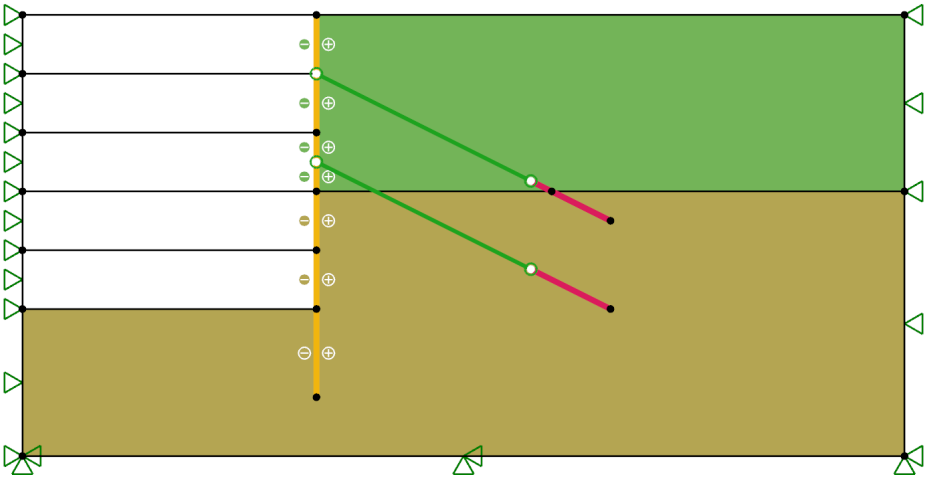
Op+um GX

DOCUMENTATION

Excavation 1

Sheet piles



Date:

Software version: OPTUM GX 2.1.312.0

TABLE OF CONTENTS

1 About

This report has been generated using OPTUM GX, a finite element application dedicated to geotechnical deformation and stability analysis. For a full description of the application, please see the accompanying manuals available at welcome window, via optumce.com/knowledge-base/gx/, or (File → Manuals).

2 Nomenclature

Symbol	Description
A	Cross sectional area.
D	Damage parameter (Hoek-Brown).
E	Young's modulus.
$E_{0,ref}$	Initial reference stiffness (HS-Small, HMC).
$E_{50,ref}$	Reference secant stiffness (HS-Small, HMC).
EA	Normal stiffness.
EA_x, EA_y	In-plane stiffness stiffness.
EI_x, EI_y, EI_z	Bending stiffness.
$E_{Oed,ref}$	Oedometer modulus (HS-Small).
E_{ur}	Unloading/reloading modulus (AUS).
$E_{ur,ref}$	Reference unloading/reloading modulus (HS-Small).
FoS	Factor of Safety.
GA	In-plane shear stiffness.
GI	Torsional stiffness.
GJ	Torsional stiffness.
G_{ref}	Norsand stiffness parameter.
GSI	Geological Strength Index (Hoek-Brown).
H_0	Norsand hardening parameter.
H_ψ	Norsand hardening parameter.
K	Bulk modulus of water.
K, K_x, K_y, K_z	Hydraulic conductivity.
K_0	Earth pressure at rest parameter.
K_0	Norsand initial state parameter.
LM	Load multiplier.
M	Bending moment.
M	Friction parameter (Drucker-Prager).
M	Cap parameter (HS-Small).
M	Multiplier.
M_{tc}	Norsand strength parameter.
N	Axial force.
N	Norsand strength parameter.
R	Norsand initial state parameter.
R_u	ULS adjustment parameter (HS-Small).
S	Norsand hardening parameter.
S_r	Residual degree of saturation.
S_s	Maximum degree of saturation.
U_{max}, |U|	Maximum absolute displacement.
V	Shear force.
X, Y, Z	Global coordinates.
b_{reset}	Stiffness reset parameter (AUS).
c	Cohesion.
c'	Cohesion.
c_1, c_2, ...	Cohesion (Multi MC).
c_u	Undrained shear strength (Mohr-Coulomb).
e	Void ratio.
f_c	Compression strength.
f_t	Tension strength.
f_y	Yield strength.

Symbol	Description
k	Strength parameter (Drucker-Prager).
m	Pressure dependency parameter (HS-Small, HMC).
m_i	Hoek-Brown strength parameter.
m_{px}, m_{py}, m_{pz}	Bending moment capacity.
$m_{px,pos}$, $m_{px,neg}$, $m_{py,pos}$, $m_{py,neg}$	Bending moment capacity.
m_{pxy}	Torsional moment capacity.
n	Van Genuchten parameter.
n_p	Yield force.
n_{px}, n_{py}, n_{pxy}	Anisotropic shell strength parameter.
p_{cav}	Cavitation pressure.
n_G	Norsand stiffness parameter.
p_{ref}	Norsand stiffness parameter.
p_{ref}	Reference pressure (mean stress).
s_{uc}	Undrained shear strength in triaxial compression (AUS).
$s_{uc,residual}$	Residual undrained shear strength in triaxial compression (AUS).
s_{ue}	Undrained shear strength in triaxial extension (AUS).
$s_{ue,residual}$	Residual undrained shear strength in triaxial extension (AUS).
t_p	Torsional capacity.
x, y, z	Local coordinates.
α	Van Genuchten parameter.
γ	Norsand critical state parameter.
γ	Unit weight.
$\gamma_{0.7}$	Hardening soil small strain stiffness parameter.
$\gamma_{c'}$	Partial factor for cohesion.
γ_{dry}	Dry unit weight.
γ_{sat}	Saturated unit weight.
γ_{Su}	Partial factor for strength (Tresca).
γ_{unity}, γ_g, γ_{user1}, γ_{user2}	Partial factors for actions.
$\gamma_{\phi'}$	Partial factor for friction angle.
$\varepsilon_{c,50}$	Axial triaxial compression strain at half strength (AUS).
$\varepsilon_{e,50}$	Axial triaxial extension strain at half strength (AUS).
ε_{scr}	Cut-off deviatoric strain for dilation.
$\varepsilon_{soft,cr,1}$	Softening parameter.
$\varepsilon_{soft,cr,2}$	Softening parameter.
$\varepsilon_{soft,suc,cr1}$	AUS material softening parameter.
$\varepsilon_{soft,suc,cr2}$	AUS material softening parameter.
$\varepsilon_{soft,sue,cr1}$	AUS material softening parameter.
$\varepsilon_{soft,sue,cr2}$	AUS material softening parameter.
ε_{vcr}	Cut-off volumetric strain for dilation.
λ	Norsand critical state parameter.
v	Poisson's ratio.
σ, σ_x, σ_y	Stress.
σ_0	Initial horizontal stress.
σ_{ci}	Compressive strength of intact rock (Hoek Brown).
ϕ_1, ϕ_2, ...	Friction angle (Multi MC).
ϕ'	Friction angle.
ϕ'_{2D}	Friction angle for 2D analysis.
ϕ'_{3D}	Friction angle for 3D analysis.

Symbol	Description
$\phi_{residual}$	Residual friction angle.
ψ	Dilation angle.
ψ_0	Norsand initial state parameter.
χ_{tc}	Norsand strength parameter.
ψ_0	Dilation angle.

3 Summary

3.1 Result overview

Table 1: *Models, stages and main results*

2D/3D	Name	From	Design approach	Analysis type	Main result	Model ref.	Result ref.
2D	Model A					p. 11	
	- Stage 1	none	Unity	Initial stresses			p. 18
	- Stage 2	Stage 1	Unity	Deformation	U_{max} = 11.5 mm		p. 19
	- Stage 3	Stage 2	Unity	Deformation	U_{max} = 19.6 mm		p. 23
	- Stage 4	Stage 3	Unity	Deformation	U_{max} = 23.9 mm		p. 26
	- Stage 5	Stage 4	Unity	Deformation	U_{max} = 24.8 mm		p. 29
	- Stage 6	Stage 5	Unity	Deformation	U_{max} = 22.3 mm		p. 32
	- Stage 7	Stage 6	Unity	Factor of safety	FoS = 1.62		p. 35

3.2 Visualization

Model A:

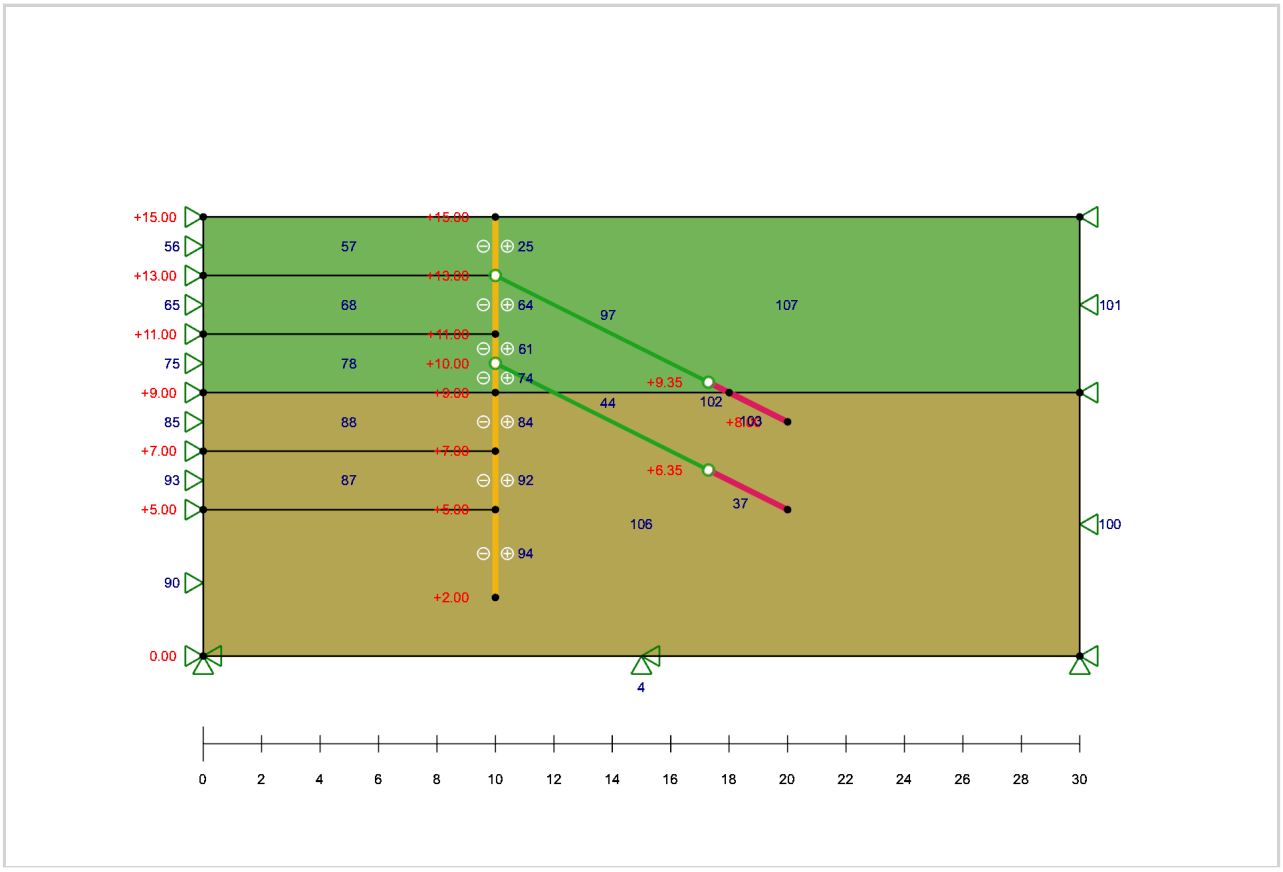


Figure 1: *Model A*

Stages:

