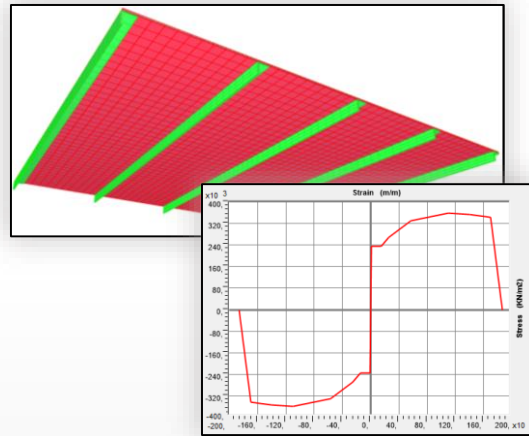
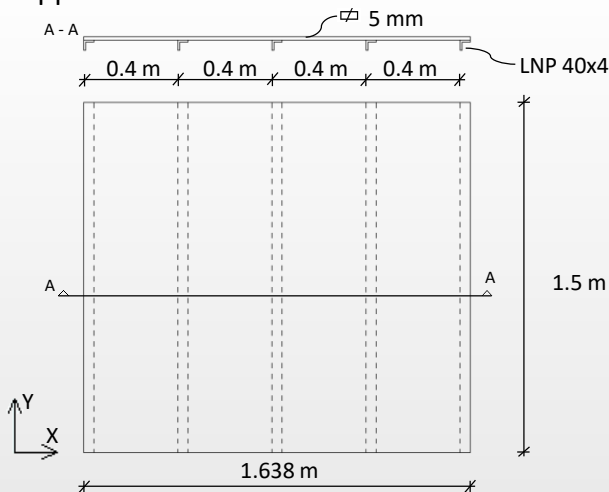


Material Nonlinearity in Steel Shell Models

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

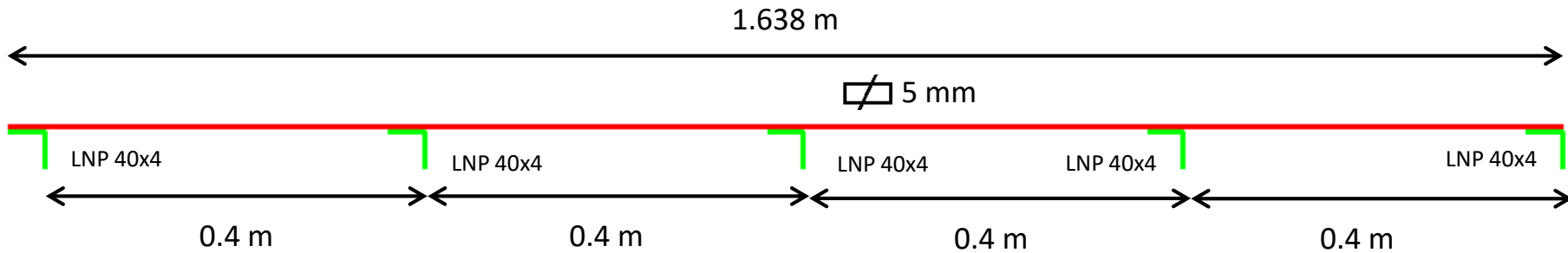
- Nonlinear Layered Shell
- Weld Constraint
- Static Nonlinear Analysis
- Save Results at Multiple States
- Continue from State at End of Nonlinear Case
- Displacement Controlled Loading
- Section Cuts
- Generalized Displacements
- Plot Functions

3.4. Nonlinear Shell Elements

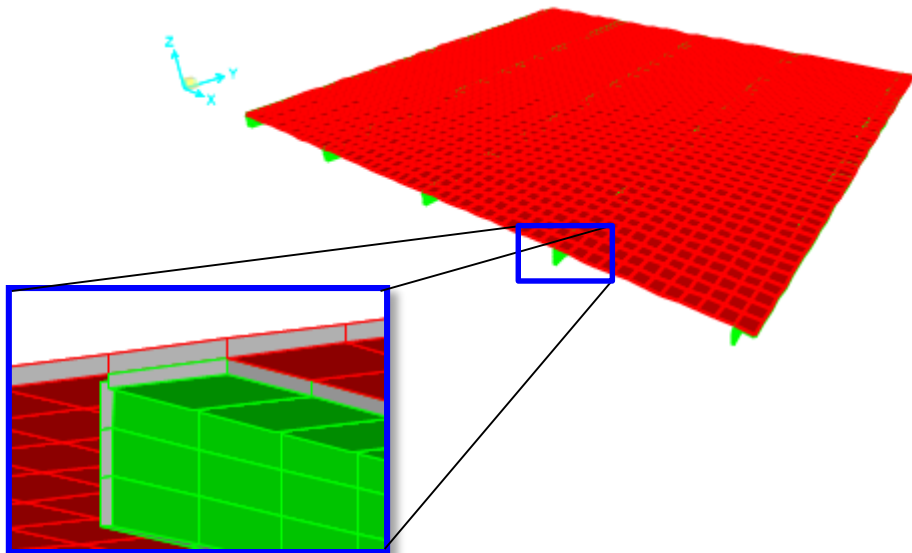
3.4.1 Steel Floor Plate

Exercise 35

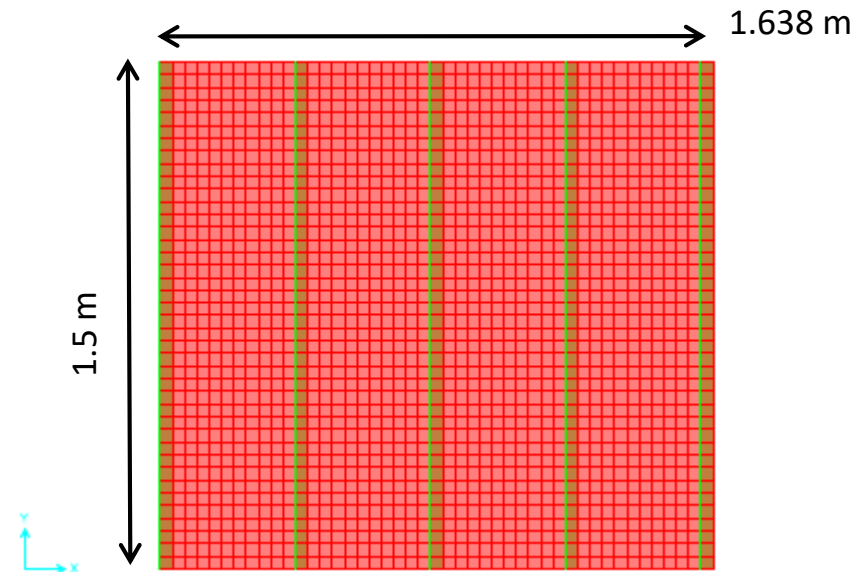
3-D View



3-D View



3-D View



3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

Exercise 35

Define > Joint Constraints > WELD

Weld Tolerance 0.01

Constrained DOFs

- Translation X
- Translation Y
- Translation Z
- Rotation X
- Rotation Y
- Rotation Z

