PROPOSAL PENGABDIAN KEPADA MASYARAKAT

REVIEW DESAIN TUNNEL NO. 5

(PEMODELAN FEM MENGGUNAKAN PLAXIS 2D) KERETA CEPAT JAKARTA BANDUNG

Ketua Tim :

Dr. techn. Indra Noer Hamdhan

Anggota:

Ahmad Faisal Amri (22-2015-225)

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

2018

HALAMAN PENGESAHAN

1.	Judul	: Review Desain Tunnel No. 5 (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
3.	Bentuk Kegiatan	: Pelatihan
4.	Waktu Kegiatan	: 1 November - 31 Desember 2018
5.	Sumber Dana	: ASEA-UNINET dan RKAT Jurusan Teknik Sipil
6.	Jumlah Dana	: Rp. 20.000.000

Bandung, 6 September 2018

Pelaksana	Ketua Jurusan Teknik Sipil
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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	
		Length（m）	Number
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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

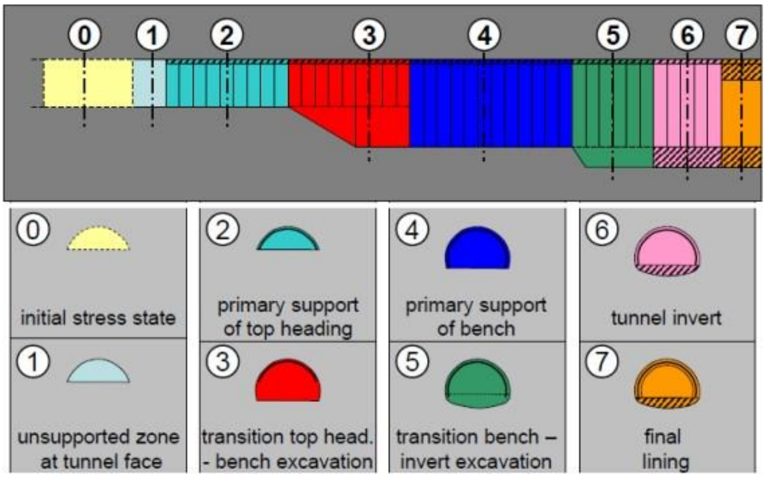
Pada masa operasional, deformasi izin pada *track* kereta cepat mengacu pada QCR9230-2016 dimana besar deformasi izinnya sebesar 15 mm. Sedangkan pada konstruksi, deformasi izin pada terowongan dapat dilihat pada **Tabel 5**.

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

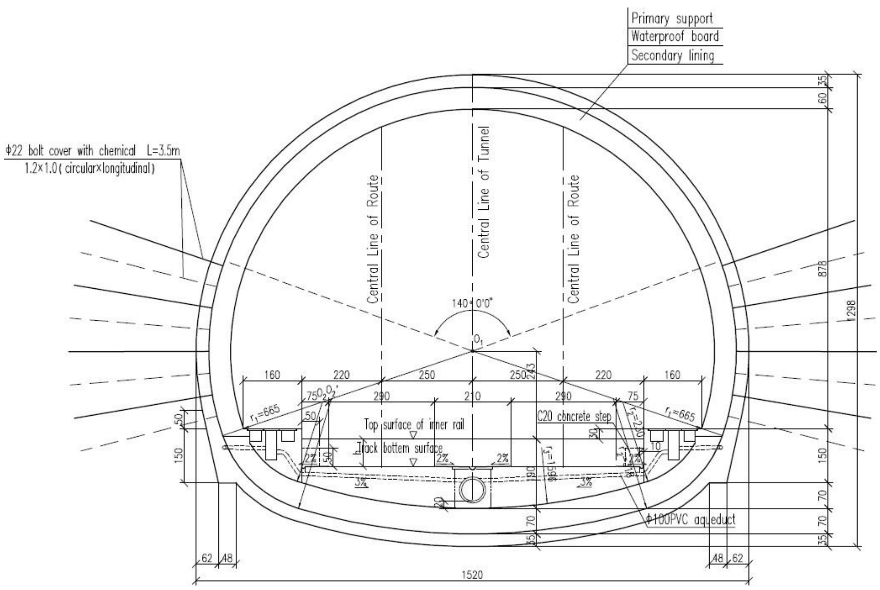
New Austrian Tunneling Method (NATM) : NATM merupakan metode *excavation* pada terowongan yang dilakukan secara manual dan bertahap. Tahapan pertama dalam metode ini adalah proses *excavation* pada area *tunnel* yang dapat dilakukan dengan menggunakan alat *twin header* dan *excavator*. Pembuangan tanah 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 No.5

Table 6 Pemilihan tipe lining berdasarkan jenis tanah/batuan

Surrounding rock	Lining type	Applicable conditions
Ⅱ	Ⅱa	Ⅱ surrounding rock area
Ⅲ	Ⅲa	Ⅲ surrounding rock area
	Ⅲb	Ⅲ surrounding rock of horizontal stratification area (Strata dip Angle≤ 15°) adverse rock area
Ⅳ	Ⅳa	Ⅳ surrounding rock of deep buried section
	Ⅳb	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
	Ⅳp	Ⅳ surrounding rock of moderate swelling rock section
Ⅴ	Ⅴr-a	Ⅴ surrounding rock of deep buried rock section
	Ⅴr-b	Ⅴ surrounding rock of shallow buried seismic fortification rock section
	Ⅴr-c	Ⅴ surrounding rock of bias, fault fracture, rock section
	Ⅴr-p	Ⅴ surrounding rock of moderate swelling rock section
	Ⅴs-a	Ⅴ surrounding rock of deep buried soil section (Natural water content is smaller)
	Ⅴs-b	Ⅴ surrounding rock of shallow buried seismic fortification soil section (or natural water content is smaller)
	Ⅴs-p-1	Ⅴ surrounding rock of expansive soil section (medium swelling)
	Ⅴs-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	Ⅵa	Ⅵ surrounding rock of soft and plastic soil or water-bearing sand layer area
	Ⅵb	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	Ⅱa	arch wall5	—	—	—	—	—	—	—	—	—	35*	35*	3~5
2	Ⅲa	arch wall12	arch wall	Φ6	25×25	arch wall	3	1.2×1.5	—	—	—	40*	50*	5~8
3	Ⅲb	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	Ⅳa	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	Ⅳb	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	Ⅳp	ring28	arch wall	Φ8	20×20	arch wall	4	1.2×1.0	I20a shape steel	ring	0.8	45*	55*	8~10
7	Ⅴr-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	Ⅴr-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	Ⅴr-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	Ⅴr-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	Ⅴs-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	Ⅴs-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	Ⅴs-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	Ⅴs-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	Ⅵa	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	Ⅵb	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

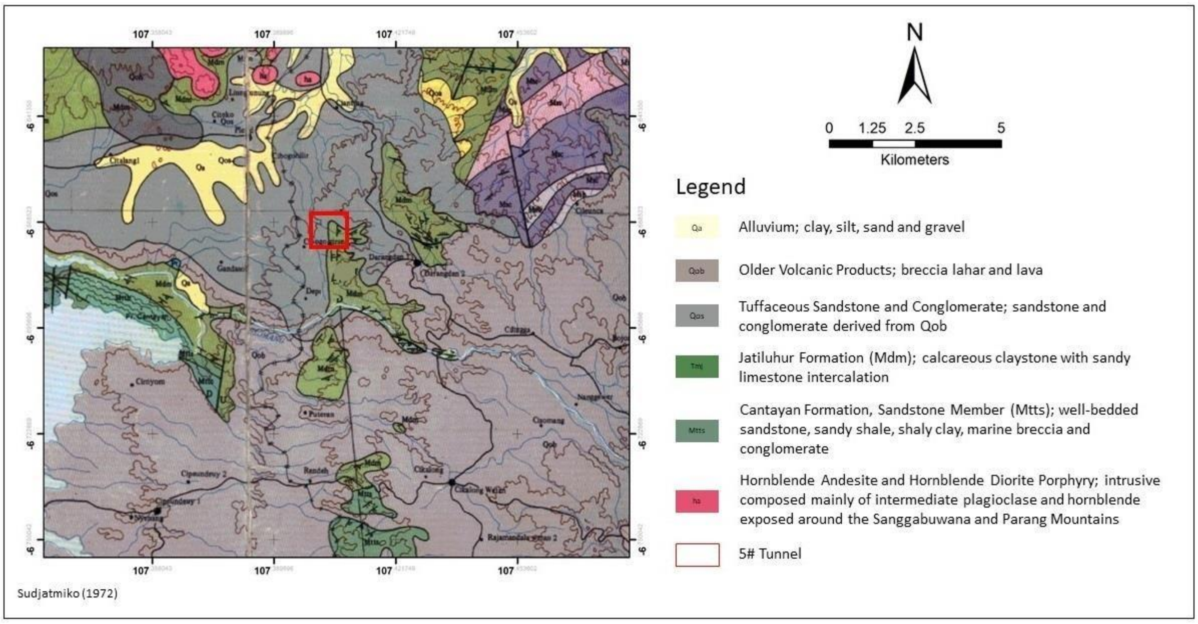
A. Data Umum Terowongan No.5

Terowongan No.5 Kereta Cepat Jakarta Bandung Jakarta, berlokasi di Purwakarta yang bertepatan di sebelah Timur Laut Waduk Jangari. Kondisi tanah disekitar lokasi terowongan mayoritas adalah Clay, Silty Clay dan sebagian Gravel. Metode konstruksi yang diterapkan pada Tunnel No.5 ini adalah metode galian NATM (New Austrian Tunneling Method). Titik awal terowongan berada pada DK86+535 dan titik akhir terowongan pada DK86+957, sehingga total panjang terowongan, yaitu 422m.

Gambar 3 Lokasi *Soil Inestigastion* Terowongan No.5

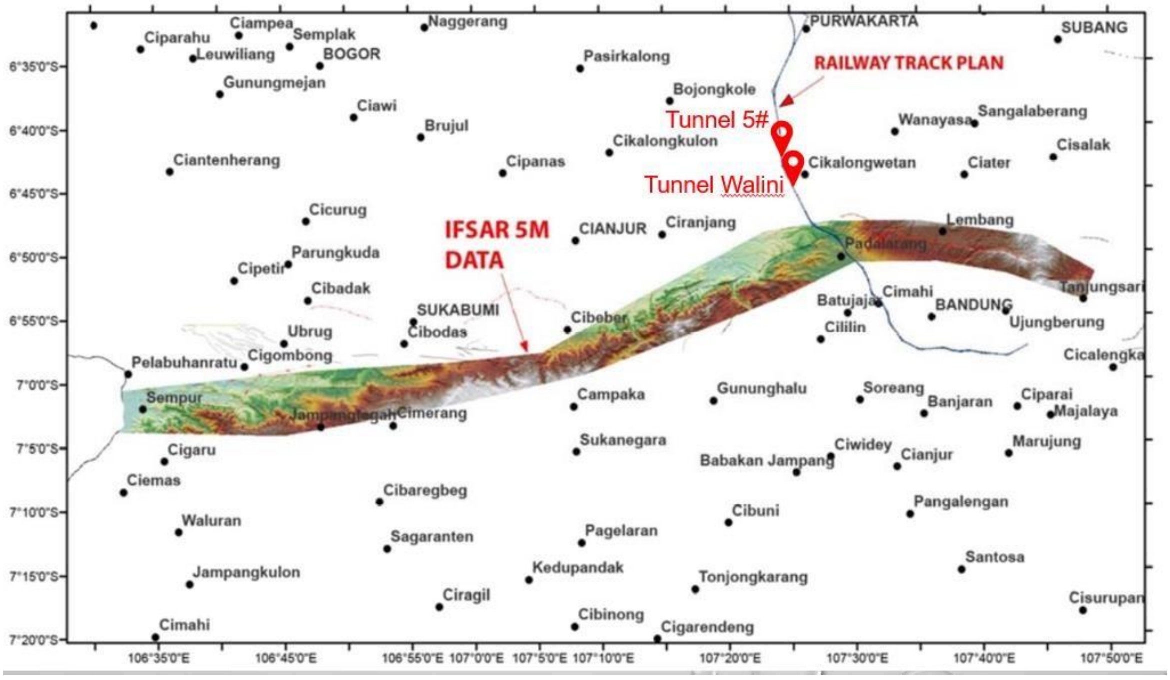
B. Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan

Berdasarkan Peta Geologi (Sudjatmiko, 1972) Terowongan No. 5 berada pada Formasi Jatiluhur (Mdm) dan *Tuffaceous Sandstone and Conglomerate* (Qos). Peta Geologi disajikan pada **Gambar 4.**



Gambar 4 Peta Geologi (Sudjatmiko, 1972)

Berdasarkan data borlog 16-ZD-193 (DK86+900.01), claystone ditemukan pada kedalaman 31 - 32 m. Jika claystone berperilaku seperti clayshale, maka tergolong kedalam tipe unfavourable rock dan perlu menggunakan parameter tersebut dalam perhitungan desain. Clay pada lokasi terowongan memiliki karakteristik weakly expansive dengan free swell ratio 40-49%.



Gambar 5 Hasil Analisis Geologi

Berdasarkan data geologi pada **Gambar 5** disebutkan bahwa pada Terowongan No.5 tidak terdapat *fault zone*.

C. Stratigrafi Tanah dan Data Borlog

Detail stratigrafi tanah di area Terowongan No.5 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 No.5 dapat dilihat dibawah ini:

Dimensi Terowongan

Tipe Lining terowongan : $V_{s\text{-}p\text{-}1}$

Diameter : 15.2 m

Ketebalan

Primary lining (Shotcrete) : 0.35 m

Secondary lining (Reinforced Concrete)

Invert Arch : 0.7 m

Wall Arch : 0.6 m

Material Terowongan

Shotcrete : C30

Reinforced Concrete : C35 dengan tulangan

Tulangan : HPB300 ($\varphi \leq 10$ mm)
HRB400 ($\varphi \geq 16$ mm)

Fill inverted arch : Beton C20

Ditch and cable duct : Beton C30

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- TB/T 3275-2011 : Concrete for Railway Construction
- GB/T14685-2011 : Pebble and Crushed Stone for Contruction
- TB/T 3275-2011 : Concrete for Railway Construction
- 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

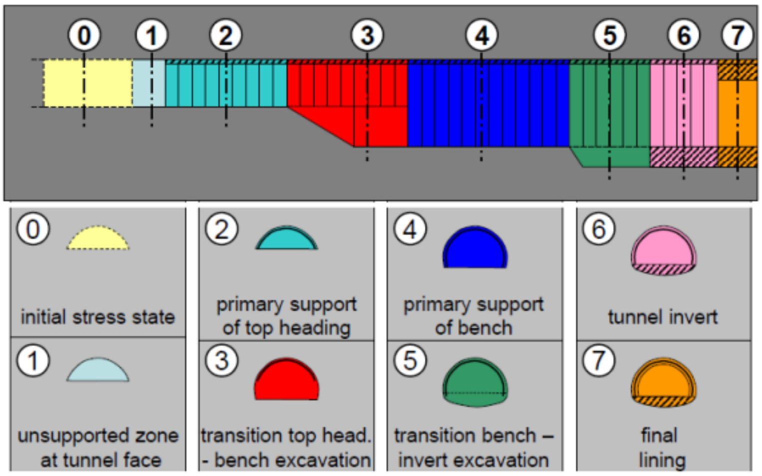
Pada masa operasional, deformasi izin pada *track* kereta cepat mengacu pada QCR9230-2016 dimana besar deformasi izinnya sebesar 15 mm. Sedangkan pada konstruksi, deformasi izin pada terowongan dapat dilihat pada **Tabel 5**.

