PROPOSAL PENGABDIAN KEPADA MASYARAKAT

REVIEW DESAIN TUNNEL WALINI
(PEMODELAN FEM MENGGUNAKAN PLAXIS 2D)
KERETA CEPAT JAKARTA BANDUNG

Ketua Tim :
Dr. techn. Indra Noer Hamdhan

Anggota:
Rinaldi Alamsyah (22-2015-225)

PROGRAM STUDI TEKNIK SIPIL
FAKULTAS TEKNIK SIPIL DAN PERENCANAAN
INSTITUT TEKNOLOGI NASIONAL BANDUNG

2018

HALAMAN PENGESAHAN

1.	Judul	: Review Desain Tunnel Walini (Pemodelan Fem Menggunakan Plaxis 2d) Kereta Cepat Jakarta Bandung
2.	Pelaksana	: Dr. tech. Indra Noer Hamdan, ST., MT.
	NIP	: 120030105
	Pangkat/Golongan	: Lektor /III D
	Jurusan	: Teknik Sipil
	Bidang Keahlian	: Geoteknik
	Anggota	: Rinaldi Alamsyah
3.	Bentuk Kegiatan	: Analisis
4.	Waktu Kegiatan	: 1 November – 31 Desember 2018
5.	Sumber Dana	: Asea-Uninet
6.	Jumlah Dana	: Rp. 20.000.000

Bandung, 13 September 2018

Pelaksana

(Dr. tech. Indra Noer Hamdan, ST., MT.)

Ketua Jurusan Teknik Sipil

(Dr. tech. Indra Noer Hamdan, ST., MT.)

Mengetahui

Kepala LP2M Itenas

itenas LPPM

(Dr. Tarsisius Kristyadi, ST., MT.)

DAFTAR ISI

1. Informasi Umum Pekerjaan Kereta Cepat Jakarta-Bandung

A. Lokasi Pekerjaan Kererta Cepat Jakarta-Bandung

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Panjang segmen JKT-BDG HSR yaitu 142.3 km, termasuk 102.24 km jembatan dan terowongan. Sepanjang jalur terdapat 4 stasiun yang direncanakan, yaitu terdiri dari Stasiun Halim, Stasiun Karawang, Stasiun Walini dan Stasiun Tegal Luar.

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Kereta cepat Jakarta-Bandung merencanakan 14 jalur ganda untuk terowongan pada jalur utamanya, dengan panjang total sebesar 16.82 km. Terowongan terpanjang merupakan terowongan No. 6, dengan panjang total 4478 m. Desain terowongan terpendek merupakan terowongan DIK81～DIK82 dengan panjang 150 m. Detail data terowongan dapat dilihat pada **Tabel 1** dan **Tabel 2**.

Table 1 Rentang dan Panjang Terowongan

S/N	Tunnel Name	Chainage		Center Chainage	length
		Entrance	Exit		
1	NO.1 Tunnel	DK2+540	DK4+425	DK3+482.5	1885
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Table 2 Panjang Terowongan

Section	Tunnel length	Double-tracked tunnel length and number	
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- GB 1499.1-2017 : Steel for The Reinforcement of Concrete—Part 1: Hot Rolled Round Bars
- GB 1499.2-2018 : Steel for The Reinforcement of Concrete—Part 2: Hot Rolled Ribbed Bars
- GB/T 228.1-2010 : Metallic Materials-Tensile Testing- Part 1: Method of Test at Room Temperature
- GB/T 232-2010 : Metallic Materials-Bend Tedt.
- SNI 2052:2017 : Indonesianconcrete Reinforcement Standard Specification**.**

B. Kriteria Deformasi

Monitoring serta kriteria deformasi pada struktur yang berdiri di atas galian terowongan ditunjukkan pada **Tabel 3.**

Table 3 Monitoring items and control values for tunnel surrounding environment

No.	Monitoring objects	Monitoring items and its control values
1	Highway pavement	Accumulative pavement settlement amount: ≤20mm; Settlement rate:≤2mm/d. For risk sensitive point, the control values shall be determined according to the specific situation.
2	Light rail	Accumulative abutment settlement: ≤16mm; Settlement rate:≤1.5mm/d; Accumulative differential settlement of adjacent abutments: ≤4mm; Differential settlement of single abutment（lateral direction）: ≤3mm; Absolute rotation angle of beam end: ≤0.8x10-3//rad; Relative rotation angle of beam end: ≤1.6x10-3//rad; Concrete crack width: ≤0.2mm.

No.	Monitoring objects	Monitoring items and its control values
3	Frame pier of Light rail bridge	Accumulative abutment settlement: ≤16mm; Settlement rate:≤1.5mm/d; Accumulative differential settlement of adjacent frame pier: ≤4mm（longitudinal direction）; Differential settlement of single frame pier: ≤6mm; Concrete crack width: ≤0.2mm （for pre-stressed structure, cracking is forbidden）.
4	Pedestrian overbridge	Accumulative abutment settlement: ≤30mm; Differential settlement of adjacent abutment of simple supported beam（longitudinal direction）: ≤8mm; Differential settlement of abutment under stairs structure: ≤3mm; Differential settlement of single abutment （lateral direction）: ≤4mm; Horizontal displacement of pier cap: ≤4mm; Settlement rate:≤3mm/d; Concrete cracking width: ≤0.2mm.
5	Surface buildings	Structure inclination rate: ≤1/1000; Accumulative settlement amount: ≤20mm; Structure differential settlement amount: ≤1‰L（Where L denotes the centre spacing of adjacent base）; Structure deformation rate: ≤1.5mm/d; Maximum concrete crack width: ≤0.2mm.
6	Highway interchange bridge	Accumulative abutment settlement amount: ≤20mm; Settlement rate:≤1.5mm/d; Accumulative differential settlement of adjacent abutments（longitudinal direction）: ≤6mm; Differential settlement of single abutment: ≤3mm; Absolute rotation angle of beam end: ≤0.8x10-3//rad; Relative rotation angle of beam end: ≤1.6x10-3//rad; Concrete crack width: ≤0.2mm（for pre-stressed structure, cracking is forbidden）.
Notes: 1. All surface buildings located within in the major construction influence range must be monitored. Buildings located within in the secondary construction influence range could be monitored. 2. Monitoring must be conducted on major underground pipelines, such as gas pipeline with medium or high pressure, major water pipeline, water source pipeline, concrete pipe with spigot joints, electricity pipeline with the voltage higher than 220KV, military optical cable and etc.		

Deformasi izin pada monitoring terhadap pernurunan di permukaan serta potensi mengembang (*heave*).

Table 4 Control Values of Monitoring Items on Ground Settlement and Heave

Monitoring Items and Soil Types		**Cumulative value （mm）**	**Rate of Change （mm/d）**
Ground settlement	Hard ~ Medium hard Soil	10~20	3
	Medium soft ~ Soft Soil	15~25	3
Ground heave		10	3

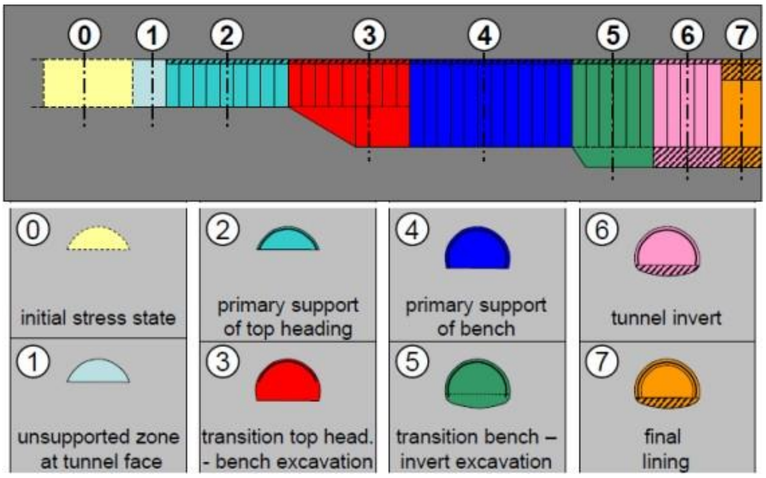
Pada masa operasional, deformasi izin pada *track* kereta cepat mengacu pada QCR9230-2016 dimana besar deformasi izinnya sebesar 15 mm. Sedangkan pada konstruksi, deformasi izin pada terowongan dapat dilihat pada **Tabel 5**.

Table 5 Control values of Monitoring Items on vertical displacement and clearance convergence

Monitoring Items and Soil Types		Cumulative value （mm）	Rate of Change （mm/d）
Shield segment settlement	Hard ~ Medium hard Soil	10~20	2
	Medium soft ~ Soft Soil	20~30	3
Segment differential settlement		0.04%Ls	——
Tunnel clearance convergence		0.2%D	3
Notes: Ls denotes the longitudinal spacing of monitoring points along the tunnel D denotes the diameter of the tunnel excavation contour			

C. Metode Konstruksi Terowongan

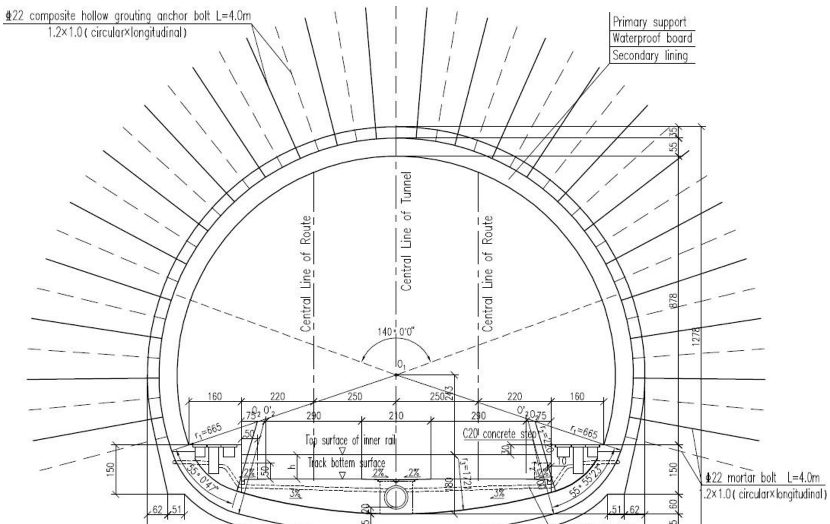
New Austrian Tunneling Method (NATM) : NATM merupakan metode *excavation* pada terowongan yang dilakukan secara manual dan bertahap. Tahapan pertama dalam metode ini adalah proses *excavation* pada area *tunnel* yang dapat dilakukan dengan menggunakan alat *twin header* dan *excavator*. Pembuangan tanah kerukan dapat menggunakan *loader* tertentu disesuaikan dengan diameter *tunnel*. Setelah itu proses excavation dilanjutkan dengan pekerjaan *temporary support* menggunakan *forepoling*, *wire mesh* dan *steel rib*. Lalu dilakukan proses proteksi pada area dinding dengan menggunakan *shotcrete*. Selanjutnya untuk pembuatan *lining tunnel*, dilakukan secara cast in situ, didahului dengan pembesian *lining* struktur dan pengecoran. Pada tahapan akhir dilakukan *back fill grout* untuk memperbaiki retak-retak yang terjadi pada dinding tunnel.



Gambar 1 Metode konstruksi terowongan dengan NATM

D. Tipe Struktur Lining

Model terowongan yang dilakukan disesuaikan dengan desain seperti yang ditunjukkan pada **Gambar 2.** Terowongan memiliki bentuk elips dengan diameter horizontal 15 m dan diameter vertikal 12.6 m. Terowongan diperkuat dengan *rockbolt* dengan panjang 4 m serta ketebalan lining dimodelkan dengan dua jenis *lining* yaitu *primary lining* dan *secondary lining* dengan variasi tebal lining tergantung kategori tanah/batuan seperti yang ditunjukkan pada **Tabel 6** dan **Tabel 7.**



Gambar 2 Contoh model terowongan Tunnel Walini

Table 6 Pemilihan tipe lining berdasarkan jenis tanah/batuan

Surrounding rock	Lining type	Applicable conditions
II	II$_a$	II surrounding rock area
III	III$_a$	III surrounding rock area
	III$_b$	III surrounding rock of horizontal stratification area (Strata dip Angle≤ 15°) adverse rock area
IV	IV$_a$	IV surrounding rock of deep buried section
	IV$_b$	IV surrounding rock of shallow buried, bias, fault fracture zone, seismic area, II、III surrounding rock within the 60m scope from the intersection between main tunnel and service gallery
	IV$_p$	IV surrounding rock of moderate swelling rock section
V	V$_{r-a}$	V surrounding rock of deep buried rock section
	V$_{r-b}$	V surrounding rock of shallow buried seismic fortification rock section
	V$_{r-c}$	V surrounding rock of bias, fault fracture, rock section
	V$_{r-p}$	V surrounding rock of moderate swelling rock section
	V$_{s-a}$	V surrounding rock of deep buried soil section (Natural water content is smaller)
	V$_{s-b}$	V surrounding rock of shallow buried seismic fortification soil section (or natural water content is smaller)
	V$_{s-p-1}$	V surrounding rock of expansive soil section (medium swelling)
	V$_{s-p-2}$	V surrounding rock of area which is sensitive to deformation such as the area underpass the existing railway or road above (corresponding to the three steps CRD)
VI	VI$_a$	VI surrounding rock of soft and plastic soil or water-bearing sand layer area
	VI$_b$	VI surrounding rock of area which is sensitive to deformation such as the area underpass the existing railway or road above (corresponding to the three steps CRD)

Table 7 Desain tebal lining berdasarkan kategori batuan

NO.	Lining type	Primary support										Secondary lining		deformation allowance (cm)
		Thickness of shotcret (cm)	Steel mesh			System rock bolt			grid,steel frame			thickness of arch wall (cm)	thickness of invert (cm)	
			position	diameter (mm)	mesh size (cm)	position	length (m)	ring, longitudinal spacping(m)	specifications	position	spacing (m)			
1	II$_a$	arch wall5	—	—	—	—	—	—	—	—	—	35*	35*	3~5
2	III$_a$	arch wall12	arch wall	Φ6	25×25	arch wall	3	1.2×1.5	—	—	—	40*	50*	5~8
3	III$_b$	arch wall23	arch wall	Φ6	25×25	arch wall	3	1.2×1.5	150grid Φ22	arch wall	1.5	40*	50*	5~8
4	IV$_a$	arch wall25 invert10	arch wall	Φ6	20×20	arch wall	3.5	1.2×1.2	180grid Φ22	arch wall	1	45*	55*	8~10
5	IV$_b$	arch wall25 invert25	arch wall	Φ6	20×20	arch wall	3.5	1.2×1.2	I18shape steel	ring	1	45*	55*	8~10
6	IV$_p$	ring28	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I20a shape steel	ring	0.8	45*	55*	8~10
7	V$_{r-a}$	ring28	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I20a shape steel	ring	0.8	50*	60*	10~15
8	V$_{r-b}$	ring28	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I20a shape steel	ring	0.6	50*	60*	10~15
9	V$_{r-c}$	ring30	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I22a shape steel	ring	0.6	55*	65*	10~15
10	V$_{r-p}$	ring35	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I25a shape steel	ring	0.6	55*	65*	15~20
11	V$_{s-a}$	ring30	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I22a shape steel	ring	0.6	50*	60*	10~15
12	V$_{s-b}$	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25a shape steel	ring	0.6	55*	65*	15~20
13	V$_{s-p-1}$	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25
14	V$_{s-p-2}$	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25
15	VI$_a$	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25
16	VI$_b$	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25

3. Pengumpulan Data-Data

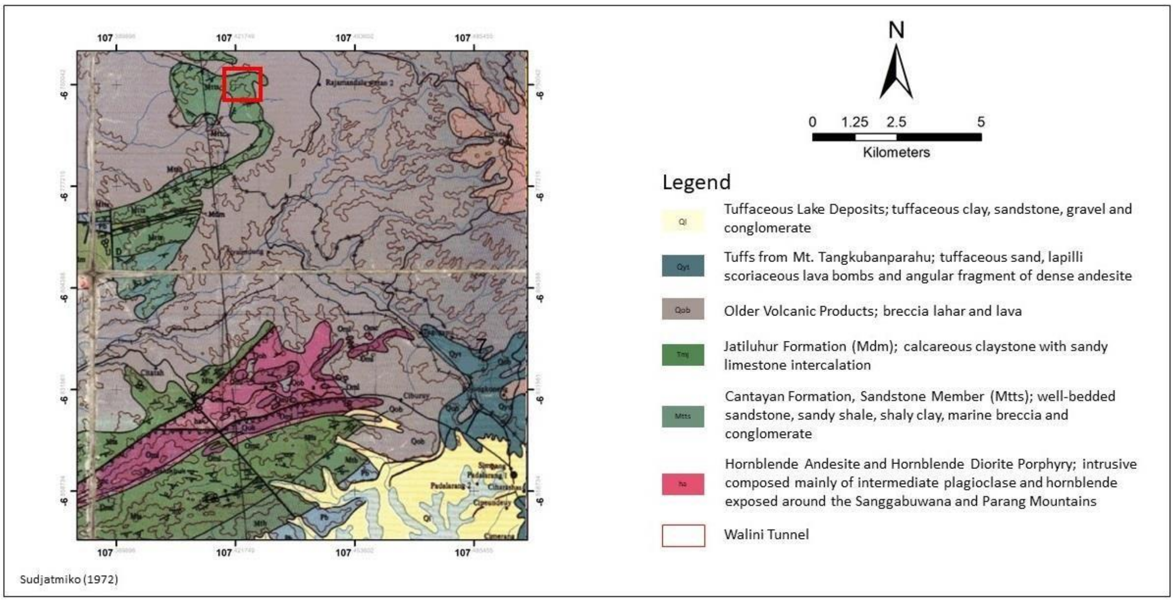
A. Data Umum Terowongan Walini

Terowongan Walini Kereta Cepat Jakarta Bandung Jakarta, berlokasi di Purwakarta yang bertepatan di Barat Daya Kecamatan Cikalong Wetan. Metode konstruksi yang diterapkan pada Tunnel Walini ini adalah metode galian NATM (New Austrian Tunneling Method). Titik awal terowongan berada pada DK95+472 dan titik akhir terowongan pada DK96+080, sehingga total panjang terowongan, yaitu 608m.

Gambar 3 Lokasi *Soil Inestigastion* Terowongan Walini

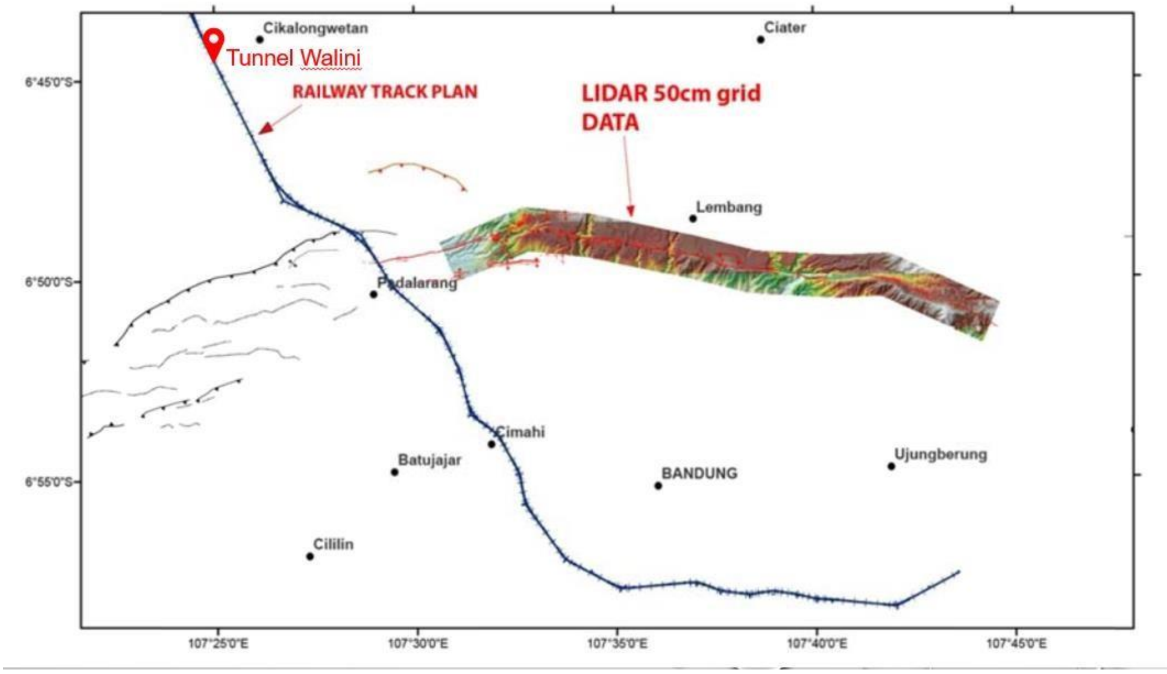
B. Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan

Berdasarkan Peta Geologi (Sudjatmiko, 1972) Terowongan Walini berada pada Formasi Cantayan, dengan sandstone member (Mtts) yang memiliki tebal 2700 m. Peta Geologi disajikan pada **Gambar 4.**



Gambar 4 Peta Geologi (Sudjatmiko, 1972)

Setelah dilakukan observasi pada area sekitar terowongan didapat kondisi tanah dan batuan yang special. Pada DK 95+000 antara DK 100+000 didapat adanya tanah ekspansif/batu ekspansif yang memiliki nilai *free swell ratio* 40-52%, hal tersebut termasuk kedalam kategori *weakly expansive*. Serta secara visual ditemukan *clayshale* pada 200 m dari sisi outlet terowongan.



Gambar 5 Hasil Analisis Geologi

Berdasarkan data geologi pada **Gambar 5** disebutkan bahwa pada Terowongan Walini tidak terdapat *fault zone*.

C. Stratigrafi Tanah dan Data Borlog

Detail stratigrafi tanah di area Terowongan Walini dapat dilihat pada **Lampiran A** dan untuk Data hasil penyelidikan tanah (SPT) dapat dilihat pada **Lampiran D**.

D. Hasil Pengujian Laboratorium

Hasil-Hasil pengujian laboratorium yang dilakukan pada beberapa sampel dari setiap borlog dapat dilihat pada **Lampiran E.**

E. Material Terowongan dan Referensi Penentuan Parameter Tanah/Batuan

Spesifikasi material yang digunakan pada Terowongan Walini dapat dilihat dibawah ini:

Dimensi Terowongan

Tipe Lining terowongan	: $V_{r\text{-}p}$
Diameter	: 15.1 m
Ketebalan	
Primary lining (Shotcrete)	: 0.35 m
Secondary lining (Reinforced Concrete)	
Invert Arch	: 0.65 m
Wall Arch	: 0.55 m

Material Terowongan

Shotcrete	: C30
Reinforced Concrete	: C35 dengan tulangan
Tulangan	: HPB300 (φ ≤ 10 mm)
	HRB400 (φ ≥ 16 mm)
Fill inverted arch	: Beton C20
Ditch and cable duct	: Beton C30

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- GB/T 8077-2012 : Methods for Testing Uniformity of Cincrete Admixture
- GB 8076-2008 : Concrete Admixture
- GB 1499.1-2017 : Steel for The Reinforcement of Concrete—Part 1: Hot Rolled Round Bars
- GB 1499.2-2018 : Steel for The Reinforcement of Concrete—Part 2: Hot Rolled Ribbed Bars
- GB/T 228.1-2010 : Metallic Materials-Tensile Testing- Part 1: Method of Test at Room Temperature
- GB/T 232-2010 : Metallic Materials-Bend Tedt.
- SNI 2052:2017 : Indonesianconcrete Reinforcement Standard Specification**.**

B. Kriteria Deformasi

Monitoring serta kriteria deformasi pada struktur yang berdiri di atas galian terowongan ditunjukkan pada **Tabel 3.**

Table 3 Monitoring items and control values for tunnel surrounding environment

No.	Monitoring objects	Monitoring items and its control values
1	Highway pavement	Accumulative pavement settlement amount: ≤20mm; Settlement rate:≤2mm/d. For risk sensitive point, the control values shall be determined according to the specific situation.
2	Light rail	Accumulative abutment settlement: ≤16mm; Settlement rate:≤1.5mm/d; Accumulative differential settlement of adjacent abutments: ≤4mm; Differential settlement of single abutment（lateral direction）: ≤3mm; Absolute rotation angle of beam end: ≤0.8x10-3//rad; Relative rotation angle of beam end: ≤1.6x10-3//rad; Concrete crack width: ≤0.2mm.

No.	Monitoring objects	Monitoring items and its control values
3	Frame pier of Light rail bridge	Accumulative abutment settlement: ≤16mm; Settlement rate:≤1.5mm/d; Accumulative differential settlement of adjacent frame pier: ≤4mm（longitudinal direction）; Differential settlement of single frame pier: ≤6mm; Concrete crack width: ≤0.2mm （for pre-stressed structure, cracking is forbidden）.
4	Pedestrian overbridge	Accumulative abutment settlement: ≤30mm; Differential settlement of adjacent abutment of simple supported beam（longitudinal direction）: ≤8mm; Differential settlement of abutment under stairs structure: ≤3mm; Differential settlement of single abutment （lateral direction）: ≤4mm; Horizontal displacement of pier cap: ≤4mm; Settlement rate:≤3mm/d; Concrete cracking width: ≤0.2mm.
5	Surface buildings	Structure inclination rate: ≤1/1000; Accumulative settlement amount: ≤20mm; Structure differential settlement amount: ≤1‰L（Where L denotes the centre spacing of adjacent base）; Structure deformation rate: ≤1.5mm/d; Maximum concrete crack width: ≤0.2mm.
6	Highway interchange bridge	Accumulative abutment settlement amount: ≤20mm; Settlement rate:≤1.5mm/d; Accumulative differential settlement of adjacent abutments（longitudinal direction）: ≤6mm; Differential settlement of single abutment: ≤3mm; Absolute rotation angle of beam end: ≤0.8x10-3//rad; Relative rotation angle of beam end: ≤1.6x10-3//rad; Concrete crack width: ≤0.2mm（for pre-stressed structure, cracking is forbidden）.
Notes: 1. All surface buildings located within in the major construction influence range must be monitored. Buildings located within in the secondary construction influence range could be monitored. 2. Monitoring must be conducted on major underground pipelines, such as gas pipeline with medium or high pressure, major water pipeline, water source pipeline, concrete pipe with spigot joints, electricity pipeline with the voltage higher than 220KV, military optical cable and etc.		

Deformasi izin pada monitoring terhadap pernurunan di permukaan serta potensi mengembang (*heave*).

Table 4 Control Values of Monitoring Items on Ground Settlement and Heave

Monitoring Items and Soil Types		**Cumulative value （mm）**	**Rate of Change （mm/d）**
Ground settlement	Hard ~ Medium hard Soil	10~20	3
	Medium soft ~ Soft Soil	15~25	3
Ground heave		10	3

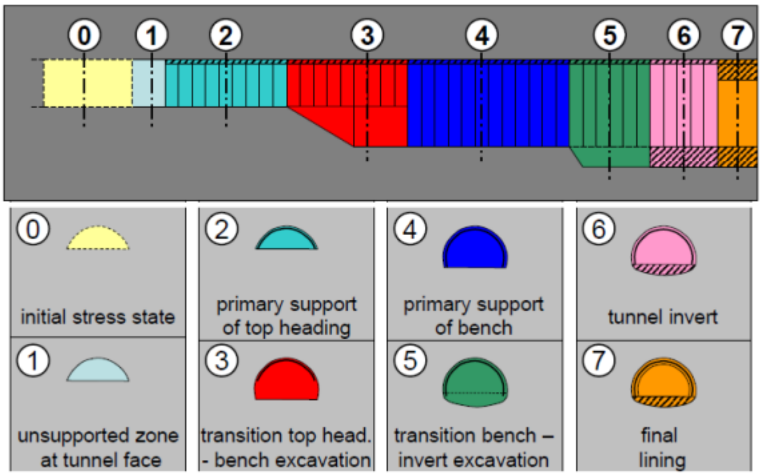
Pada masa operasional, deformasi izin pada *track* kereta cepat mengacu pada QCR9230-2016 dimana besar deformasi izinnya sebesar 15 mm. Sedangkan pada konstruksi, deformasi izin pada terowongan dapat dilihat pada **Tabel 5**.

Table 5 Control values of Monitoring Items on vertical displacement and clearance convergence

Monitoring Items and Soil Types		Cumulative value （mm）	Rate of Change （mm/d）
Shield segment settlement	Hard ~ Medium hard Soil	10~20	2
	Medium soft ~ Soft Soil	20~30	3
Segment differential settlement		0.04%Ls	——
Tunnel clearance convergence		0.2%D	3
Notes: Ls denotes the longitudinal spacing of monitoring points along the tunnel D denotes the diameter of the tunnel excavation contour			

C. Metode Konstruksi Terowongan

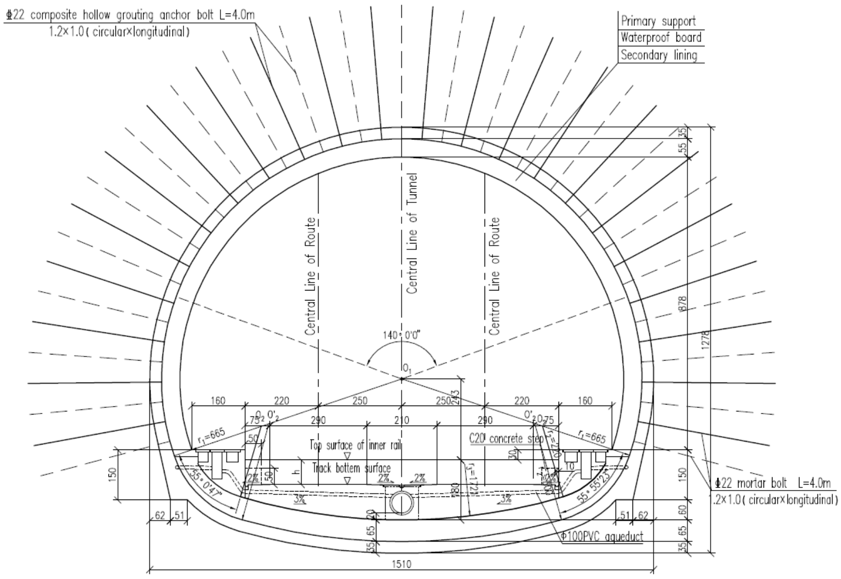
New Austrian Tunneling Method (NATM) : NATM merupakan metode *excavation* pada terowongan yang dilakukan secara manual dan bertahap. Tahapan pertama dalam metode ini adalah proses *excavation* pada area *tunnel* yang dapat dilakukan dengan menggunakan alat *twin header* dan *excavator*. Pembuangan tanah kerukan dapat menggunakan *loader* tertentu disesuaikan dengan diameter *tunnel*. Setelah itu proses excavation dilanjutkan dengan pekerjaan *temporary support* menggunakan *forepoling*, *wire mesh* dan *steel rib*. Lalu dilakukan proses proteksi pada area dinding dengan menggunakan *shotcrete*. Selanjutnya untuk pembuatan *lining tunnel*, dilakukan secara cast in situ, didahului dengan pembesian *lining* struktur dan pengecoran. Pada tahapan akhir dilakukan *back fill grout* untuk memperbaiki retak-retak yang terjadi pada dinding tunnel.



Gambar 1 Metode konstruksi terowongan dengan NATM

D. Tipe Struktur Lining

Model terowongan yang dilakukan disesuaikan dengan desain seperti yang ditunjukkan pada **Gambar 2**. Terowongan memiliki bentuk elips dengan diameter horizontal 15 m dan diameter vertikal 12.6 m. Terowongan diperkuat dengan *rockbolt* dengan panjang 4 m serta ketebalan lining dimodelkan dengan dua jenis *lining* yaitu *primary lining* dan *secondary lining* dengan variasi tebal lining tergantung kategori tanah/batuan seperti yang ditunjukkan pada **Tabel 6** dan **Tabel 7.**



Gambar 2 Contoh model terowongan Tunnel Walini

Table 6 Pemilihan tipe lining berdasarkan jenis tanah/batuan

Surrounding rock	Lining type	Applicable conditions
Ⅱ	II_a	Ⅱ surrounding rock area
Ⅲ	III_a	Ⅲ surrounding rock area
	III_b	Ⅲ surrounding rock of horizontal stratification area (Strata dip Angle≤15°) adverse rock area
Ⅳ	IV_a	Ⅳ surrounding rock of deep buried section
	IV_b	Ⅳ surrounding rock of shallow buried, bias, fault fracture zone, seismic area, Ⅱ、Ⅲ surrounding rock within the 60m scope from the intersection between main tunnel and service gallery
	IV_p	Ⅳ surrounding rock of moderate swelling rock section
Ⅴ	V_{r-a}	Ⅴ surrounding rock of deep buried rock section
	V_{r-b}	Ⅴ surrounding rock of shallow buried seismic fortification rock section
	V_{r-c}	Ⅴ surrounding rock of bias, fault fracture, rock section
	V_{r-p}	Ⅴ surrounding rock of moderate swelling rock section
	V_{s-a}	Ⅴ surrounding rock of deep buried soil section (Natural water content is smaller)
	V_{s-b}	Ⅴ surrounding rock of shallow buried seismic fortification soil section (or natural water content is smaller)
	V_{s-p-1}	Ⅴ surrounding rock of expansive soil section (medium swelling)
	V_{s-p-2}	Ⅴ surrounding rock of area which is sensitive to deformation such as the area underpass the existing railway or road above (corresponding to the three steps CRD)
Ⅵ	VI_a	Ⅵ surrounding rock of soft and plastic soil or water-bearing sand layer area
	VI_b	Ⅵ surrounding rock of area which is sensitive to deformation such as the area underpass the existing railway or road above (corresponding to the three steps CRD)

Table 7 Desain tebal lining berdasarkan kategori batuan

NO.	Lining type	Primary support										Secondary lining		deformation allowance (cm)
		Thickness of shotcret (cm)	Steel mesh			System rock bolt			grid, steel frame			thickness of arch wall (cm)	thickness of invert (cm)	
			position	diameter (mm)	mesh size (cm)	position	length (m)	ring, longitudinal spacing (m)	specifications	position	spacing (m)			
1	II_a	arch wall5	–	–	–	–	–	–	–	–	–	35*	35*	3~5
2	III_a	arch wall12	arch wall	Φ6	25×25	arch wall	3	1.2×1.5	–	–	–	40*	50*	5~8
3	III_b	arch wall23	arch wall	Φ6	25×25	arch wall	3	1.2×1.5	150grid Φ22	arch wall	1.5	40*	50*	5~8
4	IV_a	arch wall25 invert10	arch wall	Φ6	20×20	arch wall	3.5	1.2×1.2	180grid Φ22	arch wall	1	45*	55*	8~10
5	IV_b	arch wall25 invert25	arch wall	Φ6	20×20	arch wall	3.5	1.2×1.2	I18shape steel	ring	1	45*	55*	8~10
6	IV_p	ring28	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I20a shape steel	ring	0.8	45*	55*	8~10
7	V_{r-a}	ring28	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I20a shape steel	ring	0.8	50*	60*	10~15
8	V_{r-b}	ring28	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I20a shape steel	ring	0.6	50*	60*	10~15
9	V_{r-c}	ring30	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I22a shape steel	ring	0.6	55*	65*	10~15
10	V_{r-p}	ring35	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I25a shape steel	ring	0.6	55*	65*	15~20
11	V_{s-a}	ring30	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I22a shape steel	ring	0.6	50*	60*	10~15
12	V_{s-b}	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25a shape steel	ring	0.6	55*	65*	15~20
13	V_{s-p-1}	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25
14	V_{s-p-2}	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25
15	VI_a	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25
16	VI_b	ring35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25

3. Pengumpulan Data-Data

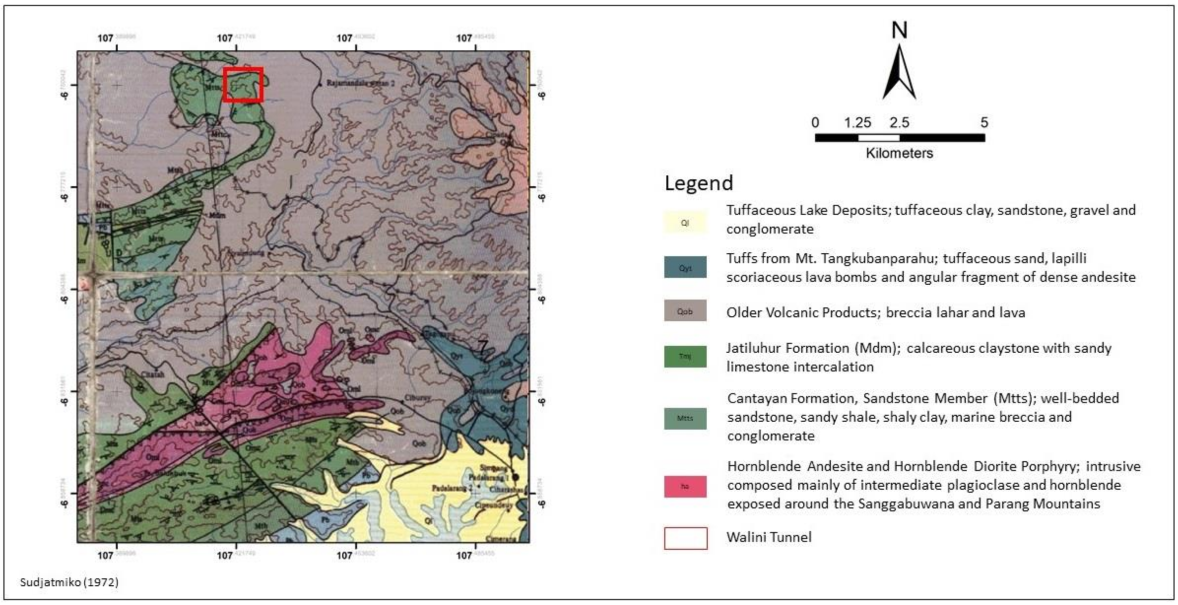
A. Data Umum Terowongan Walini

Terowongan Walini Kereta Cepat Jakarta Bandung Jakarta, berlokasi di Purwakarta yang bertepatan di Barat Daya Kecamatan Cikalong Wetan. Metode konstruksi yang diterapkan pada Tunnel Walini ini adalah metode galian NATM (New Austrian Tunneling Method). Titik awal terowongan berada pada DK95+472 dan titik akhir terowongan pada DK96+080, sehingga total panjang terowongan, yaitu 608m.

Gambar 3 Lokasi *Soil Inestigastion* Terowongan Walini

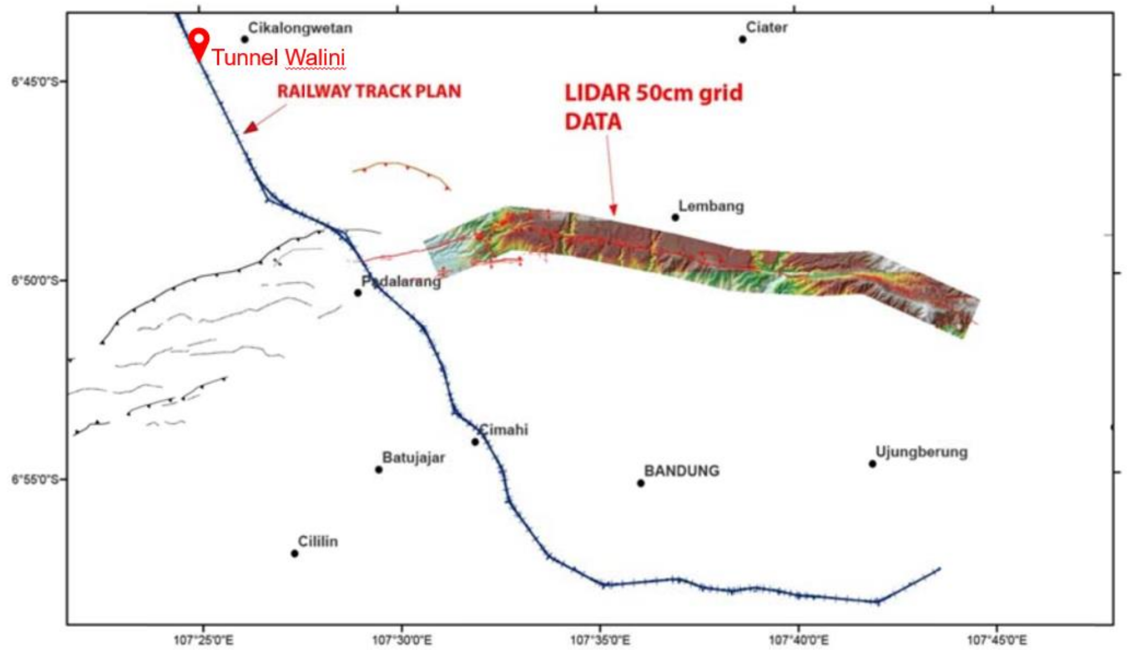
B. Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan

Berdasarkan Peta Geologi (Sudjatmiko, 1972) Terowongan Walini berada pada Formasi Cantayan, dengan sandstone member (Mtts) yang memiliki tebal 2700 m. Peta Geologi disajikan pada **Gambar 4.**



Gambar 4 Peta Geologi (Sudjatmiko, 1972)

Setelah dilakukan observasi pada area sekitar terowongan didapat kondisi tanah dan batuan yang special. Pada DK 95+000 antara DK 100+000 didapat adanya tanah ekspansif/batu ekspansif yang memiliki nilai *free swell ratio* 40-52%, hal tersebut termasuk kedalam kategori *weakly expansive*. Serta secara visual ditemukan *clayshale* pada 200 m dari sisi outlet terowongan.



Gambar 5 Hasil Analisis Geologi

Berdasarkan data geologi pada **Gambar 5** disebutkan bahwa pada Terowongan Walini tidak terdapat *fault zone*.

C. Stratigrafi Tanah dan Data Borlog

Detail stratigrafi tanah di area Terowongan Walini dapat dilihat pada **Lampiran A** dan untuk Data hasil penyelidikan tanah (SPT) dapat dilihat pada **Lampiran D**.

D. Hasil Pengujian Laboratorium

Hasil-Hasil pengujian laboratorium yang dilakukan pada beberapa sampel dari setiap borlog dapat dilihat pada **Lampiran E.**

E. Material Terowongan dan Referensi Penentuan Parameter Tanah/Batuan

Spesifikasi material yang digunakan pada Terowongan Walini dapat dilihat dibawah ini:

Dimensi Terowongan

Tipe Lining terowongan	: V_{r-p}
Diameter	: 15.1 m
Ketebalan	
Primary lining (Shotcrete)	: 0.35 m
Secondary lining (Reinforced Concrete)	
Invert Arch	: 0.65 m
Wall Arch	: 0.55 m

Material Terowongan

Shotcrete	: C30
Reinforced Concrete	: C35 dengan tulangan
Tulangan	: HPB300 (φ ≤ 10 mm) HRB400 (φ ≥ 16 mm)
Fill inverted arch	: Beton C20
Ditch and cable duct	: Beton C30

Berdasarkan data penyelidikan lapangan (Bor Log) yang didapatkan, meliputi NSPT, deskripsi tanah, kedalaman muka air tanah, dll. Data tersebut digunakan dalam menentukan parameter tanah asli di lapangan. Parameter tanah didapatkan berdasarkan hasil korelasi pendekatan dengan menggunakan dari beberapa sumber seperti untuk parameter batuan menggunakan klasifikasi yang ditunjukkan oleh **Tabel 8 s/d Tabel 11.**

Table 8 Klasifikasi Uniaxial Compressive strength (σ_{ci}), (Ameratunga et. al, 2016)

Grade	Description	Field identification	σ_c or q_u (MPa)	Rock types
S1	Very soft clay	Easily penetrated several inches by fist.	<0.025	
S2	Soft clay	Easily penetrated several inches by thumb.	0.025–0.05	
S3	Firm clay	Can be penetrated several inches by thumb with moderate effort.	0.05–0.10	
S4	Stiff clay	Readily indented by thumb, but penetrated only with great effort.	0.10–0.25[a]	
S5	Very stiff clay	Readily indented by thumbnail.	0.25[a]–0.50[a]	
S6	Hard clay	Indented with difficulty by thumbnail.	>0.5[a]	
R0	Extremely weak rock	Indented by thumb nail.	0.25–1.0	Stiff fault gouge
R1	Weak rock	Crumbles under firm blows with point of geological hammer; Can be peeled by pocket knife.	1–5	Highly weathered or altered rock
R2	Weak rock	Can be peeled by a pocket knife with difficulty; Shallow indentations made by firm blow with a point of geological hammer.	5–25	Chalk, rock salt, potash
R3	Medium strong rock	Cannot be scraped or peeled with a pocket knife; Specimen can be fractured with a single firm blow of a geological hammer.	25–50	Claystone, coal, concrete, schist, shale, siltstone
R4	Strong rock	Specimen requires more than one blow by geological hammer to fracture it.	50–100	Limestone, marble, phyllite, sandstone, schist, shale
R5	Very strong rock	Specimen requires many blows of geological hammer to fracture it.	100–250	Amphibiolite, sandstone, basalt, gabbro, gneiss, granodiorite, limestone, marble, rhyolite, tuff
R6	Extremely strong rock	Specimen can only be chipped by a geological hammer.	>250	Fresh basalt, chert, diabase, gneiss, granite, quartzite

Table 9 Values Modulus Ratios of Rocks (Ameratunga et. al, 2016)

	Texture			
	Coarse	Medium	Fine	Very fine
Sedimentary	Conglomerates	Sandstones	Siltstones	Claystones
	300–400	200–350	350–400	200–300
	Breccias		Greywackes	Shales
	230–350		350	150–250[a]
				Marls
				150–200
	Crystalline limestone	Sparitic limestone	Micritic limestone	Dolomite
	400–600	600–800	800–1000	350–500
		Gypsum	Anhydrite	Chalk
		(350)[c]	(350)[c]	1000+
Metamorphic	Marble	Hornfels	Quartzite	
	700–1000	400–700	300–450	
		Metasandstone		
		200–300		
	Migamatite	Amphibiolites	Gneiss	
	350–400	400–500	300–750[a]	
		Schists	Phyllites/Mica Schist	Slates
		250–1100[a]	300–800[a]	400–600[a]
Igneous	Granite[b]	Diorite[b]		
	300–550	300–350		
	Granodiorite			
	400–450			
	Gabro	Dolerite		
	400–500	300–400		
	Norite			
	350–400			
	Porphyries		Diabase	Peridotite
	(400)[c]		300–350	250–300
		Rhyolite	Dacite	
		300–500	350–450	
		Andesite	Basalt	
		300–500	250–450	
	Agglomerate	Volcanic Breccia	Tuff	
	400–600	(500)[c]	200–400	

After Hoek and Diederichs (2006)

[a]Highly anisotropic rocks: the modulus ratio will be significantly different if normal strain and/or loading occurs parallel (high modulus ratio) or perpendicular (low modulus ratio) to a weakness plane. Uniaxial test loading direction should be equivalent to field application

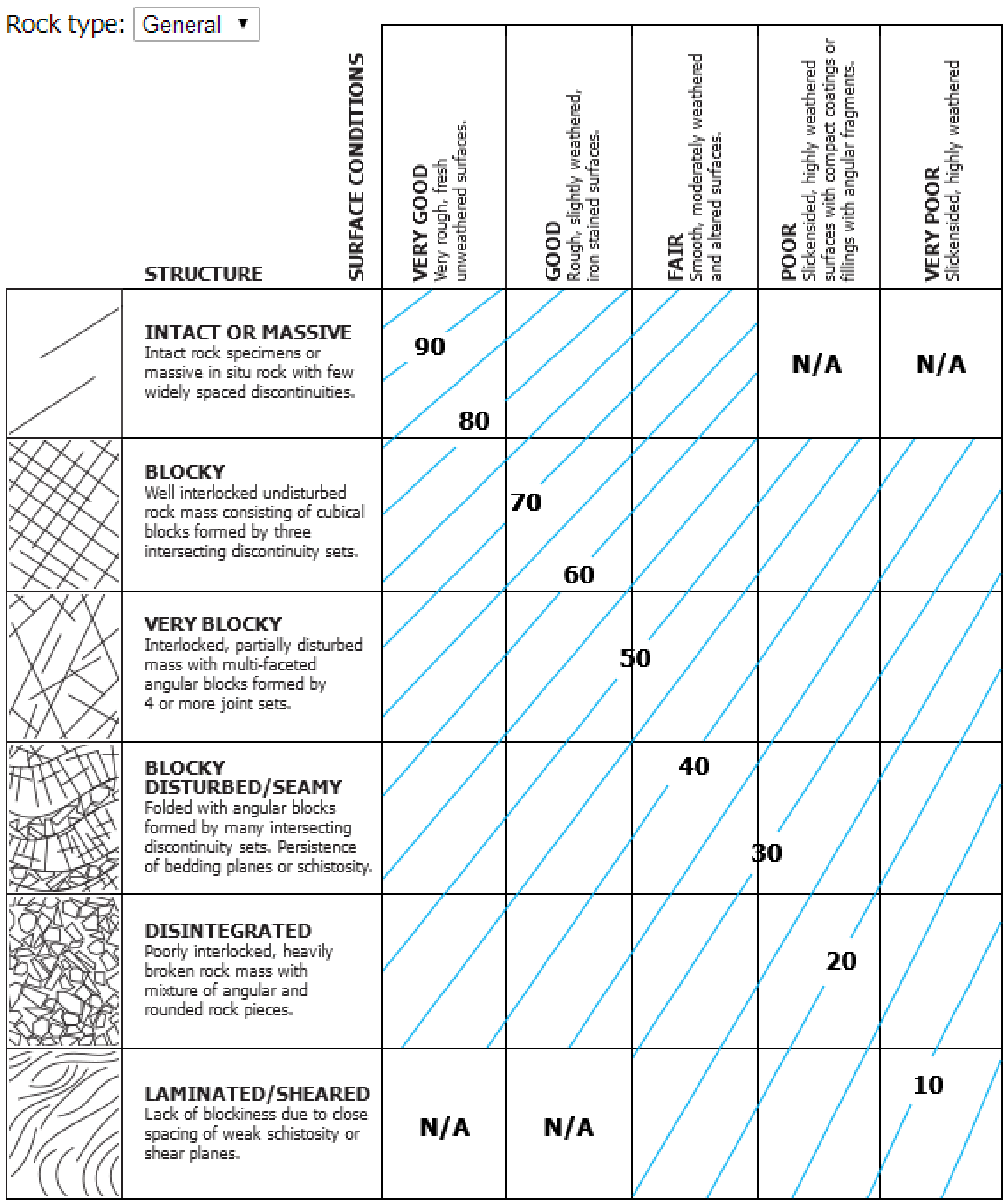
[b]Felsic Granitoids: Coarse grained or altered (High modulus ratio), fine grained (low modulus ratio)

[c]No data available; Estimated on the basis of geological logic

*Table 10 Lithology classification (**m_i**) (Brinkgreeve, 2018)*

<table>
<tr><th rowspan="2">Rock type</th><th rowspan="2">Class</th><th rowspan="2">Group</th><th colspan="4">Texture</th></tr>
<tr><th>Coarse</th><th>Medium</th><th>Fine</th><th>Very fine</th></tr>
<tr><td rowspan="4">SEDIMENTARY</td><td colspan="2">Clastic</td><td>Conglomerates (21±3)
Breccias (19±5)</td><td>Sandstones 17±4</td><td>Siltstones 7±2
Greywackes (18±3)</td><td>Claystones 4±2
Shales (6±2)
Marls (7±2)</td></tr>
<tr><td rowspan="3">Non-Clastic</td><td>Carbonates</td><td>Crystalline Limestone (12±3)</td><td>Sparitic Limestones (10±2)</td><td>Micritic Limestones (9±2)</td><td>Dolomites (9±3)</td></tr>
<tr><td>Evaporites</td><td></td><td>Gypsum 8±2</td><td>Anhydrite 12±2</td><td></td></tr>
<tr><td>Organic</td><td></td><td></td><td></td><td>Chalk 7±2</td></tr>
<tr><td rowspan="3">METAMORPHIC</td><td colspan="2">Non foliated</td><td>Marble 9±3</td><td>Hornfels (19±4)
Metasandstone (19±3)</td><td>Quartzites 20±3</td><td></td></tr>
<tr><td colspan="2">Slightly foliated</td><td>Migmatite (29±3)</td><td>Amphibolites 26±6</td><td>Gneiss 28±5</td><td></td></tr>
<tr><td colspan="2">Foliated*</td><td></td><td>Schists 12±3</td><td>Phyllites (7±3)</td><td>Slates 7±4</td></tr>
<tr><td rowspan="5">IGNEOUS</td><td rowspan="2">Plutonic</td><td>Light</td><td>Granite 32±3
Granodiorite (29±3)</td><td>Diorite 25±5</td><td></td><td></td></tr>
<tr><td>Dark</td><td>Gabbro 27±3
Norite 20±5</td><td>Dolerite (16±5)</td><td></td><td></td></tr>
<tr><td colspan="2">Hypabyssal</td><td>Porphyries (20±5)</td><td></td><td>Diabase (15±5)</td><td>Peridotite (25±5)</td></tr>
<tr><td rowspan="2">Volcanic</td><td>Lava</td><td></td><td>Rhyolite (25±5)
Andesite 25±5</td><td>Dacite (25±3)
Basalt (25±5)</td><td>Obsidian (19±3)</td></tr>
<tr><td>Pyroclastic</td><td>Agglomerate (19±3)</td><td>Breccia (19±5)</td><td>Tuff (13±5)</td><td></td></tr>
</table>

*Table 11 Klasifikasi Geological Strength Index (**GSI**) (Brinkgreeve, 2018)*



4. Pemodelan Terowongan Walini

A. Layout Geometri

Seluruh penampang geometri yang dimodelkan memiliki lebar 6D dari bagian sisi kiein kanan terowongan serta kedalaman model geometri mengacu pada setiap data penyelidikan tanah (Borlog) yang digunakan. Layout geometri disajikan pada **Tabel 12 s/d Tabel 13**. Detail peta topografi area terowongan dapat dilihat pada **Lampiran B.**

Analisis deformasi pada pemodelan terowongan dilakukan dengan mempertimbangkan beban eksisting yang bekerja pada permukaan tanah. Beban-beban yang bekerja diakibatkan oleh beberapa hal seperti beban lalu lintas maupun beban struktur berupa gedung atau sejenisnya. Dalam pemodelan, beban lalu lintas diasumsikan memiliki nilai sebesar 15 kPa berdasarkan SNI 8460:2017 serta beban bangunan gedung, rumah, dll diasumsikan sebesar 20 kPa.