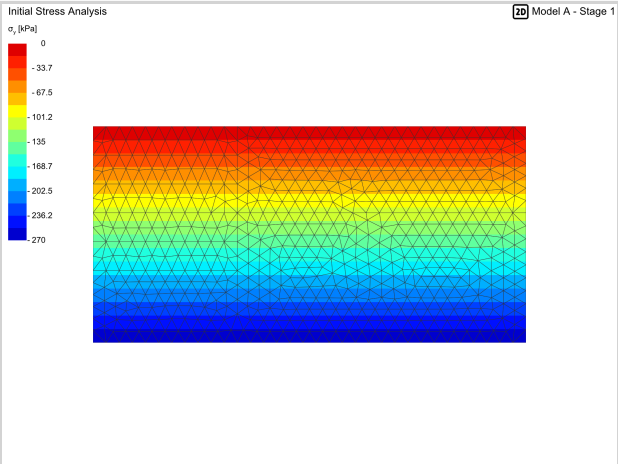


Figure 2: *Stage 1, Initial stresses, Design approach:Unity*

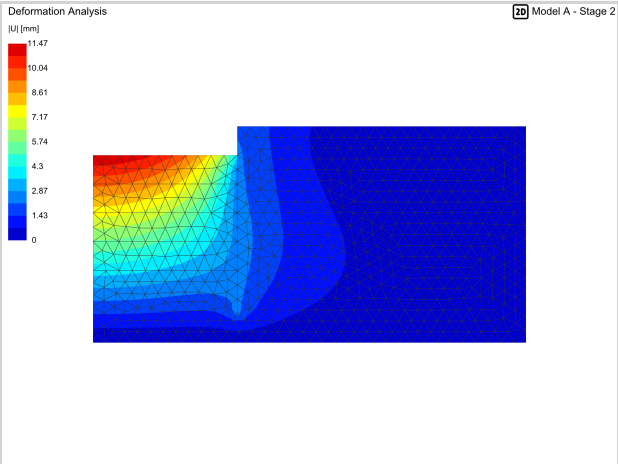


Figure 3: *Stage 2, Deformation, Design approach:Unity*

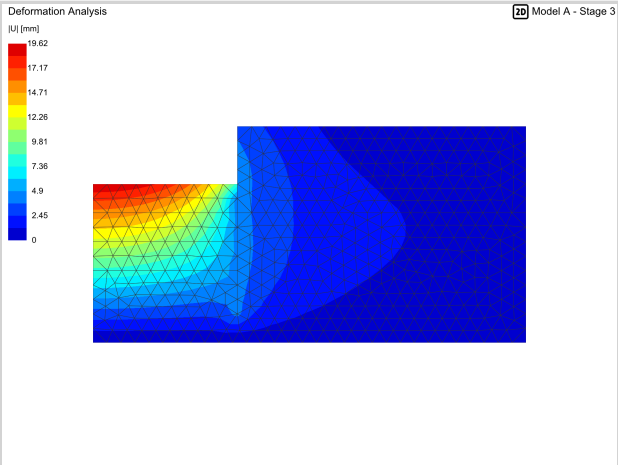


Figure 4: *Stage 3, Deformation, Design approach:Unity*

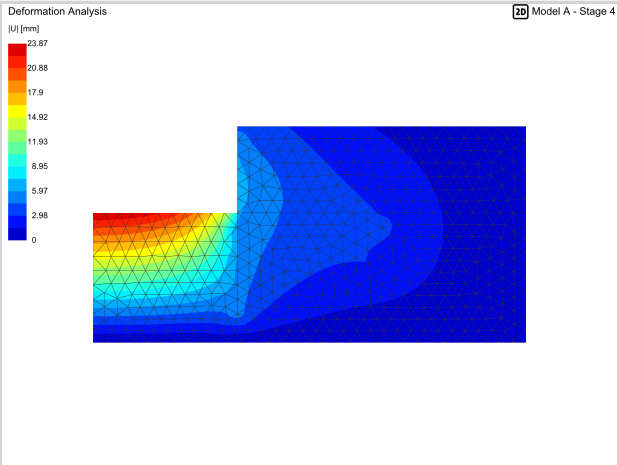


Figure 5: *Stage 4, Deformation, Design approach:Unity*

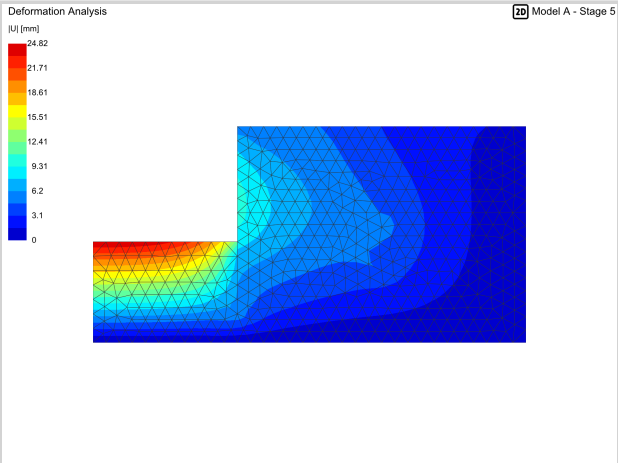


Figure 6: *Stage 5, Deformation, Design approach:Unity*

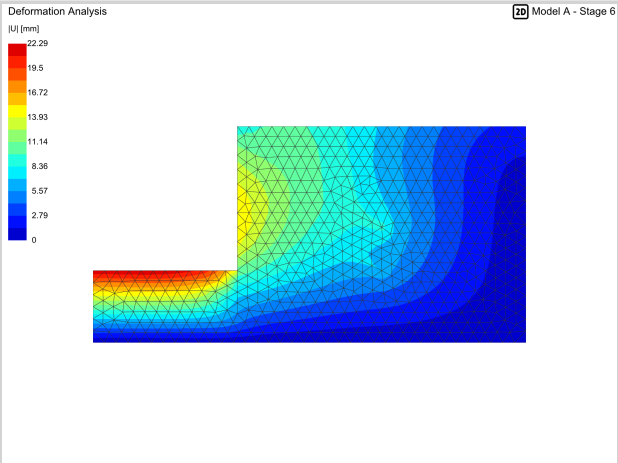


Figure 7: *Stage 6, Deformation, Design approach:Unity*

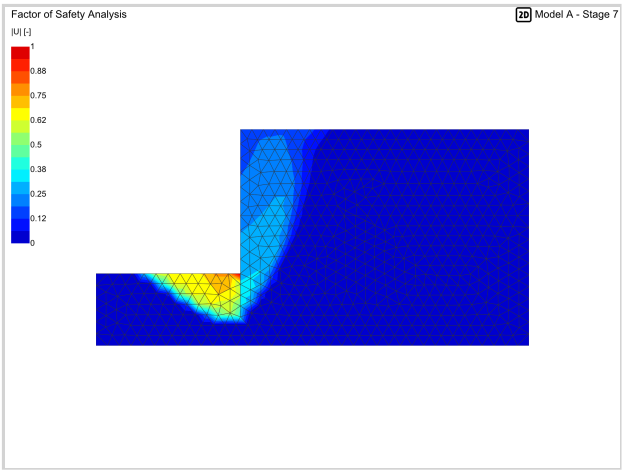


Figure 8: *Stage 7, Factor of safety, Design approach:Unity*

4 Design approaches

Table 2: *Partial factors for loads and materials for design approaches*

Partial factor	Unity
Loads, Unfavorable	
γ_{unity} (user defined, unity)	1
γ_g (dead load)	1
γ_g (live load)	1
γ_{user1} (any load)	1
γ_{user2} (any load)	1
Loads, Favorable	
γ_{unity} (user defined, unity)	1
γ_g (dead load)	1
γ_g (live load)	1
γ_{user1} (any load)	1
γ_{user2} (any load)	1
Soil	
$\gamma_{c'}$	1
$\gamma_{\phi'}$	1
γ_{Su} (Tresca)	1

5 Models

5.1 Model A

5.1.1 Model overview

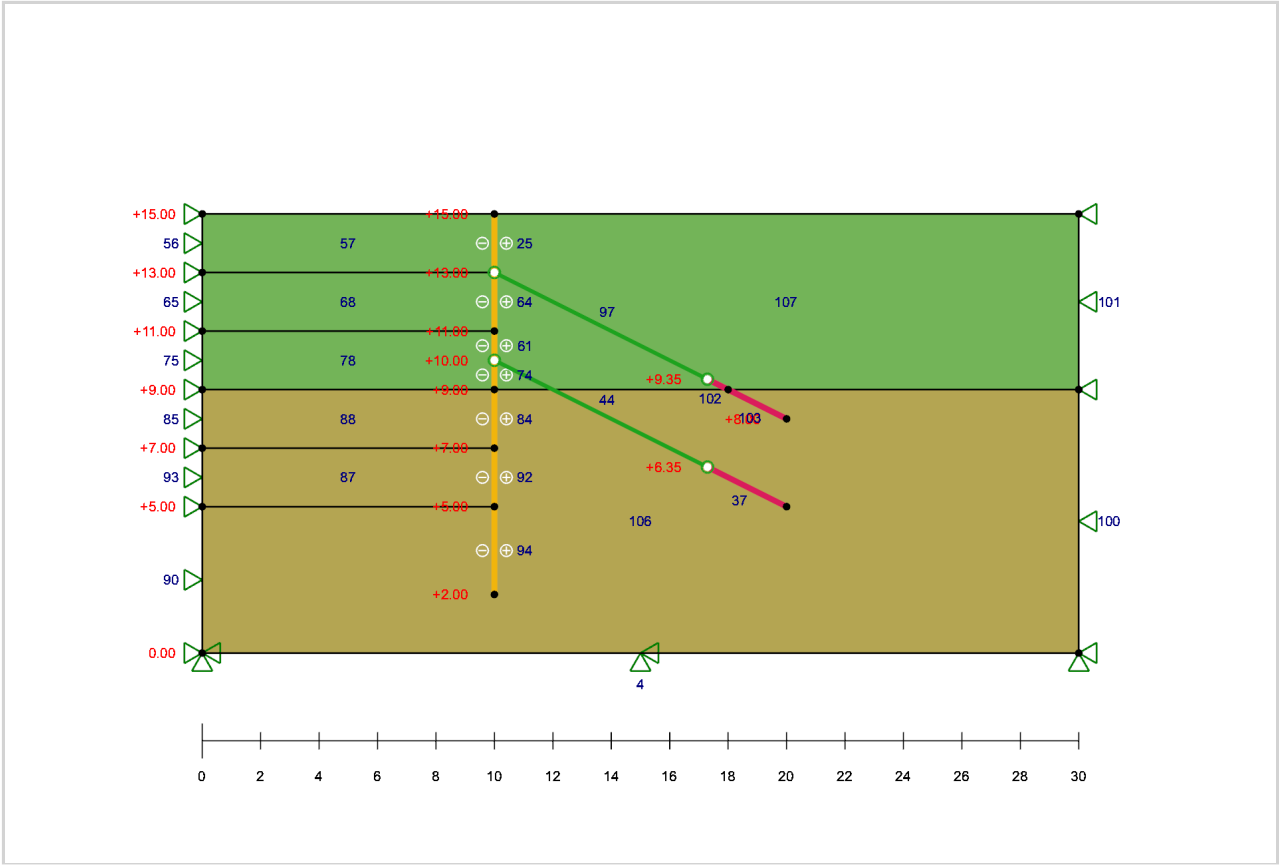


Figure 9: *Model A: Stage elevation*

Table 3: *Solid materials*

ID	Name	Material model	$\gamma_{dry}/\gamma_{sat}$ [kN/m^3]	c' [kPa]	ϕ'_{2D} [°]	c_u [kPa]
107	MC Basic A	Mohr Coulomb	1/20	0	30	-
57	MC Basic A	Mohr Coulomb	1/20	0	30	-
68	MC Basic A	Mohr Coulomb	1/20	0	30	-
78	MC Basic A	Mohr Coulomb	1/20	0	30	-
88	MC Basic B	Mohr Coulomb	1/20	0	35	-
106	MC Basic B	Mohr Coulomb	1/20	0	35	-
87	MC Basic B	Mohr Coulomb	1/20	0	35	-

Table 4: *Structural elements*

IDs	Name	Material model	Top level [m]	Bottom level [m]	Length [m]
61, 74, 92, 25, 64, 84, 94	Plate (steel)	Von Mises shell	15	2	13
97	Connector	Bar	13	9.4	8.2
44	Connector	Bar	10	6.4	8.2
103, 102	NR20	Nail row material	9.4	8	3.0
37	NR20	Nail row material	6.4	5	3.0

5.1.2 Features

Table 5: *Supports*

ID	Geometry	Direction	x-displacement	y-displacement	Rotation
85	Surface	Local	Fixed	Free	Free
65	Surface	Local	Fixed	Free	Free
100	Surface	Local	Fixed	Free	Free
4	Surface	Local	Fixed	Fixed	Free
56	Surface	Local	Fixed	Free	Free
90	Surface	Local	Fixed	Free	Free
75	Surface	Local	Fixed	Free	Free
101	Surface	Local	Fixed	Free	Free
93	Surface	Local	Fixed	Free	Free

5.1.3 Materials

Table 6:

MC Basic B					
Material model:	Mohr Coulomb		**Material category:**	Solid	
Stiffness					
Young's modulus, E:	35	MPa	**Poisson's ratio, v:**	0.250	
Strength					
Cohesion, c':	0	kPa			
Friction angle 2D, ϕ'_{2D}:	35	°	**Friction angle 3D, ϕ'_{3D}:**	31.800	°
Flow rule					
Flow rule:	Nonassociated		**Dilation cap:**	No	
Dilation angle, ψ_0:	0	°			
ε_{vcr}:	0.010		**ε_{scr}:**	0.010	
Unit weights					
γ_{dry}:	1	kN/m^3	**γ_{sat}:**	20	kN/m^3
Tension cut-off					
Tension cut-off:	No		**Tension strength, f_t:**	0	kPa
Softening					
Softening:	No		**$\phi_{residual}$:**	20	°
$\varepsilon_{soft,cr,1}$:	0.010		**$\varepsilon_{soft,cr,2}$:**	0.012	
Initial conditions					
K_0:	0.580		**σ_0:**	0	kPa
Hydraulic conductivity					
Hydraulic model:	Van Genuchten		**Excess pore pressure:**	-	
Option:	Isotropic		**K:**	0.001	m/day
Van Genutchen parameters					
S_r:	0		**S_s:**	1	
e:	1		**α:**	2	m^{-1}
n:	2				
Compression cap.					
Compression cap.:	No		**Compression strength:**	-	
Drainage					
Drainage:	Drained/Undrained				
Cavitation cap.:	No		**p_{cav}:**	-	

Table 7:

Connector				
Material model:	Bar		**Material category:**	Connector
Strength				
Yield force, n_p:	300	kN		
Stiffness				
EA:	210000	kN		
Geometry				
Spacing:	1	m		

Table 8:

NR20					
Material model:	Nail row material		**Material category:**	Nail row	
Nails					
Diameter:	300	mm	**Young's modulus, E:**	200000	MPa
Spacing:	1	m			
Soil-nail strength					
Axial strength:	500	kN/m	**Lateral strength:**	100	kN/m

Table 9:

Plate (steel)				
Material model:	Von Mises shell		**Material category:**	Shell
Strength				
Yield strength, f_y:	300	MPa		
Stiffness				
Young's modulus, E:	30000	MPa	**Poisson's ratio, v:**	0.300
Geometry				
Thickness:	0.350	m		
Unit weight				
γ:	-			

Table 10:

MC Basic A					
Material model:	Mohr Coulomb		**Material category:**	Solid	
Stiffness					
Young's modulus, E:	30	MPa	**Poisson's ratio, v:**	0.250	
Strength					
Cohesion, c':	0	kPa			
Friction angle 2D, ϕ'_{2D}:	30	°	**Friction angle 3D, ϕ'_{3D}:**	27.300	°
Flow rule					
Flow rule:	Nonassociated		**Dilation cap:**	No	
Dilation angle, ψ_0:	0	°			
ε_{vcr}:	0.010		**ε_{scr}:**	0.010	
Unit weights					
γ_{dry}:	1	kN/m^3	**γ_{sat}:**	20	kN/m^3
Tension cut-off					
Tension cut-off:	No		**Tension strength, f_t:**	0	kPa
Softening					
Softening:	No		**$\phi_{residual}$:**	20	°
$\varepsilon_{soft,cr,1}$:	0.010		**$\varepsilon_{soft,cr,2}$:**	0.012	
Initial conditions					
K_0:	0.580		**σ_0:**	0	kPa
Hydraulic conductivity					
Hydraulic model:	Van Genuchten		**Excess pore pressure:**	-	
Option:	Isotropic		**K:**	0.001	m/day
Van Genutchen parameters					
S_r:	0		**S_s:**	1	
e:	1		**α:**	2	m^{-1}
n:	2				
Compression cap.					
Compression cap.:	No		**Compression strength:**	-	
Drainage					
Drainage:	Drained/Undrained				
Cavitation cap.:	No		**p_{cav}:**	-	

