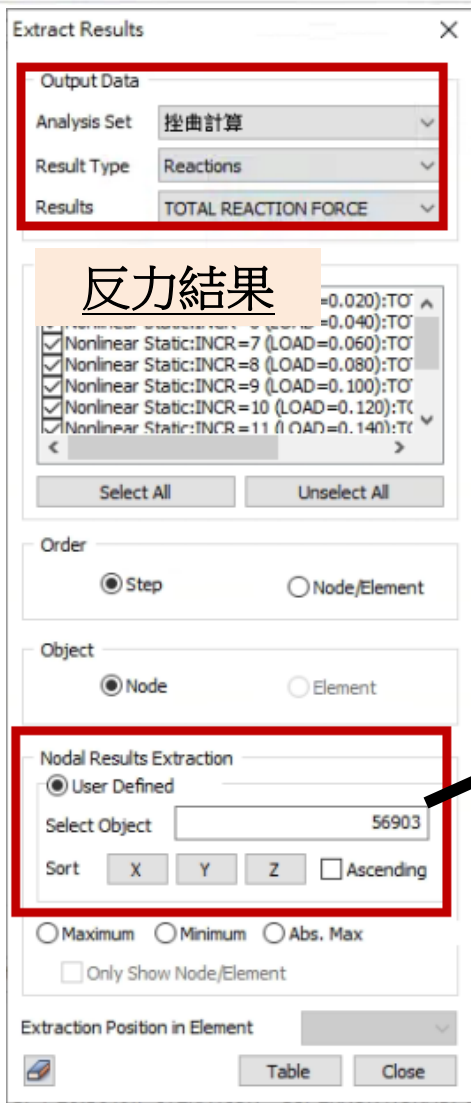
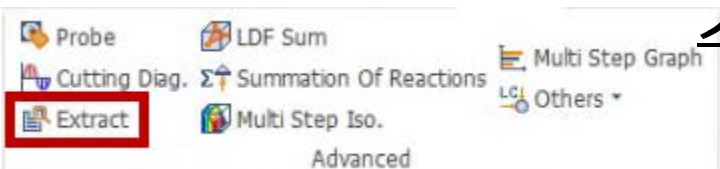
No	Step	Step Value	Node:56903 TOTAL TRANSLATION (V) (m)
1	Nonlinear Static: INCR = 5 (LOAD = 0.020)	2.000000e-002	2.000000e-002
2	Nonlinear Static: INCR = 6 (LOAD = 0.040)	4.000000e-002	4.000000e-002
3	Nonlinear Static: INCR = 7 (LOAD = 0.060)	6.000000e-002	6.000000e-002
4	Nonlinear Static: INCR = 8 (LOAD = 0.080)	8.000000e-002	8.000000e-002
5	Nonlinear Static: INCR = 9 (LOAD = 0.100)	1.000000e-001	1.000000e-001
6	Nonlinear Static: INCR = 10 (LOAD = 0.120)	1.200000e-001	1.200000e-001
7	Nonlinear Static: INCR = 11 (LOAD = 0.140)	1.400000e-001	1.400000e-001
8	Nonlinear Static: INCR = 12 (LOAD = 0.160)	1.600000e-001	1.600000e-001
9	Nonlinear Static: INCR = 13 (LOAD = 0.180)	1.800000e-001	1.800000e-001
10	Nonlinear Static: INCR = 14 (LOAD = 0.200)	2.000000e-001	2.000000e-001



提取-迭代過程結果

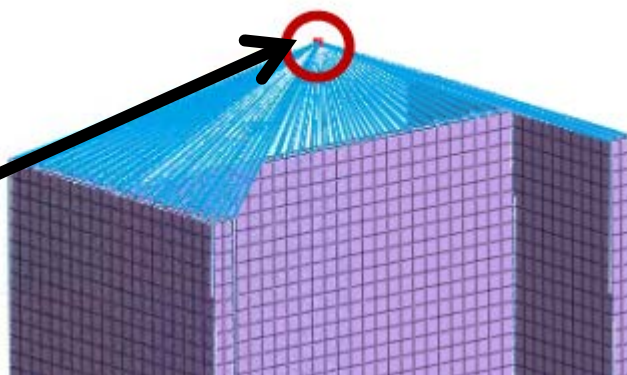
分析結果-2

迭代過程剛性中心點反力結果



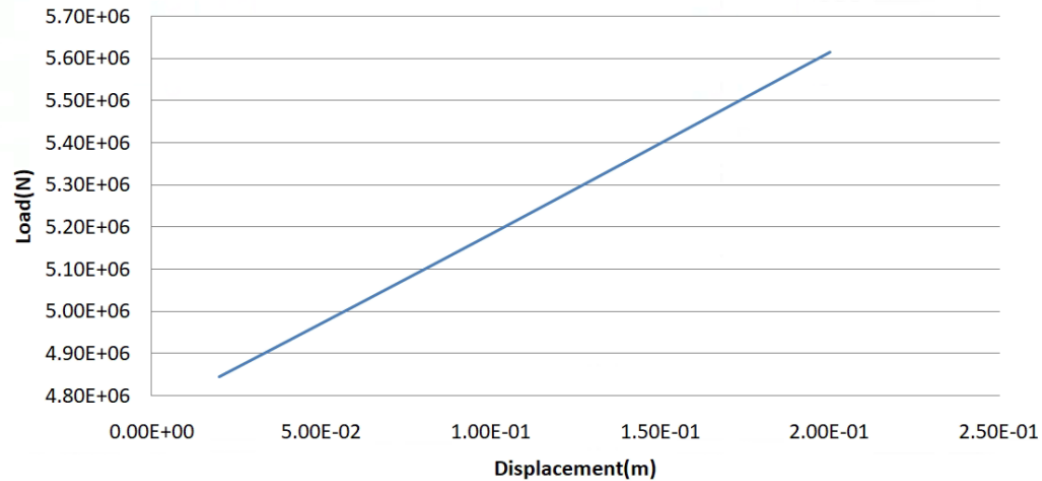
反力結果

No	Step	Step Value	Node:56903 TOTAL REACTION FORCE (N)
1	Nonlinear Static:INCR=5 (LOAD=0.020)	2.000000e-002	4.844010e+006
2	Nonlinear Static:INCR=6 (LOAD=0.040)	4.000000e-002	4.928154e+006
3	Nonlinear Static:INCR=7 (LOAD=0.060)	6.000000e-002	5.012475e+006
4	Nonlinear Static:INCR=8 (LOAD=0.080)	8.000000e-002	5.097251e+006
5	Nonlinear Static:INCR=9 (LOAD=0.100)	1.000000e-001	5.182576e+006
6	Nonlinear Static:INCR=10 (LOAD=0.120)	1.200000e-001	5.268476e+006
7	Nonlinear Static:INCR=11 (LOAD=0.140)	1.400000e-001	5.354899e+006
8	Nonlinear Static:INCR=12 (LOAD=0.160)	1.600000e-001	5.441698e+006
9	Nonlinear Static:INCR=13 (LOAD=0.180)	1.800000e-001	5.528546e+006
10	Nonlinear Static:INCR=14 (LOAD=0.200)	2.000000e-001	5.614708e+006



分析結果-3

Buckling (Displacement-Load Curve)



No	Step	Step Value	Node:56903 TOTAL TRANSLATION (V) (m)
1	Nonlinear Static:INCR=5 (LOAD=0.020)	2.000000e-002	2.000000e-002
2	Nonlinear Static:INCR=6 (LOAD=0.040)	4.000000e-002	4.000000e-002
3	Nonlinear Static:INCR=7 (LOAD=0.060)	6.000000e-002	6.000000e-002
4	Nonlinear Static:INCR=8 (LOAD=0.080)	8.000000e-002	8.000000e-002
5	Nonlinear Static:INCR=9 (LOAD=0.100)	1.000000e-001	1.000000e-001
6	Nonlinear Static:INCR=10 (LOAD=0.120)	1.200000e-001	1.200000e-001
7	Nonlinear Static:INCR=11 (LOAD=0.140)	1.400000e-001	1.400000e-001
8	Nonlinear Static:INCR=12 (LOAD=0.160)	1.600000e-001	1.600000e-001
9	Nonlinear Static:INCR=13 (LOAD=0.180)	1.800000e-001	1.800000e-001
10	Nonlinear Static:INCR=14 (LOAD=0.200)	2.000000e-001	2.000000e-001

X軸

No	Step	Step Value	Node:56903 TOTAL REACTION FORCE (N)
1	Nonlinear Static:INCR=5 (LOAD=0.020)	2.000000e-002	4.844010e+006
2	Nonlinear Static:INCR=6 (LOAD=0.040)	4.000000e-002	4.928154e+006
3	Nonlinear Static:INCR=7 (LOAD=0.060)	6.000000e-002	5.012475e+006
4	Nonlinear Static:INCR=8 (LOAD=0.080)	8.000000e-002	5.097751e+006
5	Nonlinear Static:INCR=9 (LOAD=0.100)	1.000000e-001	5.183027e+006
6	Nonlinear Static:INCR=10 (LOAD=0.120)	1.200000e-001	5.268303e+006
7	Nonlinear Static:INCR=11 (LOAD=0.140)	1.400000e-001	5.353579e+006
8	Nonlinear Static:INCR=12 (LOAD=0.160)	1.600000e-001	5.438855e+006
9	Nonlinear Static:INCR=13 (LOAD=0.180)	1.800000e-001	5.524131e+006
10	Nonlinear Static:INCR=14 (LOAD=0.200)	2.000000e-001	5.609407e+006

Y軸

FEA NX_標準教學系列

鋼骨結構-非線性分析
後挫曲分析

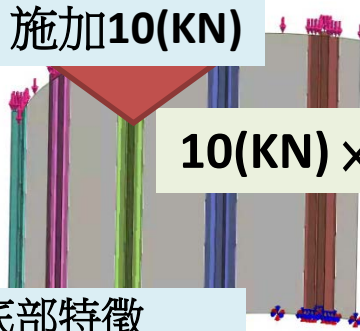
台灣邁達斯

線性挫曲&非線性挫曲

(Linear & Non-Linear Buckling)

FEA NX-線性挫曲分析(挫曲最大臨界力)

施加10(KN)



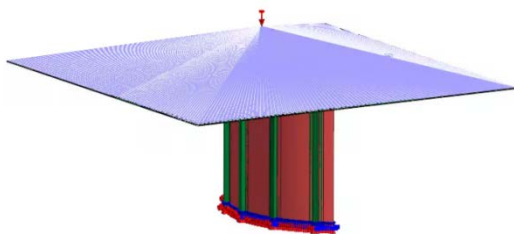
$10(\text{KN}) \times 2902.6(\text{mode 1 (Hz)}) = 29026(\text{KN})$ -挫曲最大臨界力

底部特徵
Tx/Ty/Tz/Rx/Ry/Rz

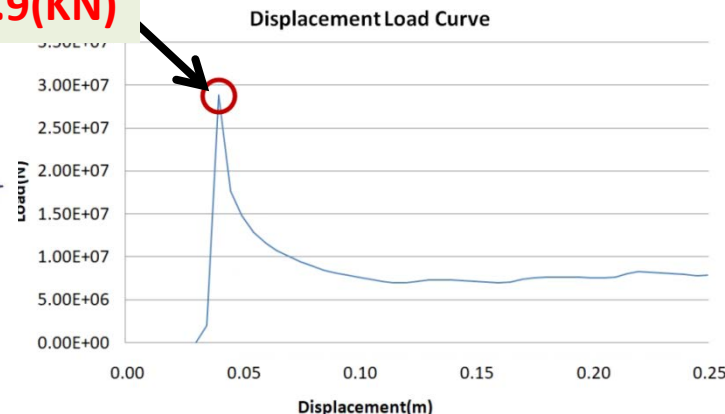
Mode 1-變形

FEA NX-非線性挫曲分析(挫曲過程載荷-位移曲線)

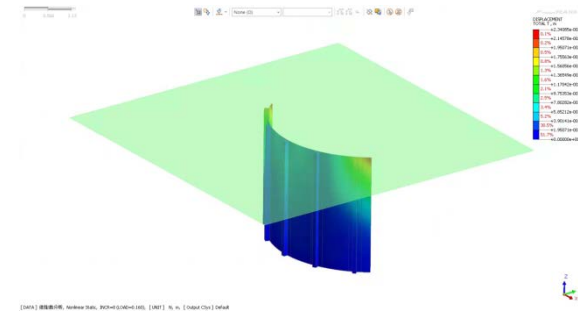
下壓0.25(m)



28832.9(KN)