Table 12 Model Analisis Terowongan 2D dengan Mempertimbangkan Beban yang Bekerja di Permukaan

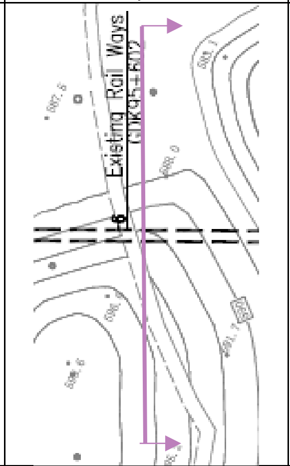
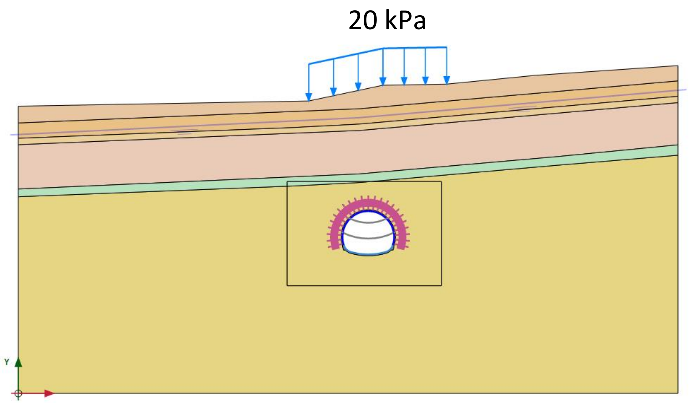
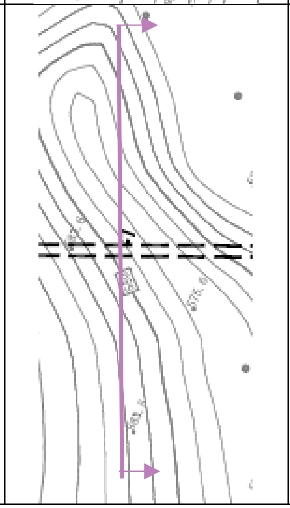
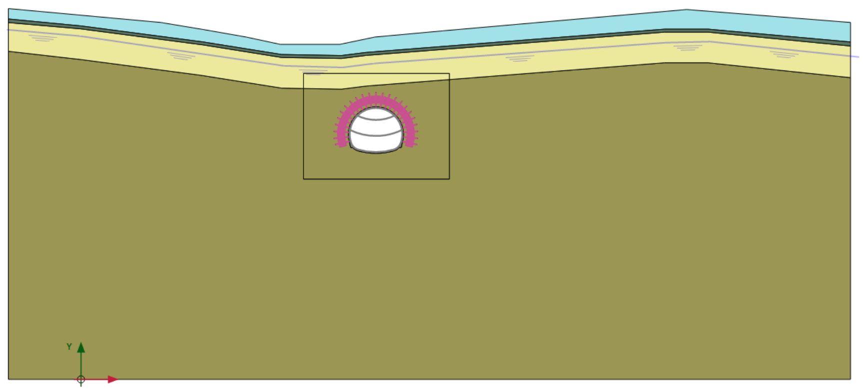
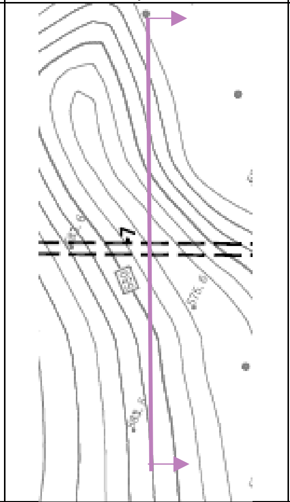
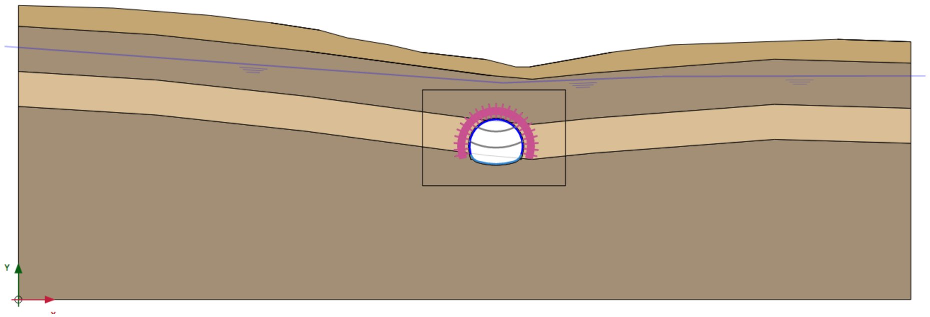
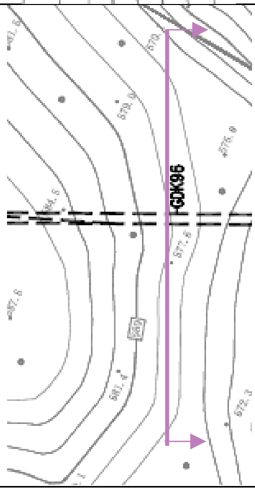
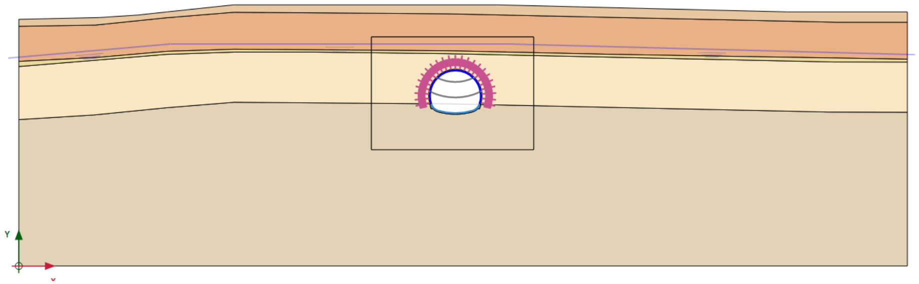
No. Potongan	Layout	Potongan Melintang	Keterangan
TUNNEL Walini (DK95+602)			Pada bagian permukaan terowongan terdapat beban Rail ways sebesar 20 kPa
TUNNEL Walini (DK95+696)			Tidak ada beban jalan dan bangunan pada permukaan

Table 13 Model Analisis Terowongan 2D dengan Mempertimbangkan Beban yang Bekerja di Permukaan (lanjutan)

No. Potongan	Layout	Potongan Melintang	Keterangan
TUNNEL Walini (DK95+715)			Tidak ada beban jalan dan bangunan pada permukaan
TUNNEL Walini (DK95+993)			Tidak ada beban jalan dan bangunan pada permukaan

B. Parameter-Parameter Pemodelan Terowongan Walini

1. Cross Section DK 95 + 602

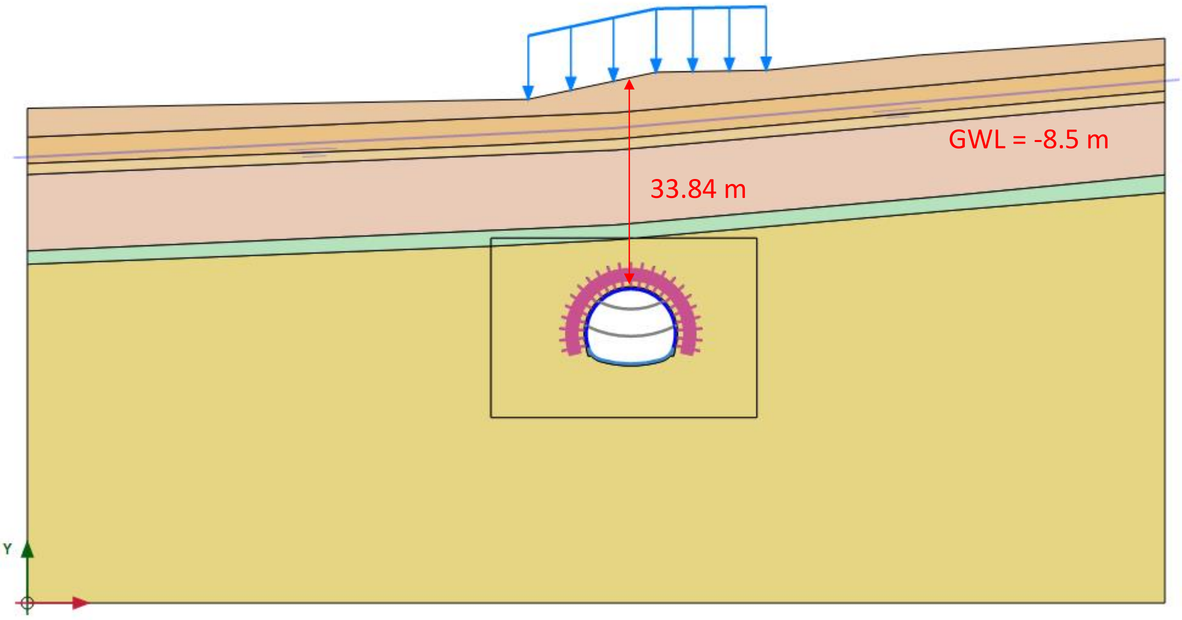


Table 14 Parameter Tanah di Tunnel Walini (DK 95 + 602)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	γunsat (kN/m3)	γsat (kN/m3)	υ	c' (kPa)	ϕ' (degrees)	k (m/day)
1	0-3.8	3,8	8	Clay	15	16	0.5	15	16	0,000864
2	3.8-8.6	4,8	16	Clay	17	18	0.5	20	17	0,000864
3	8.6-10	1,4	50	Mudstone	19	20	0.25	-	-	-
4	10-15.3	5,3	50	Mudstone	19	20	0.25	-	-	-
5	15.3-23.8	8,5	50	Sandstone	20	21	0.3	-	-	-
6	23.8-39.9	16,1	50	Sandstone	20	21	0.3	-	-	-

Table 15 Nilai Modulus Elastisas di Tunnel Walini (DK 95 + 602)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Clay	8	6000	6000	4800	18000
2	Clay	16	16000	16000	12800	48000

Table 16 Paramater Hoek Brown untuk Batuan di Tunnel Walini (DK 95 + 602)

Lapis	Jenis Tanah	N SPT	σ_{ci} (kPa) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 212	(Modulus Ratio) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 214	E_{rm} (kPa) Tomlinson, (2001)	m_i	GSI
3	Mudstone	50	2000	150	150000	6	10
4	Mudstone	50	3000	150	225000	6	10
5	Sandstone	50	3000	300	720000	17	20
6	Sandstone	50	4000	300	960000	17	20

Table 17 Parameter Primary Linning Tunnel Walini (DK 95 + 602)

ID	Value	Unit
Material	C30 Shotcrete	-
Tebal Lining	0.35	m
Unit weight (γ)	24	kN/m^3
Easticity modulus (E)	2.575×10^7	kPa

Table 18 Parameter Secondary Linning Tunnel Walini (DK 95 + 602)

ID	Value		Unit
	Invert	Arch	
Material Type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.65	0.55	m
Unit weight (γ)	24	24	kN/m^3
Easticity modulus (E)	2.781 × 10^7	2.781 × 10^7	kPa

Table 19 Parameter Grouting Anchor (Rockbolt)

ID	Value	Unit
Material (Embedded Beam)	M10 Mortar	-
Diameter	22	mm
Unit weight (γ)	24	kN/m^3
Easticity modulus (E)	1.33 × 10^7	kPa
Spasi	1	m
Panjang	4	m

2. Cross Section DK 95 + 696

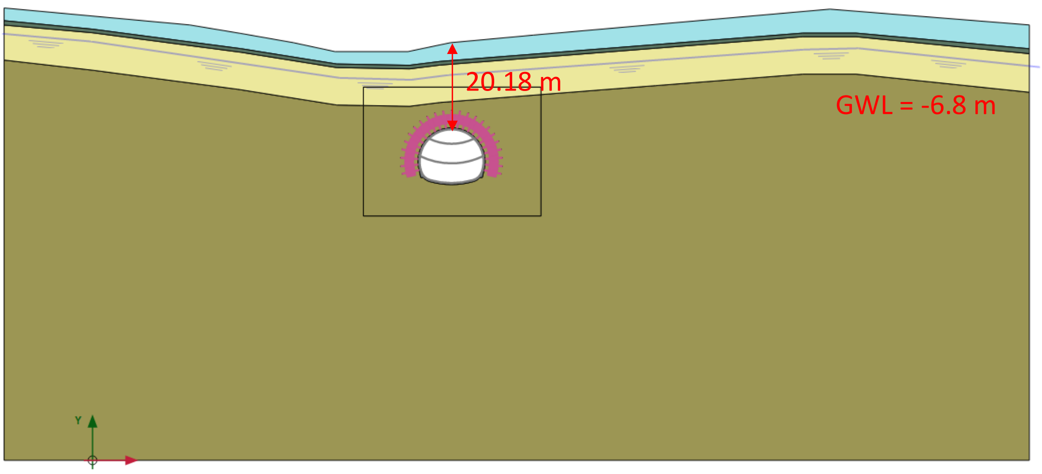


Table 20 Parameter Tanah di Tunnel Walini (DK 95 + 696)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	γunsat (kN/m3)	γsat (kN/m3)	υ	c' (kPa)	ϕ' (degrees)	k (m/day)
1	0-4.6	4.6	8	Clay	15	16	0.5	10	7	0,000864
2	4,6-5,4	0,8	50	SandStone	21	22	0.3	-	-	-
3	5,4-14,2	8,8	50	SandStone	21	22	0.3	-	-	-
4	14,2-30	15,8	50	Mudstone	21	22	0.3	-	-	-

Table 21 Nilai Modulus Elastisas di Tunnel Walini (DK 95 + 696)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Clay	8	6000	6000	4800	18000

Table 22 Paramater Hoek Brown untuk Batuan di Tunnel Walini (DK 95 + 696)

Lapis	Jenis Tanah	N SPT	σ_{ci} (kPa) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 212	(Modulus Ratio) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 214	E_{rm} (kPa) Tomlinson, (2001)	m_i	GSI
2	SandStone	50	3000	300	720000	17	20
3	SandStone	50	4000	300	960000	17	20
4	Mudstone	50	2000	150	150000	6	10

Table 23 Parameter Primary Linning Tunnel Walini (DK 95 + 696)

ID	Value	Unit
Material	C30 Shotcrete	-
Tebal Lining	0.35	m
Unit weight (γ)	24	kN/m^3
Easticity modulus (E)	2.575 × 10^7	kPa

Table 24 Parameter Secondary Linning Tunnel Walini (DK 95 + 696)

ID	Value		Unit
	Invert	Arch	
Materialn type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.65	0.55	m
Unit weight (γ)	24	24	kN/m^3
Easticity modulus (E)	2.781 × 10^7	2.781 × 10^7	kPa

Table 25 Parameter Grouting Anchor (Rockbolt)

ID	Value	Unit
Material (Embedded Beam)	M10 Mortar	-
Diameter	22	mm
Unit weight (γ)	24	kN/m^3
Easticity modulus (E)	1.33 × 10^7	kPa
Spasi	1	m
Panjang	4	m

3. Cross Section DK 95 + 715

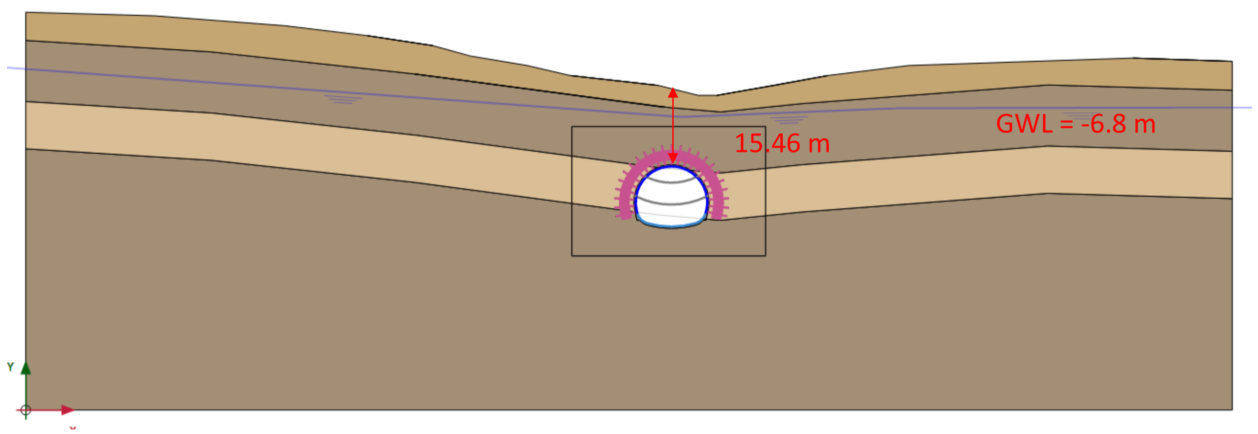


Table 26 Parameter Tanah di Tunnel Walini (DK 95 + 715)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	γunsat (kN/m3)	γsat (kN/m3)	υ	c' (kPa)	ϕ' (degrees)	k (m/day)
1	0-4.6	4.6	8	Clay	15	16	0.5	10	7	0,000864
2	4,6-5,4	0,8	50	Mudstone	20	21	0.25	-	-	-
3	5,4-14,2	8,8	50	SandStone	21	22	0.3	-	-	-
4	14,2-30	15,8	50	Mudstone	20	21	0.25	-	-	-

Table 27 Nilai Modulus Elastisas di Tunnel Walini (DK 95 + 715)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Clay	8	6000	6000	4800	18000

Table 28 Paramater Hoek Brown untuk Batuan di Tunnel Walini (DK 95 + 715)

Lapis	Jenis Tanah	N SPT	σ_{ci} (kPa) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 212	(Modulus Ratio) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 214	E_{rm} (kPa) Tomlinson, (2001)	m_i	GSI
2	Mudstone	50	3000	150	300000	6	10
3	SandStone	50	4000	300	480000	17	20
4	Mudstone	50	3000	150	300000	6	10

Table 29 Parameter Primary Linning Tunnel Walini (DK 95 + 715)

ID	Value	Unit
Material	C30 Shotcrete	-
Tebal Lining	0.35	m
Unit weight (γ)	24	kN/m^3
Easticity modulus (E)	2.575×10^7	kPa

Table 30 Parameter Secondary Linning Tunnel Walini (DK 95 + 715)

ID	Value		Unit
	Invert	Arch	
Materialn type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.65	0.55	m
Unit weight (γ)	24	24	kN/m^3
Easticity modulus (E)	2.781×10^7	2.781×10^7	kPa

Table 31 Parameter Grouting Anchor (Rockbolt)

ID	Value	Unit
Material (Embedded Beam)	M10 Mortar	-
Diameter	22	mm
Unit weight (γ)	24	kN/m^3
Easticity modulus (E)	1.33×10^7	kPa
Spasi	1	m
Panjang	4	m

4. Cross Section DK 95 + 993

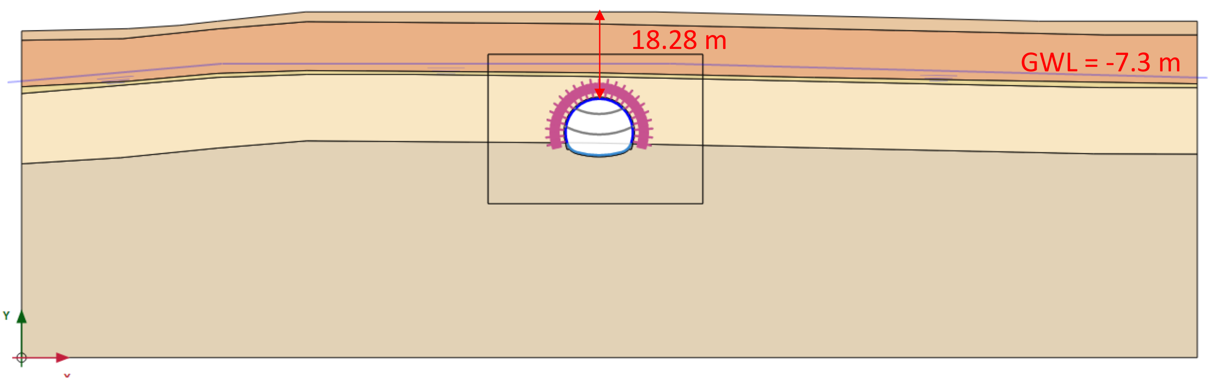


Table 32 Parameter Tanah di Tunnel Walini (DK 95 + 993)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	γunsat (kN/m3)	γsat (kN/m3)	υ	c' (kPa)	ϕ' (degrees)	k (m/day)
1	0-3	3	7	Clay	15	16	0.5	14	16	0,000864
2	3-13.5	10,5	14	Clay	17	18	0.5	18	20	0,000864
3	13.5-14.3	0,8	50	Sandstone	20	21	0.3	-	-	-
4	14.3-28.9	14,6	50	Sandstone	20	21	0.3	-	-	-
5	28.9-42	13,1	50	Mudstone	19	20	0.25	-	-	-

Table 33 Nilai Modulus Elastisas di Tunnel Walini (DK 95 + 993)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Clay	7	5250	5250	4200	15750
2	Clay	14	10500	10500	8400	31500

Table 34 Paramater Hoek Brown untuk Batuan di Tunnel Walini (DK 95 + 993)

Lapis	Jenis Tanah	N SPT	σ_{ci} (kPa) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 212	(Modulus Ratio) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 214	E_{rm} (kPa) Tomlinson, (2001)	m_i	GSI
3	Sandstone	50	3000	300	720000	17	20
4	Sandstone	50	4000	300	960000	17	20
5	Mudstone	50	3000	150	225000	6	10

Table 35 Parameter Primary Linning Tunnel Walini (DK 95 + 993)

ID	Value	Unit
Material	C30 Shotcrete	-
Tebal Lining	0.35	m
Unit weight (γ)	24	kN/m^3
Easticity modulus (E)	2.575×10^7	kPa

Table 36 Parameter Secondary Linning Tunnel Walini (DK 95 + 715)

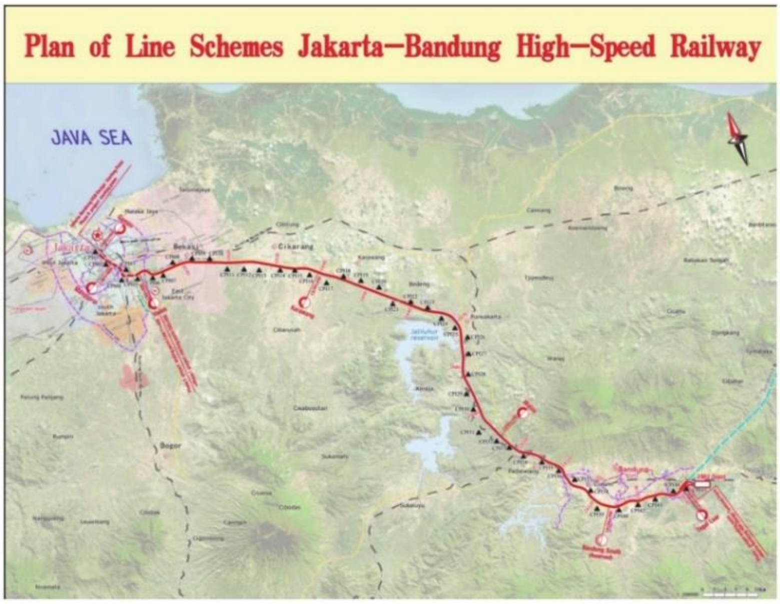
ID	Value		Unit
	Invert	Arch	
Materialn type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.65	0.55	m
Unit weight (γ)	24	24	kN/m^3
Easticity modulus (E)	2.781×10^7	2.781×10^7	kPa

Table 37 Parameter Grouting Anchor (Rockbolt)

ID	Value	Unit
Material (Embedded Beam)	M10 Mortar	-
Diameter	22	mm
Unit weight (γ)	24	kN/m^3
Easticity modulus (E)	1.33×10^7	kPa
Spasi	1	m
Panjang	4	m

C. Perhitungan Beban Gempa di Area Terowongan Walini

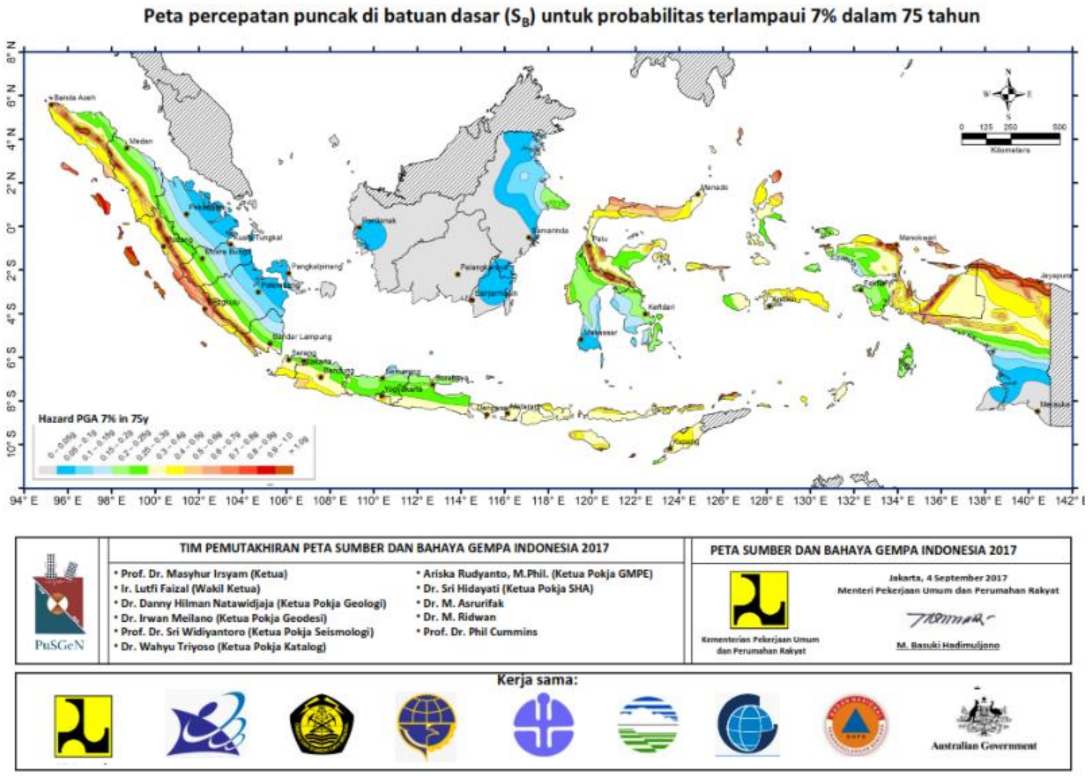
Analisis deformasi aksial dilakukan dengan menambahkan beban gempa berdasarkan peta gempa 2017. Percepatan tanah puncak gempa maksimum yang dipertimbangkan untuk bangunan bawah seperti yang tertera dalam SNI 8460 tahun 2017 (Bab 12), percepatan tanah puncak dengan 7% kemungkinan terlampaui dalam kurun waktu 75 tahun dapat digunakan sebagai acuan. Lokasi jalur kereta cepat Jakarta-Bandung dapat dilihat pada **Gambar 6**.



Gambar 6 Lokasi jalur kereta cepat Bandung – Jakarta

Berdasarkan rencana jalur kereta api cepat Jakarta – Bandung seperti yang tercantum pada **Gambar 6**, selanjutnya dilakukan penentuan nilai PGA berdasarkan peta gempa 2017 seperti yang ditunjukkan pada **Gambar 7**.

Berdasarkan peta gempa 2017, dipilih nilai PGA sesuai dengan lokasi pekerjaan. Nilai PGA untuk lokasi yang ditinjau berada pada zona kuning dengan nilai **PGA 0.3-0.4**. Analisis beban gempa pada program numerik Plaxis 2D dilakukan dengan pemodelan *pseudo-static*, dengan input yang diperlukan yaitu nilai percepatan puncak di permukaan. Nilai percepatan didapatkan dengan menentukan kelas situs, faktor amplifikasi, dan SPT desain rata-rata.



Gambar 7 Peta gempa 2017 untuk periode ulang 1000 tahun.

1. Perhitungan NSPT desain rata-rata

$$\overline{N_{60}} = \frac{\sum di}{\sum \frac{di}{N}}$$

dimana: di merupakan ketebalan lapisan dan N merupakan nilai SPT setiap ketebalan lapisan

Table 38 Desain untuk Menentukan SPT Rata-rata di Tunnel Walini (DK95+602)

DI	N	DI/N
8.6	14	0.63
6.7	50	0.13
24.6	50	0.49
5.1	50	0.10

$$\boldsymbol{\overline{N_{60}} = \frac{45}{1.35} = 33}$$

2. Penentuan Klasifikasi Situs berdasarkan NSPT rata-rata

Table 39 Klasifikasi situs berdasarkan SNI 8460

Klasifikasi Situs	$\bar{v}_s$ (m/detik)	$\bar{N}_{SPT}$ atau $\bar{N}_{SPTch}$	$\bar{s}_u$ (kPa)
SA (batuan keras)	>1.500	N/A	N/A
SB (batuan dasar)	750 sampai 1.500	N/A	N/A
SC (tanah keras, sangat padat, dan batuan lunak)	350 sampai 750	>50	≥100
SD (tanah sedang)	175 sampai 350	15 sampai 50	50 sampai 100
SE (tanah lunak)	<175	<15	<50
	Atau setiap profil tanah yang mengandung lebih dari 3 m dengan karateristik sebagai berikut: 1. Indeks Plastisitas, PI > 20, 2. Kadar air, (w) ≥ 40%, dan 3. Kuat geser niralir, $\bar{s}_u$ < 25 kPa		
SF (tanah khusus, yang membutuhkan penyelidikan geoteknik spesifik dan analisis respons spesifik-situs)	Setiap profil lapisan tanah yang memiliki salah satu atau lebih dari karakteristik seperti: - Rawan dan berpotensi gagal atau runtuh akibat beban gempa seperti mudah likuifaksi, lempung sangat sensitif, tanah tersementasi lemah - Lempung sangat organik dan/atau gambut (ketebalan, H > 3 m) - Lempung berplastisitas tinggi (ketebalan, H > 7,5 m dengan Indeks Plasitisitas, PI > 75) - Lapisan lempung lunak/setengah teguh dengan ketebalan H > 35 m dengan $\bar{s}_u$ < 50 kPa		

Keterangan: N/A = tidak dapat dipakai

3. Faktor Amplifikasi

Berdasarkan kelas situs yang didapat yaitu **Tanah Lunak (SE)**, didaparkan faktor amplifikasi sebagai berikut:

Table 40 Faktor amplifikasi berdasarkan SNI 8460

Kelas situs	$PGA \leq 0,1$ $S_S \leq 0,25$	$PGA = 0,2$ $S_S = 0,5$	$PGA = 0,3$ $S_S = 0,75$	$PGA = 0,4$ $S_S = 1,0$	$PGA \geq 0,5$ $S_S \geq 1,25$
Batuan keras (SA)	0,8	0,8	0,8	0,8	0,8
Batuan (SB)	1,0	1,0	1,0	1,0	1,0
Tanah keras (SC)	1,2	1,2	1,1	1,0	1,0
Tanah sedang (SD)	1,6	1,4	1,2	1,1	1,0
Tanah lunak (SE)	2,5	1,7	1,2	0,9	0,9
Tanah khusus (SF)	SS	SS	SS	SS	SS

Keterangan: Untuk nilai-nilai antara dapat dilakukan interpolasi linear

Faktor amplifikasi (F_{PGA}) yang didapat berdasarkan tabel di atas, menunjukkan nilai **FPGA = 1.2** (untuk PGA = 0.3)

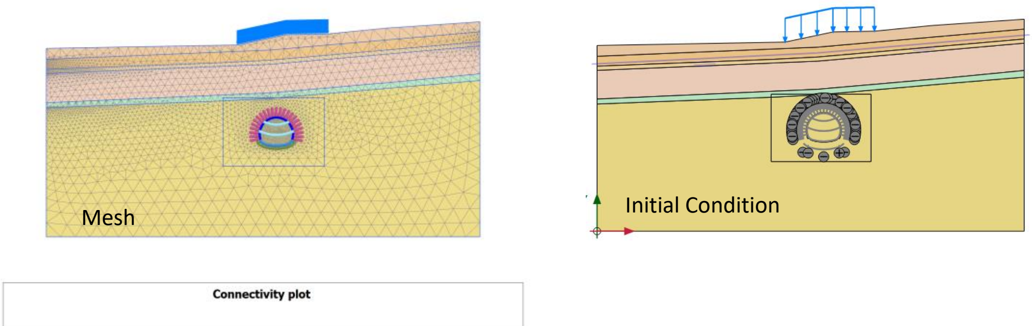
4. Percepatan Puncak

Nilai percepatan puncak di permukaan diambil dengan mengalikan terhadap koefisien horizontal yang didapat dengan persamaan *kh = (1.45-PGA)*PGA (Choukier,1997)* sehingga didapat:

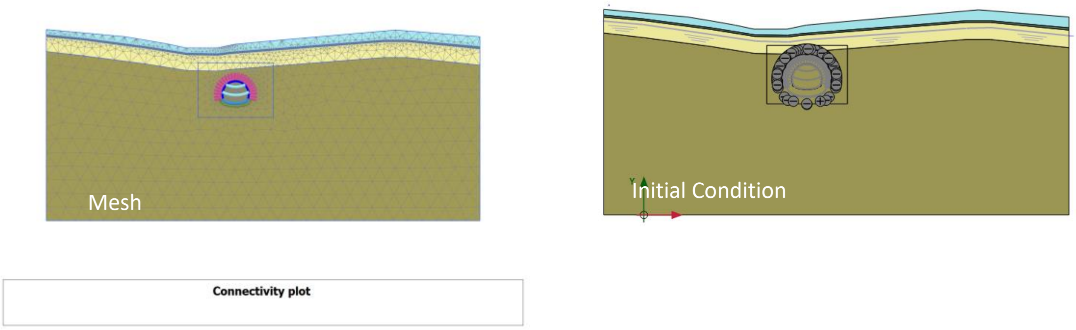
Untuk PGA 0.3 → $a = 0.3 \times 1.2 \times ((1.45 - 0.3) \times 0.3) = \mathbf{0.1242\ g}$

D. Kondisi Elemen Mesh dan *Initial Condition*

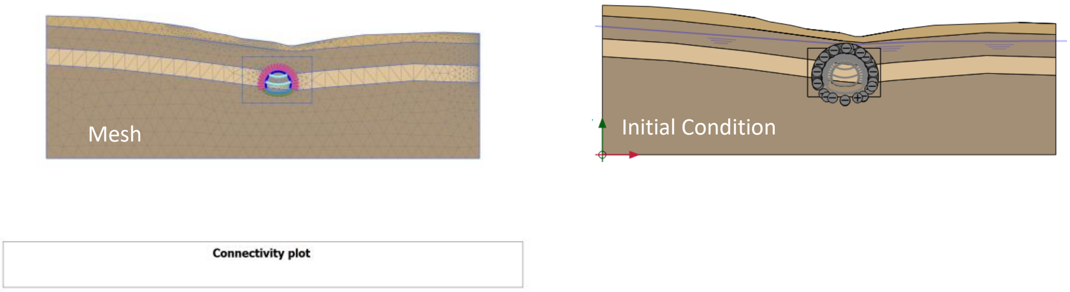
Meshing merupakan proses membagi komponen yang akan dianalisis menjadi elemen-elemen kecil yang menjadi dasar dalam perhitungan/iterasi dalam pemodelan FEM (PLAXIS 2D). *Meshing* yang digunakan dalam pemodelan ini menggunakan mesh *very fine. Initial condition* merupakan kondisi awal pemodelan pada analisis PLAXIS 2D. Berikut merupakan hasil meshing dan initial condition pada model analisis seperti yang disajikan pada **Gambar 6 s/d Gambar 9.**



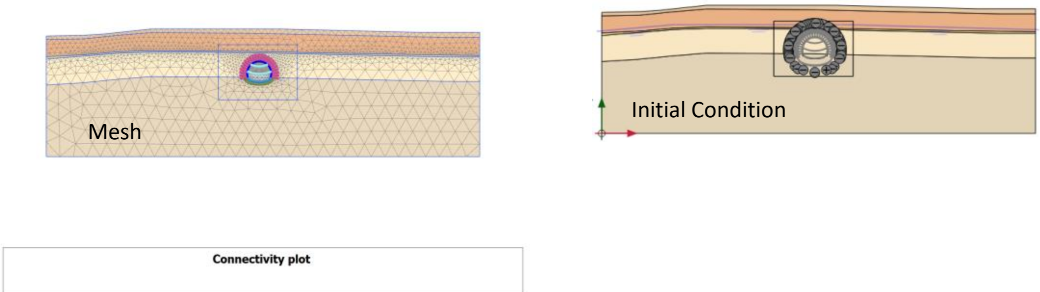
Gambar 8 *Meshing* dan *initial condition* Tunnel Walini (DK 95+602)



Gambar 9 *Meshing* dan *initial condition* Tunnel Walini (DK 95+696)



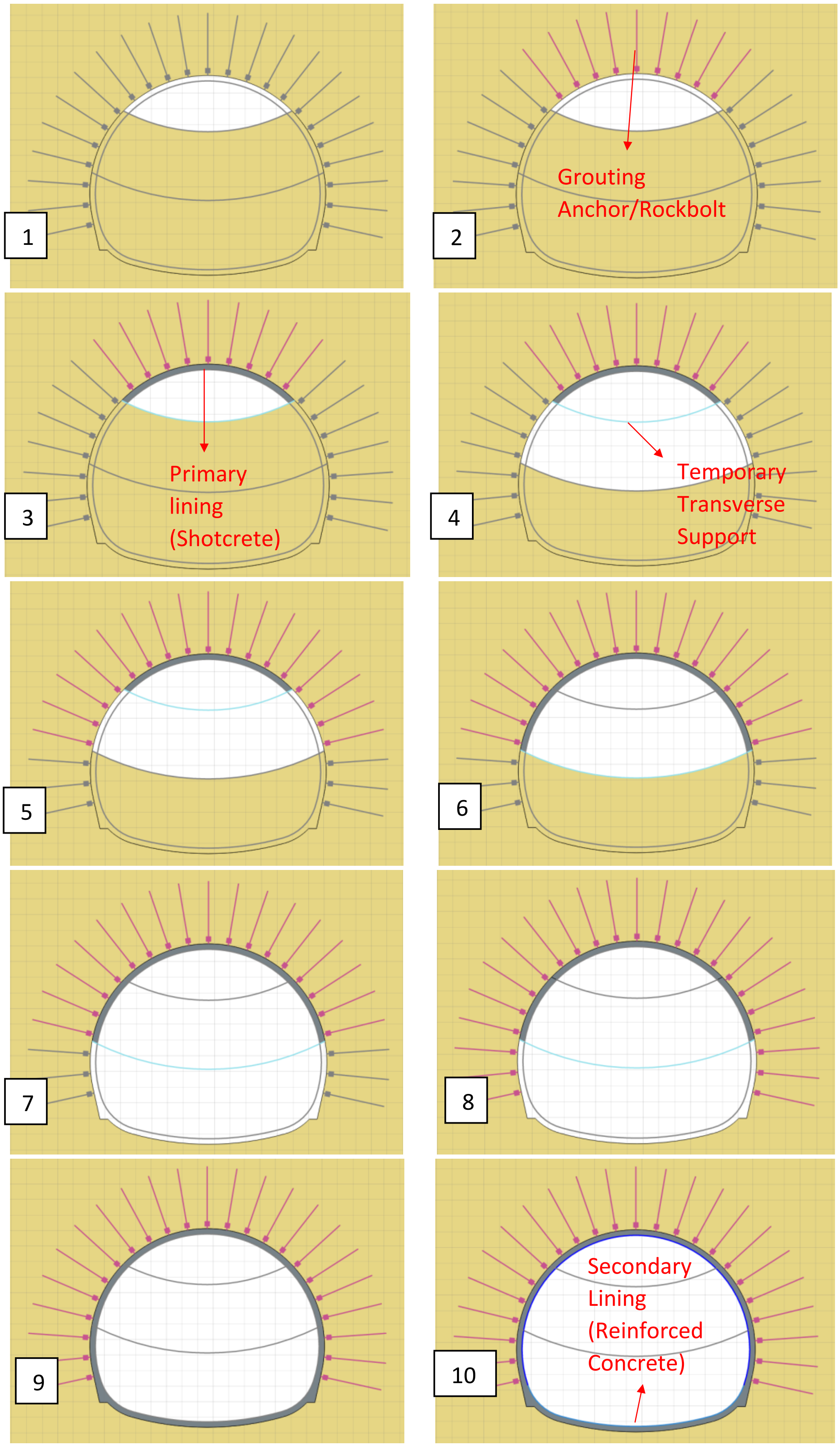
Gambar 10 *Meshing* dan *initial condition* Tunnel Walini (DK 95+715)



Gambar 11 *Meshing* dan *initial condition* Tunnel Walini (DK 95+993)

E. Tahapan Konstruksi Pemodelan Terowongan

Analisis galian terowongan yang dilakukan pada program numerik 2D terdiri dari 10 tahap konstruksi. Tahap pemodelan terowongan diawali dengan galian pada bagian upper bench **Gambar 12(1)**, Pemasangan grouting anchor/rockbolt (dimodelkan menggunakan Embedded Beam) bagian atas **Gambar 12(2)**, Pemasangan primary lining dan upper bench temporary transverse support **Gambar 12(3)**, galian pada bagian middle bench **Gambar 12(4)**, Pemasangan grouting anchor/rockbolt bagian mid **Gambar 12(5),** Pemasangan primary lining dan middle bench temporary transverse support **Gambar 12(6)**, galian pada bagian lower bench **Gambar 12(7)**, Pemasangan grouting anchor/rockbolt bagian mid **Gambar 12(8),** Pemasangan primary lining pada bagian lower bench **Gambar 12(9)**, pemasangan secondary lining (dimodelkan menggunakan plate) **Gambar 12(10)**, dan dilanjutkan analisis pada kondisi minimum excess pore pressure serta dilanjutkan analisis terhadap beban gempa.



Gambar 12 Tahapan konstruksi tunnel NATM di Tunnel Walini (DK 95+602)

F. Hasil Pemodelan (Deformasi, *Volume loss*, Gaya Dalam, dan Tegangan Tanah)

1. Perhitungan Volume Loss

Perhitungan volume loss pada permukaan biasanya dilakukan dengan mengasumsikan kurva penurunan Gauss, pengukuran deformasi maksimum yang terjadi di permukaan, mengukur kedalaman terhadap terowongan dan memperkirakan parameter K. Perhitungan volume loss dilakukan dengan menggunakan *spreadsheet* berdasarkan hasil analisis yang dilakukan pada program Plaxis. Untuk hasil rekapitulasi dapat dilihat pada **Tabel 41 s/d Tabel 44.** Untuk hasil perhitungan lebih lengkapnya dapat dilihat pada **Lampiran C.**

2. Deformasi *Tunnel*

Berdasarkan hasil analisis numerik dengan menggunakan program Plaxis 2D, didapatkan hasil berupa penurunan. Deformasi dicatat dengan mengambil nilai deformasi aksial dan lateral terbesar di sekeliling lining terowongan. Deformasi aksial global dicatat pada seluruh tahap konstruksi serta deformasi aksial dan lateral pada lining terowongan dicatat pada tahap ketika seluruh *lining* terpasang, kondisi *longterm* dan setelah gempa yang dapat dilihat pada **Gambar 13 s/d Gambar 32**. Rekapitulasi hasil deformasi dan gaya dalam yang dihasilkan dalam pemodelan PLAXIS 2D pada setiap tahapan konstruksi dapat dilihat pada **Tabel 41 s/d Tabel 44.**

Table 41 Hasil Rekapitulasi Deformasi pada Tunnel Walini (DK95+602)

Staged Construction	Deformasi Aksial Global (m)	Volume Loss (%)	Deformasi Lining Tunnel		Gaya Dalam Tunnel		
			Axial (m)	Lateral (m)	Axial (kN/m)	Shear (kN/m)	Momen (kNm/m)
Gali up bench	-0.003667	-	-	-	-	-	-
Install rockbolt up	-0.003819	-	-	-	-	-	-
Install Primary lining up	-0.003984	-	-	-	-	-	-
Gali mid bench	-0.01471	-	-	-	-	-	-
Install rockbolt mid	-0.01473	-	-	-	-	-	-
Install Primary lining mid	-0.01292	-	-	-	-	-	-
Gali bot bench	-0.03292	-	-	-	-	-	-
Install rockbolt bot	-0.03298	-	-	-	-	-	-
Install Primary lining bot	-0.03198	-	-	-	-	-	-
Install Secondary lining	-0.03554	0.48	-0.03387	0.01855	-2369	-333.7	-383.8
Longterm	-0.00314	-	-0.00218	-0.00084	-2388	-335.5	-386.5
Gempa	-0.04820	-	-0.00329	-0.01727	-3023	-459.7	-585.9

Table 42 Hasil Rekapitulasi Deformasi pada Tunnel Walini (DK95+696)

Staged Construction	Deformasi Aksial Global (m)	Volume Loss (%)	Deformasi Lining Tunnel		Gaya Dalam Tunnel		
			Axial (m)	Lateral (m)	Axial (kN/m)	Shear (kN/m)	Momen (kNm/m)
Gali up bench	-0.00342	-	-	-	-	-	-
Install rockbolt up	-0.00354	-	-	-	-	-	-
Install Primary lining up	-0.00387	-	-	-	-	-	-
Gali mid bench	-0.01836	-	-	-	-	-	-
Install rockbolt mid	-0.01846	-	-	-	-	-	-
Install Primary lining mid	-0.01655	-	-	-	-	-	-
Gali bot bench	-0.04682	-	-	-	-	-	-
Install rockbolt bot	-0.04707	-	-	-	-	-	-
Install Primary lining bot	-0.04502	-	-	-	-	-	-
Install Secondary lining	-0.04606	0.70	-0.04336	0.04200	-2106	-362.1	-435.1
Longterm	-0.00206	-	-0.00028	-0.00020	-2120	-363.5	-435.4
Gempa	-0.1355	-	-0.00233	-0.05387	-2328	393.1	-502.6

Table 43 Hasil Rekapitulasi Deformasi pada Tunnel Walini (DK95+715)

Staged Construction	Deformasi Aksial Global (m)	Volume Loss (%)	Deformasi Lining Tunnel		Gaya Dalam Tunnel		
			Axial (m)	Lateral (m)	Axial (kN/m)	Shear (kN/m)	Momen (kNm/m)
Gali up bench	-0.003417	-	-	-	-	-	-
Install rockbolt up	-0.003424	-	-	-	-	-	-
Install Primary lining up	-0.003735	-	-	-	-	-	-
Gali mid bench	-0.01170	-	-	-	-	-	-
Install rockbolt mid	-0.01171	-	-	-	-	-	-
Install Primary lining mid	-0.01006	-	-	-	-	-	-
Gali bot bench	-0.01412	-	-	-	-	-	-
Install rockbolt bot	-0.01412	-	-	-	-	-	-
Install Primary lining bot	-0.01276	-	-	-	-	-	-
Install Secondary lining	-0.01548	0.23	-0.01534	0.004050	-1966	350	-429.3
Longterm	-0.00148	-	-0.00032	-0.00017	-1990	354.1	-435.5
Gempa	-0.1097	-	-0.00273	0.04186	-2927	512.1	-747.7

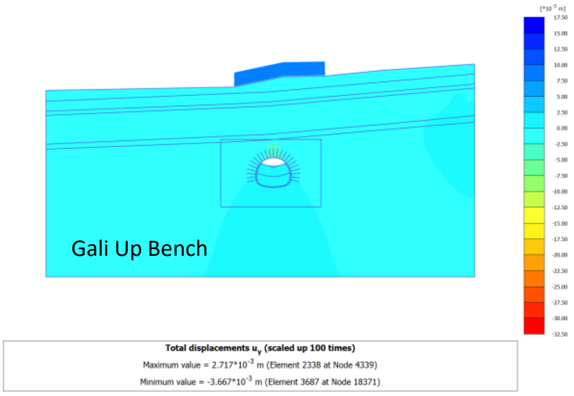
Table 44 Hasil Rekapitulasi Deformasi pada Tunnel Walini (DK95+993)

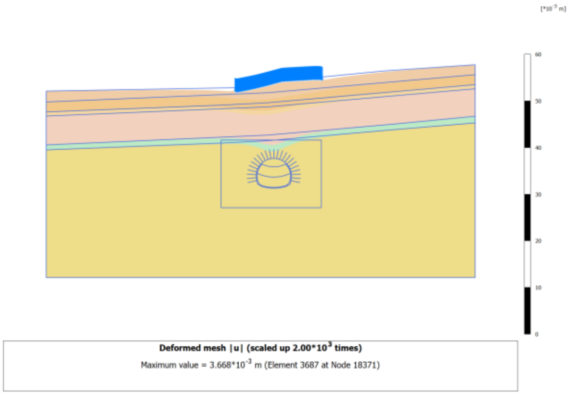
Staged Construction	Deformasi Aksial Global (m)	Volume Loss (%)	Deformasi Lining Tunnel		Gaya Dalam Tunnel		
			Axial (m)	Lateral (m)	Axial (kN/m)	Shear (kN/m)	Momen (kNm/m)
Gali up bench	-0.003437	-	-	-	-	-	-
Install rockbolt up	-0.003467	-	-	-	-	-	-
Install Primary lining up	-0.003776	-	-	-	-	-	-
Gali mid bench	-0.01210	-	-	-	-	-	-
Install rockbolt mid	-0.01213	-	-	-	-	-	-
Install Primary lining mid	-0.01115	-	-	-	-	-	-
Gali bot bench	-0.02394	-	-	-	-	-	-
Install rockbolt bot	-0.02416	-	-	-	-	-	-
Install Primary lining bot	-0.02294	-	-	-	-	-	-
Install Secondary lining	-0.02895	0.33	-0.02888	0.00404	-1742	291.4	-327.7
Longterm	-0.00668	-	-0.00052	-0.00023	-1765	295.3	-330.2
Gempa	-0.05379	-	-0.00240	-0.03081	-2215	-416.8	-537.8

Dari hasil rekapitulasi deformasi menunjukkan bahwa selisih atau Δdeformasi dari potongan DK 95+696 dengan DK 95+715 terbesar adalah **±3 cm pada install secondary lining** dengan syarat izin diferential settlement 0.04%(19 m)= 0.008 m atau sebesar 0.8 cm. Hasil tersebut tidak masuk kedalam syarat izin yaitu 0.04%(Ls).