5.1.4 Stages

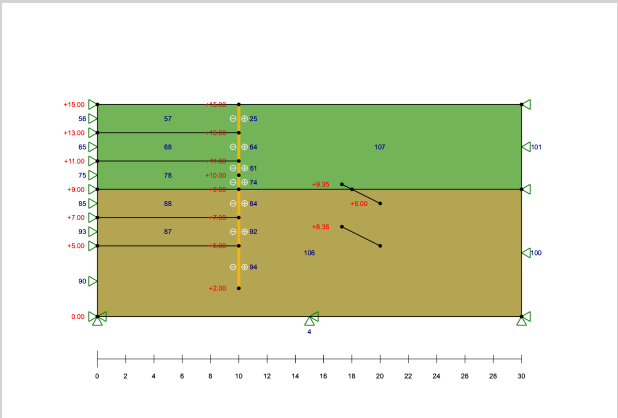


Figure 10: *Stage 1, Initial stresses, Design approach:Unity*

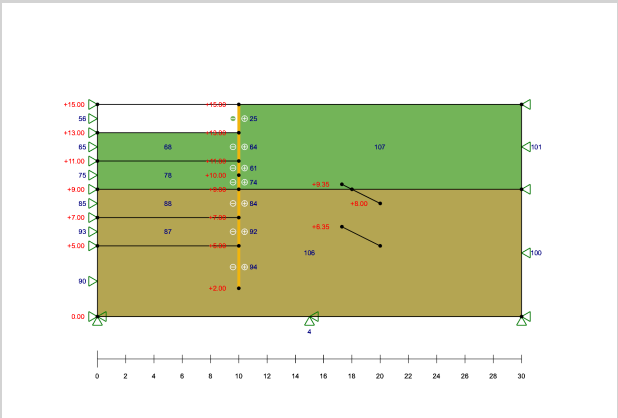


Figure 11: *Stage 2, Deformation, Design approach:Unity*

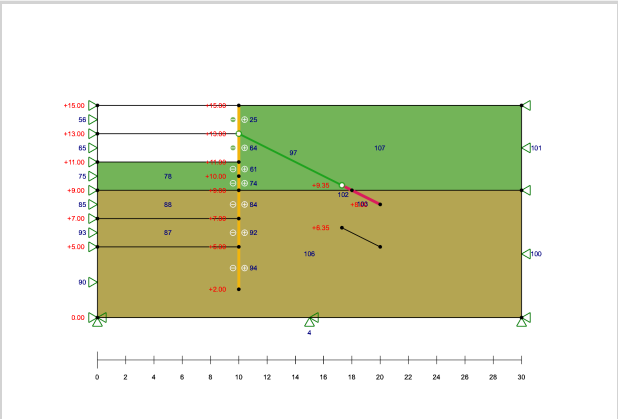


Figure 12: *Stage 3, Deformation, Design approach:Unity*

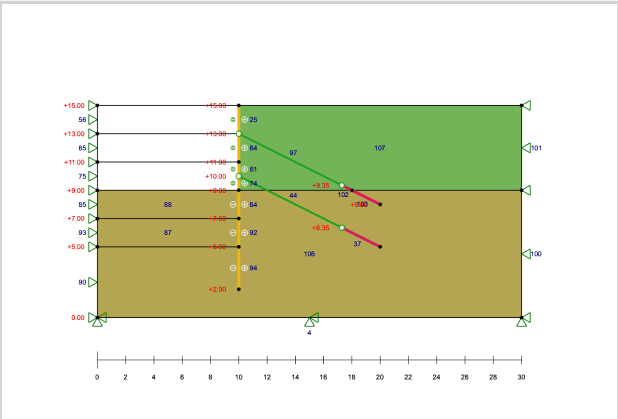


Figure 13: *Stage 4, Deformation, Design approach:Unity*

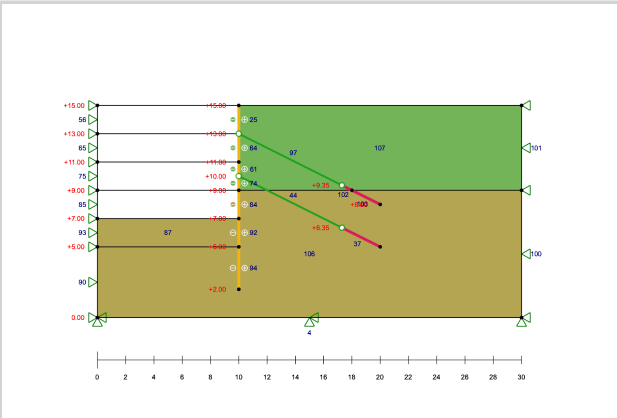


Figure 14: *Stage 5, Deformation, Design approach:Unity*

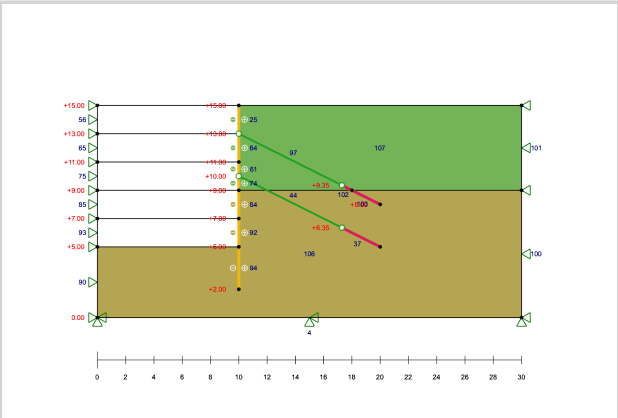


Figure 15: *Stage 6, Deformation, Design approach:Unity*

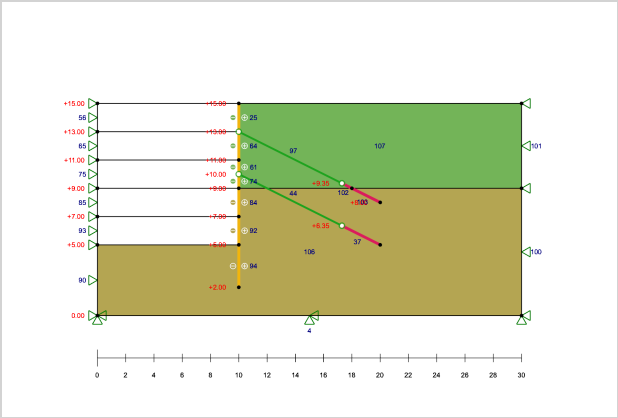


Figure 16: *Stage 7, Factor of safety, Design approach:Unity*

6 Results

6.1 Result overview

Table 11: *Models, stages and main results*

2D/3D	Name	From	Design approach	Analysis type	Main result	Model ref.	Result ref.
2D	Model A					p. 11	
	- Stage 1	none	Unity	Initial stresses			p. 18
	- Stage 2	Stage 1	Unity	Deformation	U_{max} = 11.5 mm		p. 19
	- Stage 3	Stage 2	Unity	Deformation	U_{max} = 19.6 mm		p. 23
	- Stage 4	Stage 3	Unity	Deformation	U_{max} = 23.9 mm		p. 26
	- Stage 5	Stage 4	Unity	Deformation	U_{max} = 24.8 mm		p. 29
	- Stage 6	Stage 5	Unity	Deformation	U_{max} = 22.3 mm		p. 32
	- Stage 7	Stage 6	Unity	Factor of safety	FoS = 1.62		p. 35

6.2 Model A

6.2.1 Stage 1

Design approach: Unity.
Initial stresses analysis.

Parent stage: none

Table 12: *Analysis details*

Element type:	Mixed
Element count:	1281

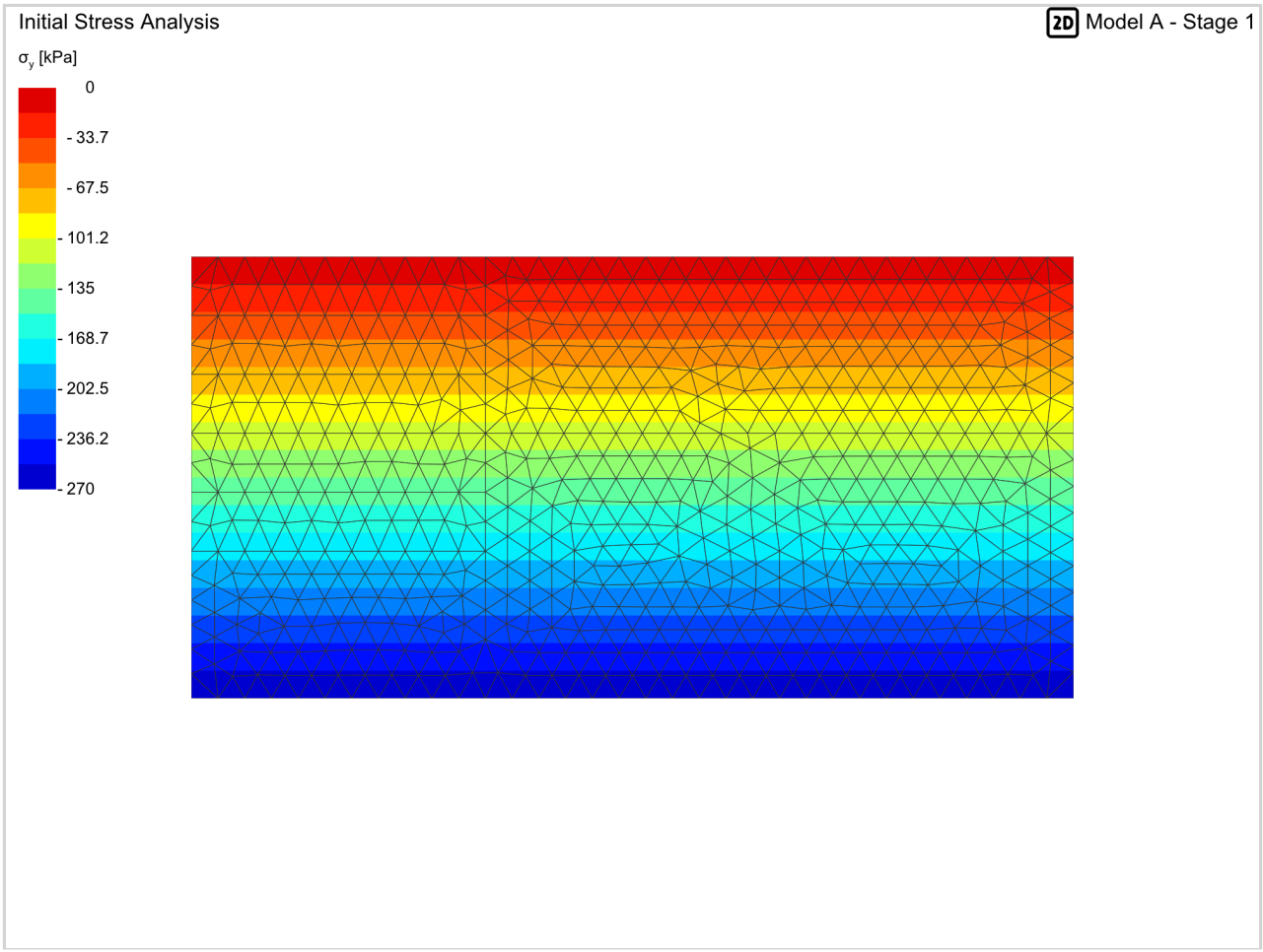


Figure 17: *Stage 1, Initial stresses, Sy*

6.2.2 Stage 2

Design approach: Unity.
Deformation analysis. U_{max} = **11.5 mm**

Parent stage: Stage 1

Table 13: *Analysis details*

Element type:	Mixed
Element count:	1301

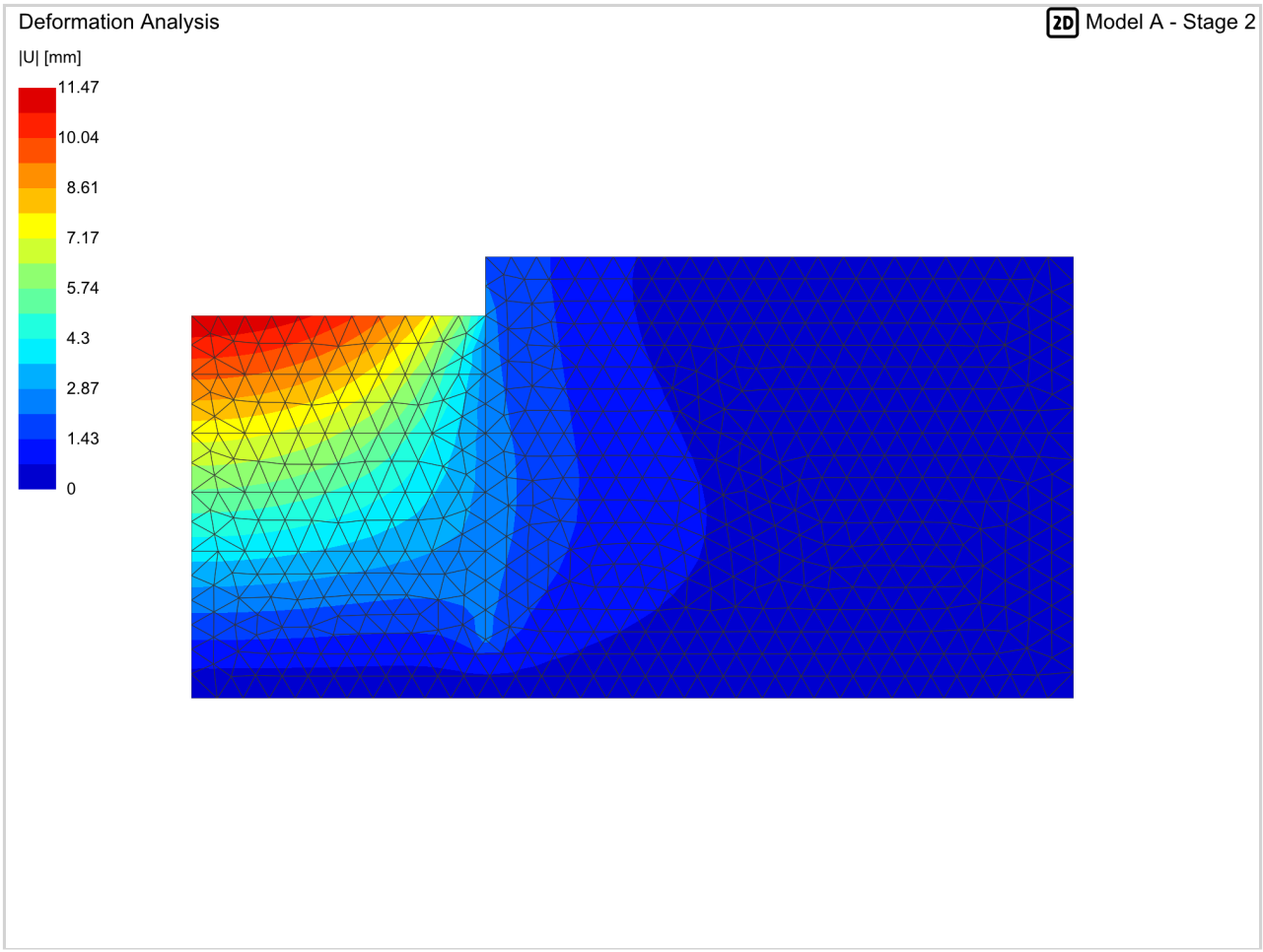


Figure 18: *Stage 2, Deformation, |U|*

Structural elements

Table 14: *Values*

	Min	Max
$M_{y,Ed}$ [kNm/m]	-7.37	10.9
$V_{y,Ed}$ [kN]	-9.15	10.4
N_{Ed} [kN]	-2.19	74.4
|U| [mm]	2.30	2.62