底部特徵
Tx/Ty/Tz/Rx/Ry/Rz



後挫曲

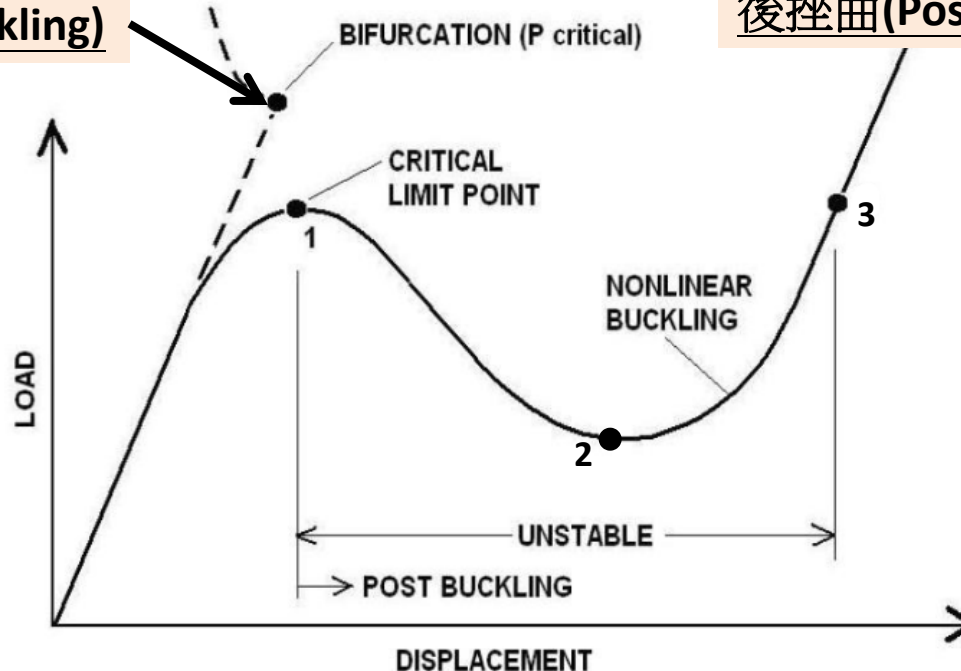
後挫曲(非線性挫曲)分析

載荷較小時分析結果與線性結果一致。當載荷逐步增大，變形逐步增加，結構響應呈現出非線性，力位移曲線開始偏離線性結果，在Point 1點承受外部載荷達到最大。

之後變形繼續變大但是結構能承受的外部載荷變小，結構發生挫曲，變形繼續變大，但是結構承受的載荷繼續變小。達到Point 2位移增加，結構承受的載荷開始增加，Point 3達到之前載荷的極限點。從Point 1到Point 3的過程稱為疾速跳過(snap through)。

線性挫曲(Linear Buckling)

後挫曲(Post Buckling)



Reference

<https://www.linkedin.com/pulse/buckling-post-buckling-abraham-imam-muttaqin>

應變硬化指數

(Strain Hardening Exponent)

應變硬化指數(Strain Hardening Exponent)

通常表示為 n ，常用於與加工硬化中的應力-應變行為相關的計算中的常量。

$$\sigma = K\epsilon^n$$

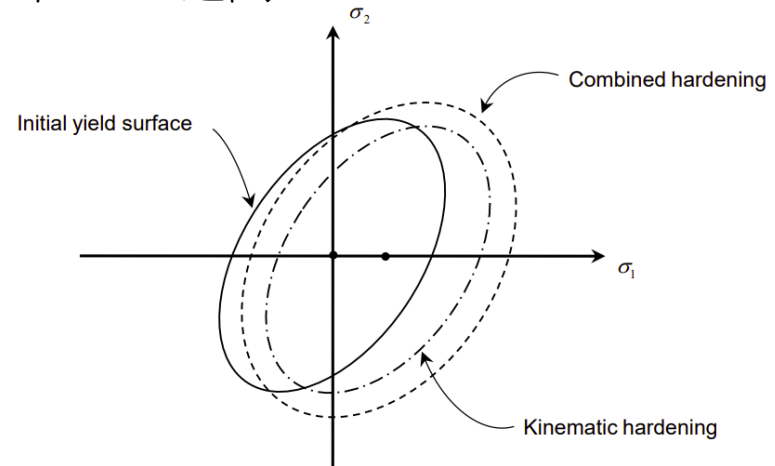
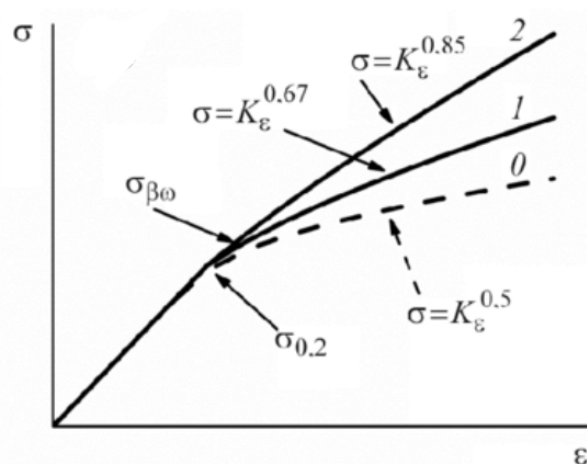
σ 真實應力

ϵ 真實應變

K 強度係數

n 應變硬化指數

應變硬化指數(n),值介於 0 和 1 之間，0 表示完全塑性，1 表示完全彈性，大多數金屬的 n 值介於 0.10 和 0.50 之間。



硬化模型-屈服面

Reference

GTS NX AND FEA NX Manual

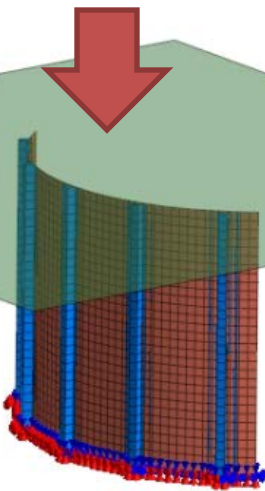
https://en.wikipedia.org/wiki/Strain_hardening_exponent

分析說明

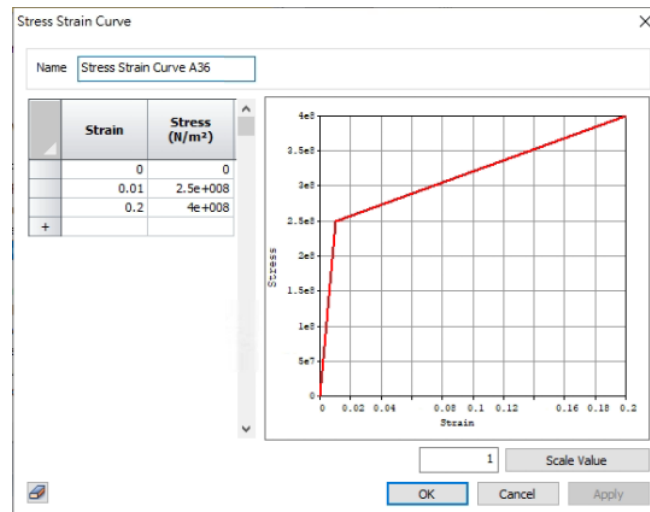
計算下壓過程位移過程所需載荷!!

材料Steel/ASTM A36

鋼板下壓0.2(m)



底部節點
 $T_x/T_y/T_z/R_x/R_y/R_z$



ASTM A36 Steel, plate

Categories: Metal, Ferrous Metal, ASTM Steel, Carbon Steel, Low Carbon Steel

Material Notes: Steel for general structural purposes including bridges and buildings.

Minimum Cu content when copper steel is specified.

Tests performed in transverse direction for plates wider than 550 mm.

Key Words: UNS K02600

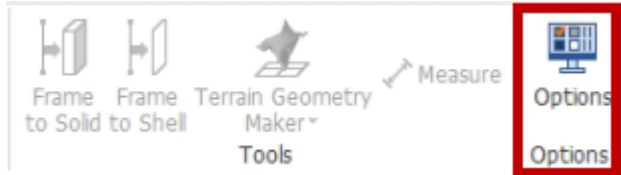
Vendors: No vendors are listed for this material. Please [click here](#) if you are a supplier and would like information on how to add your listing to this material.

[Print friendly version](#) [Download as PDF](#) [Download to Excel \(requires Excel and Windows\)](#)

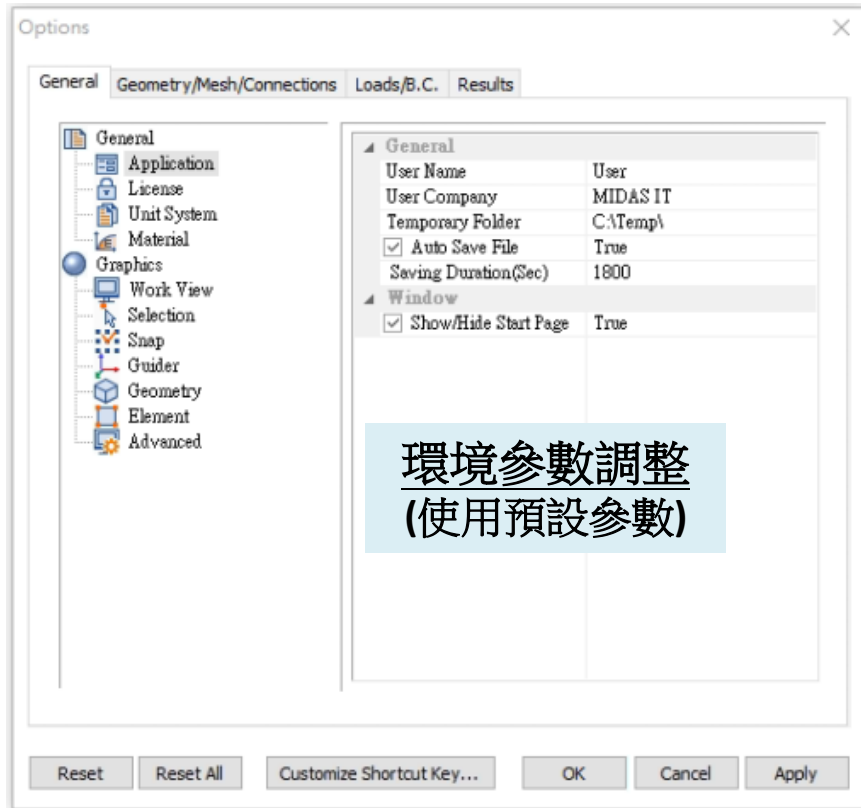
[Export data to your CAD/CAM program](#)

Physical Properties		
Metric	English	
Density	7.80 g/cc	0.282 lb/in³
Mechanical Properties		
Metric	English	
Tensile Strength, Ultimate	400 - 550 MPa	58000 - 79000 psi
Tensile Strength, Yield	250 MPa	36300 psi
Elongation at Break	20 %	20 %
	23 %	23 %
Modulus of Elasticity	200 GPa	29000 ksi
Bulk Modulus	160 GPa	23200 ksi
Poisson's Ratio	0.26	0.26
Shear Modulus	79.3 GPa	11500 ksi
Component Elements Properties		
Metric	English	
Carbon, C	0.25 - 0.29 %	0.25 - 0.29 %
Copper, Cu	0.20 %	0.20 %
Iron, Fe	98 %	98 %
Manganese, Mn	1.03 %	1.03 %
Phosphorus, P	<= 0.040 %	<= 0.040 %
Silicon, Si	0.28 %	0.28 %
Sulfur, S	<= 0.050 %	<= 0.050 %

環境



新文件



環境參數調整
(使用預設參數)

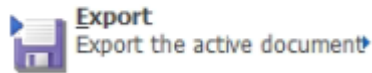


重力方向切換

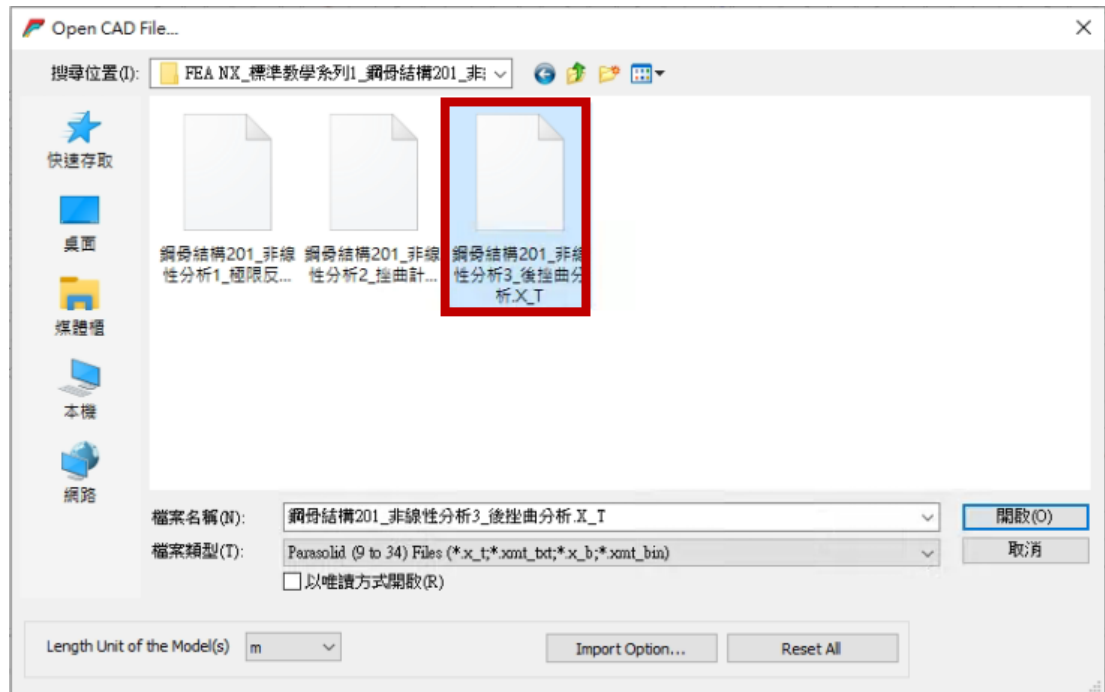
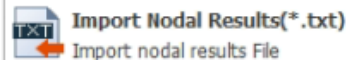
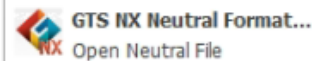
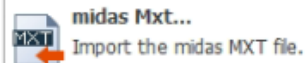
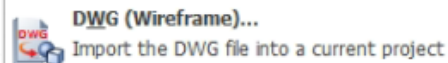
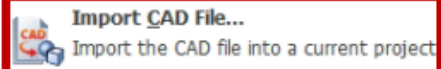
自行切換單位