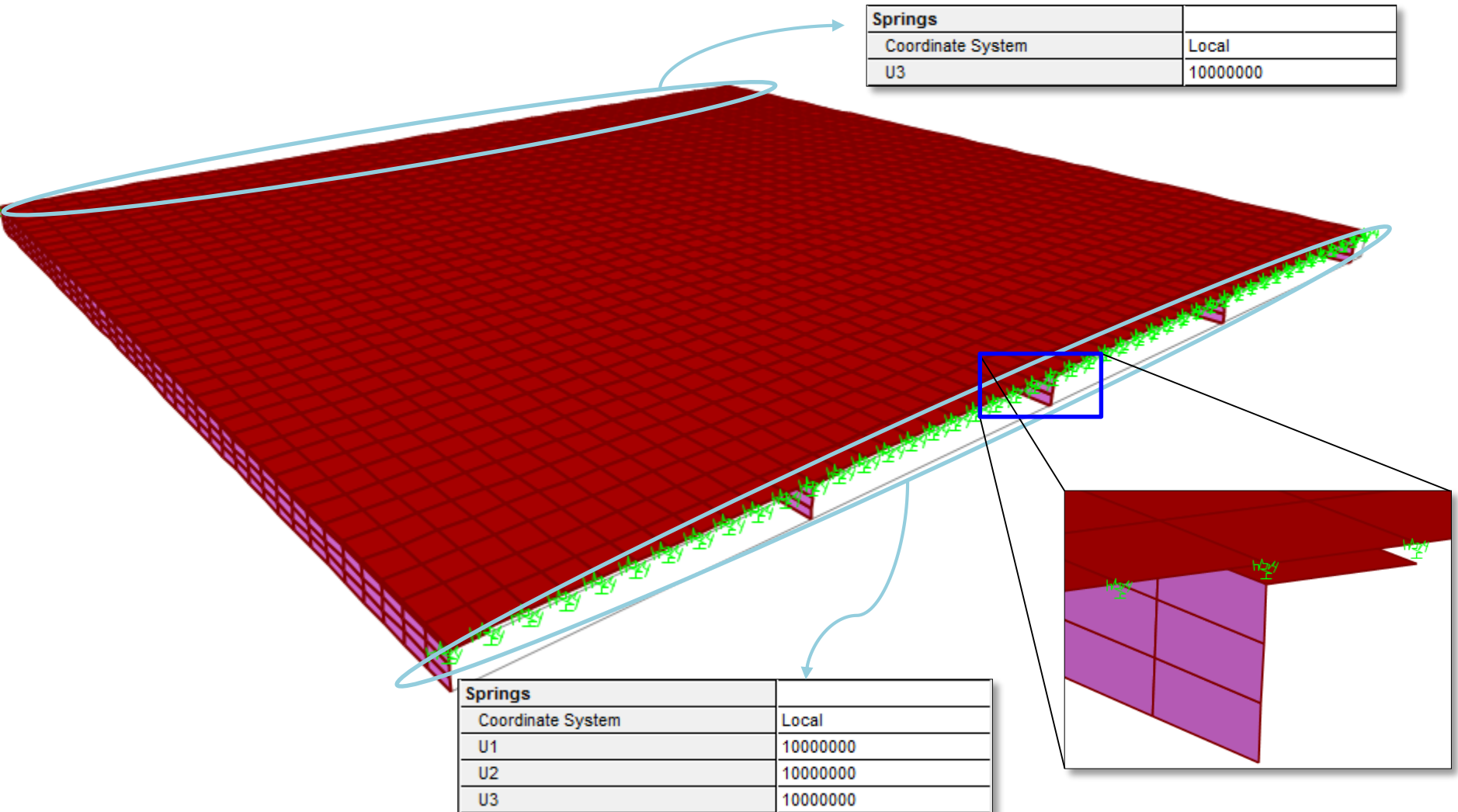
Assign > Joint > Constraints > WELD

3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

Exercise 35

3-D View



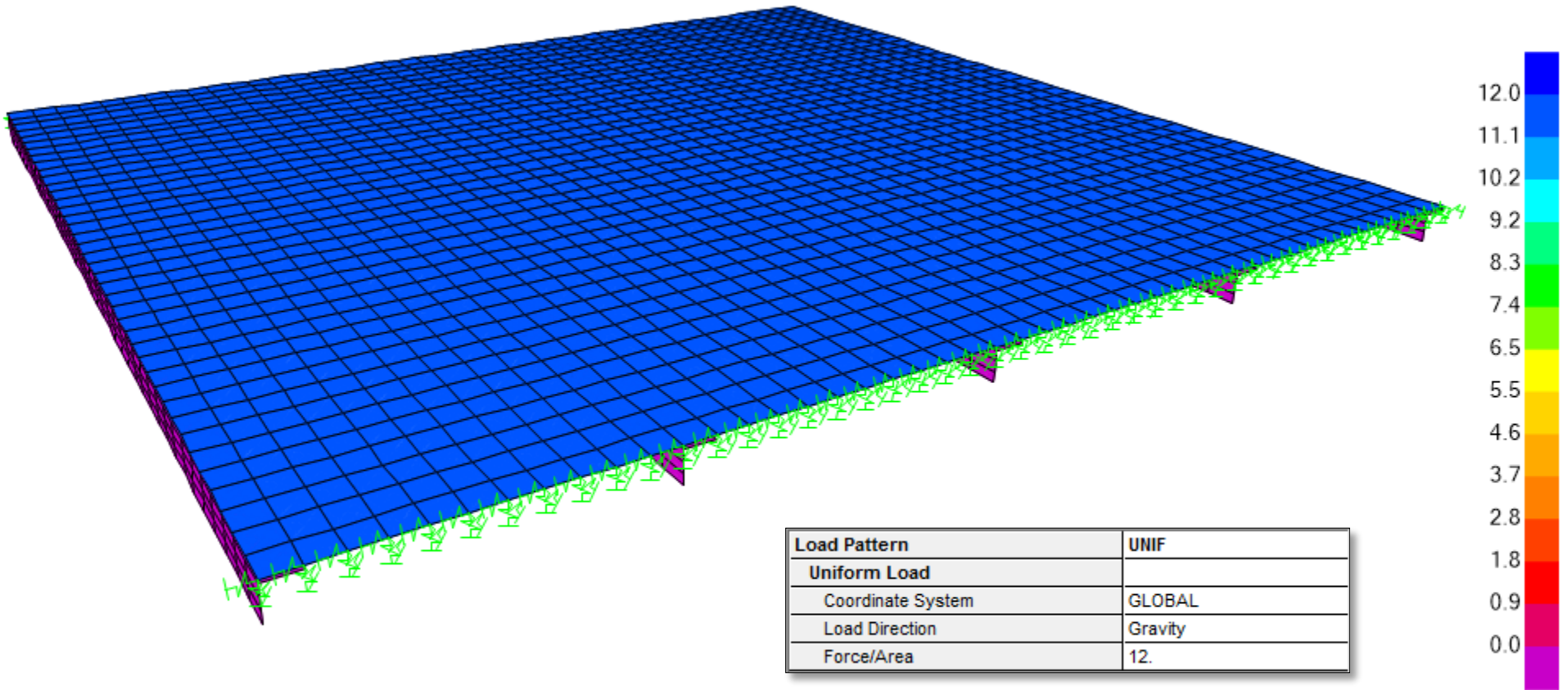
3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

Exercise 35

Area Uniform (UNIF) (GLOBAL - Gravity)

Display > Show Load Assigns > Area > UNIF



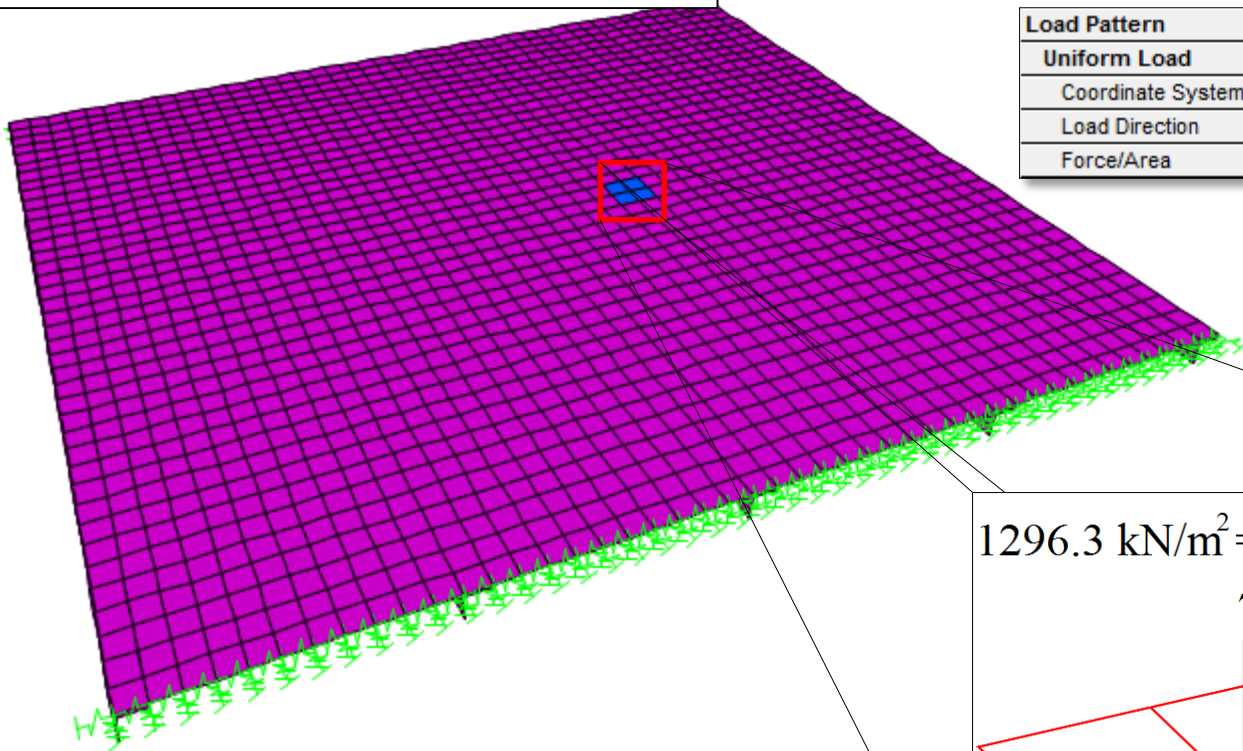
3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

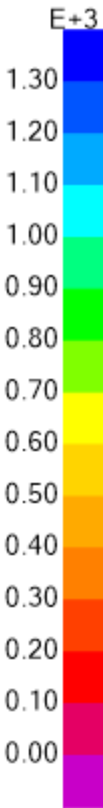
Exercise 35

Area Uniform (CONC) (GLOBAL - Gravity) X

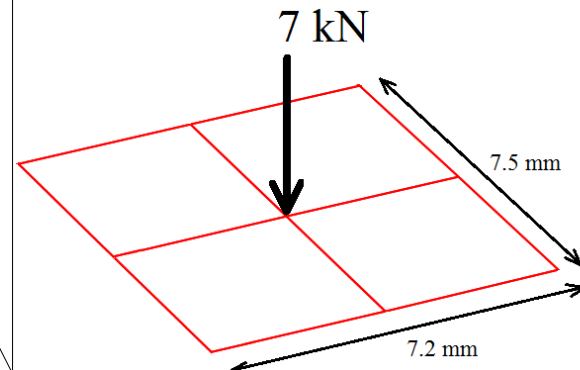
Display > Show Load Assigns > Area > CONC



Load Pattern	CONC
Uniform Load	
Coordinate System	GLOBAL
Load Direction	Gravity
Force/Area	1296.3



$$1296.3 \text{ kN/m}^2 = 7 / (0.072 \times 0.075)$$



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.