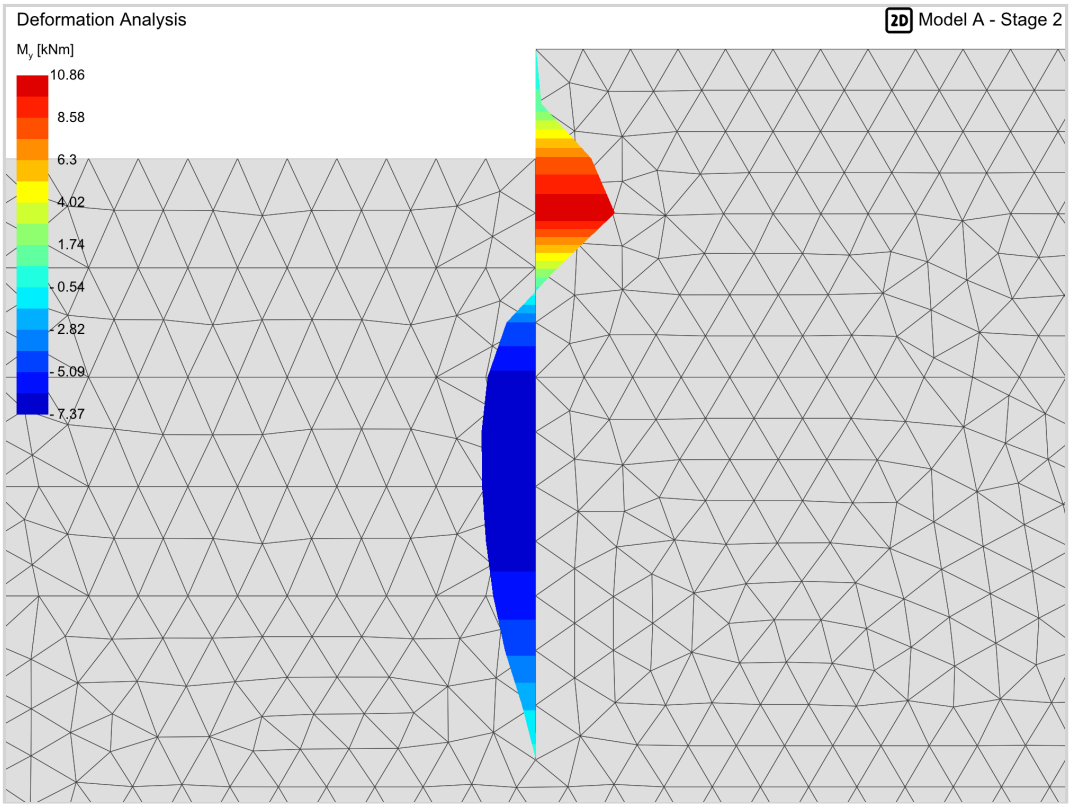


Figure 19: *Moment, M_y*

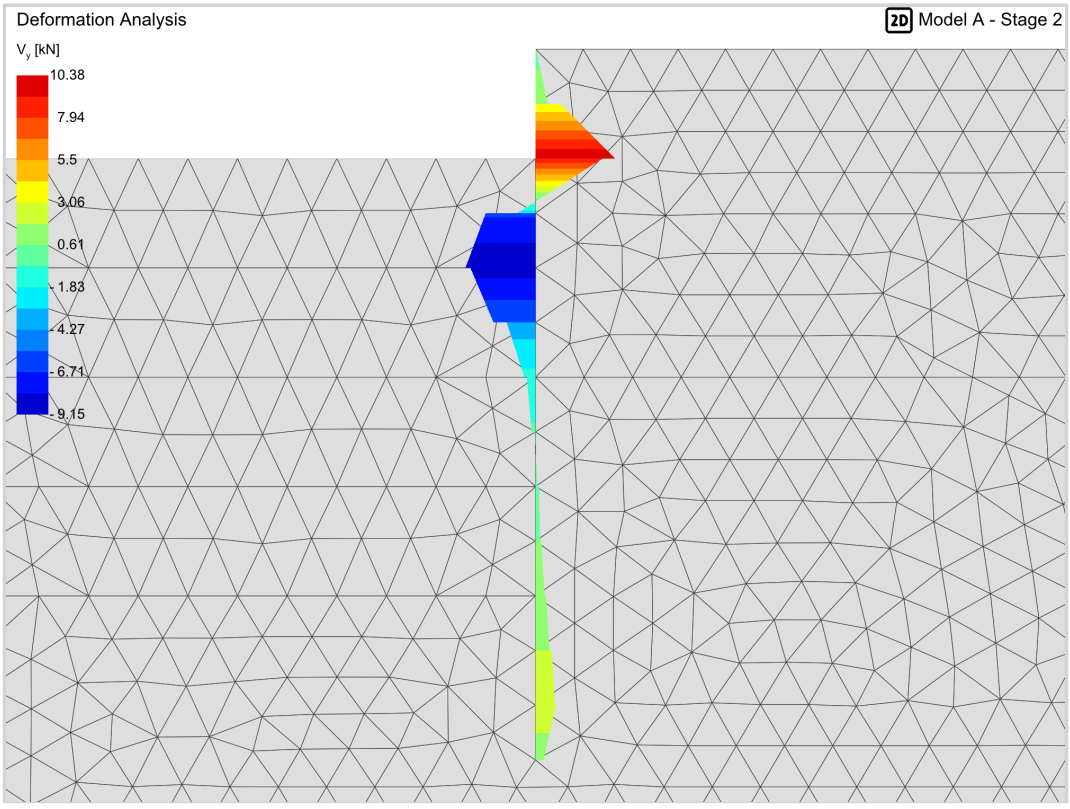


Figure 20: *Shear force, V_y*

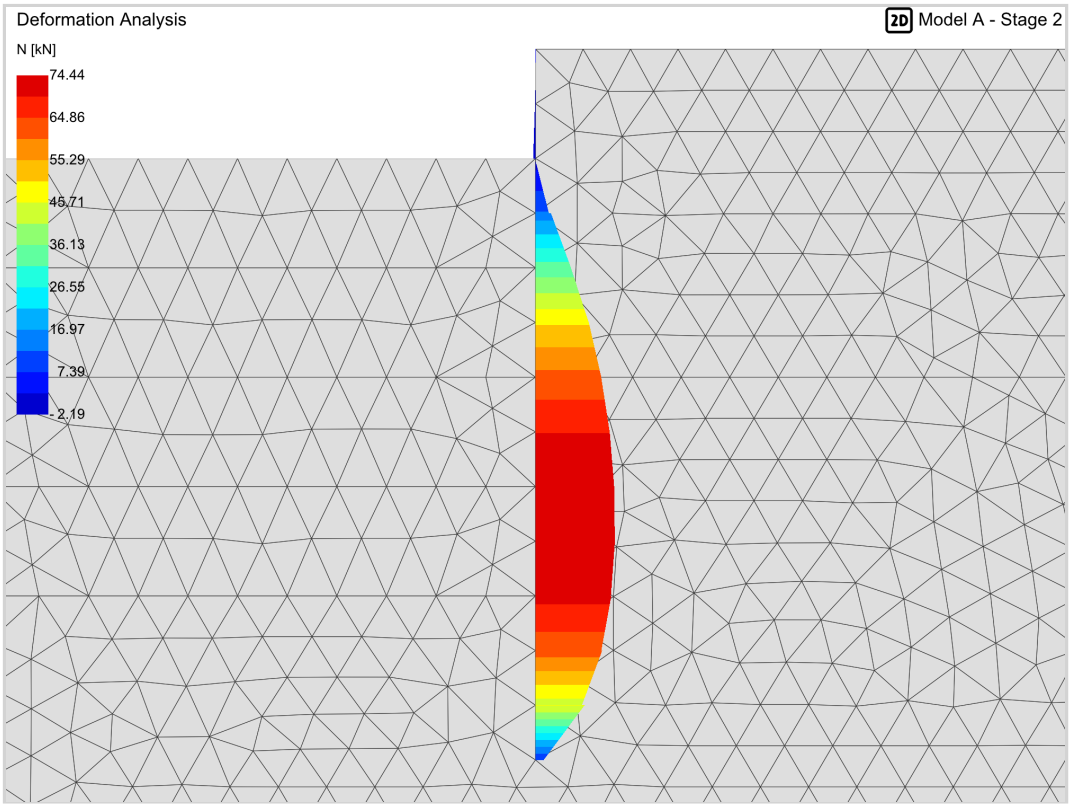


Figure 21: *Normal force, N*

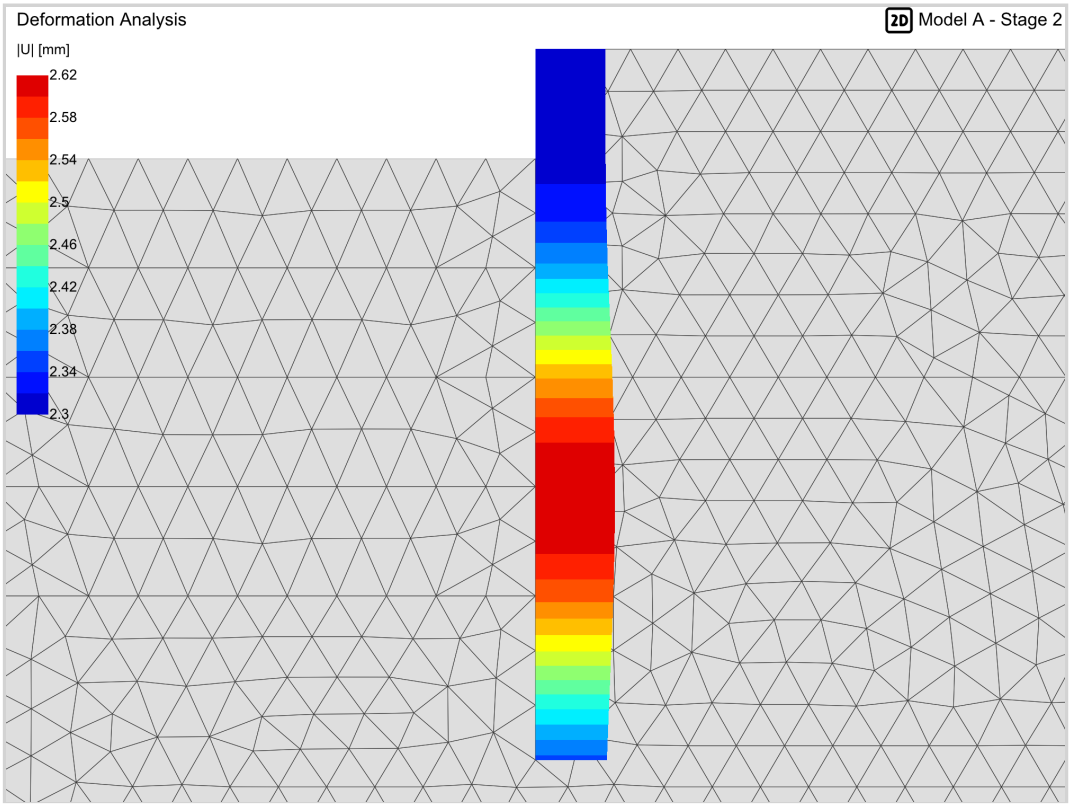


Figure 22: *Displacement, |U|*

6.2.3 Stage 3

Design approach: Unity.
Deformation analysis. U_{max} = **19.6 mm**

Parent stage: Stage 2

Table 15: *Analysis details*

Element type:	Mixed
Element count:	985

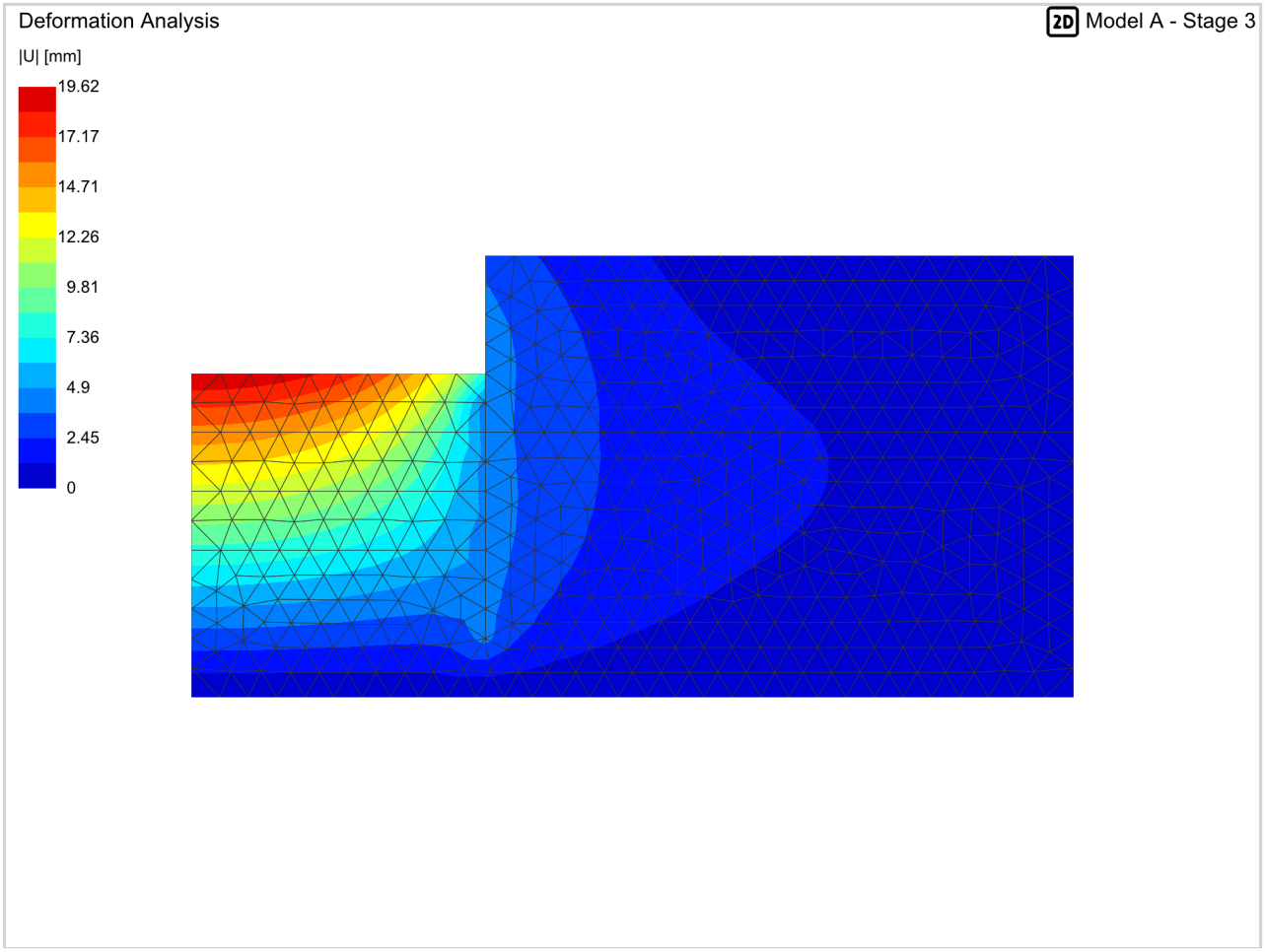


Figure 23: *Stage 3, Deformation, |U|*

Structural elements

Table 16: *Values*

	Min	Max
$M_{y,Ed}$ [kNm/m]	-21.1	16.8
$V_{y,Ed}$ [kN]	-16.9	20.2
N_{Ed} [kN]	-24.6	99.6
|U| [mm]	1.30	4.51