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

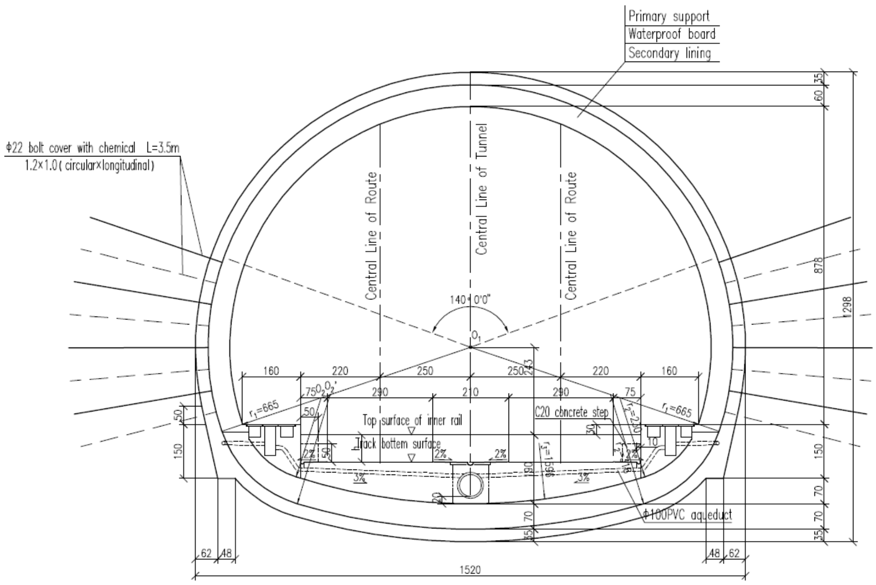
New Austrian Tunneling Method (NATM) : NATM merupakan metode *excavation* pada terowongan yang dilakukan secara manual dan bertahap. Tahapan pertama dalam metode ini adalah proses *excavation* pada area *tunnel* yang dapat dilakukan dengan menggunakan alat *twin header* dan *excavator*. Pembuangan tanah 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 No.5

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

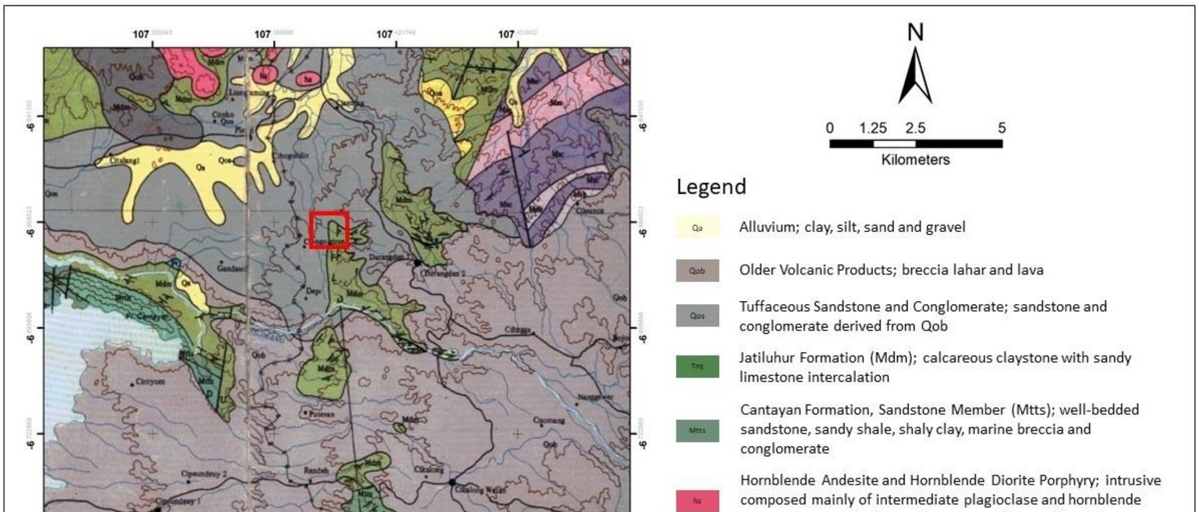
A. Data Umum Terowongan No.5

Terowongan No.5 Kereta Cepat Jakarta Bandung Jakarta, berlokasi di Purwakarta yang bertepatan di sebelah Timur Laut Waduk Jangari. Kondisi tanah disekitar lokasi terowongan mayoritas adalah Clay, Silty Clay dan sebagian Gravel. Metode konstruksi yang diterapkan pada Tunnel No.5 ini adalah metode galian NATM (New Austrian Tunneling Method). Titik awal terowongan berada pada DK86+535 dan titik akhir terowongan pada DK86+957, sehingga total panjang terowongan, yaitu 422m.

Gambar 3 Lokasi *Soil Inestigastion* Terowongan No.5

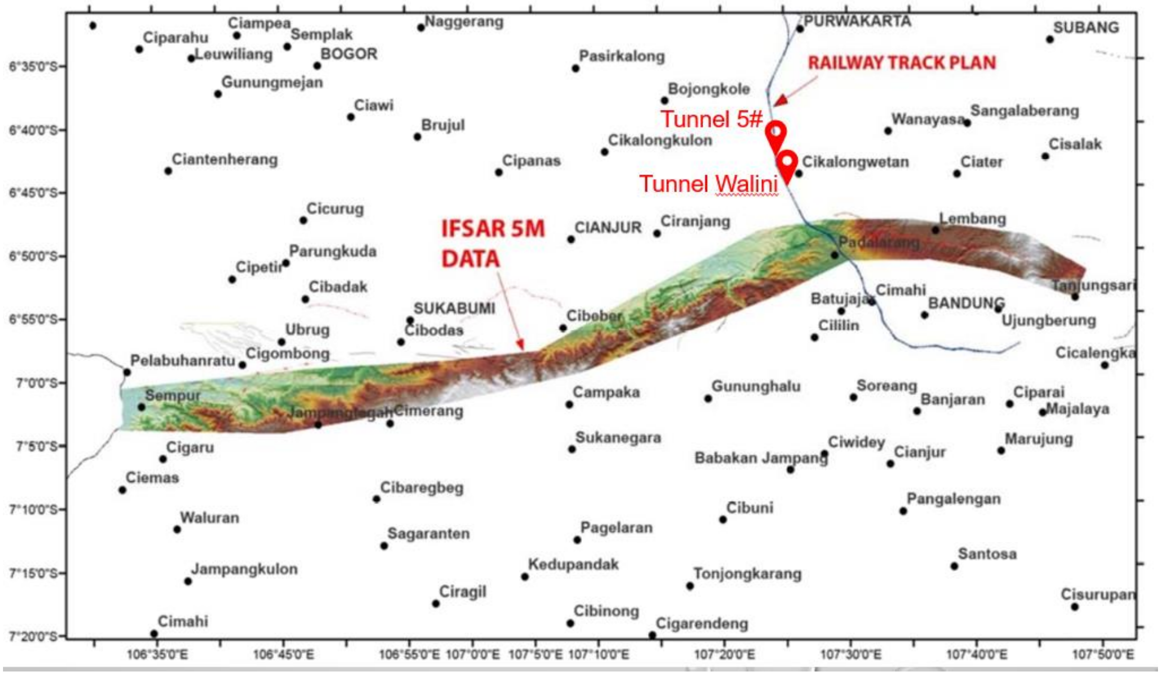
B. Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan

Berdasarkan Peta Geologi (Sudjatmiko, 1972) Terowongan No. 5 berada pada Formasi Jatiluhur (Mdm) dan *Tuffaceous Sandstone and Conglomerate* (Qos). Peta Geologi disajikan pada **Gambar 4.**



Gambar 4 Peta Geologi (Sudjatmiko, 1972)

Berdasarkan data borlog 16-ZD-193 (DK86+900.01), claystone ditemukan pada kedalaman 31 - 32 m. Jika claystone berperilaku seperti clayshale, maka tergolong kedalam tipe unfavourable rock dan perlu menggunakan parameter tersebut dalam perhitungan desain. Clay pada lokasi terowongan memiliki karakteristik weakly expansive dengan free swell ratio 40-49%.



Gambar 5 Hasil Analisis Geologi

Berdasarkan data geologi pada **Gambar 5** disebutkan bahwa pada Terowongan No.5 tidak terdapat *fault zone*.

C. Stratigrafi Tanah dan Data Borlog

Detail stratigrafi tanah di area Terowongan No.5 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 No.5 dapat dilihat dibawah ini:

Dimensi Terowongan

Tipe Lining terowongan	: $V_{s\text{-}p\text{-}1}$
Diameter	: 15.2 m

Ketebalan

Primary lining (Shotcrete)	: 0.35 m

Secondary lining (Reinforced Concrete)

Invert Arch	: 0.7 m
Wall Arch	: 0.6 m

Material Terowongan

Shotcrete	: C30
Reinforced Concrete	: C35 dengan tulangan
Tulangan	: HPB300 ($\varphi \leq 10$ mm)
	HRB400 ($\varphi \geq 16$ 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)

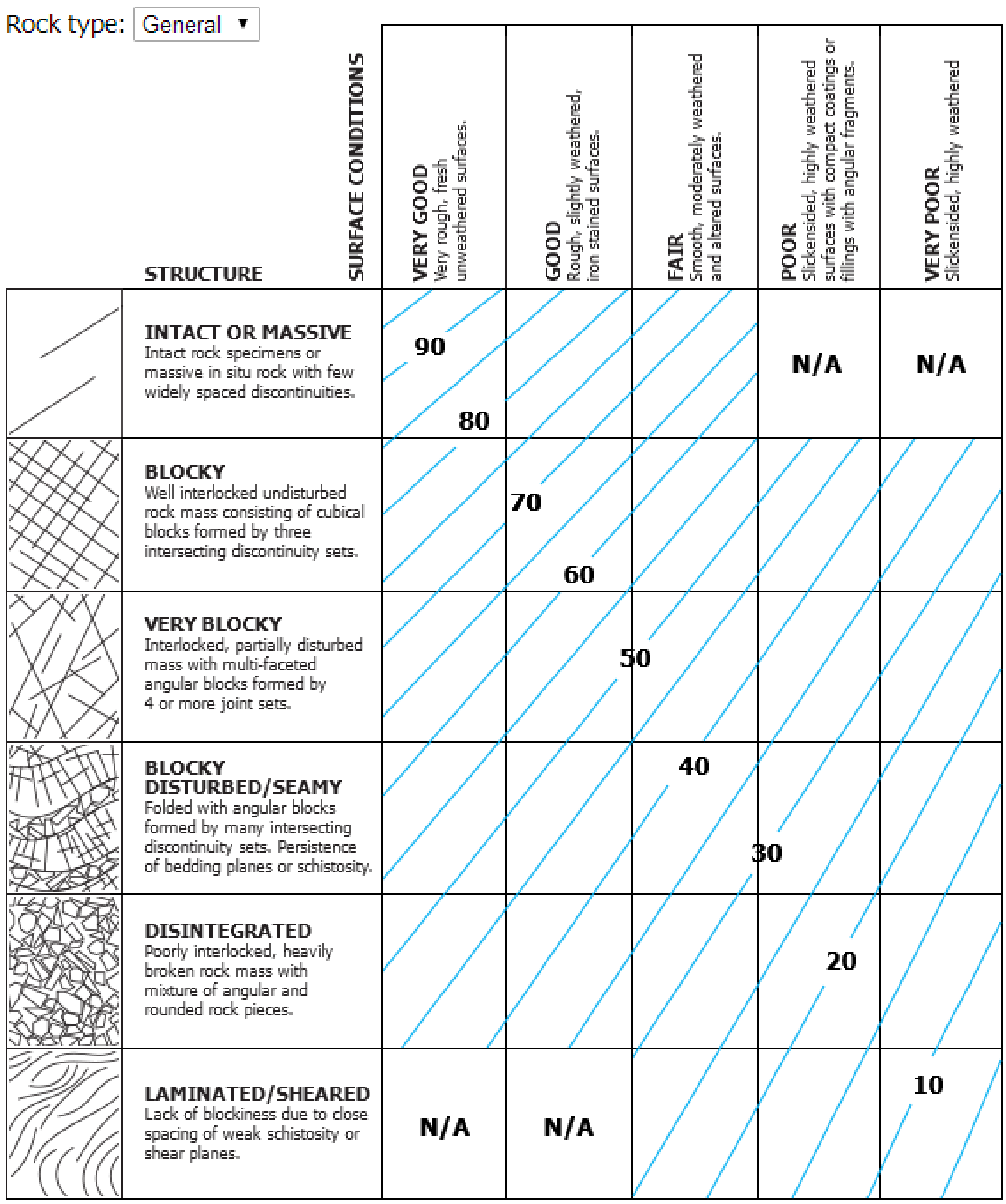
	Texture			
	Coarse	Medium	Fine	Very fine
Sedimentary	Conglomerates	Sandstones	Siltstones	Claystones
	300–400	200–350	350–400	200–300
	Breccias		Greywackes	Shales
	230–350		350	150–250[a]
				Marls
				150–200
	Crystalline limestone	Sparitic limestone	Micritic limestone	Dolomite
	400–600	600–800	800–1000	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)

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

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



4. Pemodelan Terowongan No.5

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

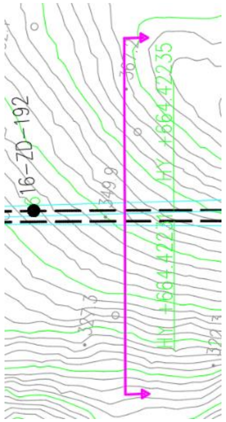
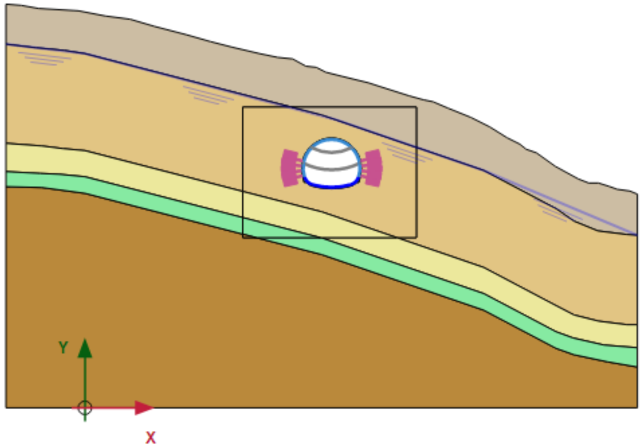
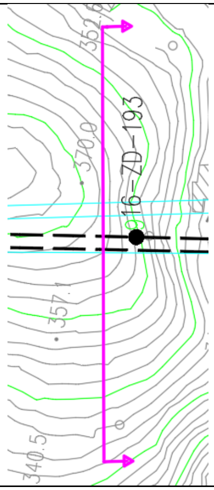
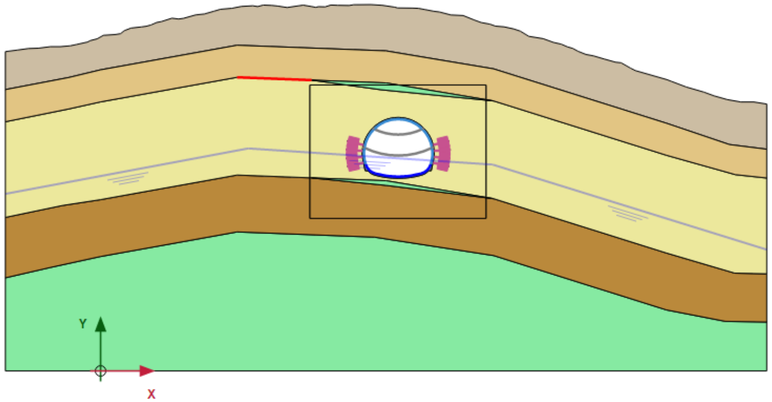
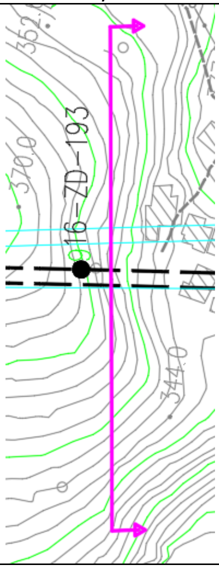
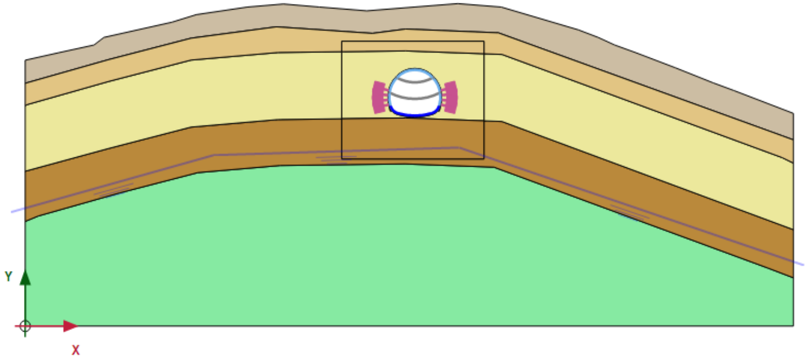
No. Potongan	Layout	Potongan Melintang	Keterangan
TUNNEL 5 (DK86+640)			Tidak ada beban jalan dan bangunan pada permukaan
TUNNEL 5 (DK86+890)			Tidak ada beban jalan dan bangunan pada permukaan