Analysis Type

- Linear
- Nonlinear
- Nonlinear Staged Construction

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.

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.

Analysis Type

- Linear
- Nonlinear
- Nonlinear Staged Construction

Load Case Name

DEAD + UNIF (NL)

Loads Applied

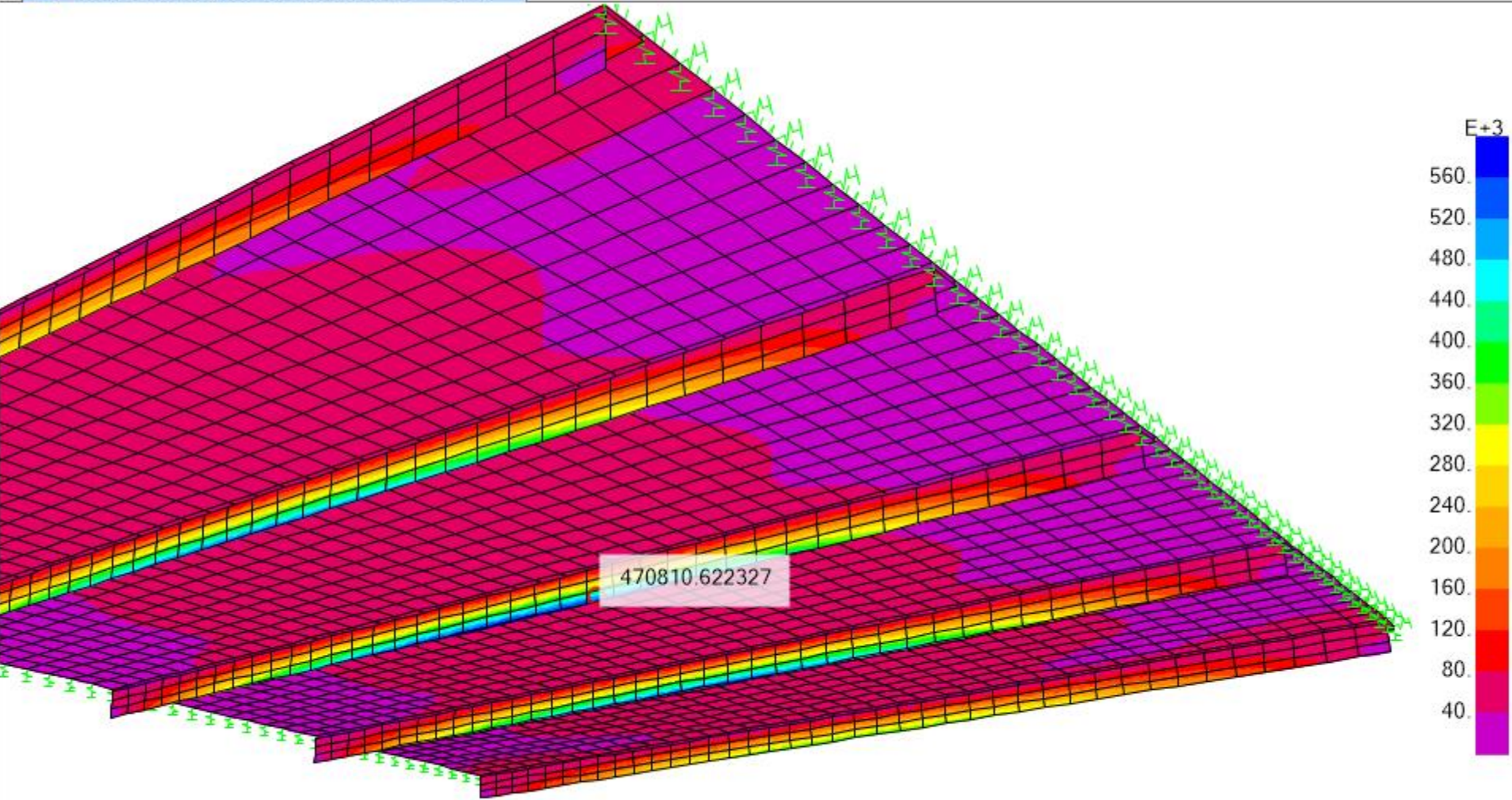
Load Type	Load Name	Scale Factor
Load Pattern	CONC	1.
Load Pattern	UNIF	1.
Load Pattern	DEAD	1.

3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

Exercise 35

Stress SVM Diagram - Abs Max (DEAD + UNIF)



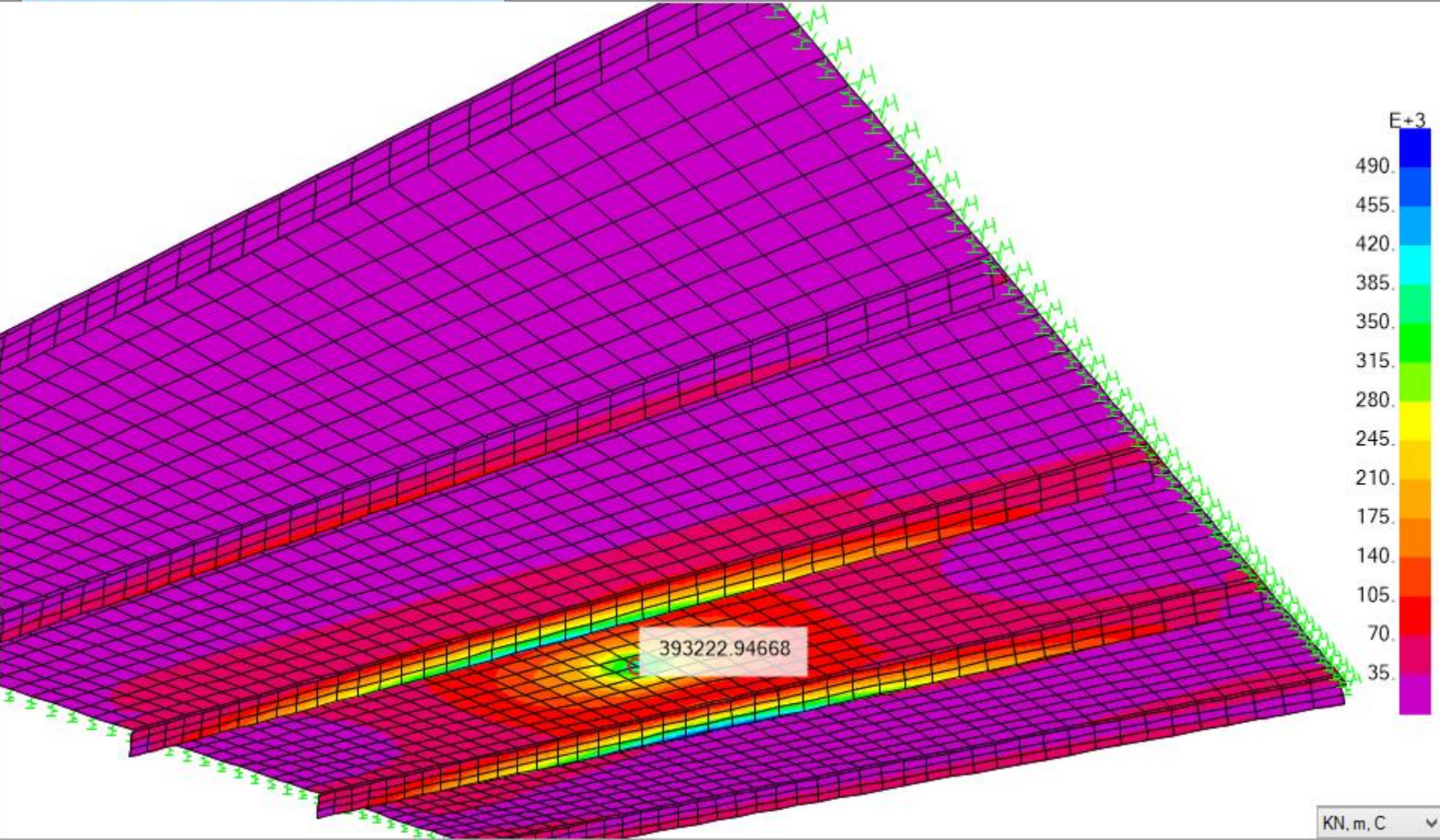
KN, m, C

3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

Exercise 35

Stress SVM Diagram - Abs Max (DEAD + CONC)