單位使用N/m/J/sec

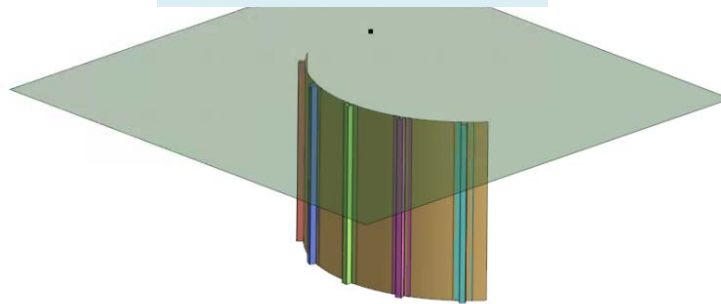
匯入模型



Import the geometries or FE model in the selected file



鋼結構3D模型



材料-1

自訂材料名稱A36

材料模型: Von Mises

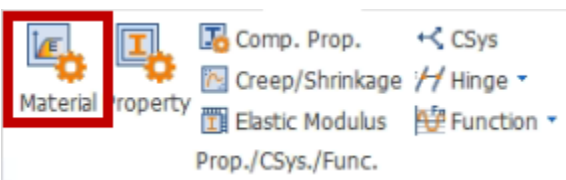
勾選Structure

選擇Stress-Strain Curve
(硬化指數: 0.45)

Steel/ASTM(S)/A36

Stress Strain Curve A36
(0,0)(0.01,2.5e8)(0.2,4e8)

註: 未勾選Structure則視為土壤材料。



材料-2

自訂材料名稱A36 Linear

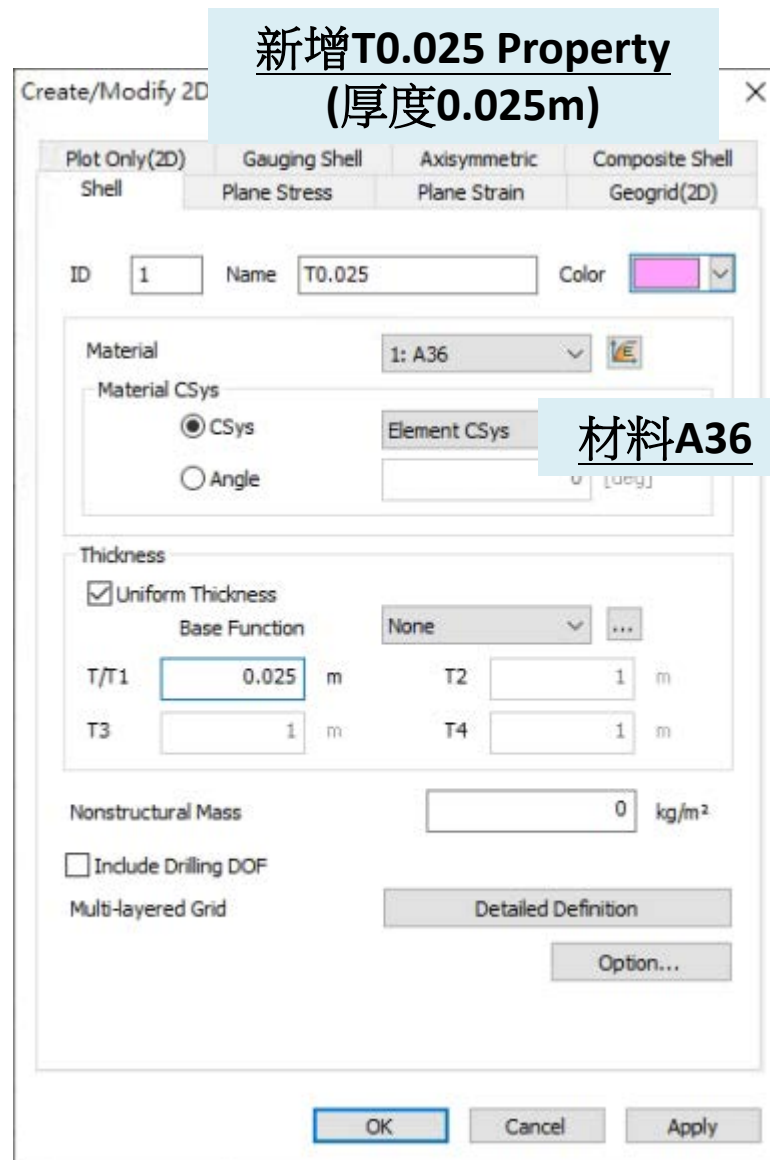
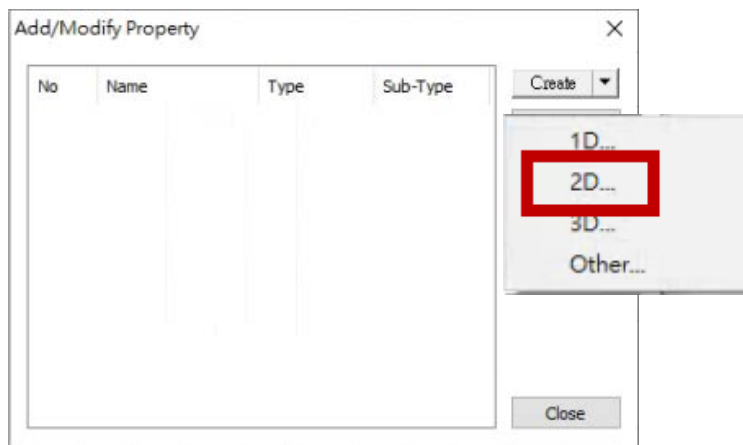
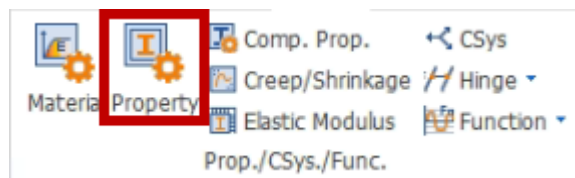
材料模型:Elastic

勾選Structure

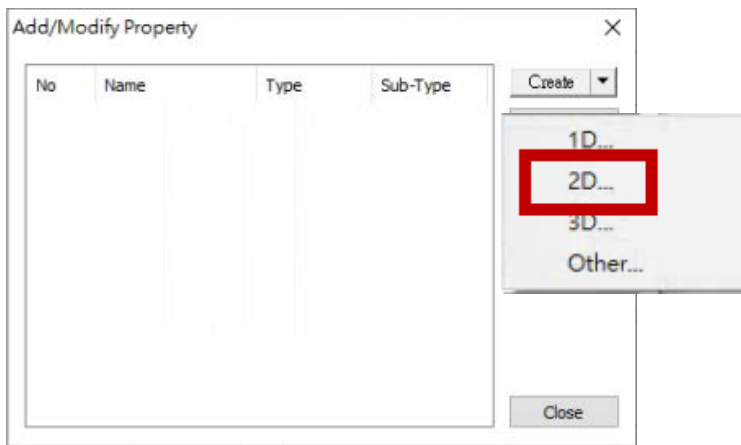
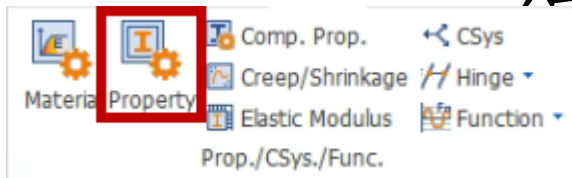
Steel/ASTM(S)/A36

A screenshot of the 'Material Properties' dialog box for 'A36 Linear'. The 'Model Type' is set to 'Elastic'. The 'Structure' checkbox is checked. The 'General' tab is active. The 'Inc. of Elastic Modulus Ref. Height' is 0 m. 'Poisson's Ratio(v)' is 0.3. 'Unit Weight(y)' is 77091.0111 N/m³. 'Initial Stress Parameters' shows 'Ko Determination' as 1, with 'Automatic' selected. 'Thermal Parameter' shows 'Thermal Coefficient' as 1.17e-005 1/[T]. 'Damping Ratio(For Dynamic)' shows 'Damping Ratio' as 0.05. 'Safety Result(Mohr-Coulomb)' shows 'Cohesion(C)' as 30000 N/m², 'Frictional Angle(φ)' as 36 [deg], and 'Tensile Strength' as 0 N/m². The 'DB' button is visible. At the bottom are 'OK', 'Cancel', and 'Apply' buttons.

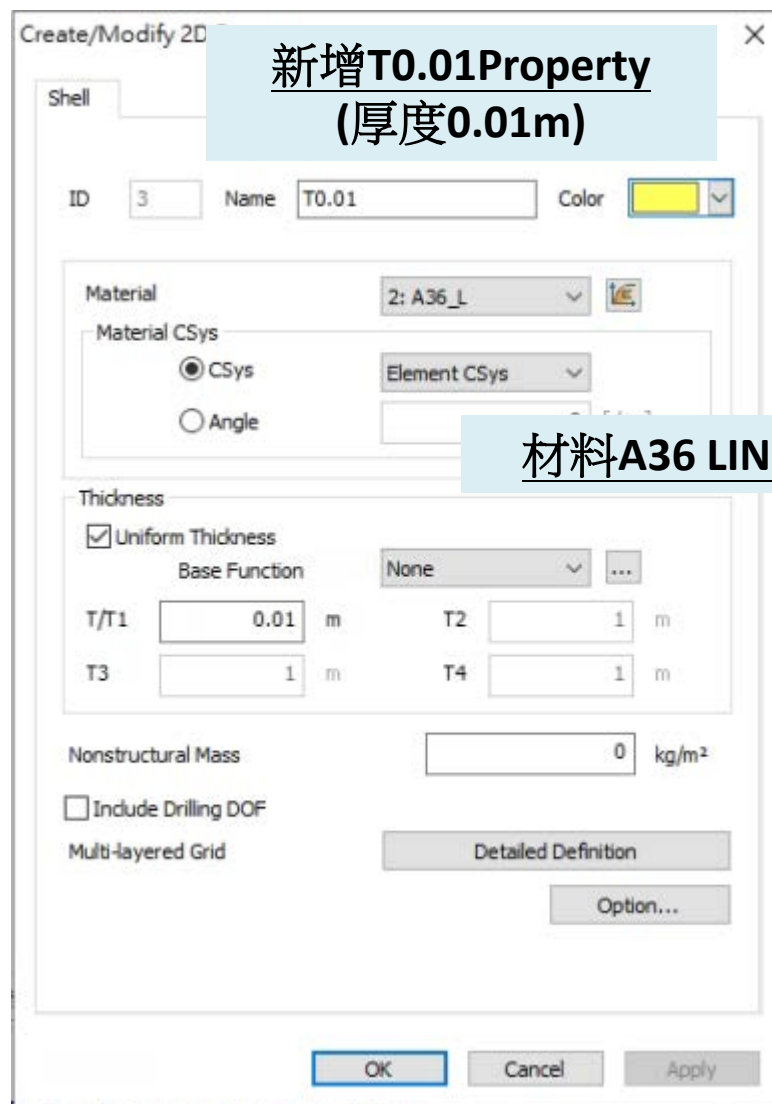
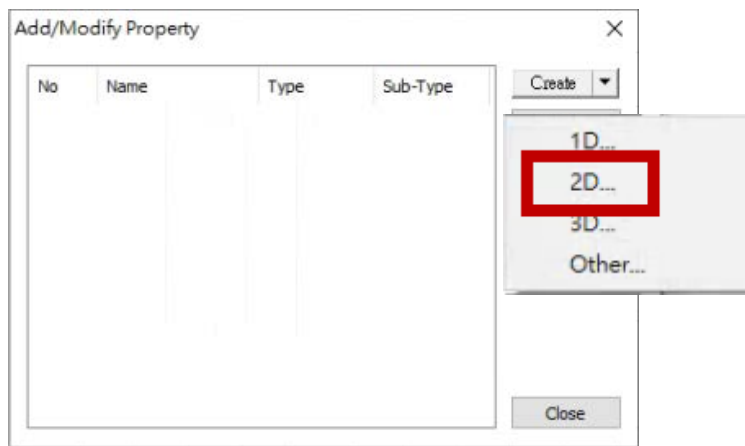
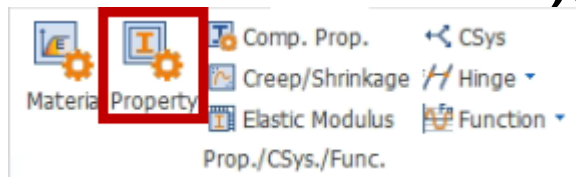
屬性-2D-T0.025