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

No. Potongan	Layout	Potongan Melintang	Keterangan
TUNNEL 5 (DK86+905)			Tidak ada beban jalan dan bangunan pada permukaan

B. Parameter-Parameter Pemodelan Terowongan No.5

1. Cross Section DK 86+640

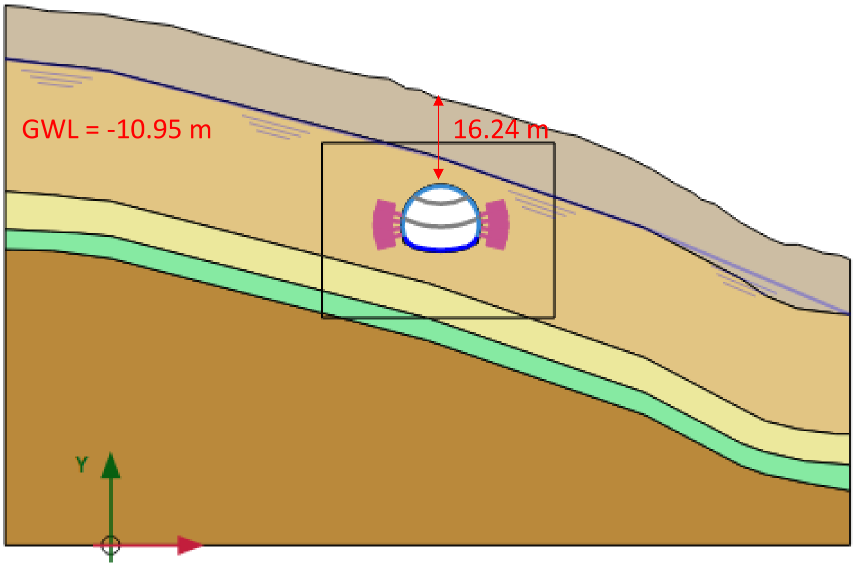


Table 14 Parameter Tanah Tunnel No.5 (DK 86 +640)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	γunsat (kN/m3)	γsat (kN/m3)	υ	c' (kPa)	ϕ' (degrees)	k (m/day)
1	0-10.45	10.45	7	Clay	15	16	0.5	15	30	0.000864
2	10.45-35	24.55	47	Silty Clay	17	18	0.5	35	47	0.00864
3	35-41.6	6.6	45	Clay	18	19	0.5	30	46	0.000864
4	41.6-45.8	4.2	50	Andesit	21	22	0.2	-	-	-
5	45.8-50	4.2	50	Clay	18	19	0.5	40	48	0.000864

Table 15 Nilai Modulus Elastisitas tanah di Tunnel No.5 (DK 86 +640)

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	Silty Clay	47	70500	70500	56400	211500
3	Clay	45	67500	67500	54000	202500
5	Clay	50	75000	75000	60000	225000

Table 16 Parameter Hoek Brown untuk Batuan di Tunnel No.5 (DK 86 +640)

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
4	Andesit	50	50000	300	12 x 10^6	25	30

Table 17 Parameter Primary Lining Tunnel No.5 (DK 86 +640)

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 Lining Tunnel No.5 (DK 86 +640)

ID	Value		Unit
	Invert	Arch	
Material Type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.7	0.6	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	3.5	m

2. Cross Section DK 86+890

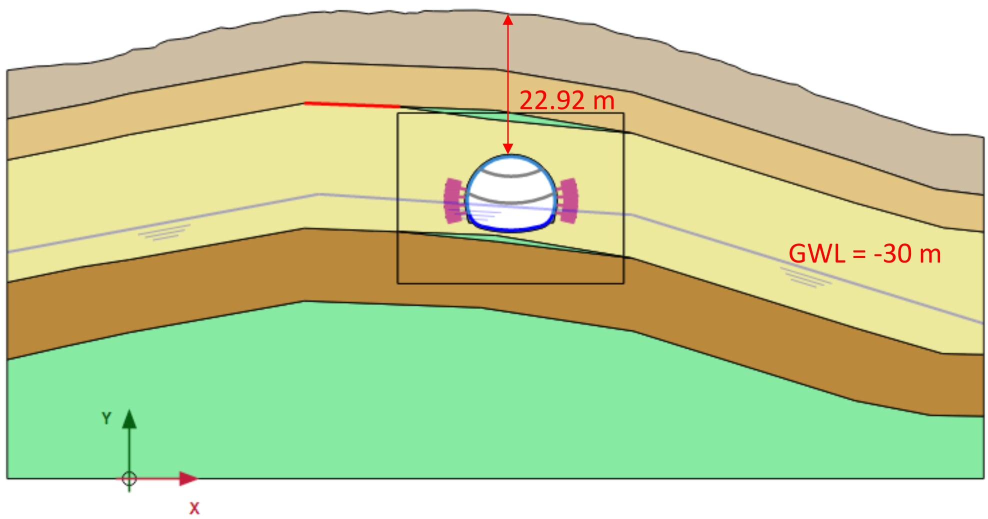


Table 20 Parameter Tanah Tunnel No.5 (DK 86 +890)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	γunsat (kN/m3)	γsat (kN/m3)	υ	c' (kPa)	ϕ' (degrees)	k (m/day)
1	0-5.5	5.5	10	Silty Clay	15	16	0.5	15	29	0.00864
2	5.5-12.3	8.8	23	Silty Clay	17	18	0.5	30	30	0.00864
3	12.3-31.9	19.6	50	Silty Clay	18	19	0.5	35	31	0.00864
4	31.9-44	12.1	50	Clay	17	18	0.5	40	31	0.000864
5	44-63	19	50	Andesit	20	21	0.2	-	-	-

Table 21 Nilai Modulus Elastisitas tanah di Tunnel No.5 (DK 86 + 890)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Silty Clay	10	7500	7500	6000	22500
2	Silty Clay	23	23000	23000	18400	69000
3	Silty Clay	50	75000	75000	60000	225000
4	Clay	50	75000	75000	60000	225000

Table 22 Parameter Hoek Brown untuk Batuan di Tunnel No.5 (DK 86 +890)

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
5	Andesit	50	50000	300	12×10^6	25	30

Table 23 Parameter Primary Lining Tunnel No.5 (DK 86 +890)

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 Lining Tunnel No.5 (DK 86 +890)

ID	Value		Unit
	Invert	Arch	
Material Type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.7	0.6	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	3.5	m

3. Cross Section DK 86+905

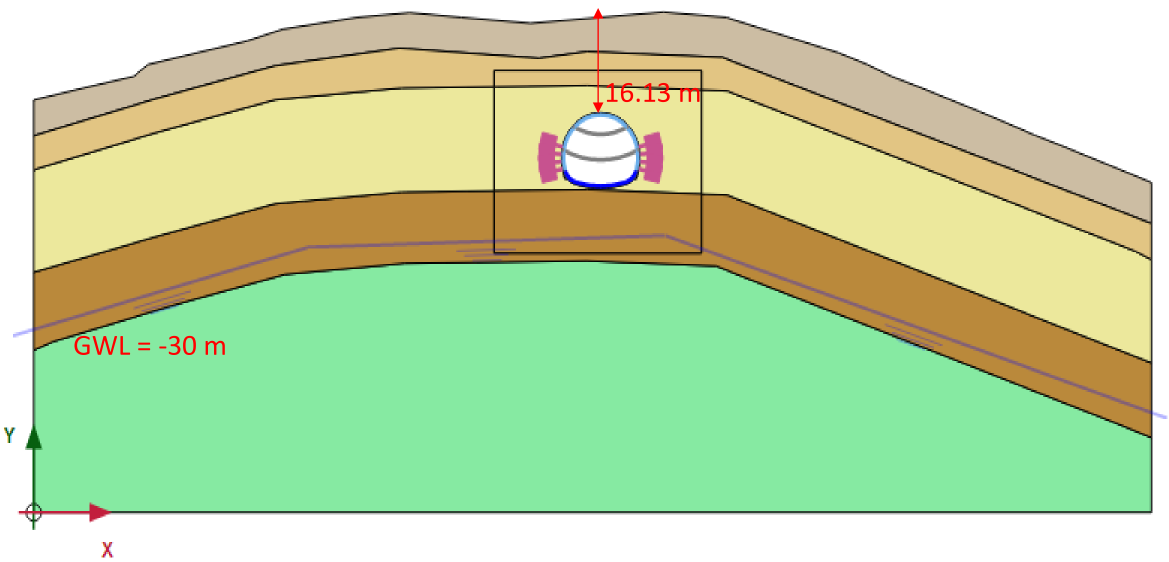


Table 26 Parameter Tanah Tunnel No.5 (DK 86 +905)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	γunsat (kN/m3)	γsat (kN/m3)	υ	c' (kPa)	ϕ' (degrees)	k (m/day)
1	0-5.5	5.5	10	Silty Clay	15	16	0.5	15	29	0.00864
2	5.5-12.3	8.8	23	Silty Clay	17	18	0.5	30	30	0.00864
3	12.3-31.9	19.6	50	Silty Clay	18	19	0.5	35	31	0.00864
4	31.9-44	12.1	50	Clay	17	18	0.5	40	31	0.000864
5	44-63	19	50	Andesit	20	21	0.2	-	-	-

Table 27 Nilai Modulus Elastisitas tanah di Tunnel No.5 (DK 86 + 905)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Silty Clay	10	7500	7500	6000	22500
2	Silty Clay	23	23000	23000	18400	69000
3	Silty Clay	50	75000	75000	60000	225000
4	Clay	50	75000	75000	60000	225000

Table 28 Parameter Hoek Brown untuk Batuan di Tunnel No.5 (DK 86 +905)

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
5	Andesit	50	50000	300	12 x 10^6	25	30

Table 29 Parameter Primary Lining Tunnel No.5 (DK 86 +905)

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 Lining Tunnel No.5 (DK 86 +905)

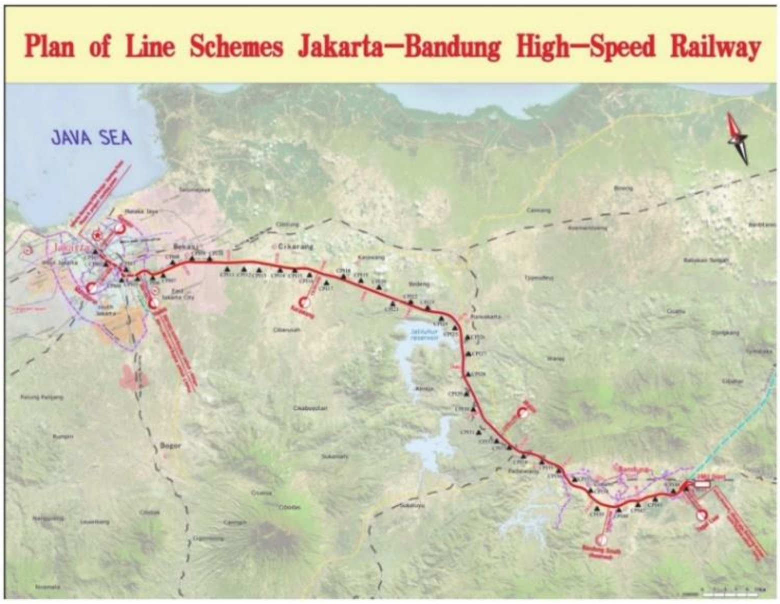
ID	Value		Unit
	Invert	Arch	
Material Type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.7	0.6	m
Unit weight (γ)	24	24	kN/m^3
Easticity modulus (E)	2.781 × 10^7	2.781 × 10^7	kPa

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	3.5	m

C. Perhitungan Beban Gempa di Area Terowongan No. 5

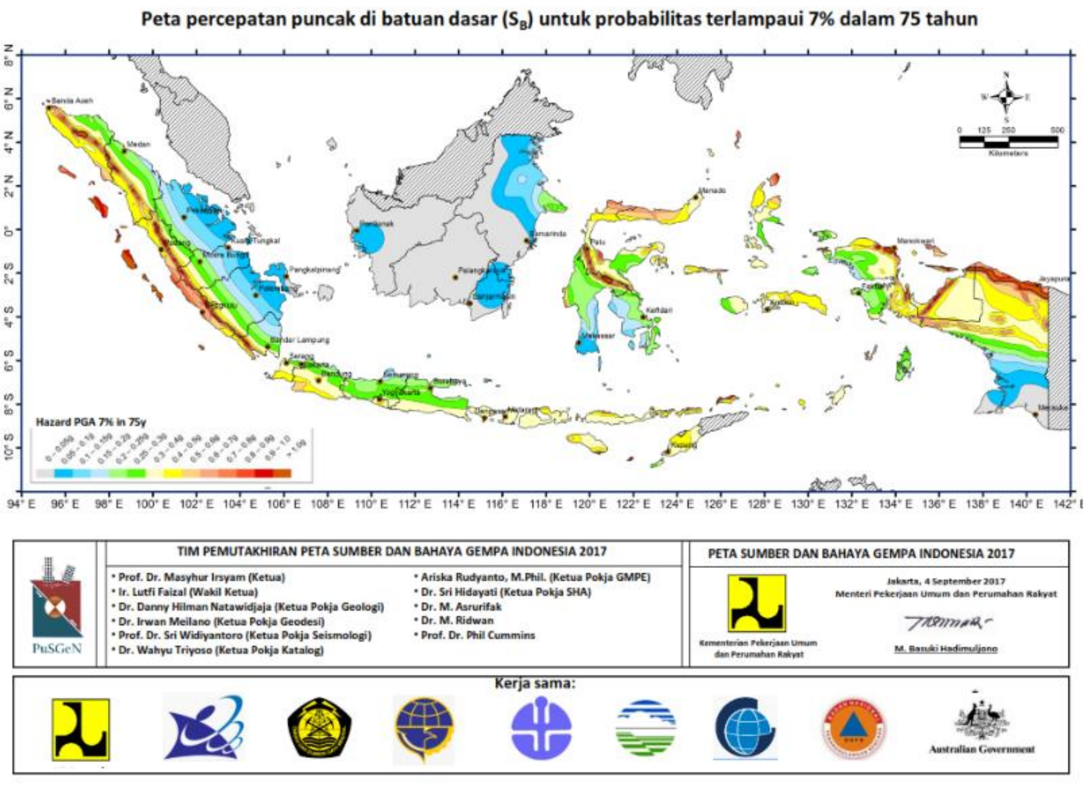
Analisis deformasi aksial dilakukan dengan menambahkan beban gempa berdasarkan peta gempa 2017. Percepatan tanah puncak gempa maksimum yang dipertimbangkan untuk bangunan bawah seperti yang tertera dalam SNI 8460 tahun 2017 (Bab 12), percepatan tanah puncak dengan 7% kemungkinan terlampaui dalam kurun 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 32 Desain untuk Menentukan SPT Rata-rata di Tunnel No.5 (DK86+890)