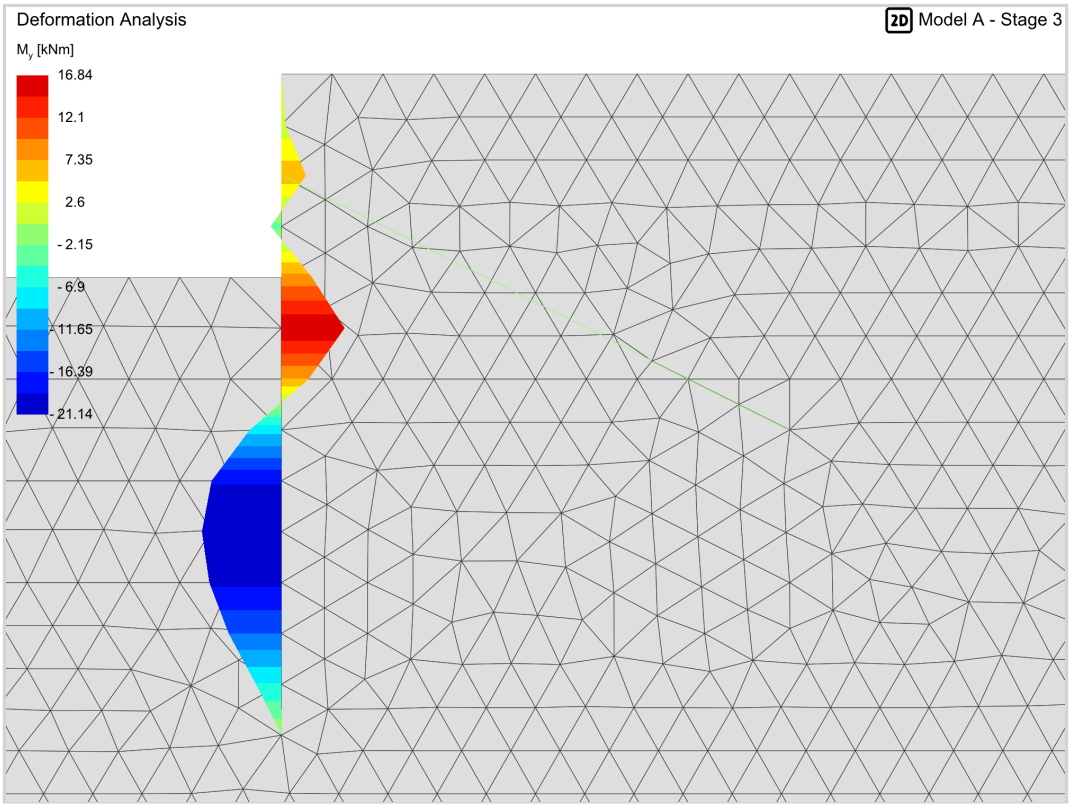


Figure 24: *Moment, M_y*

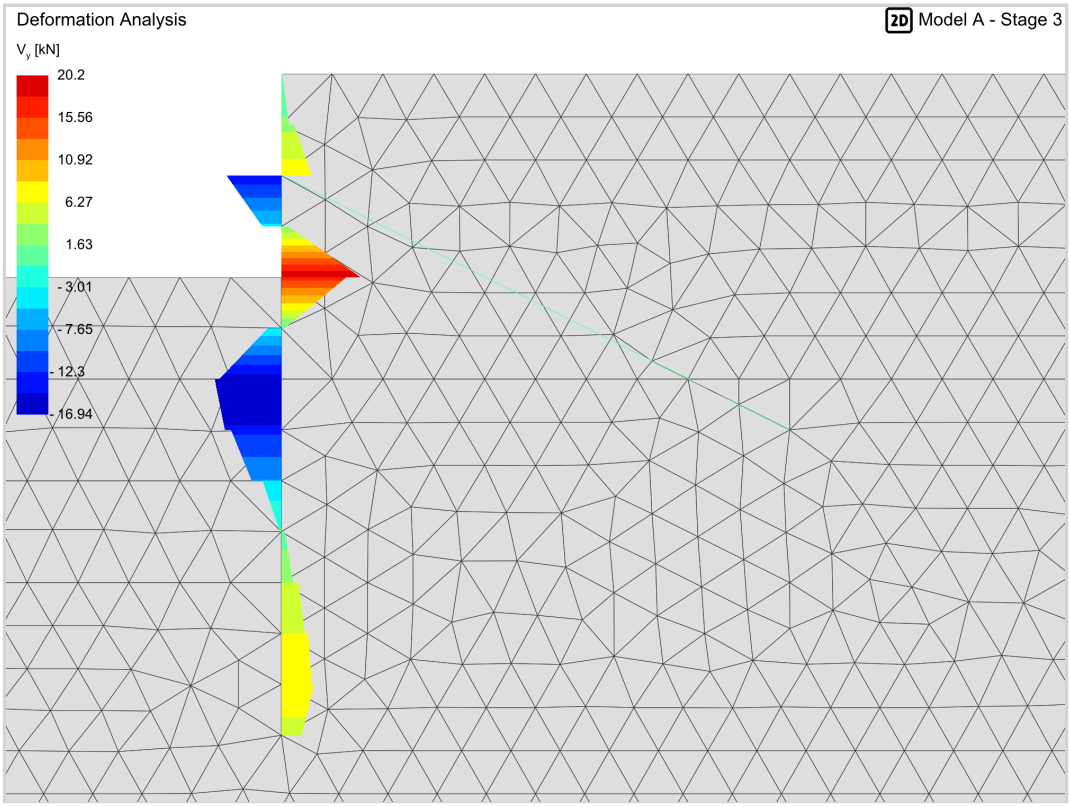


Figure 25: *Shear force, V_y*

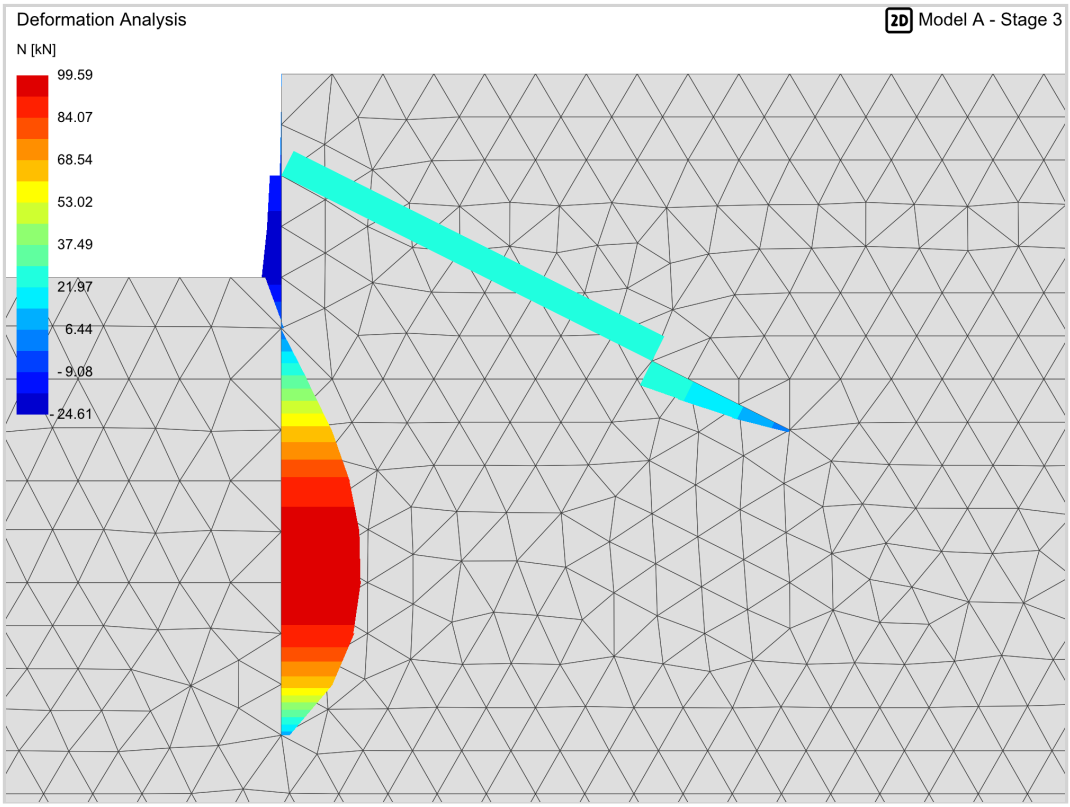


Figure 26: *Normal force, N*

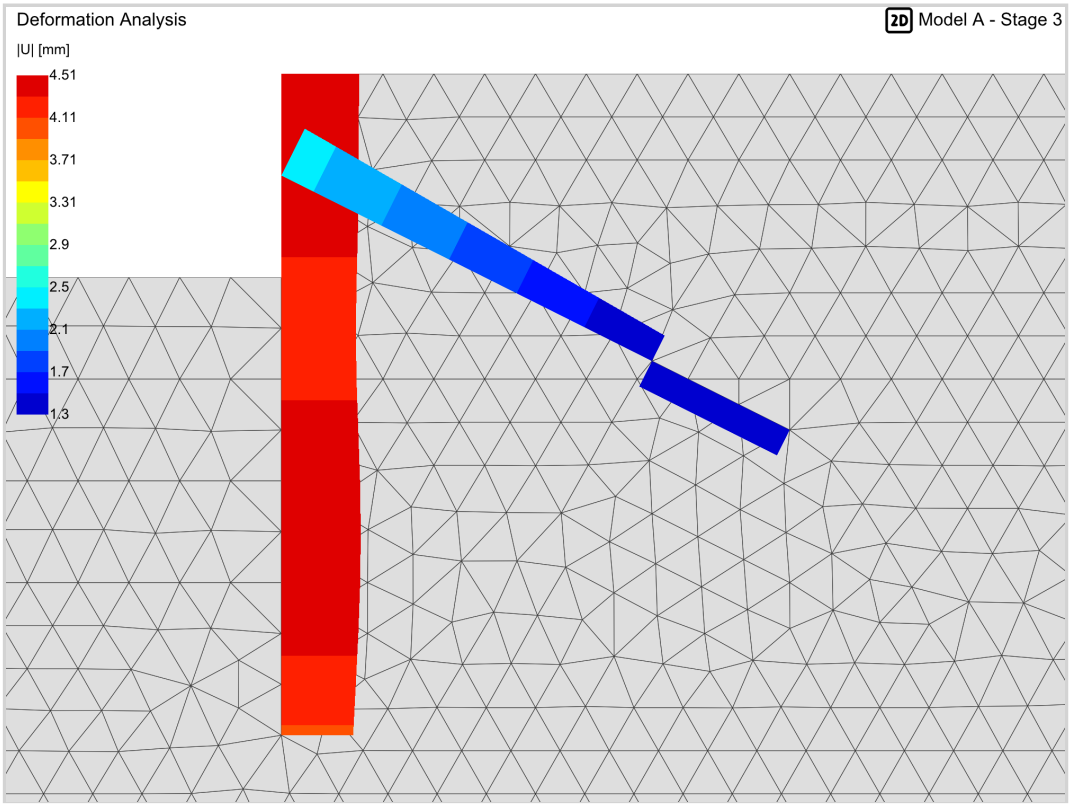


Figure 27: *Displacement, |U|*

6.2.4 Stage 4

Design approach: Unity.
Deformation analysis. U_{max} = **23.9 mm**

Parent stage: Stage 3

Table 17: *Analysis details*

Element type:	Mixed
Element count:	1021

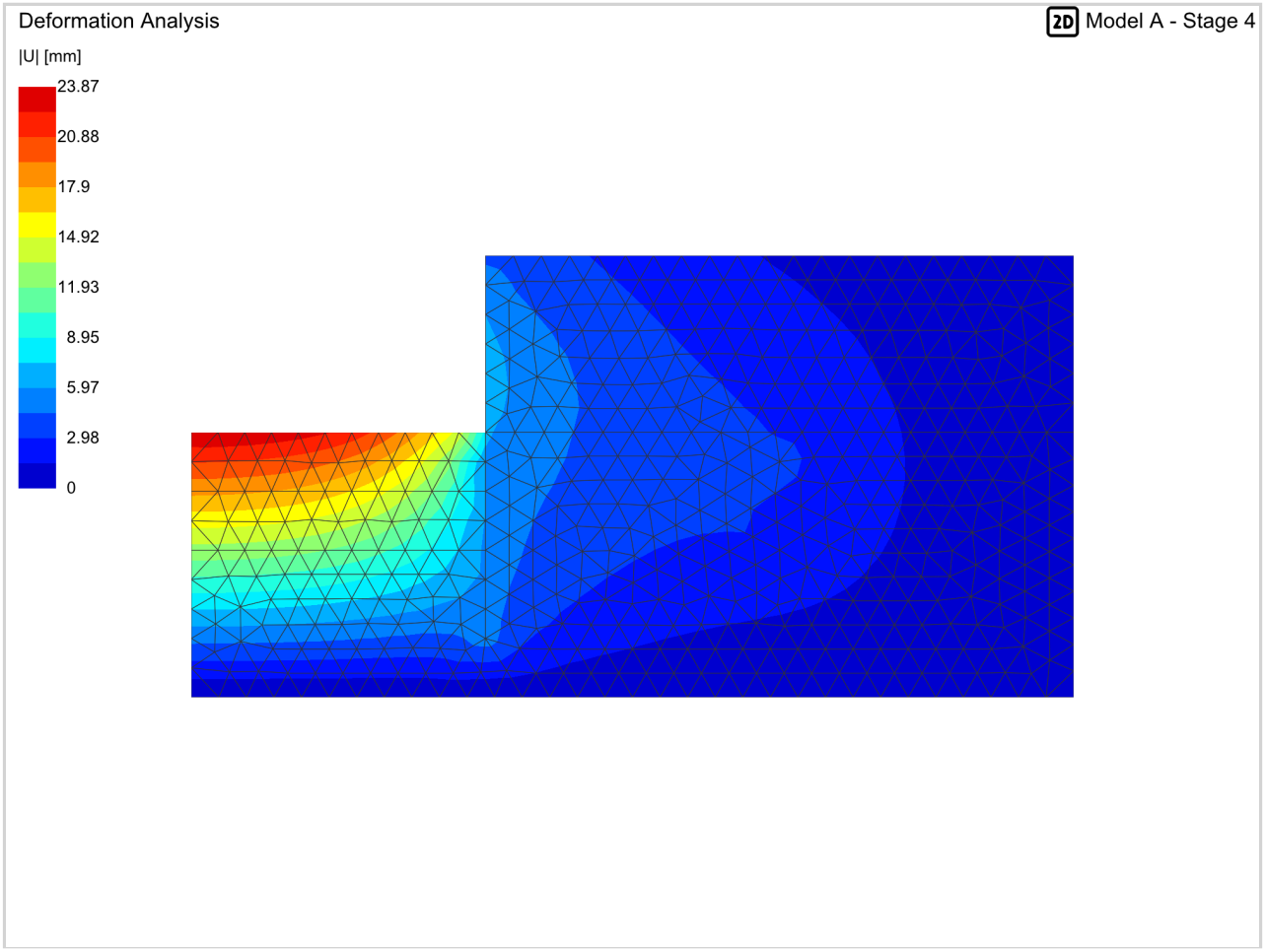


Figure 28: *Stage 4, Deformation, |U|*

Structural elements

Table 18: *Values*

	Min	Max
$M_{y,Ed}$ [kNm/m]	-34.7	12.0
$V_{y,Ed}$ [kN]	-29.6	30.2
N_{Ed} [kN]	-65.0	81.4
|U| [mm]	1.55	6.71