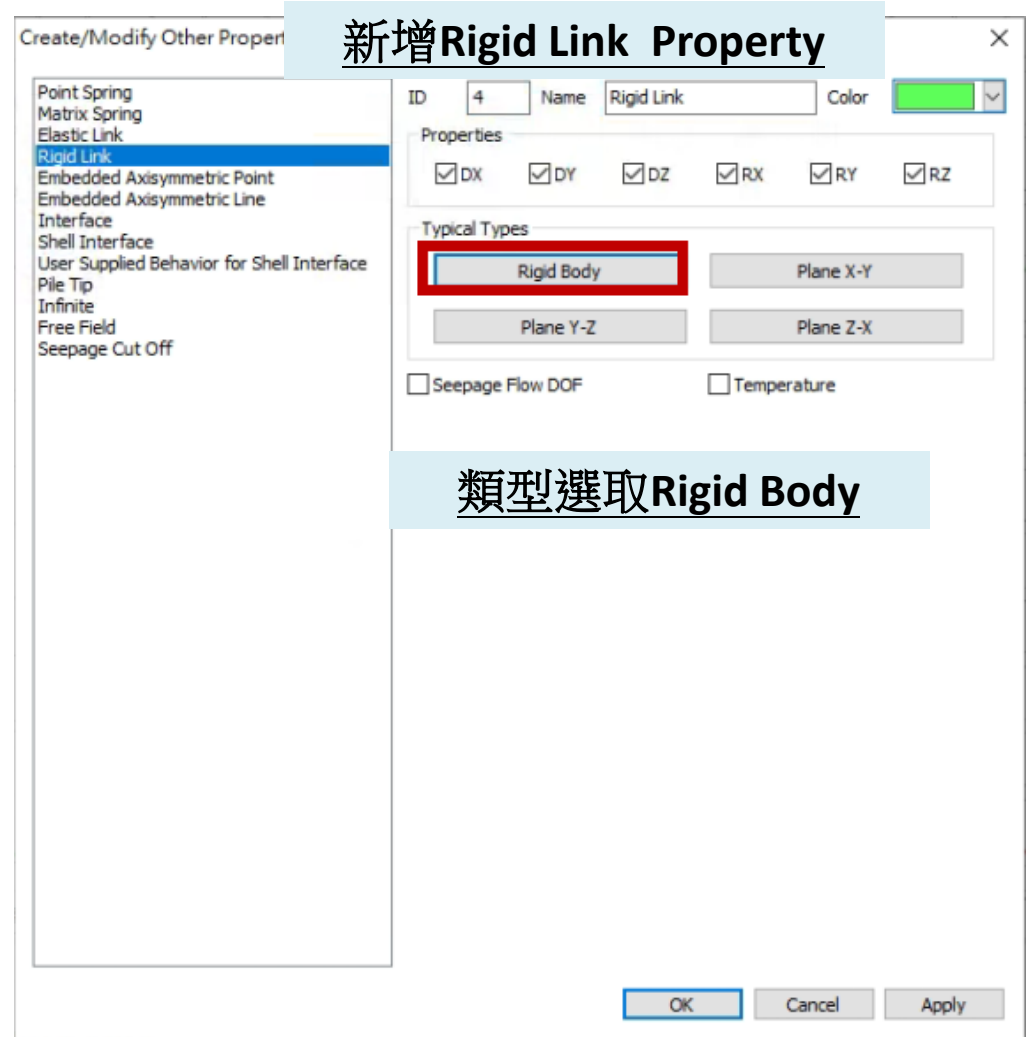
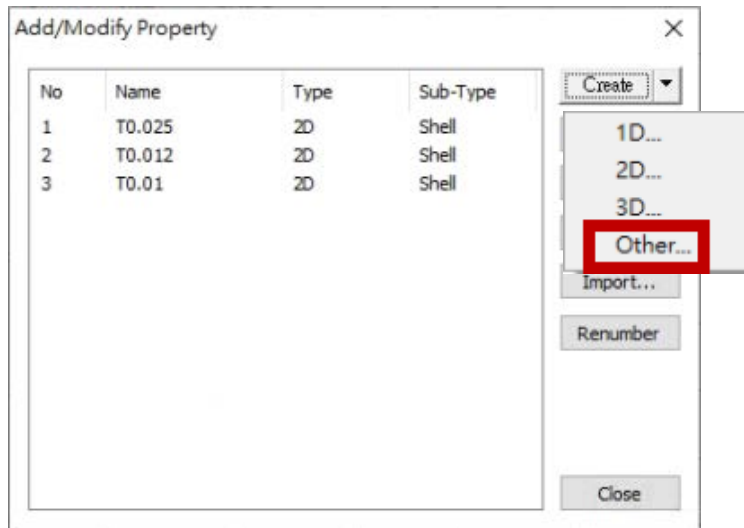
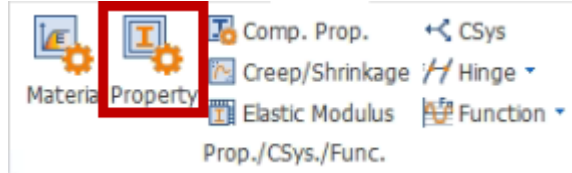
屬性-2D-T0.012



屬性-2D-T0.01



屬性-Rigid Link

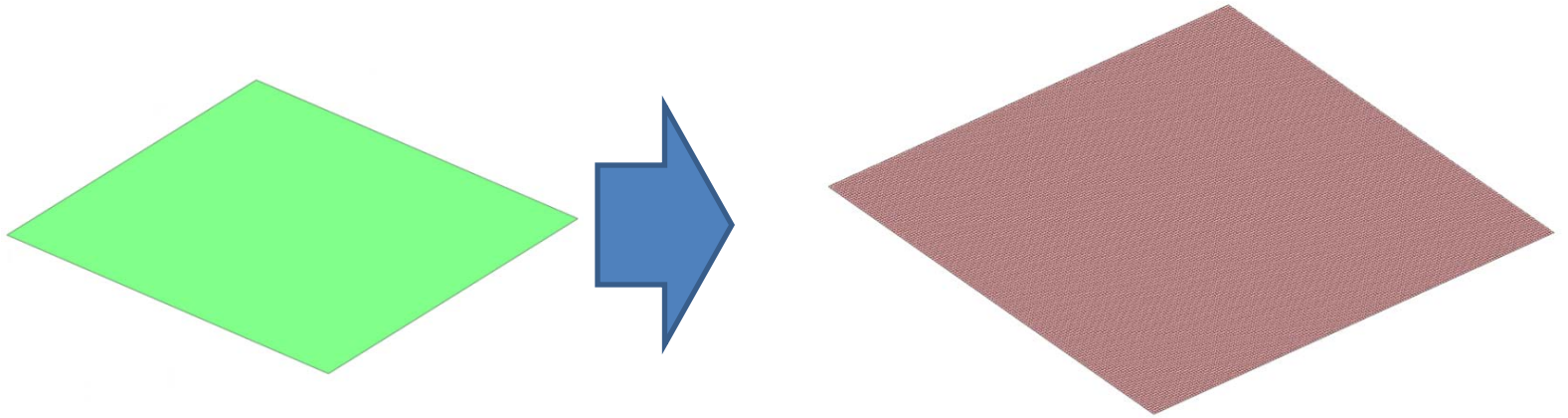


類型選取Rigid Body

2D網格-下壓板

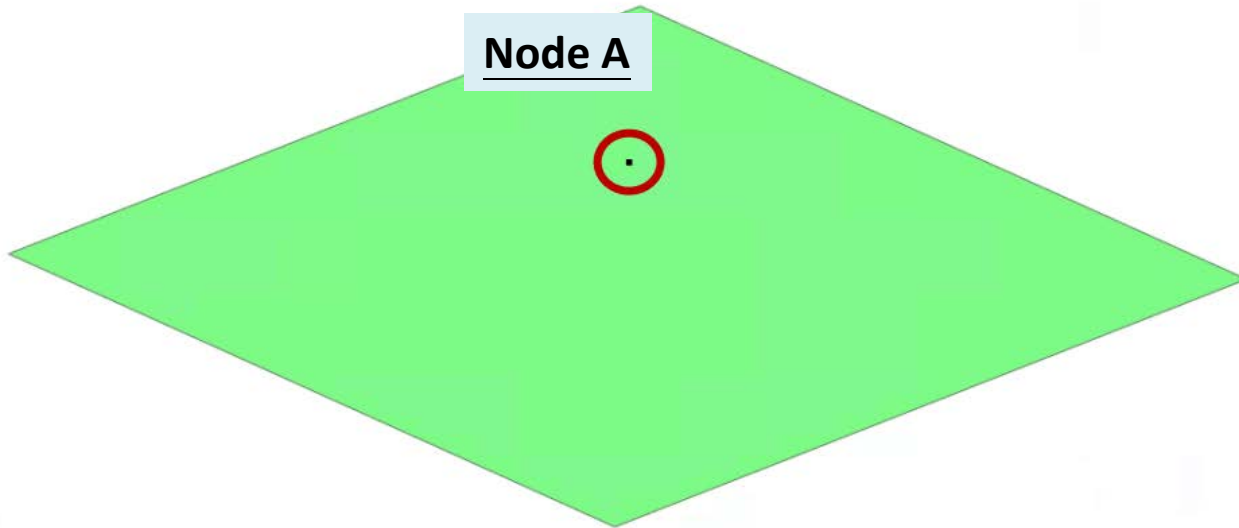
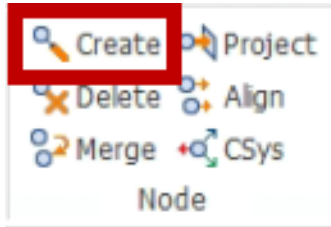


網格尺寸0.1 (m)/屬性T0.01/自訂網格集名稱(下壓板)



主控節點建立

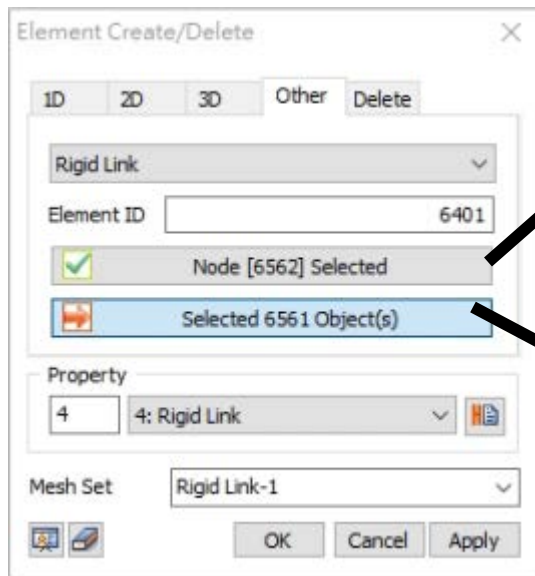
(剛性連接主控點)



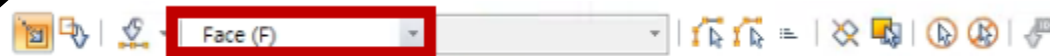
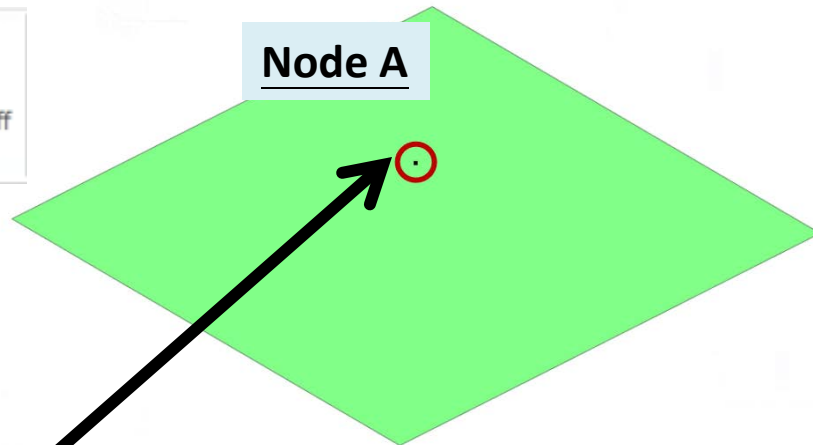
剛性連接