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

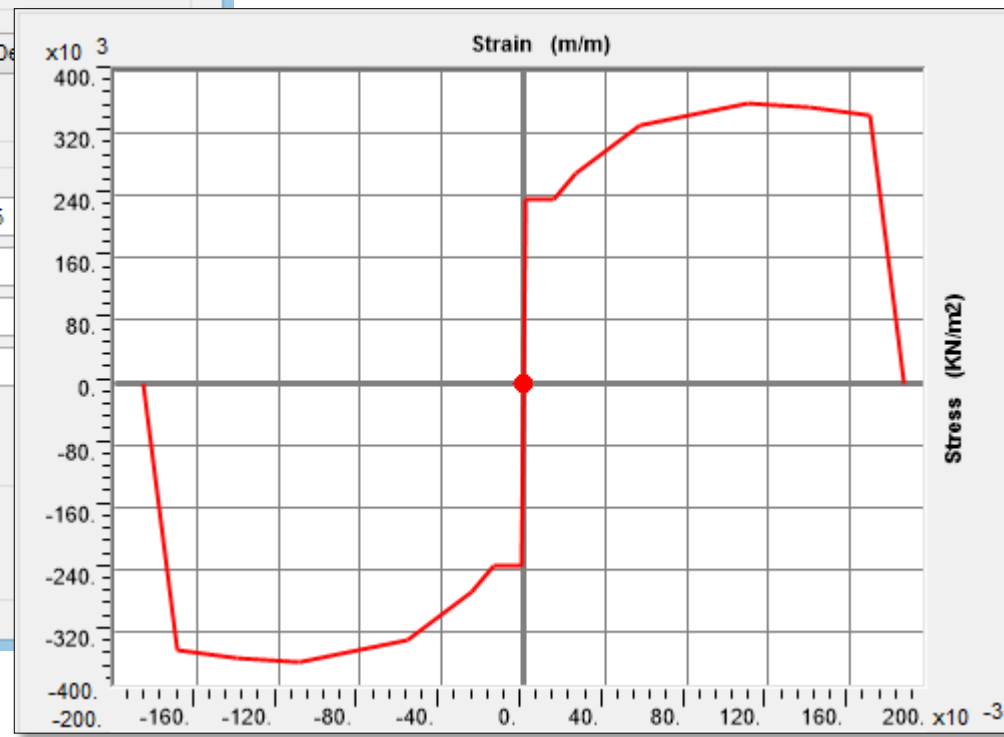
Drucker-Prager Parameters
Friction Angle
Dilatational Angle

Units
KN, m, C

Stress-Strain Curve Definition Options
 Parametric User Defined
Simple

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



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 S11	Component S22	Behavior S12
1	0.	0.005	Shell	5	S235		0.	Nonlinear	Nonlinear	Nonlinear
1	0.	0.005	Shell	5	S235		0.	Nonlinear	Nonlinear	Nonlinear

Section Name TH4mm

Shell - Layered/Nonlinear

Layer Definition Data

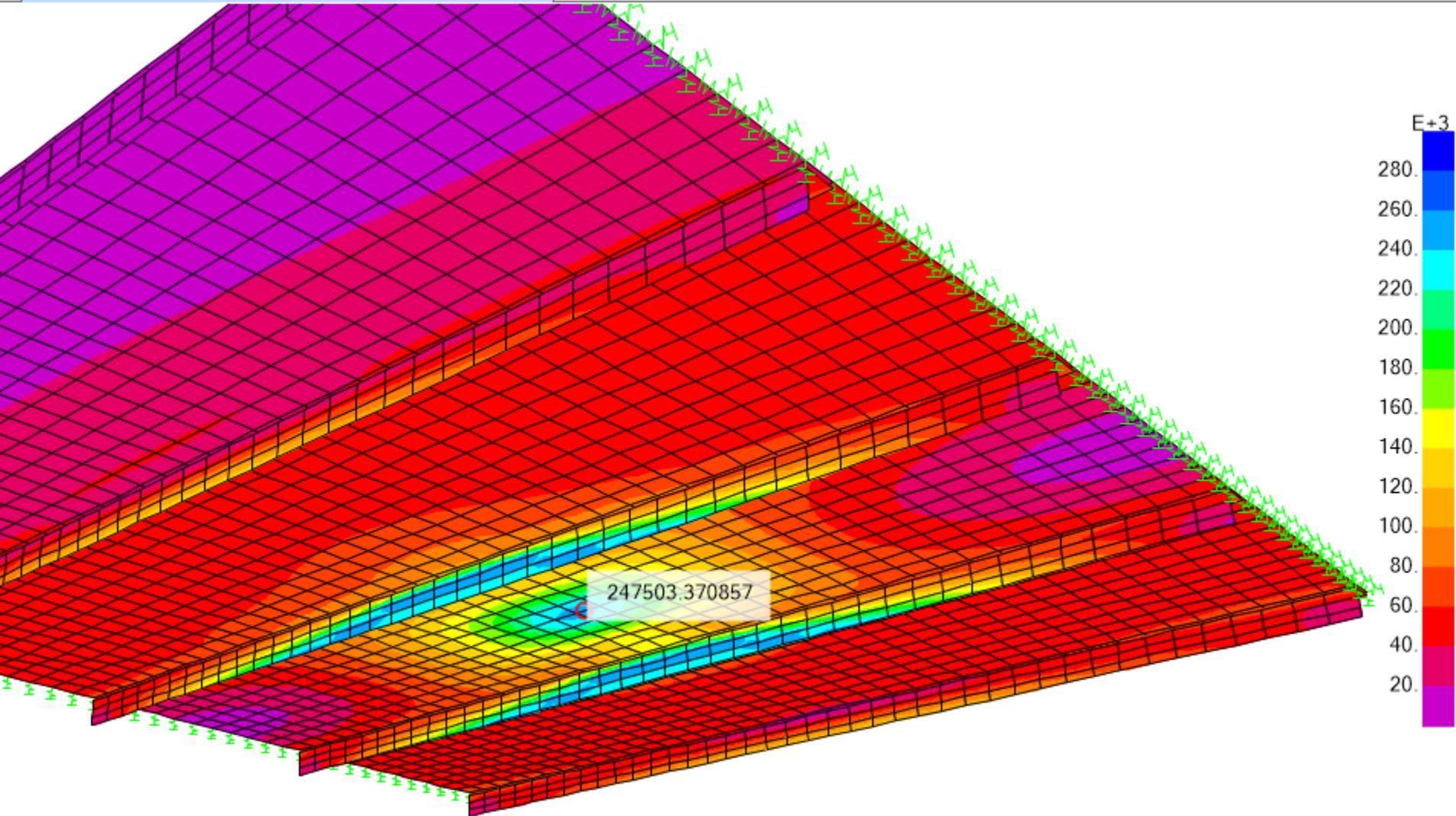
Layer Name	Distance	Thickness	Type	Num Int. Points	Material	+	Material Angle	Material S11	Component S22	Behavior S12
1	0.	0.004	Shell	2	S235		0.	Nonlinear	Nonlinear	Nonlinear
1	0.	0.004	Shell	2	S235		0.	Nonlinear	Nonlinear	Nonlinear

3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

Exercise 35

Stress SVM Diagram - Abs Max (DEAD + CONC (NL))