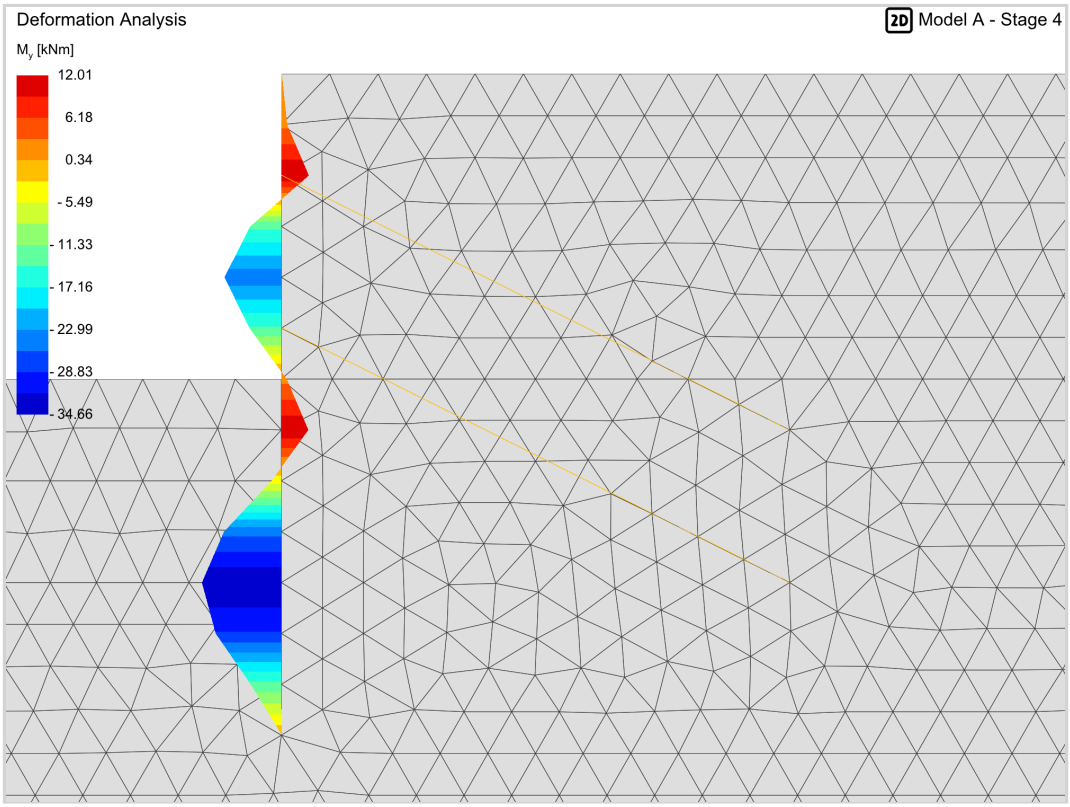


Figure 29: *Moment, M_y*

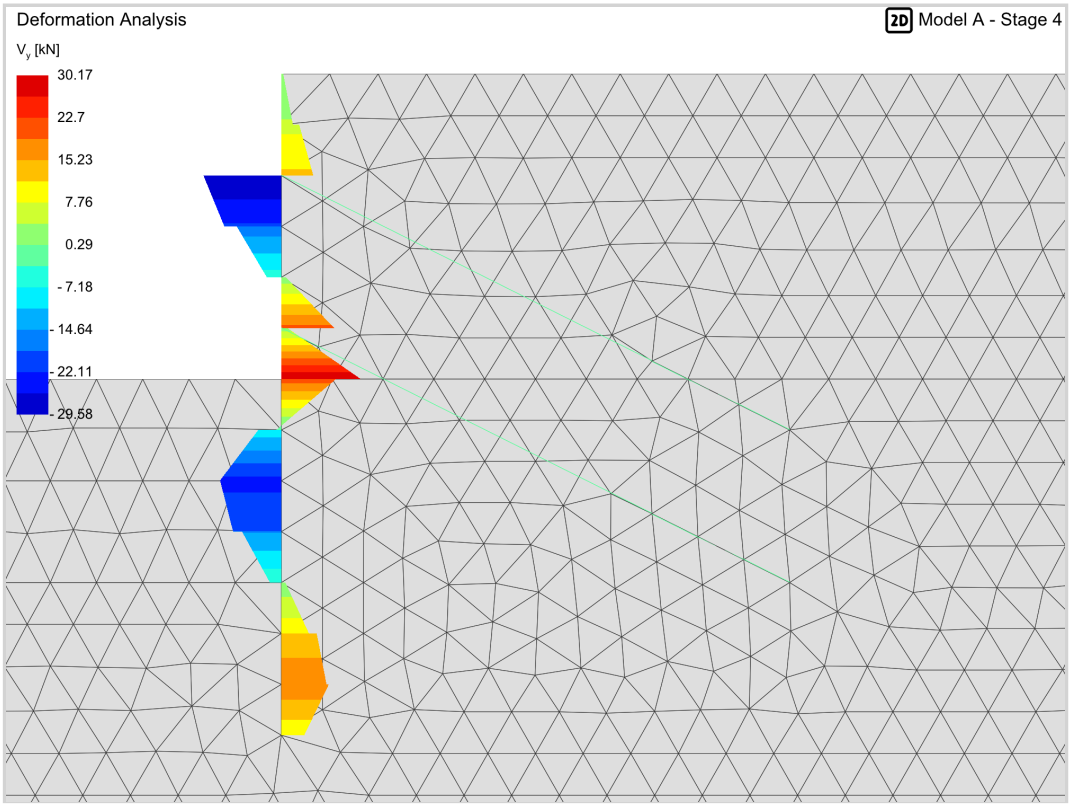


Figure 30: *Shear force, V_y*

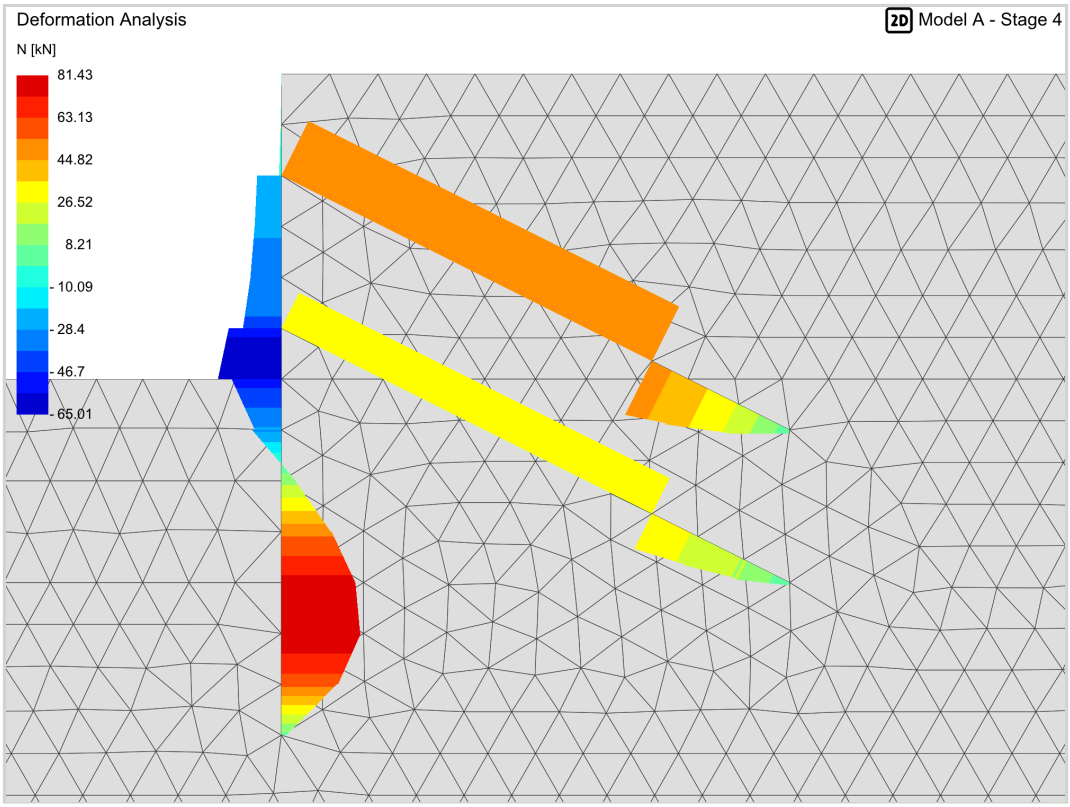


Figure 31: *Normal force, N*

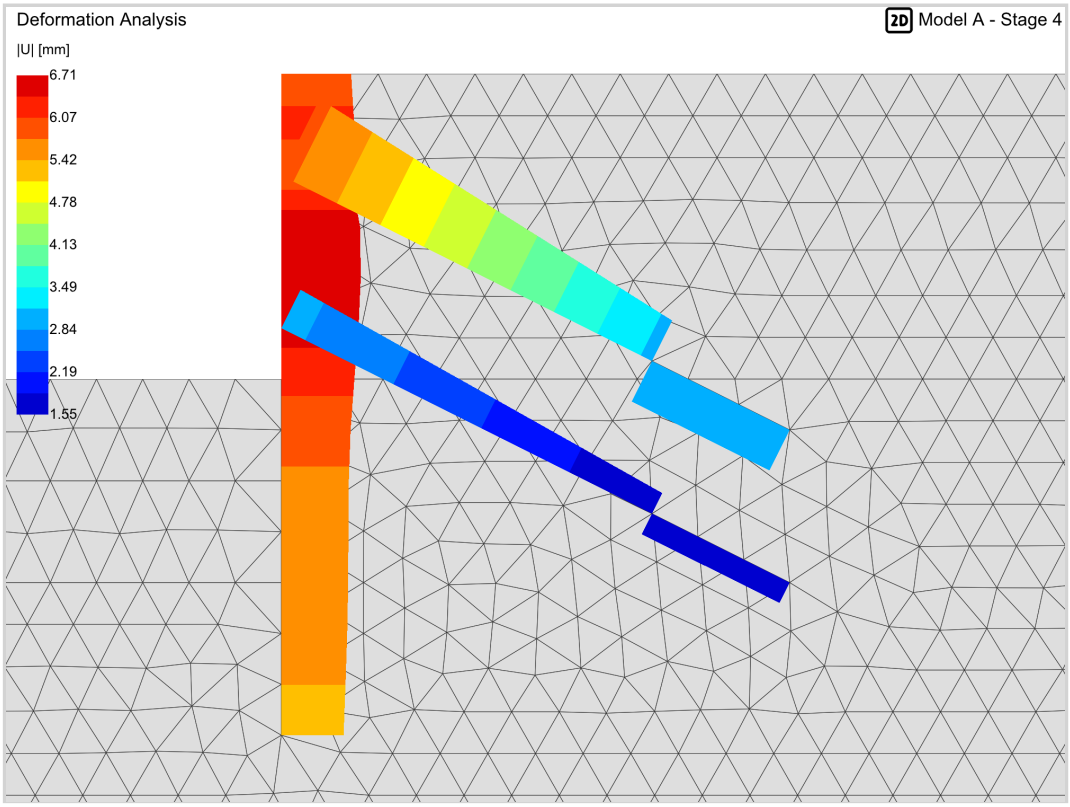


Figure 32: *Displacement, |U|*

6.2.5 Stage 5

Design approach: Unity.
Deformation analysis. U_{max} = **24.8 mm**

Parent stage: Stage 4

Table 19: *Analysis details*

Element type:	Mixed
Element count:	1046

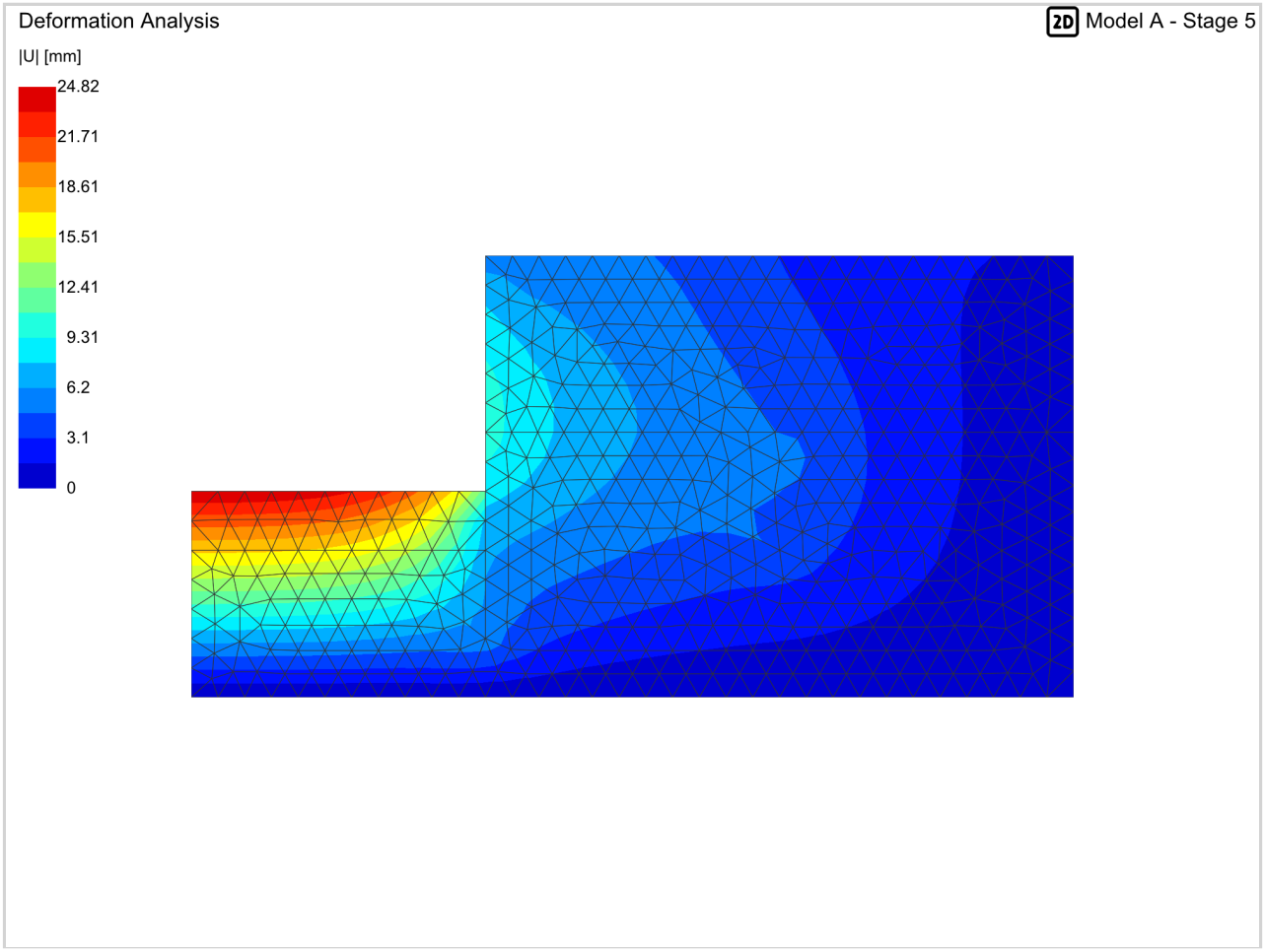


Figure 33: *Stage 5, Deformation, |U|*

Structural elements

Table 20: *Values*

	Min	Max
$M_{y,Ed}$ [kNm/m]	-68.2	19.4
$V_{y,Ed}$ [kN]	-38.7	53.0
N_{Ed} [kN]	-107	68.0
|U| [mm]	3.33	10.1

