SAP2000®

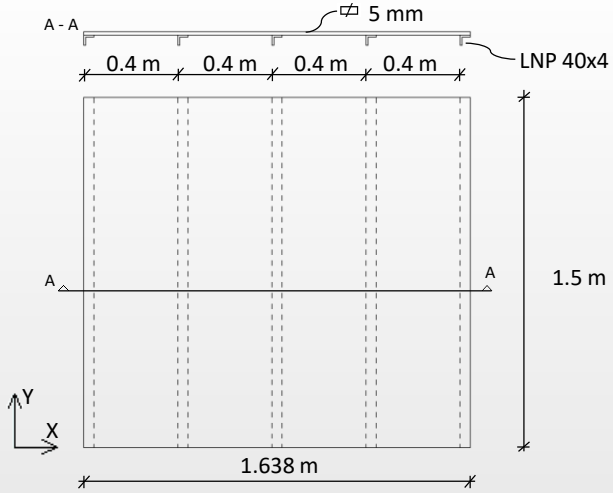
Exercise 35

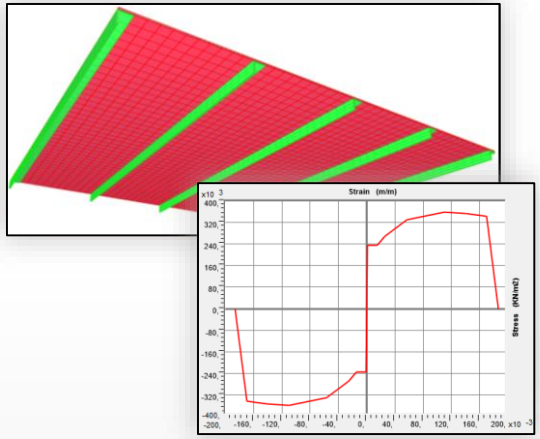
Material Nonlinearity in Steel Shell Models

Study the plastic behavior of a steel floor plate reinforced with welded steel angle stiffeners

Problem:

Model a steel floor structure with nonlinear shell elements and subject it to two different types of loading (a uniformly distributed load and a concentrated load). Define the steel stress-strain curves. Plot a load/deflection curve for a progressive application of the concentrated load.





Modeling topics

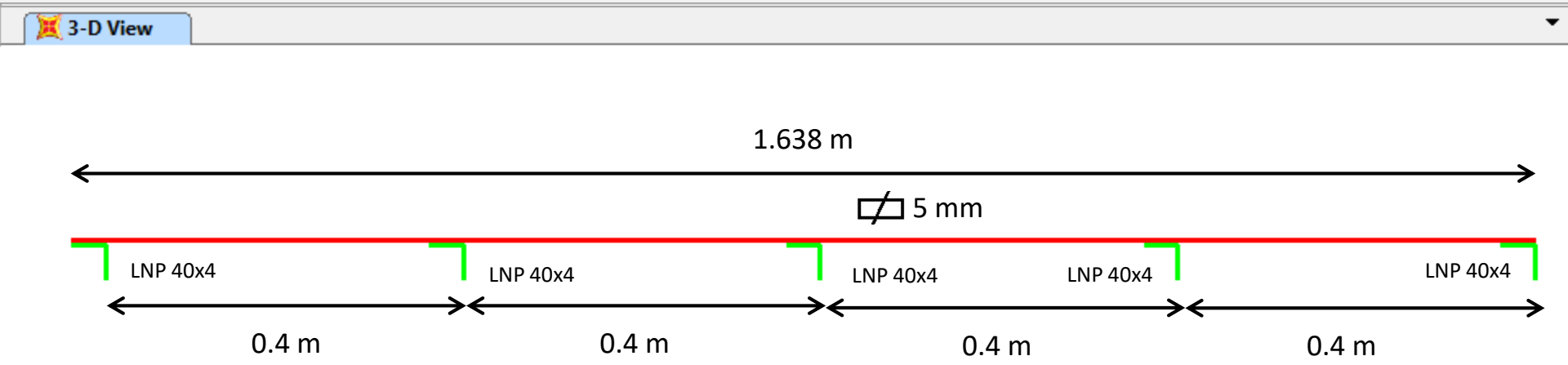
- Material Nonlinearity
- Stress-strain curves

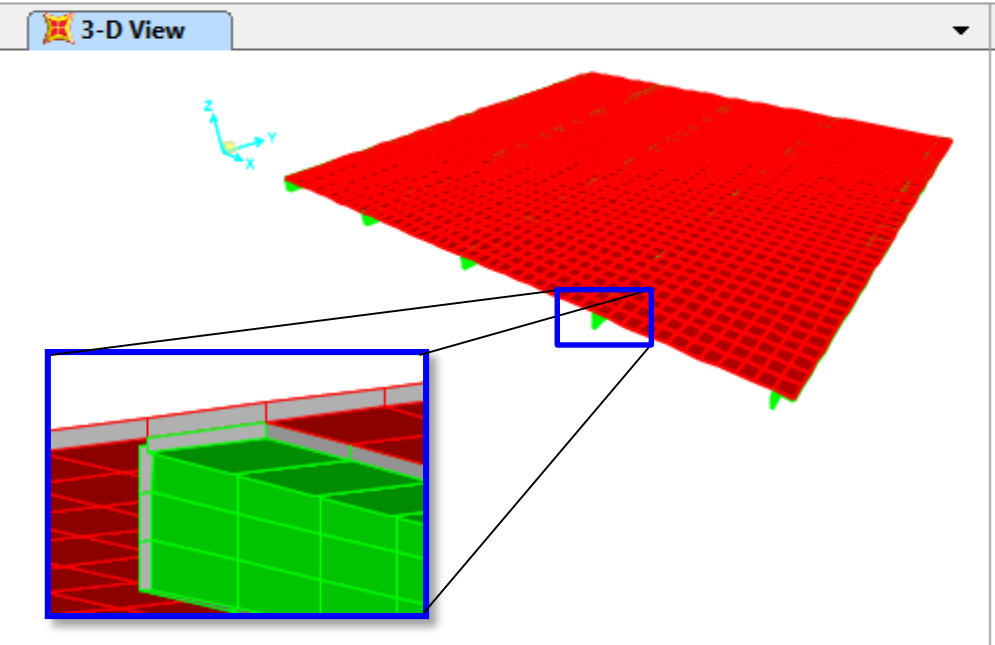
SAP2000 features

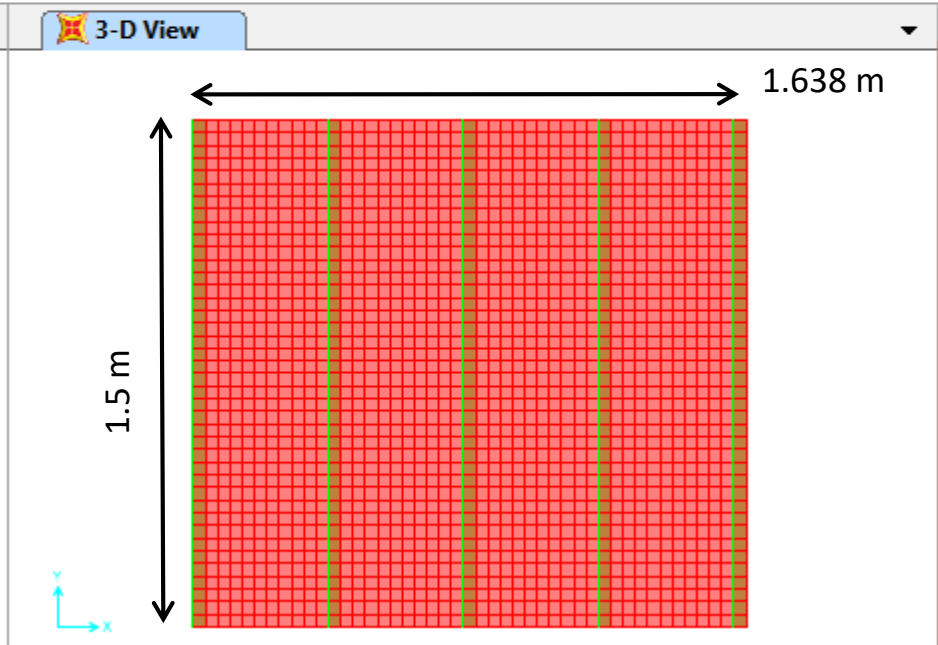
- Nonlinear Layered Shell
- Weld Constraint
- Static Nonlinear Analysis
- Save Results at Multiple States
- Continue from State at End of Nonlinear Case
- Displacement Controlled Loading
- Section Cuts
- Generalized Displacements
- Plot Functions