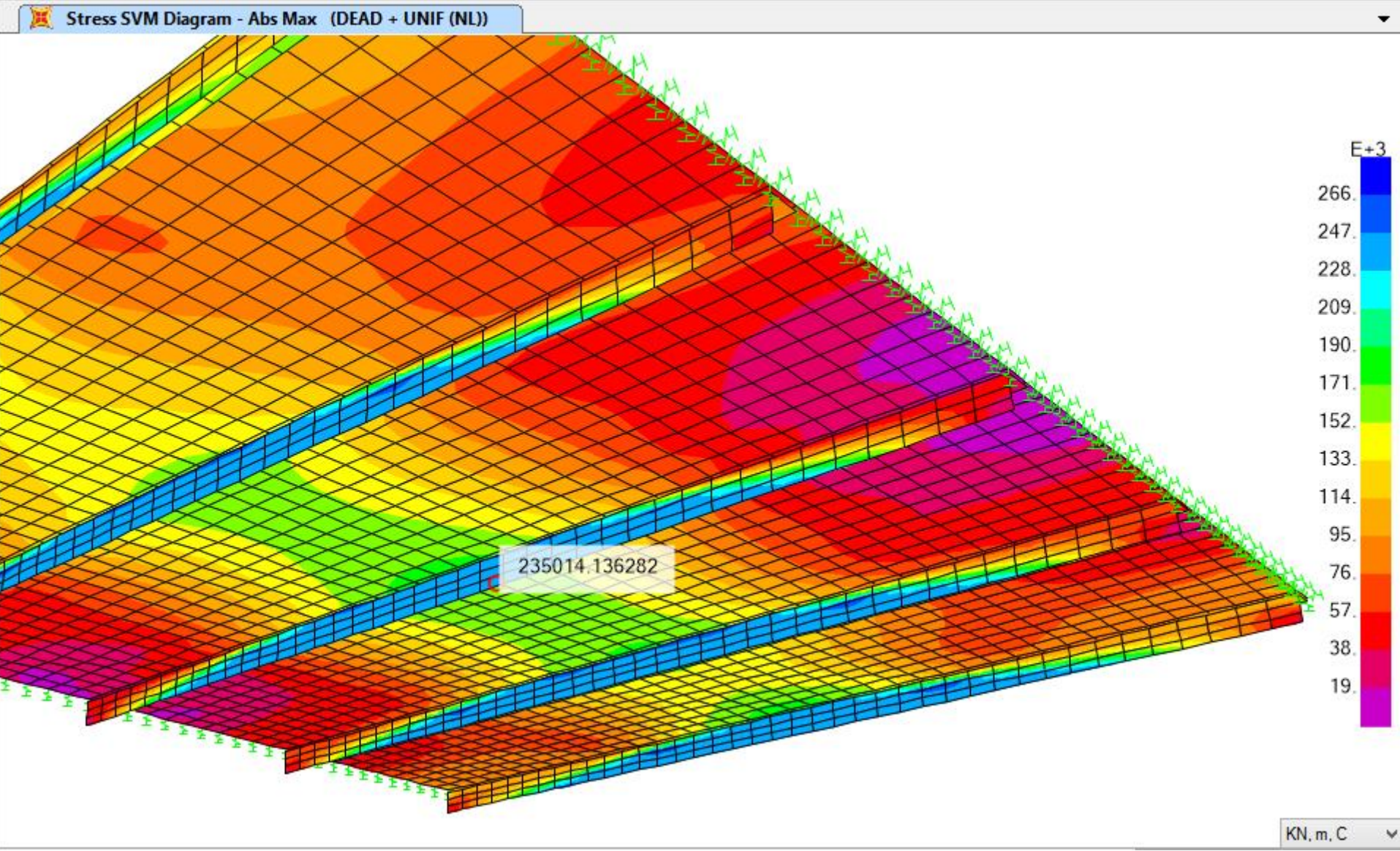


KN, m, C

3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

Exercise 35

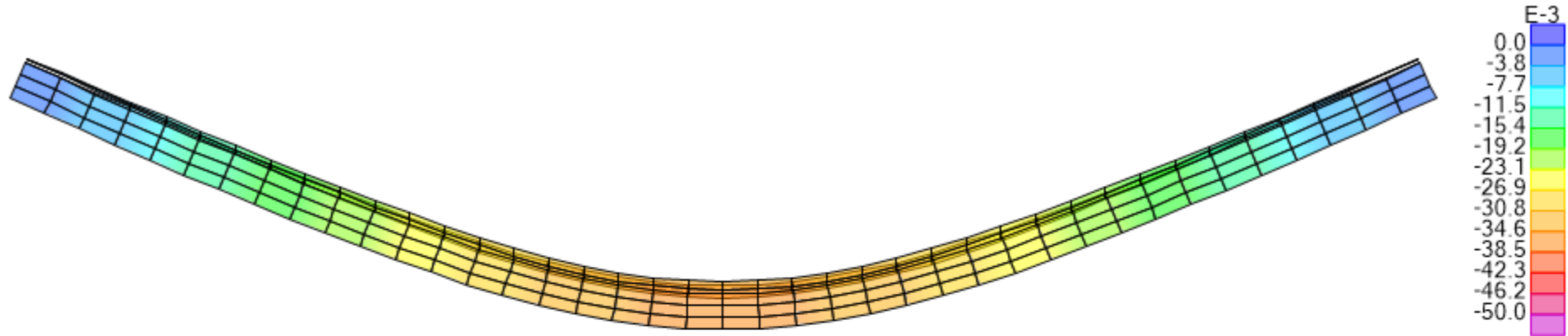


3.4. Nonlinear Shell Elements

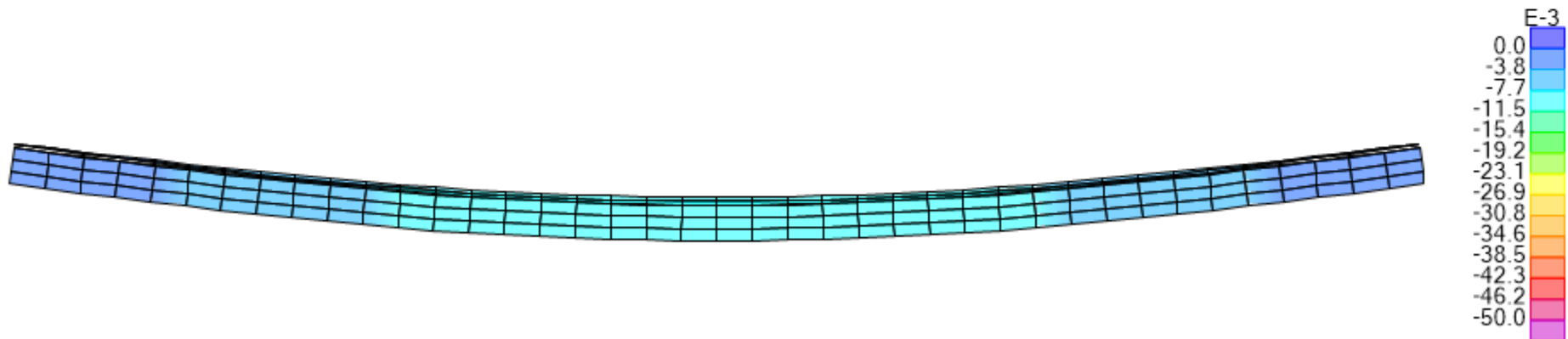
3.4.1 Steel Floor Plate

Exercise 35

Deformed Shape (DEAD + UNIF (NL))



Deformed Shape (DEAD + UNIF)

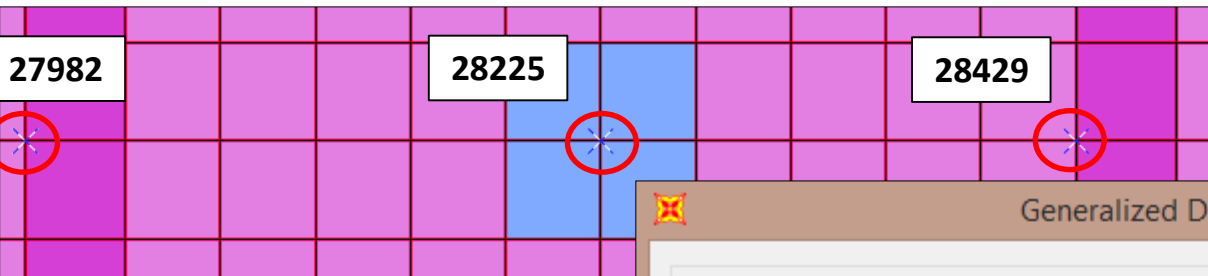


3.4. Nonlinear Shell Elements

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

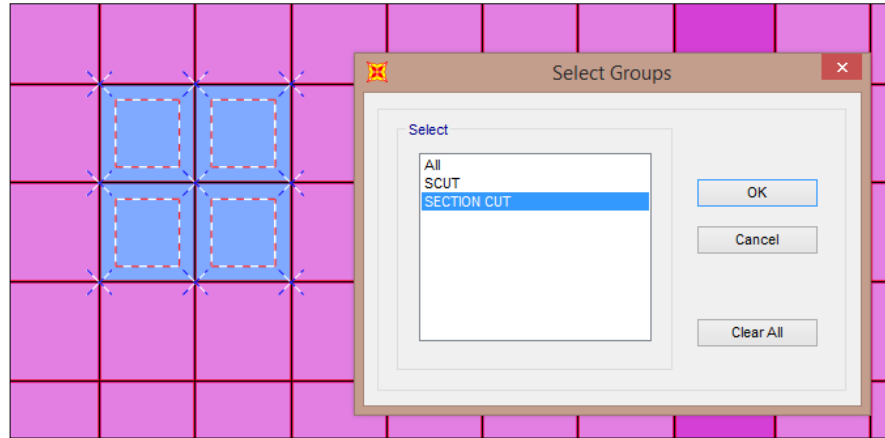
OK Cancel

3.4. Nonlinear Shell Elements

3.4.1 Steel Floor Plate

Exercise 35

Define > Groups



Define > Section Cuts

Section Cut Name: LOAD

Coordinate System: GLOBAL

Units: KN, m, C

Section Cut Defined By

- Group
- Quadrilateral Cutting Planes

Section Cut Group

Group

SECTION CUT

Section Cut Result Type

- Analysis (F1, F2, F3, M1, M2, M3)
- Design (P, V2, V3, T, M2, M3)

Section Cut Local Axes Orientation - Analysis

Rotation about Z: 0.

Rotation about Y: 0.

Rotation about X: 0.

Advanced Axes

Advanced

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

Choose Plot Functions

Define Plot Functions...