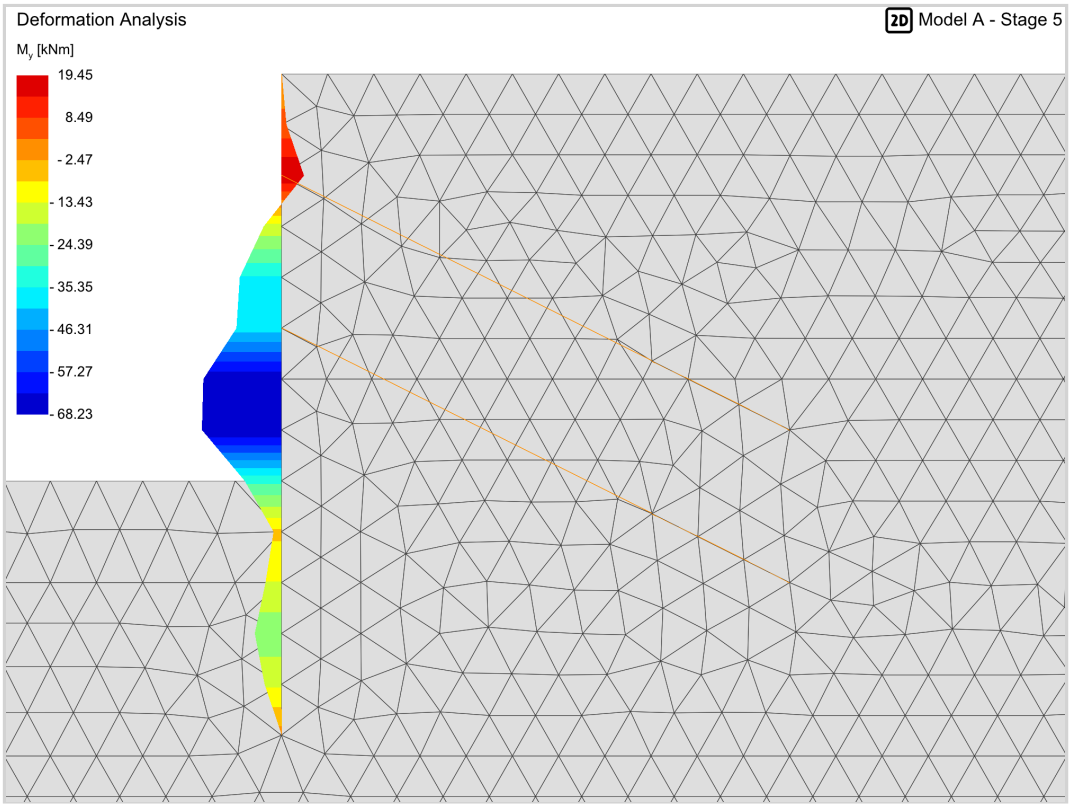


Figure 34: *Moment, M_y*

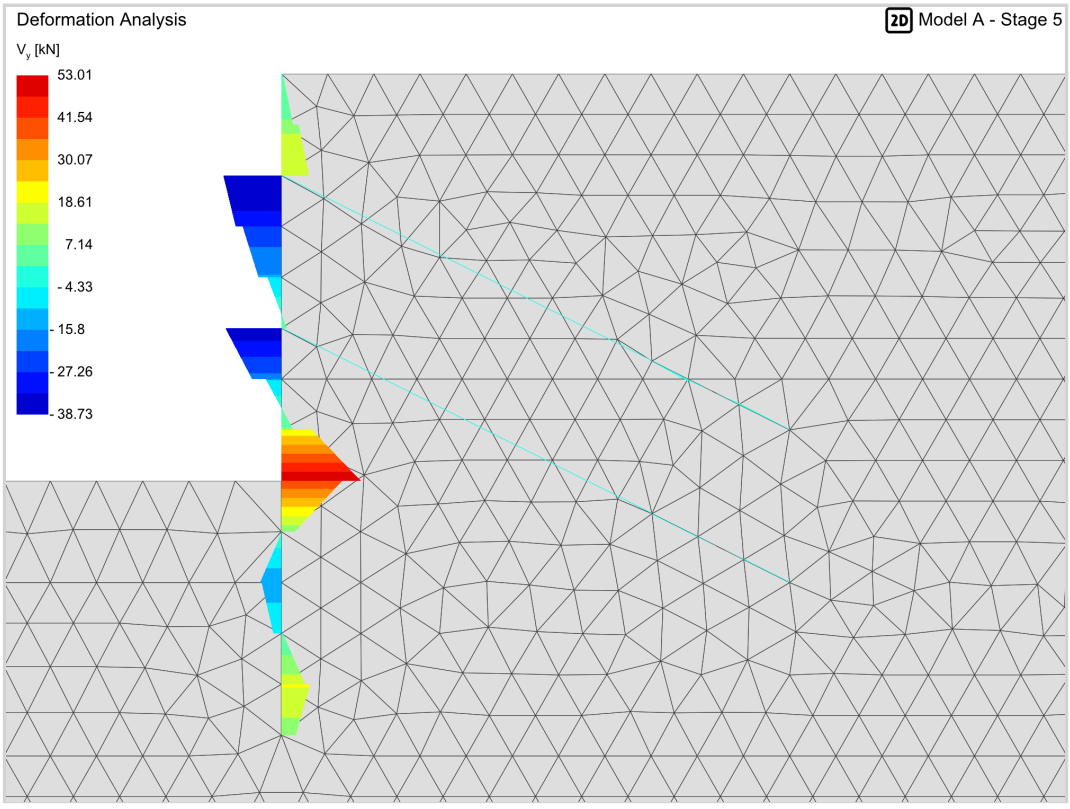


Figure 35: *Shear force, V_y*

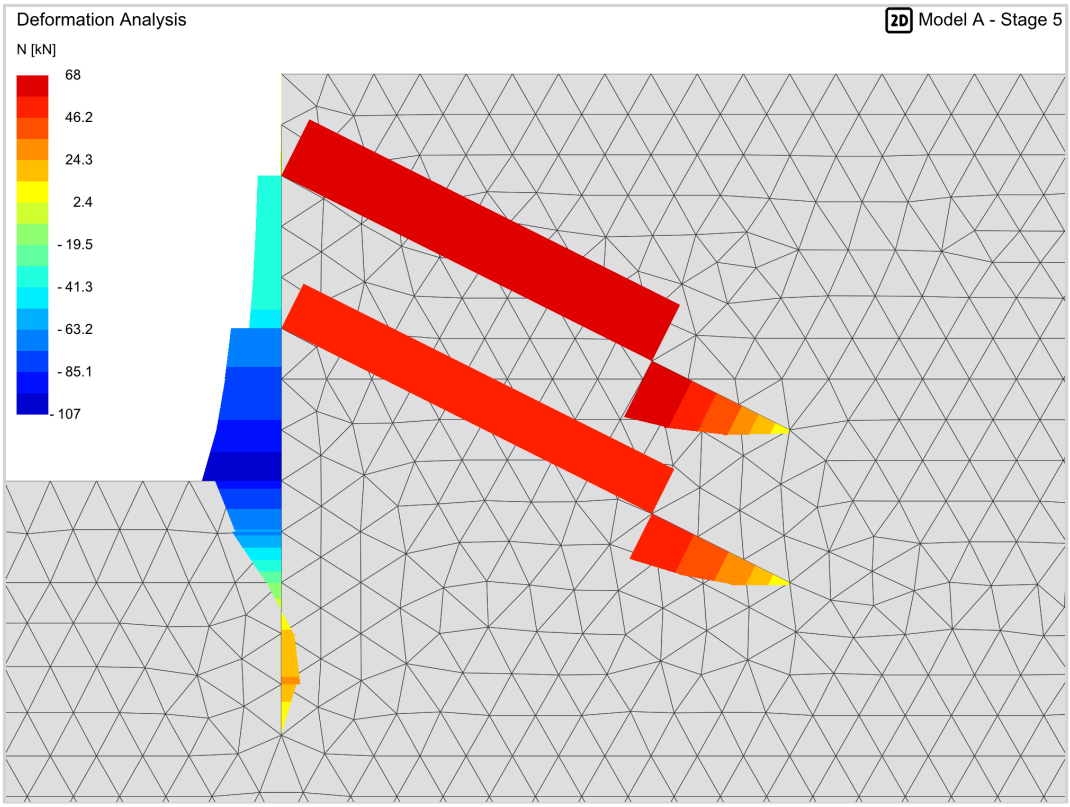


Figure 36: *Normal force, N*

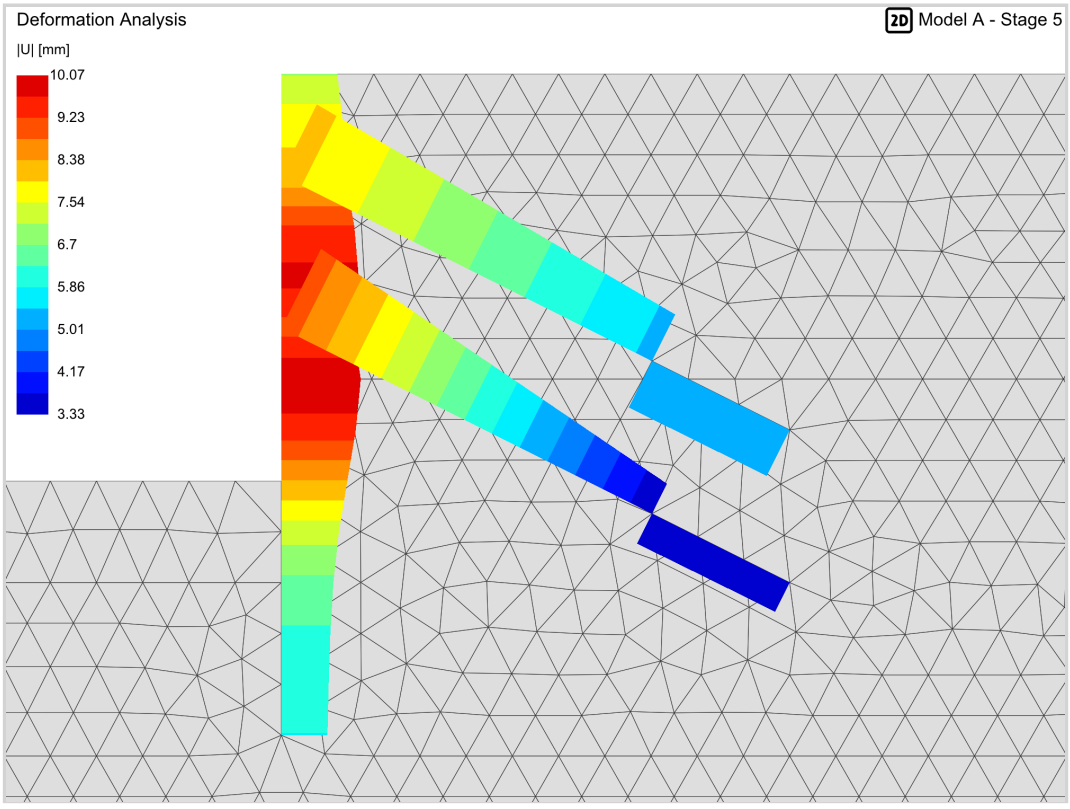


Figure 37: *Displacement, |U|*

6.2.6 Stage 6

Design approach: Unity.
Deformation analysis. U_{max} = **22.3 mm**

Parent stage: Stage 5

Table 21: *Analysis details*

Element type:	Mixed
Element count:	1265

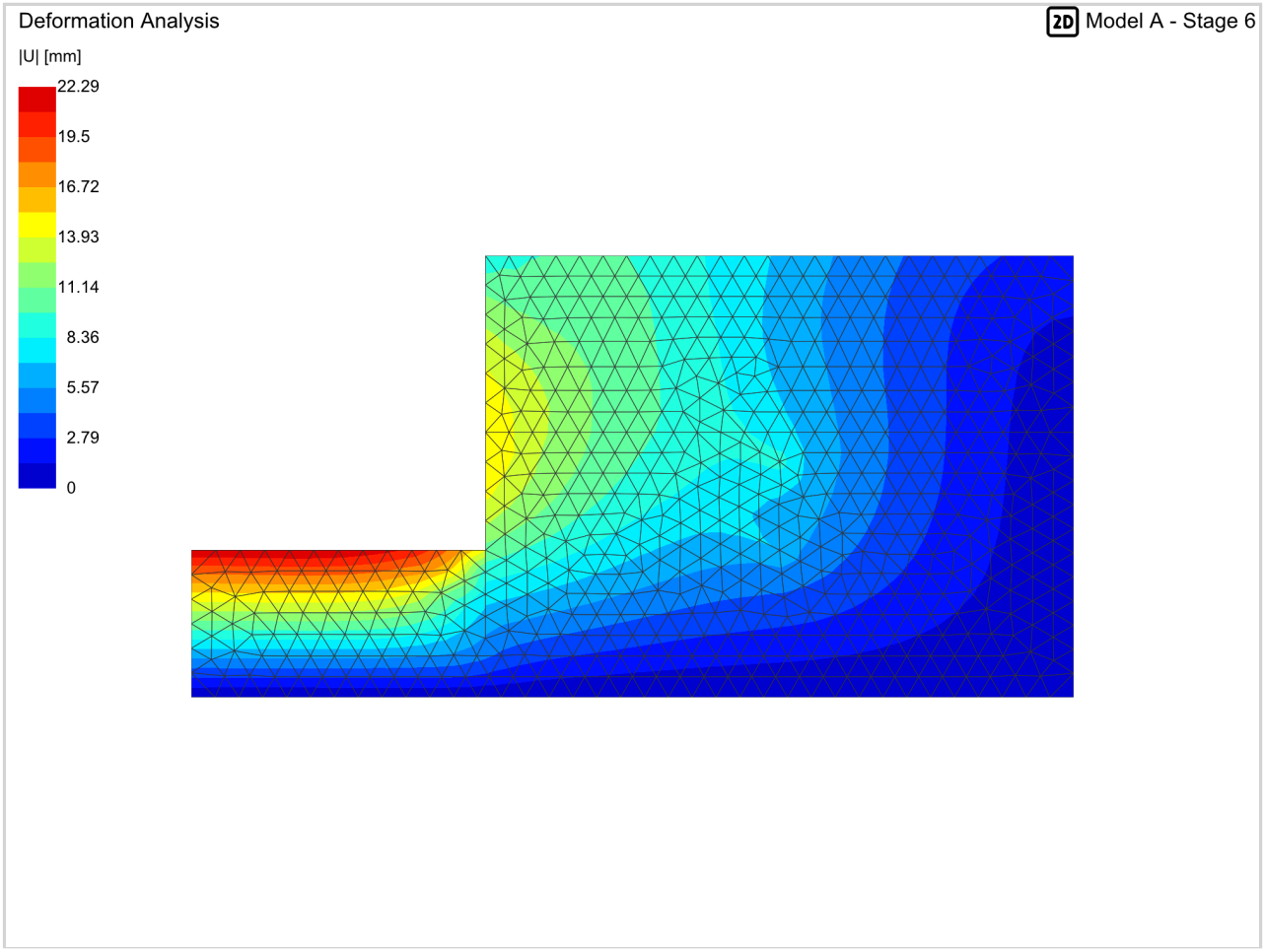


Figure 38: *Stage 6, Deformation, |U|*

Structural elements

Table 22: *Values*

	Min	Max
$M_{y,Ed}$ [kNm/m]	-153	25.8
$V_{y,Ed}$ [kN]	-60.9	84.2
N_{Ed} [kN]	-153	87.8
|U| [mm]	5.43	15.5