3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35





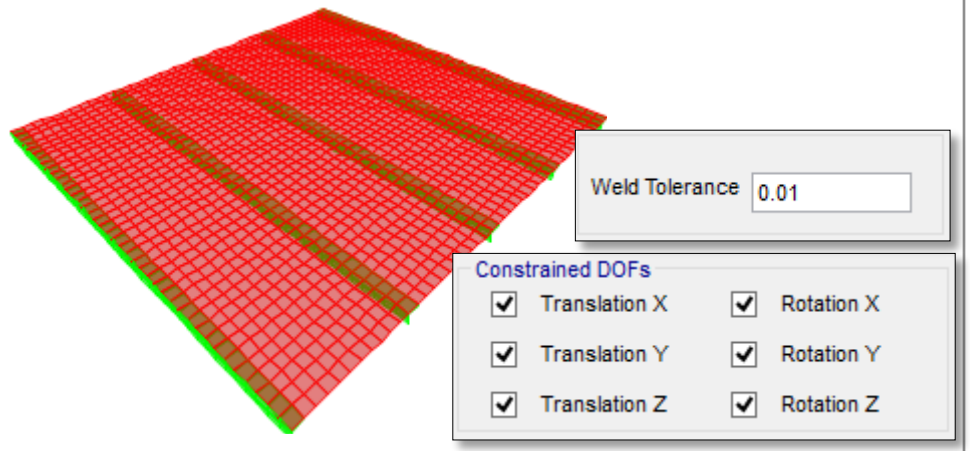


3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

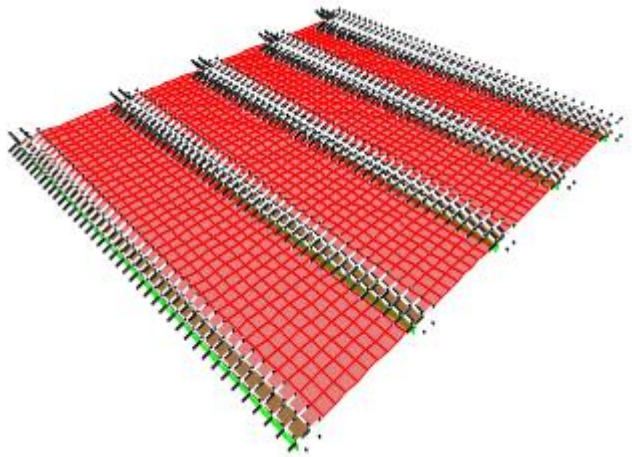
Exercise 35

3-D View

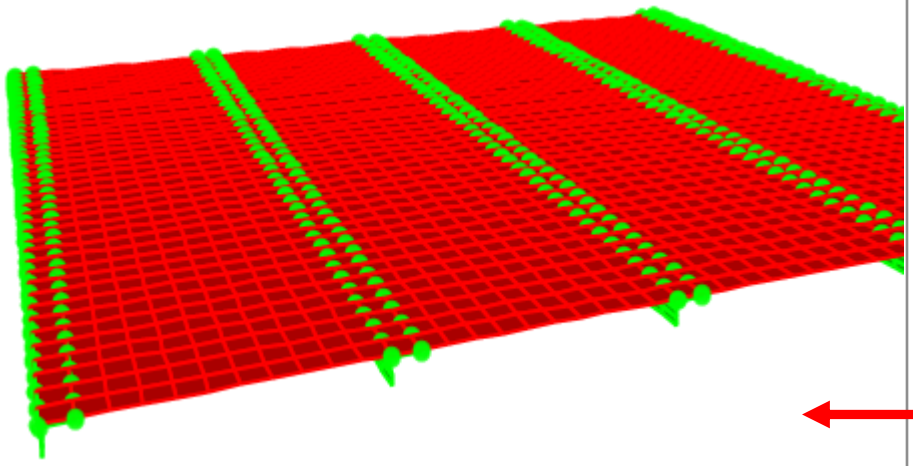
Define > Joint Constraints > WELD



3-D View

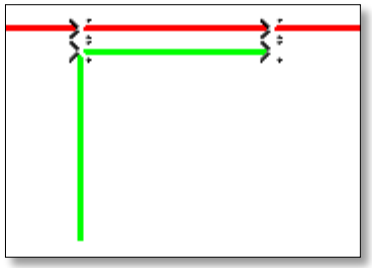


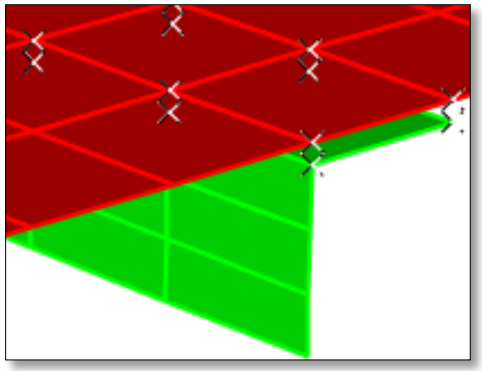
3-D View



3-D View

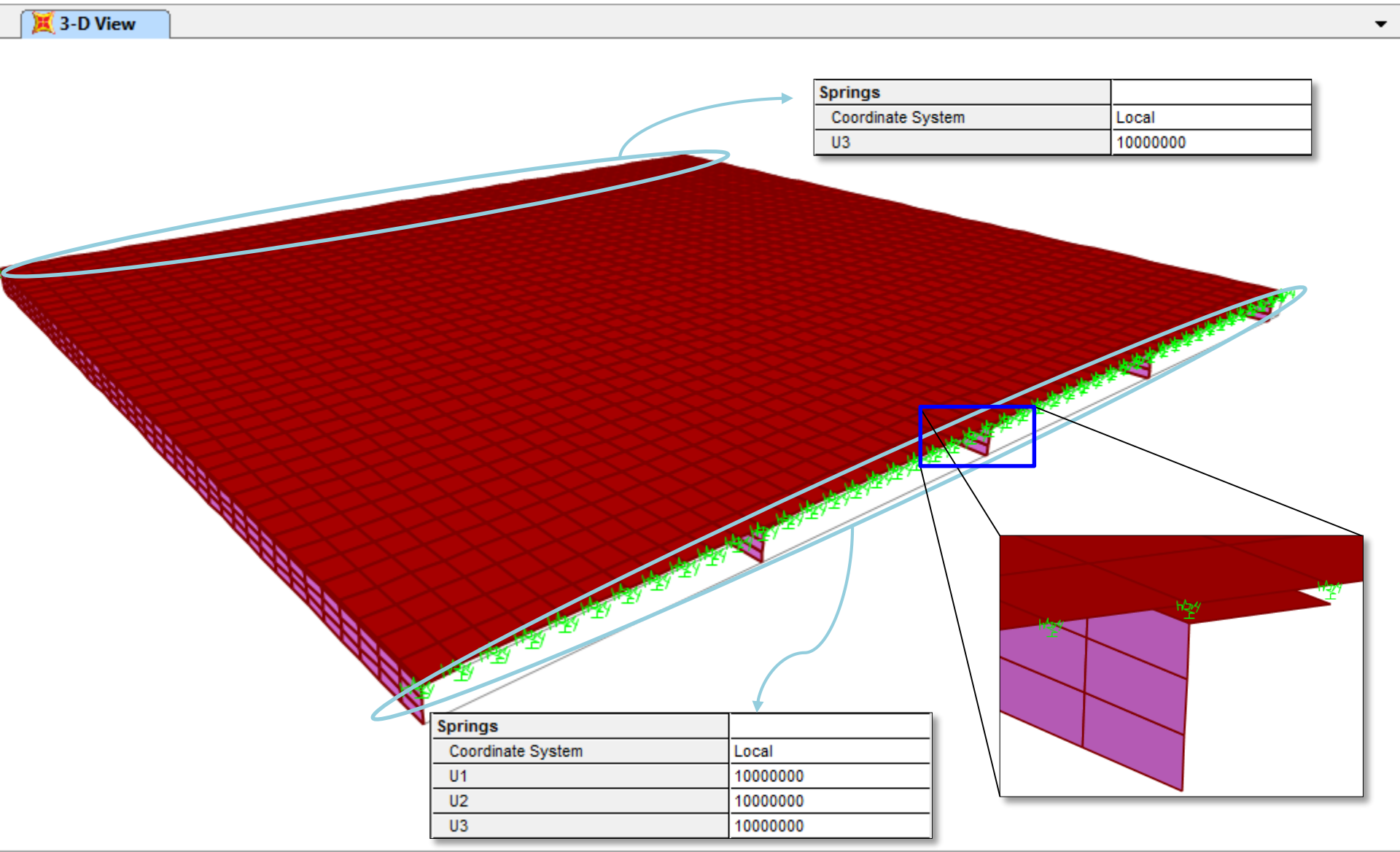
Assign > Joint > Constraints > WELD





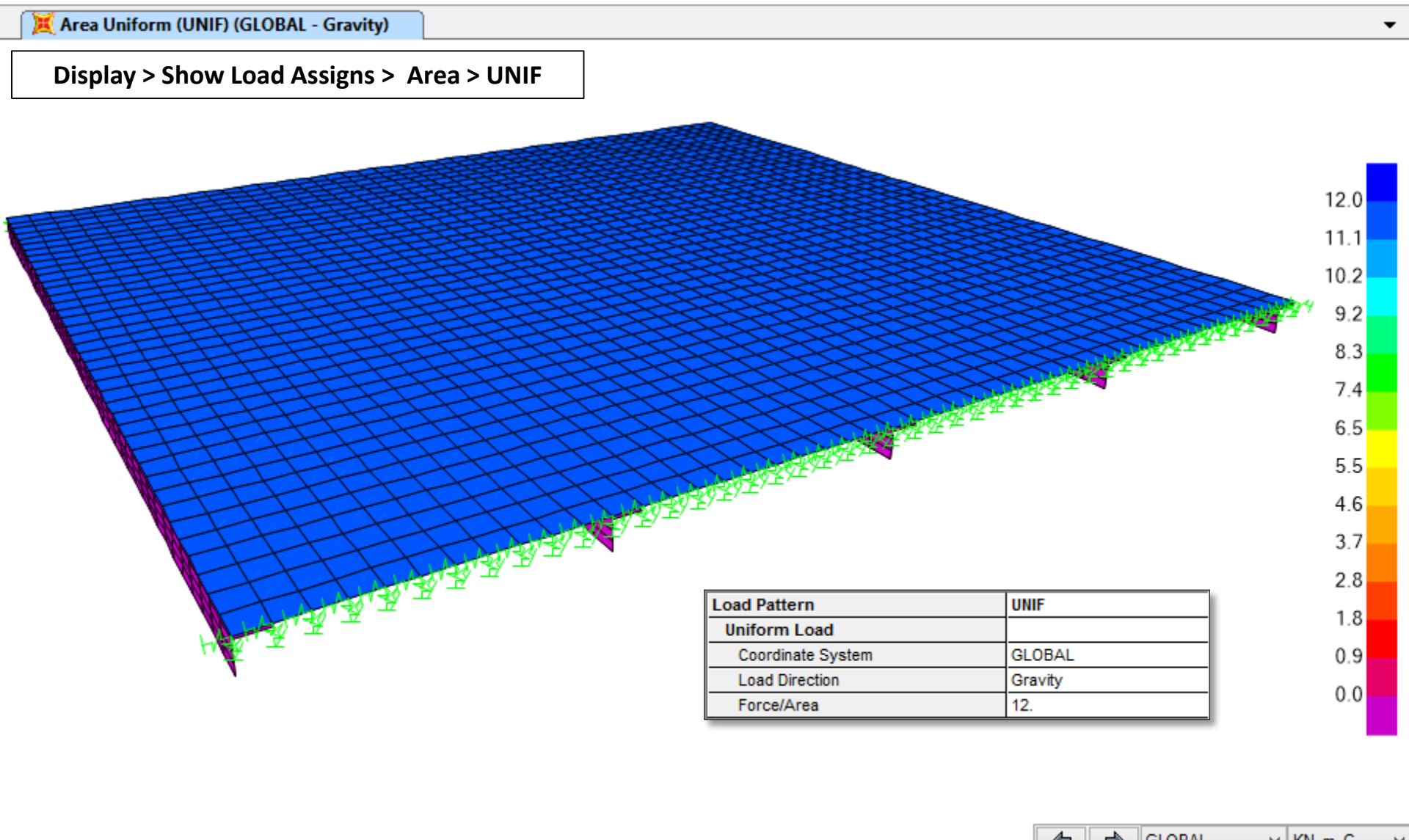
3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35



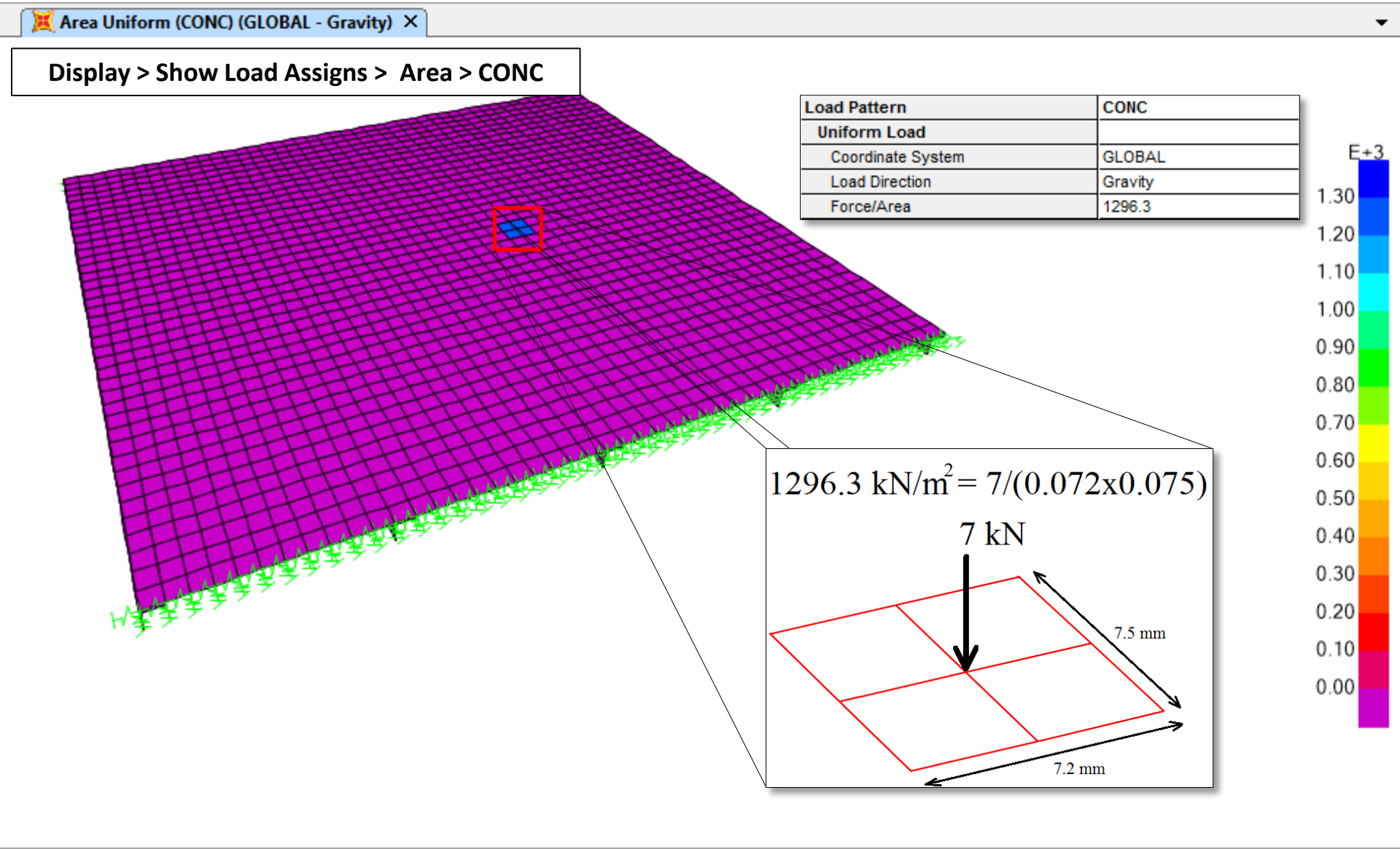
3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35