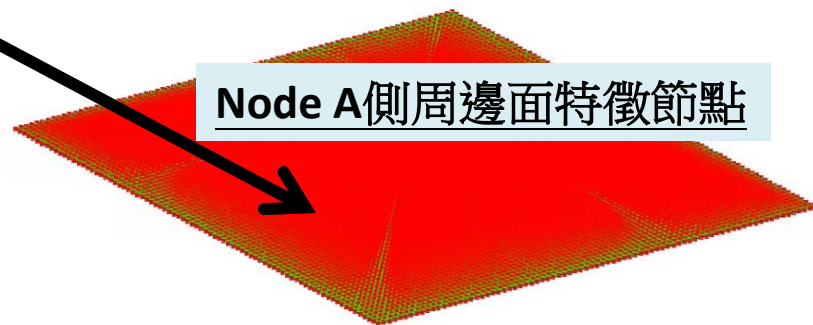
元素類型選取Rigid Link



自訂網格集Rigid Link1



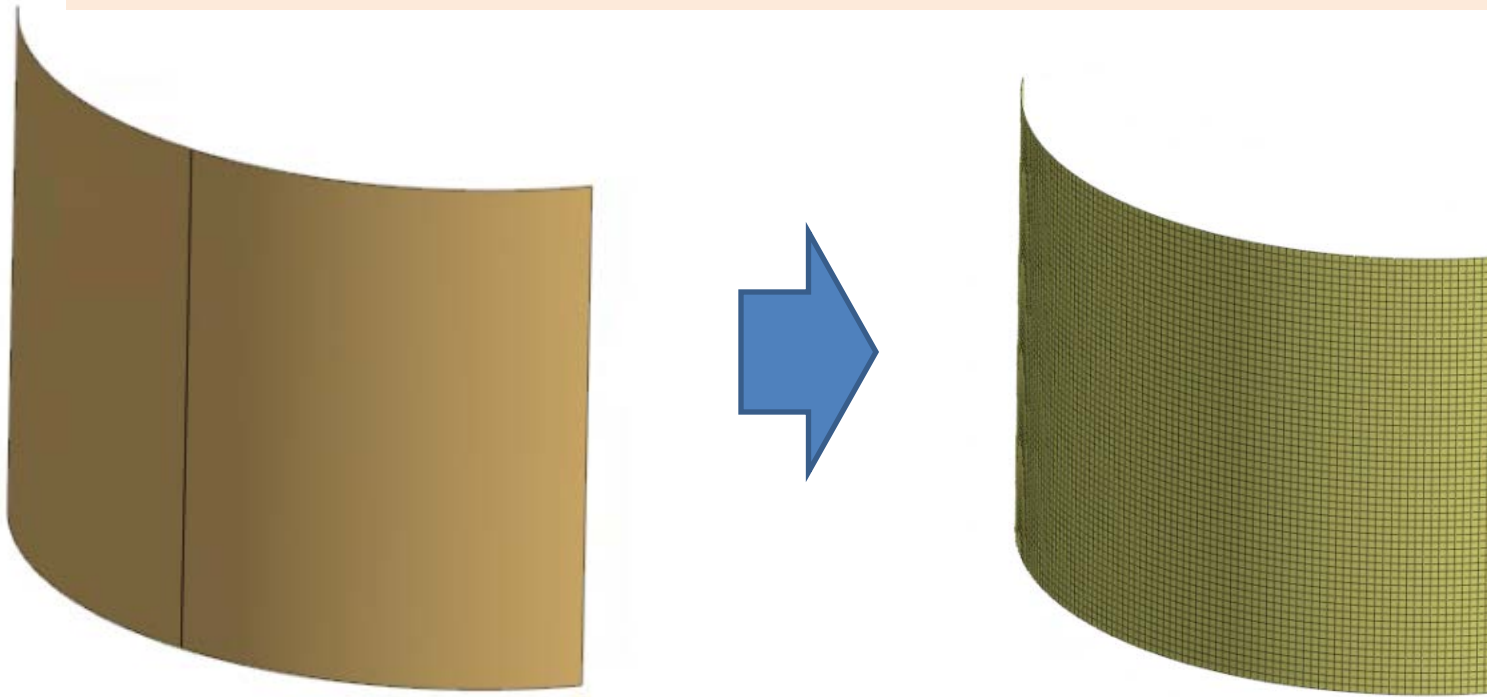
切換使用面特徵選取節點



2D網格-鋼板



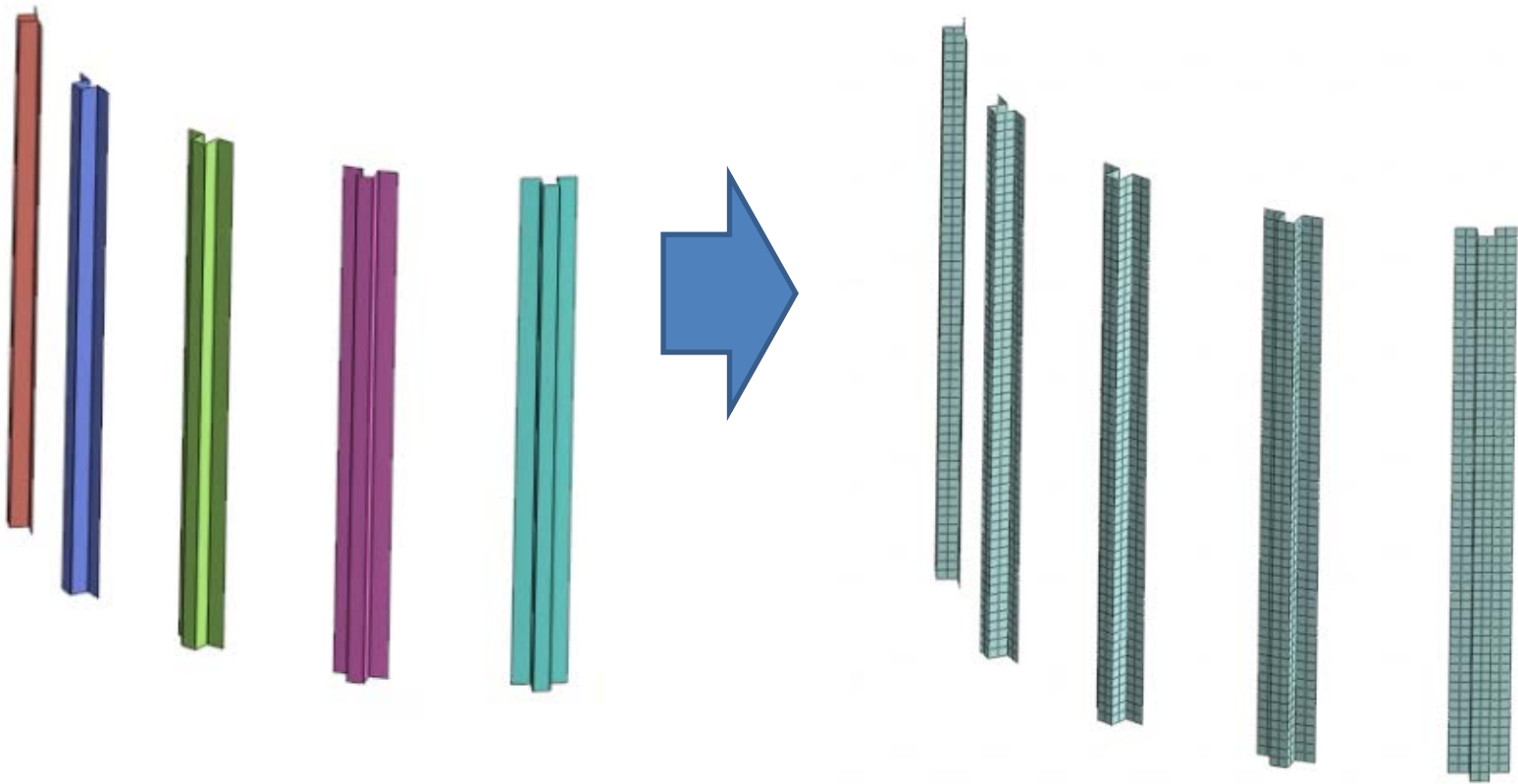
網格尺寸0.05(m)//屬性T0.025/自訂網格集名稱(鋼板)/合併節點/同一網格集



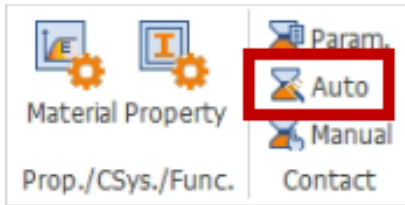
2D網格-立柱



網格尺寸0.05 (m)/屬性T0.012/自訂網格集名稱(立柱)/合併節點/同一網格集



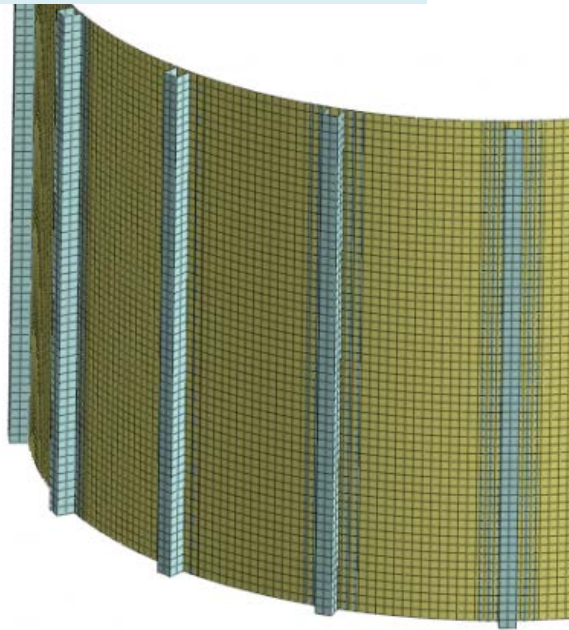
自動焊接接觸



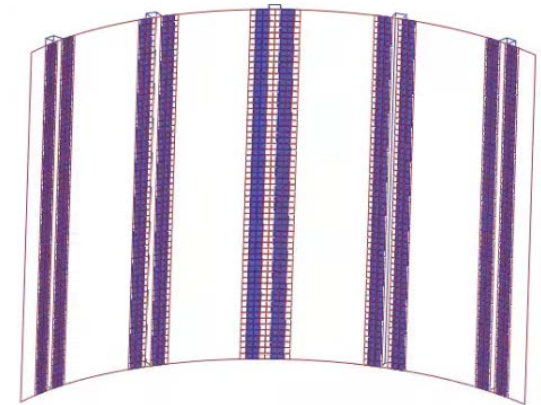
選取鋼板&立柱網格集



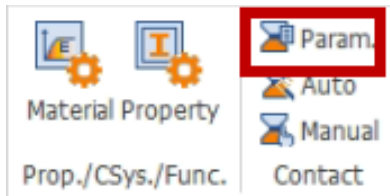
輸入判斷接觸間距0.01(m)



接觸檢視



接觸參數



Contact Parameters

ID: 4 Name: contact

Structural

Normal Stiffness Scaling Factor: 0.8

Tangential Stiffness Scaling: 0.01

☒ Contact Tolerance: 0.001 m

Master Segment Extension Ratio: 0.005

Friction Coefficient:

☒ Remove Initial Penetration by Adjusting Slave Nodes

☐ Conduction for Seepage Flow: 0 m/sec/m

Heat Transfer Analysis

☐ Thermal Conductance: 1000000 W/(m²*[T])