List of Functions

LOAD

Add ->

<- Remove

Show

Vertical Functions

DEFLECTION

Horizontal Plot Function

LOAD

Load Case (Multi-stepped Cases) CONC_PUSH

Plot Function Name DEFLECTION

Generalized Displacement DEFLECTION

Section Cut LOAD

Component

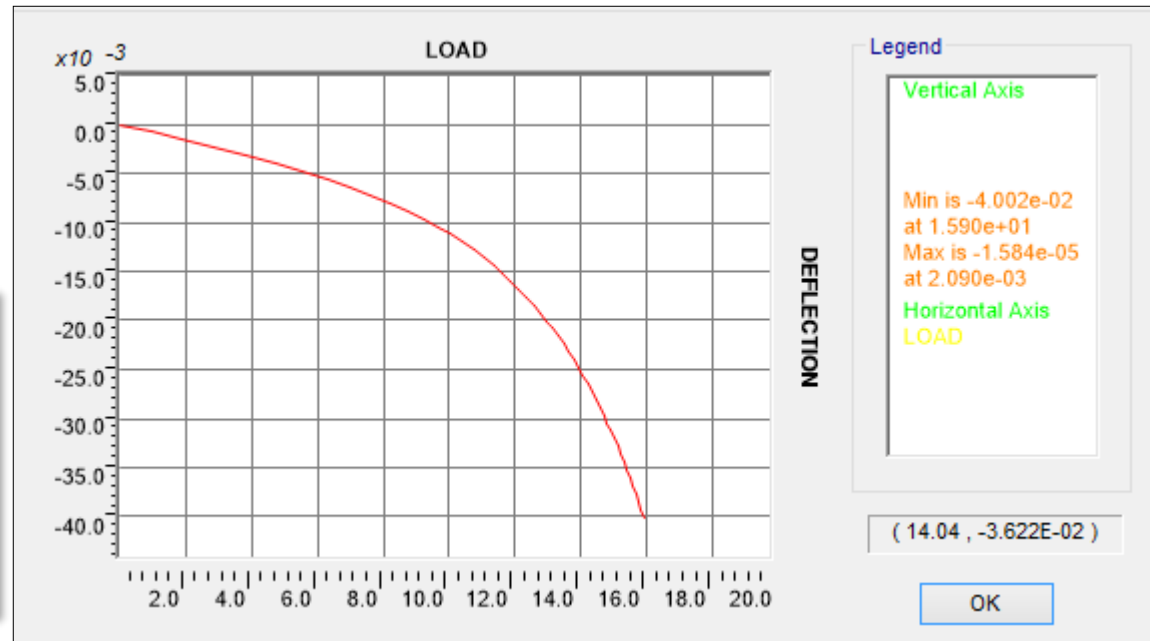
F1 M1

F2 M2

F3 M3

Mode Number

Include all

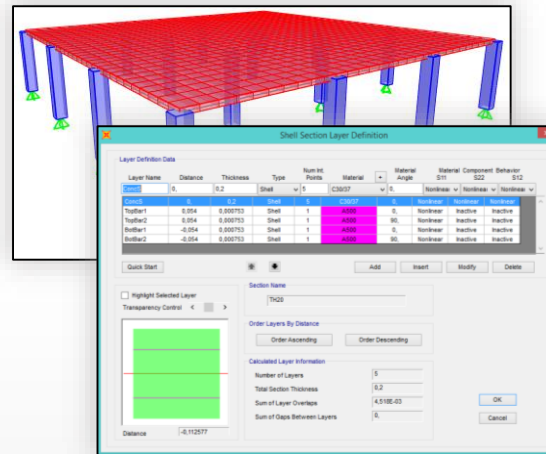


Material Nonlinearity in Reinforced Concrete Shell Models

Model a reinforced concrete slab considering material nonlinearity and cracked behavior

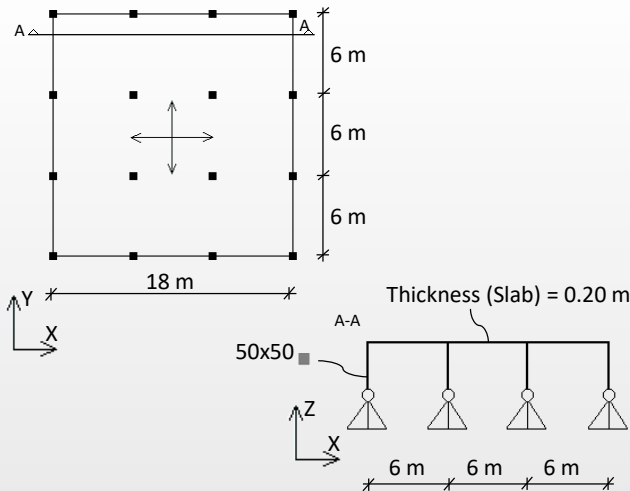
Problem:

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.



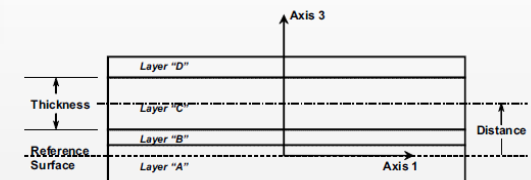
SAP2000 features

- Nonlinear Layered Shell
- Static Nonlinear Analysis



Modeling topics

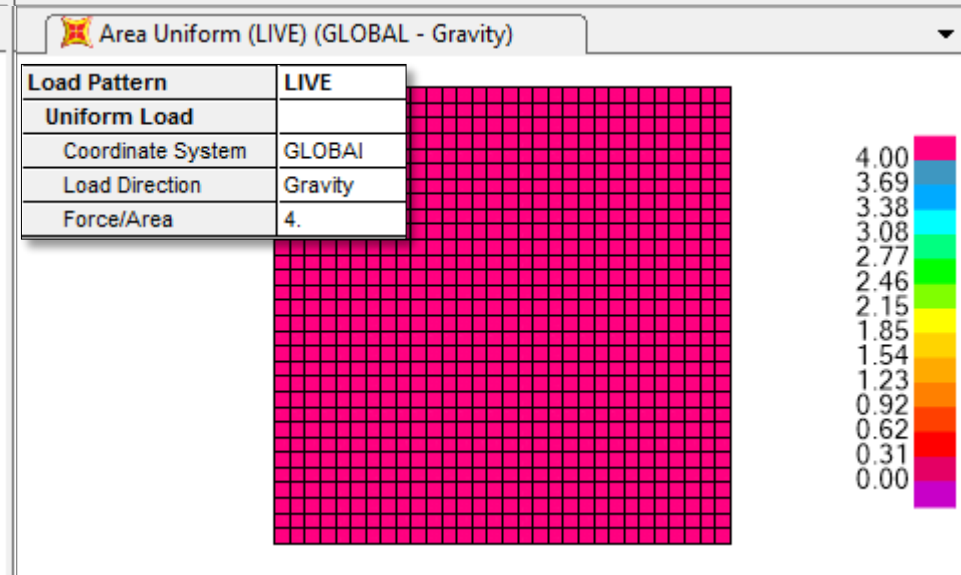
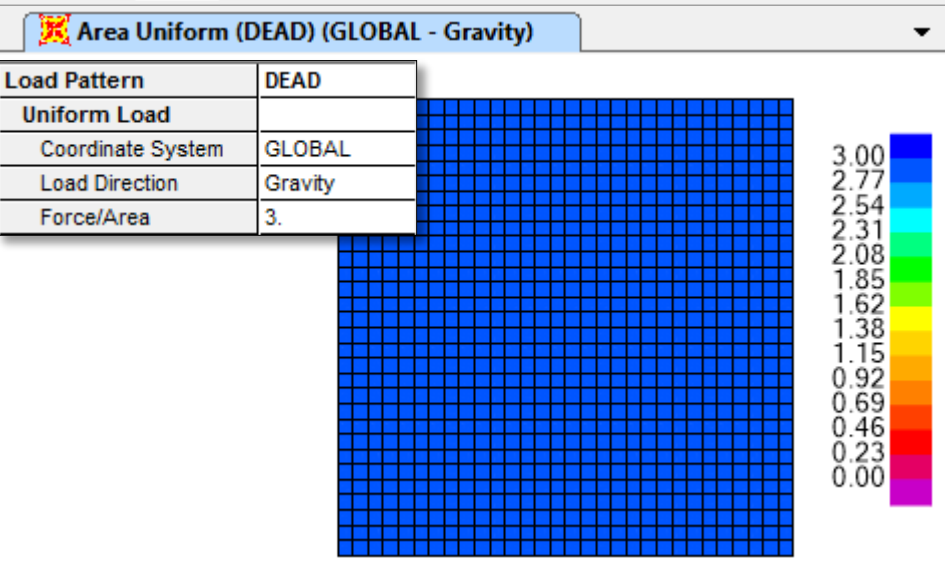
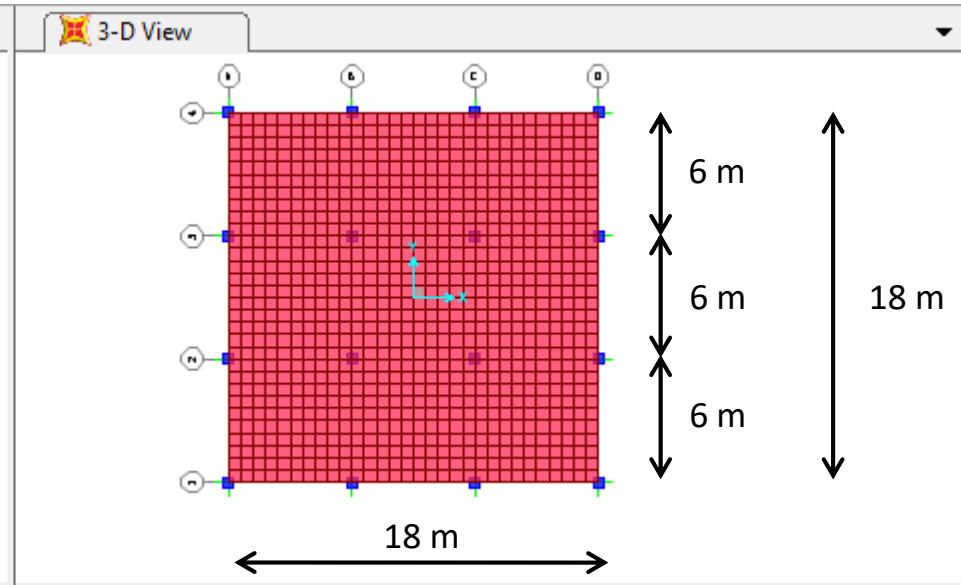
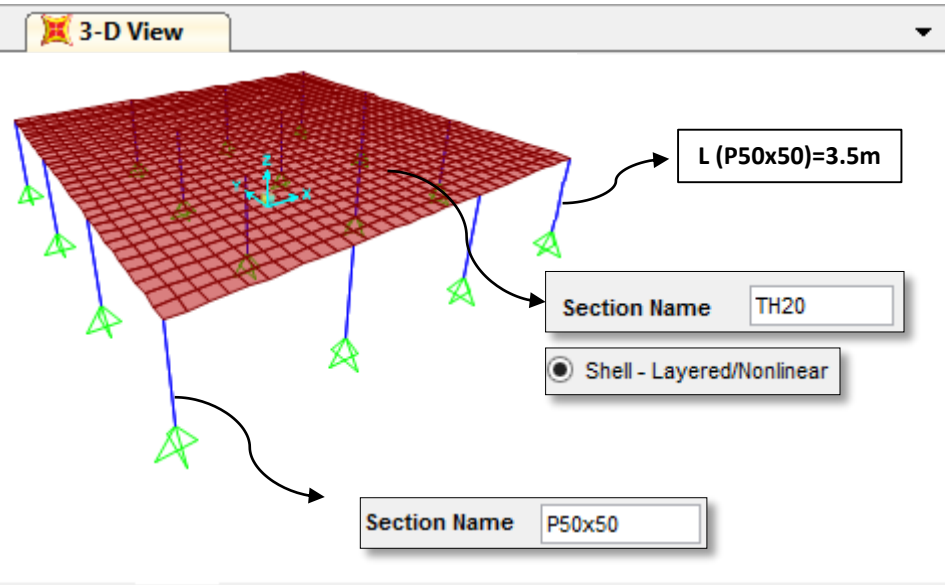
- Material Nonlinearity
- Cracked Behavior
- Stress-strain curves