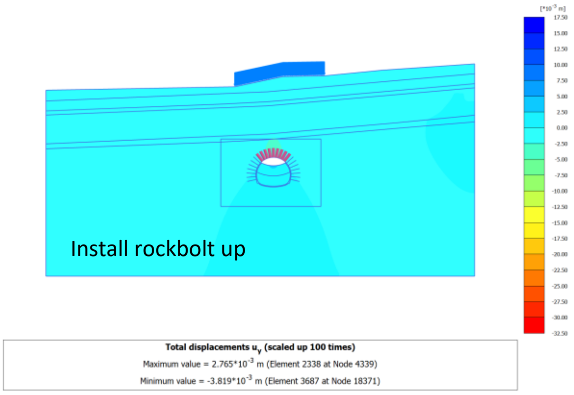
Syarat izin deformasi setelah proses konstruksi selesai (longterm) sebesar **15 mm**, dengan demikian seluruh model potongan telah memenuhi syarat karena deformasi yang dihasilkan pada kondisi longterm kurang dari **15 mm**.

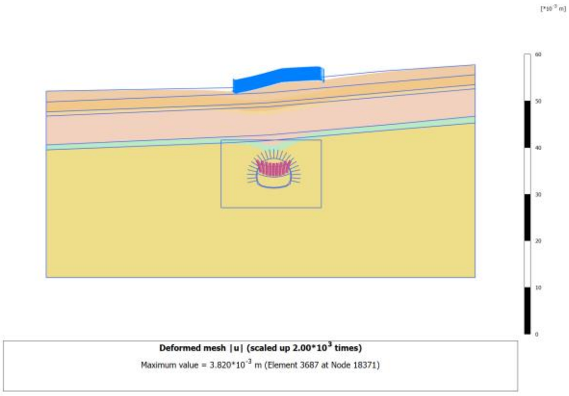
a) *Cross Section DK 95 + 602*



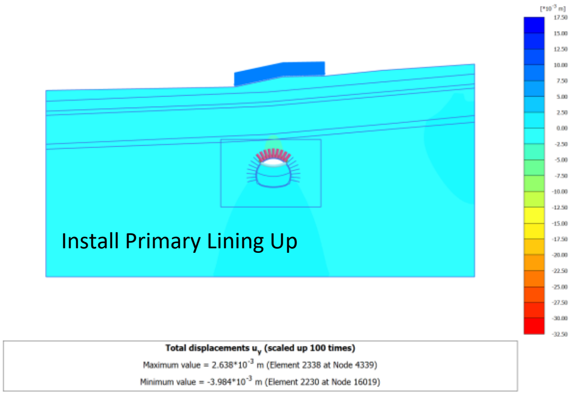


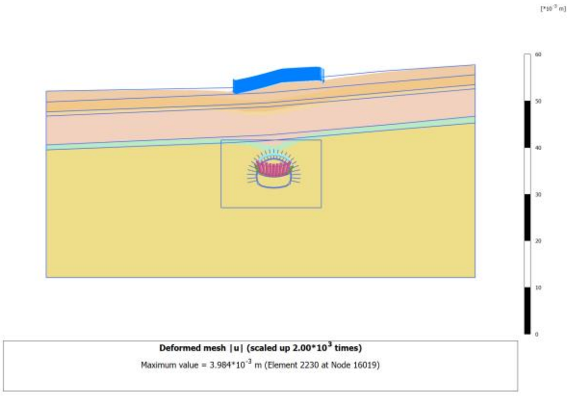
Maximum = 2.717×10^{-3} m
Minimum = -3.667×10^{-3} m





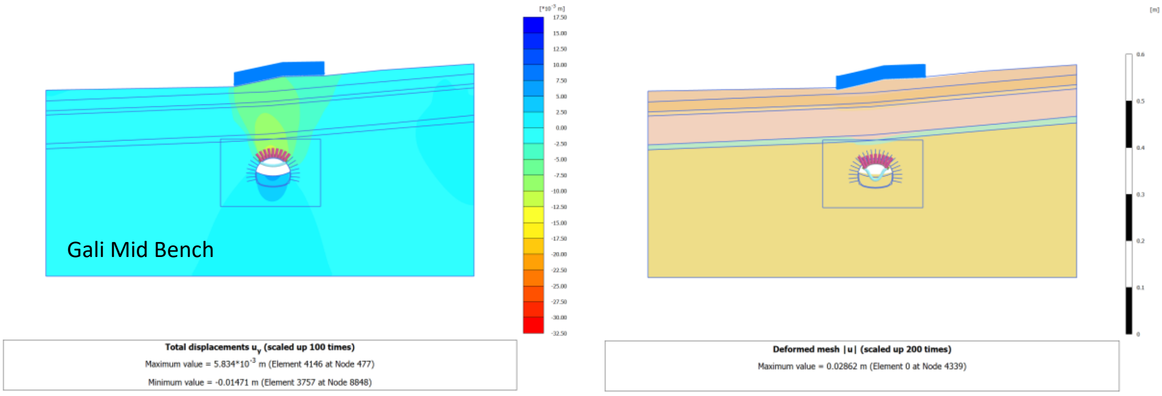
Maximum = 2.765×10^{-3} m
Minimum = -3.819×10^{-3} m



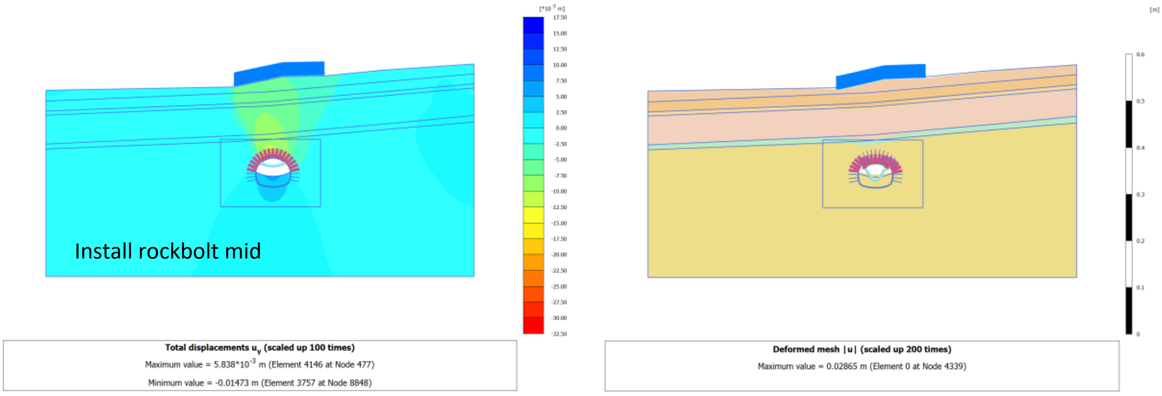


Maximum = 2.638×10^{-3} m
Minimum = -3.984×10^{-3} m

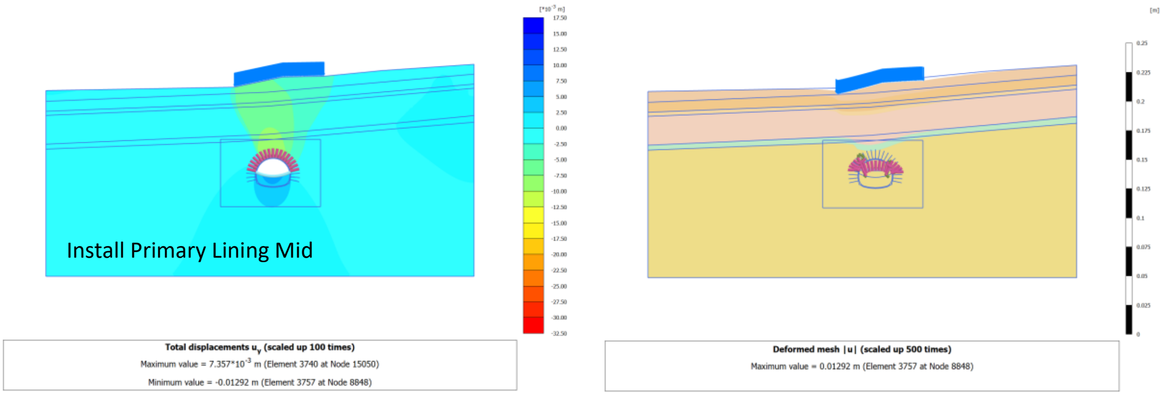
Gambar 13 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+602)



Maximum = 5.834x10^{-3} m
Minimum = -0.1471 m

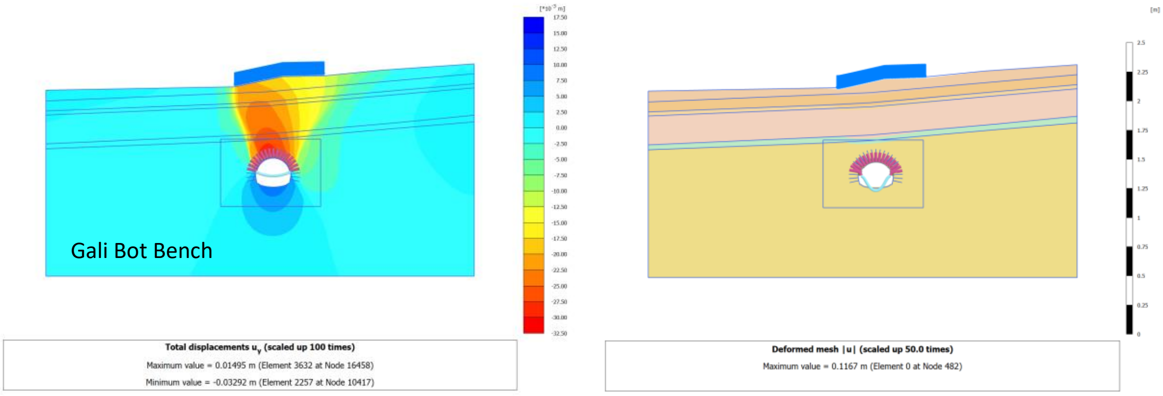


Maximum = 5.838x10^{-3} m
Minimum = -0.01473 m

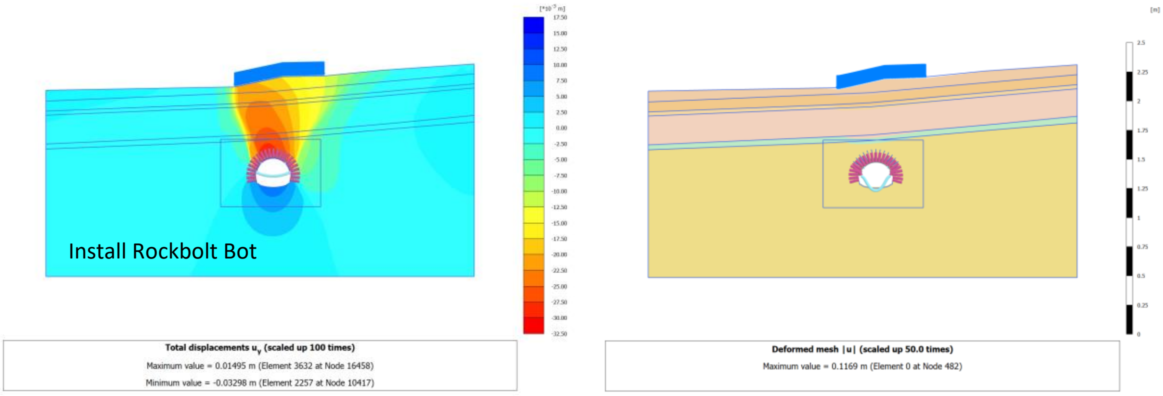


Maximum = 7.357x10^{-3} m
Minimum = -0.01292 m

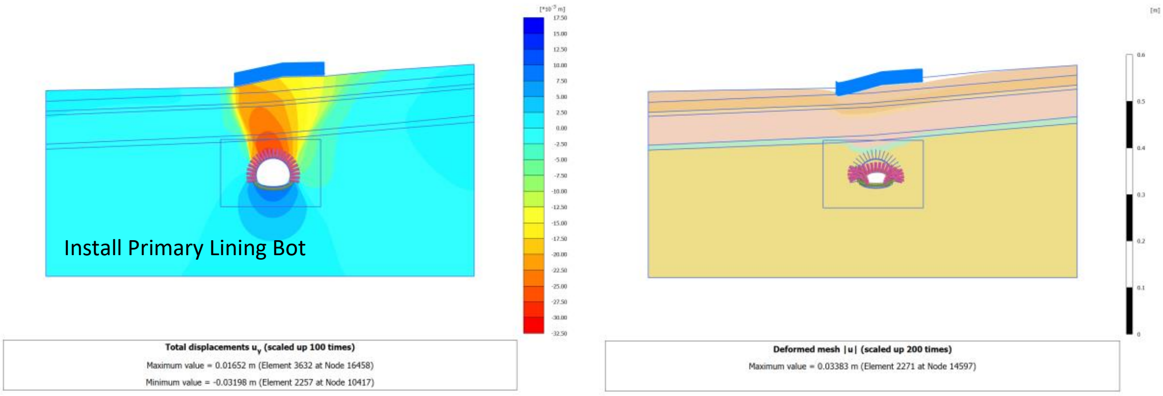
Gambar 14 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+602) (lanjutan)



Maximum = 0.01495 m
Minimum = -0.03292 m

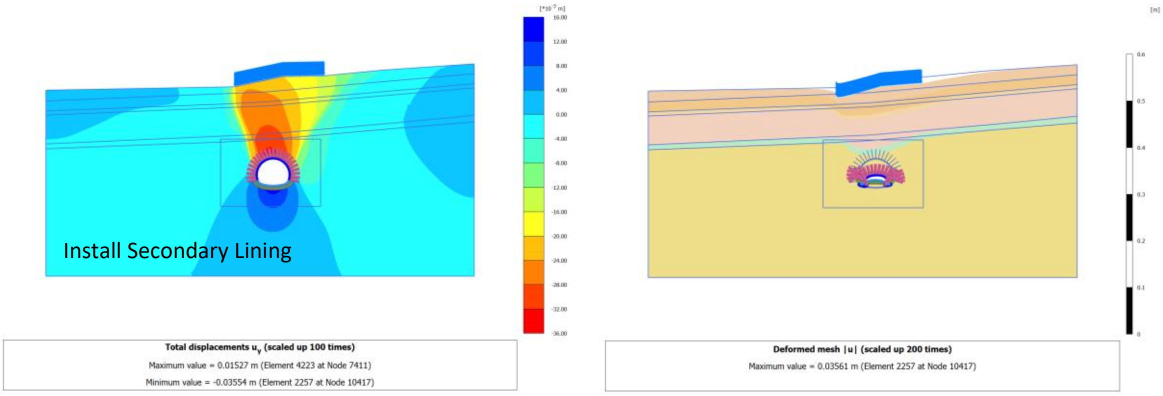


Maximum = 0.01495 m
Minimum = -0.03298 m

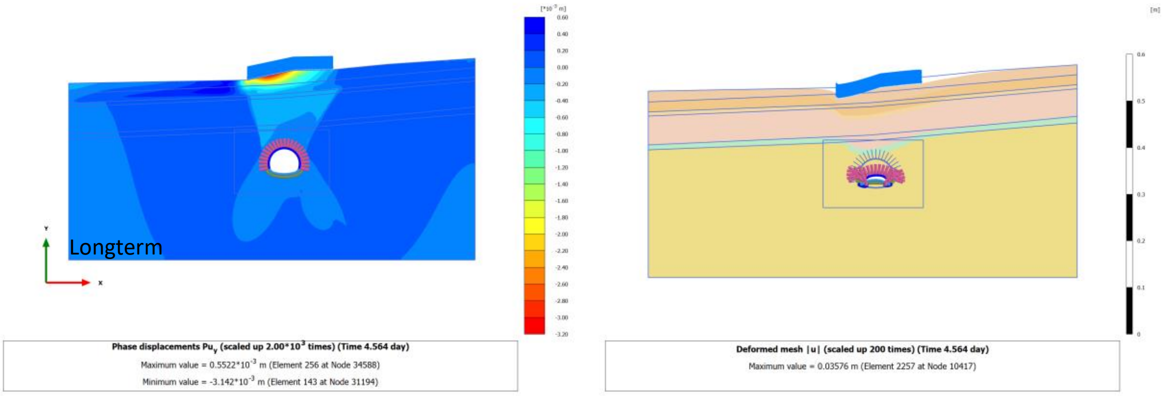


Maximum = 0.01652 m
Minimum = -0.03198 m

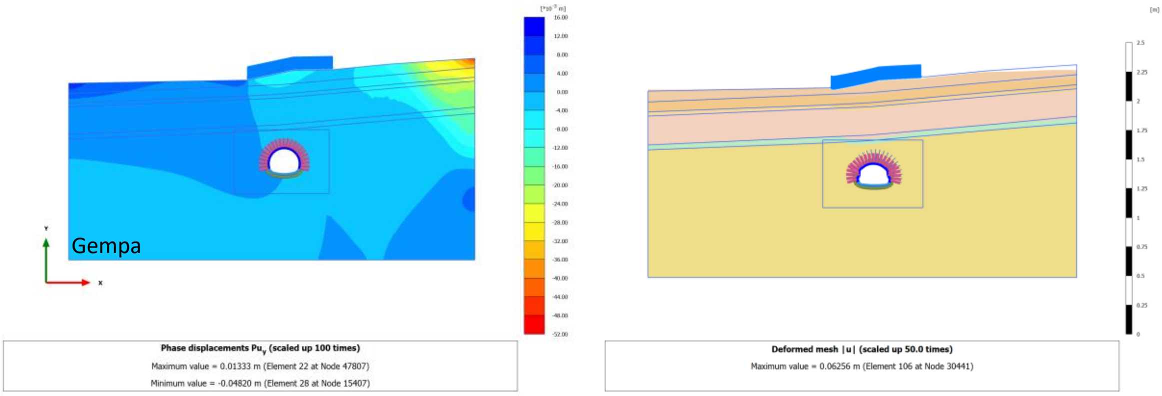
Gambar 15 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+602) (lanjutan)



Maximum = 0.01527 m
Minimum = -0.03554 m

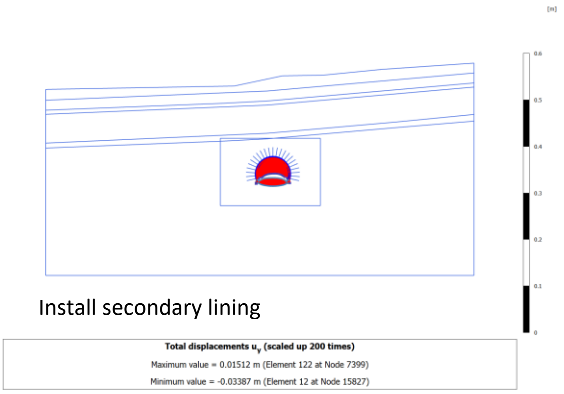


Maximum = 0.0552×10^{-3} m
Minimum = -3.142×10^{-3} m

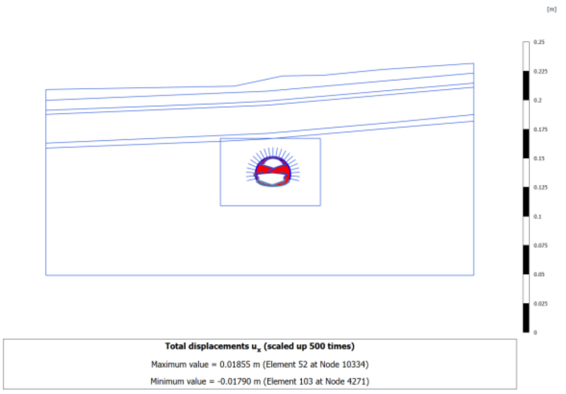


Maximum = 0.01333 m
Minimum = -0.04820 m

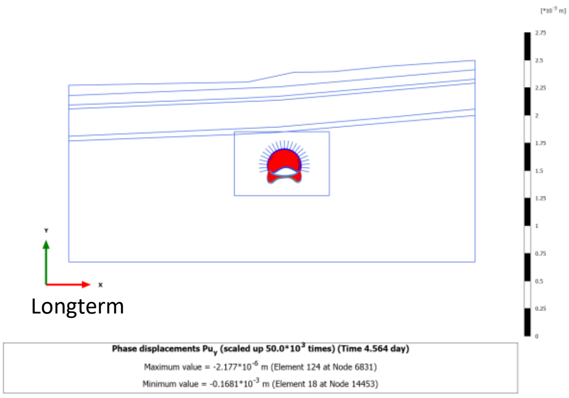
Gambar 16 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+602) (lanjutan)



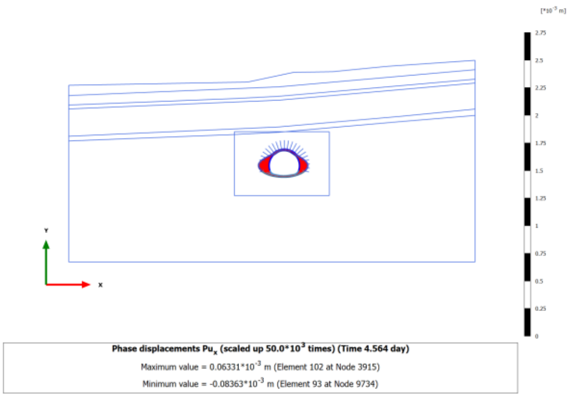
Maximum = 0.01512 m
Minimum = -0.03387 m



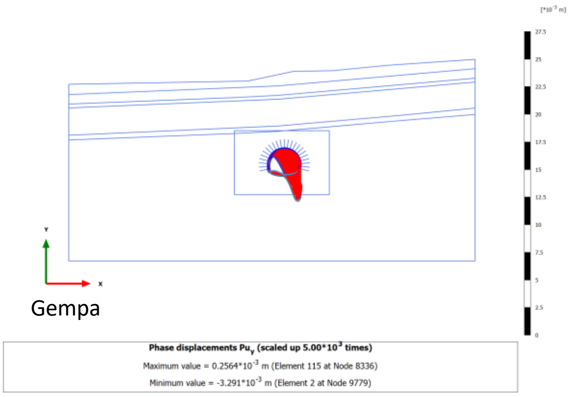
Maximum = 0.01855 m
Minimum = -0.01790 m



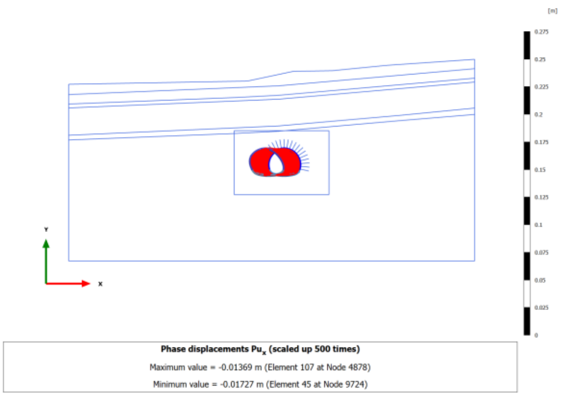
Maximum = -2.177×10^{-3} m
Minimum = -0.168×10^{-3} m



Maximum = 0.063×10^{-3} m
Minimum = -0.084×10^{-3} m



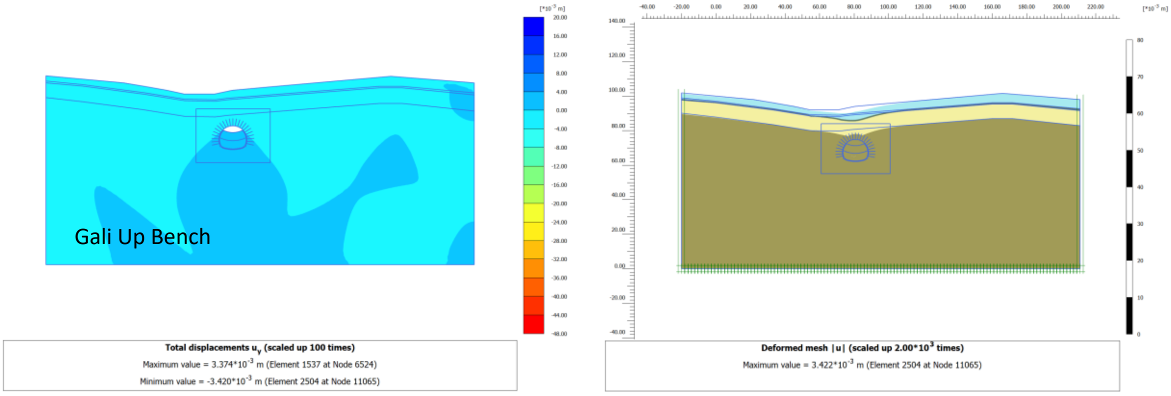
Maximum = 0.256×10^{-3} m
Minimum = -3.291×10^{-3} m



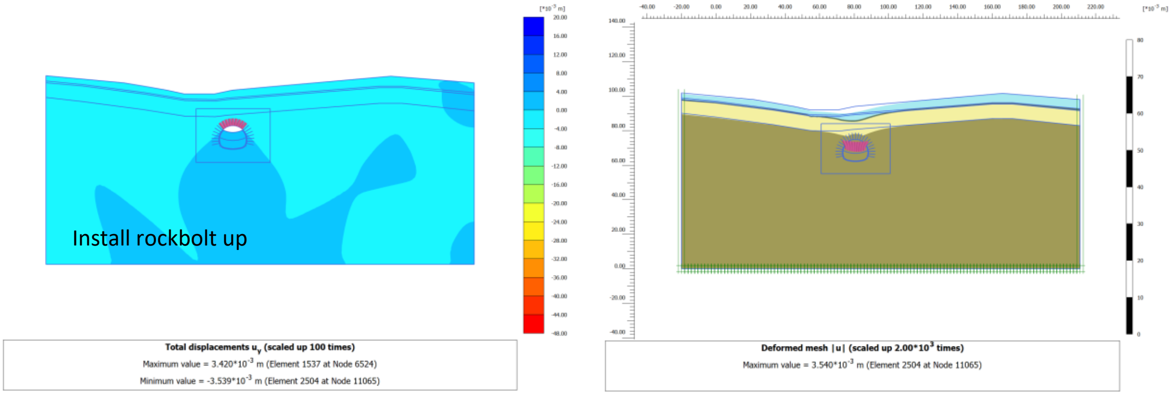
Maximum = 0.01369 m
Minimum = -0.01727 m

Gambar 17 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel Walini (DK 95+602)

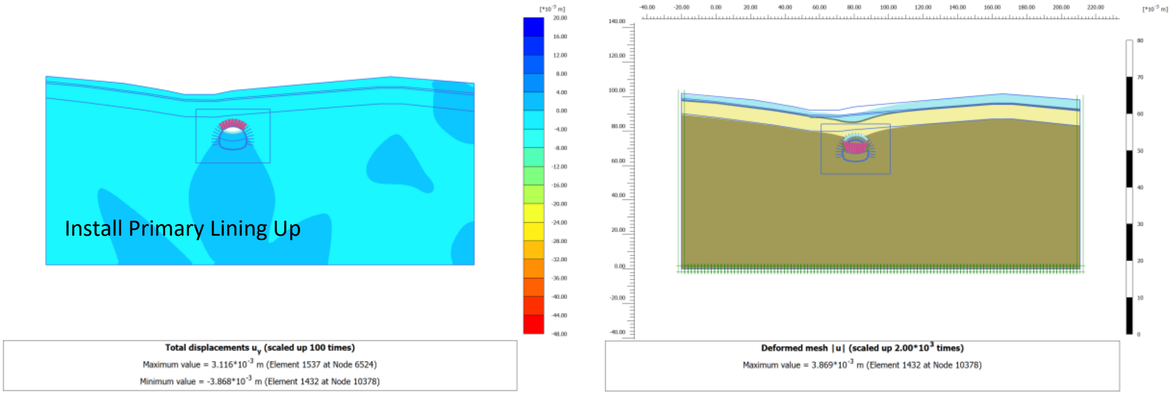
b) *Cross Section DK 95 + 696*



Maximum = 3.374×10^{-3} m
Minimum = -3.420×10^{-3} m

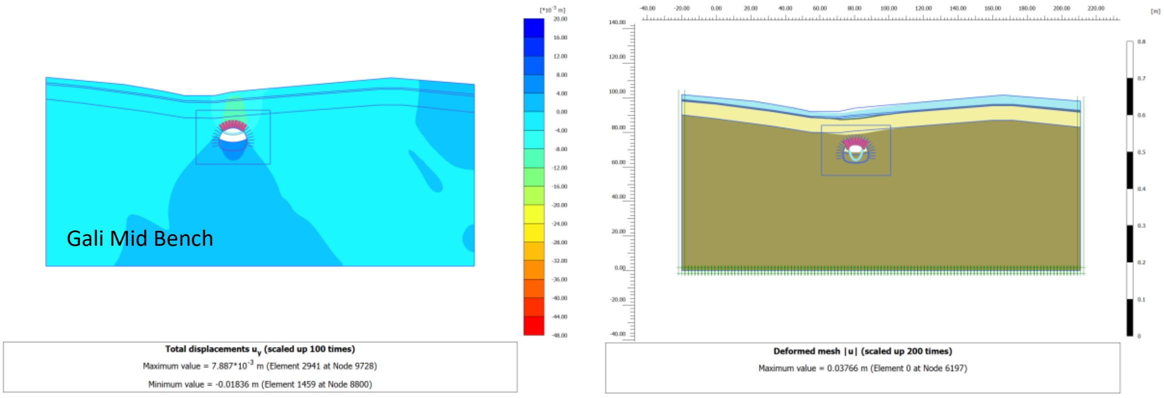


Maximum = 3.420×10^{-3} m
Minimum = -3.539×10^{-3} m

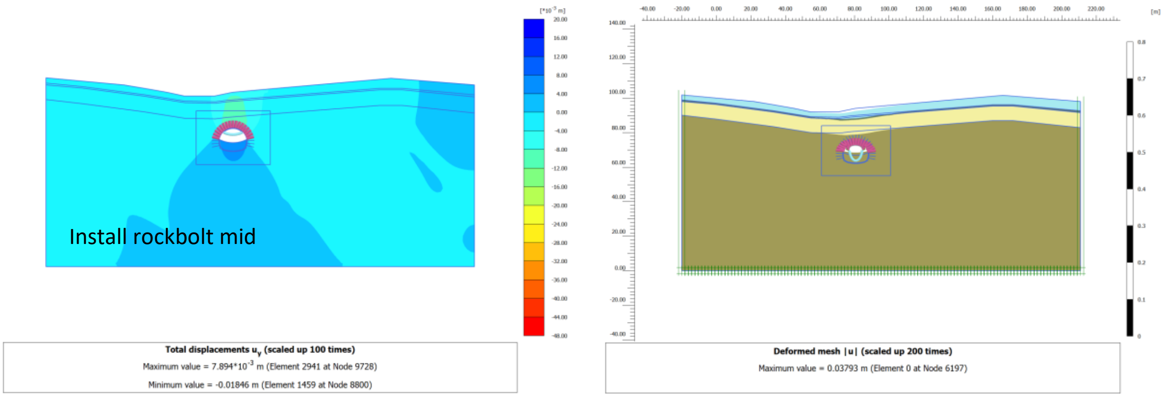


Maximum = 3.116×10^{-3} m
Minimum = -3.868×10^{-3} m

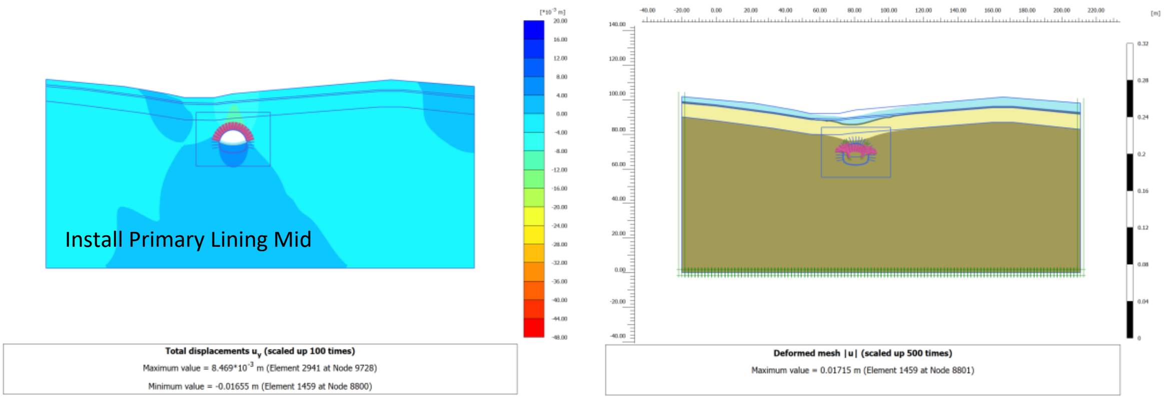
Gambar 18 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+696)



Maximum = 7.887x10^{-3} m
Minimum = -0. 01836 m

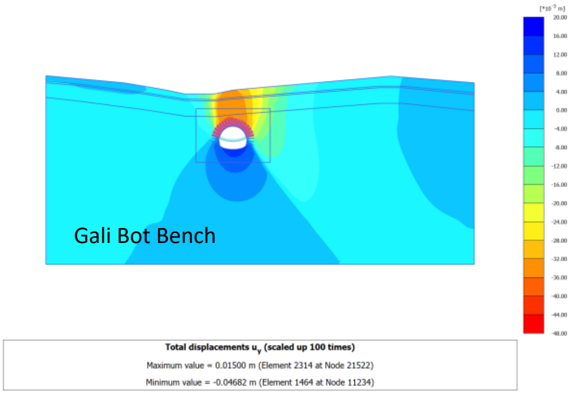


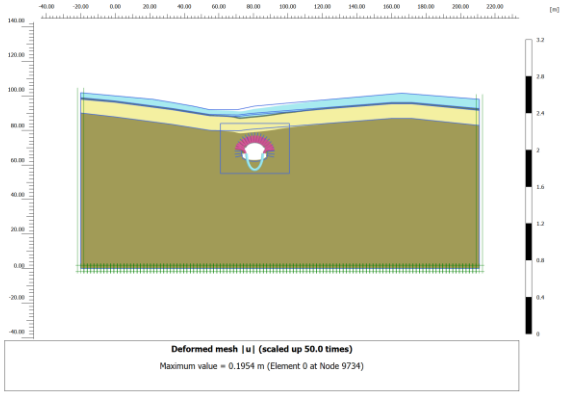
Maximum = 7.894x10^{-3} m
Minimum = -0.01846 m



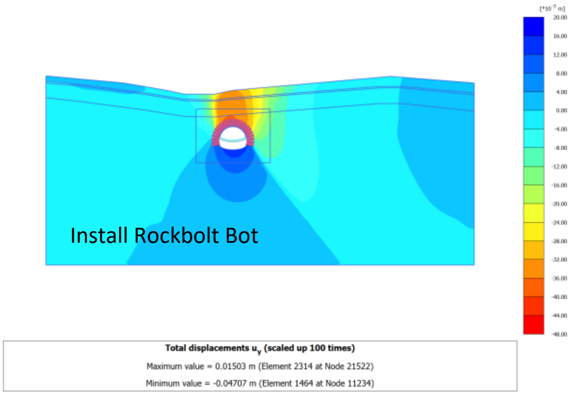
Maximum = 8.469x10^{-3} m
Minimum = -0.01655 m

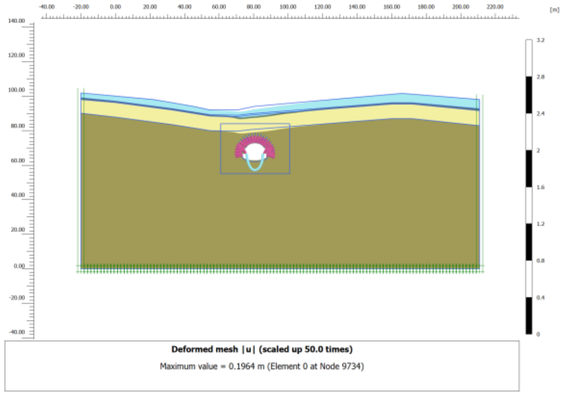
Gambar 19 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+696) (lanjutan)



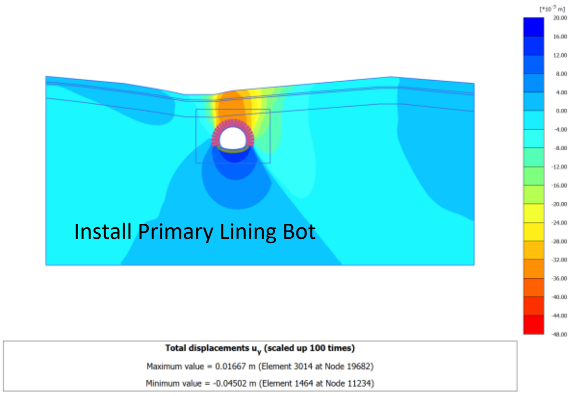


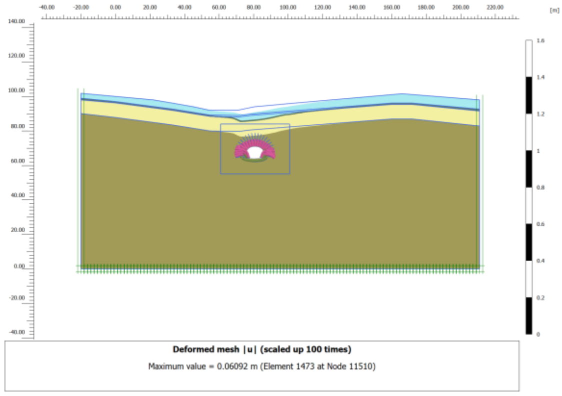
Maximum = 0.0150 m
Minimum = -0.04682 m





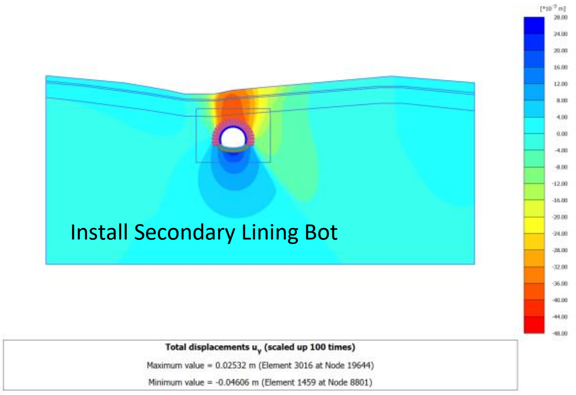
Maximum = 0.01503 m
Minimum = -0.04707 m

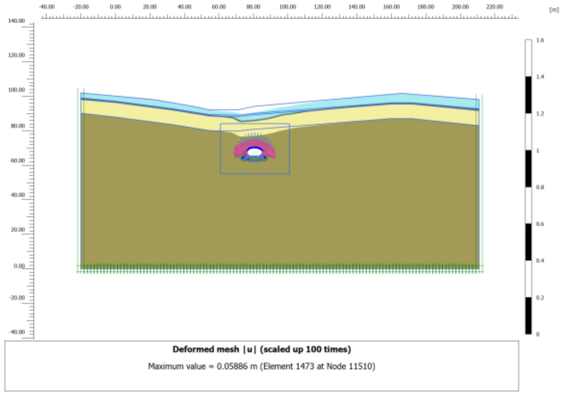




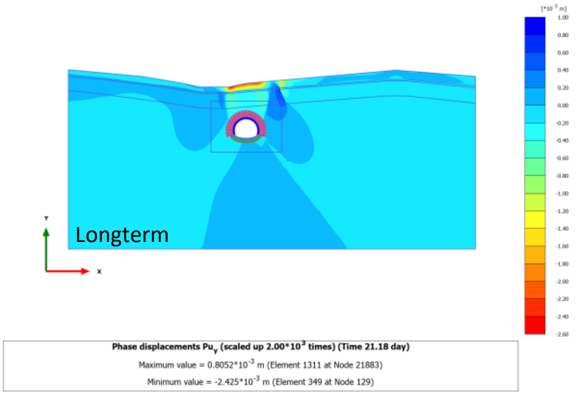
Maximum = 0.01667 m
Minimum = -0.04502 m

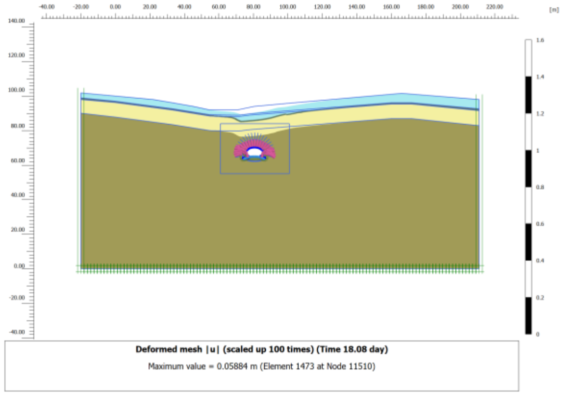
Gambar 20 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+696) (lanjutan)



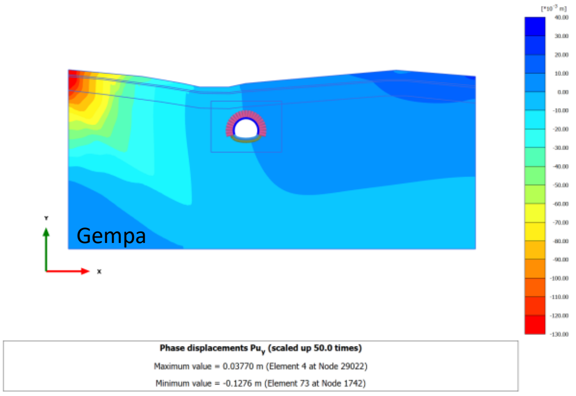


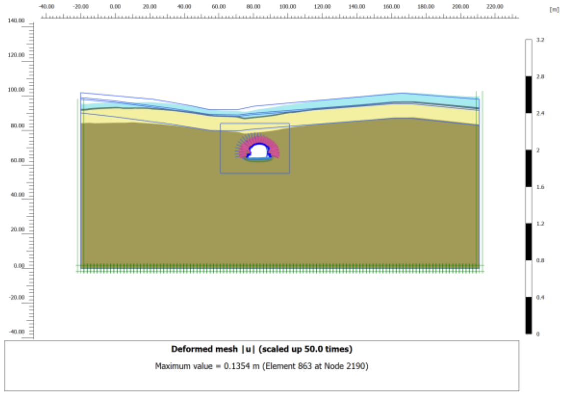
Maximum = 0.02532 m
Minimum = -0.04606 m





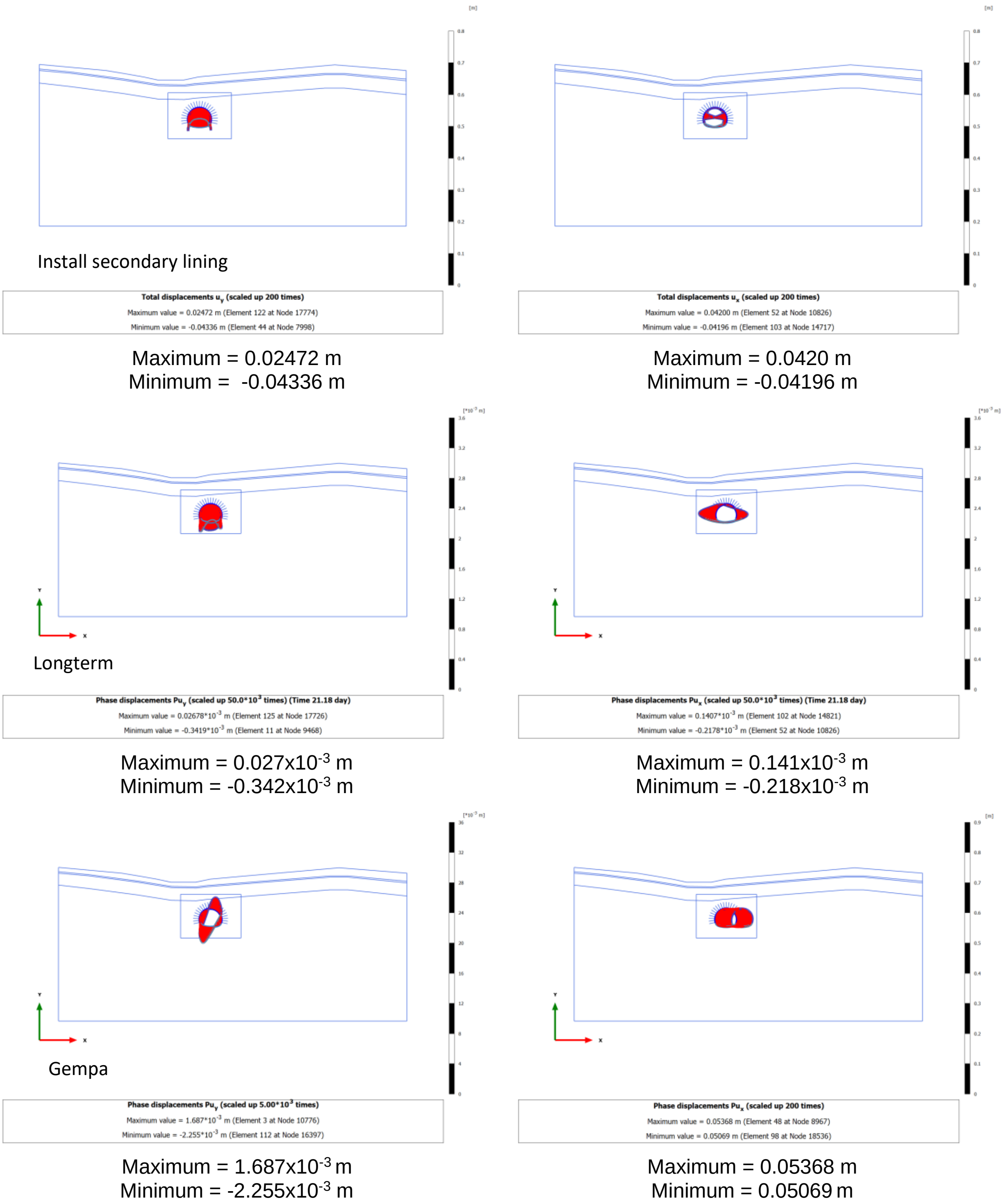
Maximum = 0.805x10^{-3} m
Minimum = -2.425x10^{-3} m





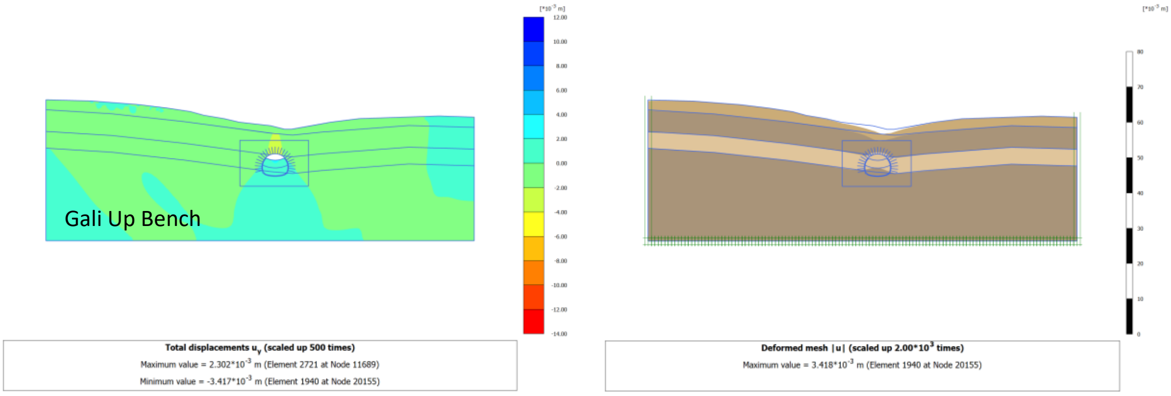
Maximum = 0.03770 m
Minimum = -0.1276 m

Gambar 21 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+696) (lanjutan)

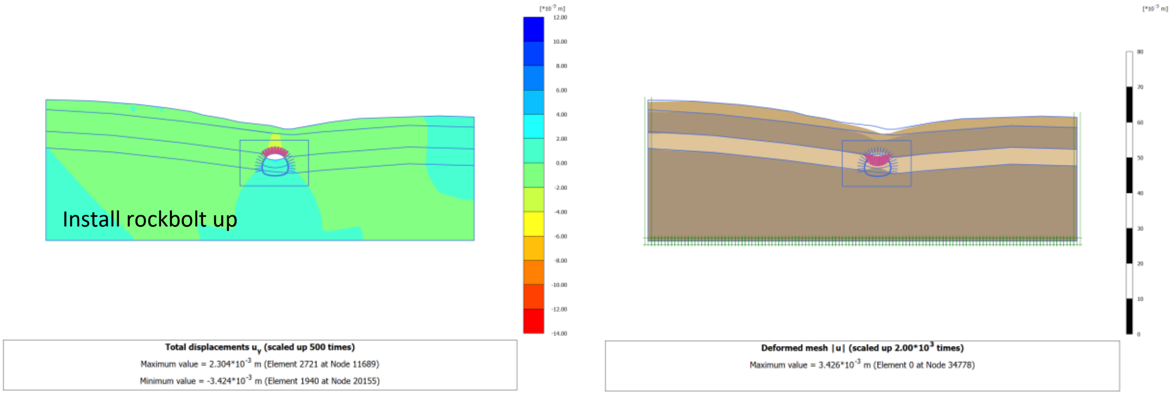


Gambar 22 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel Walini (DK 95+696)