3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35



3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35

Linear Load Cases

Load Case Name: DEAD + CONC

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	DEAD	1.
Load Pattern	DEAD	1.
Load Pattern	CONC	1.

Load Case Name: DEAD + UNIF

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	CONC	1.
Load Pattern	UNIF	1.
Load Pattern	DEAD	1.

Analysis Type
- (•) Linear
- ( ) Nonlinear
- ( ) Nonlinear Staged Construction

Nonlinear Load Cases

Load Case Name: DEAD + CONC (NL)

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	DEAD	1.
Load Pattern	DEAD	1.
Load Pattern	CONC	1.

Load Case Name: DEAD + UNIF (NL)

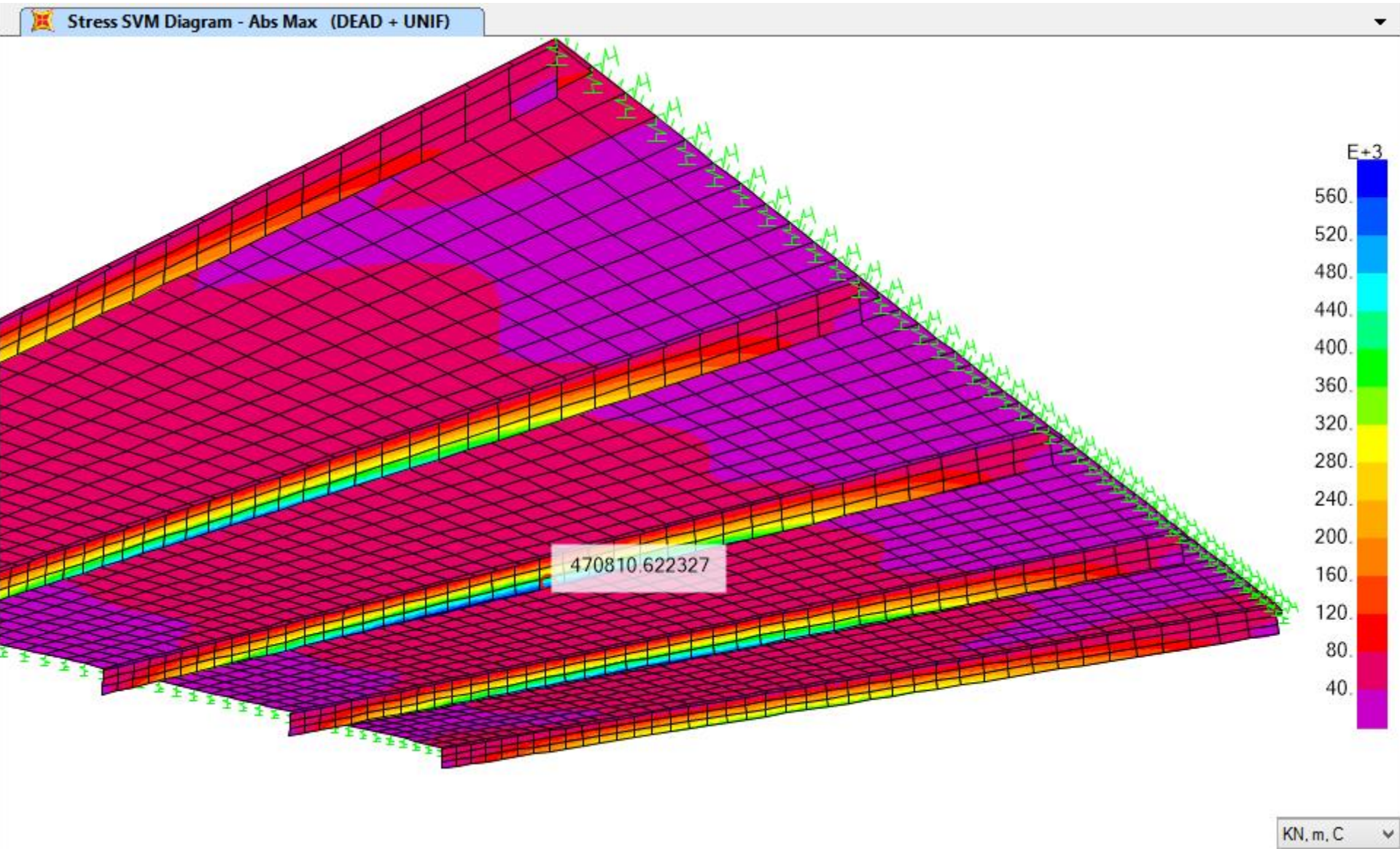
Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	CONC	1.
Load Pattern	UNIF	1.
Load Pattern	DEAD	1.

Analysis Type
- ( ) Linear
- (•) Nonlinear
- ( ) Nonlinear Staged Construction

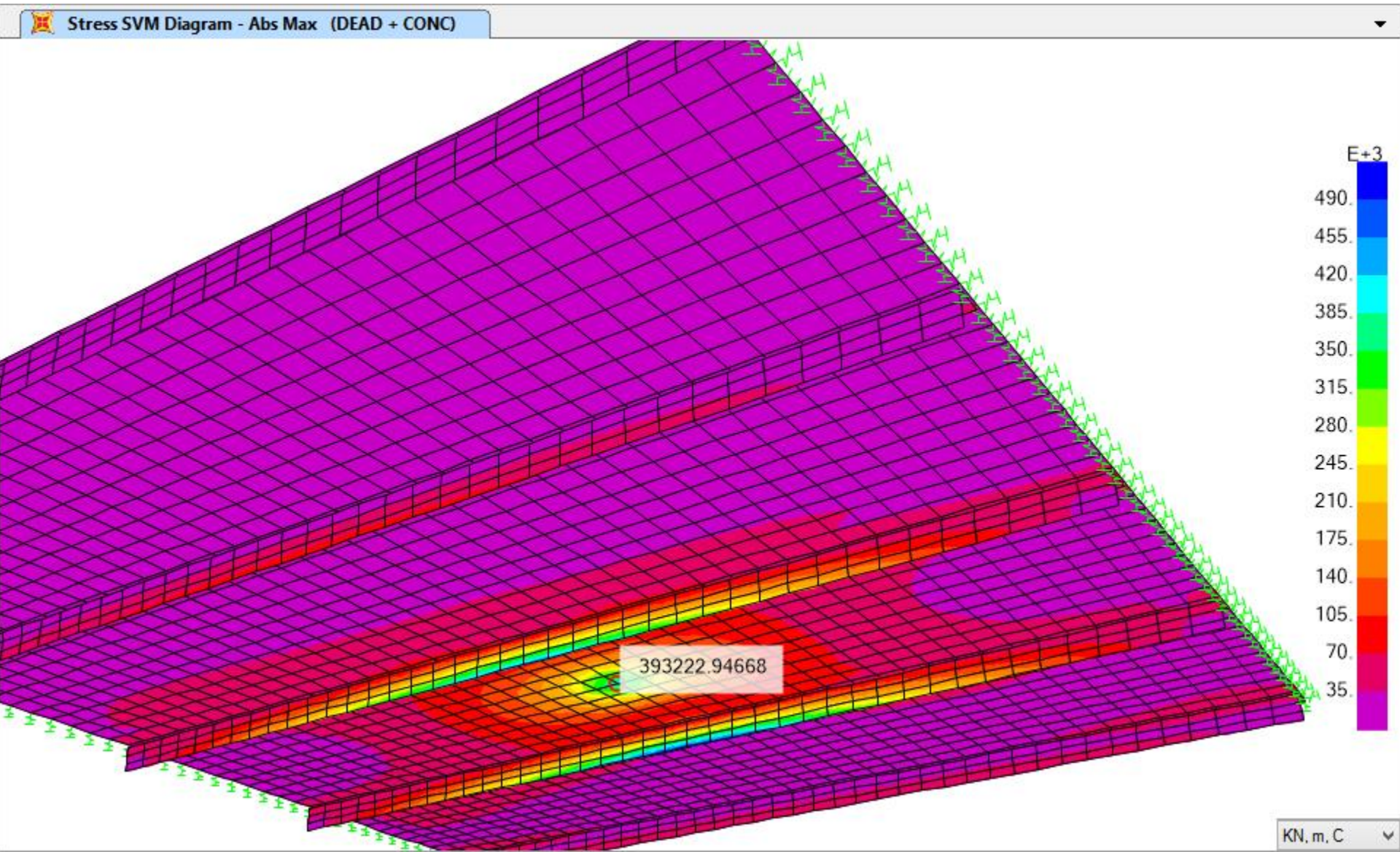
3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35



3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35



3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35

Nonlinear Material Data

Edit

Material Name: S235

Material Type: Steel

Hysteresis Type: Kinematic

Drucker-Prager Parameters
Friction Angle
Dilatational Angle

Units: KN, m, C

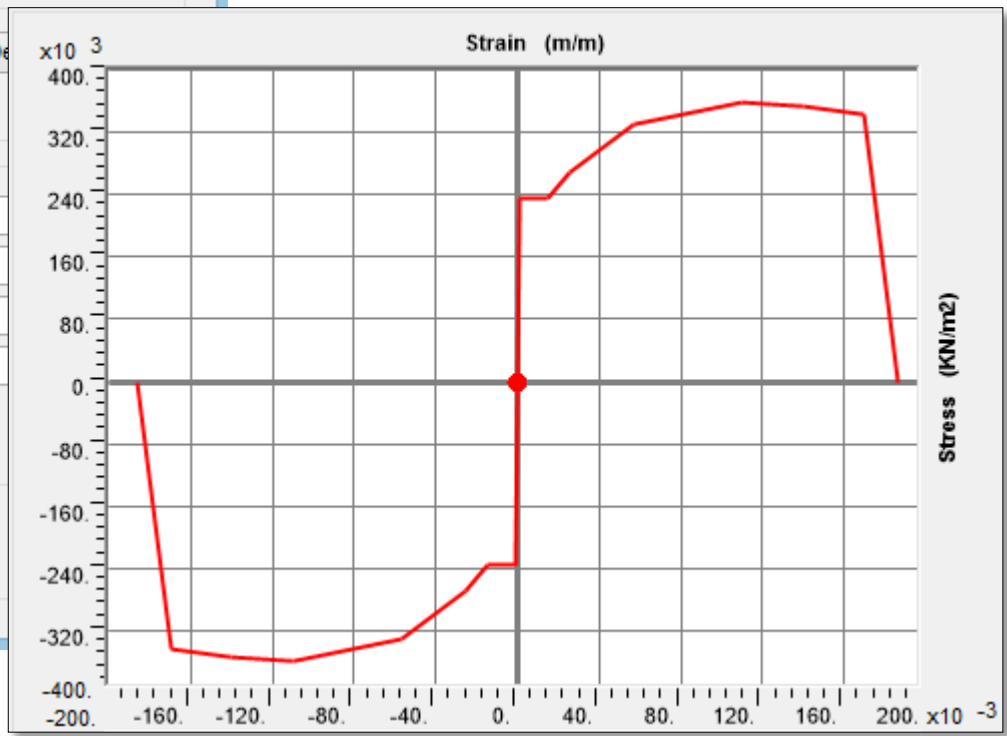
Stress-Strain Curve Definition Options
Parametric
User Defined
Simple
Convert To User De

Parametric Strain Data

Strain At Onset of Strain Hardening	0.015
Strain At Maximum Stress	0.11
Strain At Rupture	0.17
Final Slope (Multiplier on E)	-0.1

Show Stress-Strain Plot...