DI	N	DI/N
12.3	17	0.75
18.1	50	0.36
13.1	50	0.26

$$\overline{N_{60}} = \frac{43.5}{1.37} = 32$$

2. Penentuan Klasifikasi Situs berdasarkan NSPT rata-rata

Table 33 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 34 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)

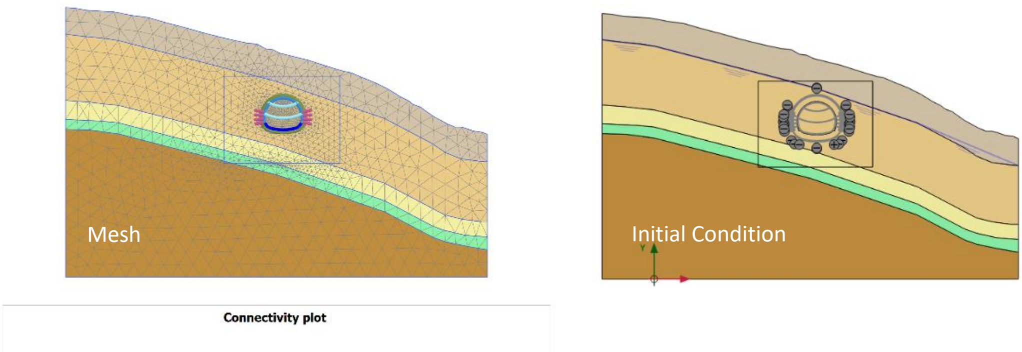
4. Percepatan Puncak

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

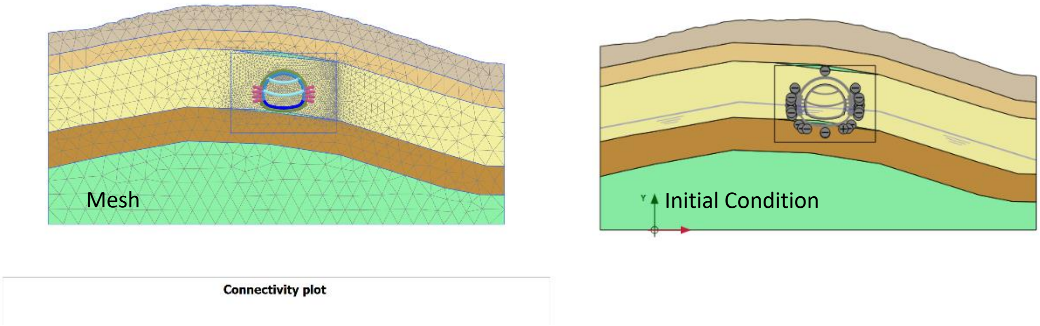
Untuk PGA 0.3 → $a = 0.3 \times 1.2 \times ((1.45 - 0.3) \times 0.3) = \mathbf{0.1242\ g}$

D. Kondisi Elemen Mesh dan *Initial Condition*

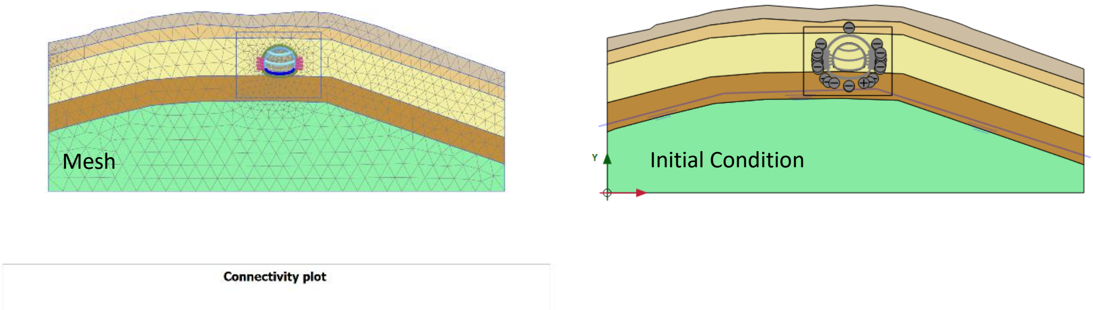
Meshing merupakan proses membagi komponen yang akan dianalisis menjadi elemen-elemen kecil yang menjadi dasar dalam perhitungan/iterasi dalam pemodelan FEM (PLAXIS 2D). *Meshing* yang digunakan dalam pemodelan ini menggunakan mesh *very fine. Initial condition* merupakan kondisi awal pemodelan pada analisis PLAXIS 2D. Berikut merupakan hasil meshing dan initial condition pada model analisis seperti yang disajikan pada **Gambar 8 s/d Gambar 10.**



Gambar 8 *Meshing* dan *initial condition* Tunnel No.5 (DK 86+640)



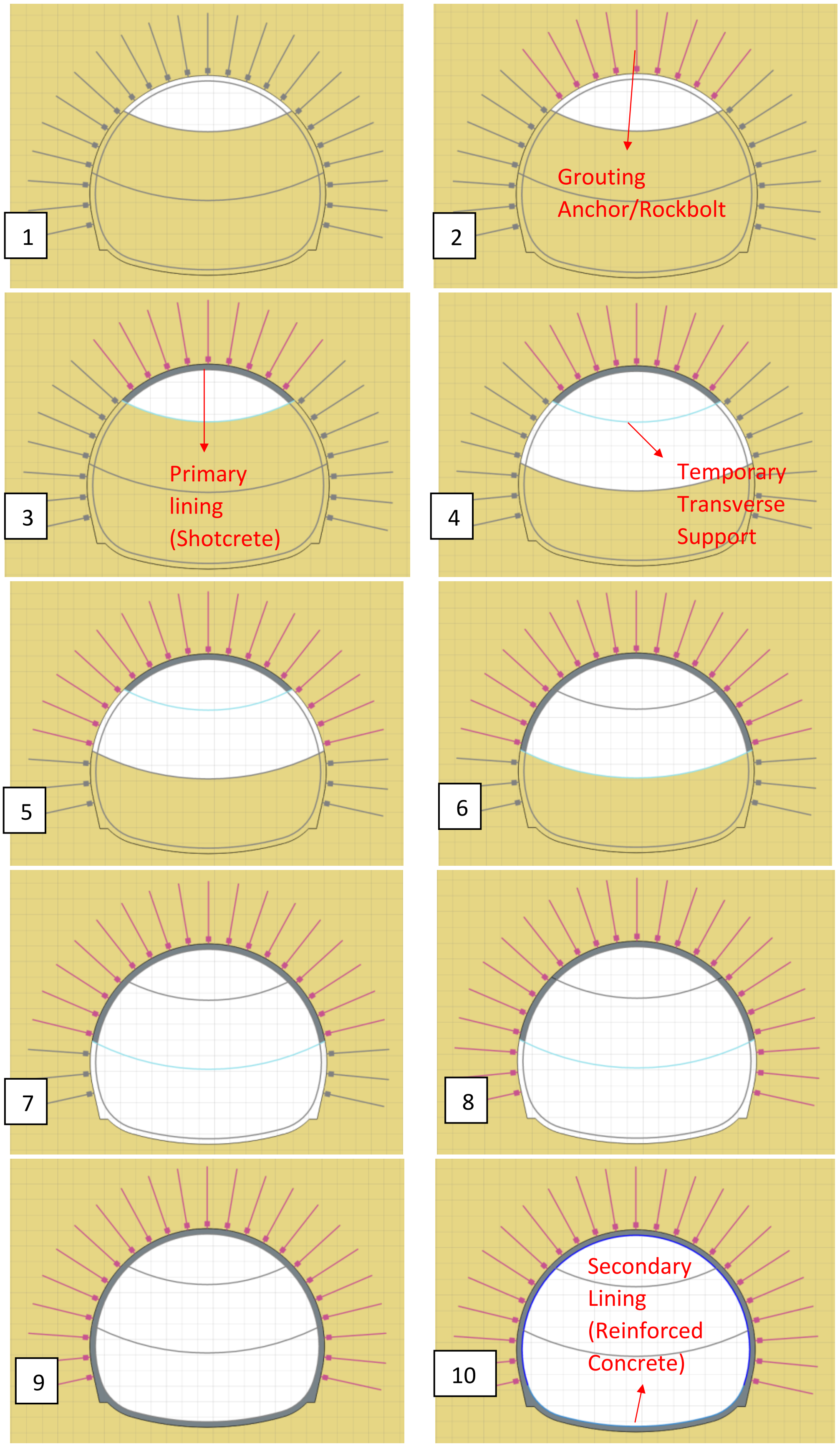
Gambar 9 *Meshing* dan *initial condition* Tunnel No.5 (DK 86+890)



Gambar 10 *Meshing* dan *initial condition* Tunnel No.5 (DK 86+905)

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 11(1)**, Pemasangan grouting anchor/rockbolt (dimodelkan menggunakan Embedded Beam) bagian atas **Gambar 11(2)**, Pemasangan primary lining dan upper bench temporary transverse support **Gambar 11(3)**, galian pada bagian middle bench **Gambar 11(4)**, Pemasangan grouting anchor/rockbolt bagian mid **Gambar 11(5),** Pemasangan primary lining dan middle bench temporary transverse support **Gambar 11(6)**, galian pada bagian lower bench **Gambar 11(7)**, Pemasangan grouting anchor/rockbolt bagian mid **Gambar 11(8),** Pemasangan primary lining pada bagian lower bench **Gambar 11(9)**, pemasangan secondary lining (dimodelkan menggunakan plate) **Gambar 11(10)**, dan dilanjutkan analisis pada kondisi minimum excess pore pressure serta dilanjutkan analisis terhadap beban gempa.



Gambar 11 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 35 s/d Tabel 37.** 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 12 s/d Gambar 25**. Rekapitulasi hasil deformasi dan gaya dalam yang dihasilkan dalam pemodelan PLAXIS 2D pada setiap tahapan konstruksi dapat dilihat pada **Tabel 35 s/d Tabel 37.**

Table 35 Hasil Rekapitulasi Deformasi pada Tunnel No.5 (DK86+640)

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	-0.01489	-	-	-	-	-	-
Install Primary lining up	-0.01561	-	-	-	-	-	-
Gali mid bench	-0.05795	-	-	-	-	-	-
Install Primary lining mid	-0.05730	-	-	-	-	-	-
Gali bot bench	-0.09053	-	-	-	-	-	-
Install Rockbolt bot	-0.09075	-	-	-	-	-	-
Install Primary lining bot	-0.09074	-	-	-	-	-	-
Install Secondary lining	-0.09409	1.23	-0.09132	0.05348	-1587	294.6	-435.0
Longterm	-0.02045	-	-0.00853	0.01405	-2519	508.8	830.3
Gempa	0.02287	-	0.00284	-0.01462	-2273	468.6	807.6

Table 36 Hasil Rekapitulasi Deformasi pada Tunnel No.5 (DK86+890)

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	-9.141×10^{-3}	-	-	-	-	-	-
Install Primary lining up	-9.425×10^{-3}	-	-	-	-	-	-
Gali mid bench	-0.02044	-	-	-	-	-	-
Install Primary lining mid	-0.02059	-	-	-	-	-	-
Gali bot bench	-0.02630	-	-	-	-	-	-
Install Rockbolt bot	-0.02699	-	-	-	-	-	-
Install Primary lining bot	-0.02693	-	-	-	-	-	-
Install Secondary lining	-0.03017	0.32	-0.02976	0.006381	-1500	240.9	-256.3
Longterm	-0.02264	-	-0.01760	0.00907	-2730	544.2	710.5
Gempa	-0.1493	-	-0.00708	0.01832	-3385	668.8	-901.9

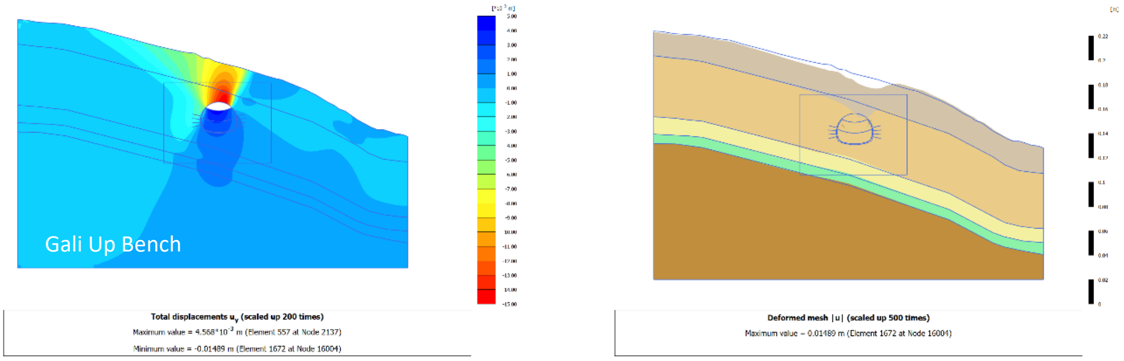
Table 37 Hasil Rekapitulasi Deformasi pada Tunnel No.5 (DK86+905)

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	-8.686×10^{-3}	-	-	-	-	-	-
Install Primary lining up	-9.037×10^{-3}	-	-	-	-	-	-
Gali mid bench	-0.01989	-	-	-	-	-	-
Install Primary lining mid	-0.01999	-	-	-	-	-	-
Gali bot bench	-0.02548	-	-	-	-	-	-
Install Rockbolt bot	-0.02605	-	-	-	-	-	-
Install Primary lining bot	-0.02594	-	-	-	-	-	-
Install Secondary lining	-0.02919	0.31	-0.02911	0.005653	-1179	199.5	-221.5
Longterm	-0.01078	-	-0.00 511	0.00414	-1694	312.2	399.4
Gempa	-0.3662	-	-0.00945	0.02556	-2668	515.7	-785.0

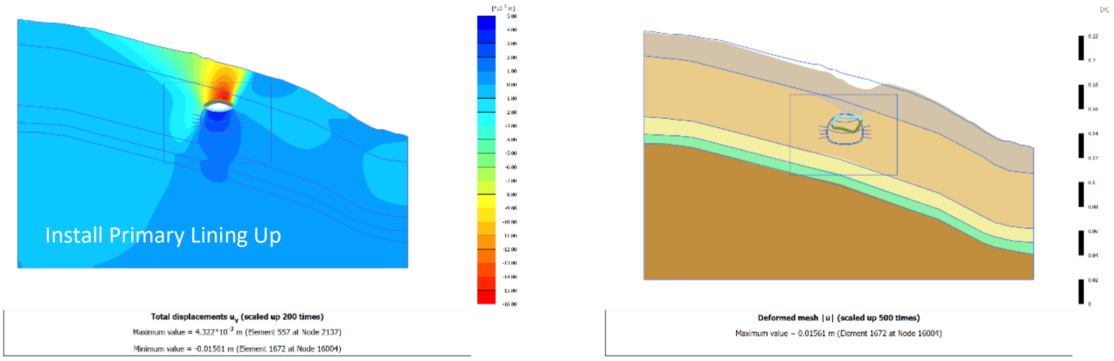
Dari hasil rekapitulasi deformasi menunjukkan bahwa selisih atau Δdeformasi dari potongan DK 86+890 dengan DK 86+905 terbesar adalah ±**1 cm pada kondisi longterm** dengan syarat izin diferential settlement 0.04%(15 m)= 0.006 m atau sebesar 0.6 cm. Hasil tersebut tidak memenuhi kedalam syarat izin yaitu 0.04%(Ls).