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

Nonlinear Material Data

Edit

Material Name
A500

Material Type
Rebar

Hysteresis Type
Kinematic

Drucker-Prager Parameters
Friction Angle
Dilatational Angle

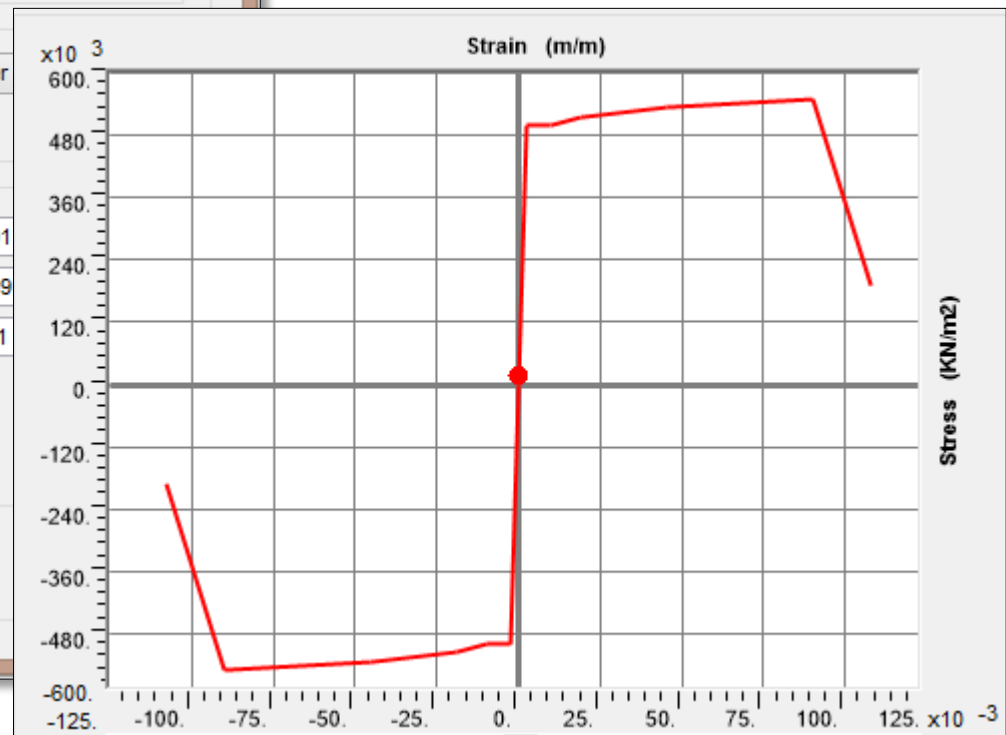
Units
KN, m, C

Stress-Strain Curve Definition Options
 Parametric User Defined
Simple

Parametric Strain Data
Strain At Onset of Strain Hardening: 0.01
Ultimate Strain Capacity: 0.09
Final Slope (Multiplier on E): -0.1
 Use Caltrans Default Controlling Strain Values (Bar Size Dependent)

Show Stress-Strain Plot...

OK Cancel



3.4. Nonlinear Shell Elements

3.4.2 Reinforced Concrete Slab

C30/37

Exercise 36

Stress-Strain Curve Definition Options

Parametric

User Defined

User Stress-Strain Curve Data

Number of Points in Stress-Strain Curve

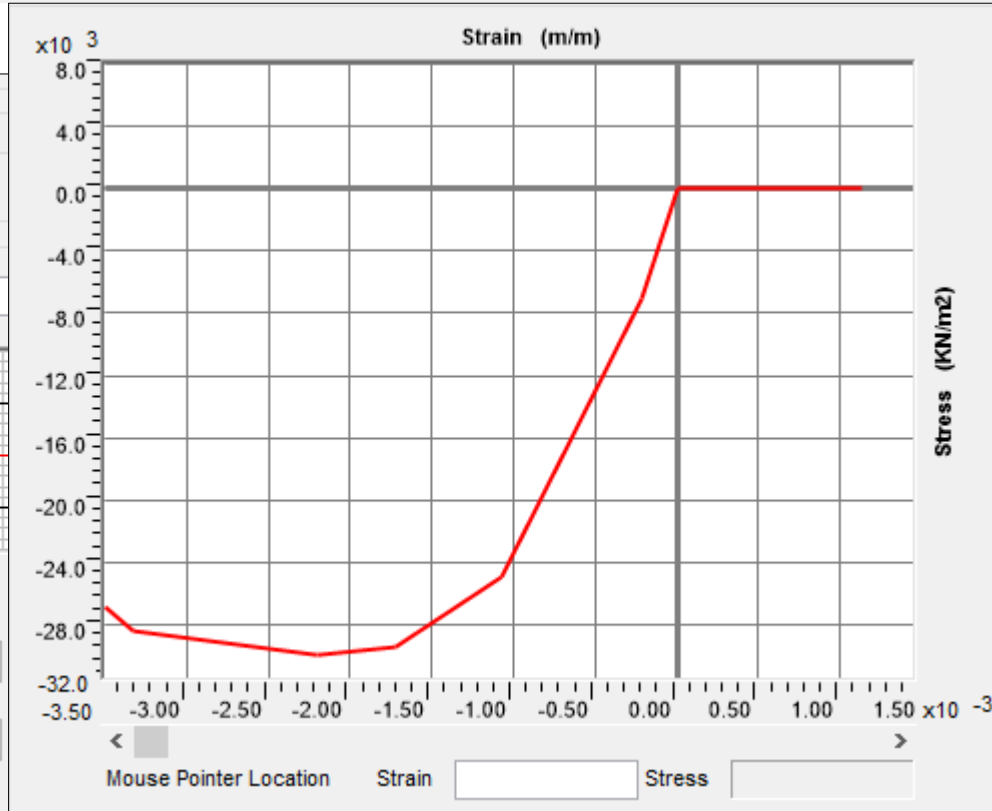
8

	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

Ultimate Unconfined Strain Capacity

Final Compression Slope (Multiplier on E)