OK Cancel



3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35

Define > Section Property > Area Sections

Section Name: TH5mm

Shell - Layered/Nonlinear

Layer Definition Data

Layer Name	Distance	Thickness	Type	Num Int. Points	Material	Material Angle	Material Behavior S11	Material Behavior S22	Material Behavior S12
1	0.	0.005	Shell	5	S235	0.	Nonlinear	Nonlinear	Nonlinear

Section Name: TH4mm

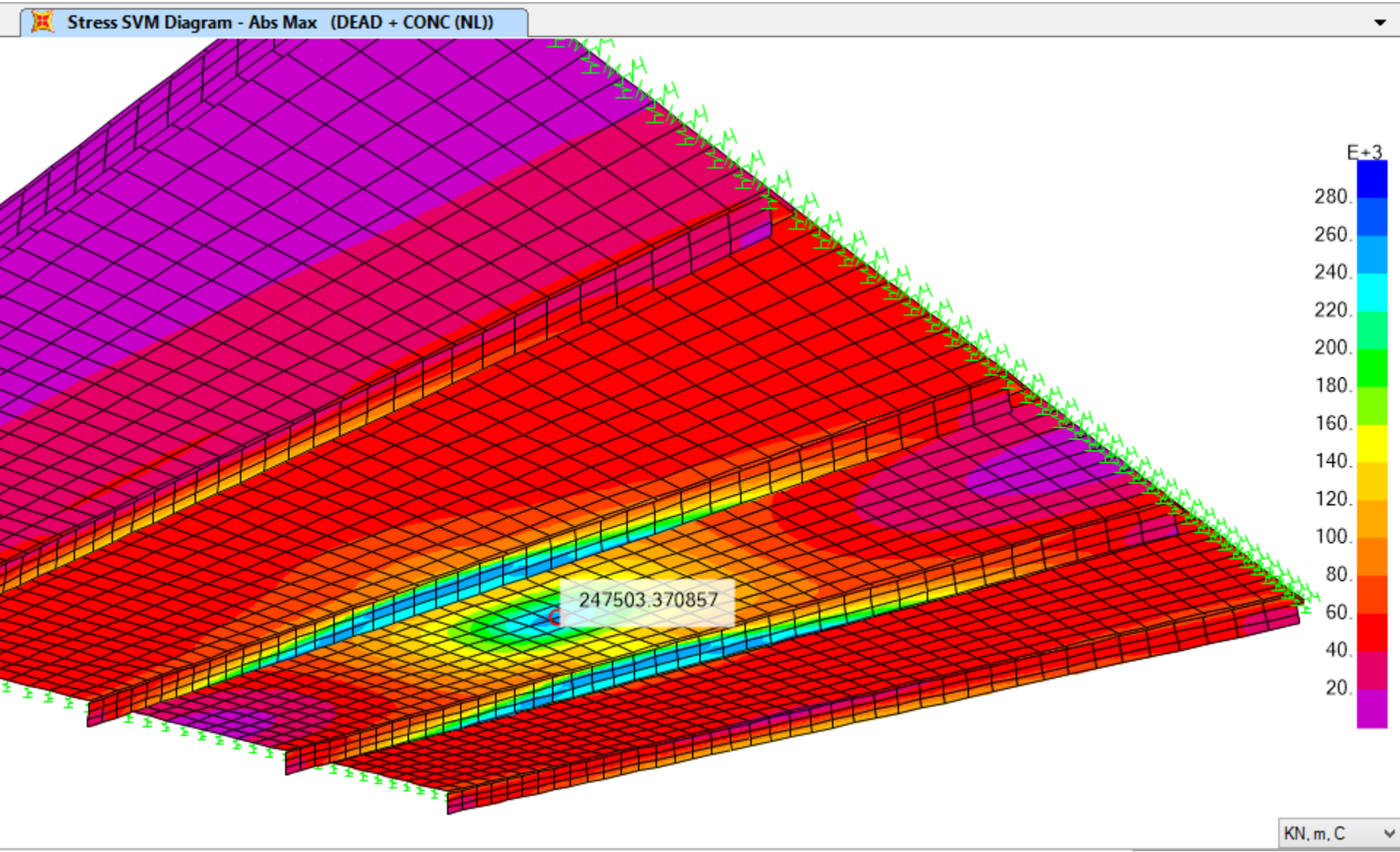
Shell - Layered/Nonlinear

Layer Definition Data

Layer Name	Distance	Thickness	Type	Num Int. Points	Material	Material Angle	Material Behavior S11	Material Behavior S22	Material Behavior S12
1	0.	0.004	Shell	2	S235	0.	Nonlinear	Nonlinear	Nonlinear

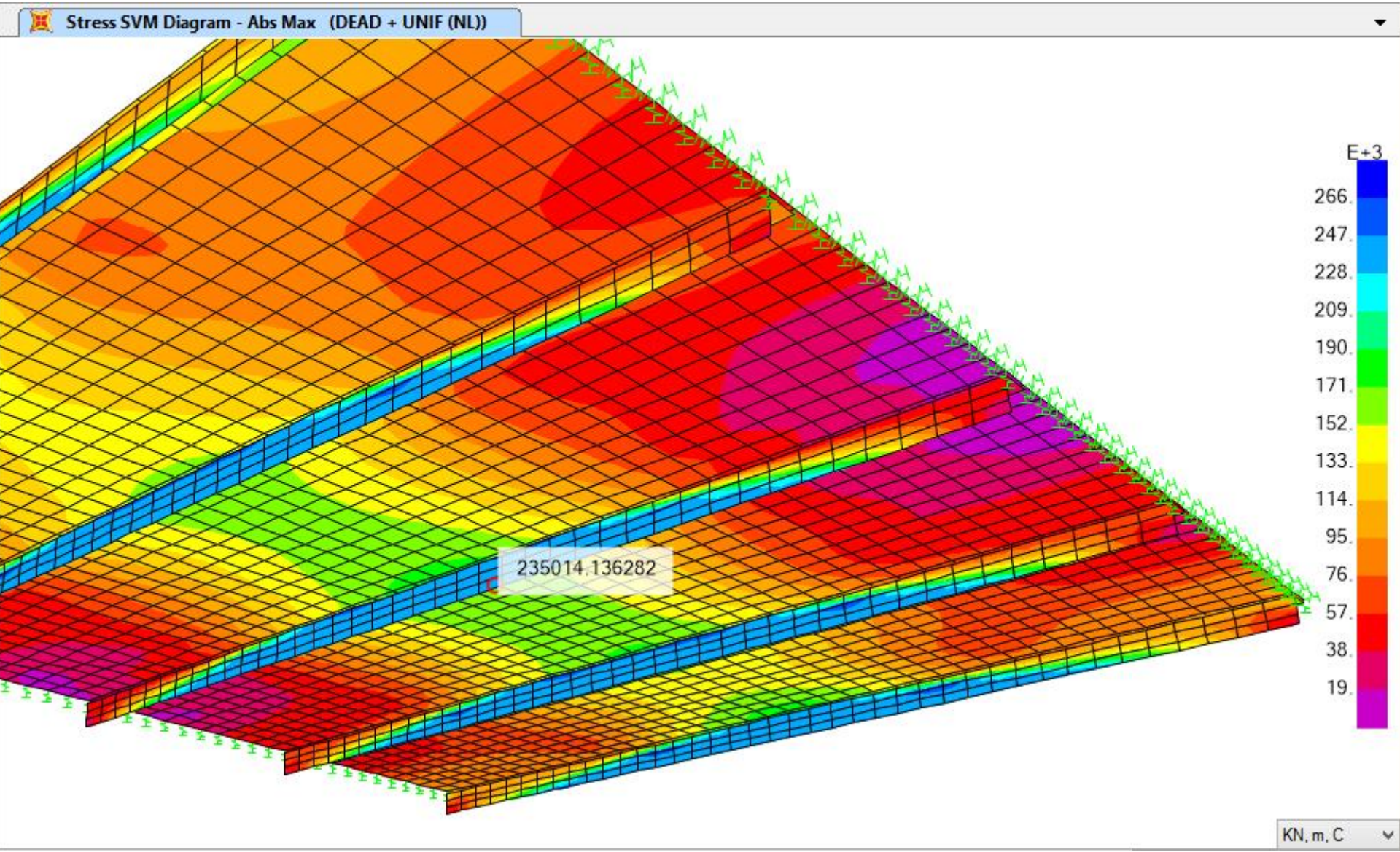
3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35



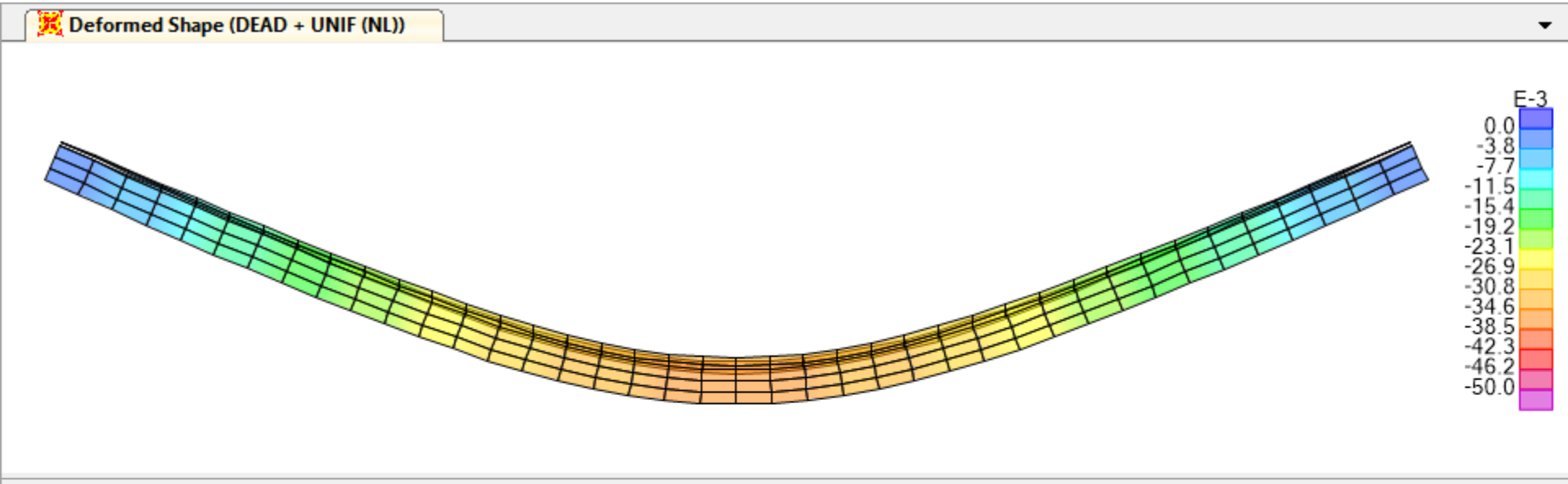
3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