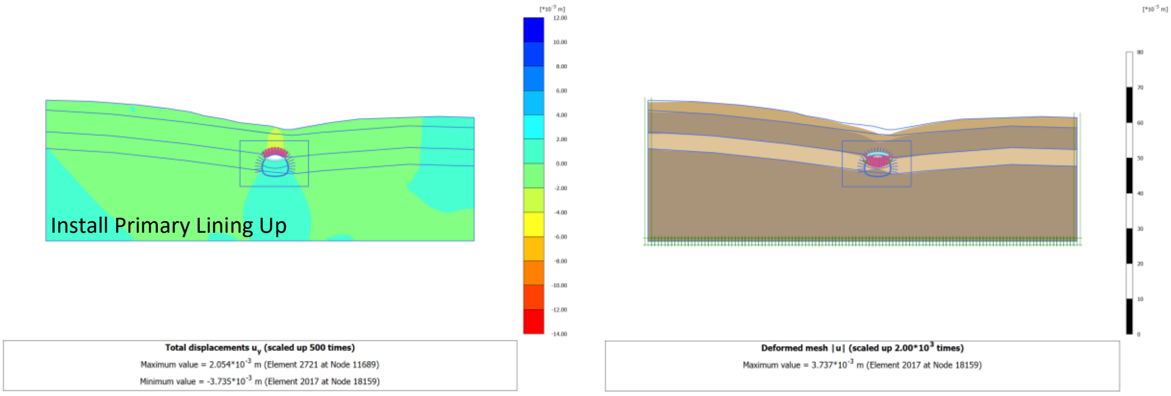
c) *Cross Section DK 95 + 715*



Maximum = 2.302×10^{-3} m
Minimum = -3.417×10^{-3} m

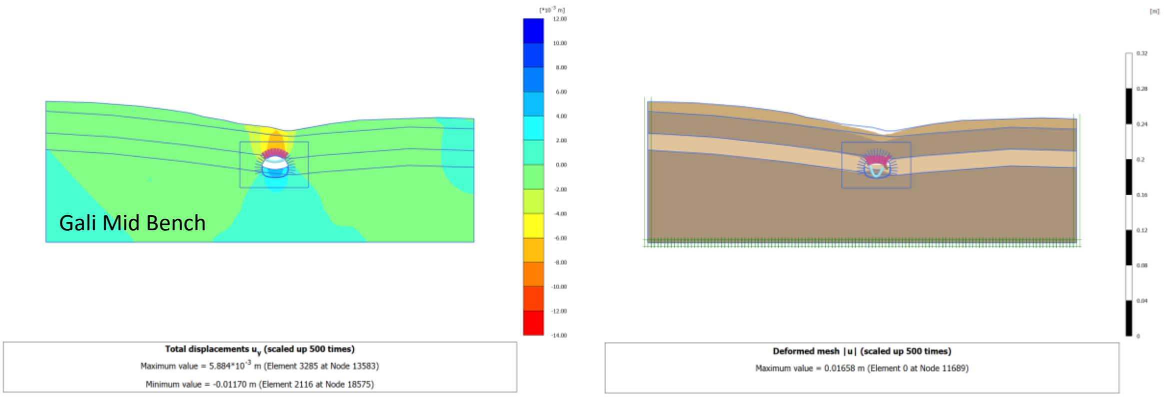


Maximum = 2.304×10^{-3} m
Minimum = -3.424×10^{-3} m

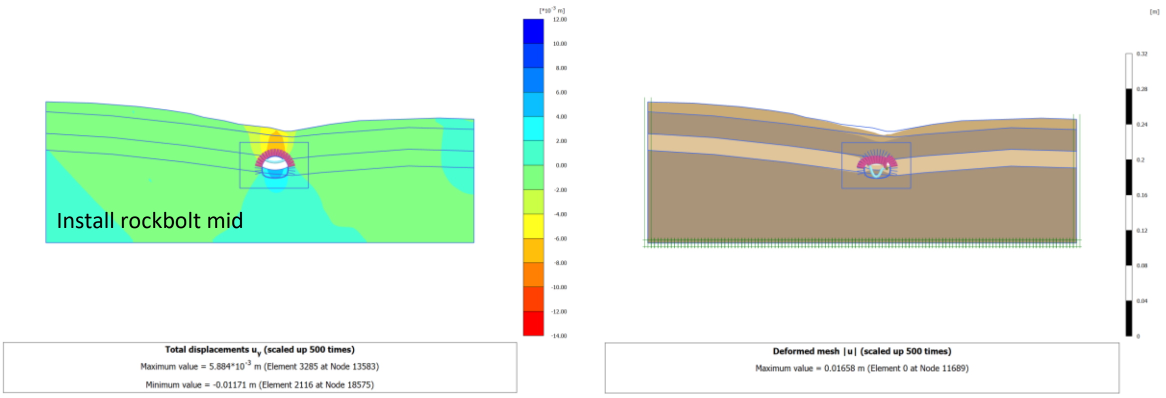


Maximum = 2.054×10^{-3} m
Minimum = -3.735×10^{-3} m

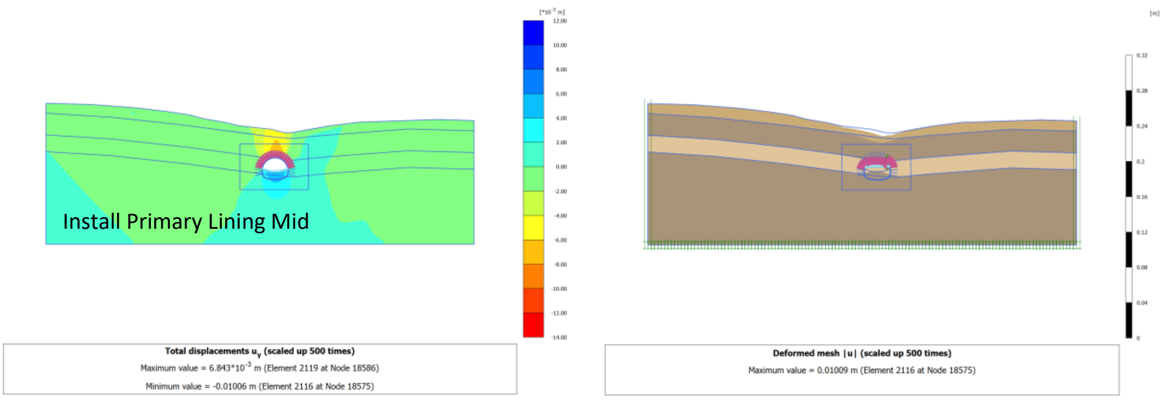
Gambar 23 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+715)



Maximum = 5.884×10^{-3} m
Minimum = -0.01170 m

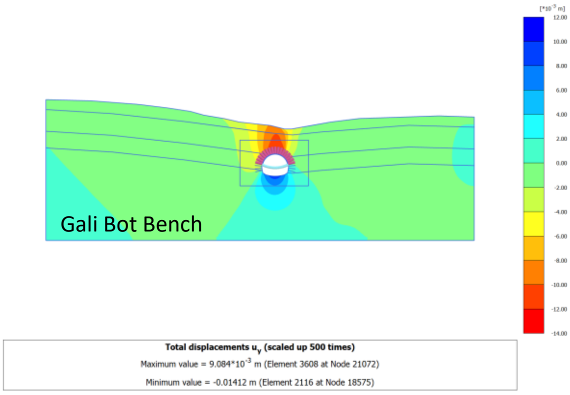


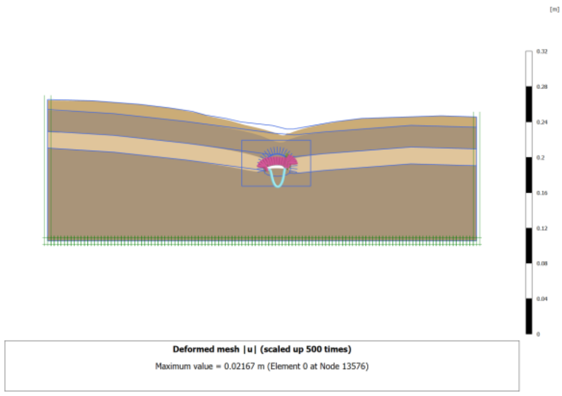
Maximum = 5.884×10^{-3} m
Minimum = -0.01171 m



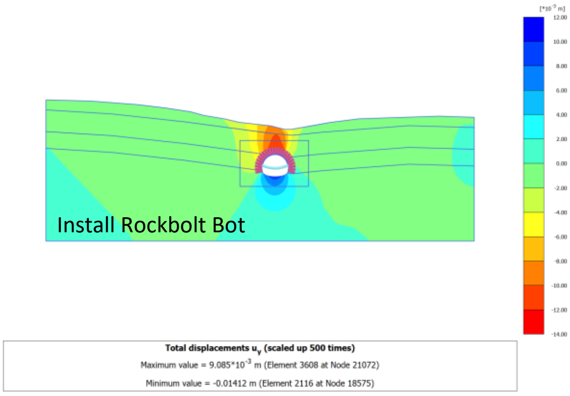
Maximum = 6.843×10^{-3} m
Minimum = -0.01006 m

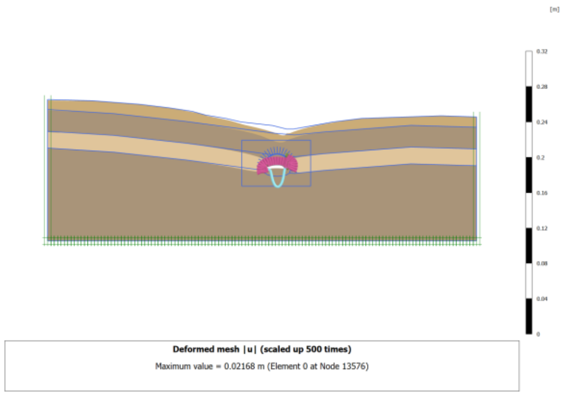
Gambar 24 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+715) (lanjutan)



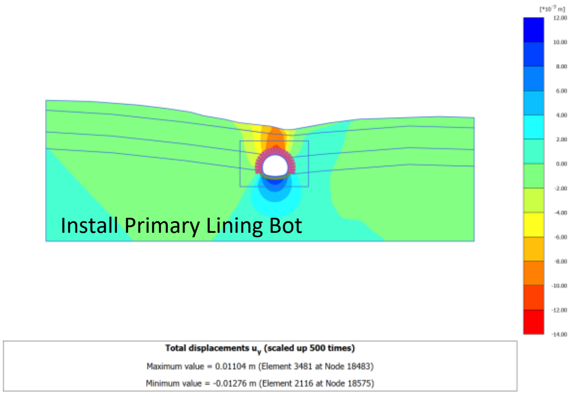


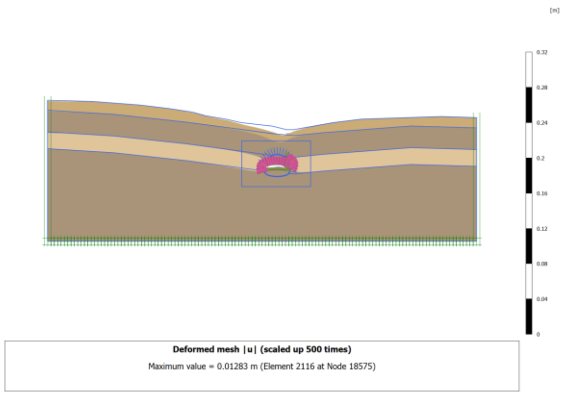
Maximum = 9.084×10^{-3} m
Minimum = -0.01412 m





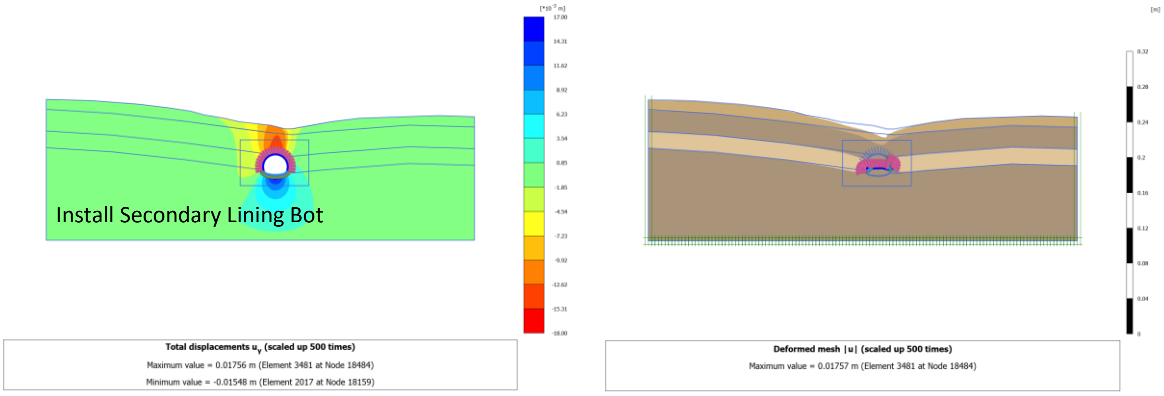
Maximum = 9.085×10^{-3} m
Minimum = -0.01412 m



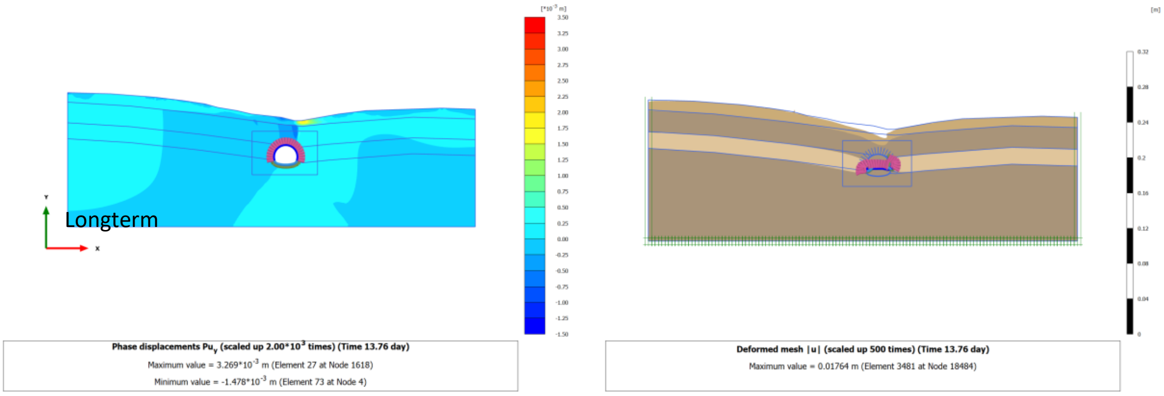


Maximum = 0.01104 m
Minimum = -0.01276 m

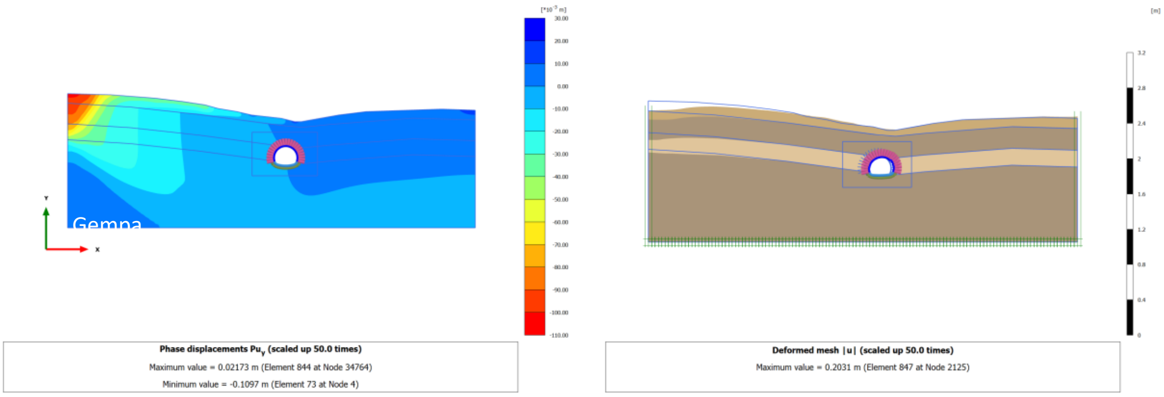
Gambar 25 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+715) (lanjutan)



Maximum = 0.01756 m
Minimum = -0.01548 m

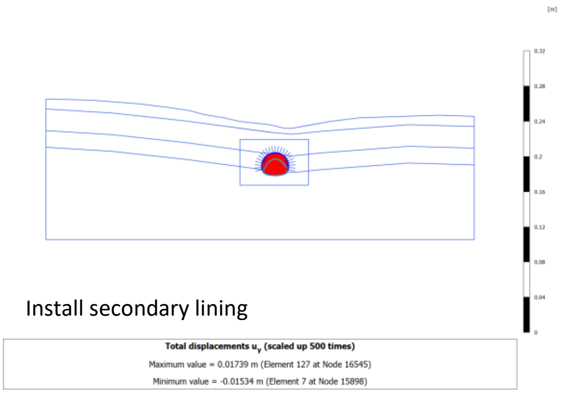


Maximum = $3.269x10^{-3}$ m
Minimum = $-1.478x10^{-3}$ m

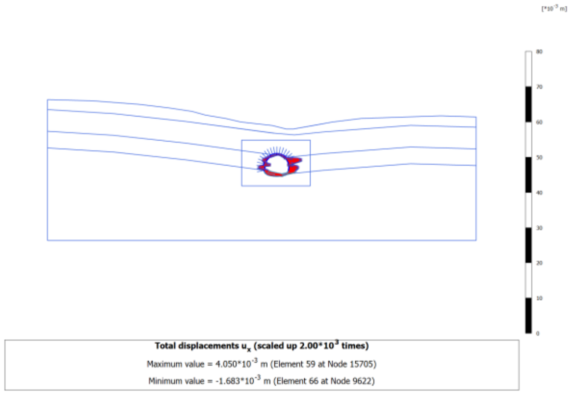


Maximum = 0.02173 m
Minimum = -0.1097 m

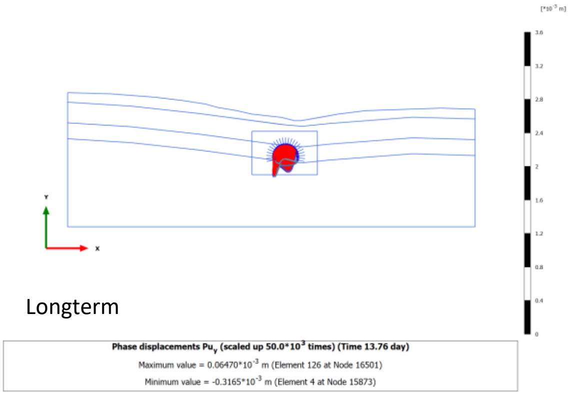
Gambar 26 Hasil analisis deformasi aksial global Tunnel Walini (DK 95+715) (lanjutan)



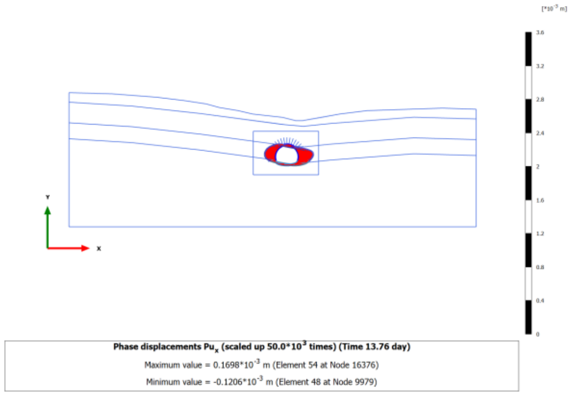
Maximum = 0.01739 m
Minimum = -0.01534 m



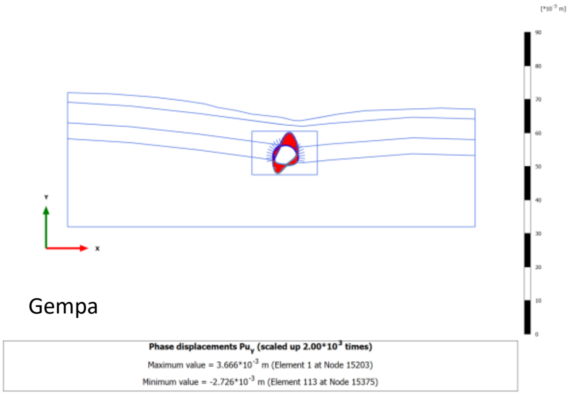
Maximum = 4.050×10^{-3} m
Minimum = -1.683×10^{-3} m



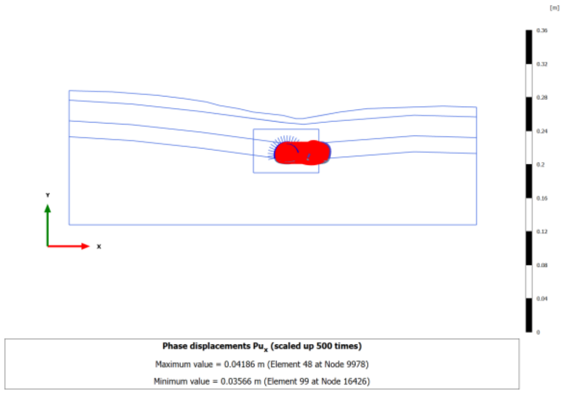
Maximum = 0.065×10^{-3} m
Minimum = -0.317×10^{-3} m



Maximum = 0.169×10^{-3} m
Minimum = -0.121×10^{-3} m



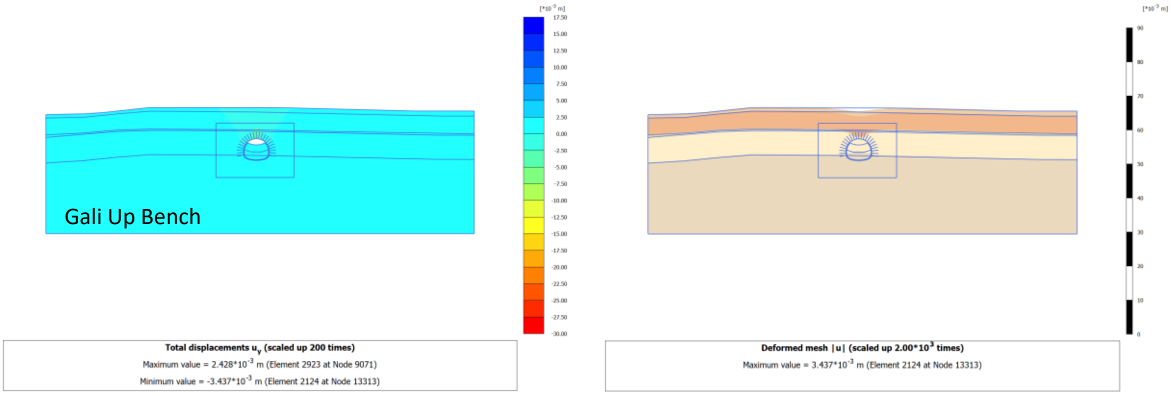
Maximum = 3.666×10^{-3} m
Minimum = -2.726×10^{-3} m



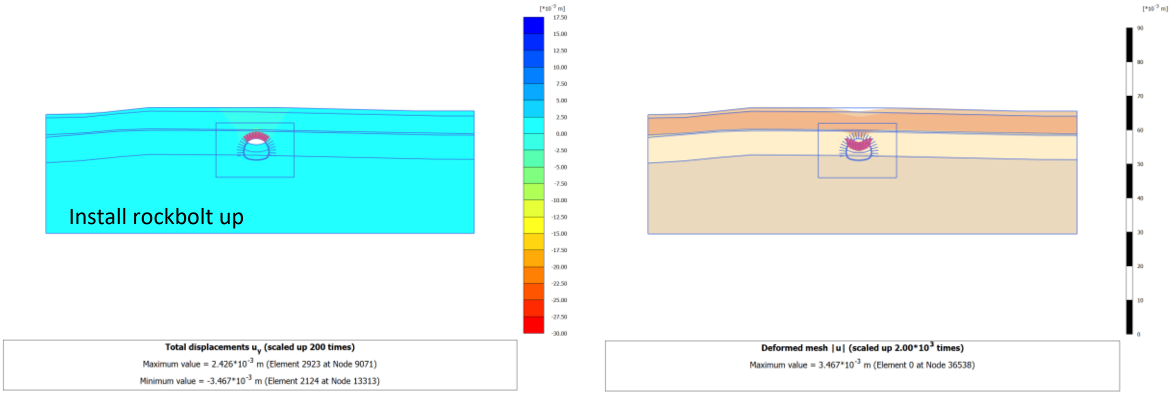
Maximum = 0.04186 m
Minimum = -0.03566 m

Gambar 27 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel Walini (DK 95+715)

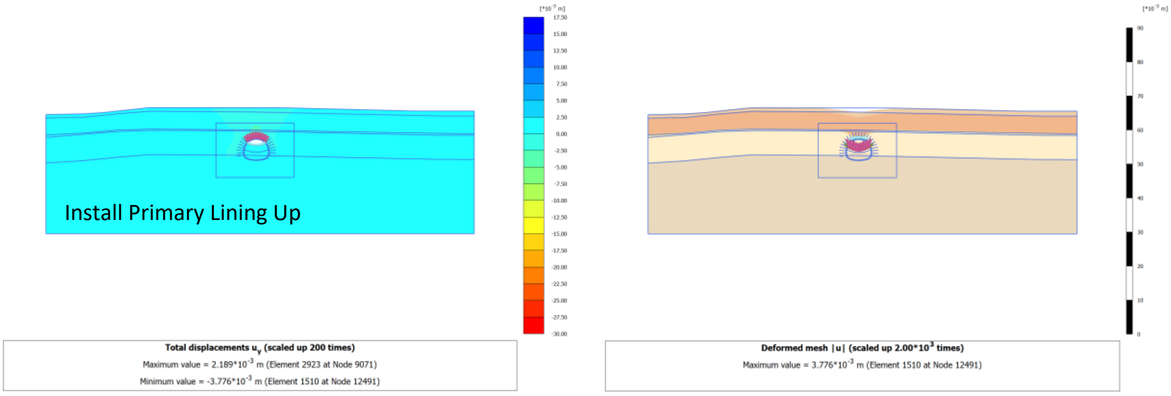
d) Cross Section DK 95 + 993



Maximum = 2.428x10^{-3} m
Minimum = -3.437x10^{-3} m

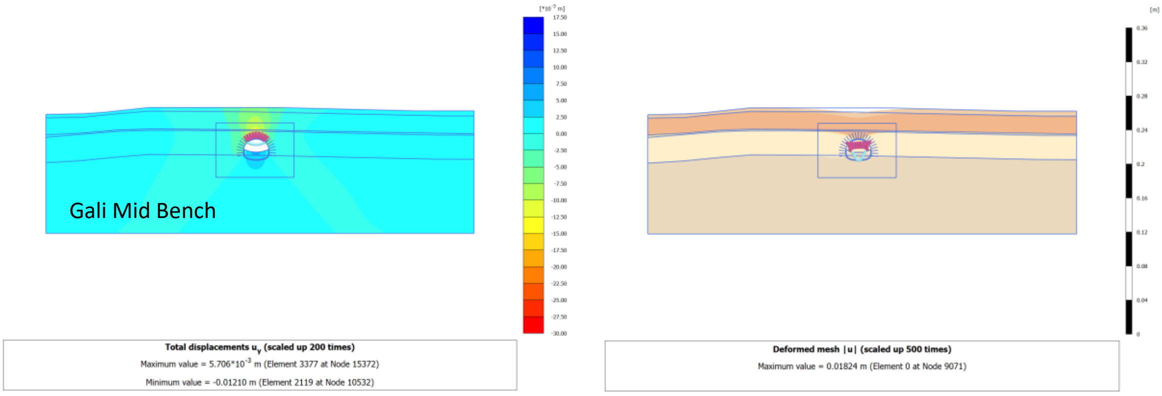


Maximum = 2.426x10^{-3} m
Minimum = -3.467x10^{-3} m

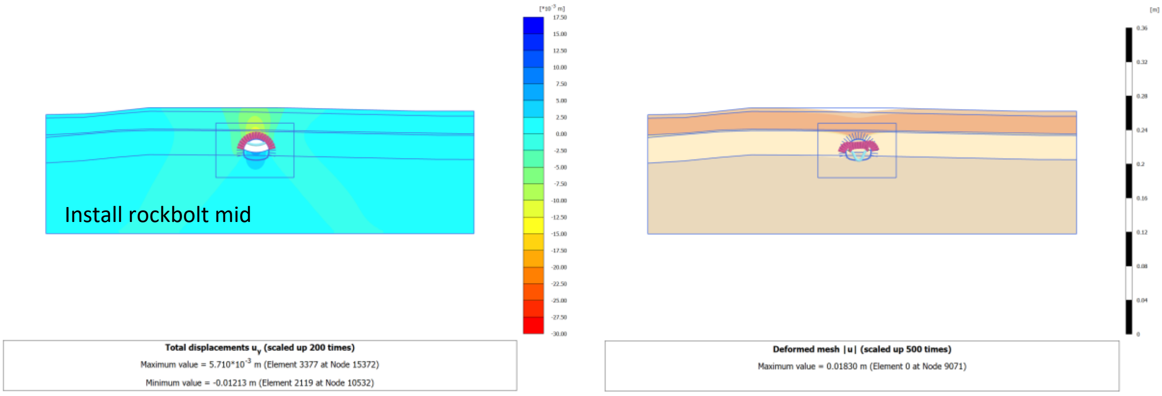


Maximum = 2.189x10^{-3} m
Minimum = -3.776x10^{-3} m

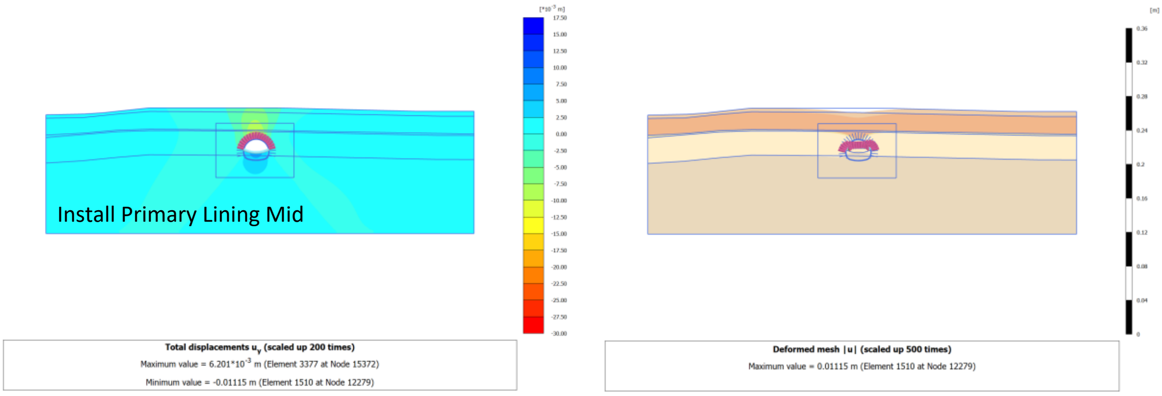
Gambar 28 Hasil analisis deformasi aksial global di Tunnel Walini (DK 95+993)



Maximum = 5.706x10^{-3} m
Minimum = -0.01210 m

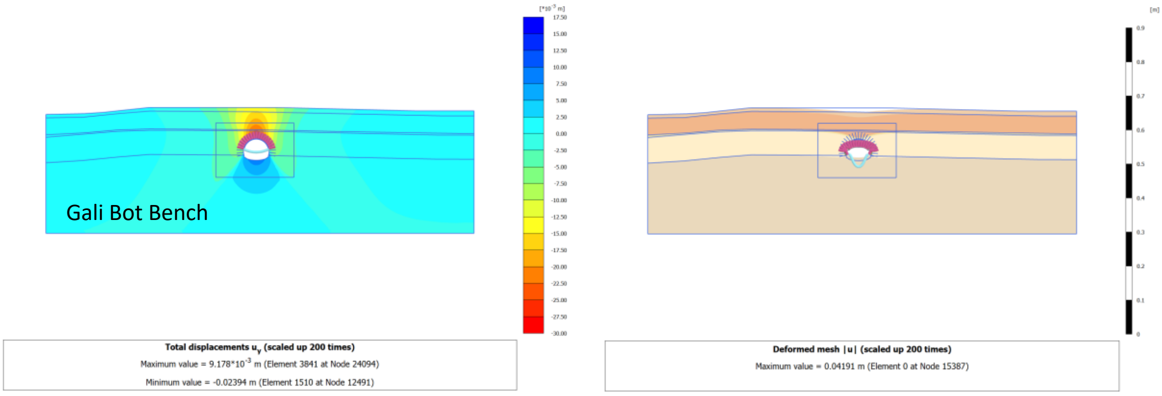


Maximum = 5.710x10^{-3} m
Minimum = -0.01213 m

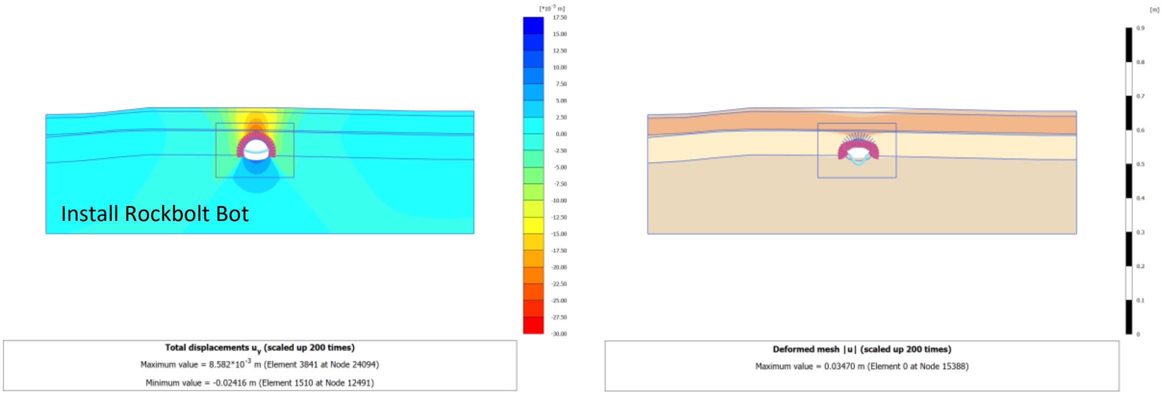


Maximum = 6.201x10^{-3} m
Minimum = -0.01115 m

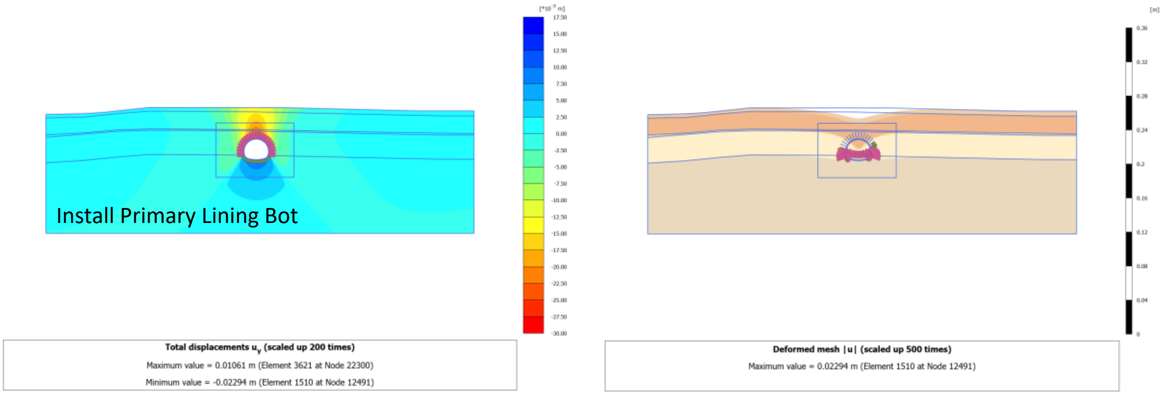
Gambar 29 Hasil analisis deformasi aksial global di Tunnel Walini (DK 95+993) (lanjutan)



Maximum = 9.718x10^{-3} m
Minimum = -0.02394 m

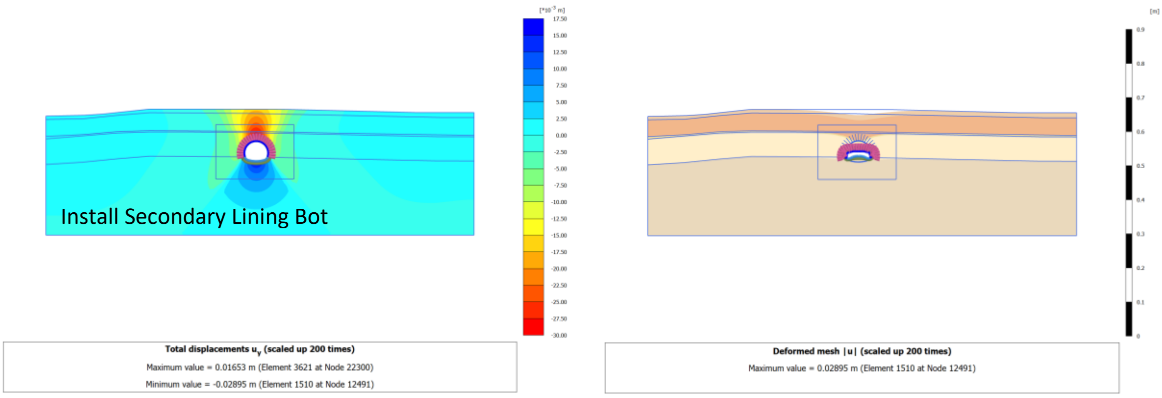


Maximum = 8.582x10^{-3} m
Minimum = -0.02416 m

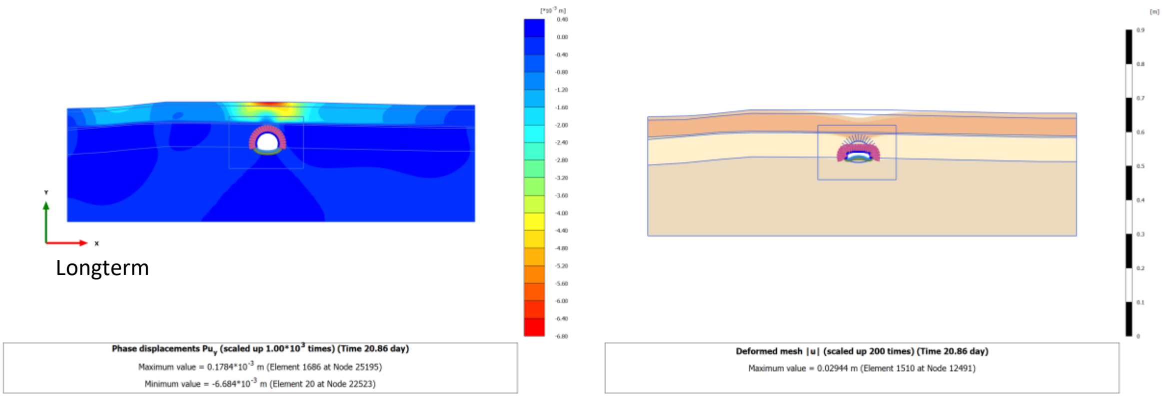


Maximum = 0.01061 m
Minimum = -0.02294 m

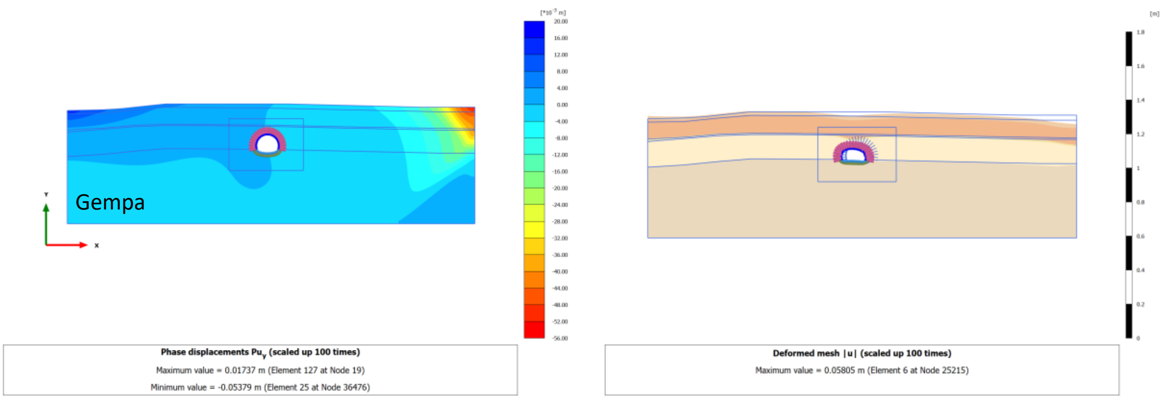
Gambar 30 Hasil analisis deformasi aksial global di Tunnel Walini (DK 95+993) (lanjutan)



Maximum = 0.01653 m
Minimum = -0.02895 m

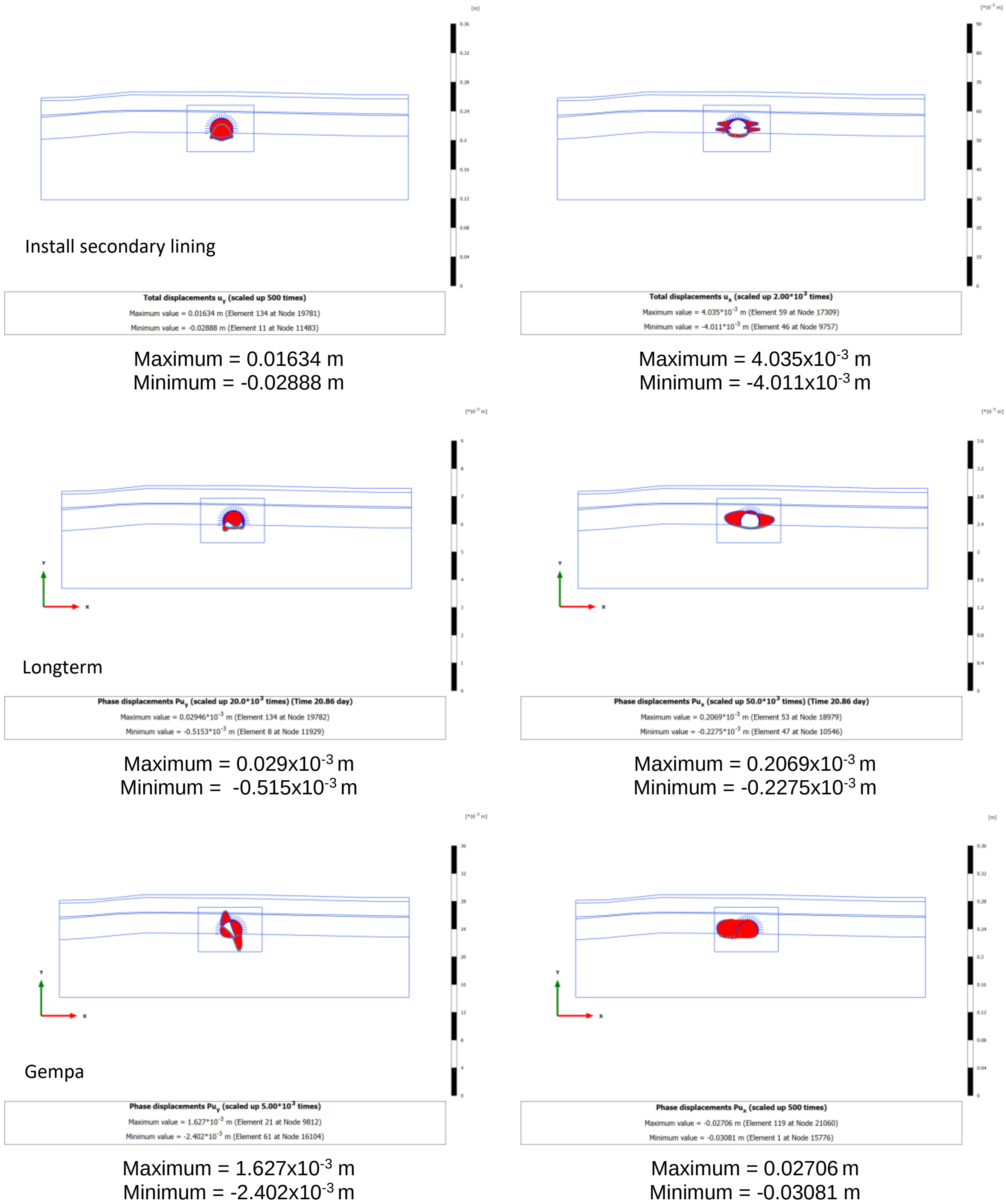


Maximum = 0.178×10^{-3} m
Minimum = -6.684×10^{-3} m



Maximum = 0.01737 m
Minimum = -0.05379 m

Gambar 31 Hasil analisis deformasi aksial global di Tunnel Walini (DK 95+993) (lanjutan)

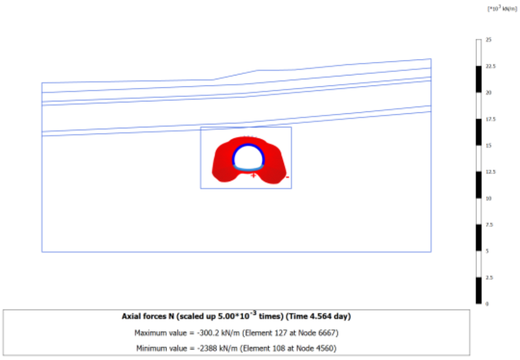


Gambar 32 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel Walini (DK 95+993)

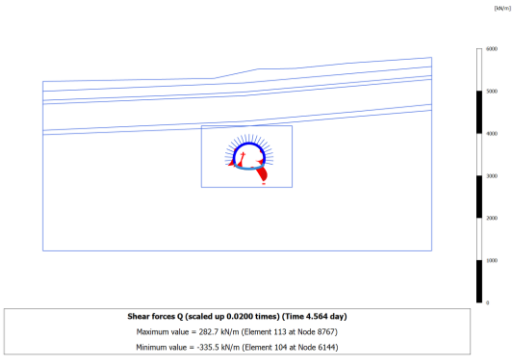
3. Gaya Dalam pada Lining Terowongan

Berdasarkan hasil analisis yang dilakukan dengan model numerik, gaya dalam yang bekerja pada lining terowongan dapat diperiksa. Gaya yang bekerja pada lining terowongan diantaranya gaya aksial, gaya geser dan momen lentur. Nilai gaya dalam yang dicantumkan merupakan nilai gaya dalam pada kondisi *longterm* dan kondisi setelah gempa. Gaya-gaya yang bekerja pada hasil analisis pemodelan dapat dilihat pada **Gambar 33** s/d **Gambar 40**.