Syarat izin deformasi setelah proses konstruksi selesai (longterm) sebesar **15 mm**, dengan demikian pada potongan DK 86+890 tidak memenuhi syarat karena deformasi yang dihasilkan pada kondisi longterm sebesar **-0.0176 m atau 17.6 mm**.

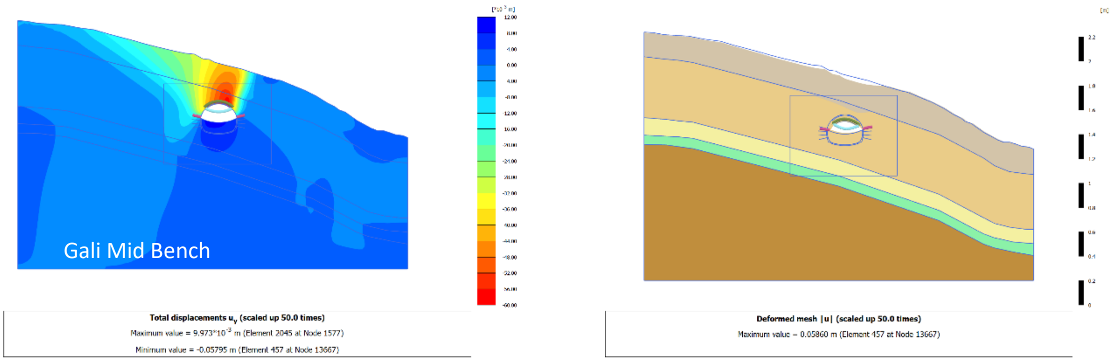
a) *Cross Section DK 86+640*



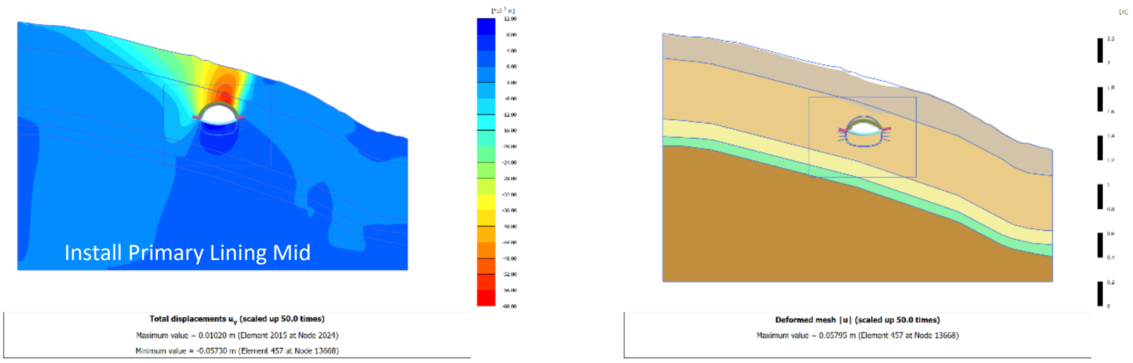
Maximum = 4.568×10^{-3} m
Minimum = -0.01489 m



Maximum = 4.322×10^{-3} m
Minimum = -0.01561 m

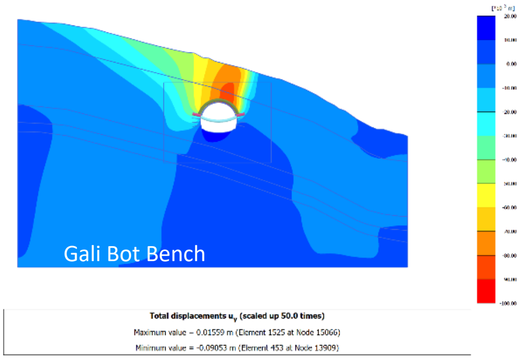


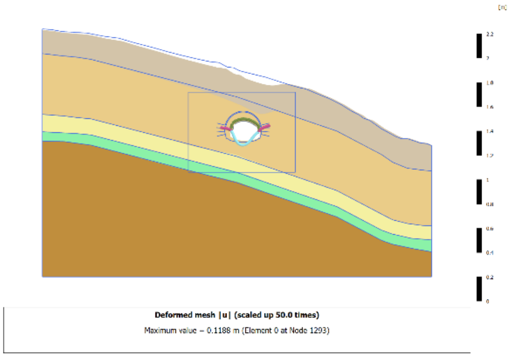
Maximum = 9.973×10^{-3} m
Minimum = -0.05795 m



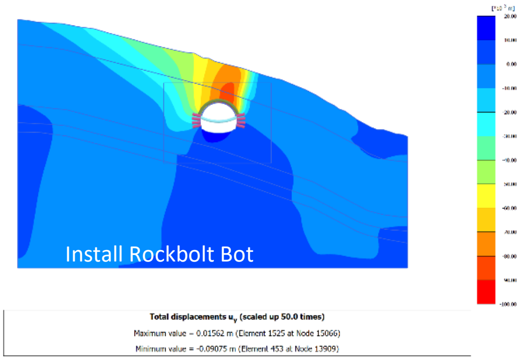
Maximum = 0.01020 m
Minimum = -0.05730 m

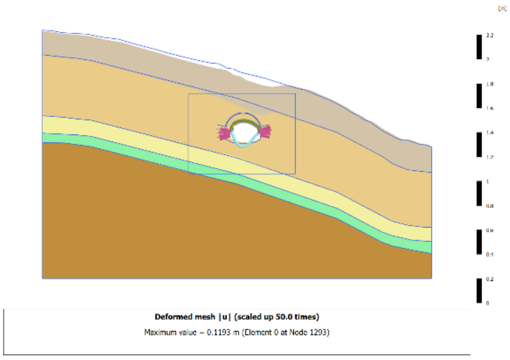
Gambar 12 Hasil analisis deformasi terowongan aksial global Tunnel No.5 (DK 86+640)



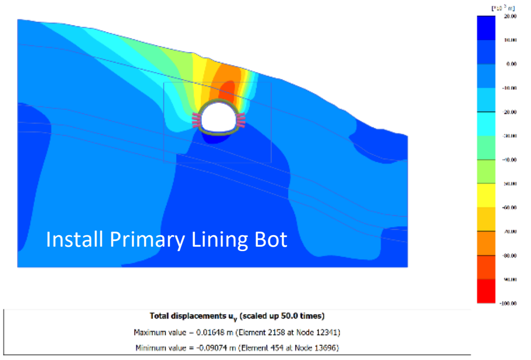


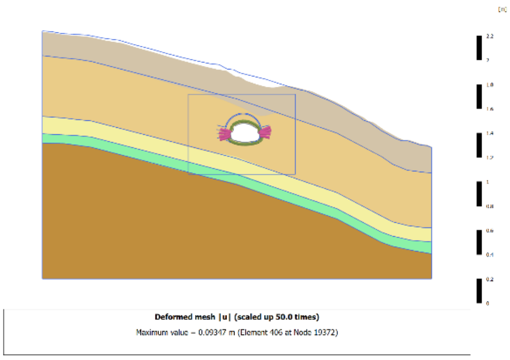
Maximum = 0.01559 m
Minimum = -0.09053 m



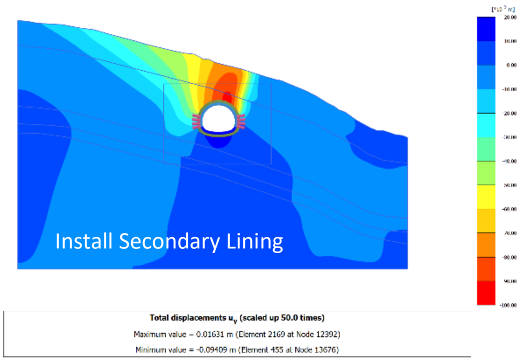


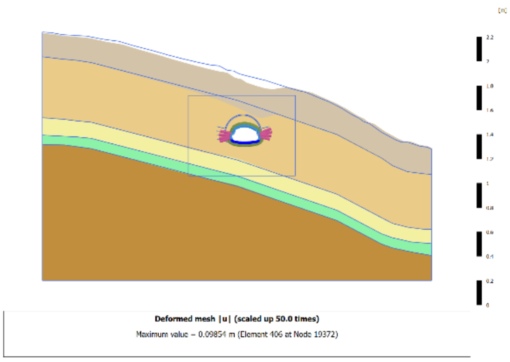
Maximum = 0.01562 m
Minimum = -0.09075 m





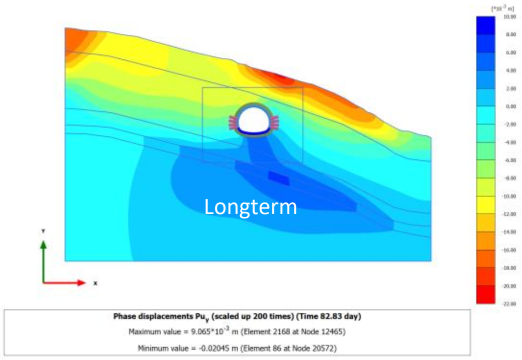
Maksimum = 0.01648 m
Minimum = -0.09074 m

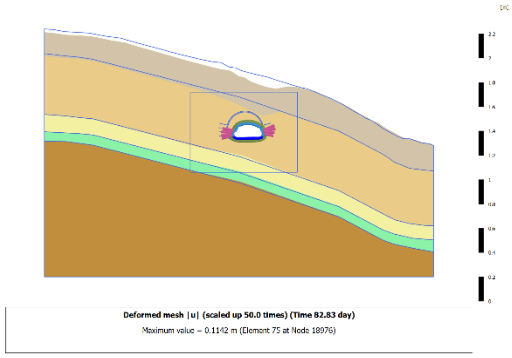




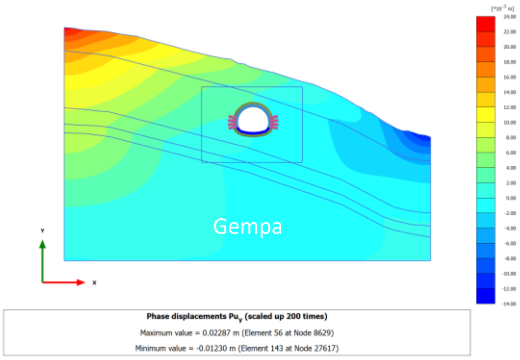
Maximum = 0.01631 m
Minimum = -0.09409 m

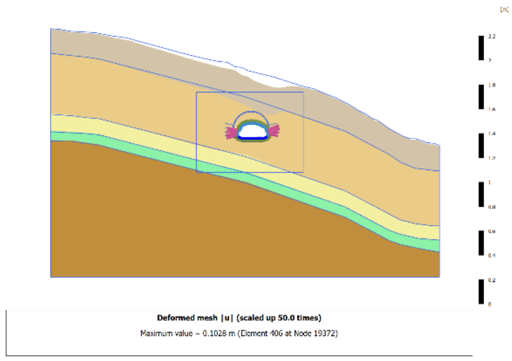
Gambar 13 Hasil analisis deformasi terowongan aksial global Tunnel No.5 (DK 86+640) (lanjutan)





Maximum = 9.065x 10^{-3} m
Minimum = -0.02045 m

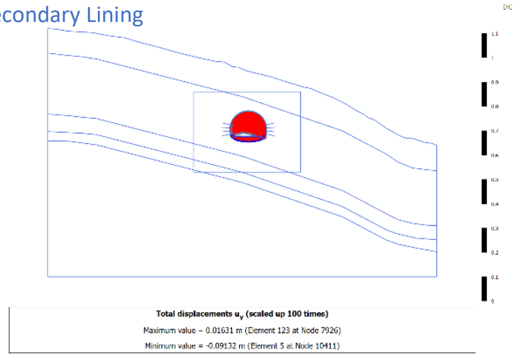


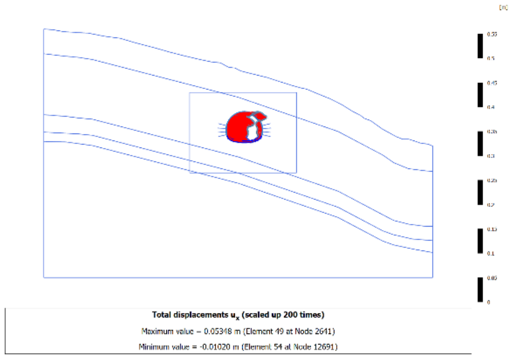


Maximum = 0.02287 m
Minimum = -0.01230 m

Gambar 14 Hasil analisis deformasi terowongan aksial global Tunnel No.5 (DK 86+640) (lanjutan)

Secondary Lining

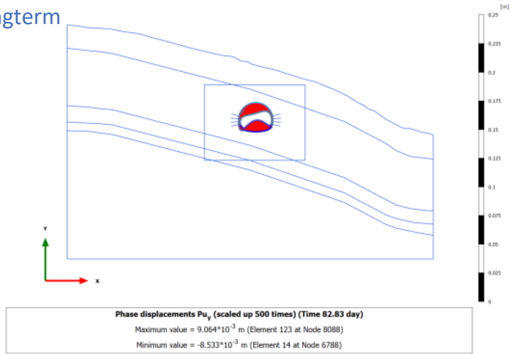


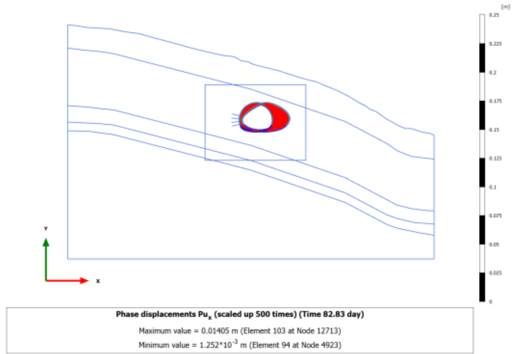


Maximum = 0.01631 m
Minimum = -0.09132 m

Maximum = 0.05348 m
Minimum = -0.01020 m

Longterm

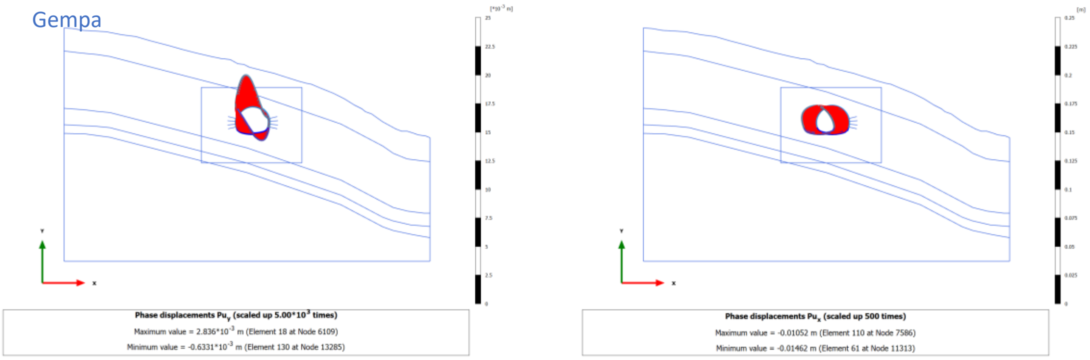




Maximum = 9.064 x 10^{-3} m
Minimum = -8.533 x 10^{-3} m

Maximum = 0.01405 m
Minimum = 1.252 x 10^{-3} m

Gambar 15 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+640)