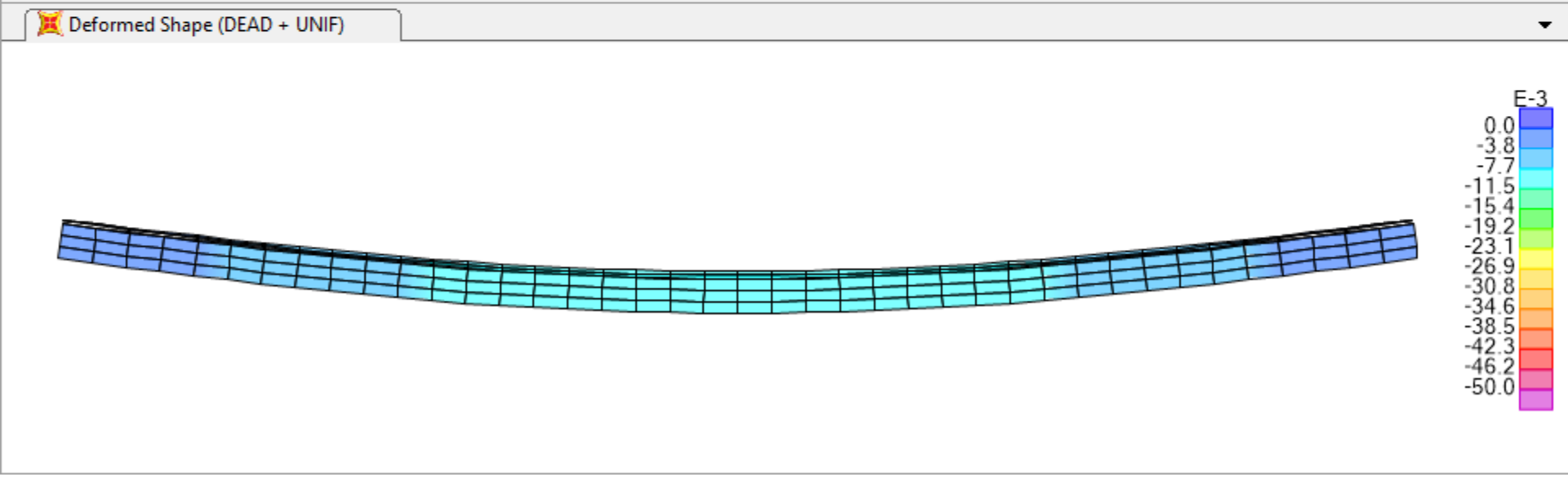
Exercise 35



3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35

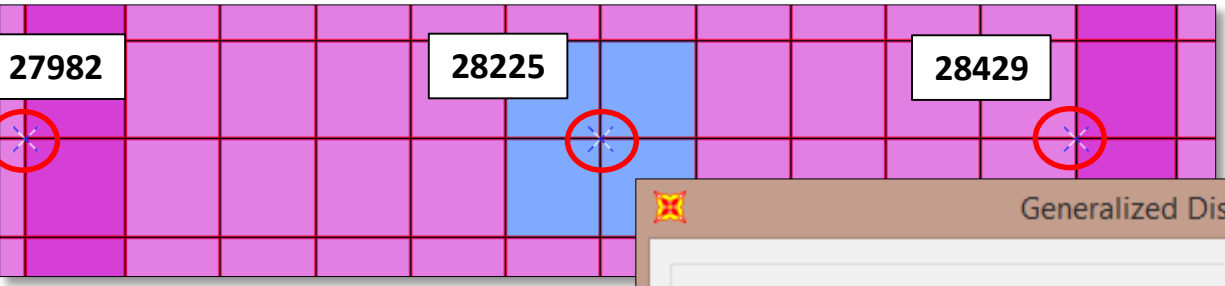




3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35

Define > Generalized Displacements



Generalized Displacement Definition

Generalized Displacement Name: DEFLECTION

Type: Translational / Rotational

Scale Factors

Joint	U1	U2	U3	R1	R2	R3
27982	0.	0.	-0.5	0.	0.	0.
27982	0.	0.	-0.5	0.	0.	0.
28225	0.	0.	1.	0.	0.	0.
28429	0.	0.	-0.5	0.	0.	0.

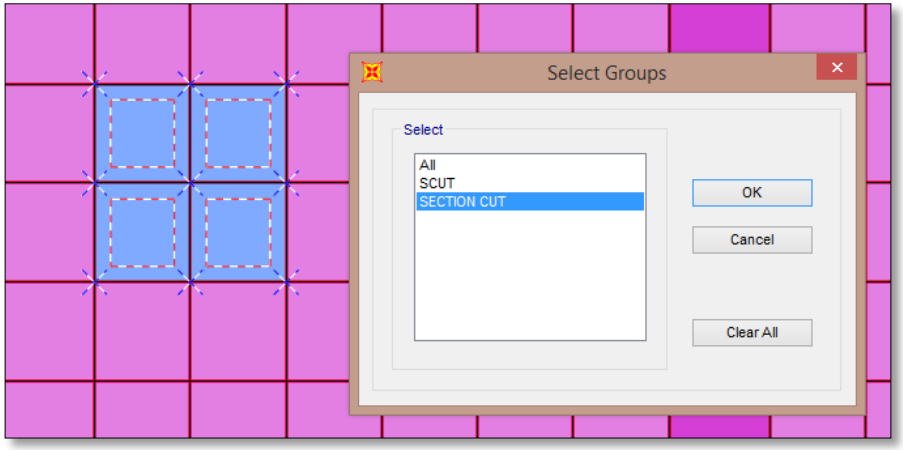
Add | Modify | Delete

OK | Cancel

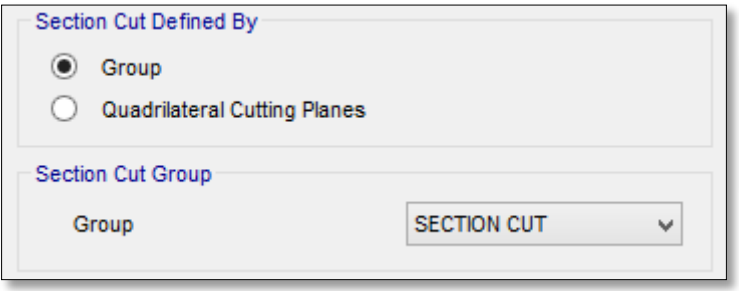
3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

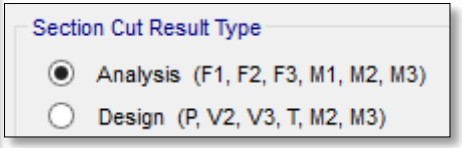
Exercise 35

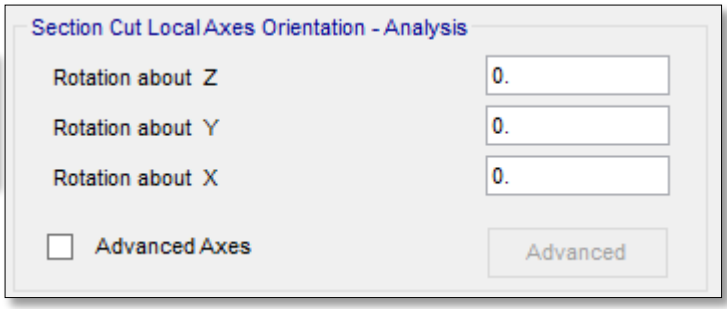
Define > Groups



Define > Section Cuts







3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

Exercise 35

DEAD_NL

Load Case Name: DEAD_NL

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	DEAD	1
Load Pattern	DEAD	1

Analysis Type
- ○ Linear
- ◉ Nonlinear
- ○ Nonlinear Staged Construction

CONC_PUSH

Load Case Name: CONC_PUSH

Initial Conditions
- ○ Zero Initial Conditions - Start from Unstressed State
- ◉ Continue from State at End of Nonlinear Case: DEAD_NL

Important Note: Loads from this previous case are included in the current case

Analysis Type
- ○ Linear
- ◉ Nonlinear
- ○ Nonlinear Staged Construction

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	CONC	1.
Load Pattern	CONC	1.

Load Application Control
- ○ Full Load
- ◉ Displacement Control

Control Displacement
- ○ Use Conjugate Displacement
- ◉ Use Monitored Displacement

Load to a Monitored Displacement Magnitude of: 0.04

Monitored Displacement
- ○ DOF at Joint
- ◉ Generalized Displacement: DEFLECTION

For Each Stage

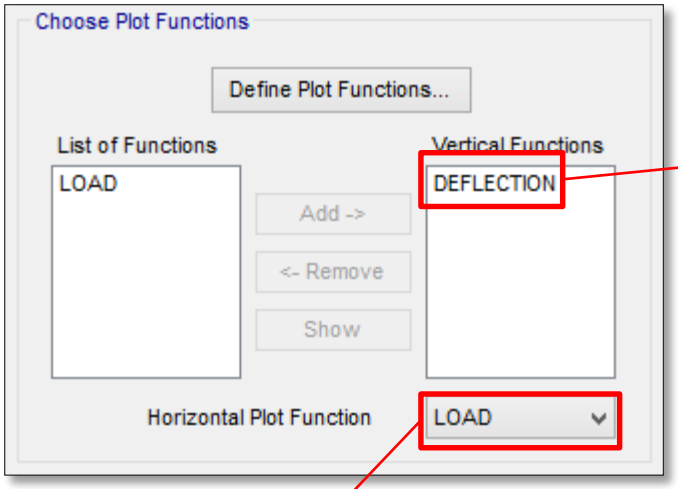
Minimum Number of Saved States: 50

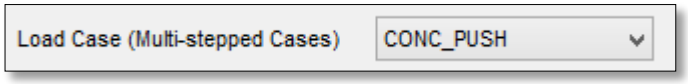
Maximum Number of Saved States: 100

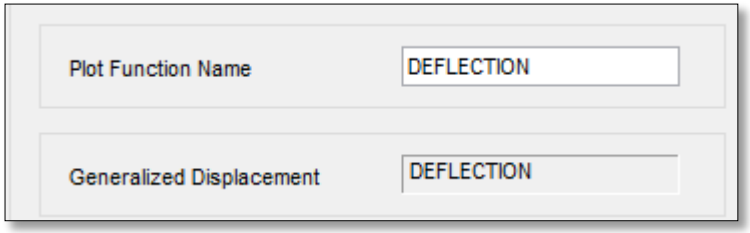
3.4. Nonlinear Shell Elements
3.4.1 Steel Floor Plate