Breaking-Weld

Normal Failure Force: 0 N

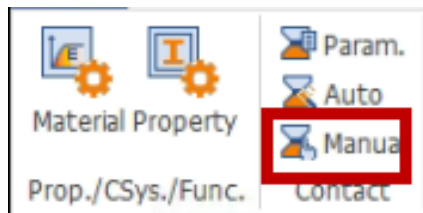
Shear Failure Force: 0 N

OK Cancel Apply

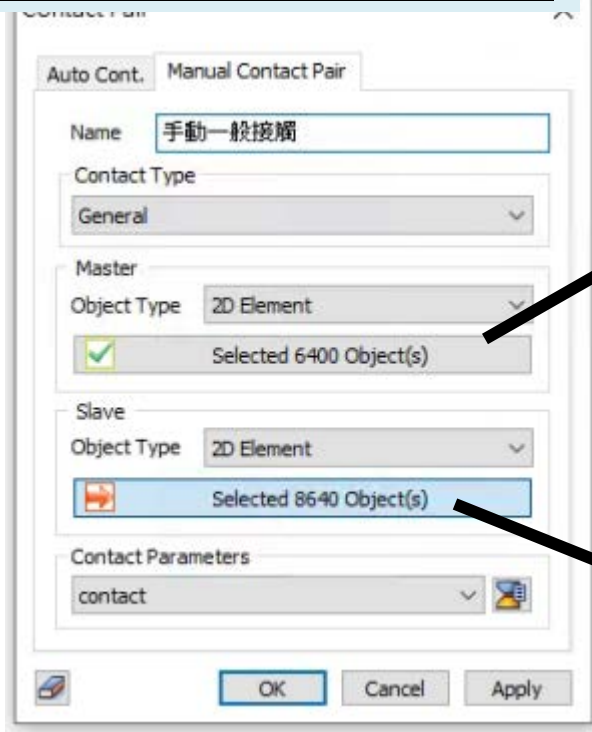
自定接觸參數名稱

調整接觸剛度/定義接觸間隙

手動一般接觸

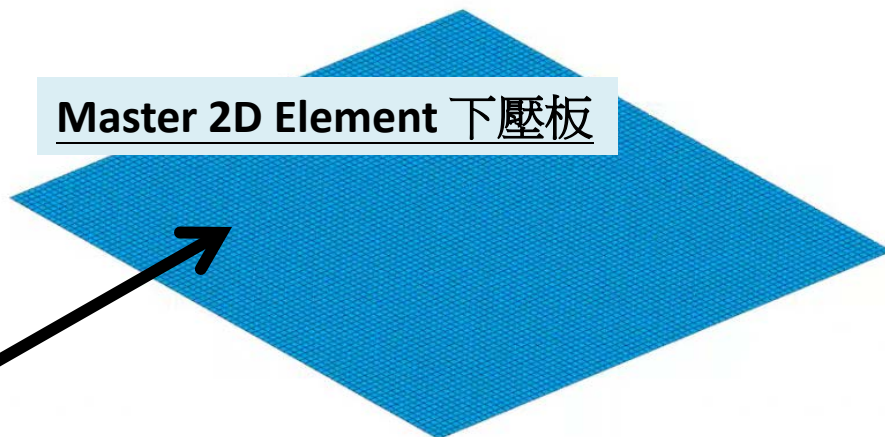


自定接觸參數名稱/General Contact

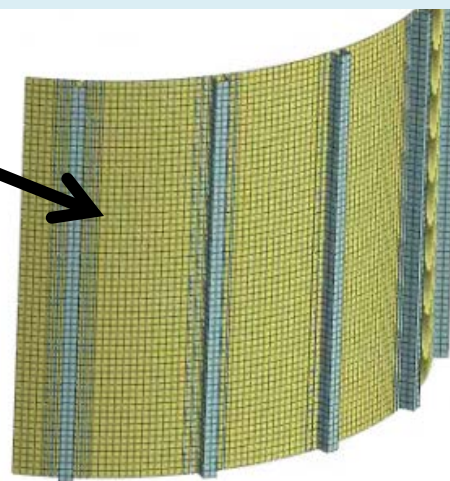


使用上一步驟接觸參數

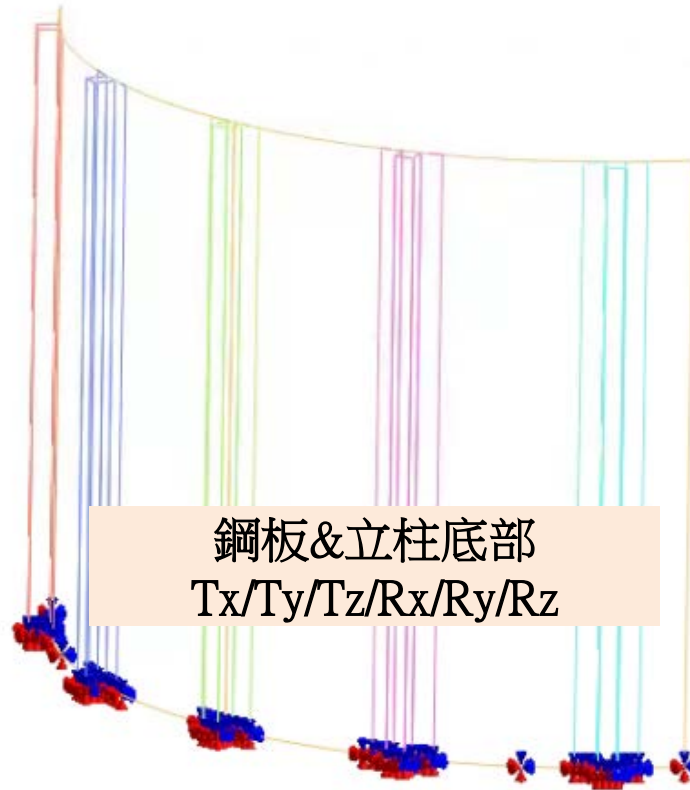
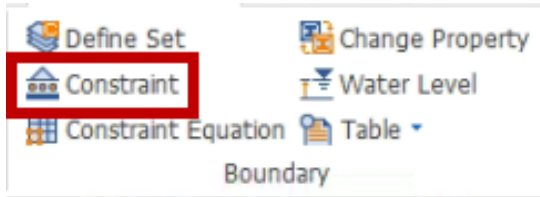
Master 2D Element 下壓板



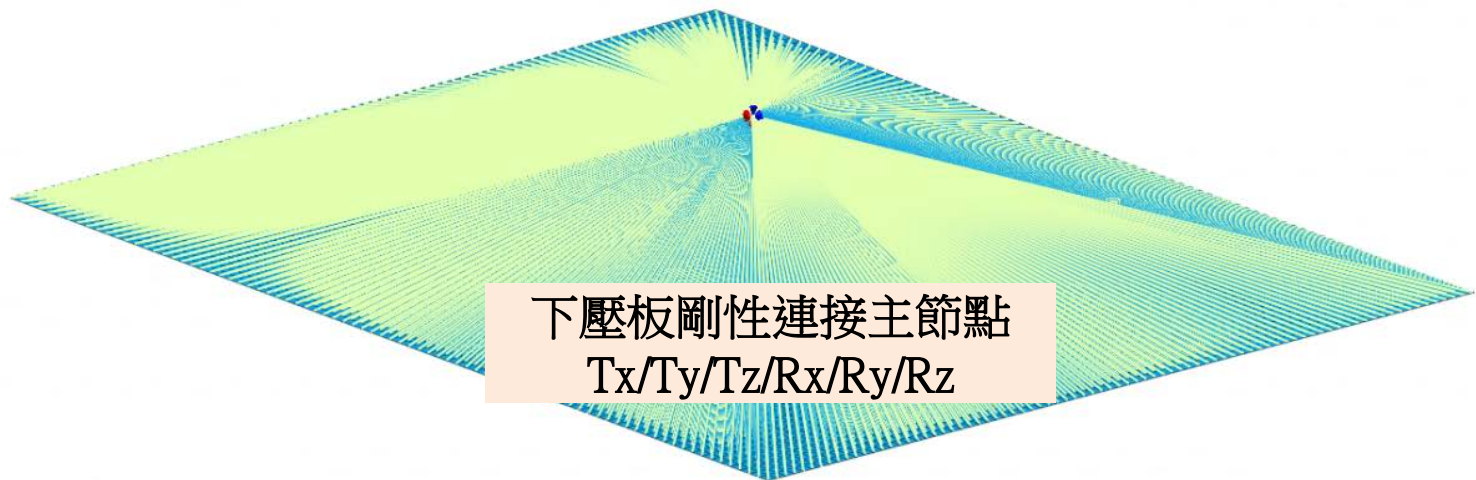
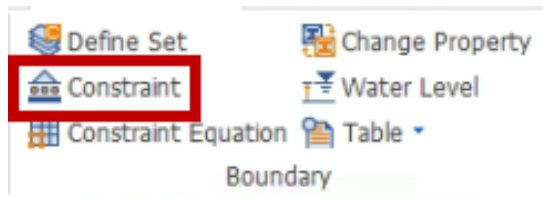
Slave 2D Element 鋼板&立柱



邊界(鋼板&立柱)



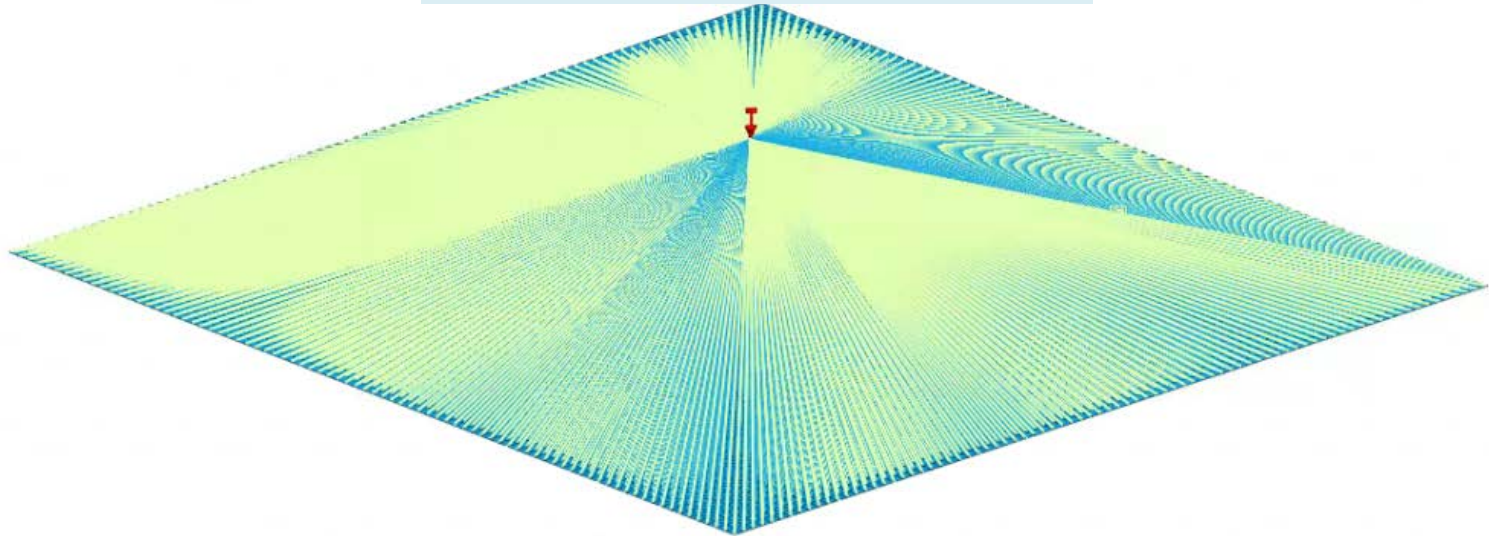
邊界(下壓板剛連接)

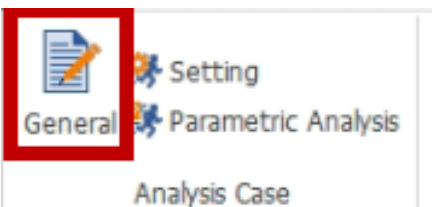


位移

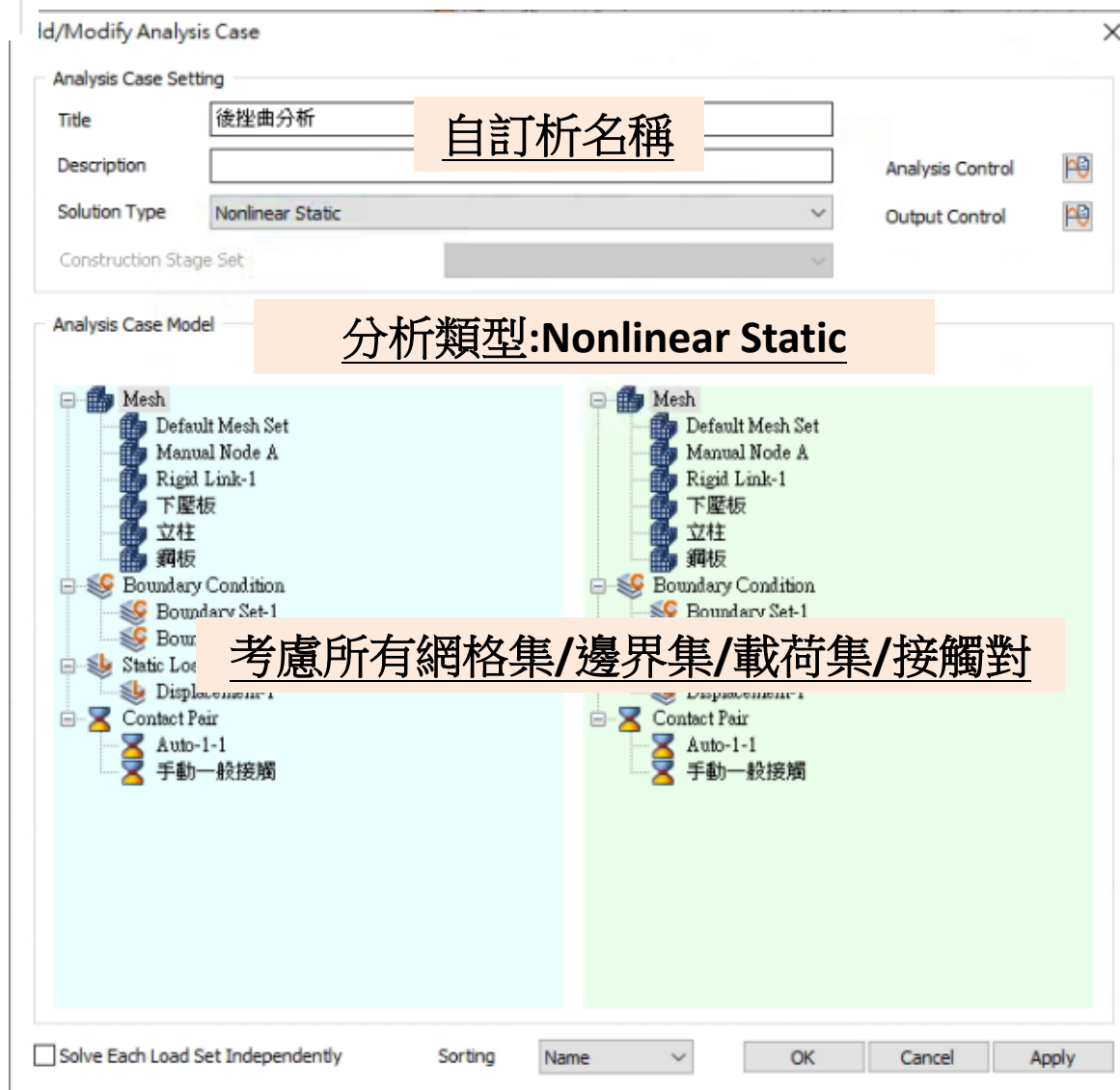


依照Global座標施加 $T_z = -0.2(m)$





非線性分析-1



非線性分析-2

非線性控制

預設計算材料非線性,勾選才計算幾何&邊界(接觸)非線性

增量數分成50等份/輸出每次增量結果

每一增量增加變形量 $0.2(\text{m})/50=0.004(\text{m})$

收斂判斷採Displacement(放寬收斂標準)

使用修正牛頓法

調整增量收斂計算次數

Analysis Control

General Nonlinear

Geometry Nonlinearity

☒ Consider Geometric Nonlinear Effects

☐ Update Pore Pressure with Deformation

Basic Nonlinear Parameters

☒ Load Steps

☒ Number of Increments: 50

Intermediate Output Request: Every Increment

☐ Manual with User-Defined Steps: Load Step...

☐ Time Steps

☒ Time(Duration): 86400 sec

Number of Increments: 1

Iterative Scheme

☒ General ☐ Enhanced Init Stress

Convergence Criteria / Error Tolerance

☒ Displacement(U): 0.005

☐ Load(P): 0.001

☐ Work(W): 1e-006

☐ Use Iteration Method

☒ Arc-Length Method ☐ Displacement-Control Method

Min. Arc-Length Adjustment Ratio: 0.25

Max. Arc-Length Adjustment Ratio: 4

Max Arc-Length Increments: 5

Advanced Nonlinear Setting...