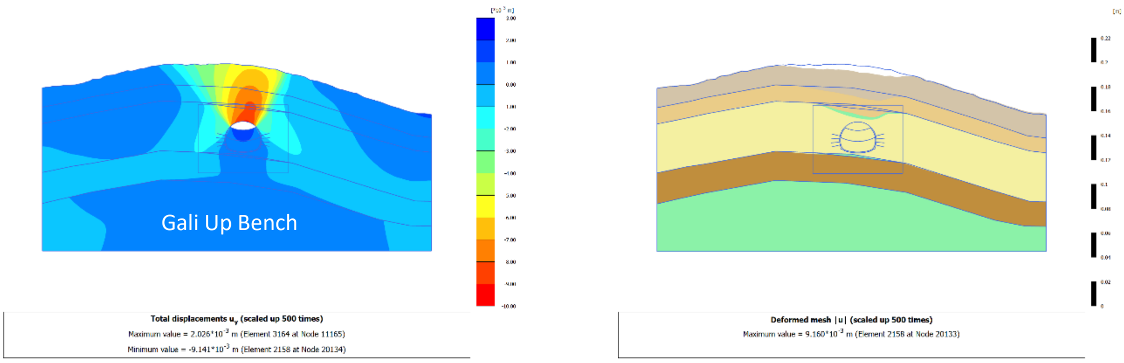


Maximum = 2.836x 10^{-3} m
Minimum = -0.633x 10^{-3} m

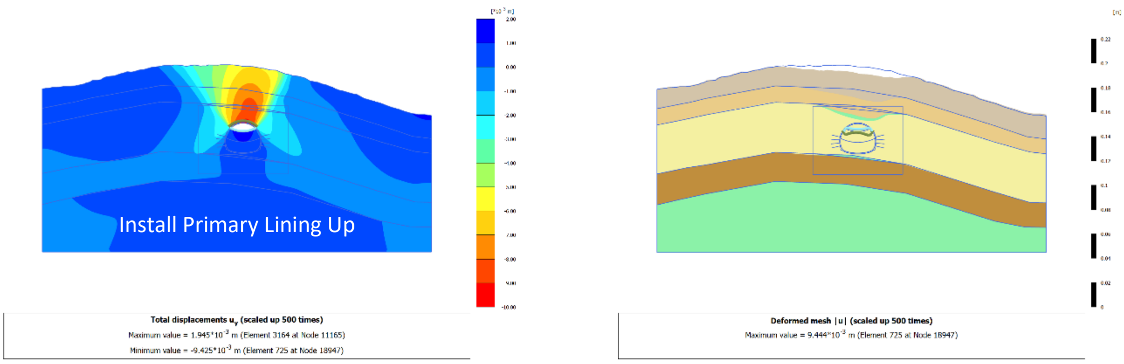
Maximum = -0.1052 m
Minimum = -0.01462 m

Gambar 16 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+640) (lanjutan)

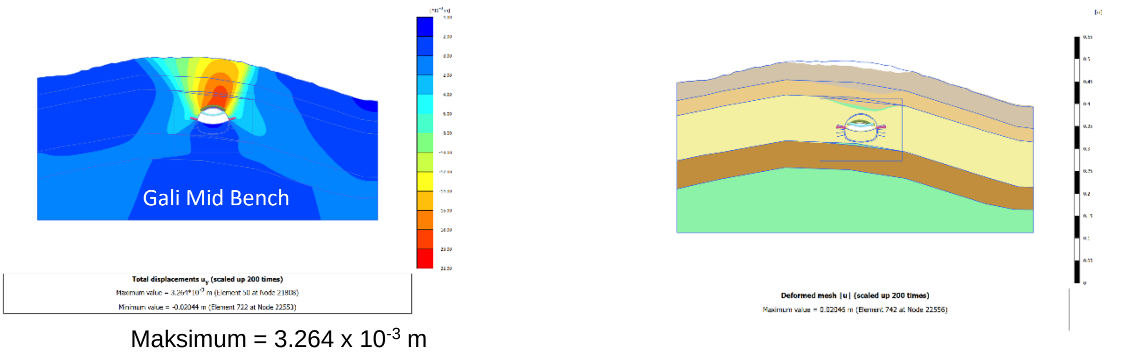
b) *Cross Section DK 86+890*



Maksimum = 2.026 x 10^{-3} m
Minimum = -9.141 x 10^{-3} m

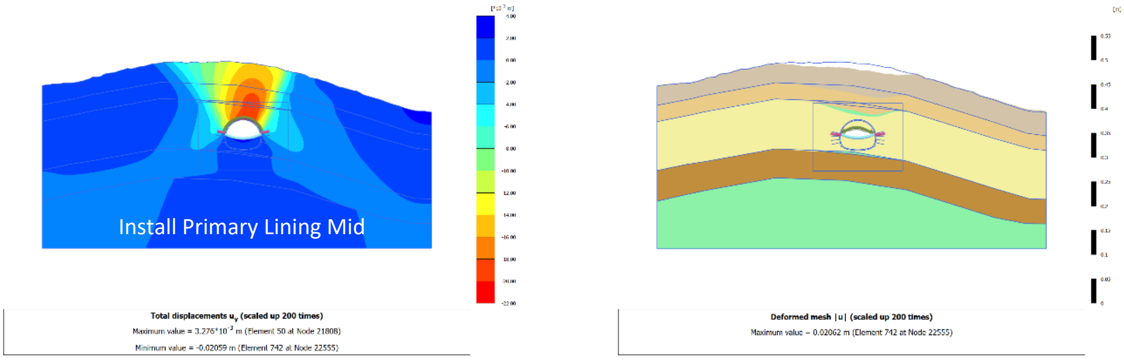


Maximum = 1.945 x 10^{-3} m
Minimum = -9.425 x 10^{-3} m

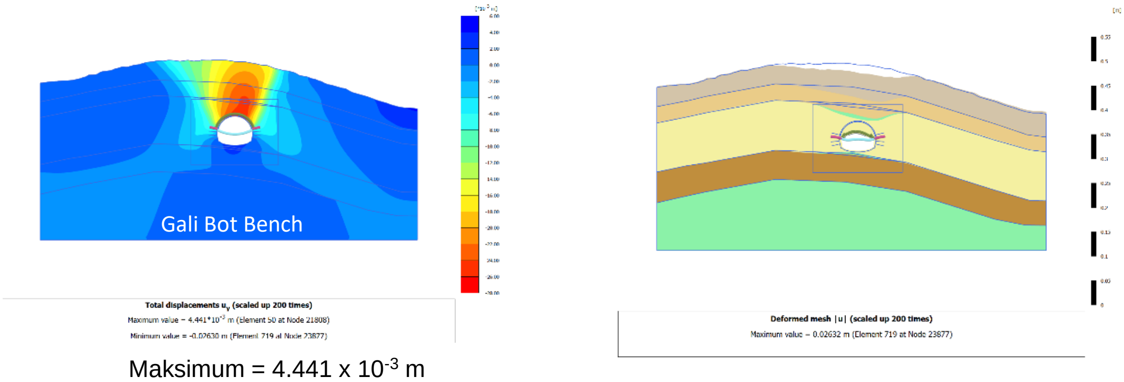


Maksimum = 3.264 x 10^{-3} m
Minimum = -0.02044 m

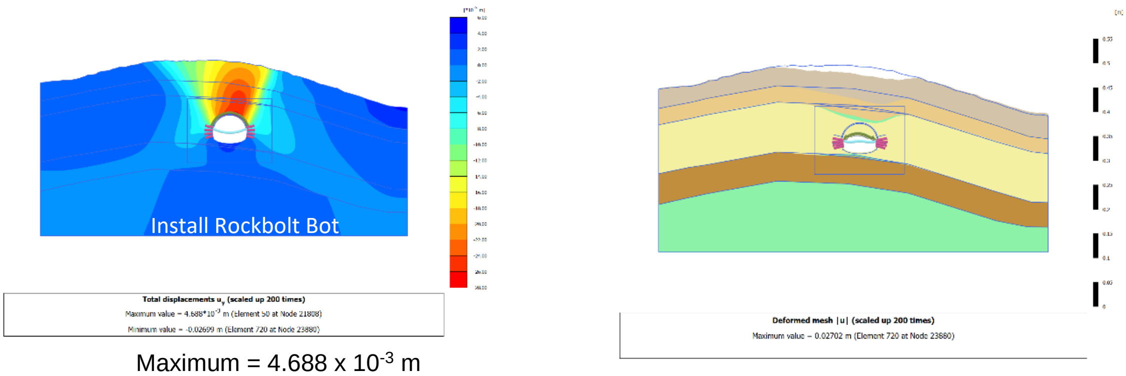
Gambar 17 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+890)



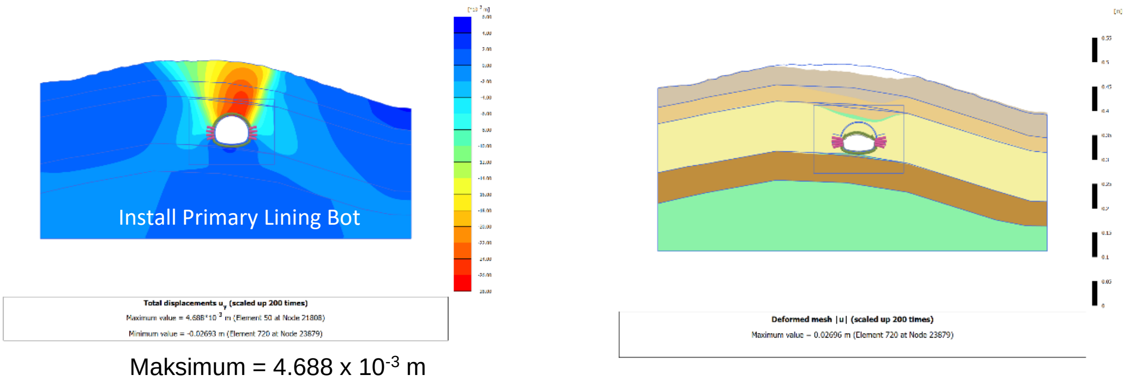
Maksimum = 3.276 x 10^{-3} m
Minimum = -0.02059 m



Maksimum = 4.441 x 10^{-3} m
Minimum = -0.02630 m

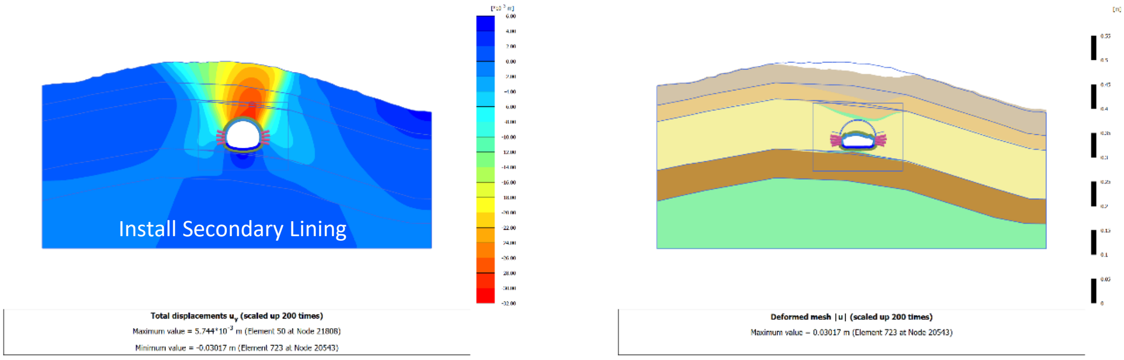


Maximum = 4.688 x 10^{-3} m
Minimum = -0.02699 m

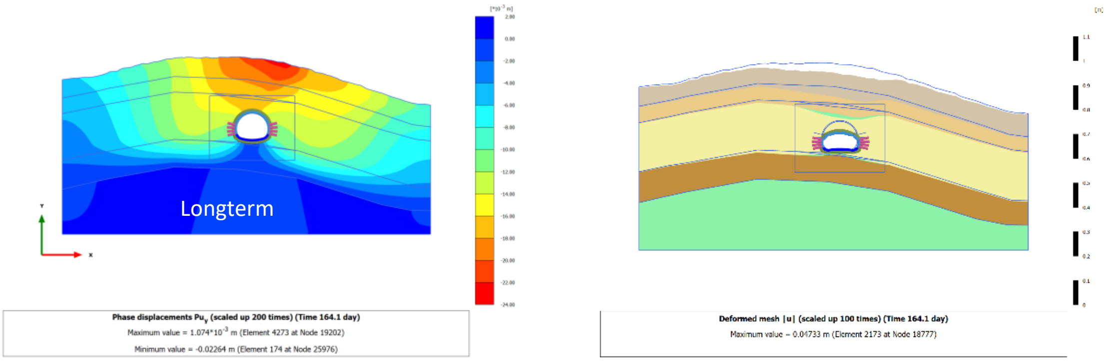


Maksimum = 4.688 x 10^{-3} m
Minimum = -0.02693 m

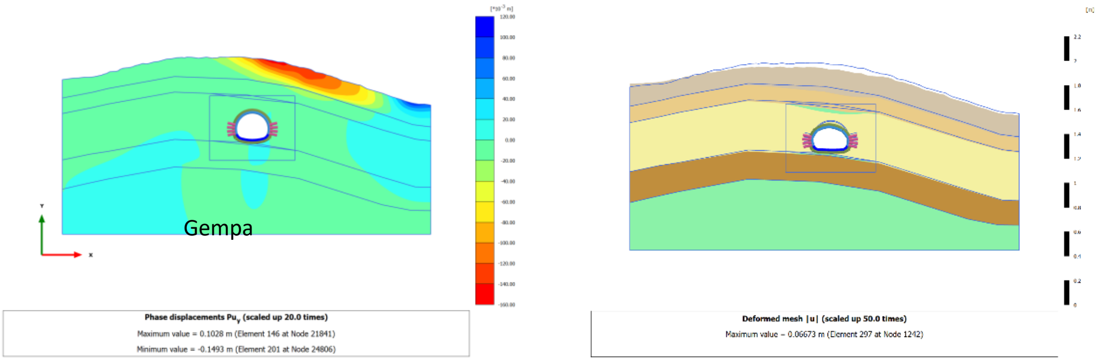
Gambar 18 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+890) (lanjutan)



Maximum = 5.744 x 10^{-3} m
Minimum = -0.03017 m

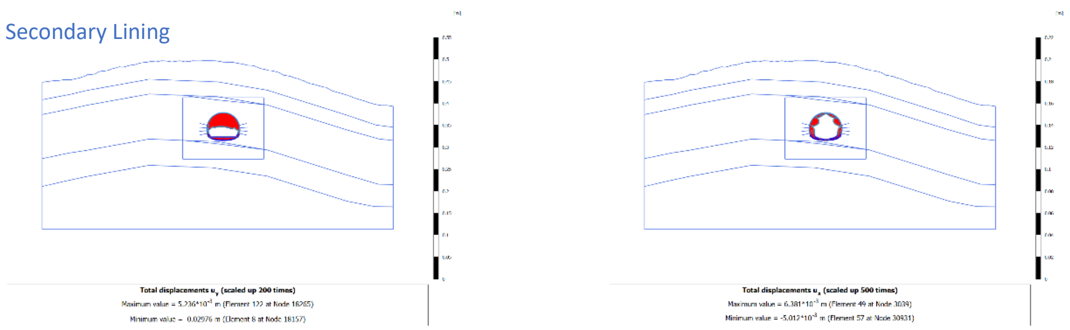


Maximum = 1.074 x 10^{-3} m
Minimum = -0.02264 m



Maximum = 0.1028 m
Minimum = -0.1493 m

Gambar 19 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+890) (lanjutan)