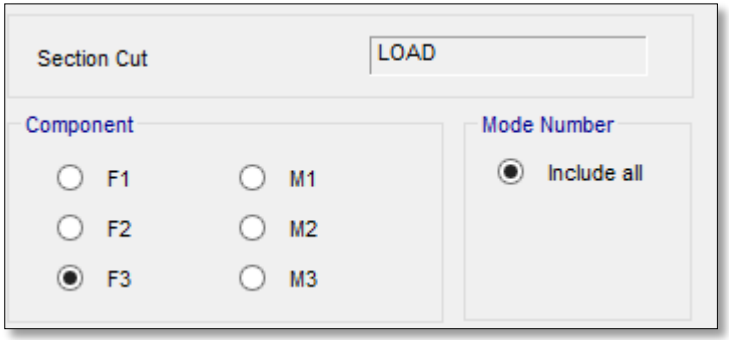
Exercise 35

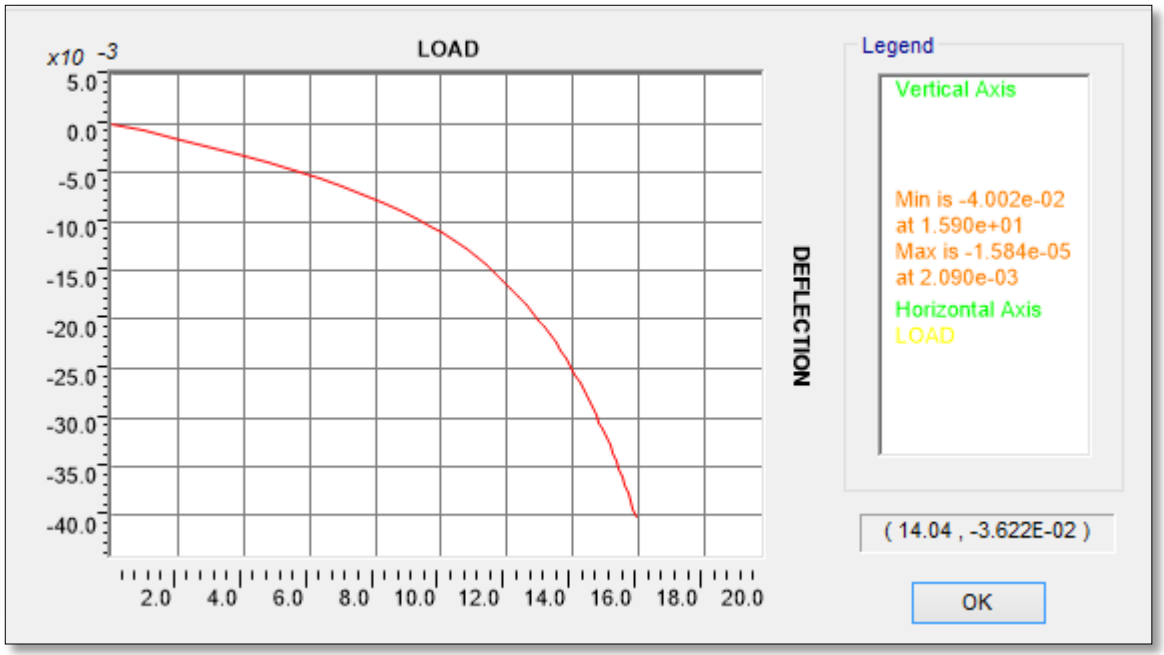
Display > Show Plot Functions











SAP2000®

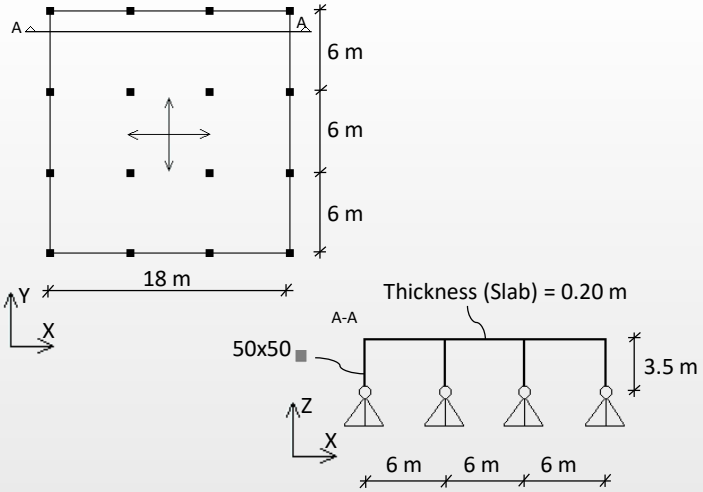
Exercise 36

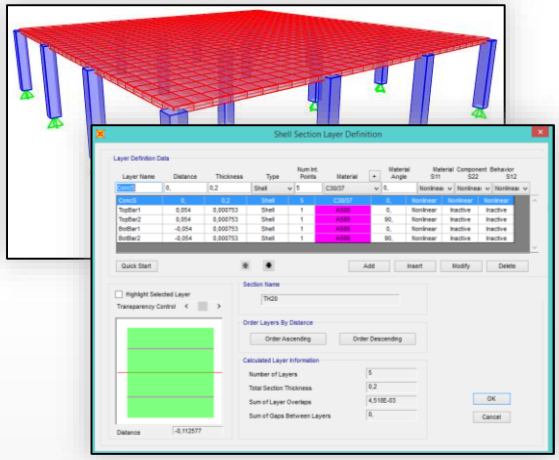
Material Nonlinearity in Reinforced Concrete Shell Models

Model a reinforced concrete slab considering material nonlinearity and cracked behavior

Problem:

Model a reinforced concrete flat slab with nonlinear layered shell elements. Define the rebar layers and the concrete and rebar steel stress-strain curves. Compare results obtained from linear and nonlinear analysis and display stress maps for each layer.



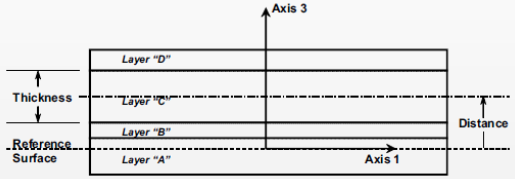


Modeling topics

- Material Nonlinearity
- Cracked Behavior
- Stress-strain curves

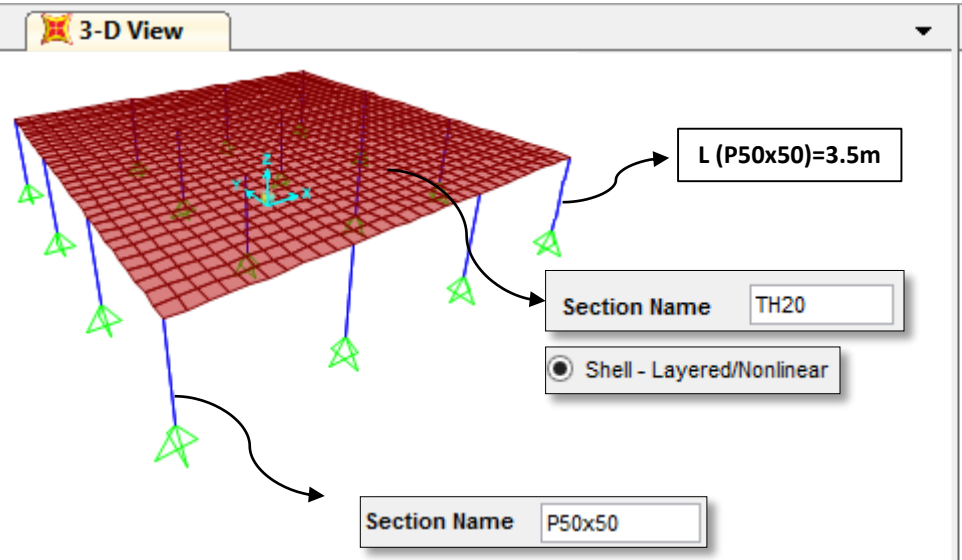
SAP2000 features

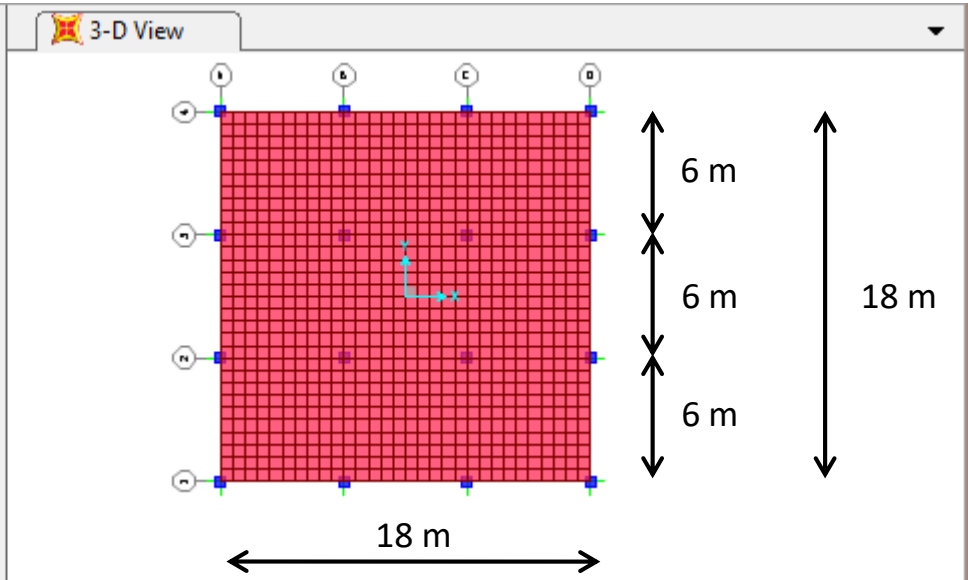
- Nonlinear Layered Shell
- Static Nonlinear Analysis

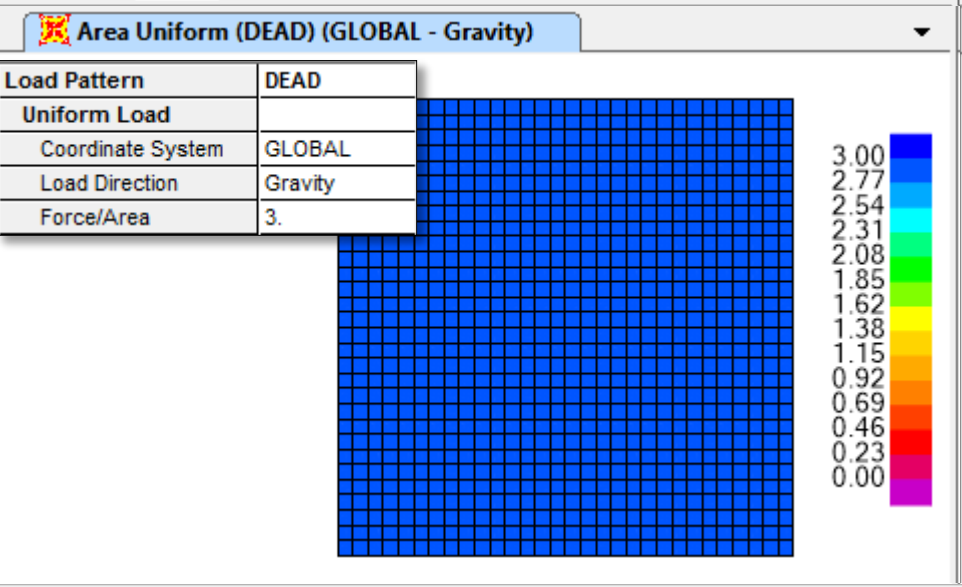


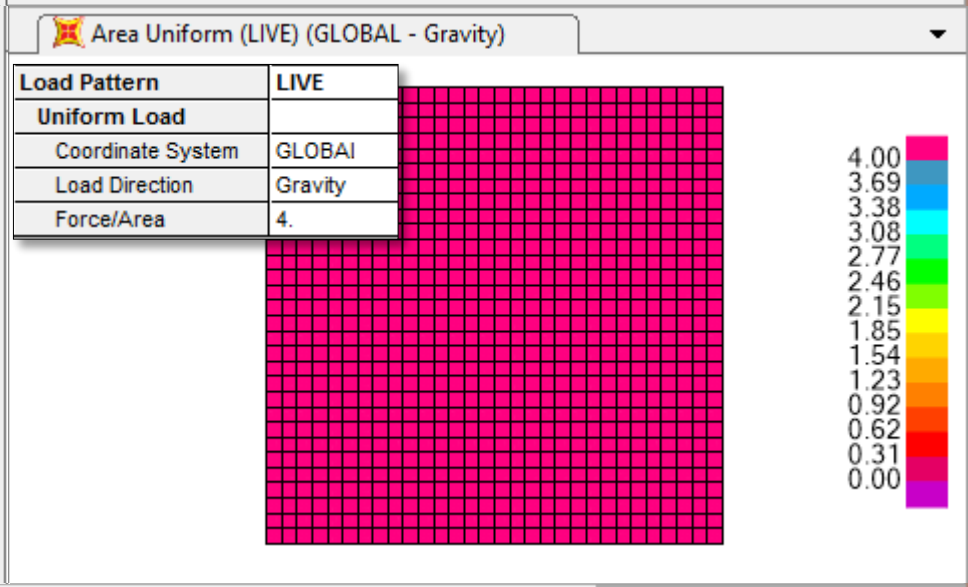
3.4. Nonlinear Shell Elements
3.4.2 Reinforced Concrete Slab