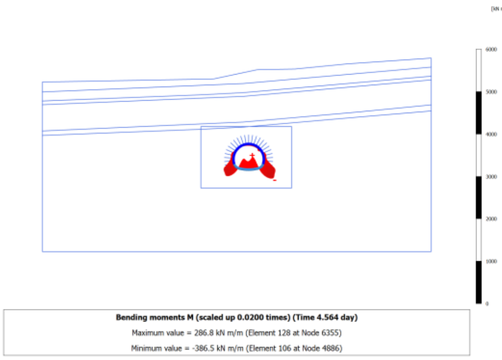
a) *Cross Section DK 95+602*



Maximum = -300.2 kN/m
Minimum = -2388 kN/m

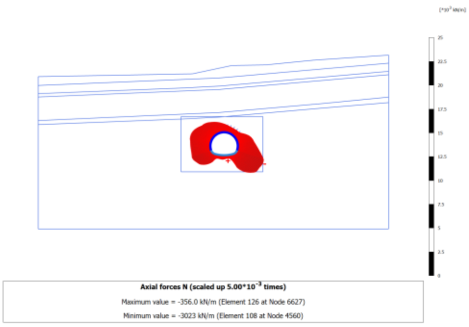


Maximum = 282.7 kN/m
Minimum = -335.5 kN/m

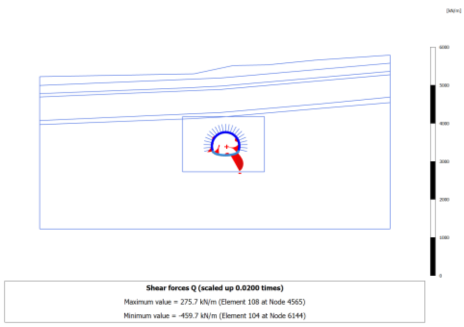


Maximum = 286.8 kN m/m
Minimum = -386.5 kN m/m

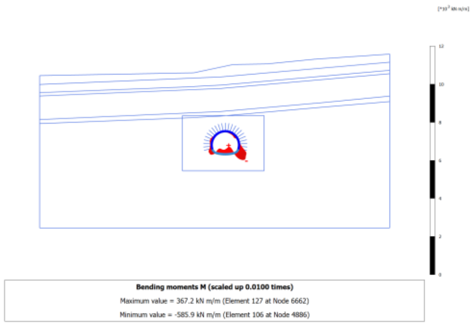
Gambar 33 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel Walini (DK 95+602)



Maximum = 356.0 kN/m
Minimum = -3023 kN/m



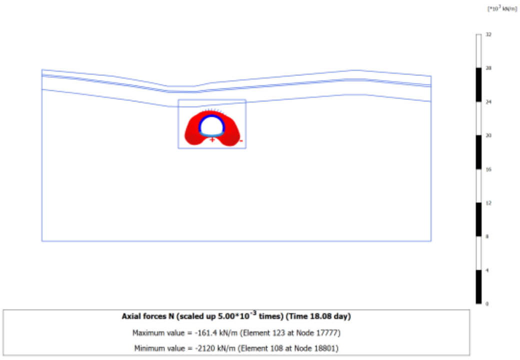
Maximum = 275.7 kN/m
Minimum = -459.7 kN/m



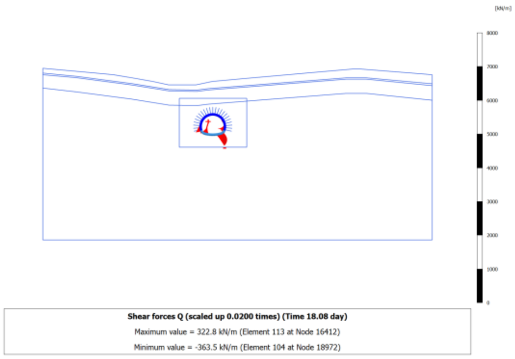
Maximum = 367.2 kN m/m
Minimum = -585.9 kN m/m

Gambar 34 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel Walini (DK 95+602)

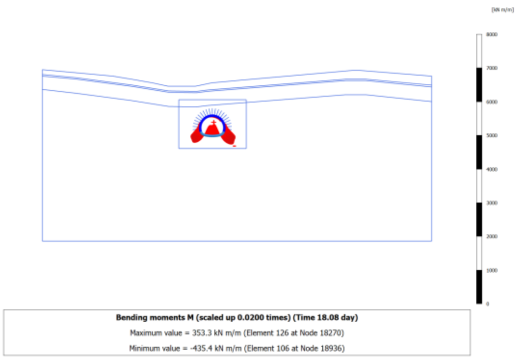
b) *Cross Section DK 95+696*



Maximum = -161.4 kN/m
Minimum = -2120 kN/m

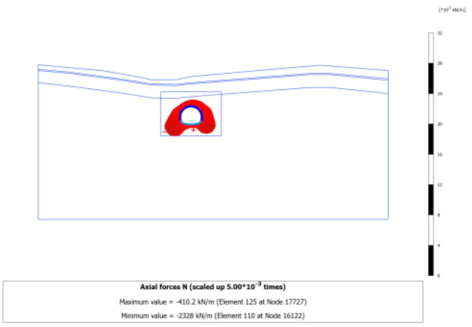


Maximum = 322.8 kN/m
Minimum = -363.5 kN/m

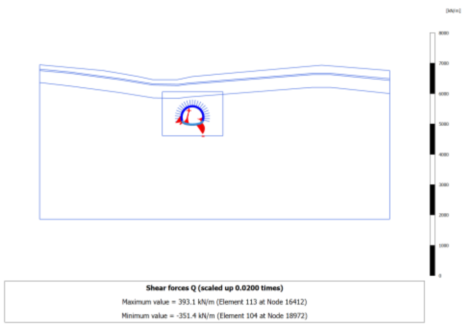


Maximum = 353.3 kN m/m
Minimum = -435.4 kN m/m

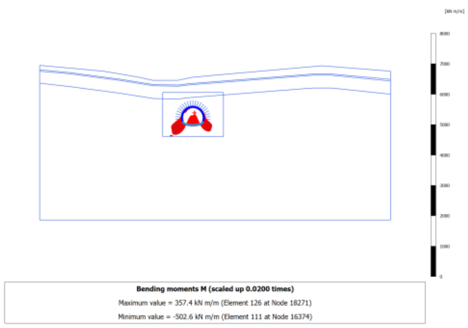
Gambar 35 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel Walini (DK 95+696)



Maximum = -410.2 kN/m
Minimum = -2328 kN/m



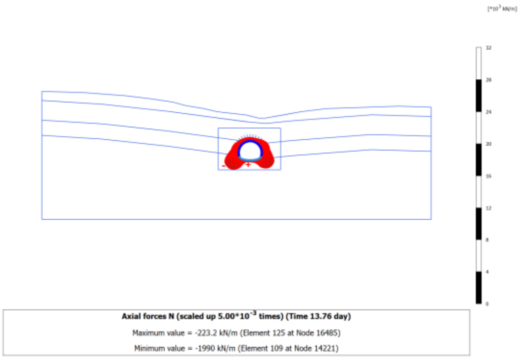
Maximum = 393.1 kN/m
Minimum = -351.4 kN/m



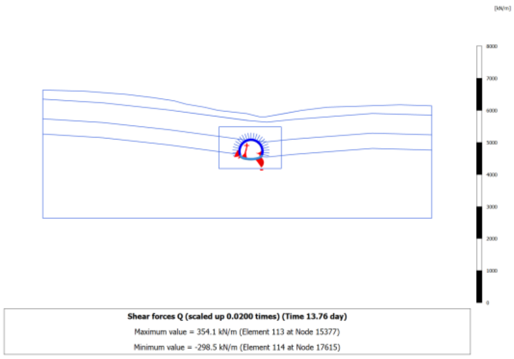
Maximum = 357.4 kN m/m
Minimum = -502.6 kN m/m

Gambar 36 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel Walini (DK 95+696)

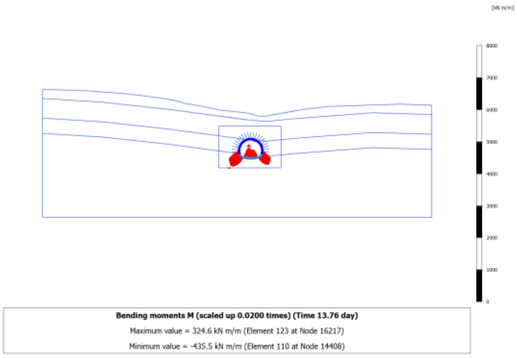
c) *Cross Section DK 95+715*



Maximum = -223.2 kN/m
Minimum = -1990 kN/m

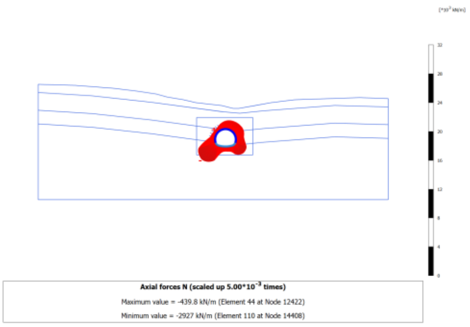


Maximum = 354.1 kN/m
Minimum = -298.5 kN/m

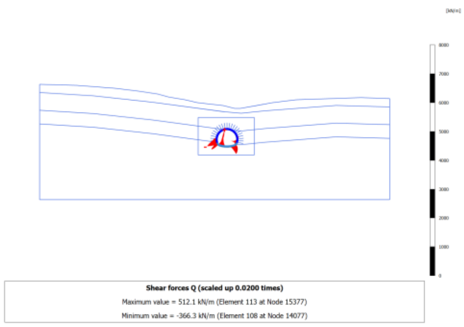


Maximum = 324.6 kN m/m
Minimum = -435.5 kN m/m

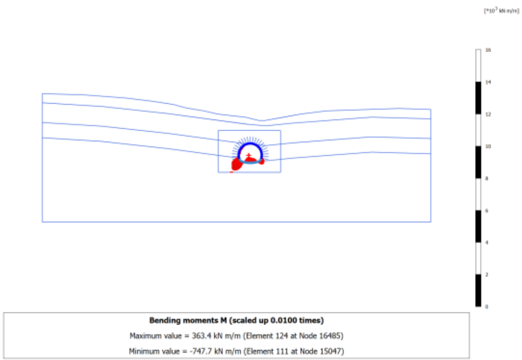
Gambar 37 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel Walini (DK 95+715)



Maximum = -439.8 kN/m
Minimum = -2927 kN/m



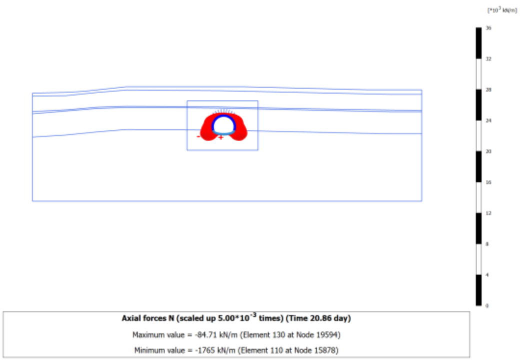
Maximum = 512.1 kN/m
Minimum = -366.3 kN/m



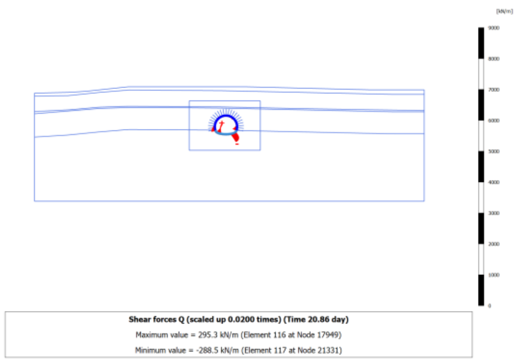
Maximum = 363.4 kN m/m
Minimum = -747.7 kN m/m

Gambar 38 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel Walini (DK 95+715)

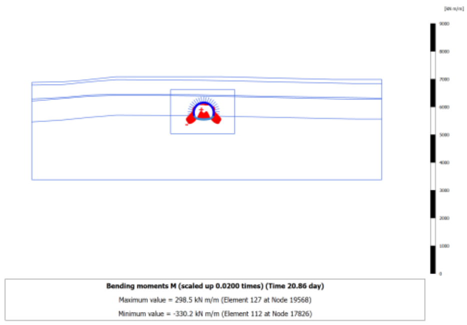
d) Cross Section DK 95+993



Maximum = -84.71 kN/m
Minimum = -1765 kN/m

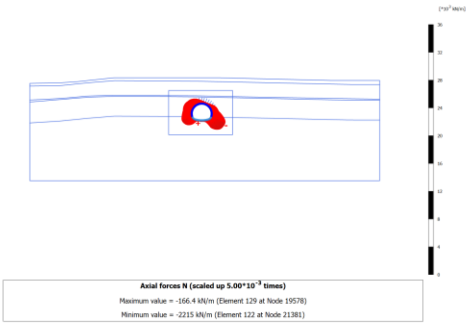


Maximum = 295.3 kN/m
Minimum = -288.5 kN/m

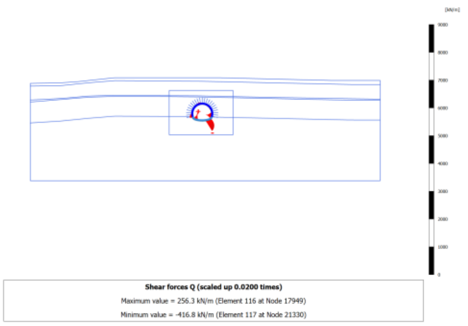


Maximum = 298.5 kN m/m
Minimum = -330.2 kN m/m

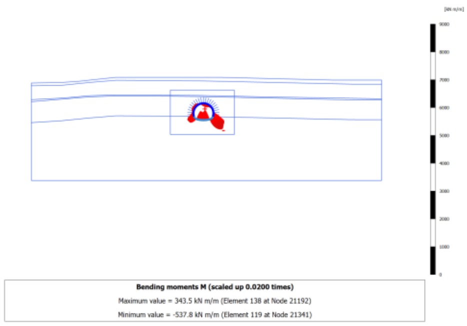
Gambar 39 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel Walini (DK 95+993)



Maximum = -166.4 kN/m
Minimum = -2215 kN/m



Maximum = 256.3 kN/m
Minimum = -416.8 kN/m



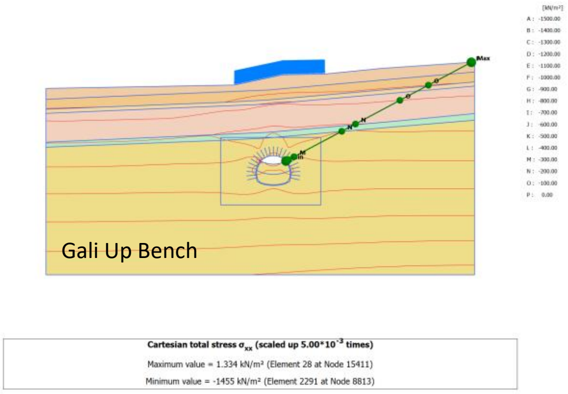
Maximum = 343.5 kN m/m
Minimum = -537.8 kN m/m

Gambar 40 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel Walini (DK 95+993)

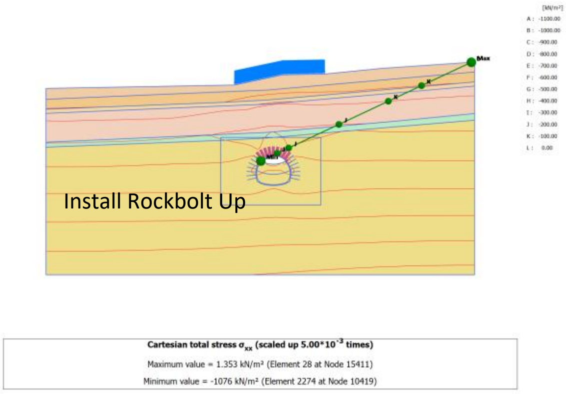
4. Tegangan Dalam Tanah

Berdasarkan hasil analisis yang dilakukan pada model numerik PLAXIS 2D, tegangan-tegangan dalam tanah yang dihasilkan dapat diperiksa. Tegangan dalam tanah berupa distribusi tegangan vertikal/σ_y, horizontal/σ_x, maksimum/σ_1, minimum/σ_3. Nilai tegangan dalam tanah yang dicantumkan merupakan besaran tegangan pada semua kondisi tahap galian. Tegangan-tegangan yang dihasilkan pada analisis pemodelan dapat dilihat pada **Gambar 41** s/d **Gambar 80**.

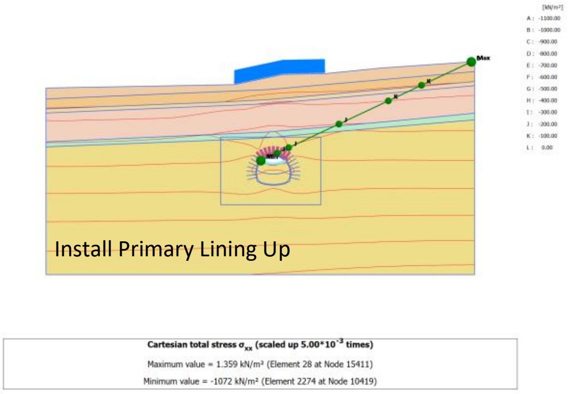
a) *Cross Section DK 95+602*



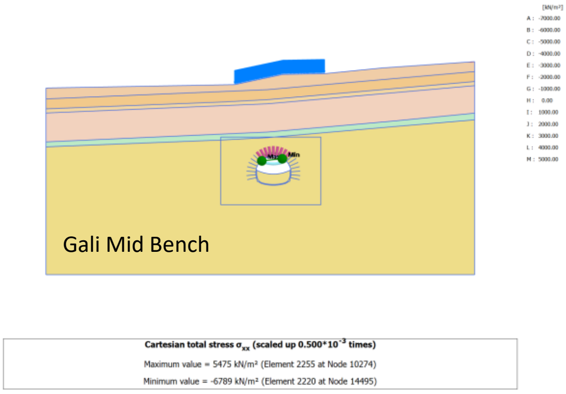
Maximum = 1.334 kN/m^2
Minimum = -1455 kN/m^2



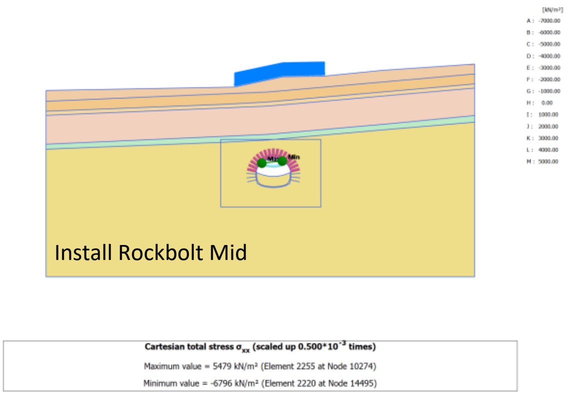
Maximum = 1.353 kN/m^2
Minimum = -1076 kN/m^2



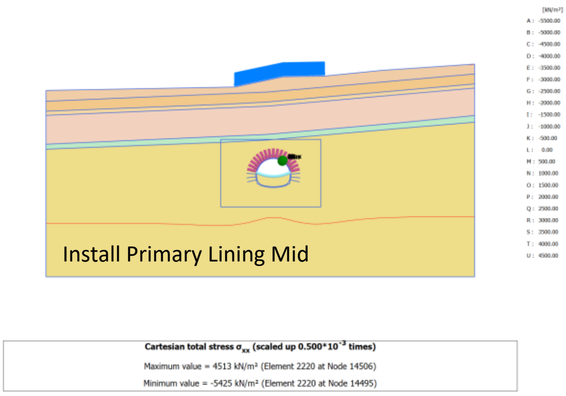
Maximum = 1.359 kN/m^2
Minimum = -1072 kN/m^2



Maximum = 5475 kN/m^2
Minimum = -6789 kN/m^2

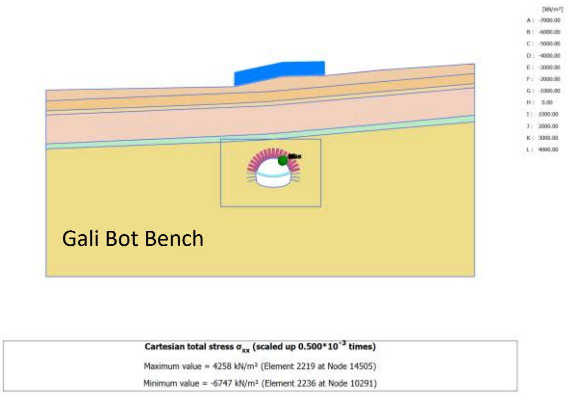


Maximum = 5479 kN/m^2
Minimum = -6796 kN/m^2

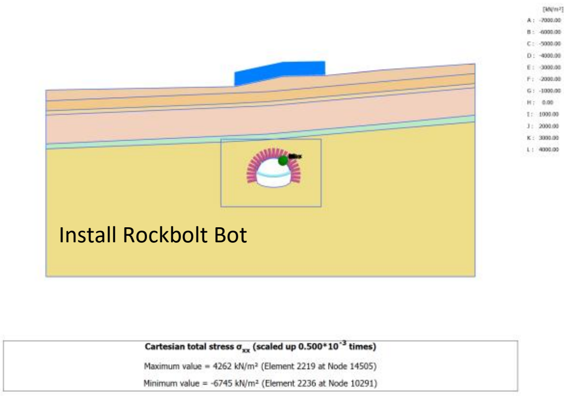


Maximum = 4513 kN/m^2
Minimum = -5425 kN/m^2

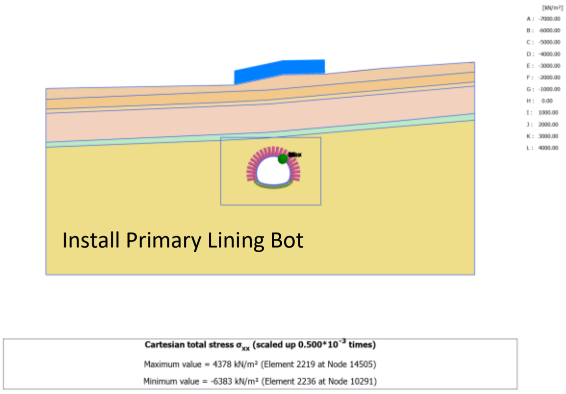
Gambar 41 Hasil analisis tegangan horizontal (σ_x) pada Tunnel Walini (DK 95+602)



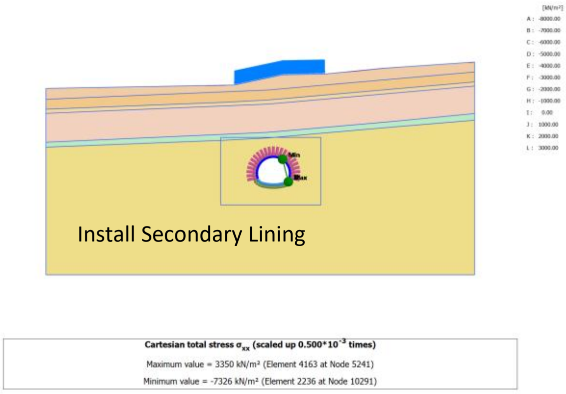
Maksimum = 4258 kN/m^2
Minimum = -6747 kN/m^2



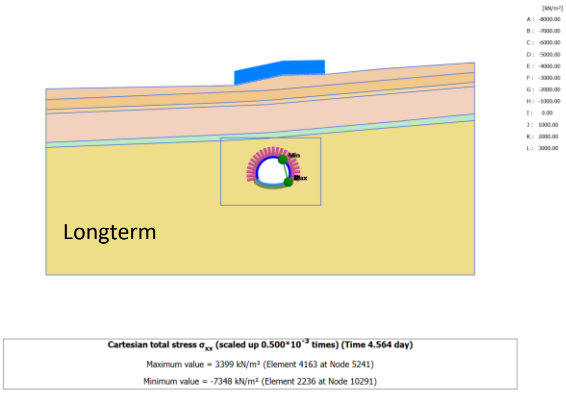
Maximum = 4262 kN/m^2
Minimum = -6745 kN/m^2



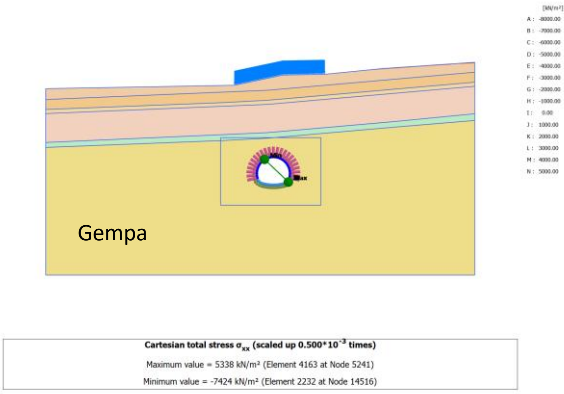
Maximum = 4378 kN/m^2
Minimum = -6383 kN/m^2



Maximum = 3350 kN/m^2
Minimum = -7326 kN/m^2

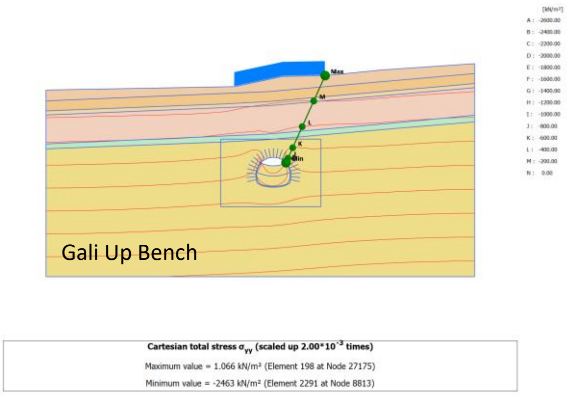


Maksimum = 3399 kN/m^2
Minimum = -7348 kN/m^2

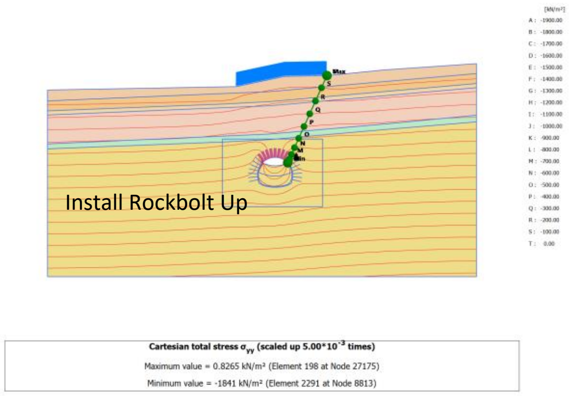


Maximum = 5338 kN/m^2
Minimum = -7424 kN/m^2

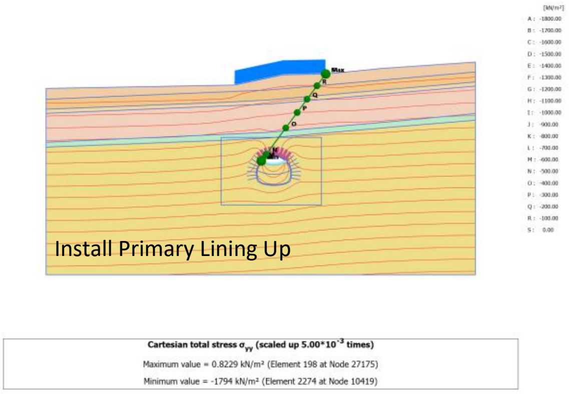
Gambar 42 Hasil analisis tegangan horizontal (σ_x) pada Tunnel Walini (DK 95+602) (lanjutan)



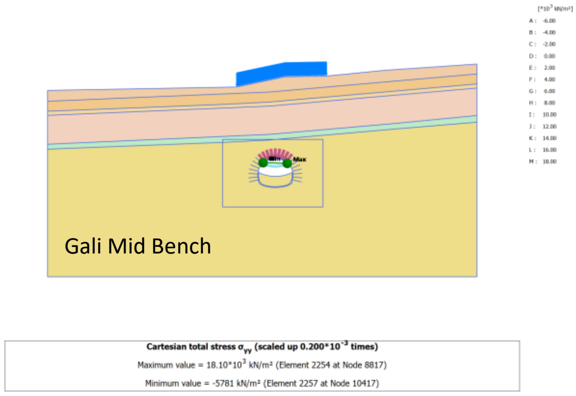
Maximum = 1.066 kN/m^2
Minimum = -2463 kN/m^2



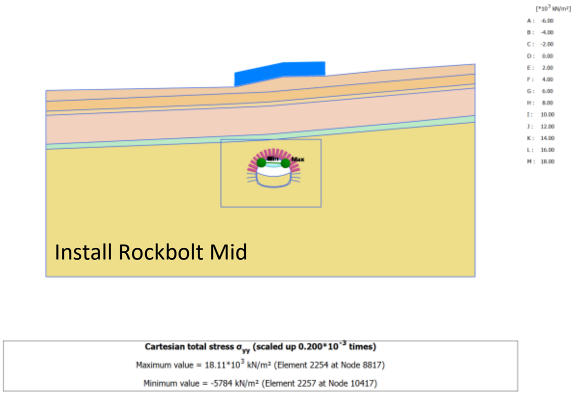
Maximum = 0.8265 kN/m^2
Minimum = -1841 kN/m^2



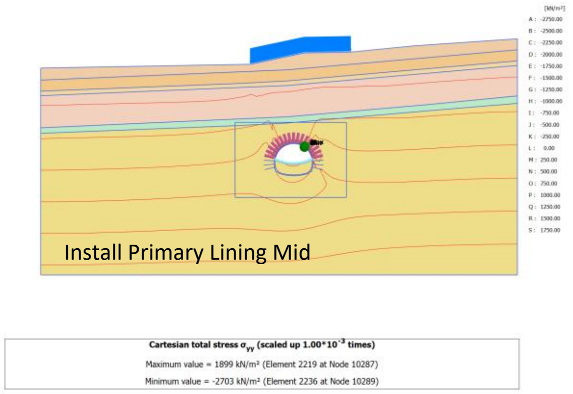
Maximum = 0.8229 kN/m^2
Minimum = -1794 kN/m^2



Maximum = 18.10x10^3 kN/m^2
Minimum = -5781 kN/m^2

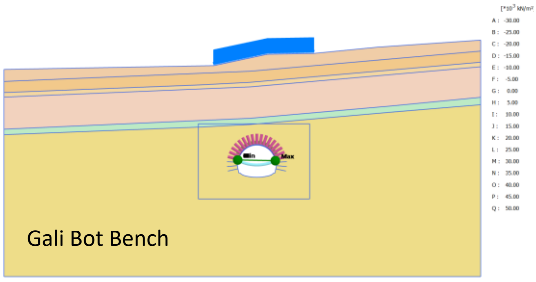


Maximum = 18.10x10^3 kN/m^2
Minimum = -5784 kN/m^2



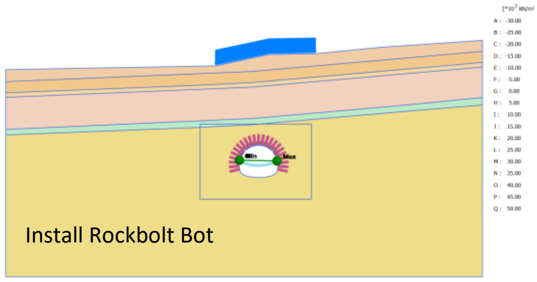
Maximum = 1899 kN/m^2
Minimum = -2703 kN/m^2

Gambar 43 Hasil analisis tegangan vertikal (σy) pada Tunnel Walini (DK 95+602)



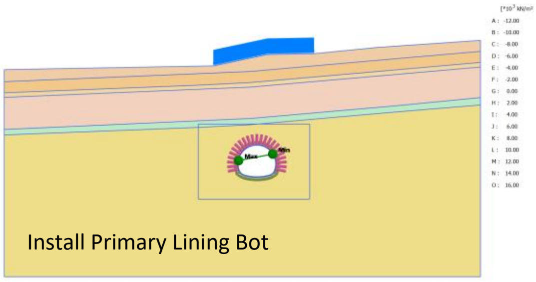
Cartesian total stress σ_{yy} (scaled up 0.0500*10^-3 times)
Maximum value = 54.70*10^3 kN/m² (Element 2290 at Node 4271)
Minimum value = -28.99*10^3 kN/m² (Element 2271 at Node 14598)

Maksimum = 54.70x10^3 kN/m^2
Minimum = -28.99x10^3 kN/m^2



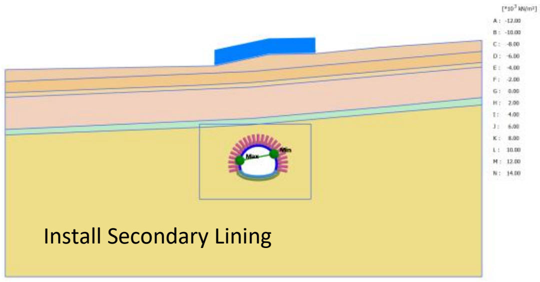
Cartesian total stress σ_{yy} (scaled up 0.0500*10^-3 times)
Maximum value = 54.76*10^3 kN/m² (Element 2290 at Node 4271)
Minimum value = -29.03*10^3 kN/m² (Element 2271 at Node 14598)

Maximum = 54.76x10^3 kN/m^2
Minimum = -29.03x10^3 kN/m^2



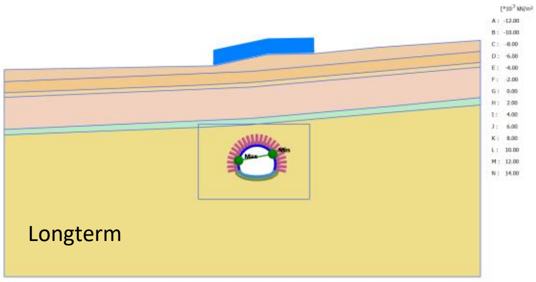
Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times)
Maximum value = 16.86*10^3 kN/m² (Element 2273 at Node 10320)
Minimum value = -10.07*10^3 kN/m² (Element 2280 at Node 6219)

Maximum = 16.86x10^3 kN/m^2
Minimum = -10.07x10^3 kN/m^2



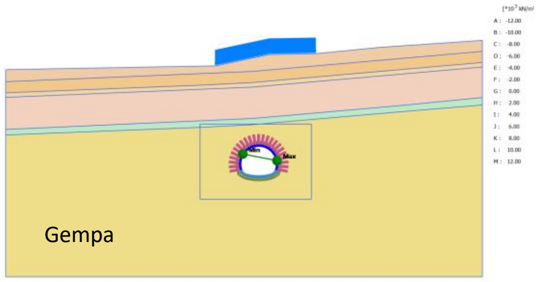
Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times)
Maximum value = 14.11*10^3 kN/m² (Element 2273 at Node 10320)
Minimum value = -11.55*10^3 kN/m² (Element 2280 at Node 6219)

Maximum = 14.11x10^3 kN/m^2
Minimum = -11.55x10^3 kN/m^2



Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times) (Time 4.564 day)
Maximum value = 14.05*10^3 kN/m² (Element 2273 at Node 10320)
Minimum value = -11.57*10^3 kN/m² (Element 2280 at Node 6219)

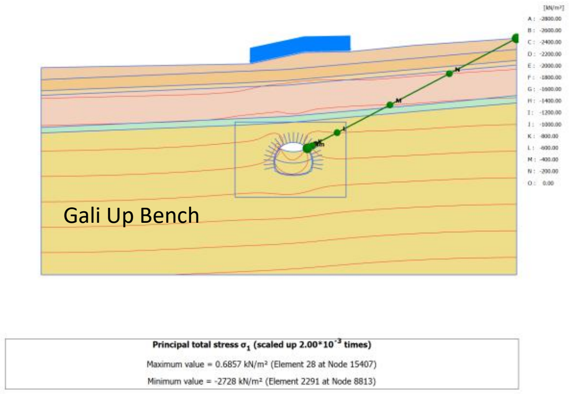
Maksimum = 14.05x10^3 kN/m^2
Minimum = -11.57x10^3 kN/m^2



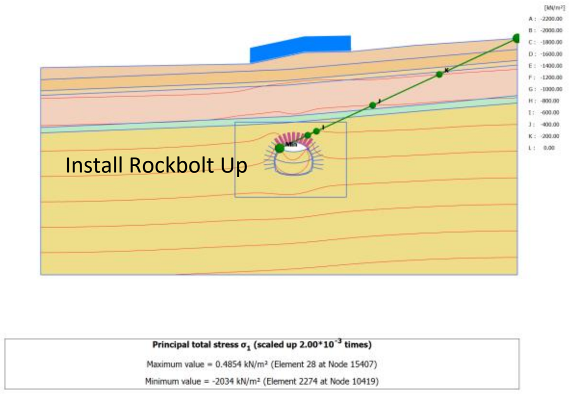
Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times)
Maximum value = 13.61*10^3 kN/m² (Element 2290 at Node 4265)
Minimum value = -11.50*10^3 kN/m² (Element 2266 at Node 9931)

Maximum = 13.61x10^3 kN/m^2
Minimum = -11.50x10^3 kN/m^2

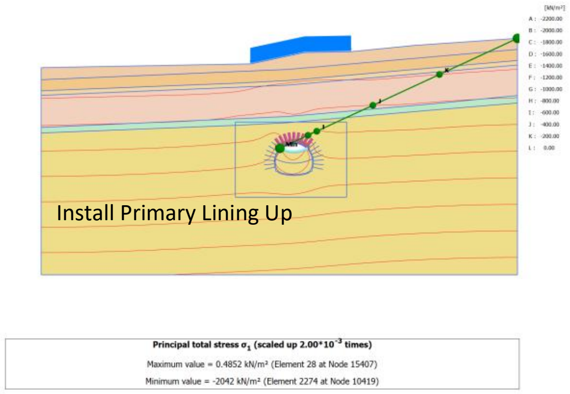
Gambar 44 Hasil analisis tegangan vertikal (σ_y) pada Tunnel Walini (DK 95+602) (lanjutan)



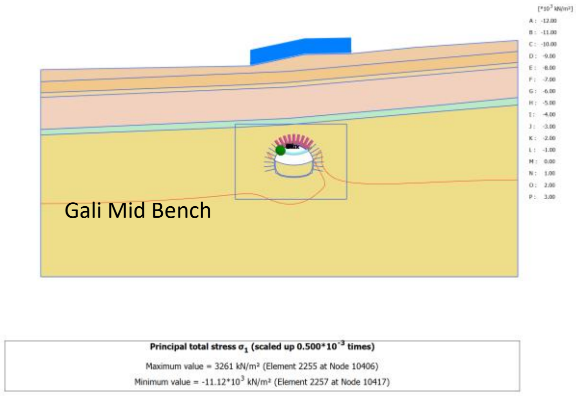
Maximum = 0.6857 kN/m^2
Minimum = -2728 kN/m^2



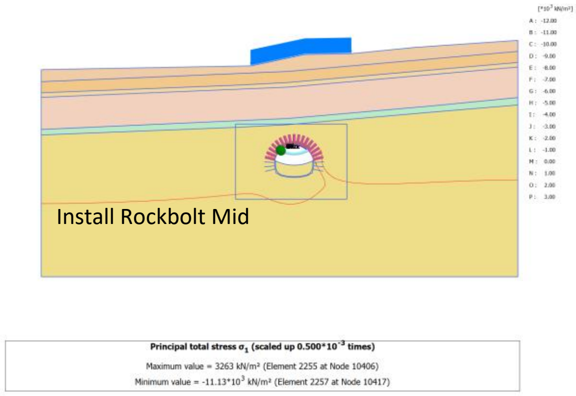
Maximum = 0.4854 kN/m^2
Minimum = -2034 kN/m^2



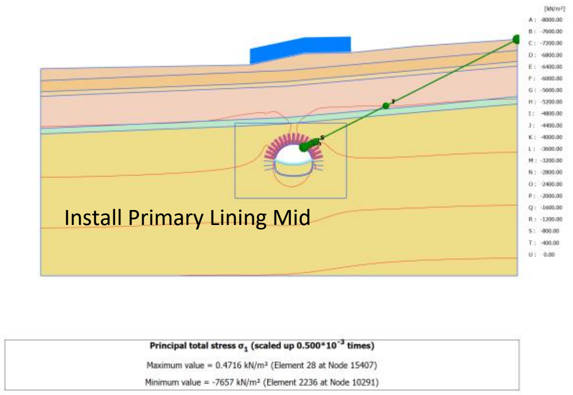
Maximum = 0.4852 kN/m^2
Minimum = -2042 kN/m^2



Maximum = 3261 kN/m^2
Minimum = -11.12x10^3 kN/m^2

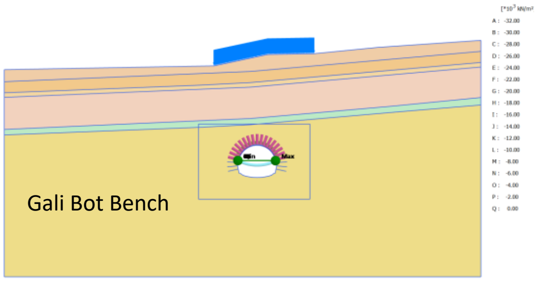


Maximum = 3263 kN/m^2
Minimum = -11.13x10^3 kN/m^2



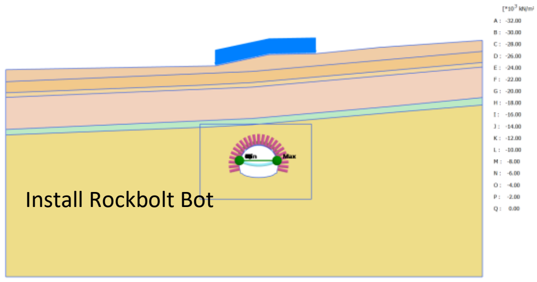
Maximum = 0.4716 kN/m^2
Minimum = -7657 kN/m^2

Gambar 45 Hasil analisis tegangan maksimum (σ1) pada Tunnel Walini (DK 95+602)



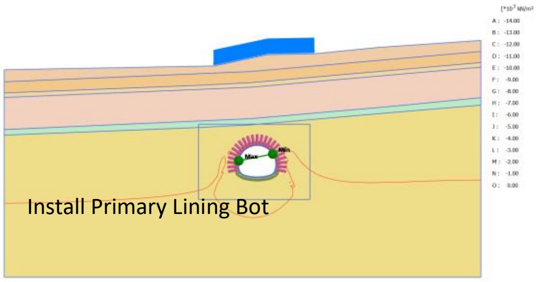
Principal total stress σ_1 (scaled up 0.200*10⁻³ times)
Maximum value = 1445 kN/m² (Element 2290 at Node 4265)
Minimum value = -31.51*10³ kN/m² (Element 2271 at Node 14595)

Maksimum = 1445 kN/m^2
Minimum = -31.51x10^3 kN/m^2



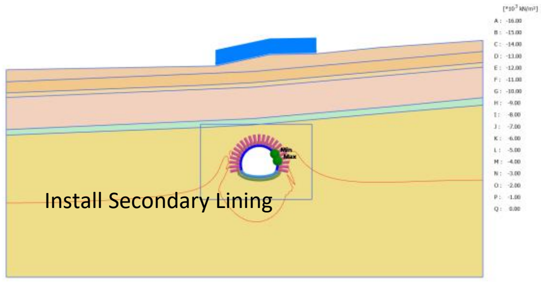
Principal total stress σ_1 (scaled up 0.200*10⁻³ times)
Maximum value = 1447 kN/m² (Element 2290 at Node 4265)
Minimum value = -31.55*10³ kN/m² (Element 2271 at Node 14595)

Maximum = 1447 kN/m^2
Minimum = -31.55x10^3 kN/m^2



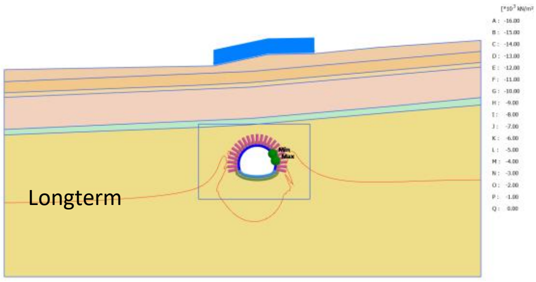
Principal total stress σ_1 (scaled up 0.500*10⁻³ times)
Maximum value = 708.5 kN/m² (Element 2273 at Node 10320)
Minimum value = -13.81*10³ kN/m² (Element 2276 at Node 6237)

Maximum = 708.5 kN/m^2
Minimum = -13.81x10^3 kN/m^2



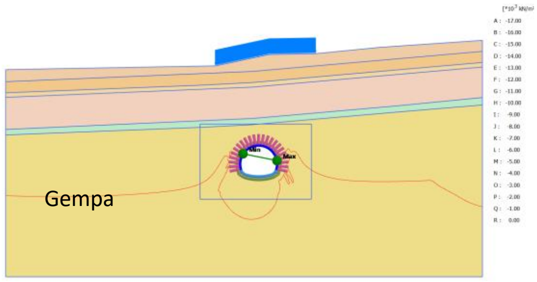
Principal total stress σ_1 (scaled up 0.500*10⁻³ times)
Maximum value = 583.9 kN/m² (Element 2290 at Node 4265)
Minimum value = -15.77*10³ kN/m² (Element 2276 at Node 6237)

Maximum = 583.9 kN/m^2
Minimum = -15.77x10^3 kN/m^2



Principal total stress σ_1 (scaled up 0.500*10⁻³ times) (Time 4.564 day)
Maximum value = 579.6 kN/m² (Element 2290 at Node 4265)
Minimum value = -15.80*10³ kN/m² (Element 2276 at Node 6237)

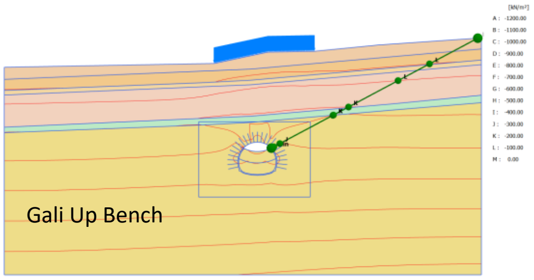
Maksimum = 579.6 kN/m^2
Minimum = -15.80x10^3 kN/m^2



Principal total stress σ_1 (scaled up 0.500*10⁻³ times)
Maximum value = 623.9 kN/m² (Element 2290 at Node 4265)
Minimum value = -16.02*10³ kN/m² (Element 2258 at Node 9937)

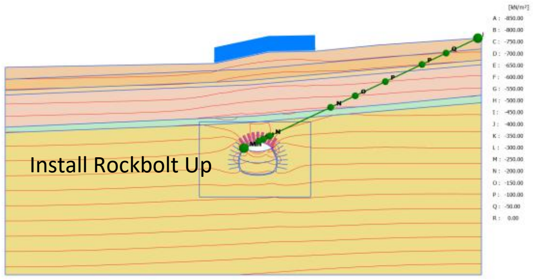
Maximum = 623.9 kN/m^2
Minimum = -16.02x10^3 kN/m^2

Gambar 46 Hasil analisis tegangan maksimum (σ1) pada Tunnel Walini (DK 95+602) (lanjutan)



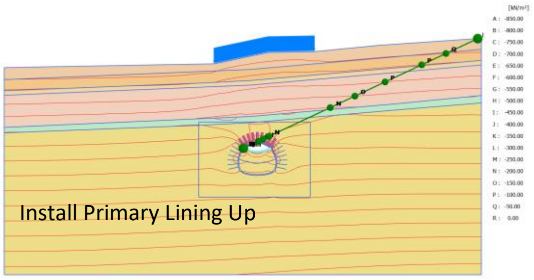
Principal total stress σ_3 (scaled up $5.00*10^{-3}$ times)
Maximum value = 1.339 kN/m² (Element 28 at Node 15411)
Minimum value = -1189 kN/m² (Element 2291 at Node 8813)

Maximum = 1.339 kN/m^2
Minimum = -1189 kN/m^2



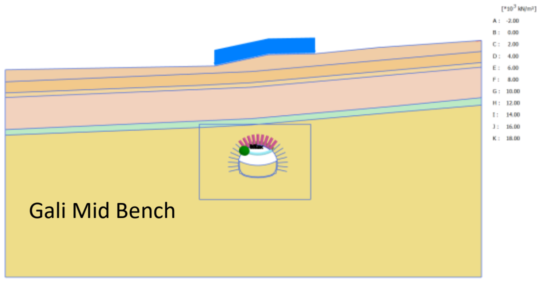
Principal total stress σ_3 (scaled up $5.00*10^{-3}$ times)
Maximum value = 1.366 kN/m² (Element 28 at Node 15411)
Minimum value = -822.9 kN/m² (Element 2274 at Node 10419)

Maximum = 1.366 kN/m^2
Minimum = -822.9kN/m^2



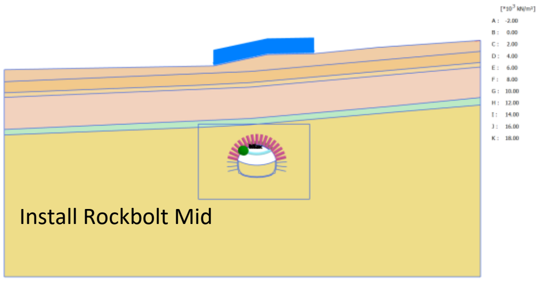
Principal total stress σ_3 (scaled up $5.00*10^{-3}$ times)
Maximum value = 1.372 kN/m² (Element 28 at Node 15411)
Minimum value = -823.8 kN/m² (Element 2274 at Node 10419)

Maximum = 1.372 kN/m^2
Minimum = -823.8 kN/m^2



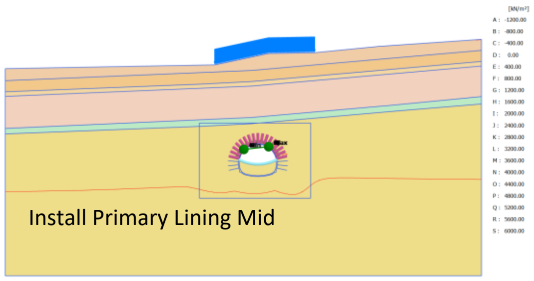
Principal total stress σ_3 (scaled up $0.200*10^{-3}$ times)
Maximum value = $19.05*10^3$ kN/m² (Element 2255 at Node 10406)
Minimum value = -1118 kN/m² (Element 3744 at Node 15034)

Maximum = 19.05x10^3 kN/m^2
Minimum = -1118 kN/m^2



Principal total stress σ_3 (scaled up $0.200*10^{-3}$ times)
Maximum value = $19.06*10^3$ kN/m² (Element 2255 at Node 10406)
Minimum value = -1119 kN/m² (Element 3744 at Node 15034)

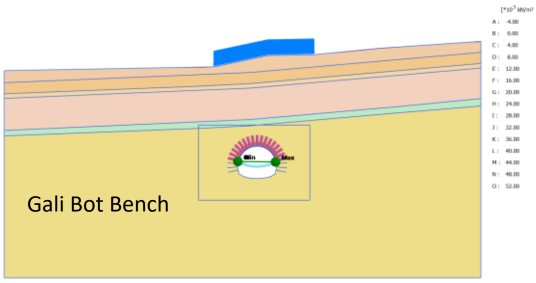
Maximum = 19.06x10^3 kN/m^2
Minimum = -1119 kN/m^2



Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times)
Maximum value = 6383 kN/m² (Element 2219 at Node 14505)
Minimum value = -923.6 kN/m² (Element 3744 at Node 15034)

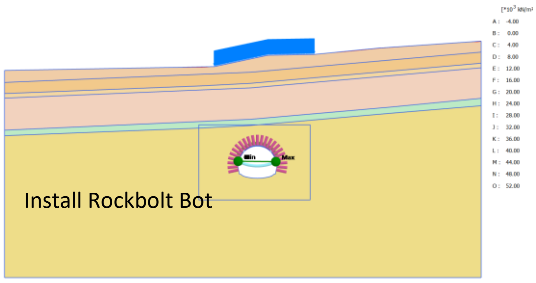
Maximum = 6383 kN/m^2
Minimum = -923.6 kN/m^2

Gambar 47 Hasil analisis tegangan minimum (σ3) pada Tunnel Walini (DK 95+602)



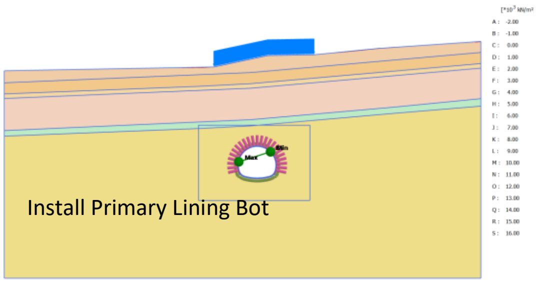
Principal total stress σ_3 (scaled up $0.100*10^{-3}$ times)
Maximum value = $54.71*10^3$ kN/m² (Element 2290 at Node 4271)
Minimum value = -3590 kN/m² (Element 2271 at Node 14595)

Maksimum = $54.71x10^3$ kN/m^2
Minimum = -3590 kN/m^2



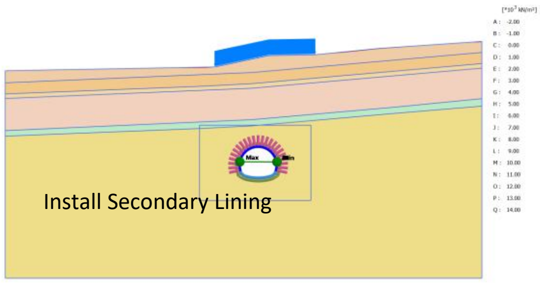
Principal total stress σ_3 (scaled up $0.100*10^{-3}$ times)
Maximum value = $54.78*10^3$ kN/m² (Element 2290 at Node 4271)
Minimum value = -3595 kN/m² (Element 2271 at Node 14595)

Maximum = $54.78x10^3$ kN/m^2
Minimum = -3595 kN/m^2



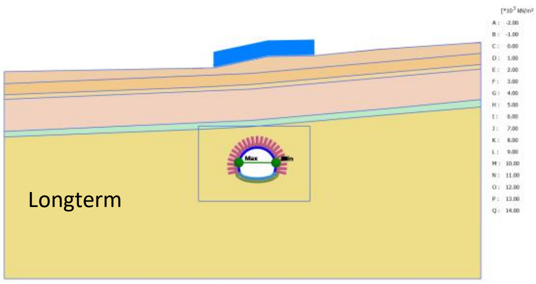
Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times)
Maximum value = $16.88*10^3$ kN/m² (Element 2273 at Node 10320)
Minimum value = -1274 kN/m² (Element 2256 at Node 8809)

Maximum = $16.88x10^3$ kN/m^2
Minimum = -1274 kN/m^2



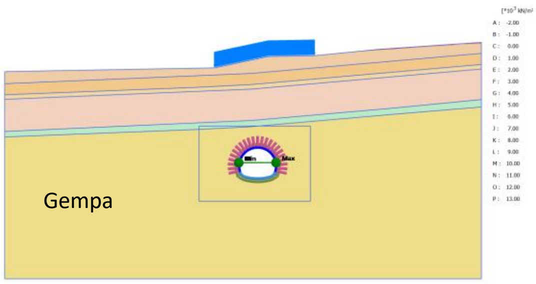
Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times)
Maximum value = $14.11*10^3$ kN/m² (Element 2273 at Node 10320)
Minimum value = -1635 kN/m² (Element 2290 at Node 4273)

Maximum = $14.11x10^3$ kN/m^2
Minimum = -1635 kN/m^2



Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times) (Time 4.564 day)
Maximum value = $14.05*10^3$ kN/m² (Element 2273 at Node 10320)
Minimum value = -1637 kN/m² (Element 2290 at Node 4273)

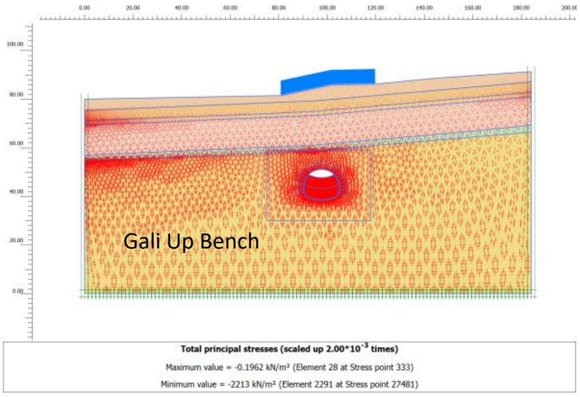
Maksimum = $14.05x10^3$ kN/m^2
Minimum = -1637 kN/m^2



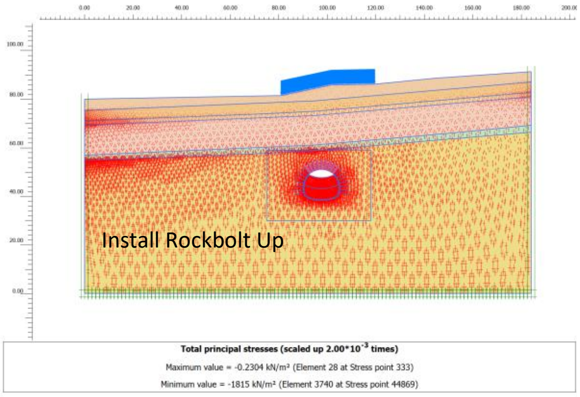
Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times)
Maximum value = $13.61*10^3$ kN/m² (Element 2290 at Node 4265)
Minimum value = -1709 kN/m² (Element 2273 at Node 10336)

Maximum = $13.61x10^3$ kN/m^2
Minimum = -1709 kN/m^2

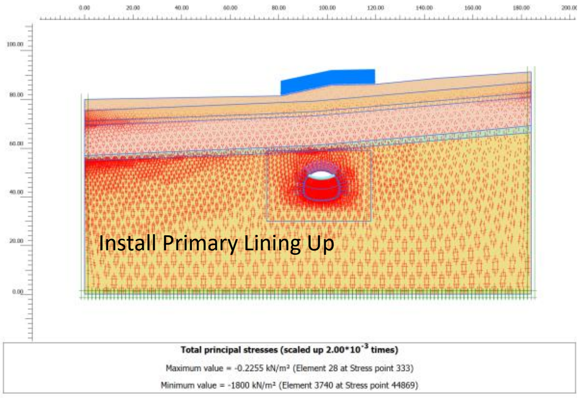
Gambar 48 Hasil analisis tegangan minimum (σ_3) pada Tunnel Walini (DK 95+602) (lanjutan)



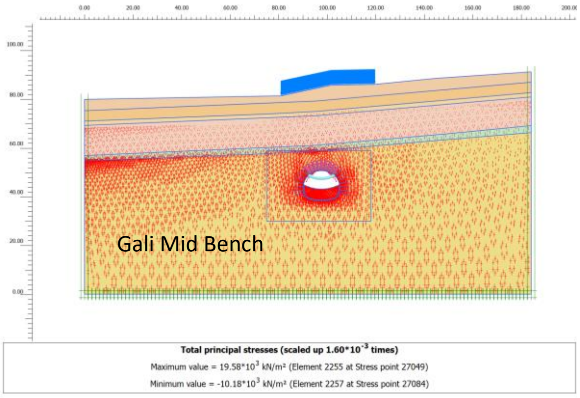
Maximum = -0.1962 kN/m^2
Minimum = -2213 kN/m^2