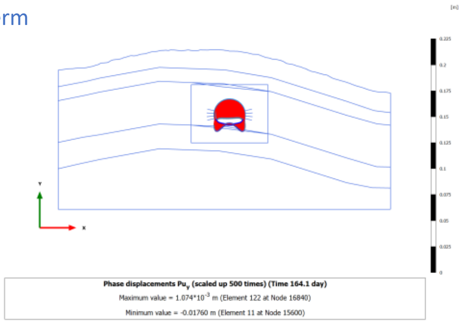


Maximum = 5.236 x 10^{-3} m
Minimum = -0.02976 m

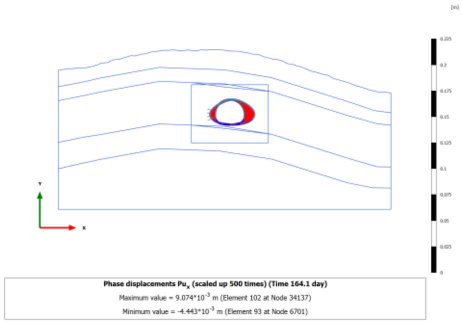
Maximum = 6.381 x 10^{-3} m
Minimum = -5.012 x 10^{-3} m

Gambar 20 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+890)

Longterm

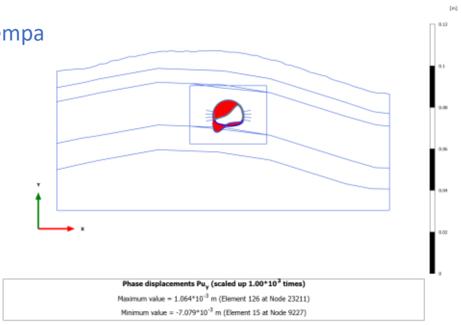


Maximum = 1.074 x 10^{-3} m
Minimum = -0.01760 m

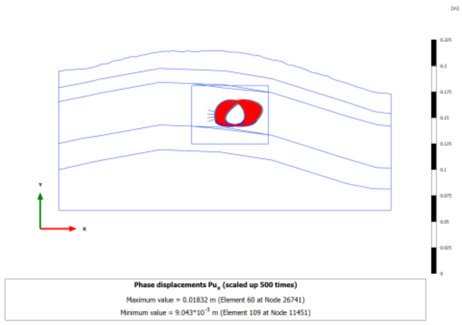


Maximum = 9.074 x 10^{-3} m
Minimum = -4.443 x 10^{-3} m

Gempa



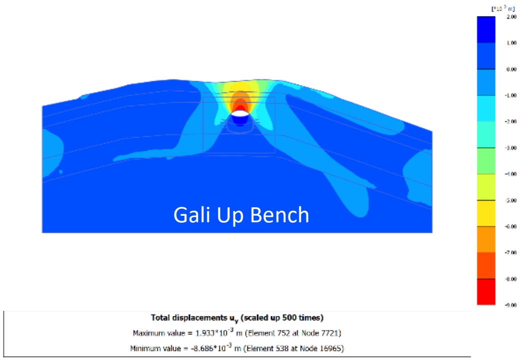
Maximum = 1.064 x 10^{-3} m
Minimum = -7.079 x 10^{-3} m

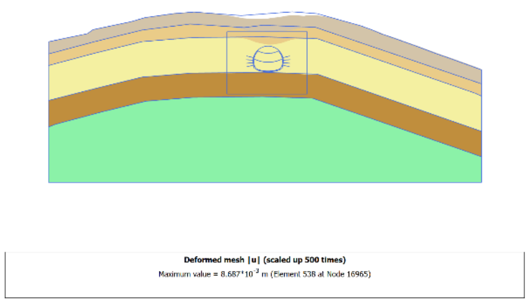


Maksimum = 0.01832 m
Minimum = 9.043 x 10^{-3} m

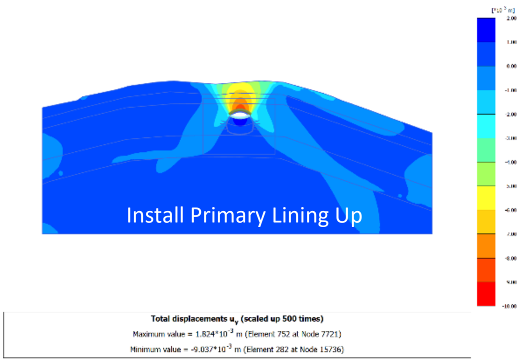
Gambar 21 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+890) (lanjutan)

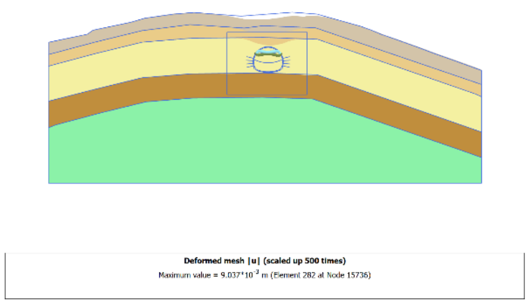
c) *Cross Section DK 86+905*





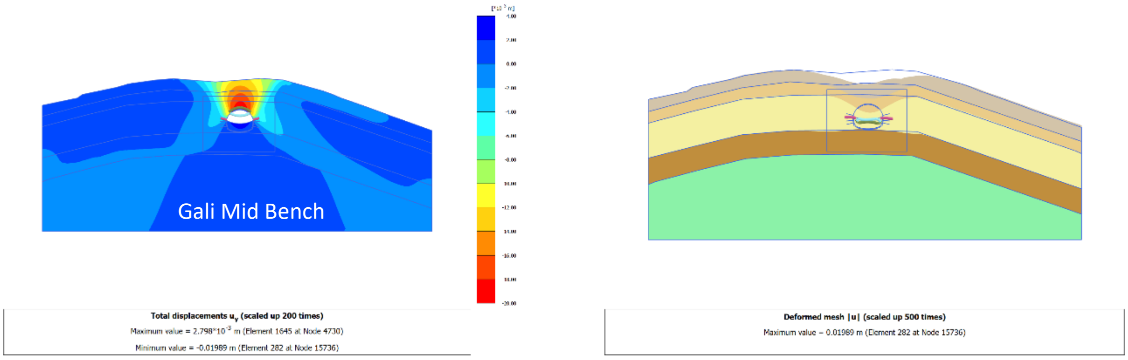
Maximum = 1.933 x 10^{-3} m
Minimum = -8.686 x 10^{-3} m



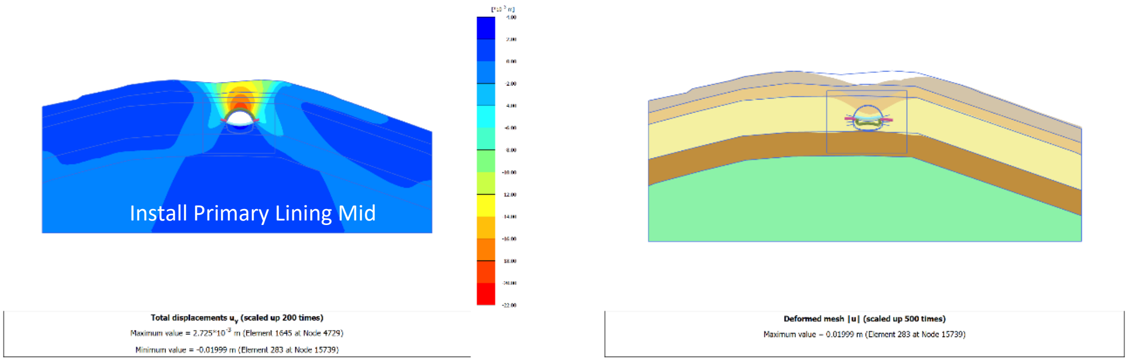


Maksimum = 1.842 x 10^{-3} m
Minimum = -9.037 x 10^{-3} m

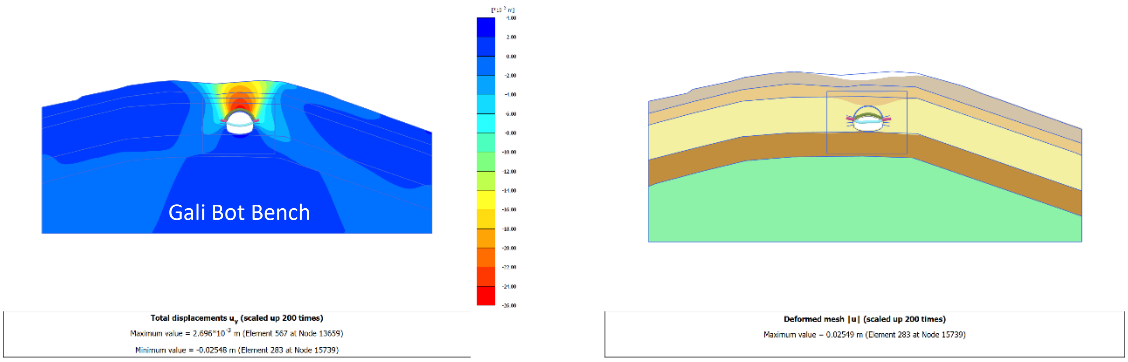
Gambar 22 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+905)



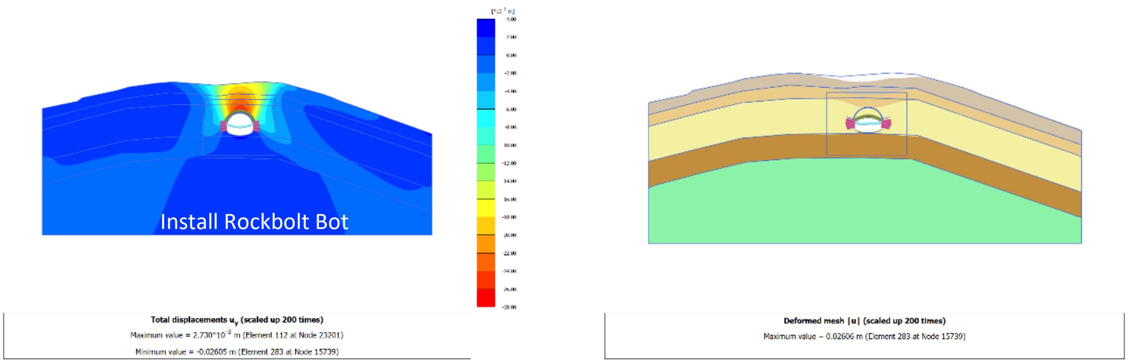
Maximum = 2.798 x 10^{-3} m
Minimum = -0.01989 m



Maximum = 2.725 x 10-3 m
Minimum = -0.01999 m

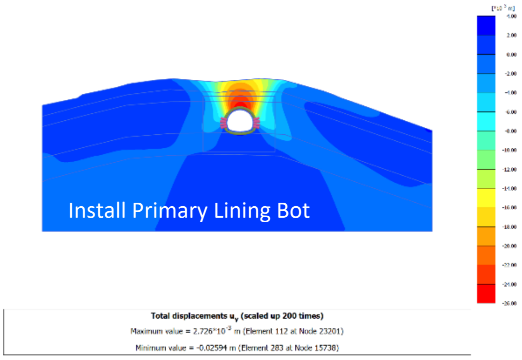


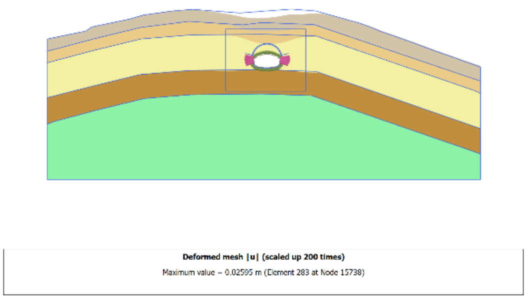
Maksimum = 2.696 x 10-3 m
Minimum = -0.02548 m



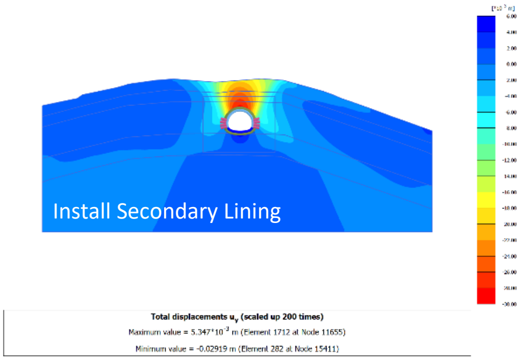
Maximum = 2.730 x 10-3 m
Minimum = -0.02605 m

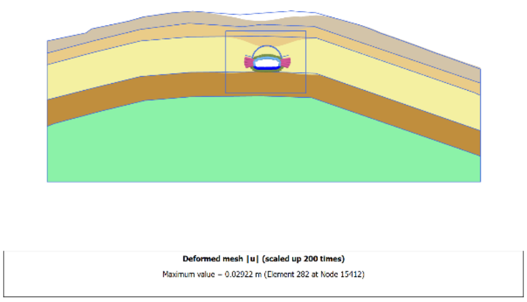
Gambar 23 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+905) (lanjutan)



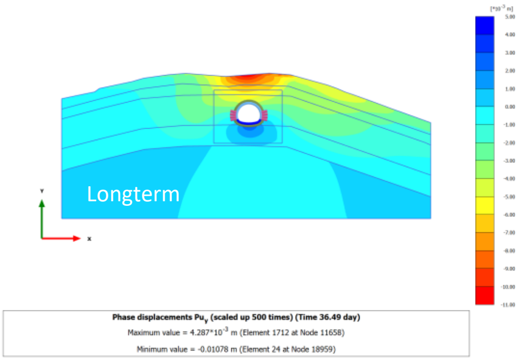


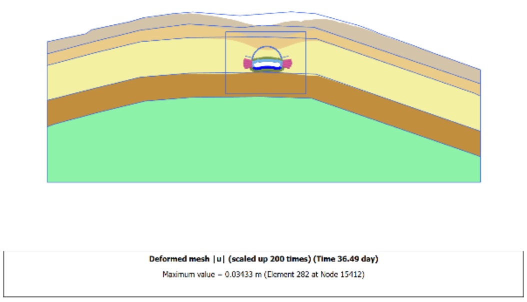
Maximum = 2.726 x 10-3 m
Minimum = -0.02594 m



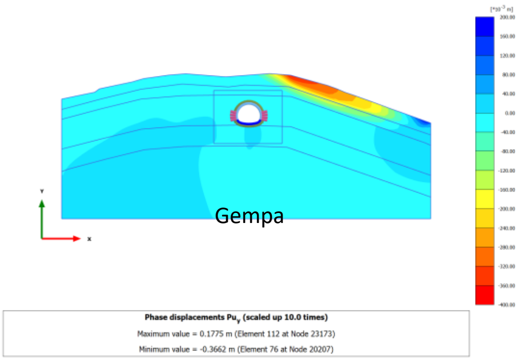


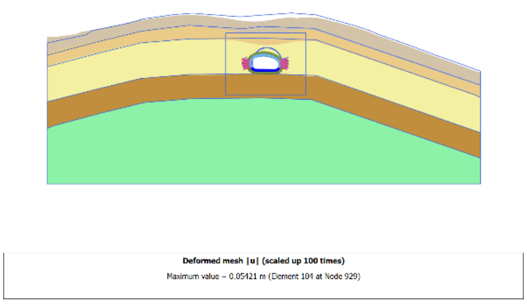
Maximum = 5.347 x 10^{-3} m
Minimum = -0.02919 m