Exercise 36



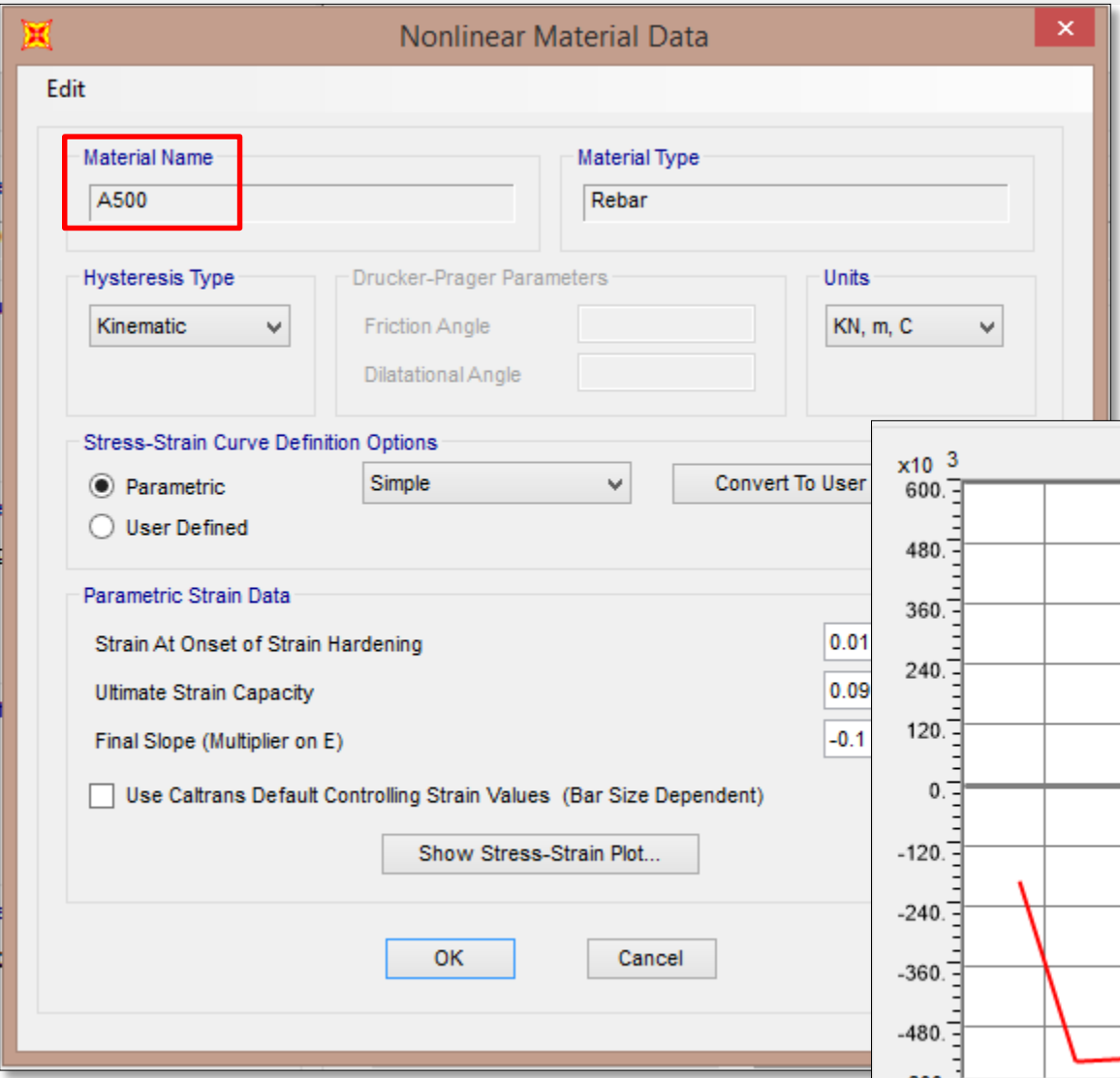


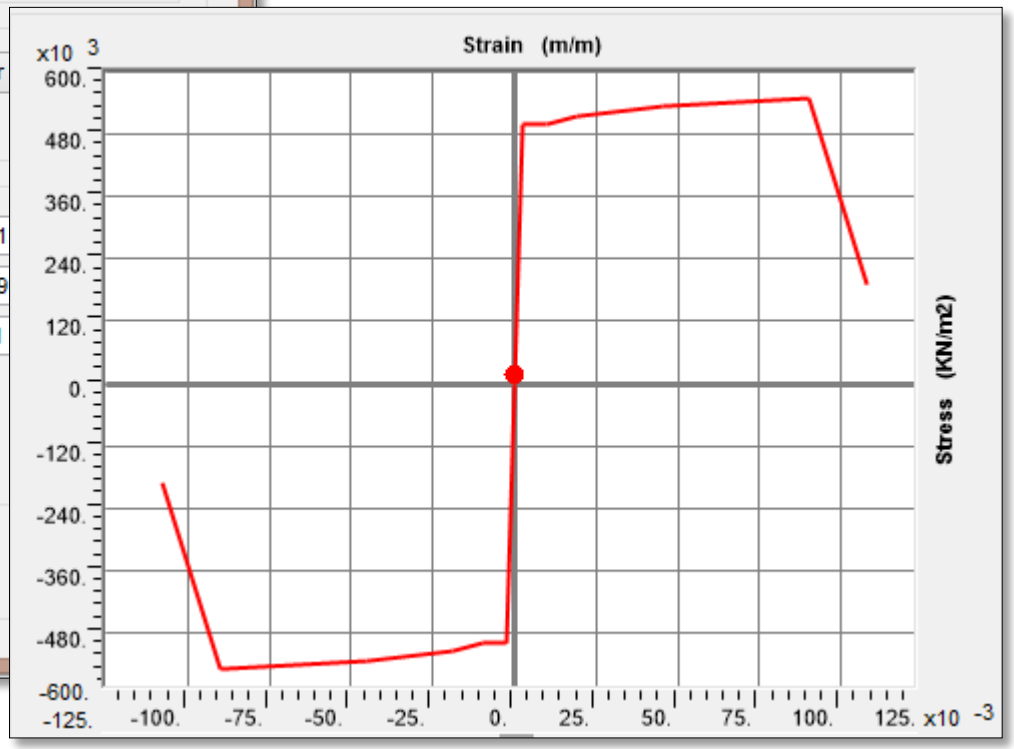




3.4. Nonlinear Shell Elements
3.4.2 Reinforced Concrete Slab

Exercise 36





3.4. Nonlinear Shell Elements
3.4.2 Reinforced Concrete Slab

C30/37

Exercise 36

Stress-Strain Curve Definition Options

- (○) Parametric — Convert To User Defined
- (●) User Defined

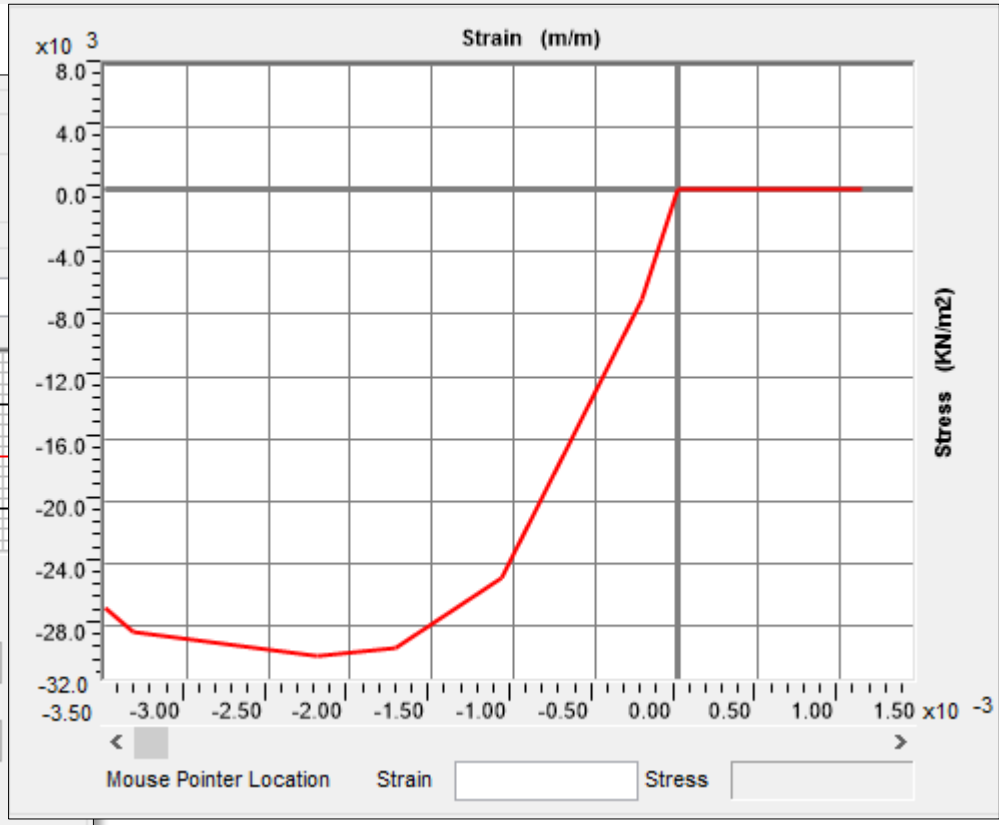
User Stress-Strain Curve Data

Number of Points in Stress-Strain Curve: 8

	Strain	Stress	Point ID
1	-3.500E-03	-26868.87	-E
2	-3.326E-03	-28345.13	
3	-2.200E-03	-30000.	-C
4	-1.725E-03	-29370.44	
5	-1.074E-03	-24983.2	
6	-2.200E-04	-7061.86	
7	0.	0.	A
8	1.137E-03	0.	E

Order Rows

Show Plot...