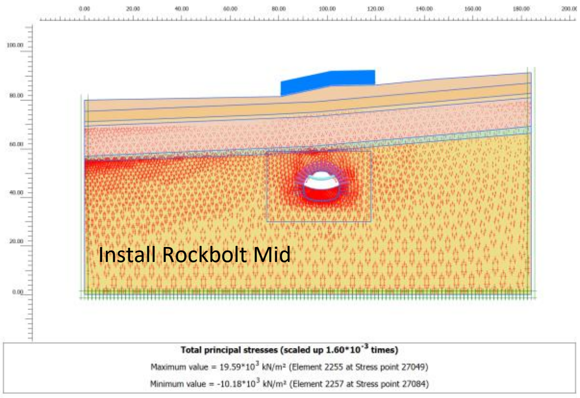
Maximum = -0.2304 kN/m^2
Minimum = -1815 kN/m^2



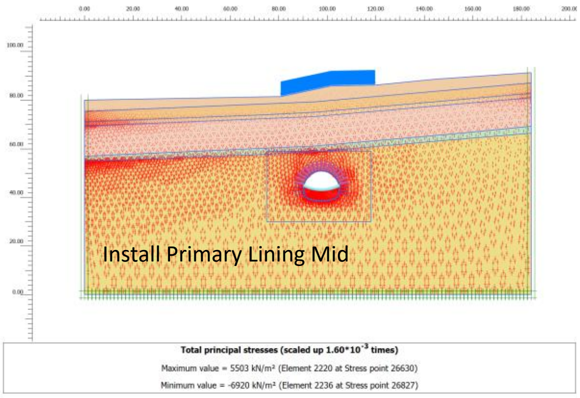
Maximum = -0.2255 kN/m^2
Minimum = -1800 kN/m^2



Maximum = 19.58x10^3 kN/m^2
Minimum = -10.18x10^3 kN/m^2

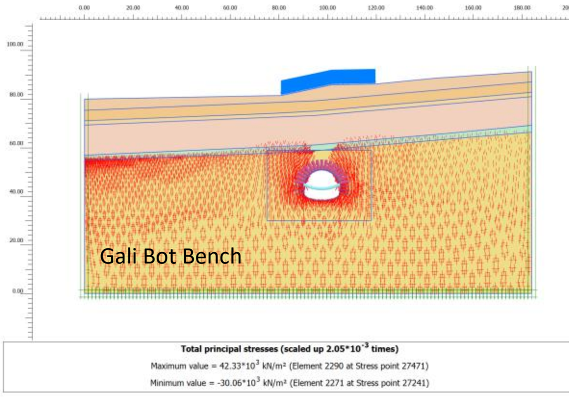


Maximum = 19.59x10^3 kN/m^2
Minimum = -10.18x10^3 kN/m^2

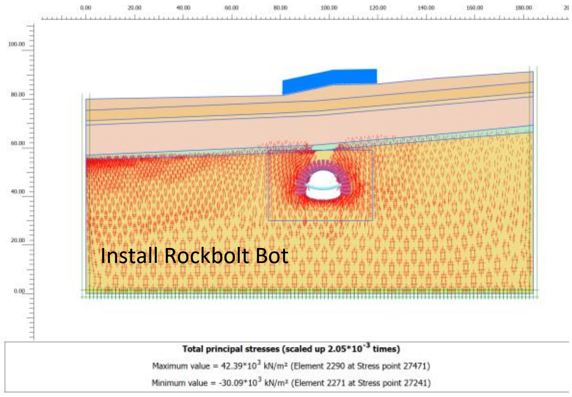


Maximum = 5503 kN/m^2
Minimum = -6920 kN/m^2

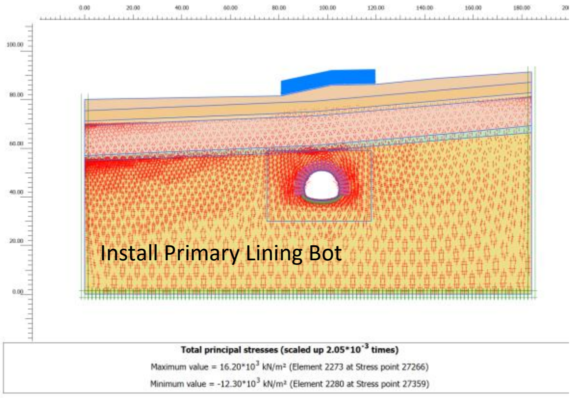
Gambar 49 Hasil analisis Total Principal Stresses pada Tunnel Walini (DK 95+602)



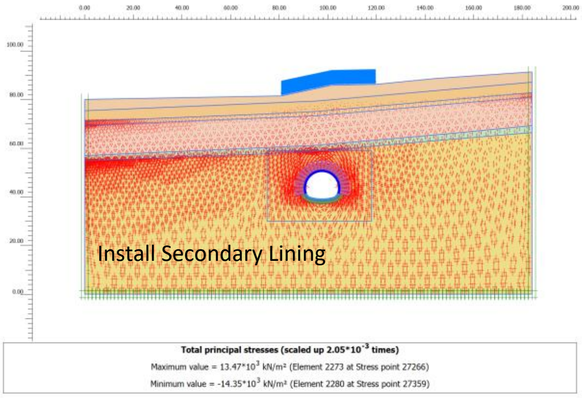
Maksimum = 42.33x10^3 kN/m^2
Minimum = -30.06 x10^3 kN/m^2



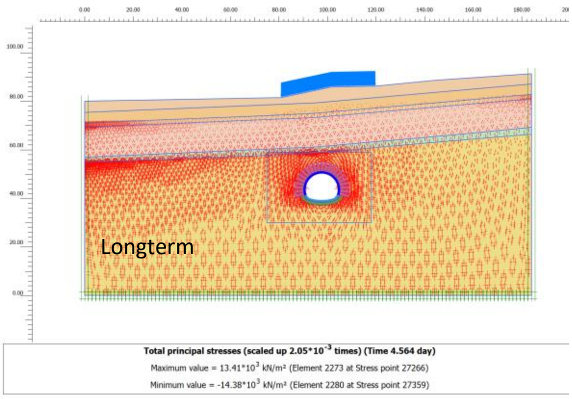
Maximum = 42.39 x10^3 kN/m^2
Minimum = -30.09 x10^3 kN/m^2



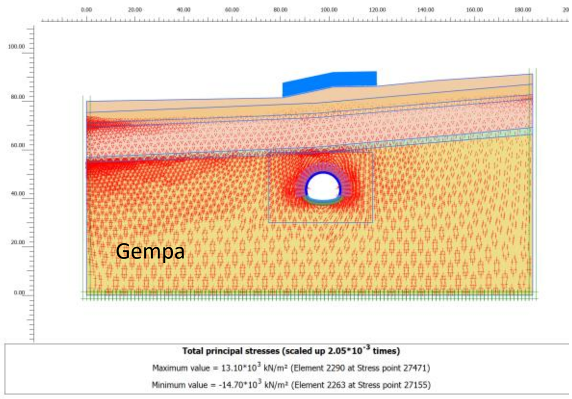
Maximum = 16.20 x10^3 kN/m^2
Minimum = -12.30 x10^3 kN/m^2



Maximum = 13.47 x10^3 kN/m^2
Minimum = -14.35 x10^3 kN/m^2



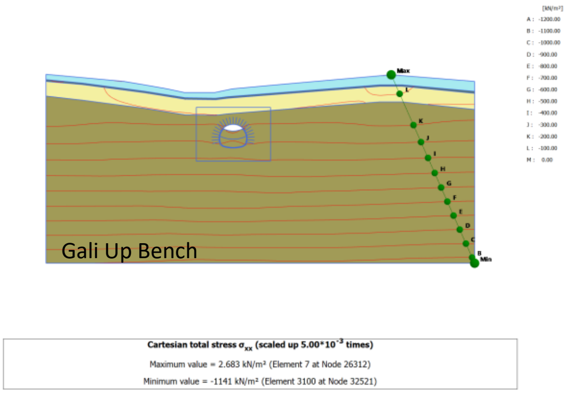
Maksimum = 13.41 x10^3 kN/m^2
Minimum = -14.38 x10^3 kN/m^2



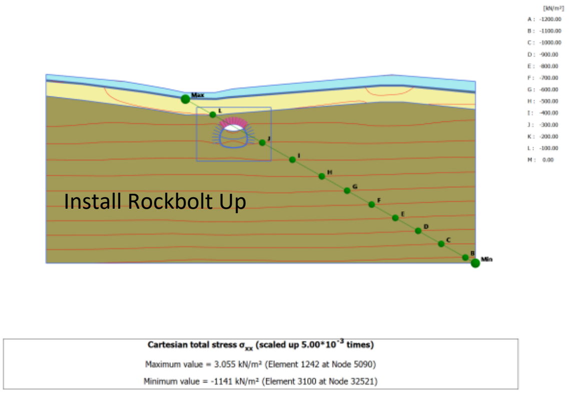
Maximum = 13.10 x10^3 kN/m^2
Minimum = -14.70 x10^3 kN/m^2

Gambar 50 Hasil analisis Total Principal Stresses pada Tunnel Walini (DK 95+602) (lanjutan)

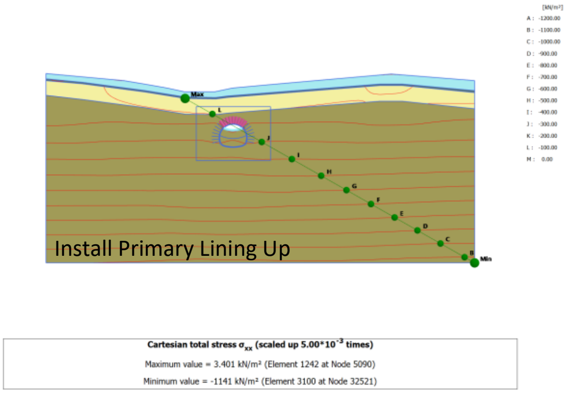
b) *Cross Section DK 95+696*



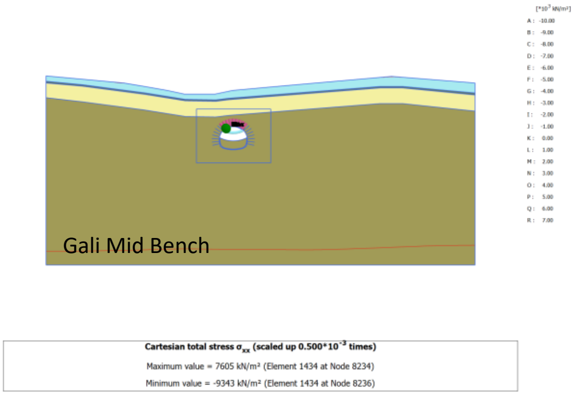
Maximum = 2.683 kN/m^2
Minimum = -1141 kN/m^2



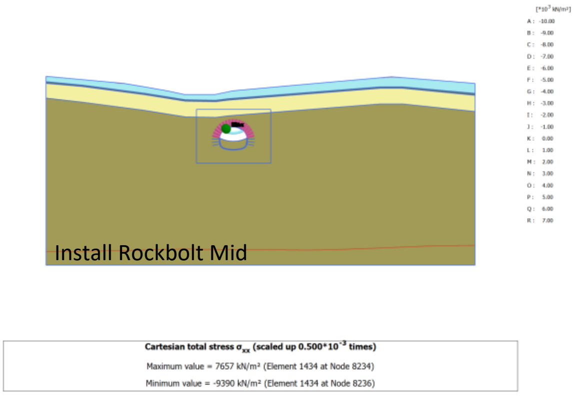
Maximum = 3.055 kN/m^2
Minimum = -1141 kN/m^2



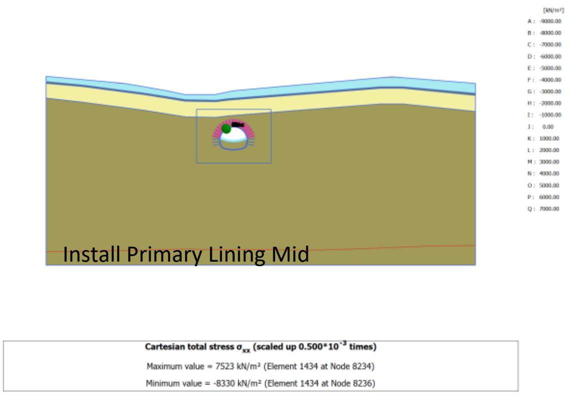
Maximum = 3.401 kN/m^2
Minimum = -1141 kN/m^2



Maximum = 7605 kN/m^2
Minimum = -9343 kN/m^2

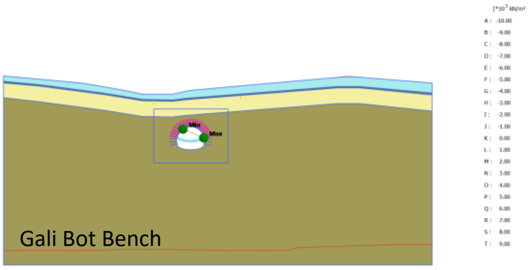


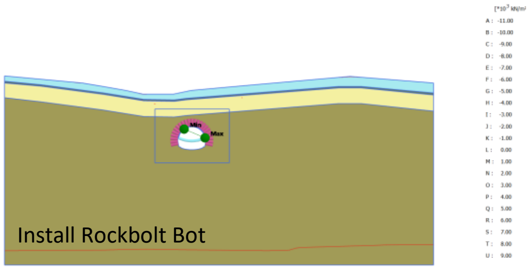
Maximum = 7657 kN/m^2
Minimum = -9390 kN/m^2



Maximum = 7523 kN/m^2
Minimum = -8330 kN/m^2

Gambar 51 Hasil analisis tegangan horizontal (σx) pada Tunnel Walini (DK 95+696)



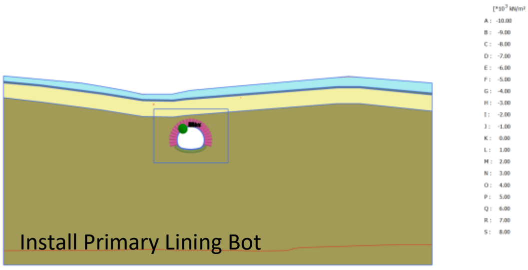


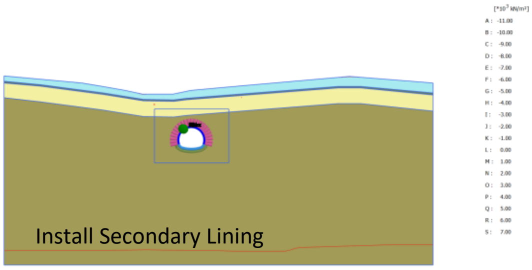
Cartesian total stress σ_{xx} (scaled up $0.500*10^{-3}$ times)
Maximum value = 9739 kN/m² (Element 1492 at Node 17305)
Minimum value = -9959 kN/m² (Element 1438 at Node 5677)

Maksimum = 9739 kN/m^2
Minimum = -9959 kN/m^2

Cartesian total stress σ_{xx} (scaled up $0.500*10^{-3}$ times)
Maximum value = 9720 kN/m² (Element 1492 at Node 17305)
Minimum value = -9981 kN/m² (Element 1438 at Node 5677)

Maximum =9720 kN/m^2
Minimum = -9981 kN/m^2



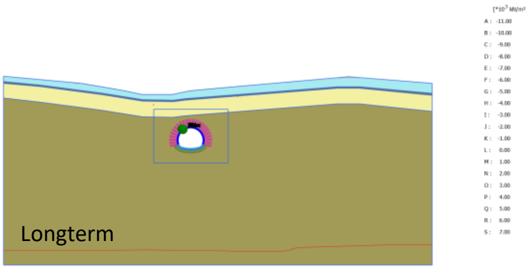


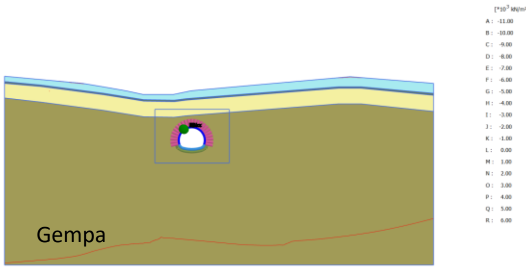
Cartesian total stress σ_{xx} (scaled up $0.500*10^{-3}$ times)
Maximum value = 8096 kN/m² (Element 1433 at Node 5665)
Minimum value = -9619 kN/m² (Element 1438 at Node 5677)

Maximum = 8096 kN/m^2
Minimum = -9619 kN/m^2

Cartesian total stress σ_{xx} (scaled up $0.500*10^{-3}$ times)
Maximum value = 7040 kN/m² (Element 1433 at Node 5667)
Minimum value = $-10.48*10^3$ kN/m² (Element 1438 at Node 5677)

Maximum = 7040 kN/m^2
Minimum = -10.48 x10^3 kN/m^2





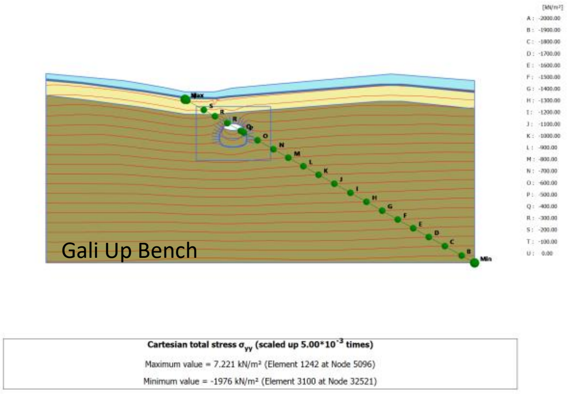
Cartesian total stress σ_{xx} (scaled up $0.500*10^{-3}$ times) (Time 18.08 day)
Maximum value = 7010 kN/m² (Element 1433 at Node 5667)
Minimum value = $-10.49*10^3$ kN/m² (Element 1438 at Node 5677)

Maksimum = 7010 kN/m^2
Minimum = -10.49 x10^3 kN/m^2

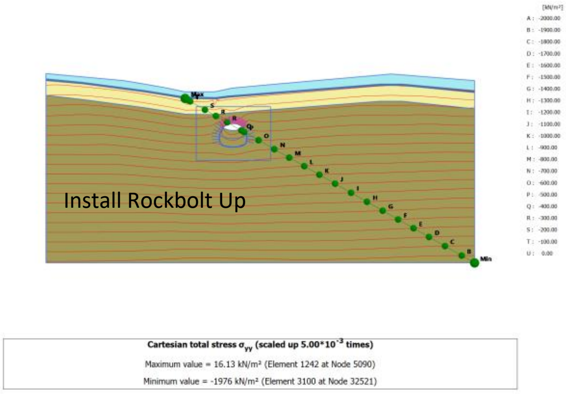
Cartesian total stress σ_{xx} (scaled up $0.500*10^{-3}$ times)
Maximum value = 6521 kN/m² (Element 1433 at Node 5667)
Minimum value = $-10.47*10^3$ kN/m² (Element 1438 at Node 5677)

Maximum = 6521 kN/m^2
Minimum = -10.47 x10^3 kN/m^2

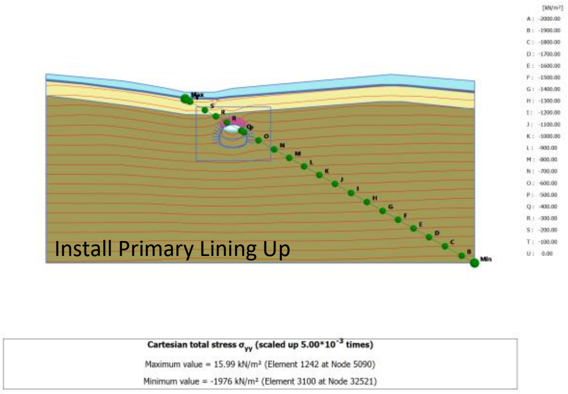
Gambar 52 Hasil analisis tegangan horizontal (σx) pada Tunnel Walini (DK 95+696) (lanjutan)



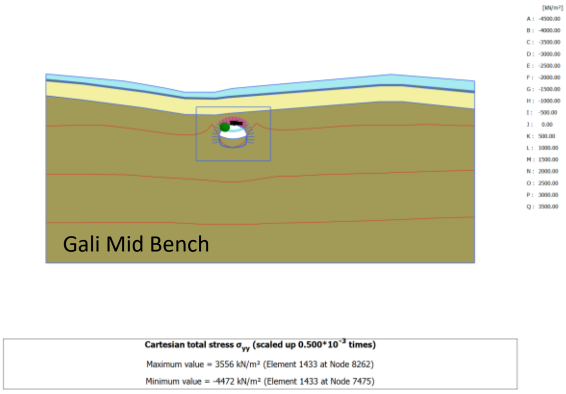
Maximum = 7.221 kN/m^2
Minimum = -1976 kN/m^2



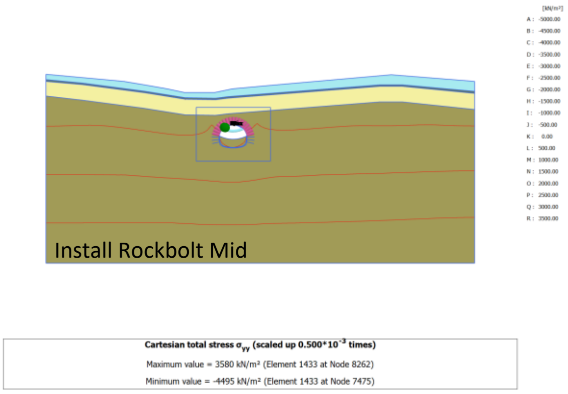
Maximum = 16.13 kN/m^2
Minimum = -1976 kN/m^2



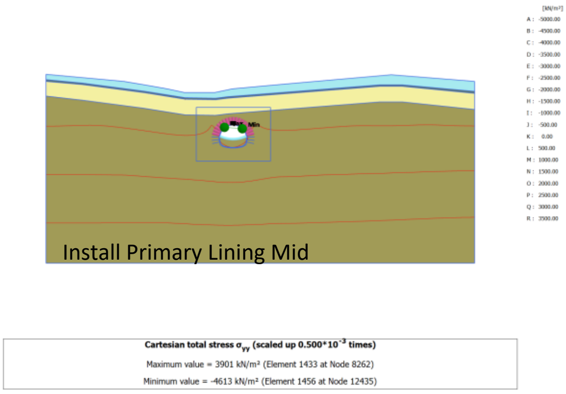
Maximum = 15.99 kN/m^2
Minimum = -1976 kN/m^2



Maximum = 3556 kN/m^2
Minimum = -4472 kN/m^2

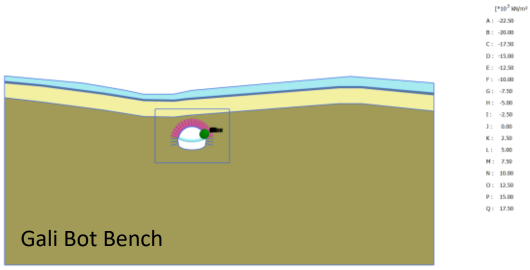


Maximum = 3580 kN/m^2
Minimum = -4495 kN/m^2



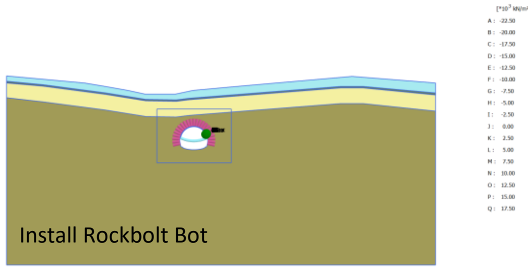
Maximum = 3901 kN/m^2
Minimum = -4613 kN/m^2

Gambar 53 Hasil analisis tegangan vertikal (σy) pada Tunnel Walini (DK 95+696)



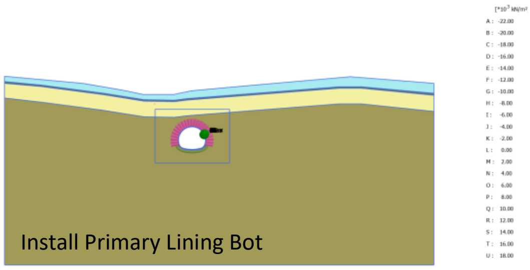
Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times)
Maximum value = 19.66*10^3 kN/m² (Element 1479 at Node 15869)
Minimum value = -20.95*10^3 kN/m² (Element 1479 at Node 15870)

Maksimum = 19.66 kN/m^2
Minimum = -20.95 x10^3 kN/m^2



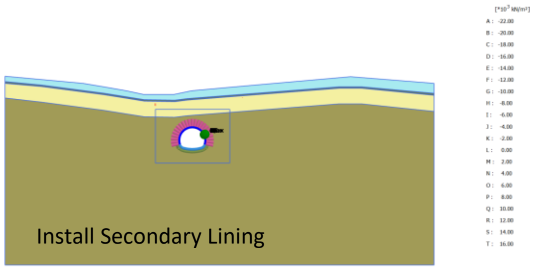
Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times)
Maximum value = 19.68*10^3 kN/m² (Element 1479 at Node 15869)
Minimum value = -20.95*10^3 kN/m² (Element 1479 at Node 15870)

Maximum = 19.68 x10^3 kN/m^2
Minimum = -20.95 x10^3 kN/m^2



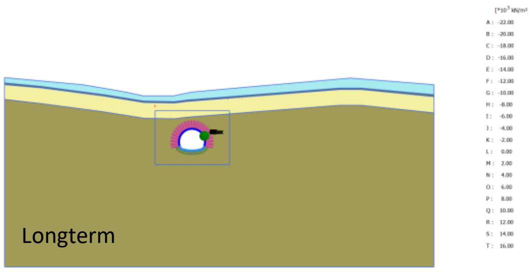
Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times)
Maximum value = 18.99*10^3 kN/m² (Element 1479 at Node 15869)
Minimum value = -20.24*10^3 kN/m² (Element 1479 at Node 15870)

Maximum = 18.99 x10^3 kN/m^2
Minimum = -20.24 x10^3 kN/m^2



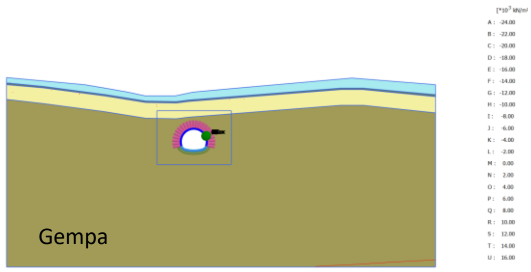
Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times)
Maximum value = 17.70*10^3 kN/m² (Element 1479 at Node 15868)
Minimum value = -21.76*10^3 kN/m² (Element 1479 at Node 15870)

Maximum = 17.70 x10^3 kN/m^2
Minimum = -21.76 x10^3 kN/m^2



Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times) (Time 18.08 day)
Maximum value = 17.71*10^3 kN/m² (Element 1479 at Node 15868)
Minimum value = -21.81*10^3 kN/m² (Element 1479 at Node 15870)

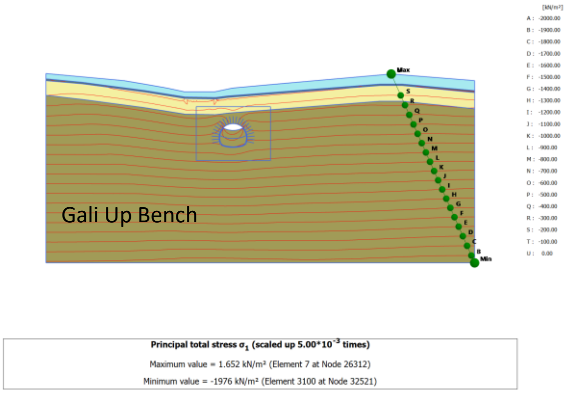
Maksimum = 17.71 x10^3 kN/m^2
Minimum = -21.81 x10^3 kN/m^2



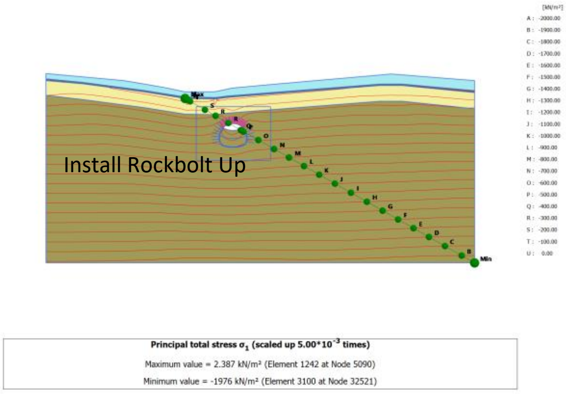
Cartesian total stress σ_{yy} (scaled up 0.200*10^-3 times)
Maximum value = 17.71*10^3 kN/m² (Element 1479 at Node 15868)
Minimum value = -22.05*10^3 kN/m² (Element 1479 at Node 15870)

Maximum = 17.71 x10^3 kN/m^2
Minimum = -22.05v kN/m^2

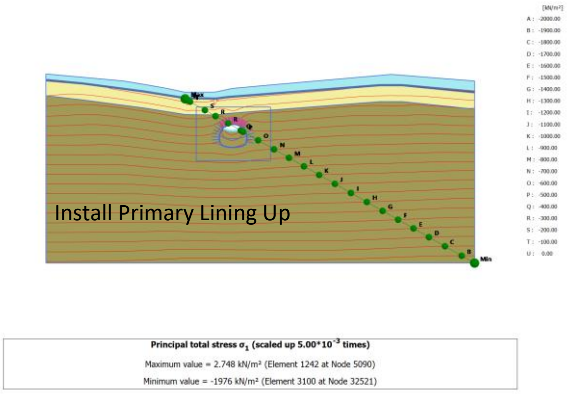
Gambar 54 Hasil analisis tegangan vertikal (σy) pada Tunnel Walini (DK 95+696) (lanjutan)



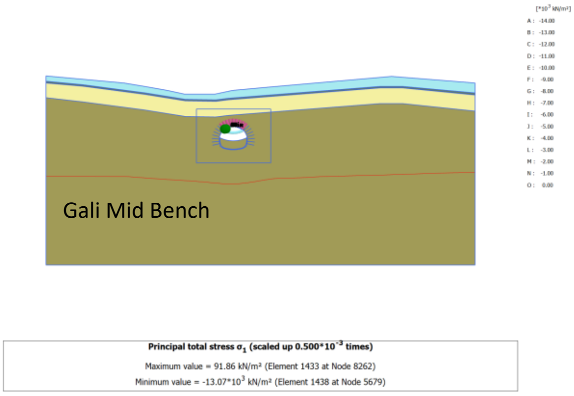
Maximum = 1.652 kN/m^2
Minimum = -1976 kN/m^2



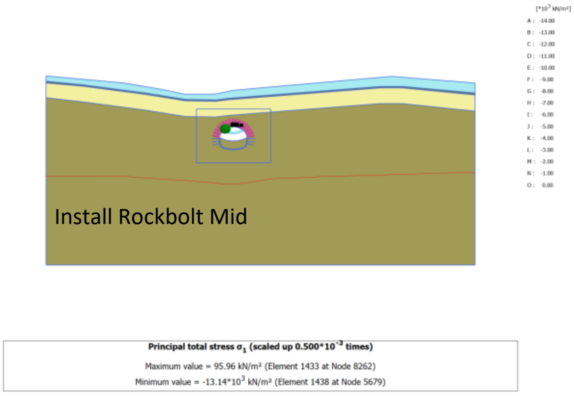
Maximum = 2.387 kN/m^2
Minimum = -1976 kN/m^2



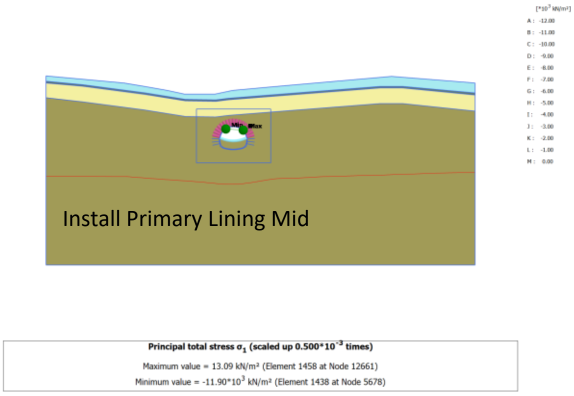
Maximum = 2.748 kN/m^2
Minimum = -1976 kN/m^2



Maximum = 91.86 kN/m^2
Minimum = -13.07 x10^3 kN/m^2

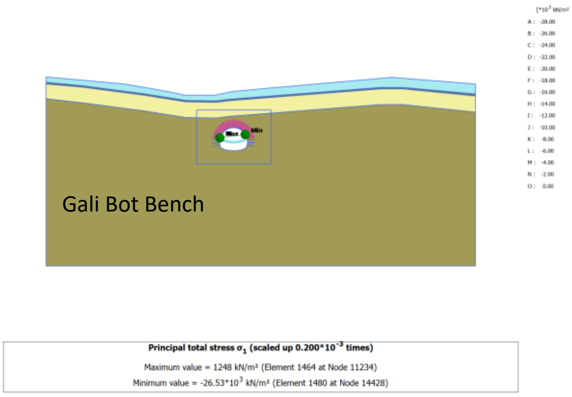


Maximum = 95.96 kN/m^2
Minimum = -13.14 x10^3 kN/m^2

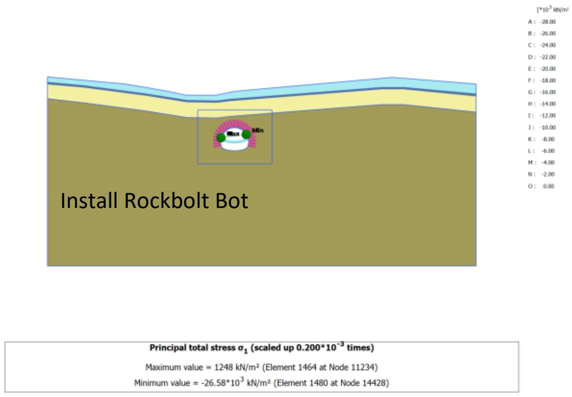


Maximum = 13.09 kN/m^2
Minimum = -11.90 x10^3 kN/m^2

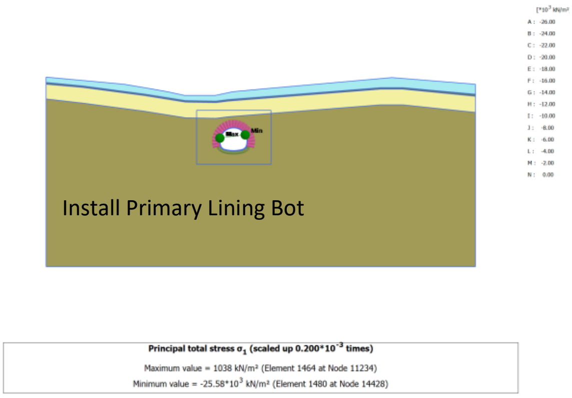
Gambar 55 Hasil analisis tegangan maksimum (σ1) pada Tunnel Walini (DK 95+696)



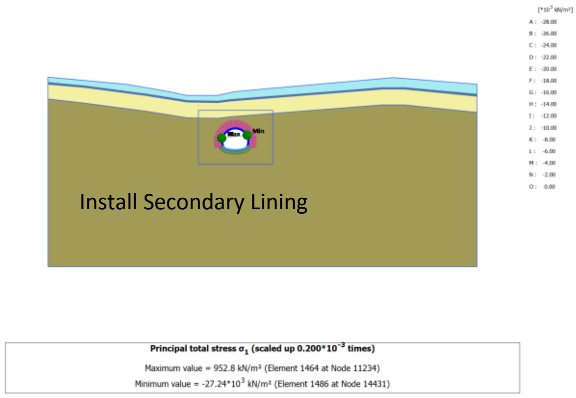
Maksimum = 1248 kN/m^2
Minimum = -26.53 x10^3 kN/m^2



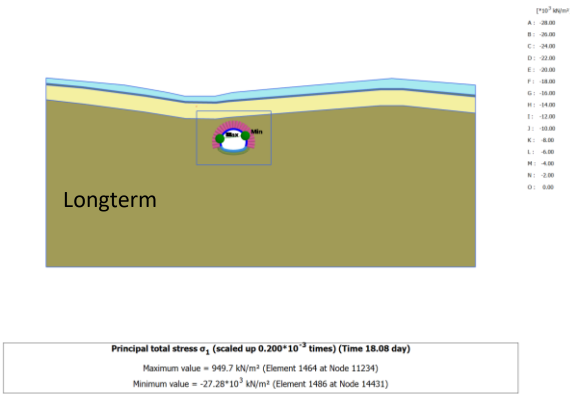
Maximum = 1248 kN/m^2
Minimum = -26.58 x10^3 kN/m^2



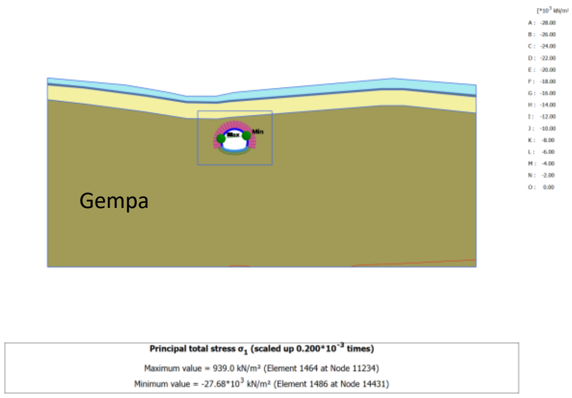
Maximum = 1038 kN/m^2
Minimum = -25.58 x10^3 kN/m^2



Maximum = 952.8 kN/m^2
Minimum = -27.24 x10^3 kN/m^2

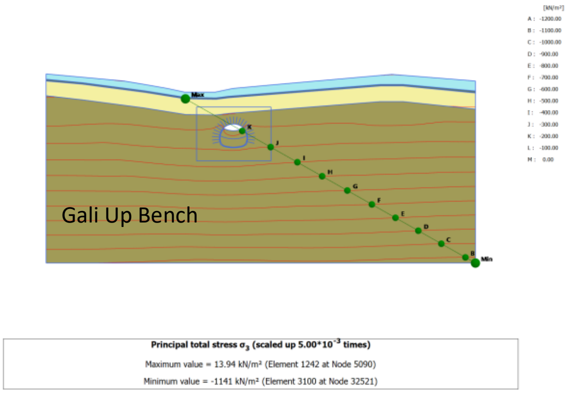


Maksimum = 949.7 kN/m^2
Minimum = -27.28 x10^3 kN/m^2

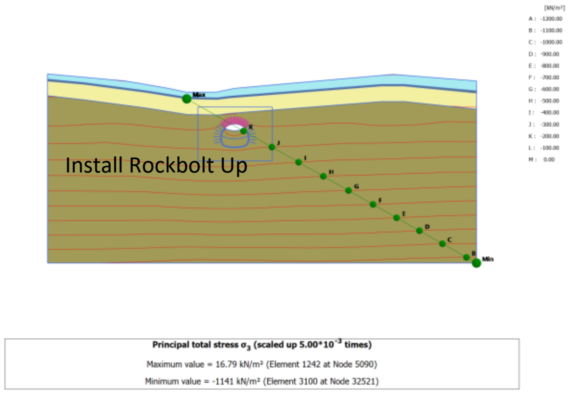


Maximum = 939.0 kN/m^2
Minimum = -27.68 x10^3 kN/m^2

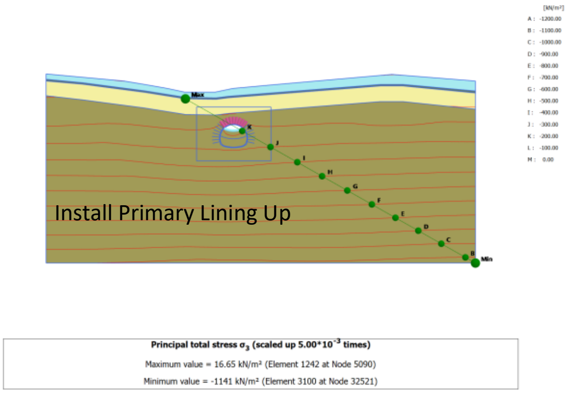
Gambar 56 Hasil analisis tegangan maksimum (σ1) pada Tunnel Walini (DK 95+696) (lanjutan)



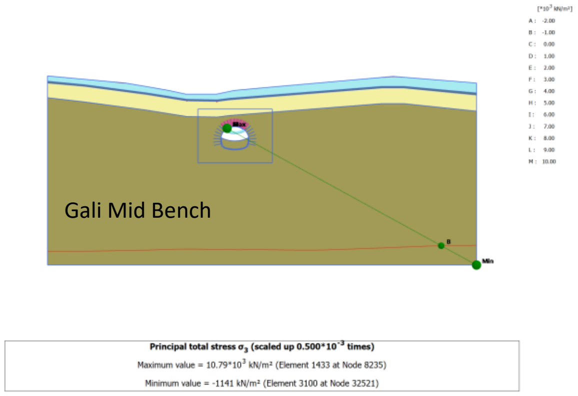
Maximum = 13.94 kN/m^2
Minimum = -1141 kN/m^2



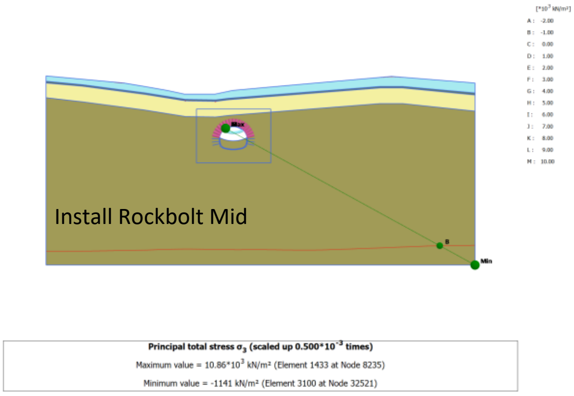
Maximum = 16.79 kN/m^2
Minimum = -1141 kN/m^2



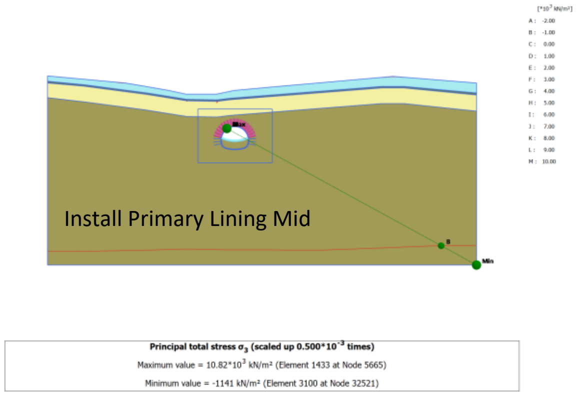
Maximum = 16.65 kN/m^2
Minimum = -1141 kN/m^2



Maximum = 10.79 x10^3 kN/m^2
Minimum = -1141 kN/m^2

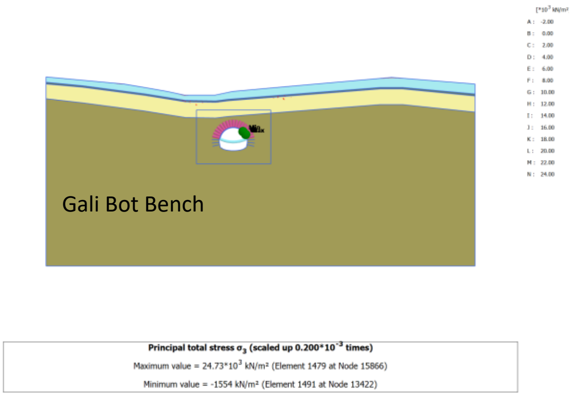


Maximum = 10.86 x10^3 kN/m^2
Minimum = -1141 kN/m^2

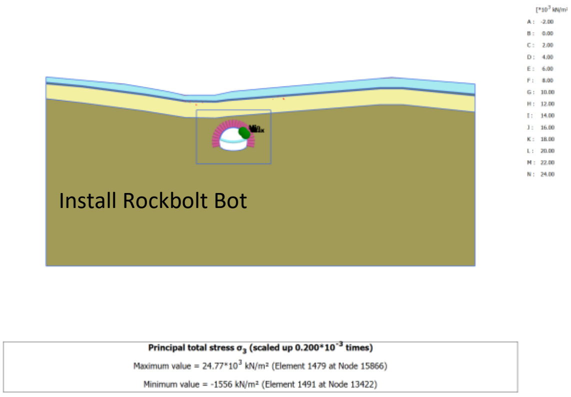


Maximum = 10.82 x10^3 kN/m^2
Minimum = -1141 kN/m^2

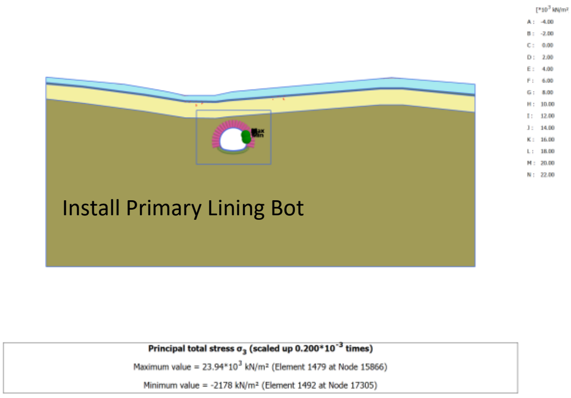
Gambar 57 Hasil analisis tegangan minimum ($\sigma 3$) pada Tunnel Walini (DK 95+696)



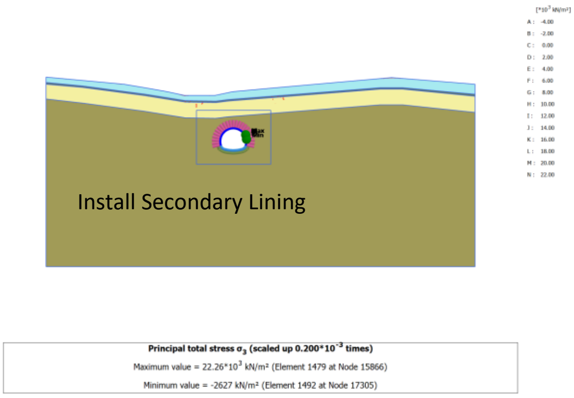
Maksimum = 24.73 x10^3 kN/m^2
Minimum = -1554 kN/m^2



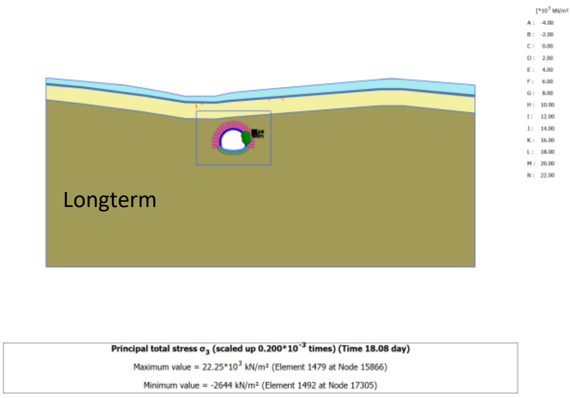
Maximum = 24.77 x10^3 kN/m^2
Minimum = -1556 kN/m^2



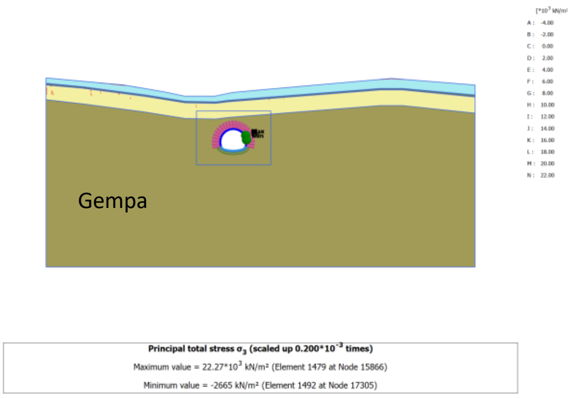
Maximum = 23.94 x10^3 kN/m^2
Minimum = -2178 kN/m^2



Maximum = 22.26 x10^3 kN/m^2
Minimum = -2627 kN/m^2

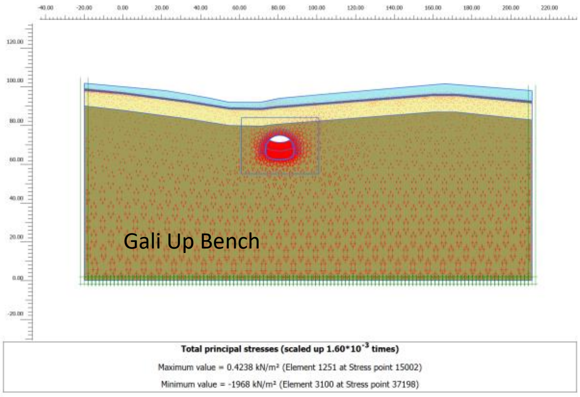


Maksimum = 22.25 x10^3 kN/m^2
Minimum = -2644 kN/m^2

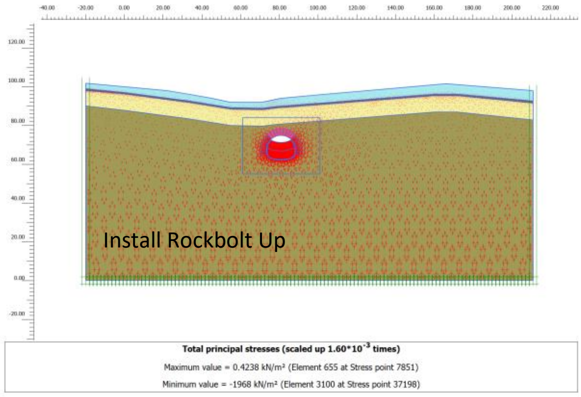


Maximum = 22.27 x10^3 kN/m^2
Minimum = -2665 kN/m^2

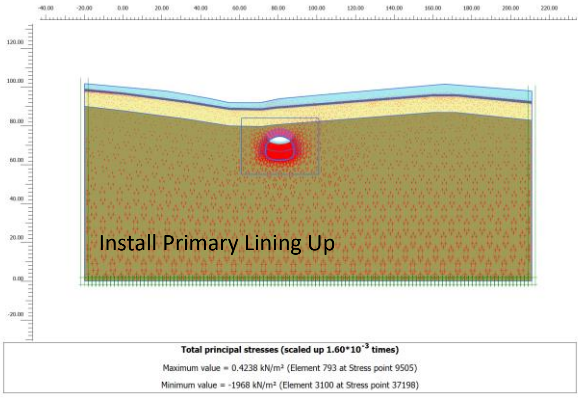
Gambar 58 Hasil analisis tegangan minimum ($\sigma 3$) pada Tunnel Walini (DK 95+696) (lanjutan)



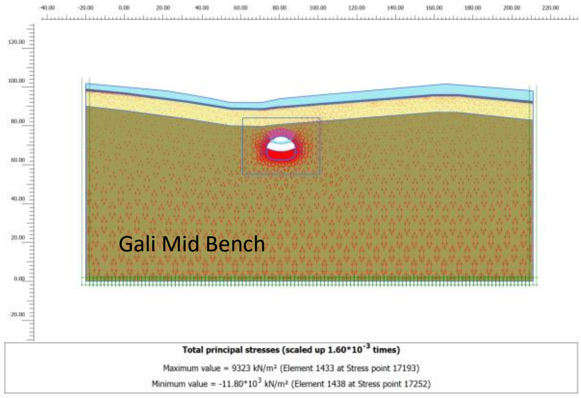
Maximum = 0.4238 kN/m^2
Minimum = -1968 kN/m^2