OK Cancel

Advanced Nonlinear Parameter

Nonlinear Solver Parameters

☐ Use Default Settings

Stiffness Update Scheme Parameter

Stiffness Update Scheme: Modified Newton

Custom Update Method: Semi-Automatic

No. of iterations before Stiffness Update (ITER and SEMI Methods): 50

Max. No. of Quasi-Newton Vectors: 5

☐ Enhanced Predictor Disp.

Analysis Option

☐ Terminate Analysis on Failed Convergence

Max No. of Iterations per Increment: 25

Max. Bisection Level: 10

☐ Enable Line Search

Max. Line Search per Iteration: 4

Line Search: 5

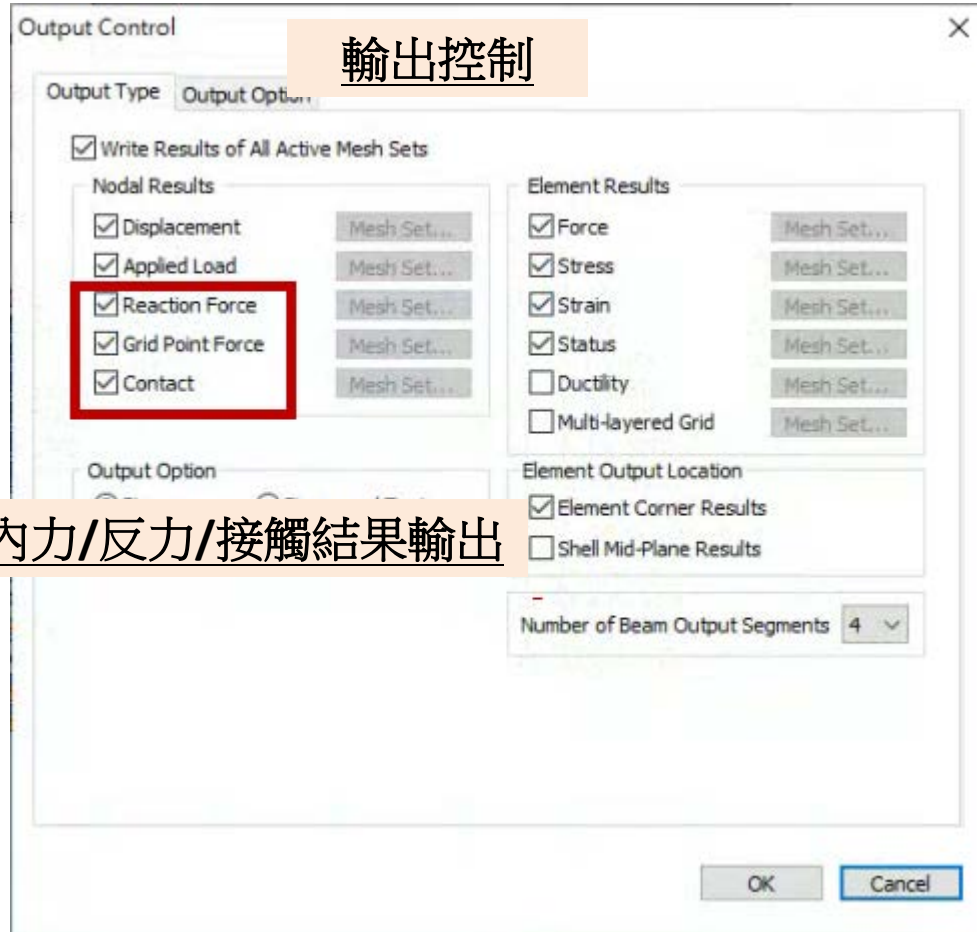
☐ Over-Relaxation: 1.2

☒ None

Divergence Threshold: 3

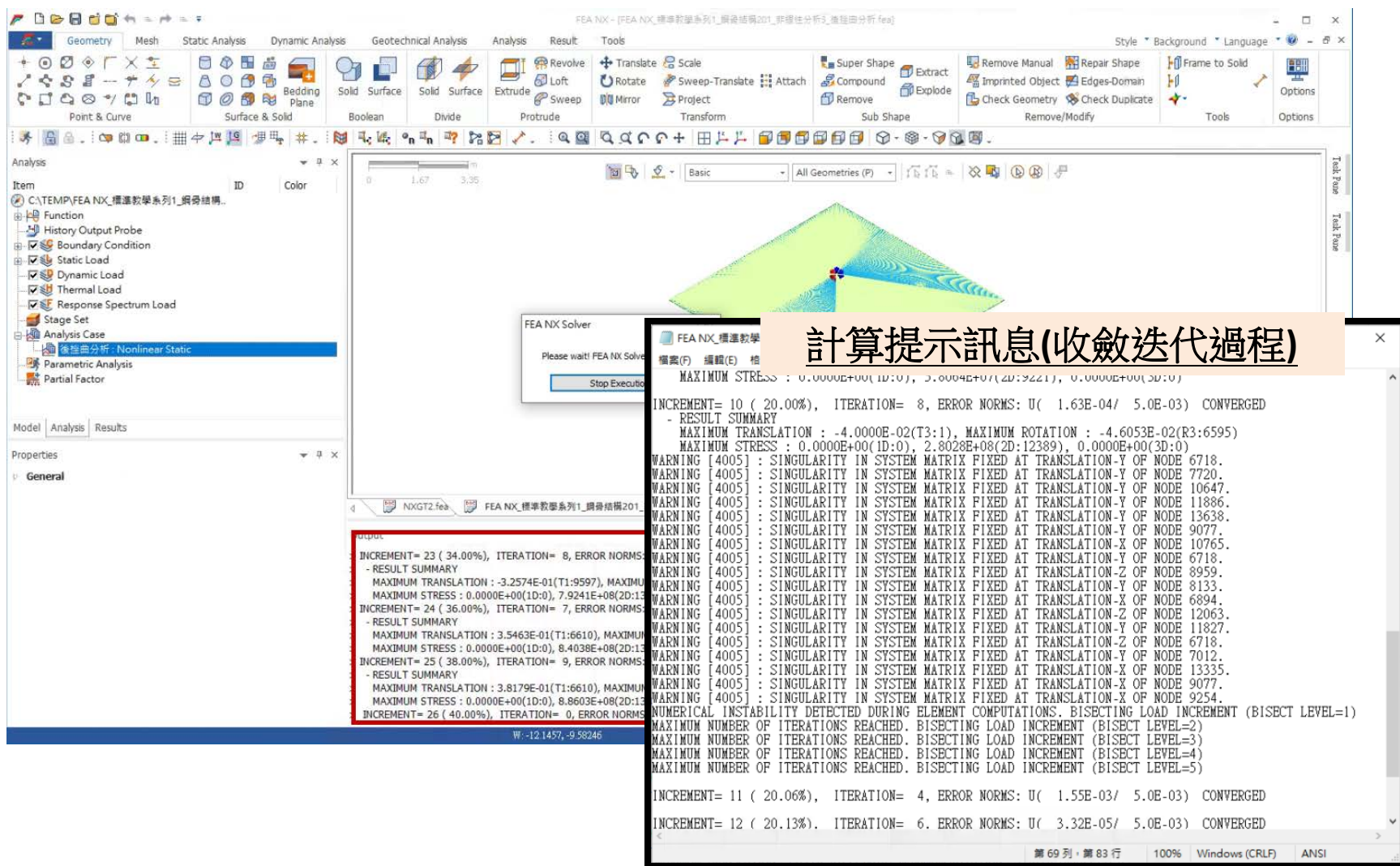
OK Cancel

非線性分析-3



內力/反力/接觸結果輸出

執行分析



FEA NX - [FEA NX_標準教學系列1_鋼骨結構201_非線性分析3_進階分析.fea]

Geometry Mesh Static Analysis Dynamic Analysis Geotechnical Analysis Analysis Result Tools

Point & Curve Surface & Solid Boolean Divide Protrude Revolve Rotate Sweep-Mirror Transform Scale Rotate Sweep-Translate Attach Super Shape Extract Remove Manual Repair Shape Imprinted Object Edges-Domain Frame to Solid Options

Analysis

Item ID Color

CAETMP/FEA NX_標準教學系列1_鋼骨結構...

Function

History Output Probe

Boundary Condition

Static Load

Dynamic Load

Thermal Load

Response Spectrum Load

Stage Set

Analysis Case

Nonlinear Static

Parametric Analysis

Partial Factor

Model Analysis Results

Properties

General

FEA NX Solver

Please wait! FEA NX Solver is running.

Stop Execution

FEA NX_標準教學

檔案(F) 編輯(E) 視

MAXIMUM STRESS : 0.0000E+00(1D:0), 2.8028E+08(2D:12389), 0.0000E+00(3D:0)

INCREMENT= 10 (20.00%), ITERATION= 8, ERROR NORMS: U(1.63E-04/ 5.0E-03) CONVERGED

- RESULT SUMMARY

MAXIMUM TRANSLATION : -4.0000E-02(T3:1), MAXIMUM ROTATION : -4.6053E-02(R3:6595)

MAXIMUM STRESS : 0.0000E+00(1D:0), 2.8028E+08(2D:12389), 0.0000E+00(3D:0)

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Y OF NODE 6718.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Y OF NODE 7720.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Y OF NODE 10647.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Y OF NODE 11886.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Y OF NODE 13638.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Y OF NODE 9077.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-X OF NODE 10765.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Z OF NODE 6894.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Z OF NODE 12063.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Z OF NODE 6718.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-Z OF NODE 7012.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-X OF NODE 13335.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-X OF NODE 9077.

WARNING [4005]: SINGULARITY IN SYSTEM MATRIX FIXED AT TRANSLATION-X OF NODE 9254.

NUMERICAL INSTABILITY DETECTED DURING ELEMENT COMPUTATIONS. BISECTING LOAD INCREMENT (BISECT LEVEL=1)

MAXIMUM NUMBER OF ITERATIONS REACHED. BISECTING LOAD INCREMENT (BISECT LEVEL=2)

MAXIMUM NUMBER OF ITERATIONS REACHED. BISECTING LOAD INCREMENT (BISECT LEVEL=3)

MAXIMUM NUMBER OF ITERATIONS REACHED. BISECTING LOAD INCREMENT (BISECT LEVEL=4)

MAXIMUM NUMBER OF ITERATIONS REACHED. BISECTING LOAD INCREMENT (BISECT LEVEL=5)

INCREMENT= 11 (20.06%), ITERATION= 4, ERROR NORMS: U(1.55E-03/ 5.0E-03) CONVERGED

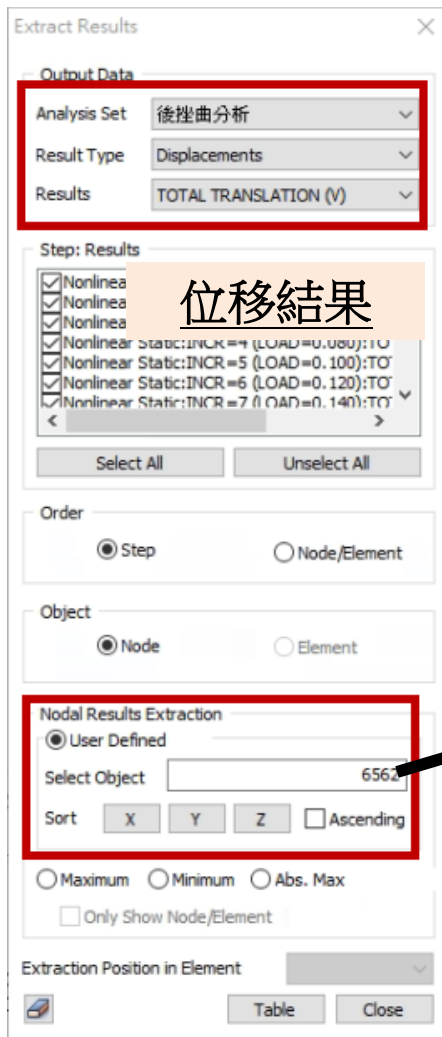
INCREMENT= 12 (20.13%), ITERATION= 6, ERROR NORMS: U(3.32E-05/ 5.0E-03) CONVERGED