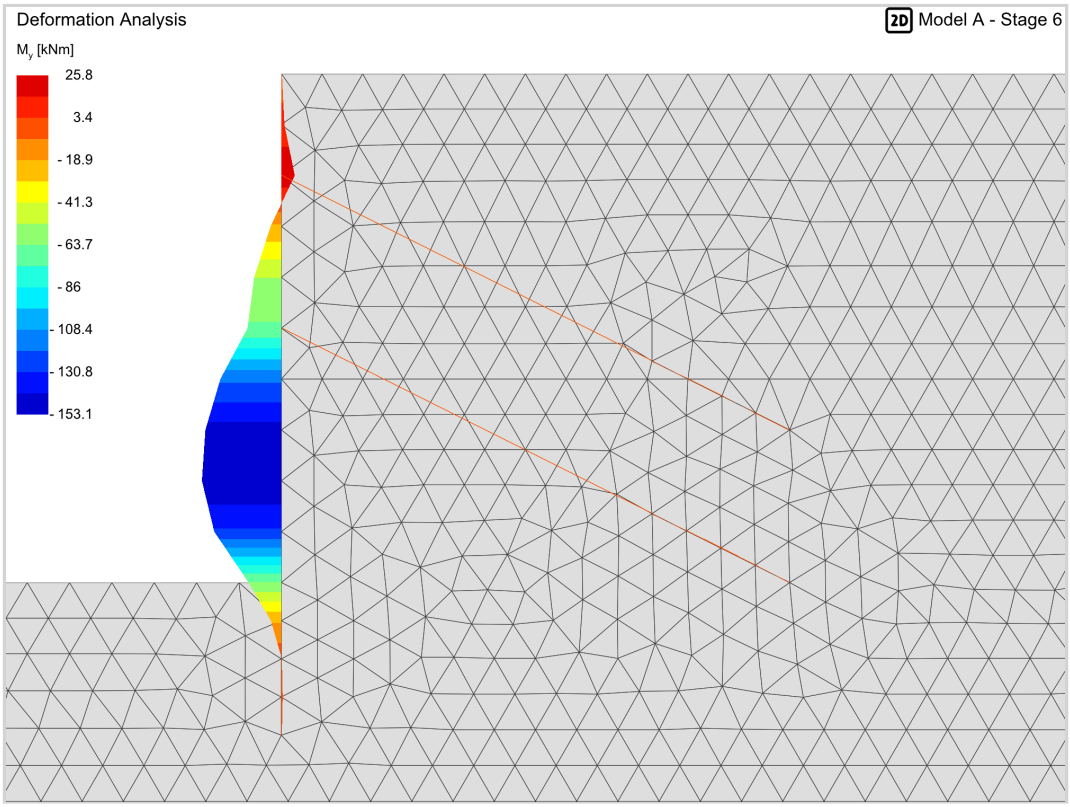


Figure 39: *Moment, M_y*

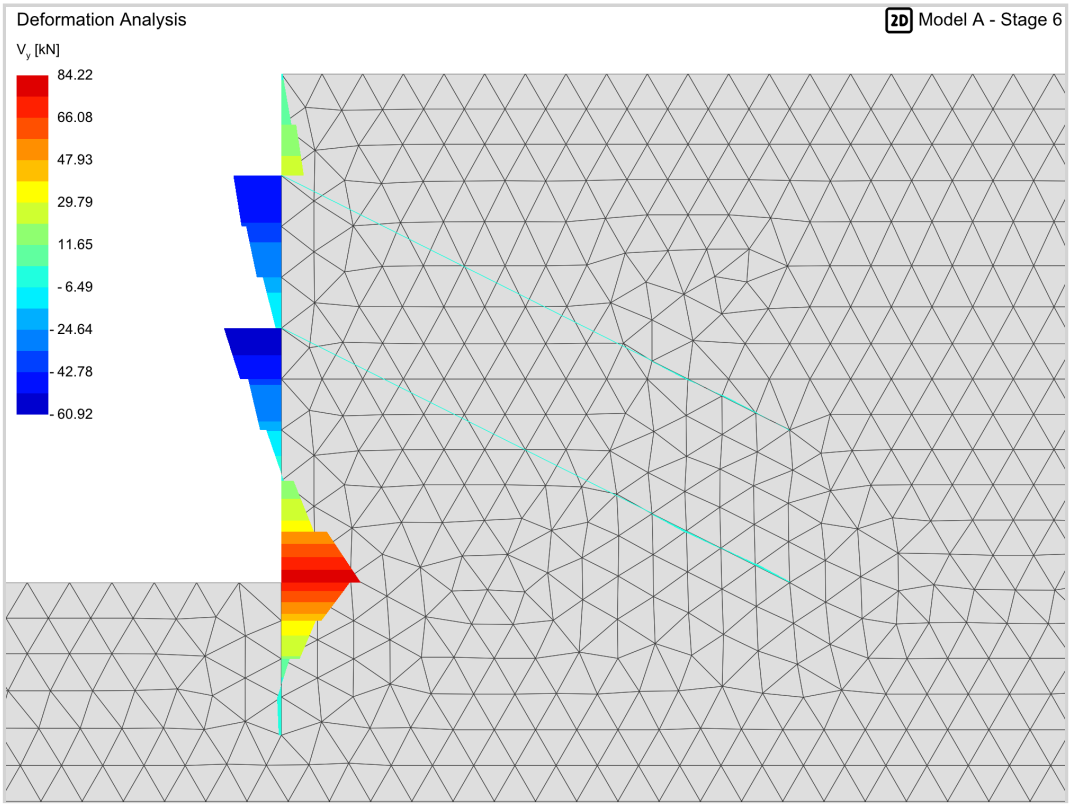


Figure 40: *Shear force, V_y*

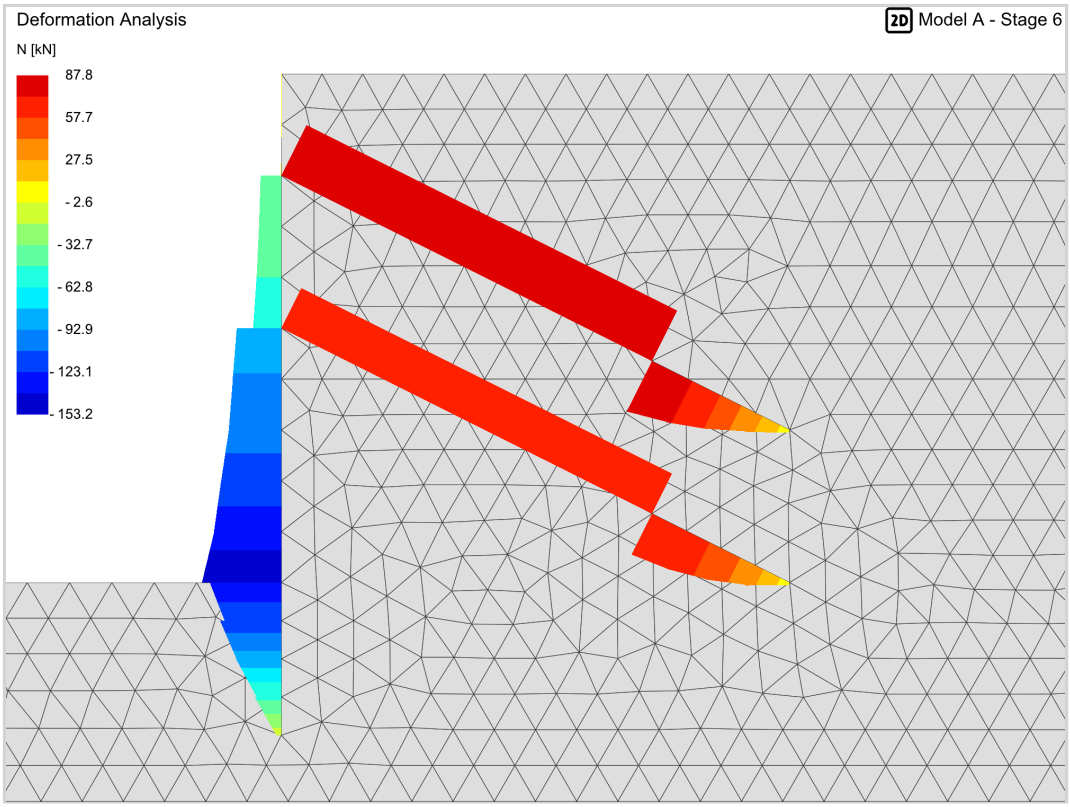


Figure 41: *Normal force, N*

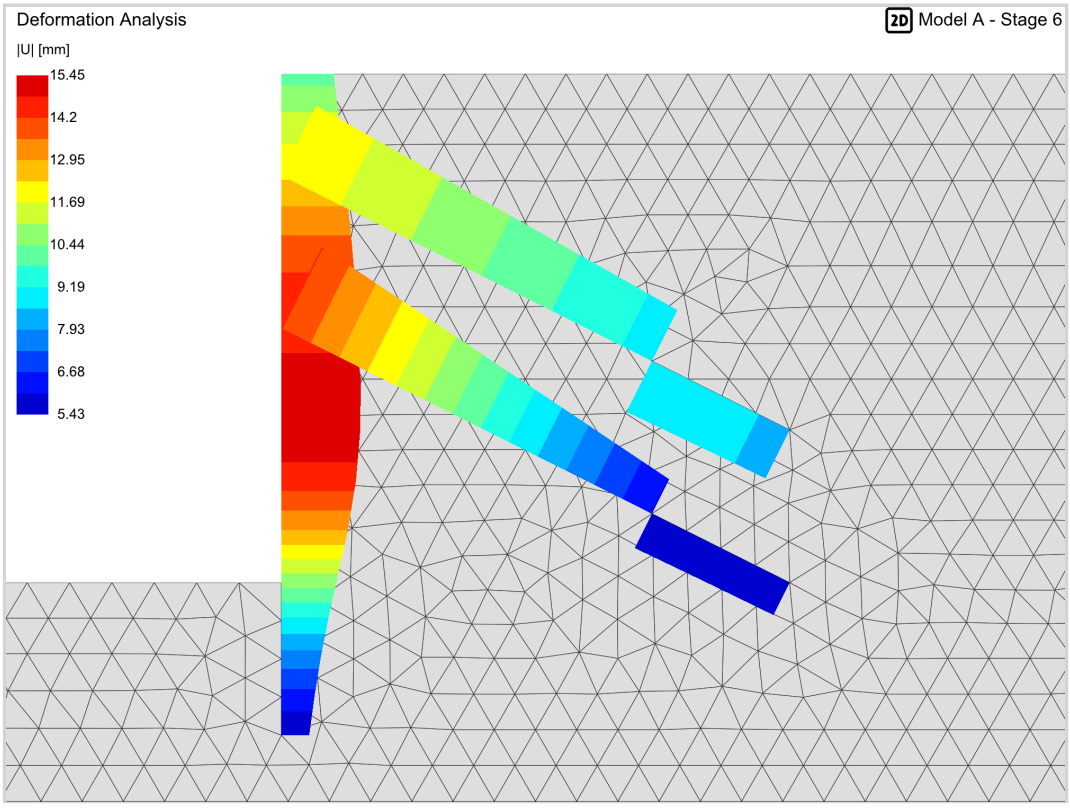


Figure 42: *Displacement, |U|*

6.2.7 Stage 7

Design approach: Unity.
Factor of safety analysis. FoS = **1.62**

Parent stage: Stage 6

Table 23: *Analysis details*

Element type:	Mixed
Element count:	1265

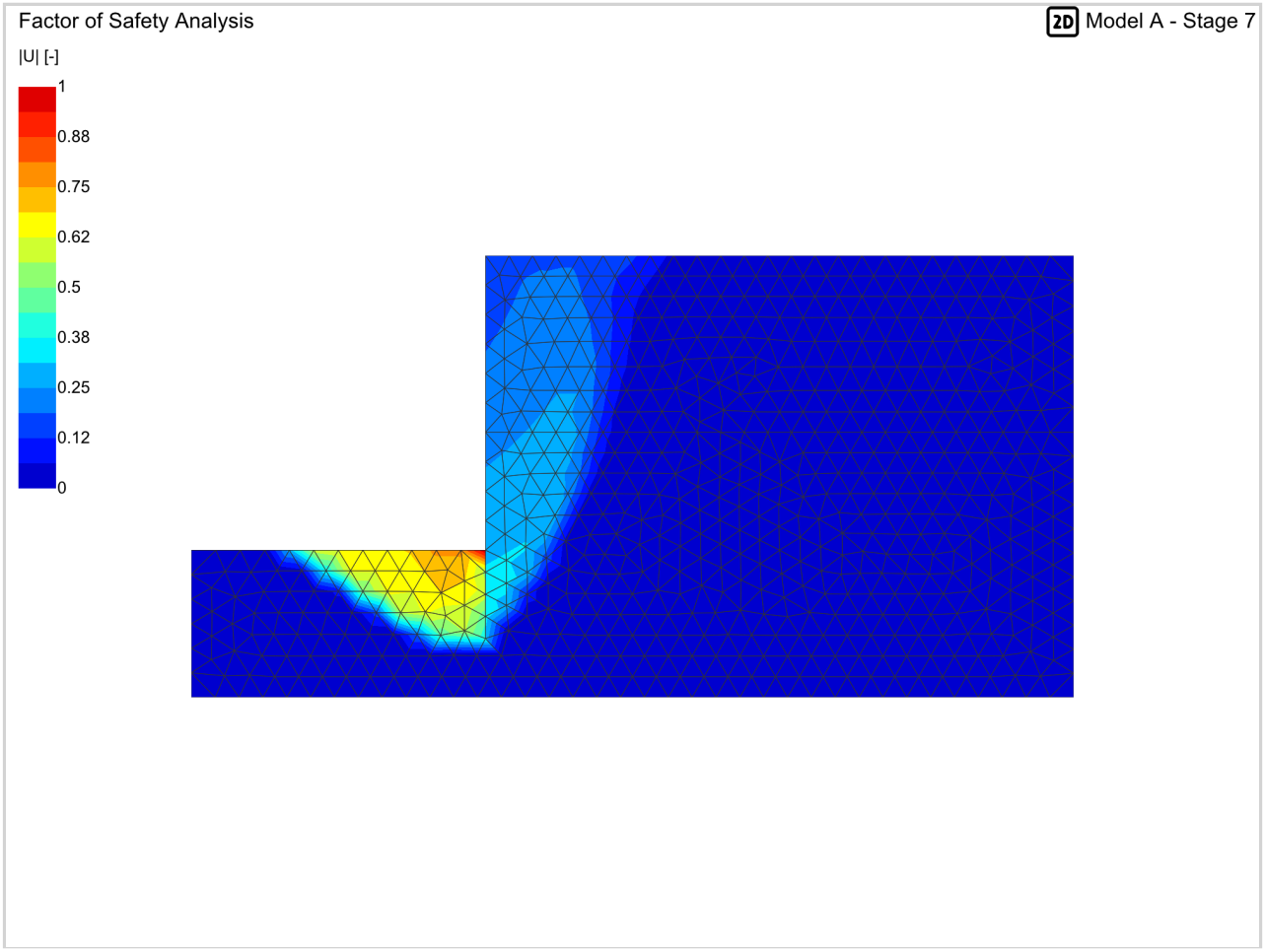


Figure 43: *Stage 7, Factor of safety, |U|*