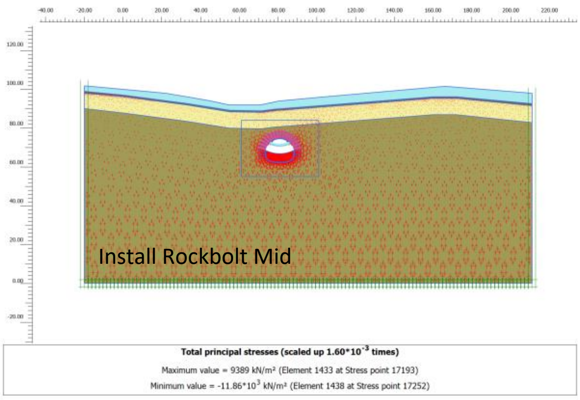
Maximum = 0.4238 kN/m^2
Minimum = -1968 kN/m^2



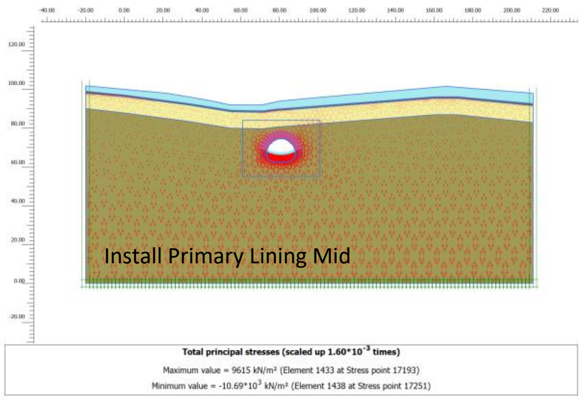
Maximum = 0.4238 kN/m^2
Minimum = -1968 kN/m^2



Maximum = 9323 kN/m^2
Minimum = -11.80 x10^3 kN/m^2

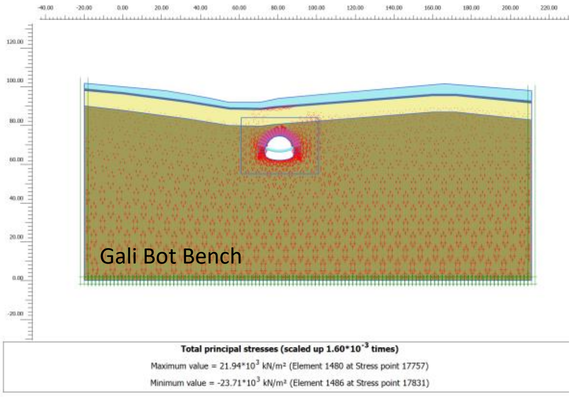


Maximum = 9389 kN/m^2
Minimum = -11.86 x10^3 kN/m^2

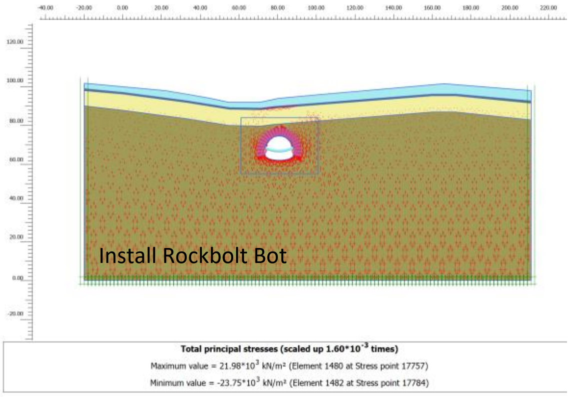


Maximum = 9615 kN/m^2
Minimum = -10.69 x10^3 kN/m^2

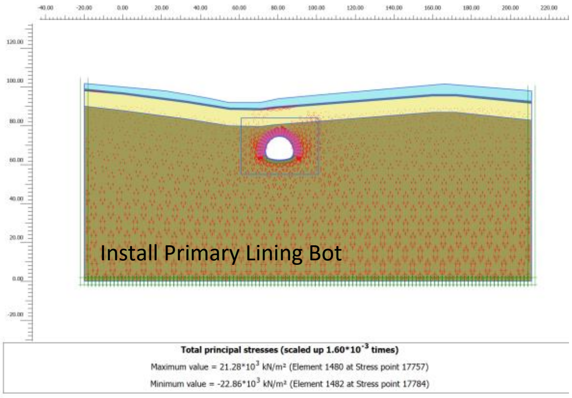
Gambar 59 Hasil analisis Total Principal Stresses pada Tunnel Walini (DK 95+696)



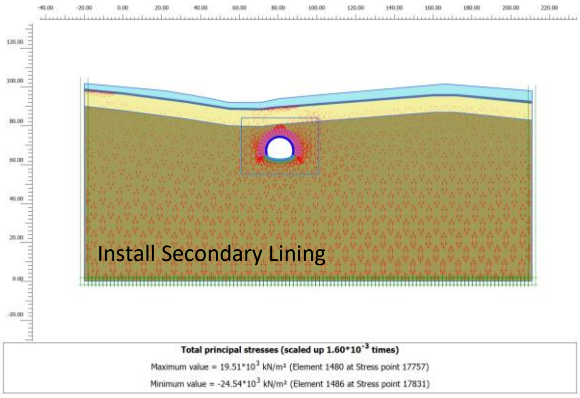
Maksimum = 21.94 x10^3 kN/m^2
Minimum = -23.71 x10^3 kN/m^2



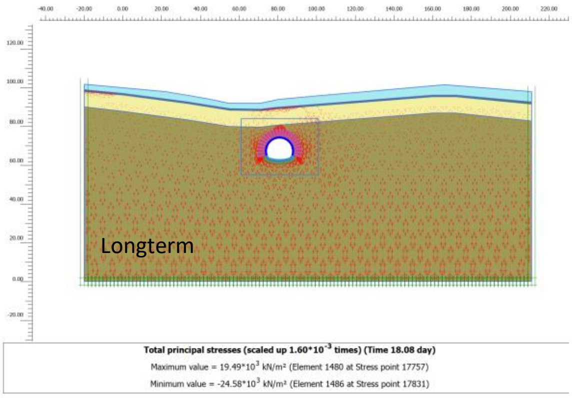
Maximum = 21.98 x10^3 kN/m^2
Minimum = -23.75 x10^3 kN/m^2



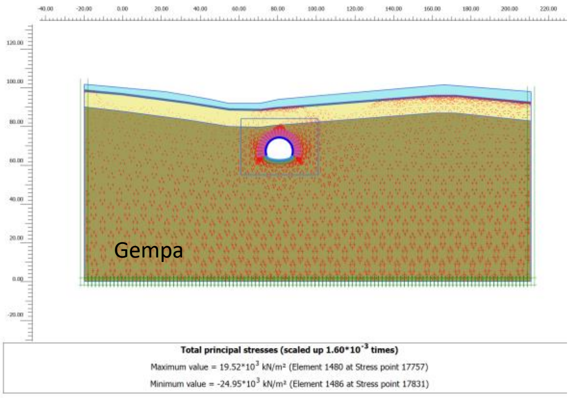
Maximum = 21.28 x10^3kN/m^2
Minimum = -22.86 x10^3 kN/m^2



Maximum = 19.51 x10^3 kN/m^2
Minimum = -24.54 x10^3 kN/m^2



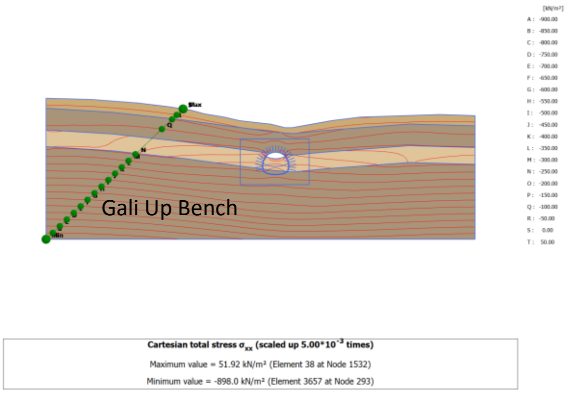
Maksimum = 19.49 x10^3 kN/m^2
Minimum = -24.49 x10^3 kN/m^2



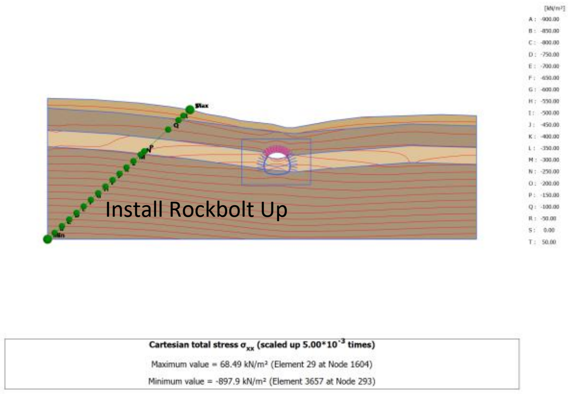
Maximum = 19.52 x10^3 kN/m^2
Minimum = -24.95 x10^3 kN/m^2

Gambar 60 Hasil analisis Total Principal Stresses pada Tunnel Walini (DK 95+696) (lanjutan)

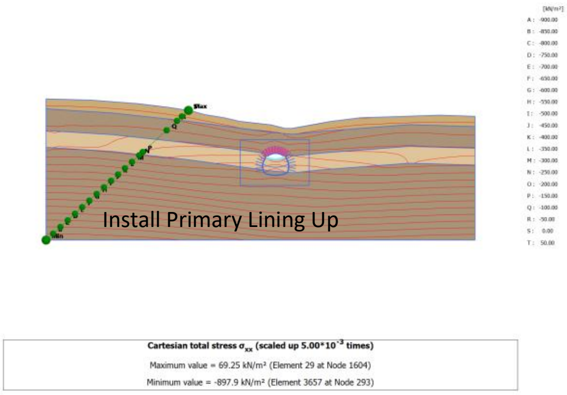
c) *Cross Section DK 95+715*



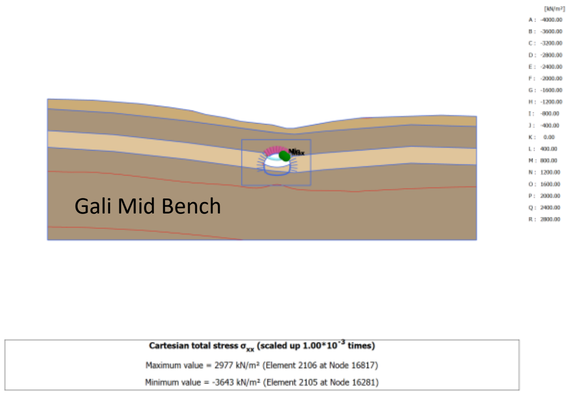
Maximum = 51.92 kN/m^2
Minimum = -898.0 kN/m^2



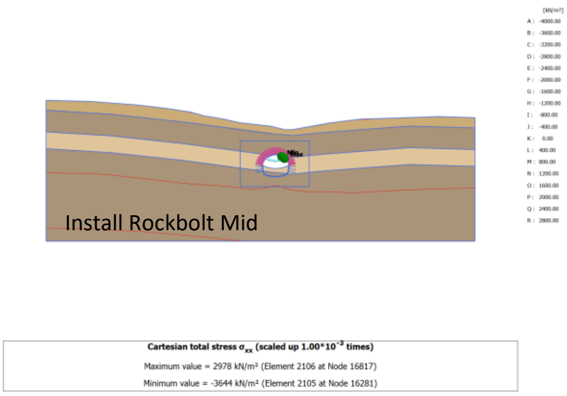
Maximum = 68.49 kN/m^2
Minimum = -897.9 kN/m^2



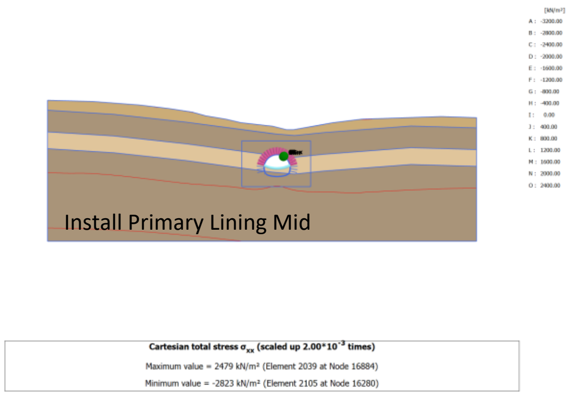
Maximum = 69.25 kN/m^2
Minimum = -897.9 kN/m^2



Maximum = 2977 kN/m^2
Minimum = -3643 kN/m^2

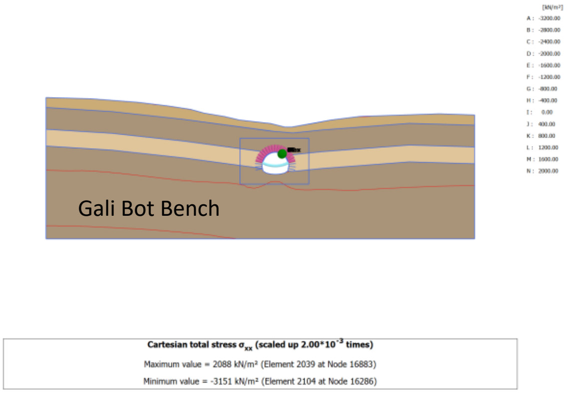


Maximum = 2978 kN/m^2
Minimum = -3644 kN/m^2

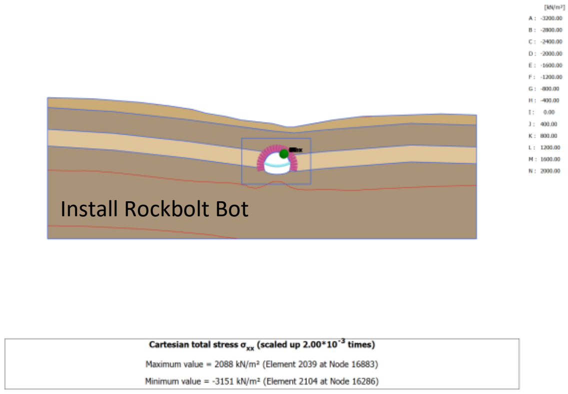


Maximum = 2479 kN/m^2
Minimum = -2823 kN/m^2

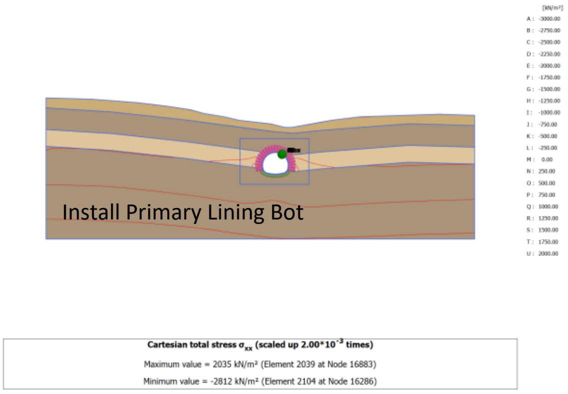
Gambar 61 Hasil analisis tegangan horizontal (σx) pada Tunnel Walini (DK 95+715)



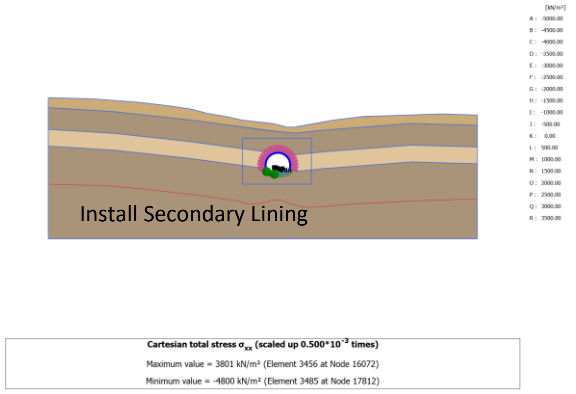
Maksimum = 2088 kN/m^2
Minimum = -3151 kN/m^2



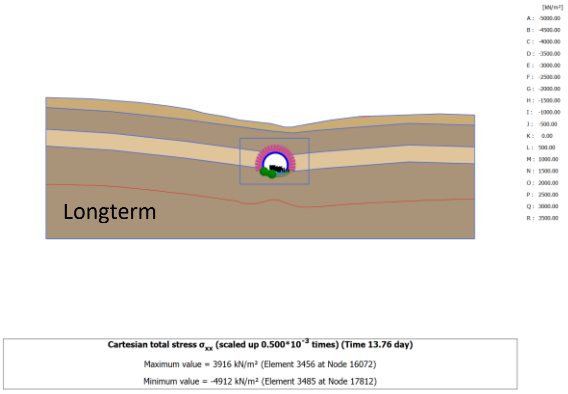
Maximum = 2088 kN/m^2
Minimum = -3151 kN/m^2



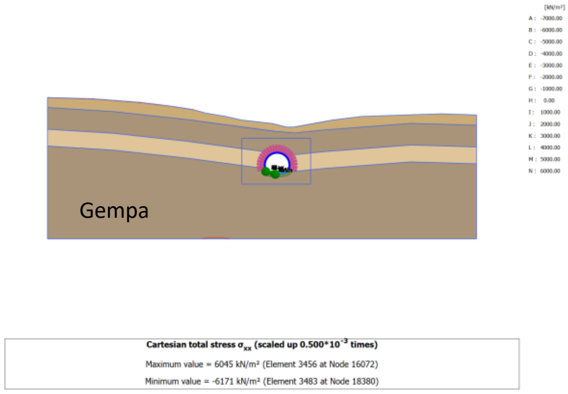
Maximum = 2035 kN/m^2
Minimum = -2812 kN/m^2



Maximum = 3801 kN/m^2
Minimum = -4800 kN/m^2

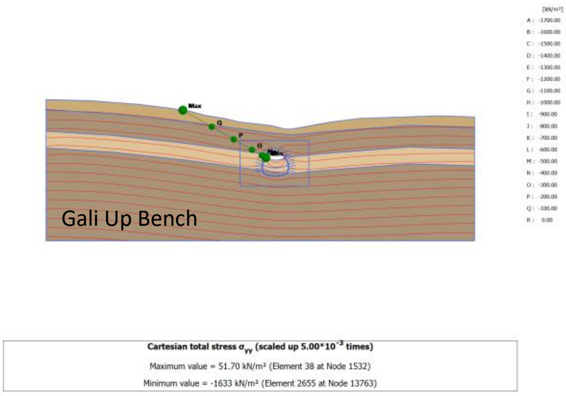


Maksimum = 3916 kN/m^2
Minimum = -4912 kN/m^2

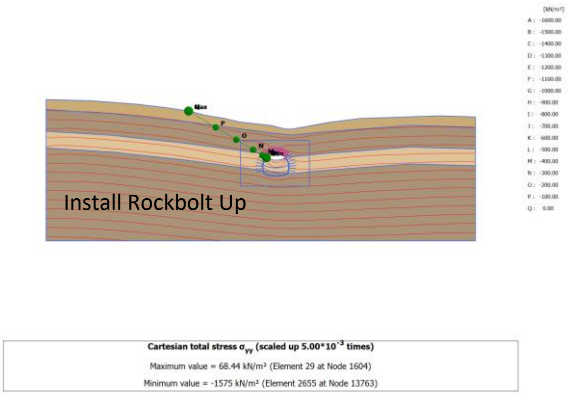


Maximum = 6045 kN/m^2
Minimum = -6171 kN/m^2

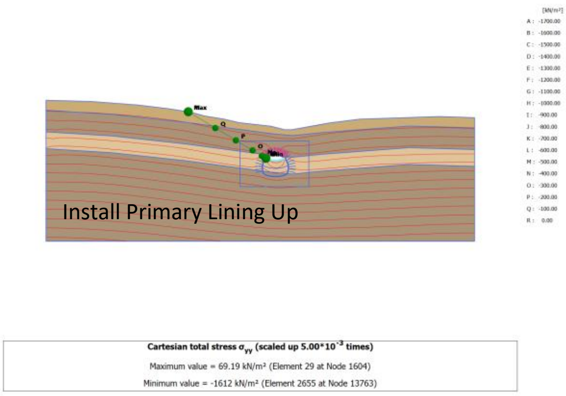
Gambar 62 Hasil analisis tegangan horizontal (σ_x) pada Tunnel Walini (DK 95+715) (lanjutan)



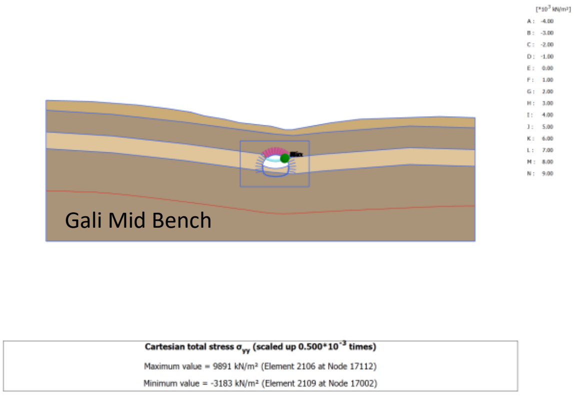
Maximum = 51.70 kN/m^2
Minimum = -1633 kN/m^2



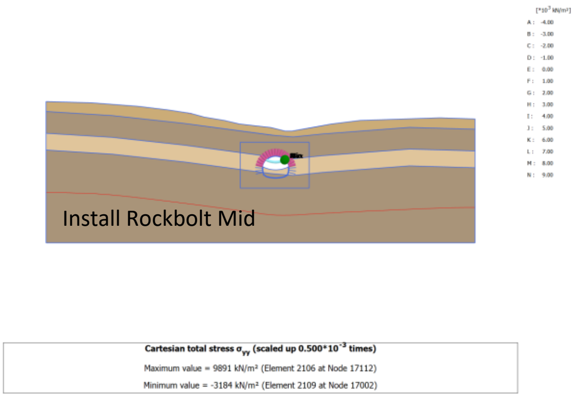
Maximum = 68.44 kN/m^2
Minimum = -1575 kN/m^2



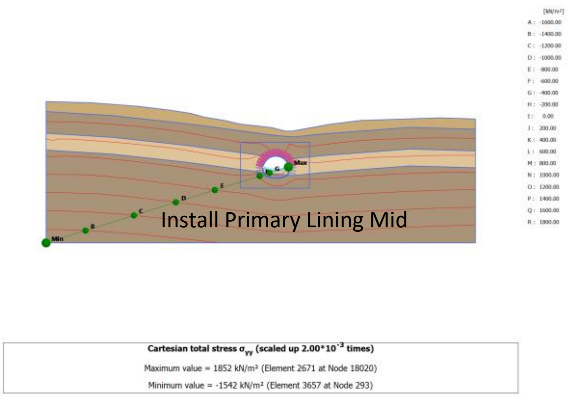
Maximum = 69.19 kN/m^2
Minimum = -1612 kN/m^2



Maximum = 9891 kN/m^2
Minimum = -3183 kN/m^2

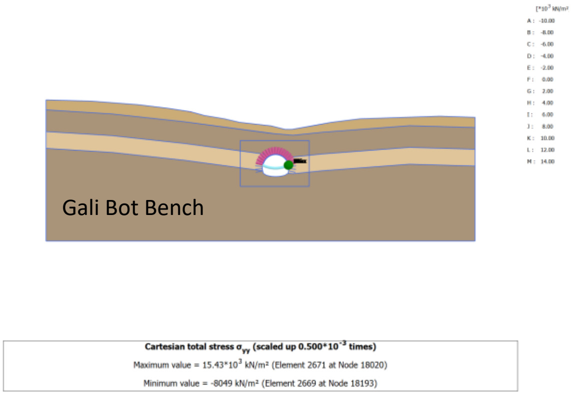


Maximum = 9891 kN/m^2
Minimum = -3184 kN/m^2

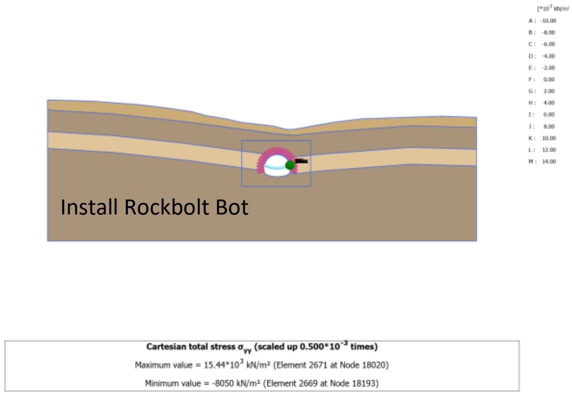


Maximum = 1852 kN/m^2
Minimum = -1542 kN/m^2

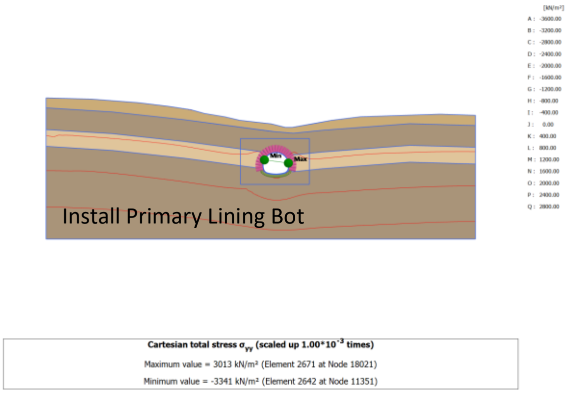
Gambar 63 Hasil analisis tegangan vertikal (σy) pada Tunnel Walini (DK 95+715)



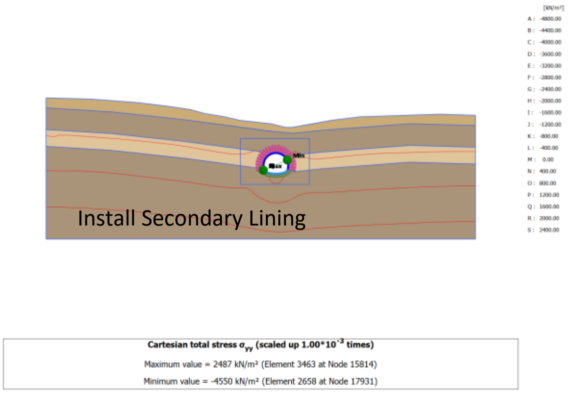
Maksimum = 15.43 x10^3 kN/m^2
Minimum = -8049 kN/m^2



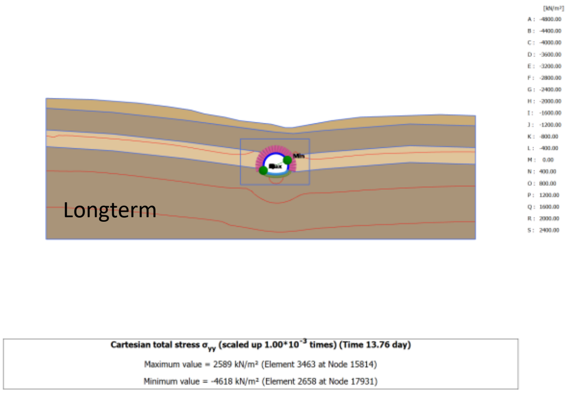
Maximum = 15.44 x10^3 kN/m^2
Minimum = -8050 kN/m^2



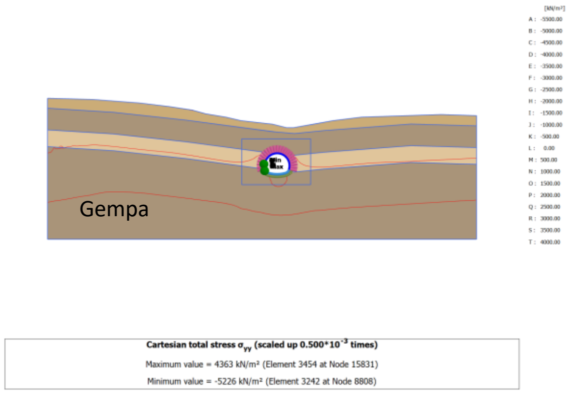
Maximum = 3013 kN/m^2
Minimum = -3341 kN/m^2



Maximum = 2487 kN/m^2
Minimum = -4550 kN/m^2

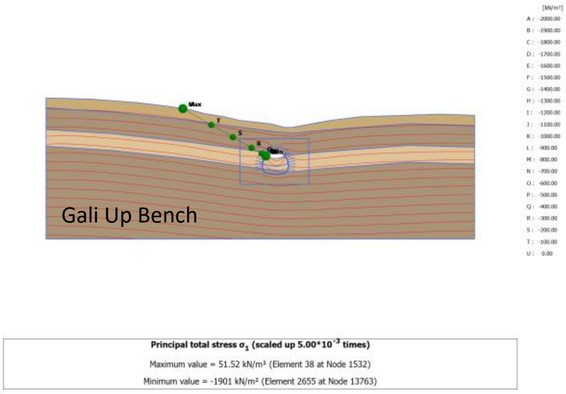


Maksimum = 2589 kN/m^2
Minimum = -4618 kN/m^2

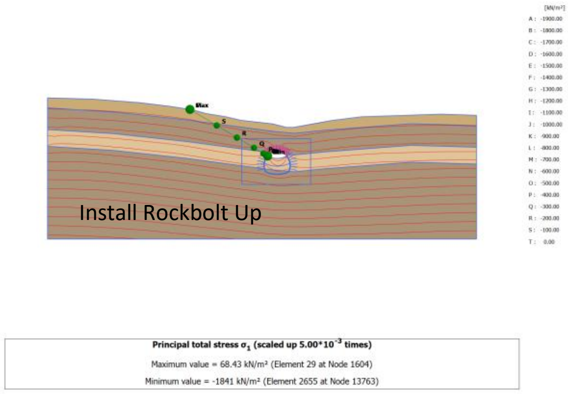


Maximum = 4363 kN/m^2
Minimum = -5226 kN/m^2

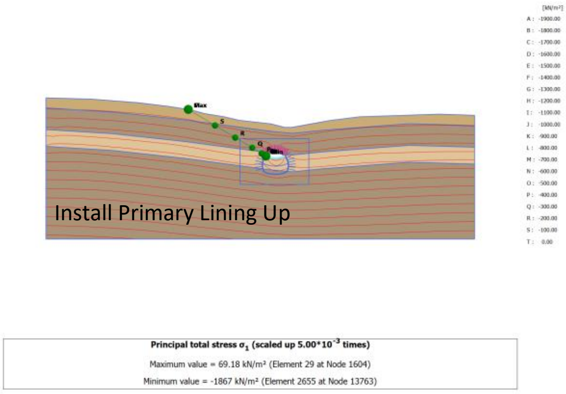
Gambar 64 Hasil analisis tegangan vertikal (σy) pada Tunnel Walini (DK 95+715) (lanjutan)



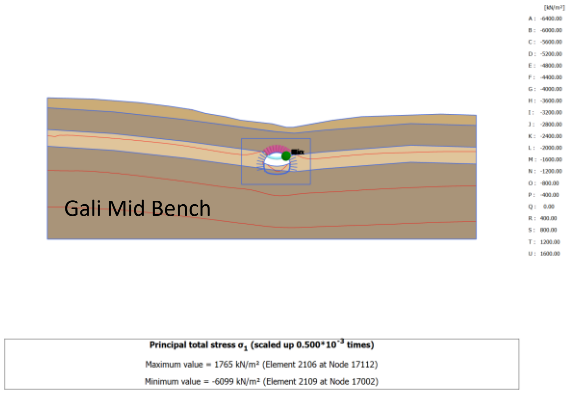
Maximum = 51.52 kN/m^2
Minimum = -1901 kN/m^2



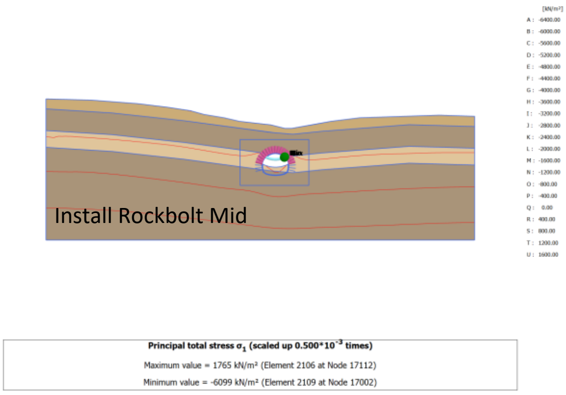
Maximum = 68.43 kN/m^2
Minimum = -1841 kN/m^2



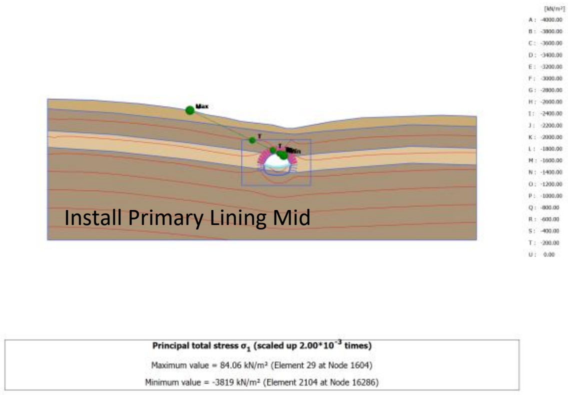
Maximum = 69.18 kN/m^2
Minimum = -1867 kN/m^2



Maximum = 1765 kN/m^2
Minimum = -6099 kN/m^2

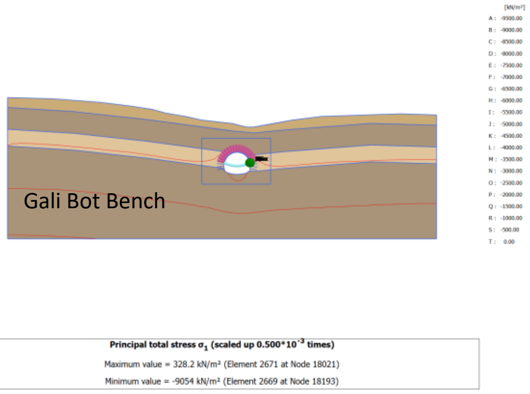


Maximum = 1765 kN/m^2
Minimum = -6099 kN/m^2

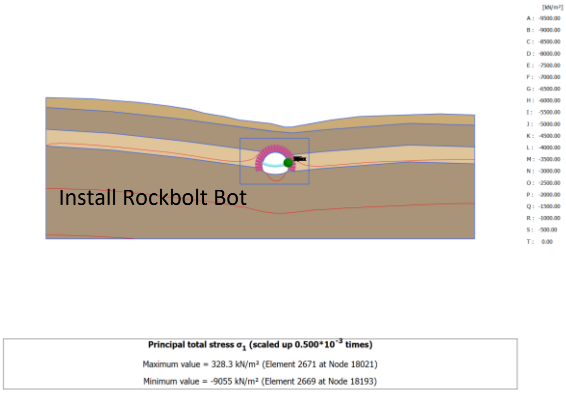


Maximum = 84.06 kN/m^2
Minimum = -3819 kN/m^2

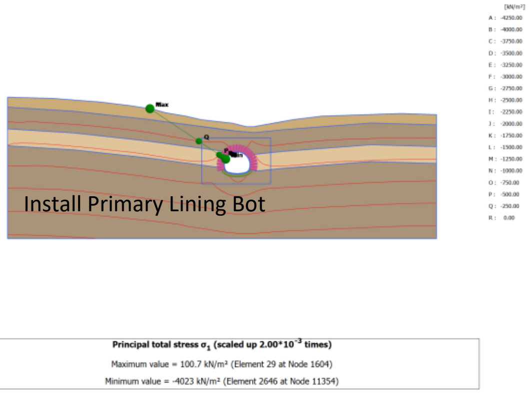
Gambar 65 Hasil analisis tegangan maksimum ($\sigma 1$) pada Tunnel Walini (DK 95+715)



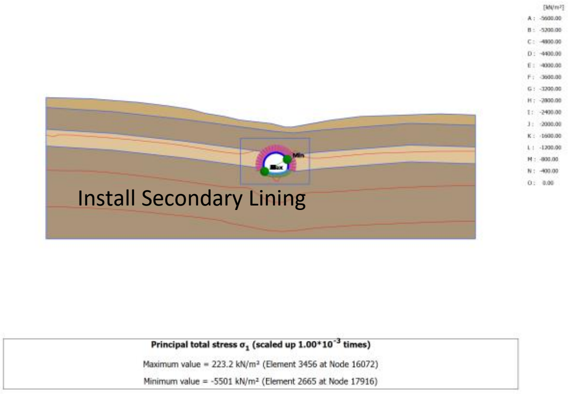
Maksimum = 328.2 kN/m^2
Minimum = -9054 kN/m^2



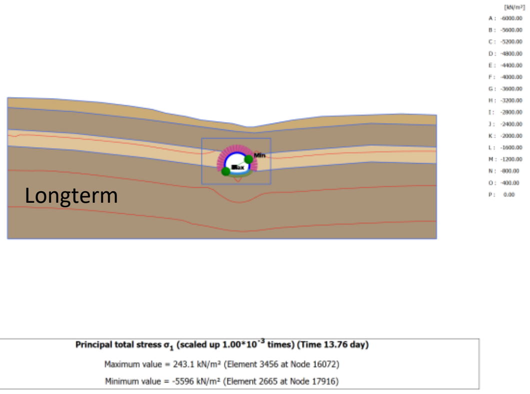
Maximum = 328.3 kN/m^2
Minimum = -9055 kN/m^2



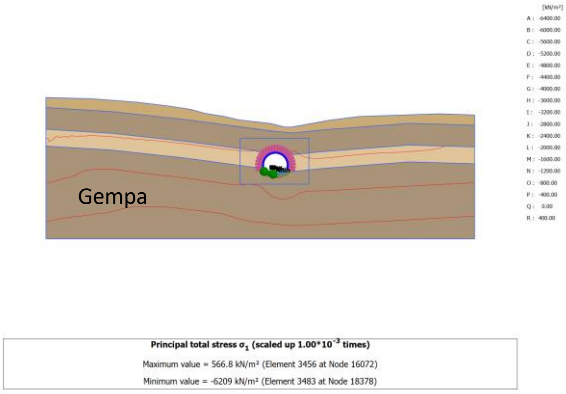
Maximum = 100.7 kN/m^2
Minimum = -4023 kN/m^2



Maximum = 223.2 kN/m^2
Minimum = -5501 kN/m^2

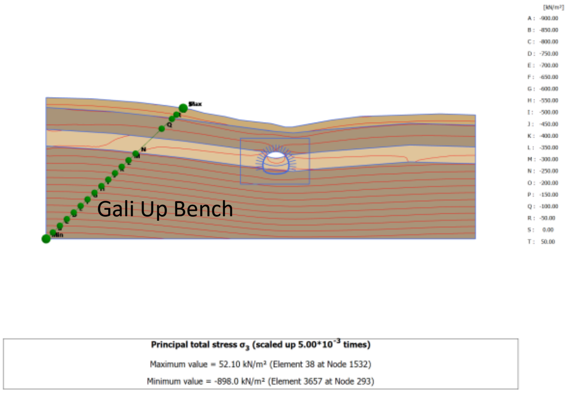


Maksimum = 243.1 kN/m^2
Minimum = -5596 kN/m^2

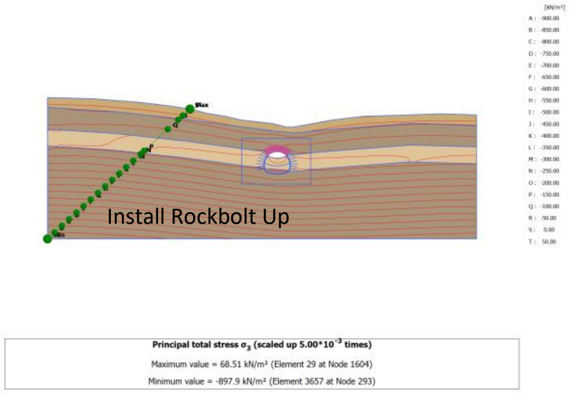


Maximum = 566.8 kN/m^2
Minimum = -6209 kN/m^2

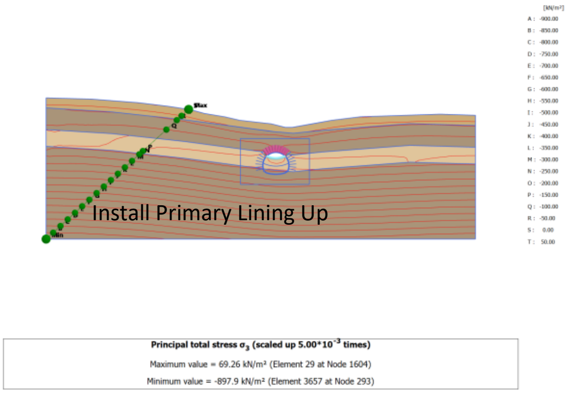
Gambar 66 Hasil analisis tegangan maksimum (σ1) pada Tunnel Walini (DK 95+715) (lanjutan)



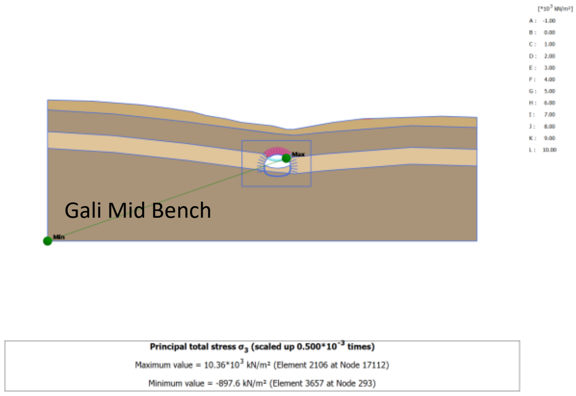
Maximum = 52.10 kN/m^2
Minimum = -898.0 kN/m^2



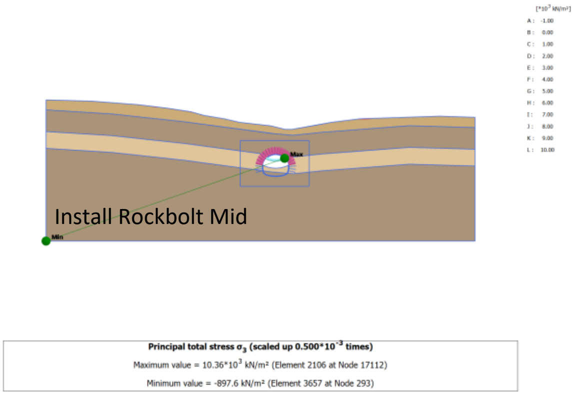
Maximum = 68.51 kN/m^2
Minimum = -897.9 kN/m^2



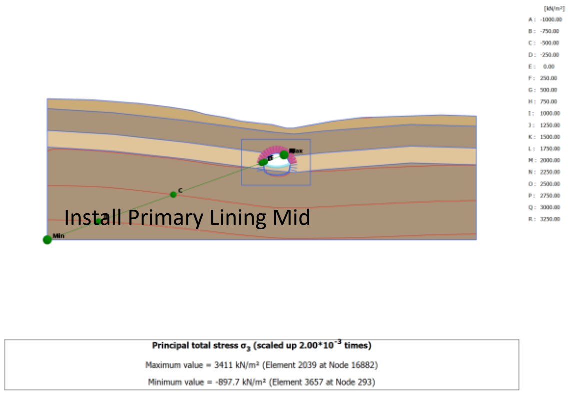
Maximum = 69.26 kN/m^2
Minimum = -897.9 kN/m^2



Maximum = 10.36 x10^3 kN/m^2
Minimum = -897.6 kN/m^2

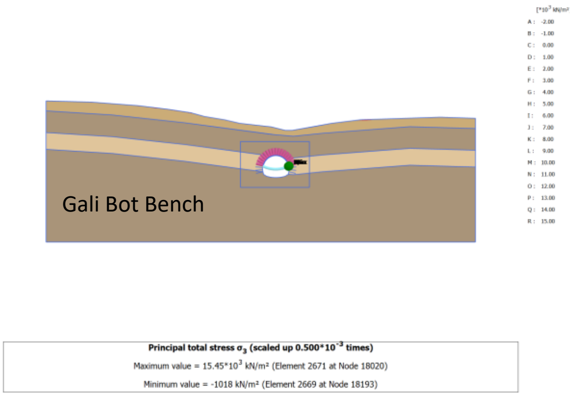


Maximum = 10.36 x10^3 kN/m^2
Minimum = -897.6 kN/m^2

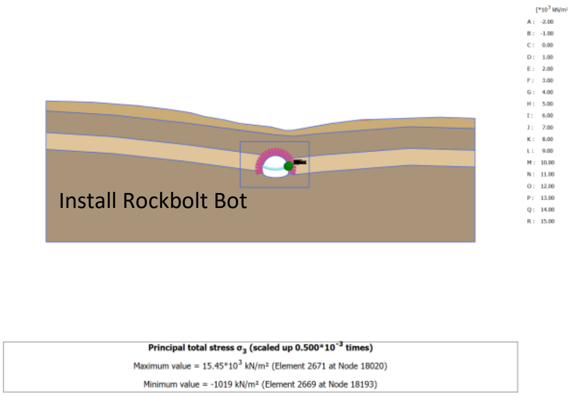


Maximum = 3411 kN/m^2
Minimum = -897.7 kN/m^2

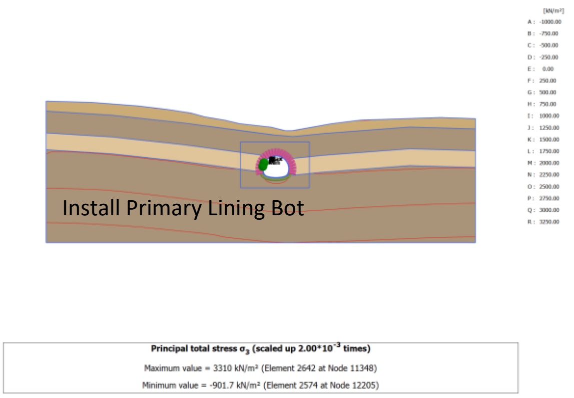
Gambar 67 Hasil analisis tegangan minimum (σ_3) pada Tunnel Walini (DK 95+715)



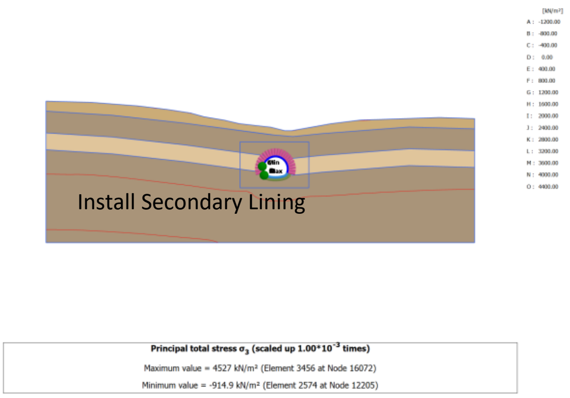
Maksimum = 15.45 x10^3 kN/m^2
Minimum = -1018 kN/m^2



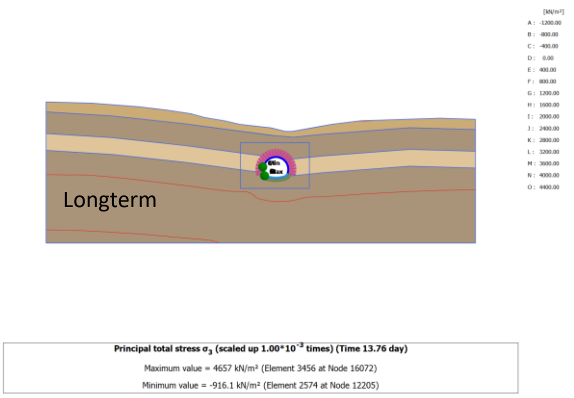
Maximum = 15.45 x10^3 kN/m^2
Minimum = -1019 kN/m^2



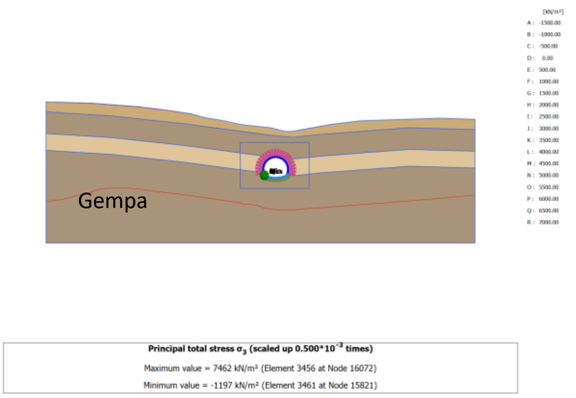
Maximum = 3310 kN/m^2
Minimum = -901.7 kN/m^2



Maximum = 4527 kN/m^2
Minimum = -914.9 kN/m^2

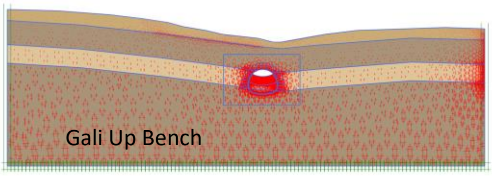


Maksimum = 4657 kN/m^2
Minimum = -916.1 kN/m^2



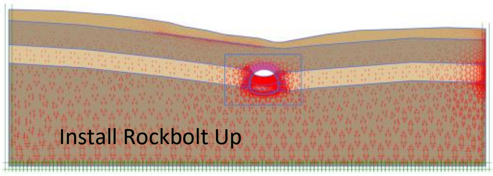
Maximum = 7462 kN/m^2
Minimum = -1197 kN/m^2

Gambar 68 Hasil analisis tegangan minimum (σ3) pada Tunnel Walini (DK 95+715) (lanjutan)



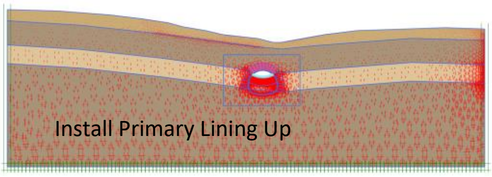
Total principal stresses (scaled up $2.50*10^{-3}$ times)
Maximum value = 186.0 kN/m² (Element 37 at Stress point 439)
Minimum value = -1534 kN/m² (Element 3657 at Stress point 43881)

Maximum = 186.0 kN/m^2
Minimum = -1534 kN/m^2



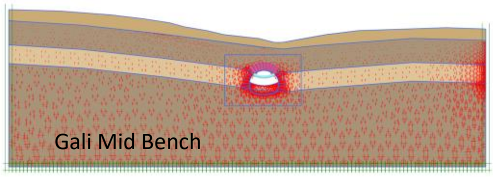
Total principal stresses (scaled up $2.50*10^{-3}$ times)
Maximum value = 262.2 kN/m² (Element 30 at Stress point 357)
Minimum value = -1534 kN/m² (Element 3657 at Stress point 43881)

Maximum = 262.2 kN/m^2
Minimum = -1534 kN/m^2



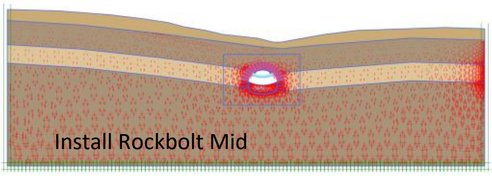
Total principal stresses (scaled up $2.50*10^{-3}$ times)
Maximum value = 265.1 kN/m² (Element 30 at Stress point 357)
Minimum value = -1534 kN/m² (Element 3657 at Stress point 43881)

Maximum = 265.1 kN/m^2
Minimum = -1534 kN/m^2



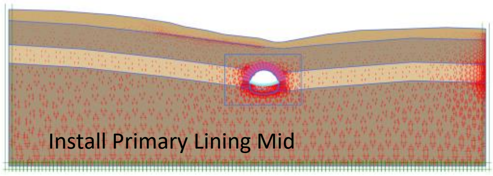
Total principal stresses (scaled up $2.50*10^{-3}$ times)
Maximum value = $10.74*10^3$ kN/m² (Element 2106 at Stress point 25261)
Minimum value = -5583 kN/m² (Element 2109 at Stress point 25304)

Maximum = 10.74 x10^3 kN/m^2
Minimum = -5583 kN/m^2



Total principal stresses (scaled up $2.50*10^{-3}$ times)
Maximum value = $10.75*10^3$ kN/m² (Element 2106 at Stress point 25261)
Minimum value = -5584 kN/m² (Element 2109 at Stress point 25304)

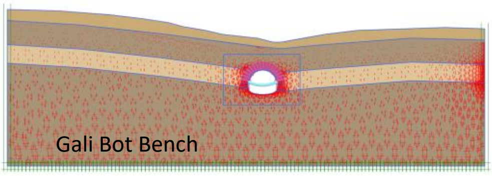
Maximum = 10.75 x10^3 kN/m^2
Minimum = -5584 kN/m^2