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

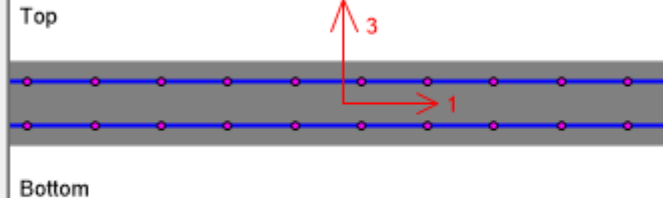
Top Bars - Direction 1 + 12d @ 0.15 Cover 0.04

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

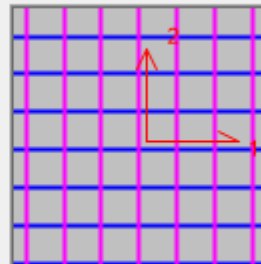
Shell Section Elevation View



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

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 S11	Component S22	Behavior S12
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

Load Case Name

LIVE

Loads Applied

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

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	LIVE	1.
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	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
DEAD	Linear Static	1.35
LIVE	Linear Static	1.5

Linear Add

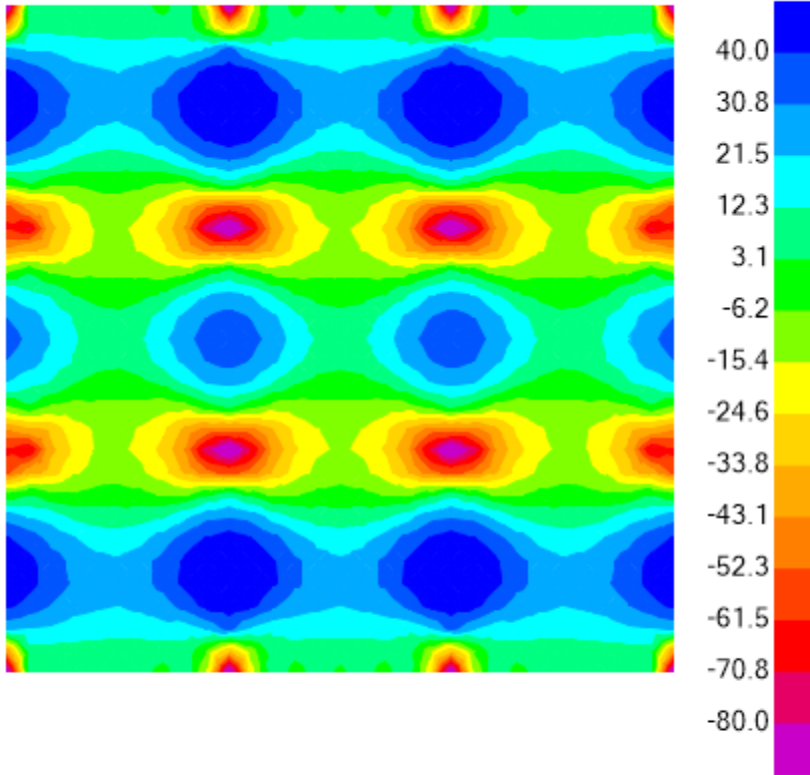


3.4. Nonlinear Shell Elements

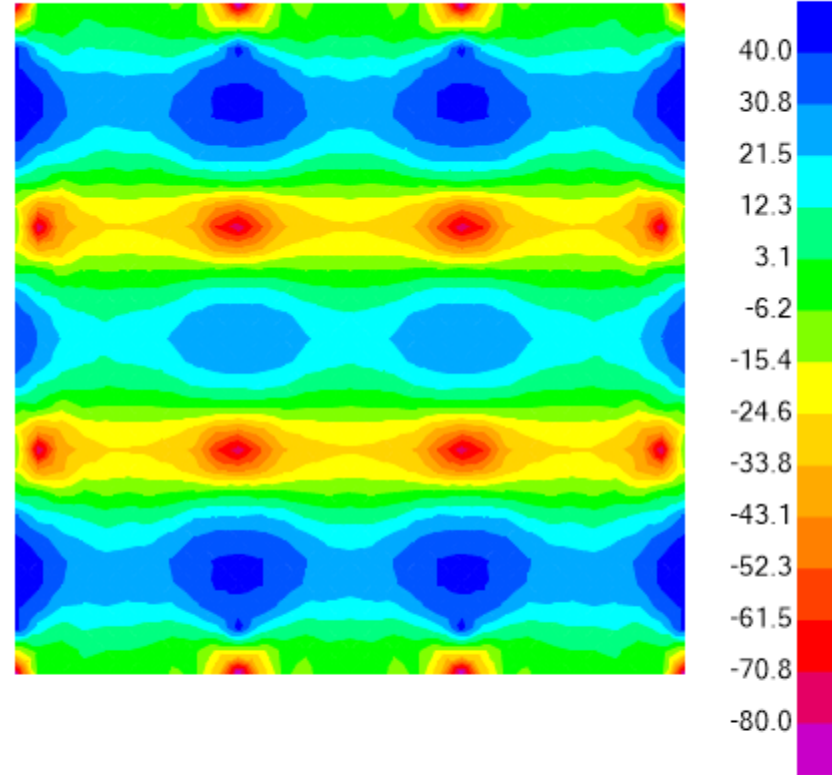
3.4.2 Reinforced Concrete Slab

Exercise 36

Resultant M22 Diagram (ULS)



Resultant M22 Diagram (ULS_NL)

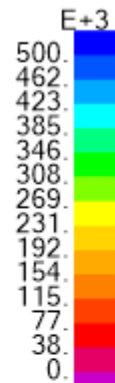
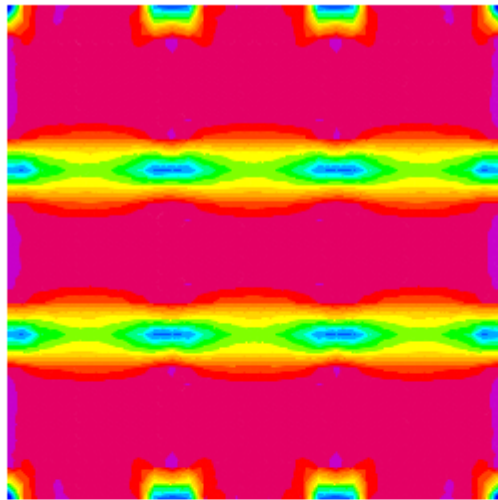


3.4. Nonlinear Shell Elements

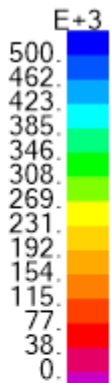
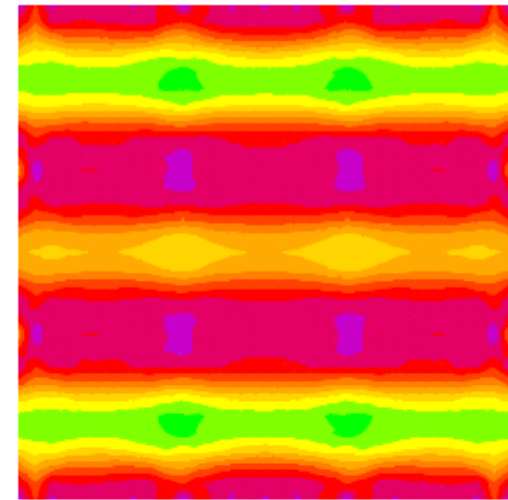
3.4.2 Reinforced Concrete Slab

Exercise 36

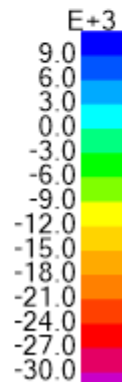
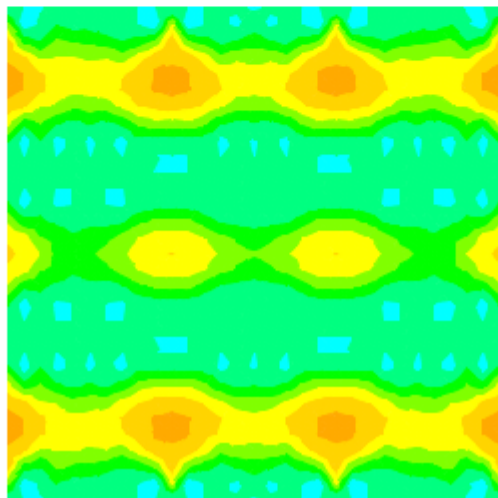
Layer Stress S22 Diagram - TH20, TopBar2, 0. (ULS_NL) X



Layer Stress S22 Diagram - TH20, BotBar2, 1. (ULS_NL)



Layer Stress S22 Diagram - TH20, ConcS, 1. (ULS_NL)



Layer Stress S22 Diagram - TH20, ConcS, -1. (ULS_NL)