Parametric Strain Data

Strain At Unconfined Compressive Strength, f'c	2.219E-03
Ultimate Unconfined Strain Capacity	5.000E-03
Final Compression Slope (Multiplier on E)	-0.1

The Concrete Stress Strain curve was generated parametrically, and then converted into User-Defined to set the tension stiffness to zero. (see Section 1.7)

3.4. Nonlinear Shell Elements
3.4.2 Reinforced Concrete Slab

Exercise 36

Define > Section Property > Area Sections > Modify/Show Layer Definition > Quick Start

Section Name: TH20

Rebar Layers
- ○ One Layer
- ◉ Two Layers

Material Data And Concrete Thickness

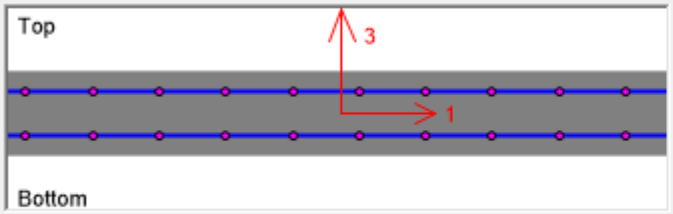
Concrete Material	+	C30/37
Rebar Material	+	A500
Concrete Thickness		0.2

Rebar Size, Spacing and Clear Cover

☑ Size and Spacing Is the Same For All Rebar

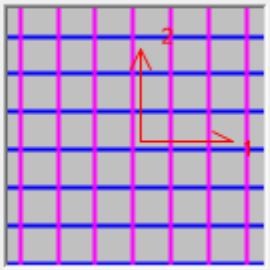
Top Bars - Direction 1	+	12d	@	0.15	Cover	0.04
Top Bars - Direction 2		12d	@	0.15	Cover	0.04
Bottom Bars - Direction 1		12d	@	0.15	Cover	0.04
Bottom Bars - Direction 2		12d	@	0.15	Cover	0.04

Shell Section Elevation View



◉ Show Elevation 1-3 ○ Show Elevation 2-3

Shell Section Plan View



◉ Top ○ Bot

In-Plane Element Component Behavior
- ☑ S11 Nonlinear
- ☑ S22 Nonlinear
- ☑ S12 Nonlinear

Out-of-Plane Element Component Behavior
- ◉ Same as In-Plane
- ○ Linear

3.4. Nonlinear Shell Elements
3.4.2 Reinforced Concrete Slab

Exercise 36

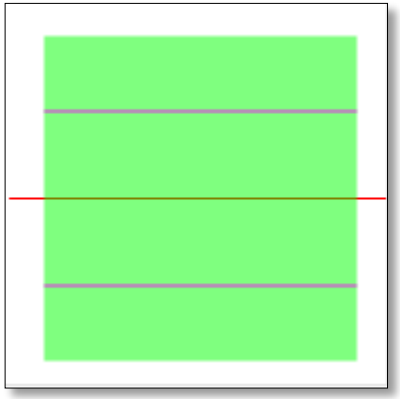
Define > Section Property > Area Sections > Modify/Show Layer Definition

Section Name TH20

Shell - Layered/Nonlinear

Layer Definition Data

Layer Name	Distance	Thickness	Type	Num Int. Points	Material	+	Material Angle	Material Component Behavior S11	Material Component Behavior S22	Material Component Behavior S12
ConcS	0.	0.2	Shell	5	C30/37		0.	Nonlinear	Nonlinear	Nonlinear
ConcS	0.	0.2	Shell	5	C30/37		0.	Nonlinear	Nonlinear	Nonlinear
TopBar1	0.054	0.000753	Shell	1	A500		0.	Nonlinear	Inactive	Inactive
TopBar2	0.054	0.000753	Shell	1	A500		90.	Nonlinear	Inactive	Inactive
BotBar1	-0.054	0.000753	Shell	1	A500		0.	Nonlinear	Inactive	Inactive
BotBar2	-0.054	0.000753	Shell	1	A500		90.	Nonlinear	Inactive	Inactive



Calculated Layer Information

Number of Layers	5
Total Section Thickness	0.2
Sum of Layer Overlaps	4.518E-03
Sum of Gaps Between Layers	0.

3.4. Nonlinear Shell Elements
3.4.2 Reinforced Concrete Slab

Exercise 36

Linear Load Cases

Load Case Name: DEAD

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	DEAD	1.

Load Case Name: LIVE

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	LIVE	1.

Analysis Type
- (•) Linear
- ( ) Nonlinear
- ( ) Nonlinear Staged Construction

NonLinear Load Case

Load Case Name: ULS_NL

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	DEAD	1.35
Load Pattern	LIVE	1.5

Analysis Type
- ( ) Linear
- (•) Nonlinear
- ( ) Nonlinear Staged Construction

Linear Combination

Load Combination Name: ULS

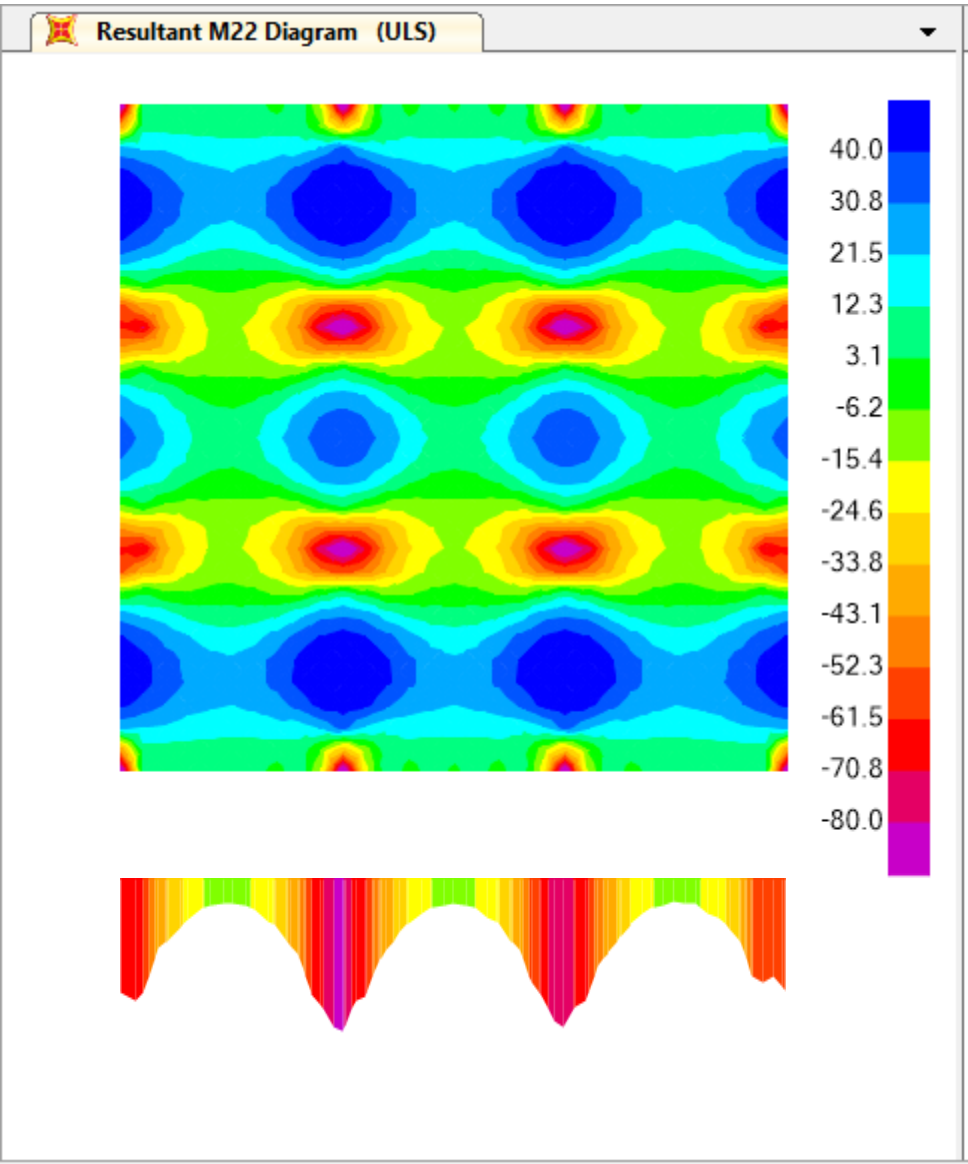
Define Combination of Load Case Results

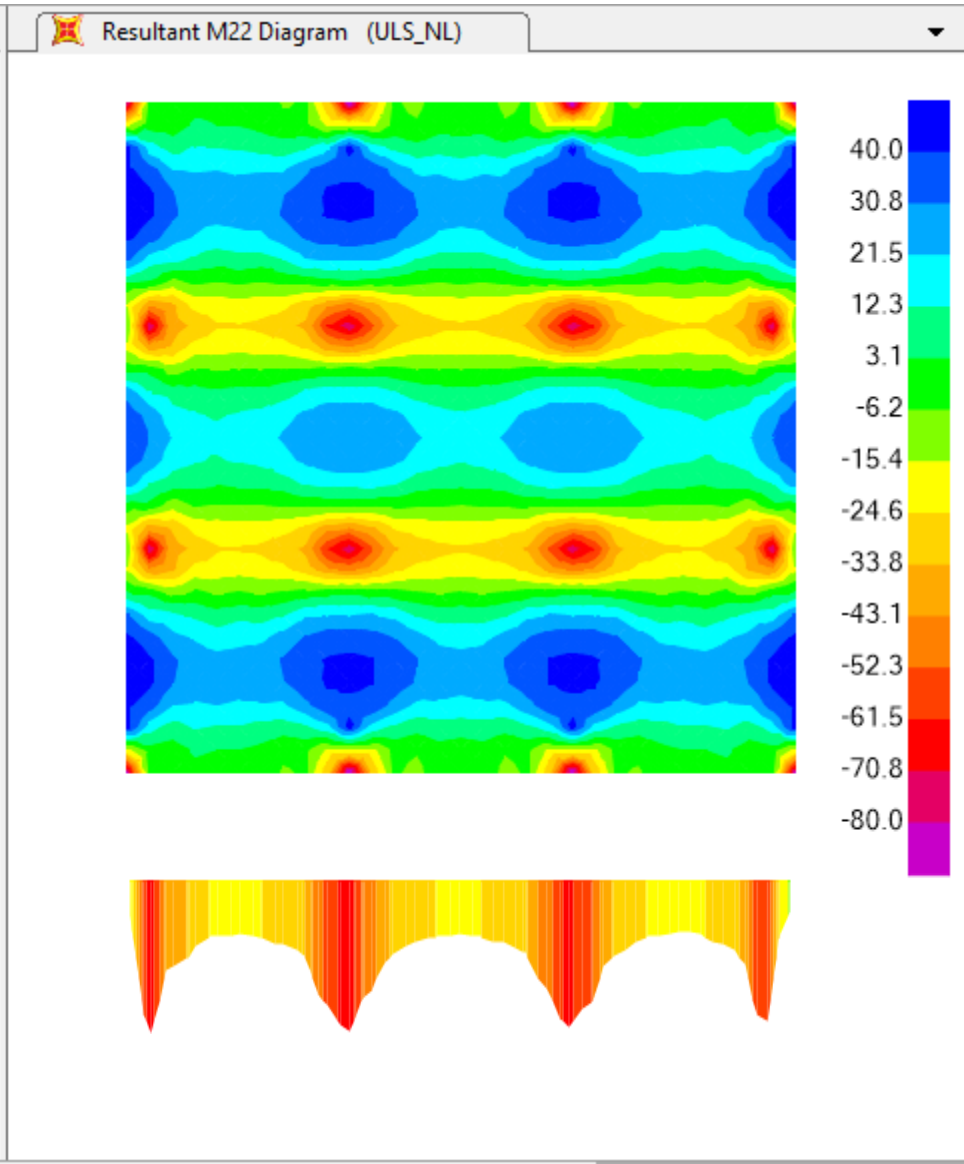
Load Case Name	Load Case Type	Scale Factor
DEAD	Linear Static	1.35
LIVE	Linear Static	1.5

Linear Add

3.4. Nonlinear Shell Elements
3.4.2 Reinforced Concrete Slab

Exercise 36





3.4. Nonlinear Shell Elements
3.4.2 Reinforced Concrete Slab

Exercise 36