第 69 列, 第 83 行 100% Windows (CRLF) ANSI

註:後挫曲屬於大變形計算,分析過程計算不穩定。

提取-迭代過程結果

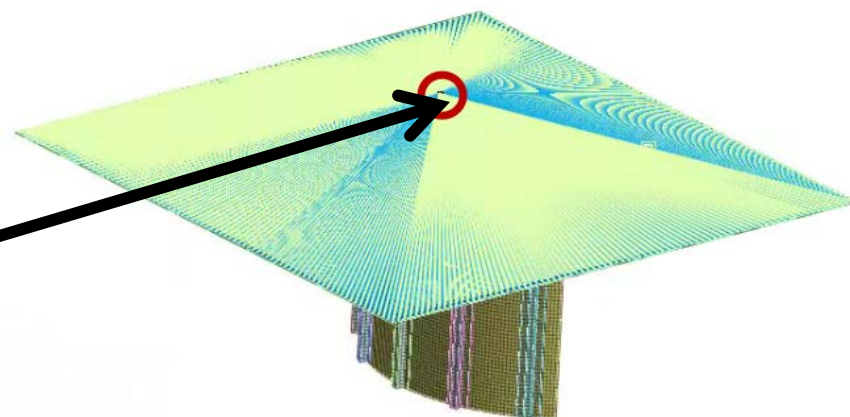
分析結果-1



位移結果

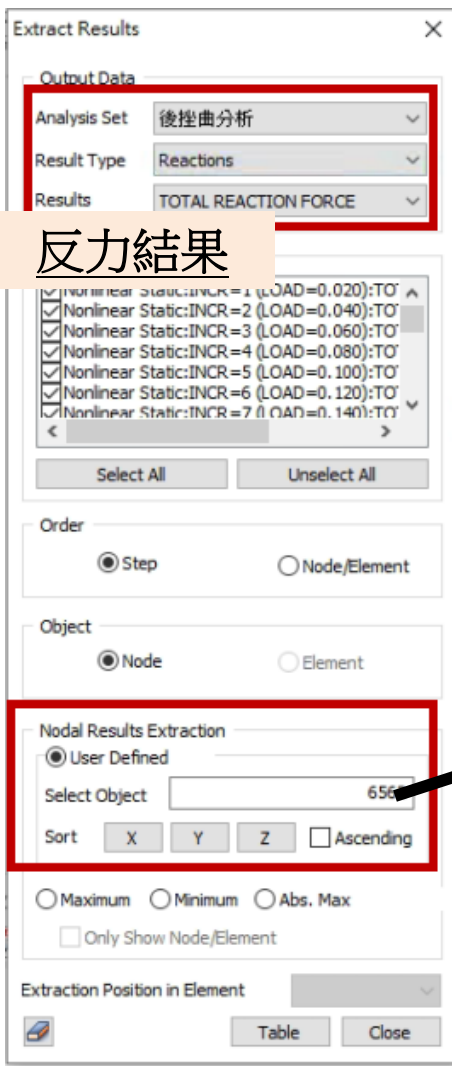
迭代過程剛性中心點位移結果

3	Nonlinear Static: INCR=3 (LOAD=0.060)	6.000000e-002	1.200000e-002
4	Nonlinear Static: INCR=4 (LOAD=0.080)	8.000000e-002	1.600000e-002
5	Nonlinear Static: INCR=5 (LOAD=0.100)	1.000000e-001	2.000000e-002
6	Nonlinear Static: INCR=6 (LOAD=0.120)	1.200000e-001	2.400000e-002
7	Nonlinear Static: INCR=7 (LOAD=0.140)	1.400000e-001	2.800000e-002
8	Nonlinear Static: INCR=8 (LOAD=0.160)	1.600000e-001	3.200000e-002
9	Nonlinear Static: INCR=9 (LOAD=0.180)	1.800000e-001	3.600000e-002
10	Nonlinear Static: INCR=10 (LOAD=0.200)	2.000000e-001	4.000000e-002
11	Nonlinear Static: INCR=16 (LOAD=0.220)	2.200000e-001	4.400000e-002
12	Nonlinear Static: INCR=17 (LOAD=0.240)	2.400000e-001	4.800000e-002
13	Nonlinear Static: INCR=19 (LOAD=0.260)	2.600000e-001	5.200000e-002
14	Nonlinear Static: INCR=20 (LOAD=0.280)	2.800000e-001	5.600000e-002
15	Nonlinear Static: INCR=21 (LOAD=0.300)	3.000000e-001	6.000000e-002
16	Nonlinear Static: INCR=22 (LOAD=0.320)	3.200000e-001	6.400000e-002
17	Nonlinear Static: INCR=23 (LOAD=0.340)	3.400000e-001	6.800000e-002
18	Nonlinear Static: INCR=24 (LOAD=0.360)	3.600000e-001	7.200000e-002
19	Nonlinear Static: INCR=25 (LOAD=0.380)	3.800000e-001	7.600000e-002
20	Nonlinear Static: INCR=26 (LOAD=0.400)	4.000000e-001	8.000000e-002
21	Nonlinear Static: INCR=27 (LOAD=0.420)	4.200000e-001	8.400000e-002
22	Nonlinear Static: INCR=28 (LOAD=0.440)	4.400000e-001	8.800000e-002
23	Nonlinear Static: INCR=29 (LOAD=0.460)	4.600000e-001	9.200000e-002
24	Nonlinear Static: INCR=30 (LOAD=0.480)	4.800000e-001	9.600000e-002
25	Nonlinear Static: INCR=31 (LOAD=0.500)	5.000000e-001	1.000000e-001
26	Nonlinear Static: INCR=32 (LOAD=0.520)	5.200000e-001	1.040000e-001
27	Nonlinear Static: INCR=33 (LOAD=0.540)	5.400000e-001	1.080000e-001
28	Nonlinear Static: INCR=34 (LOAD=0.560)	5.600000e-001	1.120000e-001
29	Nonlinear Static: INCR=35 (LOAD=0.580)	5.800000e-001	1.160000e-001



提取-迭代過程結果

分析結果-2

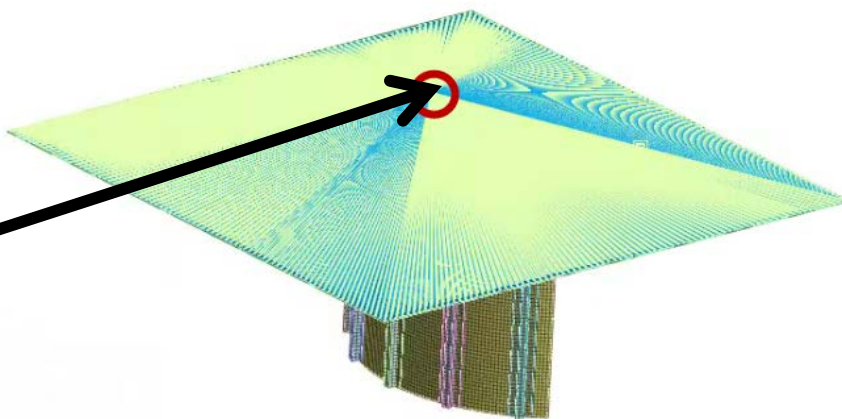


反力結果

迭代過程剛性中心點反力結果

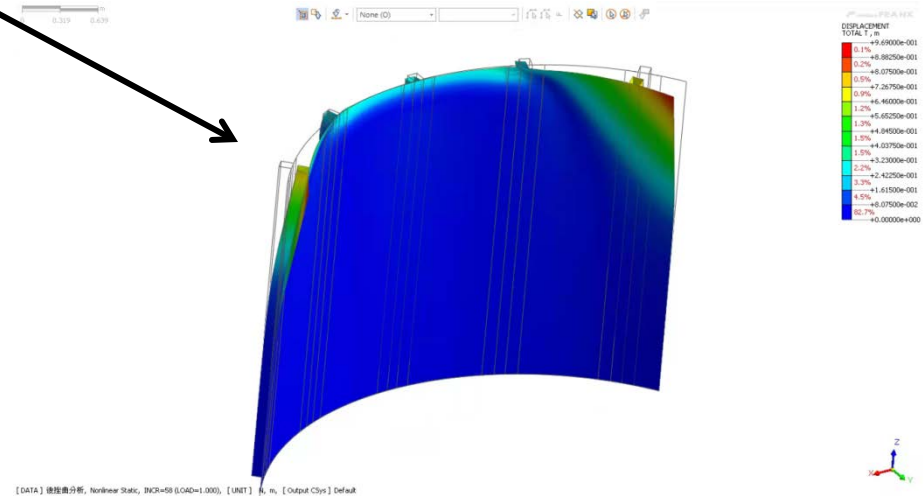
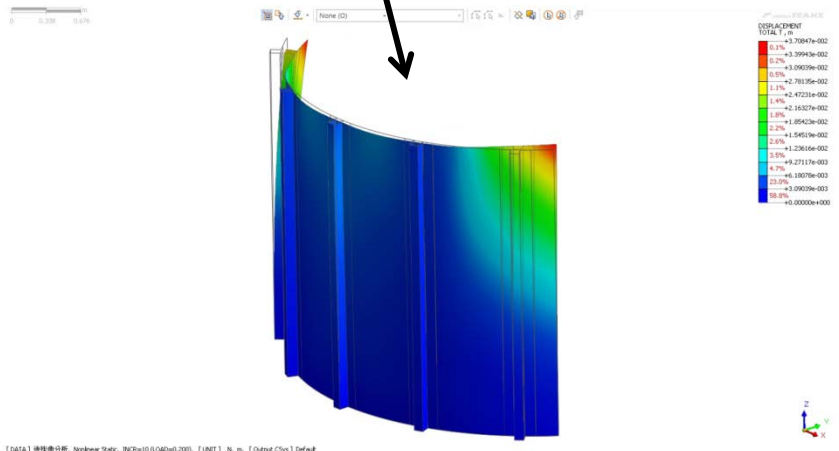
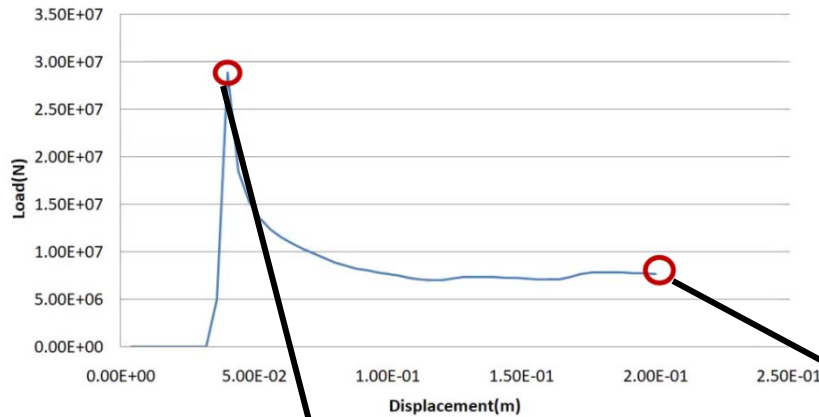
2	Nonlinear Static: INCR=2 (LOAD=0.040)	4.000000e-002	0.000000e+000
3	Nonlinear Static: INCR=3 (LOAD=0.060)	6.000000e-002	0.000000e+000
4	Nonlinear Static: INCR=4 (LOAD=0.080)	8.000000e-002	0.000000e+000
5	Nonlinear Static: INCR=5 (LOAD=0.100)	1.000000e-001	0.000000e+000
6	Nonlinear Static: INCR=6 (LOAD=0.120)	1.200000e-001	0.000000e+000
7	Nonlinear Static: INCR=7 (LOAD=0.140)	1.400000e-001	0.000000e+000
8	Nonlinear Static: INCR=8 (LOAD=0.160)	1.600000e-001	7.642497e+003
9	Nonlinear Static: INCR=9 (LOAD=0.180)	1.800000e-001	4.984495e+006
10	Nonlinear Static: INCR=10 (LOAD=0.200)	2.000000e-001	2.883290e+007
11	Nonlinear Static: INCR=16 (LOAD=0.220)	2.200000e-001	1.842622e+007
12	Nonlinear Static: INCR=17 (LOAD=0.240)	2.400000e-001	1.527795e+007
13	Nonlinear Static: INCR=19 (LOAD=0.260)	2.600000e-001	1.350124e+007
14	Nonlinear Static: INCR=20 (LOAD=0.280)	2.800000e-001	1.232806e+007
15	Nonlinear Static: INCR=21 (LOAD=0.300)	3.000000e-001	1.148340e+007
16	Nonlinear Static: INCR=22 (LOAD=0.320)	3.200000e-001	1.083479e+007
17	Nonlinear Static: INCR=23 (LOAD=0.340)	3.400000e-001	1.029085e+007
18	Nonlinear Static: INCR=24 (LOAD=0.360)	3.600000e-001	9.789326e+006
19	Nonlinear Static: INCR=25 (LOAD=0.380)	3.800000e-001	9.305513e+006
20	Nonlinear Static: INCR=26 (LOAD=0.400)	4.000000e-001	8.898454e+006
21	Nonlinear Static: INCR=27 (LOAD=0.420)	4.200000e-001	8.541397e+006
22	Nonlinear Static: INCR=28 (LOAD=0.440)	4.400000e-001	8.251520e+006
23	Nonlinear Static: INCR=29 (LOAD=0.460)	4.600000e-001	8.023455e+006
24	Nonlinear Static: INCR=30 (LOAD=0.480)	4.800000e-001	7.824082e+006
25	Nonlinear Static: INCR=31 (LOAD=0.500)	5.000000e-001	7.633784e+006
26	Nonlinear Static: INCR=32 (LOAD=0.520)	5.200000e-001	7.451970e+006
27	Nonlinear Static: INCR=33 (LOAD=0.540)	5.400000e-001	7.281841e+006
28	Nonlinear Static: INCR=34 (LOAD=0.560)	5.600000e-001	7.123520e+006
29	Nonlinear Static: INCR=35 (LOAD=0.580)	5.800000e-001	6.984035e+006
30	Nonlinear Static: INCR=36 (LOAD=0.600)	6.000000e-001	7.007681e+006

1



分析結果-3

28832900(N)=>近似線性挫曲結果



[DATA] 總挫曲分析, Nonlinear Static, BUCK=10 (LOAD=0.200), [UNIT] N, m, [Output Chys] Default

[DATA] 總挫曲分析, Nonlinear Static, BUCK=50 (LOAD=1.000), [UNIT] N, m, [Output Chys] Default