Total principal stresses (scaled up $2.50*10^{-3}$ times)
Maximum value = 3216 kN/m² (Element 2107 at Stress point 25282)
Minimum value = -3619 kN/m² (Element 2104 at Stress point 25245)

Maximum = 3216 kN/m^2
Minimum = -3619 kN/m^2

Gambar 69 Hasil analisis Total Principal Stresses pada Tunnel Walini (DK 95+715)

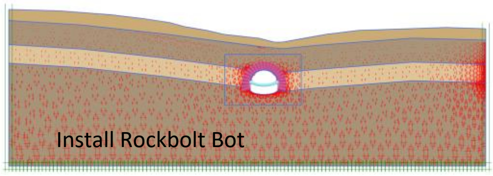


Total principal stresses (scaled up $2.50*10^{-3}$ times)

Maximum value = $11.87*10^{3}$ kN/m² (Element 2671 at Stress point 32043)

Minimum value = -8543 kN/m² (Element 2669 at Stress point 32017)

Maksimum = 11.87 x10^3 kN/m^2
Minimum = -8543 kN/m^2

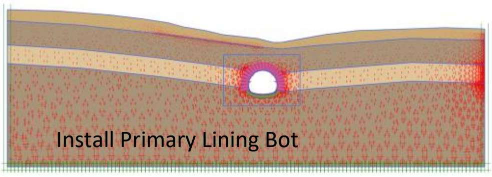


Total principal stresses (scaled up $2.50*10^{-3}$ times)

Maximum value = $11.87*10^{3}$ kN/m² (Element 2671 at Stress point 32043)

Minimum value = -8544 kN/m² (Element 2669 at Stress point 32017)

Maximum = 11.87 x10^3 kN/m^2
Minimum = -8544 kN/m^2

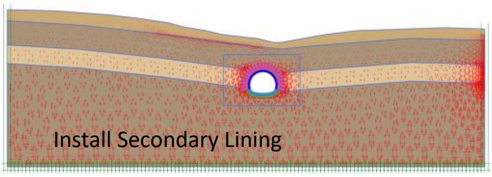


Total principal stresses (scaled up $2.50*10^{-3}$ times)

Maximum value = 3222 kN/m² (Element 2671 at Stress point 32043)

Minimum value = -3706 kN/m² (Element 2104 at Stress point 25245)

Maximum = 3222 kN/m^2
Minimum = -3706 kN/m^2

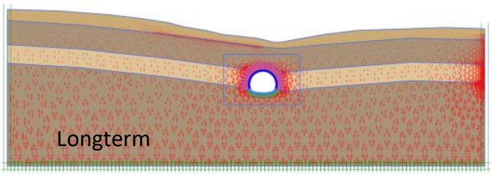


Total principal stresses (scaled up $2.50*10^{-3}$ times)

Maximum value = 4228 kN/m² (Element 3458 at Stress point 41486)

Minimum value = -5080 kN/m² (Element 2665 at Stress point 31980)

Maximum = 4228 kN/m^2
Minimum = -5080 kN/m^2

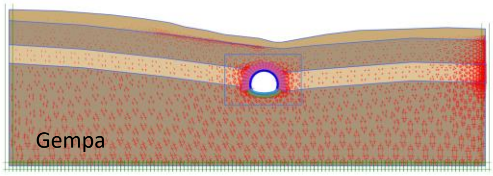


Total principal stresses (scaled up $2.50*10^{-3}$ times) (Time 13.76 day)

Maximum value = 4344 kN/m² (Element 3458 at Stress point 41486)

Minimum value = -5163 kN/m² (Element 2665 at Stress point 31980)

Maksimum = 4344 kN/m^2
Minimum = -5163 kN/m^2



Total principal stresses (scaled up $2.50*10^{-3}$ times)

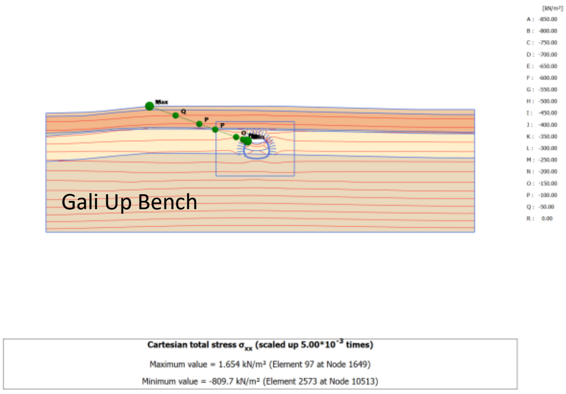
Maximum value = 7201 kN/m² (Element 3458 at Stress point 41486)

Minimum value = -5968 kN/m² (Element 2104 at Stress point 25245)

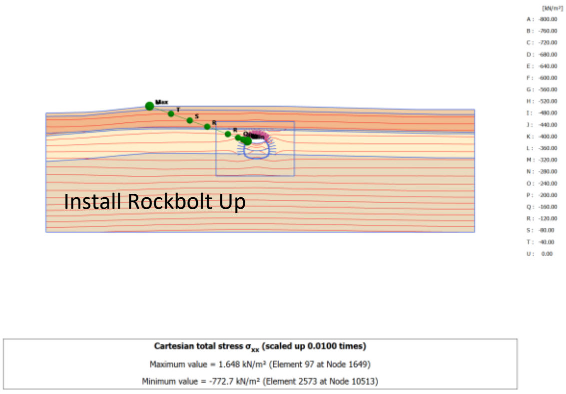
Maximum = 7201 kN/m^2
Minimum = -5968 kN/m^2

Gambar 70 Hasil analisis Total Principal Stresses pada Tunnel Walini (DK 95+715) (lanjutan)

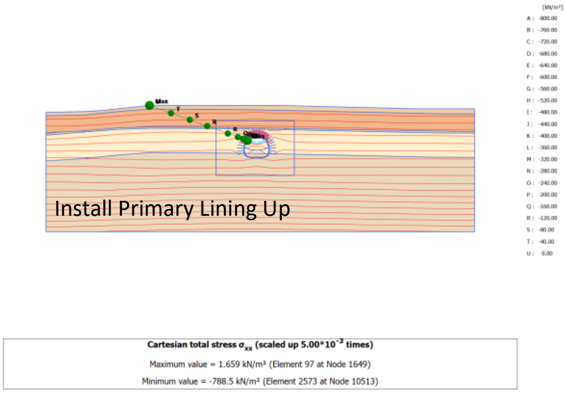
d) *Cross Section DK 95+993*



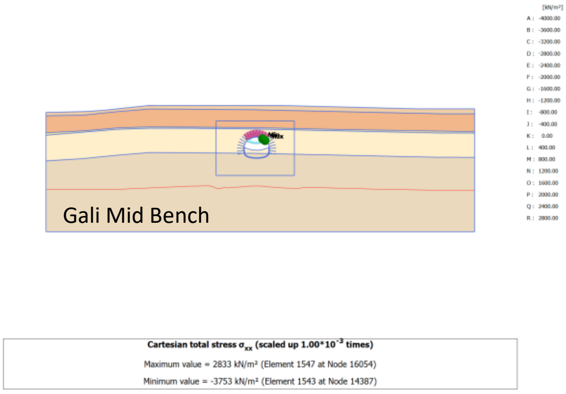
Maximum = 1.654 kN/m^2
Minimum = -809.7 kN/m^2



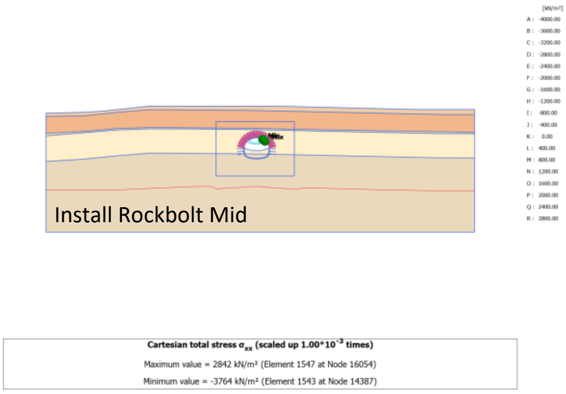
Maximum = 1.648 kN/m^2
Minimum = -772.7 kN/m^2



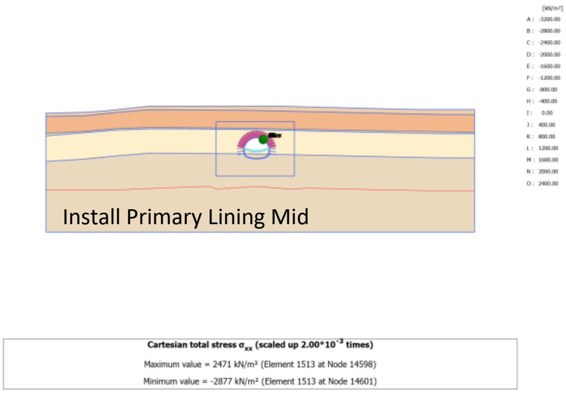
Maximum = 1.659 kN/m^2
Minimum = -788.5 kN/m^2



Maximum = 2833 kN/m^2
Minimum = -3753 kN/m^2

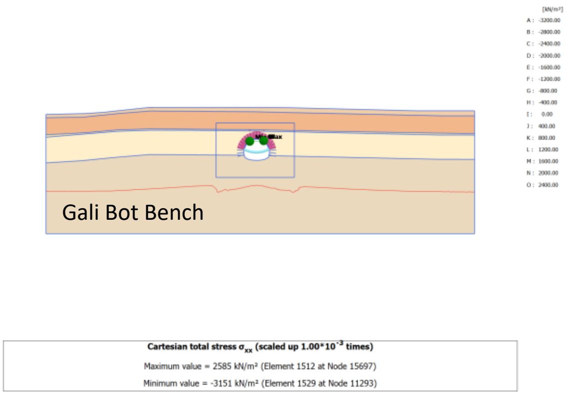


Maximum = 2842 kN/m^2
Minimum = -3764 kN/m^2

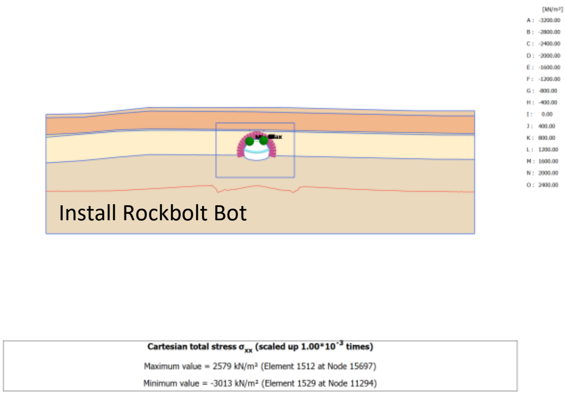


Maximum = 2471 kN/m^2
Minimum = -2877 kN/m^2

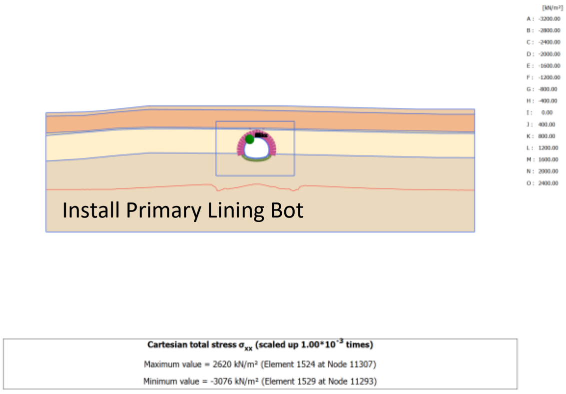
Gambar 71 Hasil analisis tegangan horizontal (σ_x) pada Tunnel Walini (DK 95+993)



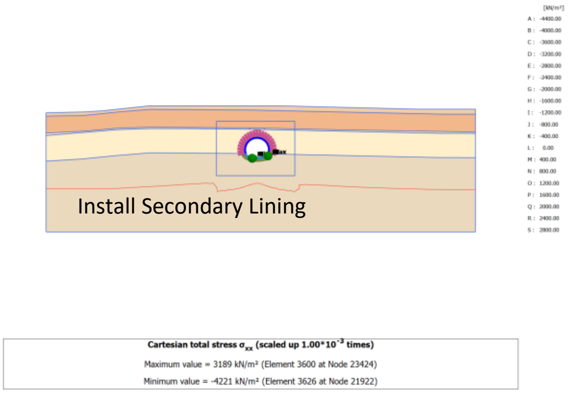
Maksimum = 2585 kN/m^2
Minimum = -3151 kN/m^2



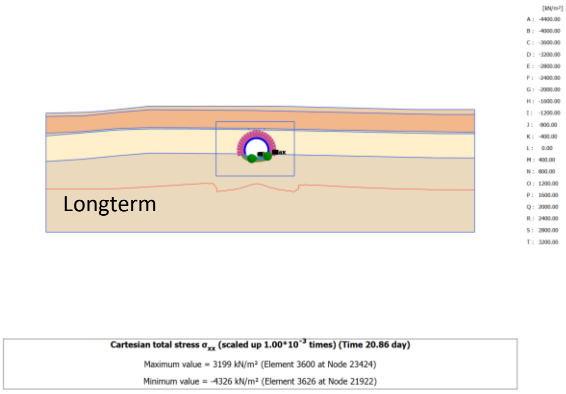
Maximum = 2576 kN/m^2
Minimum = -3013 kN/m^2



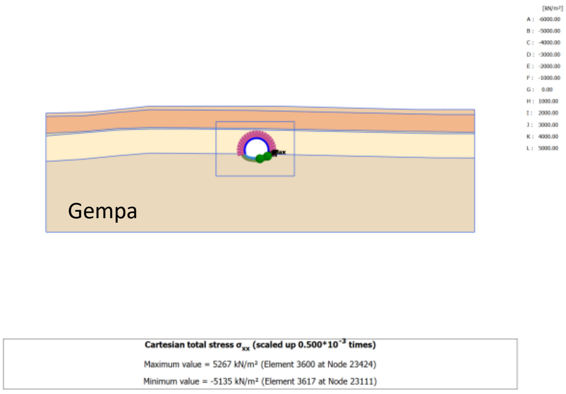
Maximum = 2620 kN/m^2
Minimum = -3076 kN/m^2



Maximum = 3189 kN/m^2
Minimum = -4221 kN/m^2

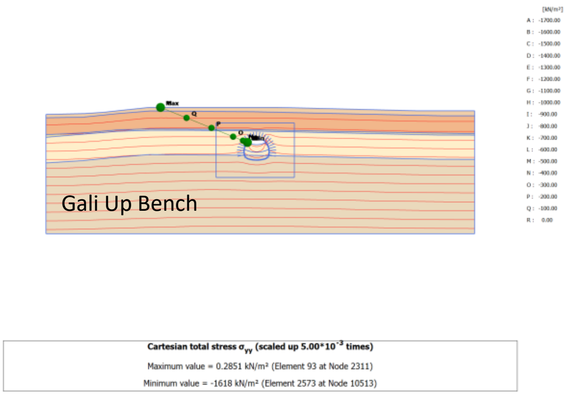


Maksimum = 3199 kN/m^2
Minimum = -4326 kN/m^2

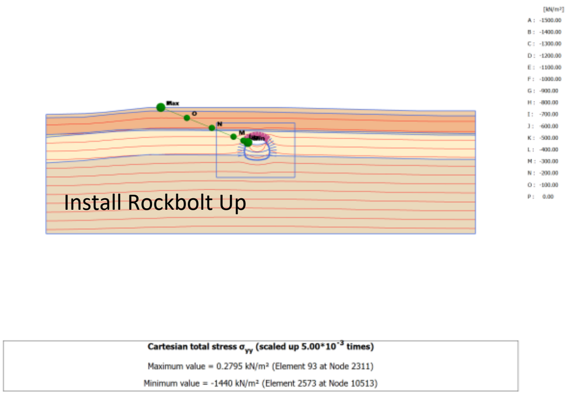


Maximum = 5267 kN/m^2
Minimum = -5135 kN/m^2

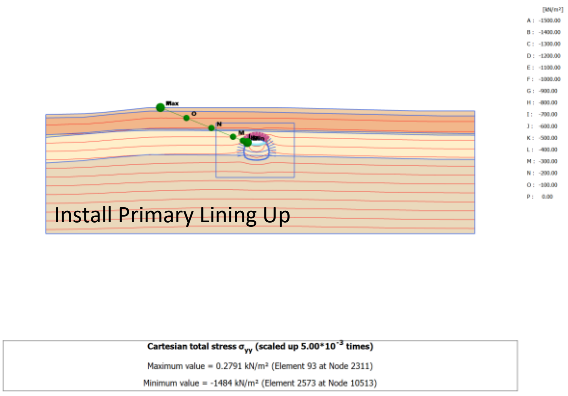
Gambar 72 Hasil analisis tegangan horizontal (σ_x) pada Tunnel Walini (DK 95+993) (lanjutan)



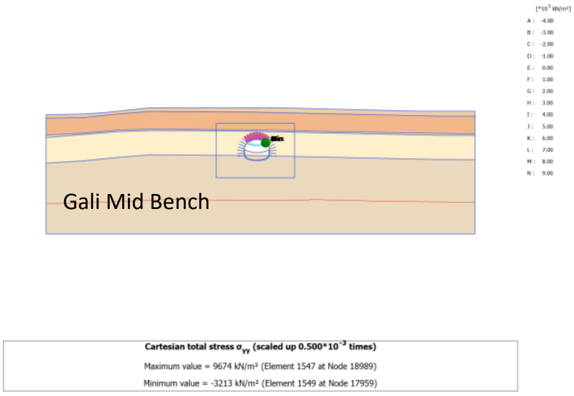
Maximum = 0.2851 kN/m^2
Minimum = -1618 kN/m^2



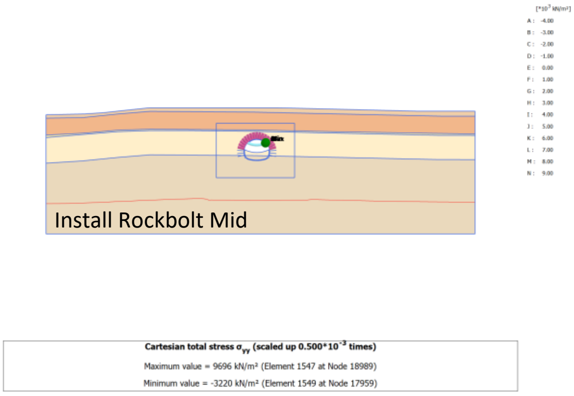
Maximum = 0.2795 kN/m^2
Minimum = -1440 kN/m^2



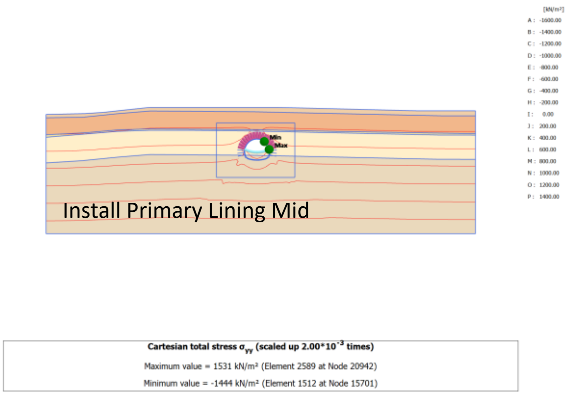
Maximum = 0.2791 kN/m^2
Minimum = -1484 kN/m^2



Maximum = 9674 kN/m^2
Minimum = -3213 kN/m^2

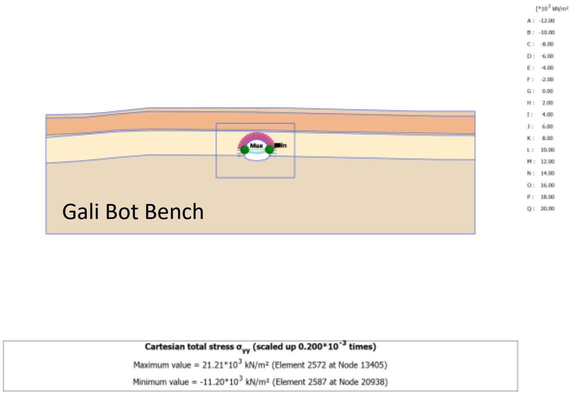


Maximum = 9696 kN/m^2
Minimum = -3220 kN/m^2

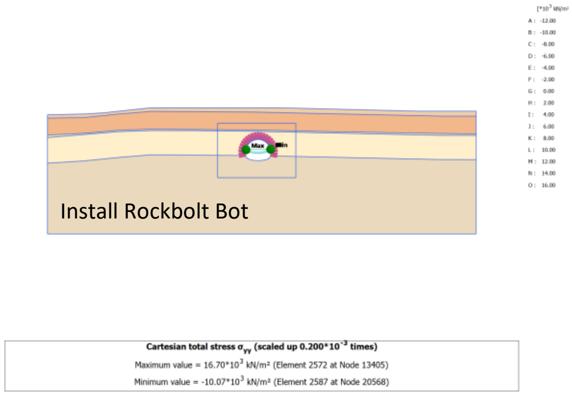


Maximum = 1531 kN/m^2
Minimum = -1444 kN/m^2

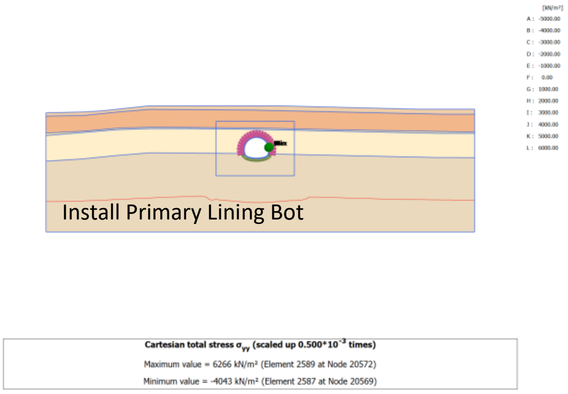
Gambar 73 Hasil analisis tegangan vertikal (σy) pada Tunnel Walini (DK 95+993)



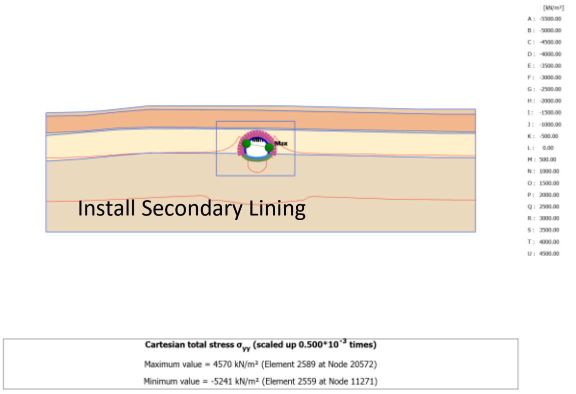
Maksimum = 21.21 x10^3 kN/m^2
Minimum = -11.20 x10^3 kN/m^2



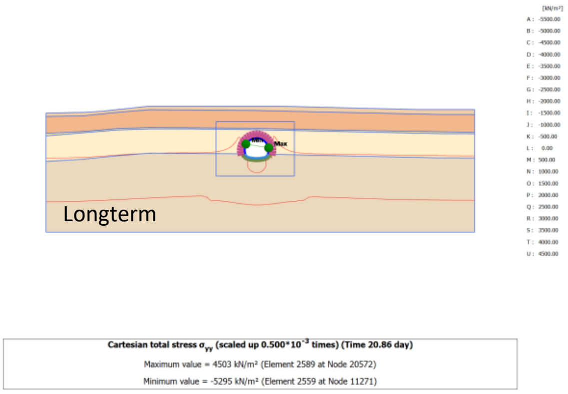
Maximum = 16.70 x10^3 kN/m^2
Minimum = -10.07 x10^3 kN/m^2



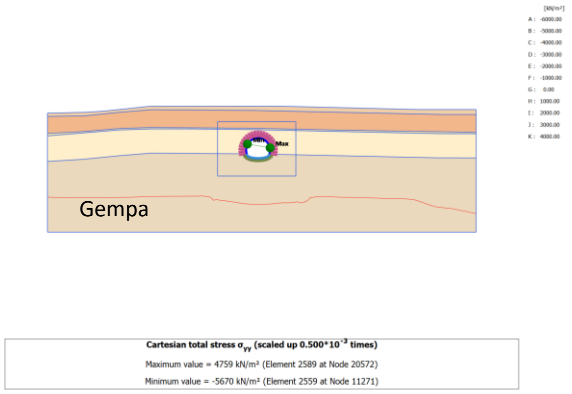
Maximum = 6266 kN/m^2
Minimum = -4043 kN/m^2



Maximum = 4570 kN/m^2
Minimum = -5241 kN/m^2

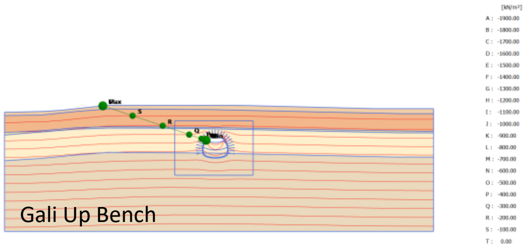


Maksimum = 4503 kN/m^2
Minimum = -5295 kN/m^2



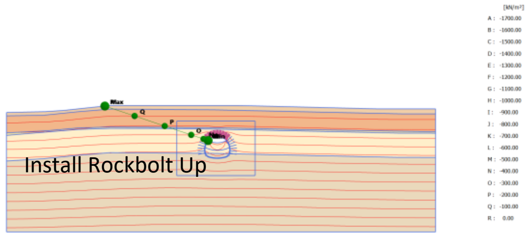
Maximum = 4759 kN/m^2
Minimum = -5670 kN/m^2

Gambar 74 Hasil analisis tegangan vertikal (σy) pada Tunnel Walini (DK 95+993) (lanjutan)



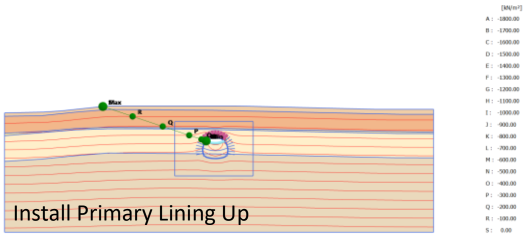
Principal total stress σ_1 (scaled up 5.00×10^{-3} times)
Maximum value = 0.2499 kN/m² (Element 104 at Node 1097)
Minimum value = -1862 kN/m² (Element 2573 at Node 10513)

Maximum = 0.2499 kN/m^2
Minimum = -1862 kN/m^2



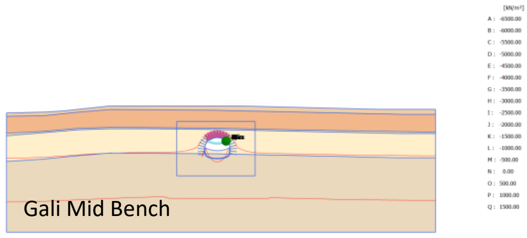
Principal total stress σ_1 (scaled up 5.00×10^{-3} times)
Maximum value = 0.2336 kN/m² (Element 104 at Node 1097)
Minimum value = -1679 kN/m² (Element 2573 at Node 10513)

Maximum = 0.2336 kN/m^2
Minimum = -1679 kN/m^2



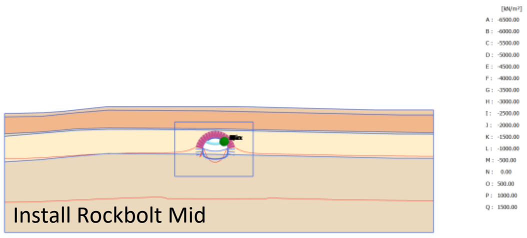
Principal total stress σ_1 (scaled up 5.00×10^{-3} times)
Maximum value = 0.2354 kN/m² (Element 104 at Node 1097)
Minimum value = -1712 kN/m² (Element 2573 at Node 10513)

Maximum = 0.02354 kN/m^2
Minimum = -1712 kN/m^2



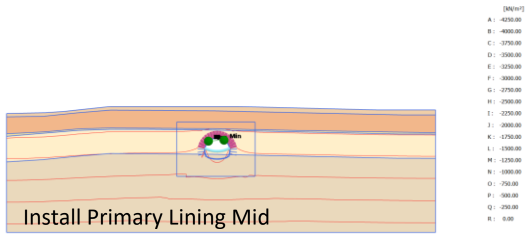
Principal total stress σ_1 (scaled up 0.500×10^{-3} times)
Maximum value = 1780 kN/m² (Element 1547 at Node 18989)
Minimum value = -6266 kN/m² (Element 1549 at Node 17958)

Maximum = 1780 kN/m^2
Minimum = -6266 kN/m^2



Principal total stress σ_1 (scaled up 0.500×10^{-3} times)
Maximum value = 1783 kN/m² (Element 1547 at Node 18989)
Minimum value = -6279 kN/m² (Element 1549 at Node 17958)

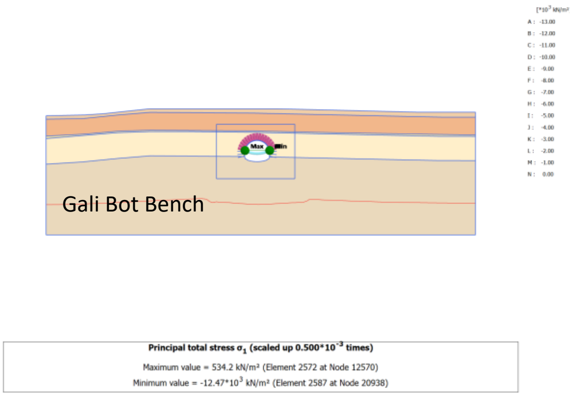
Maximum = 1783 kN/m^2
Minimum = -6279 kN/m^2



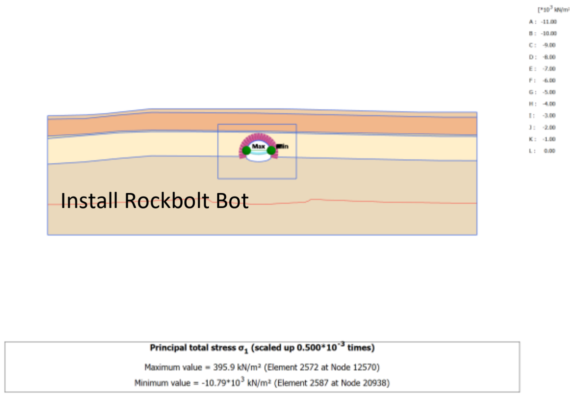
Principal total stress σ_1 (scaled up 2.00×10^{-3} times)
Maximum value = 4.957 kN/m² (Element 1550 at Node 10514)
Minimum value = -4029 kN/m² (Element 1544 at Node 14604)

Maximum = 4.957 kN/m^2
Minimum = -4029 kN/m^2

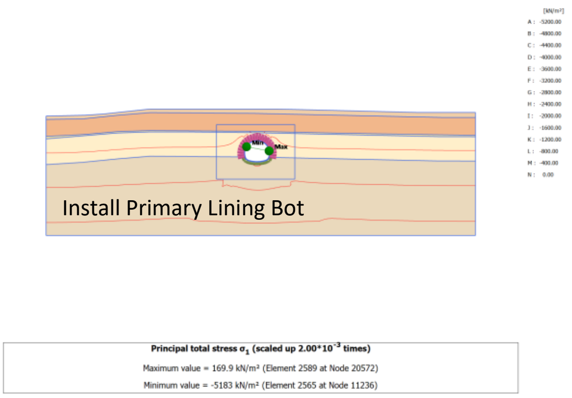
Gambar 75 Hasil analisis tegangan maksimum (σ1) pada Tunnel Walini (DK 95+993)



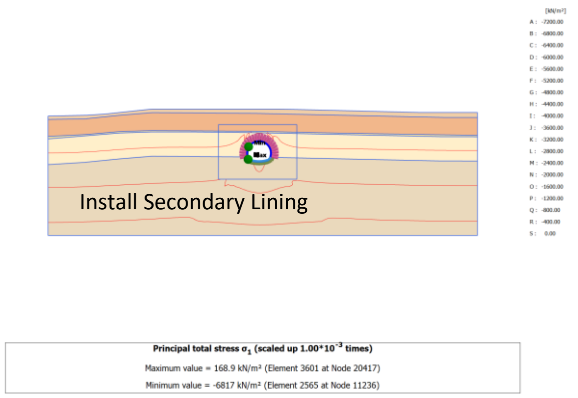
Maksimum = 534.2 kN/m^2
Minimum = -12.47 x10^3 kN/m^2



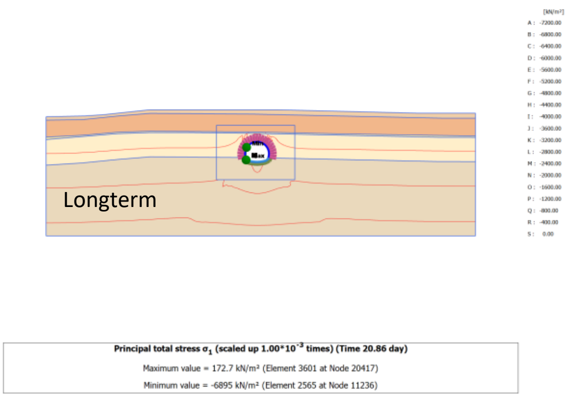
Maximum = 395.9 kN/m^2
Minimum = -10.79 x10^3 kN/m^2



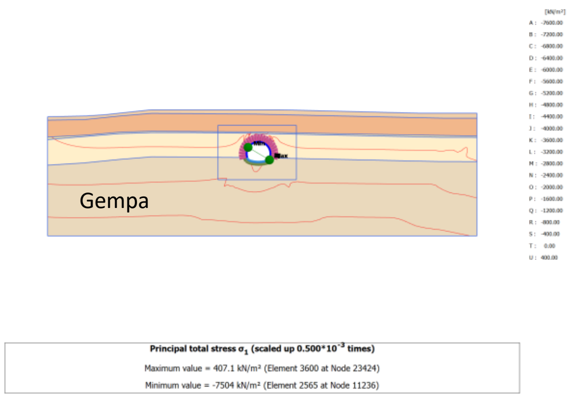
Maximum = 169.9 kN/m^2
Minimum = -5183 kN/m^2



Maximum = 168.9 kN/m^2
Minimum = -6817 kN/m^2

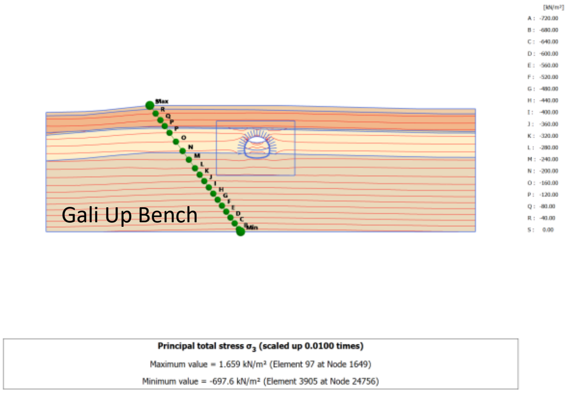


Maksimum = 172.7 kN/m^2
Minimum = -6895 kN/m^2

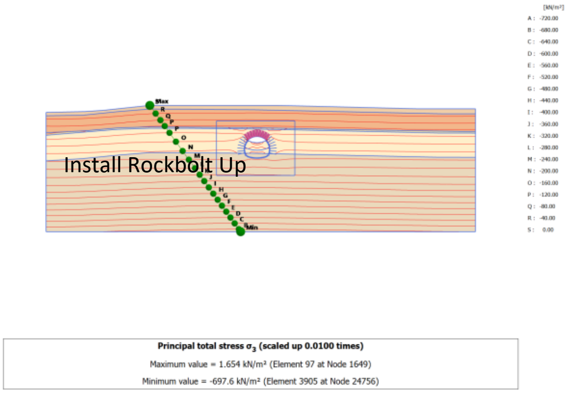


Maximum = 407.1 kN/m^2
Minimum = -7504 kN/m^2

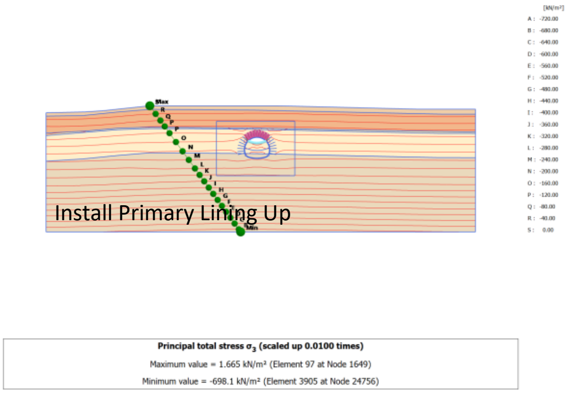
Gambar 76 Hasil analisis tegangan maksimum (σ1) pada Tunnel Walini (DK 95+993) (lanjutan)



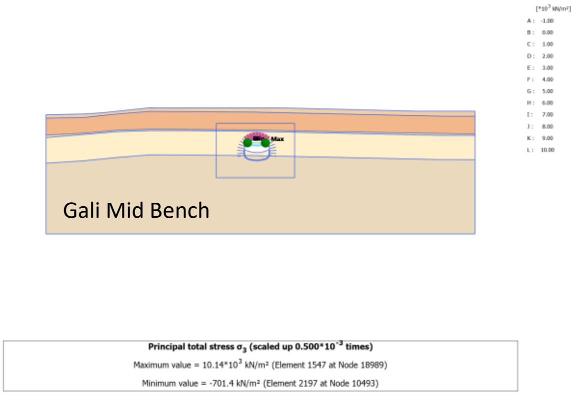
Maximum = 1.659 kN/m^2
Minimum = -697.6 kN/m^2



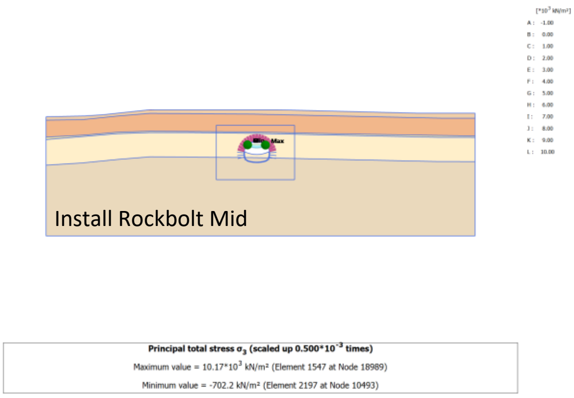
Maximum = 1.654 kN/m^2
Minimum = -697.6 kN/m^2



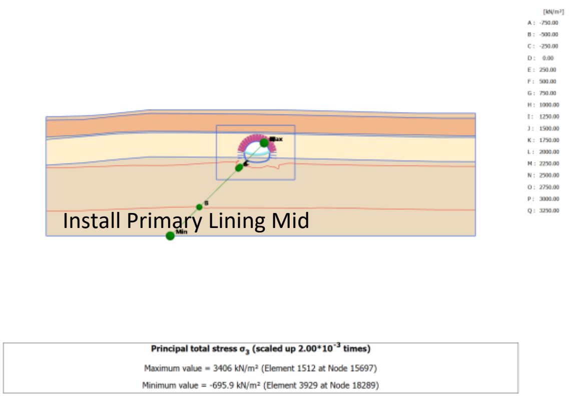
Maximum = 1.665 kN/m^2
Minimum = -698.1 kN/m^2



Maximum = 10.14 x10^3 kN/m^2
Minimum = -701.4 kN/m^2

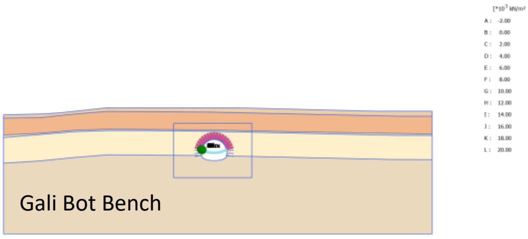


Maximum = 10.17 x10^3 kN/m^2
Minimum = -702.2 kN/m^2



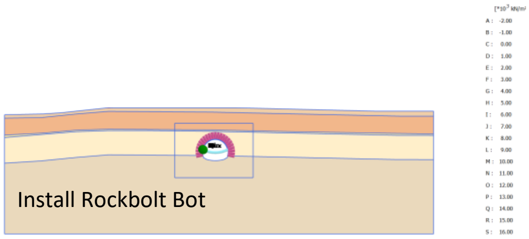
Maximum = 3406 kN/m^2
Minimum = -695.9 kN/m^2

Gambar 77 Hasil analisis tegangan minimum (σ3) pada Tunnel Walini (DK 95+993)



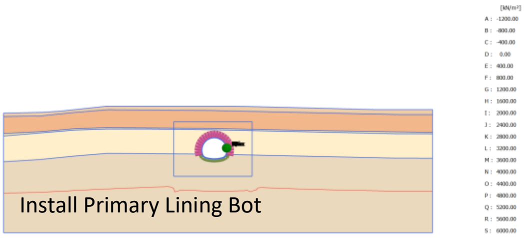
Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times)
Maximum value = $21.23*10^3$ kN/m² (Element 2572 at Node 13405)
Minimum value = -1404 kN/m² (Element 2570 at Node 13401)

Maksimum = 21.23 x10^3 kN/m^2
Minimum = -1404 kN/m^2



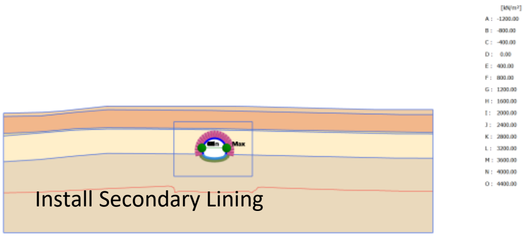
Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times)
Maximum value = $16.70*10^3$ kN/m² (Element 2572 at Node 13405)
Minimum value = -1521 kN/m² (Element 2570 at Node 13401)

Maximum = 16.70 x10^3 kN/m^2
Minimum = -1521 kN/m^2



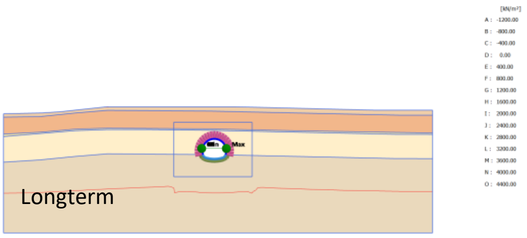
Principal total stress σ_3 (scaled up $1.00*10^{-3}$ times)
Maximum value = 6293 kN/m² (Element 2589 at Node 20572)
Minimum value = -879.0 kN/m² (Element 2094 at Node 22940)

Maximum = 6293 kN/m^2
Minimum = -879.0 kN/m^2



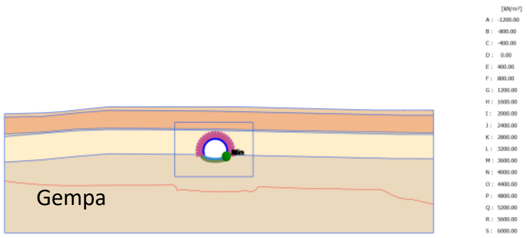
Principal total stress σ_3 (scaled up $2.00*10^{-3}$ times)
Maximum value = 4571 kN/m² (Element 2589 at Node 20572)
Minimum value = -941.4 kN/m² (Element 2093 at Node 14191)

Maximum = 4571 kN/m^2
Minimum = -941.4 kN/m^2



Principal total stress σ_3 (scaled up $2.00*10^{-3}$ times) (Time 20.86 day)
Maximum value = 4503 kN/m² (Element 2589 at Node 20572)
Minimum value = -944.2 kN/m² (Element 2093 at Node 14191)

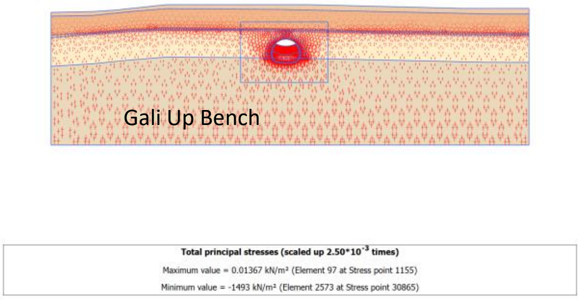
Maksimum = 4503 kN/m^2
Minimum = -944.2 kN/m^2



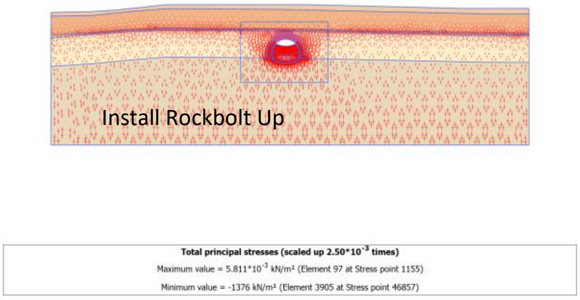
Principal total stress σ_3 (scaled up $1.00*10^{-3}$ times)
Maximum value = 6336 kN/m² (Element 3600 at Node 23424)
Minimum value = -1002 kN/m² (Element 3631 at Node 23389)

Maximum = 6336 kN/m^2
Minimum = -1002 kN/m^2

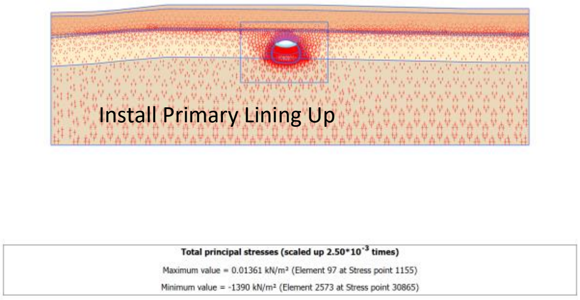
Gambar 78 Hasil analisis tegangan minimum (σ3) pada Tunnel Walini (DK 95+993) (lanjutan)



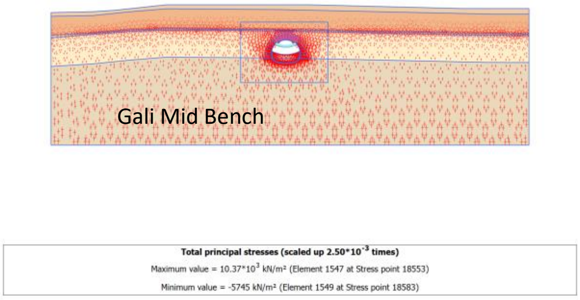
Maximum = 0.01367 kN/m^2
Minimum = -1493 kN/m^2



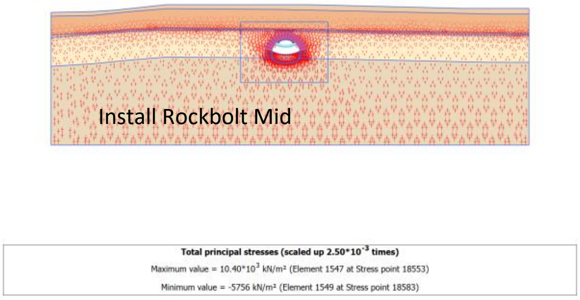
Maximum = 5.811 x10^{-3} kN/m^2
Minimum = -1376 kN/m^2



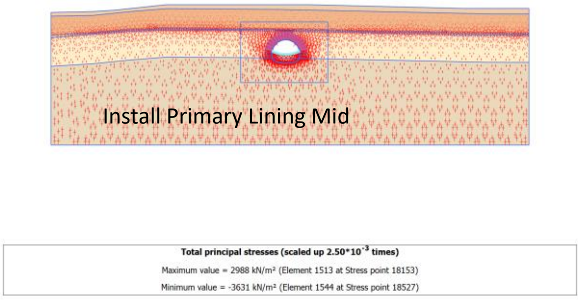
Maximum = 0.01361 kN/m^2
Minimum = -1390 kN/m^2



Maximum = 10.37 x10^3 kN/m^2
Minimum = -5745 kN/m^2

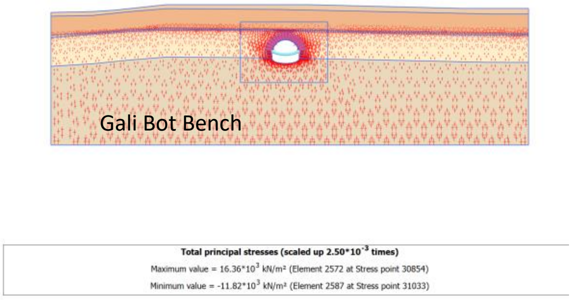


Maximum = 10.40 x10^3 kN/m^2
Minimum = -5756 kN/m^2

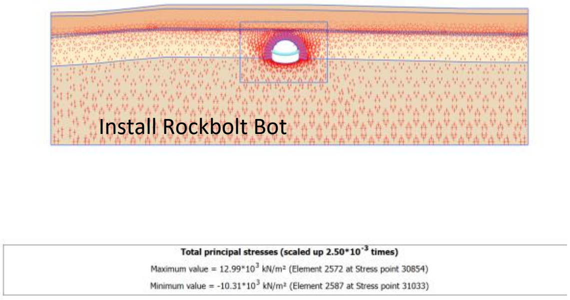


Maximum = 2988 kN/m^2
Minimum = -3631 kN/m^2

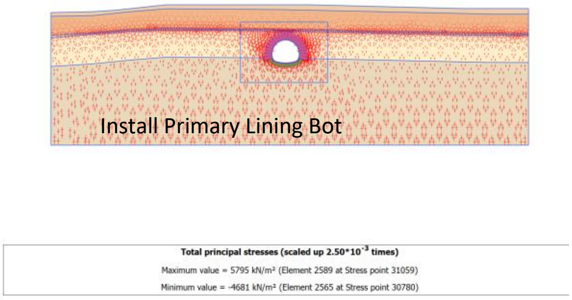
Gambar 79 Hasil analisis Total Principal Stresses pada Tunnel Walini (DK 95+993)



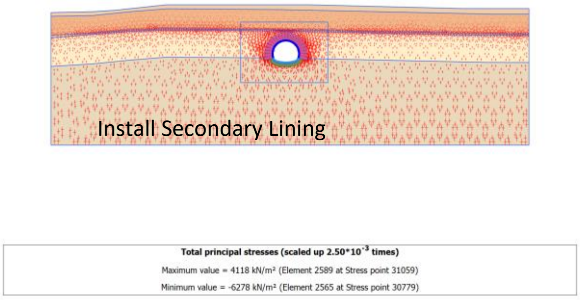
Maksimum = 16.36 x10^3 kN/m^2
Minimum = -11.82 x10^3 kN/m^2



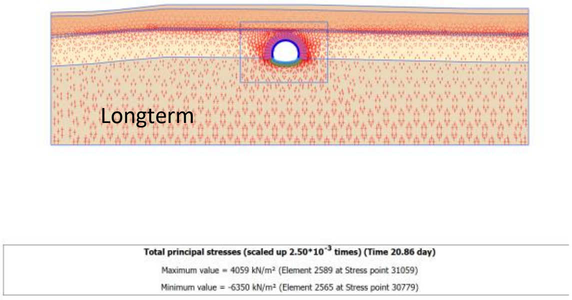
Maximum = 12.99 x10^3 kN/m^2
Minimum = -10.31 x10^3 kN/m^2



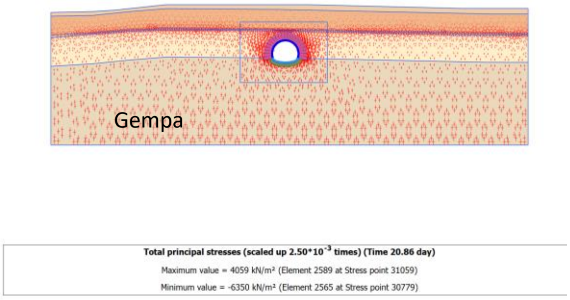
Maximum = 5795 kN/m^2
Minimum = -4681 kN/m^2



Maximum = 4118 kN/m^2
Minimum = -6278 kN/m^2



Maksimum = 4059 kN/m^2
Minimum = -6350 kN/m^2



Maximum = 4059 kN/m^2
Minimum = -6350 kN/m^2

Gambar 80 Hasil analisis Total Principal Stresses pada Tunnel Walini (DK 95+993) (lanjutan)