Maximum = 4.287 x 10^{-3} m
Minimum = -0.01078 m

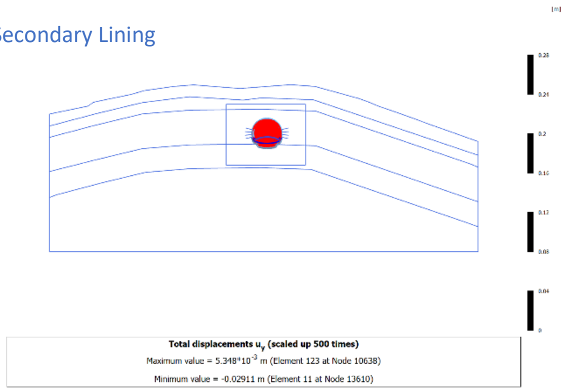




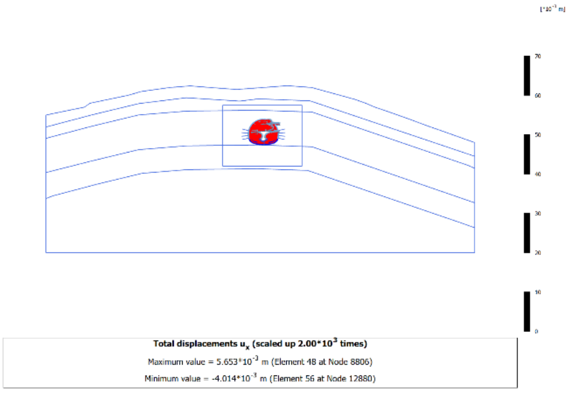
Maximum = 0.1775 m
Minimum = -0.3662 m

Gambar 24 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+905) (lanjutan)

Secondary Lining

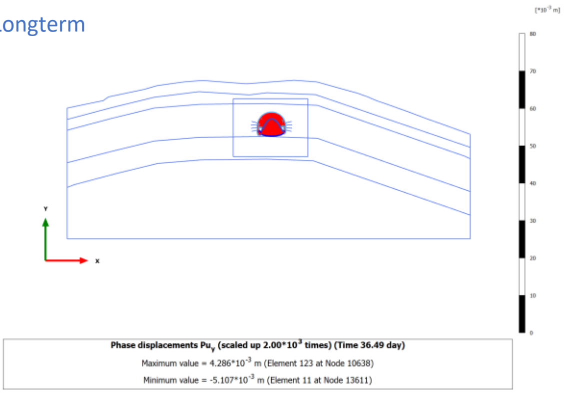


Maximum = 5.348 x 10^{-3} m
Minimum = -0.02911 m

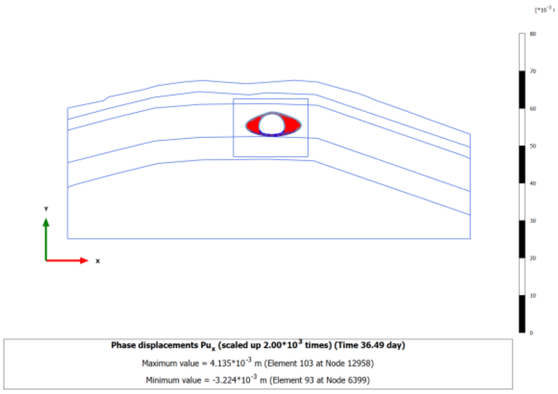


Maximum = 5.653 x 10^{-3} m
Minimum = -4.014 x 10^{-3} m

Longterm

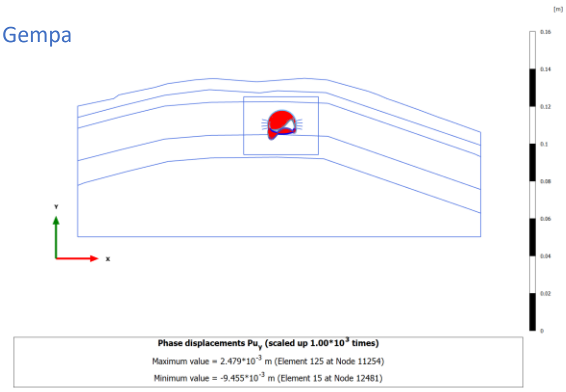


Maximum = 4.286 x 10^{-3} m
Minimum = -5.107 x 10^{-3} m

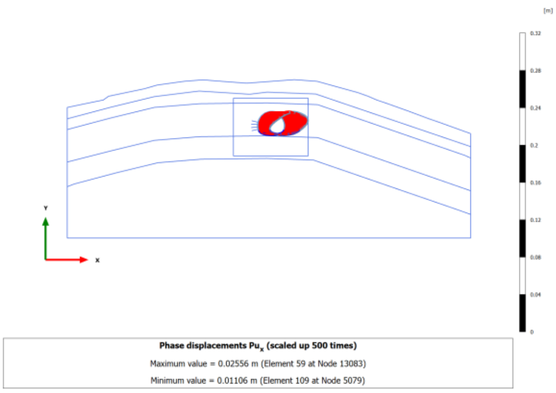


Maximum = 4.135 x 10^{-3} m
Minimum = -3.224 x 10^{-3} m

Gempa



Maximum = 2.479 x 10^{-3} m
Minimum = -9.455 x 10^{-3} m



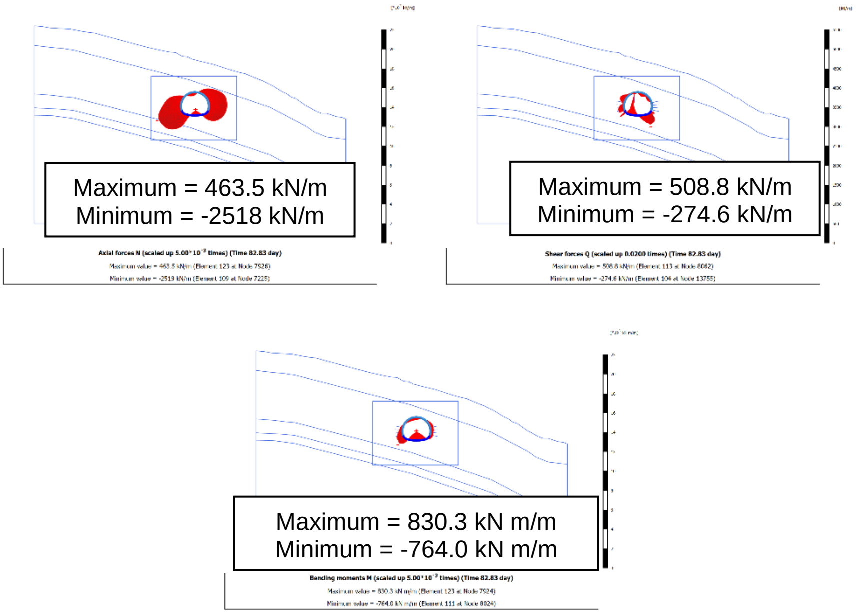
Maksimum = 0.02556 m
Minimum = 0.01106 m

Gambar 25 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+905)

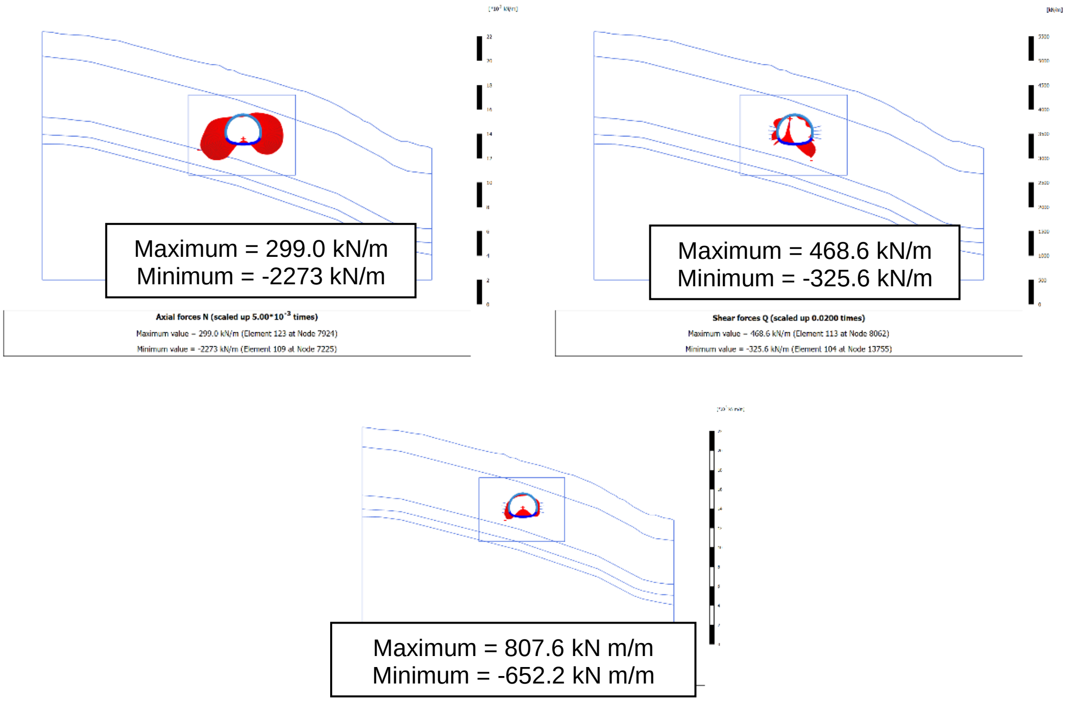
3. Gaya Dalam pada Lining Terowongan

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 26** s/d **Gambar 31**.

a) *Cross Section DK 86+640*

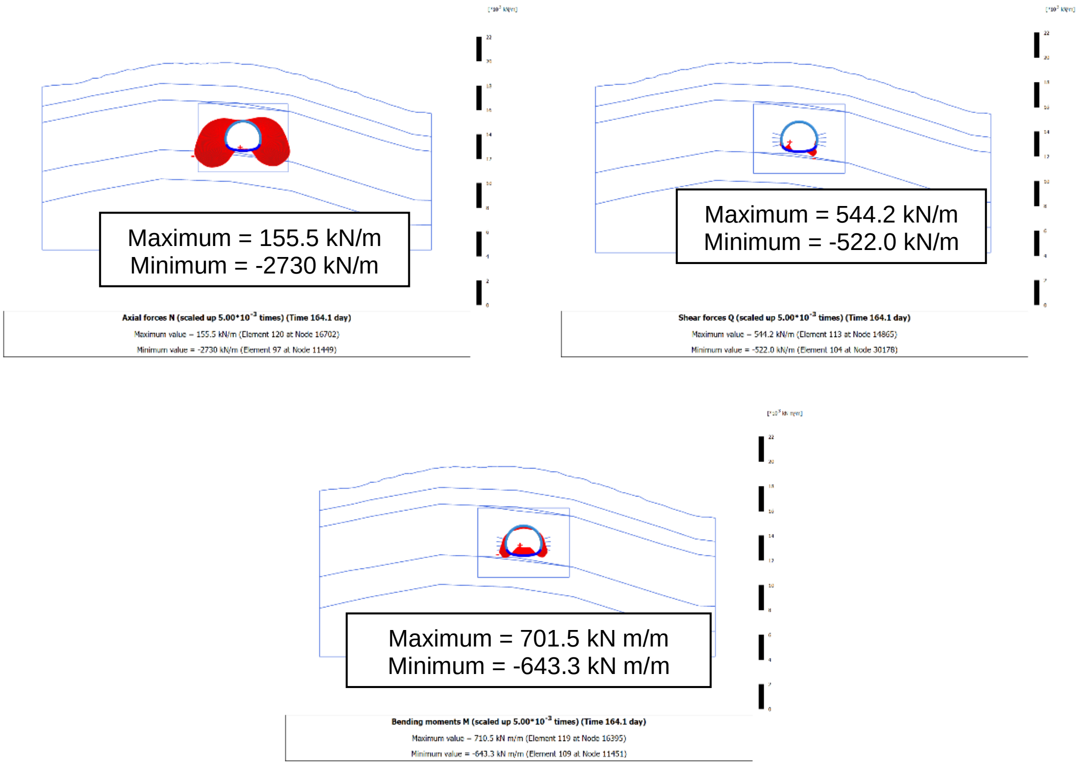


Gambar 26 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel No.5 (DK 86+640)

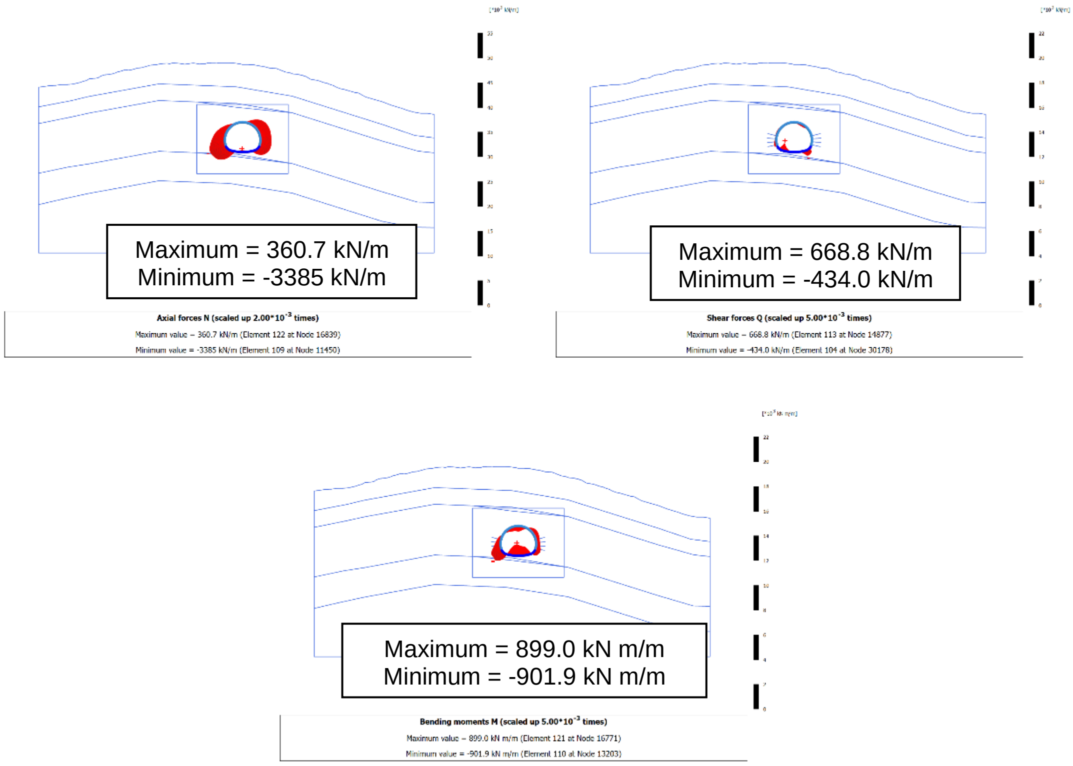


Gambar 27 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No.5 (DK 86+640)

b) *Cross Section DK 86+890*

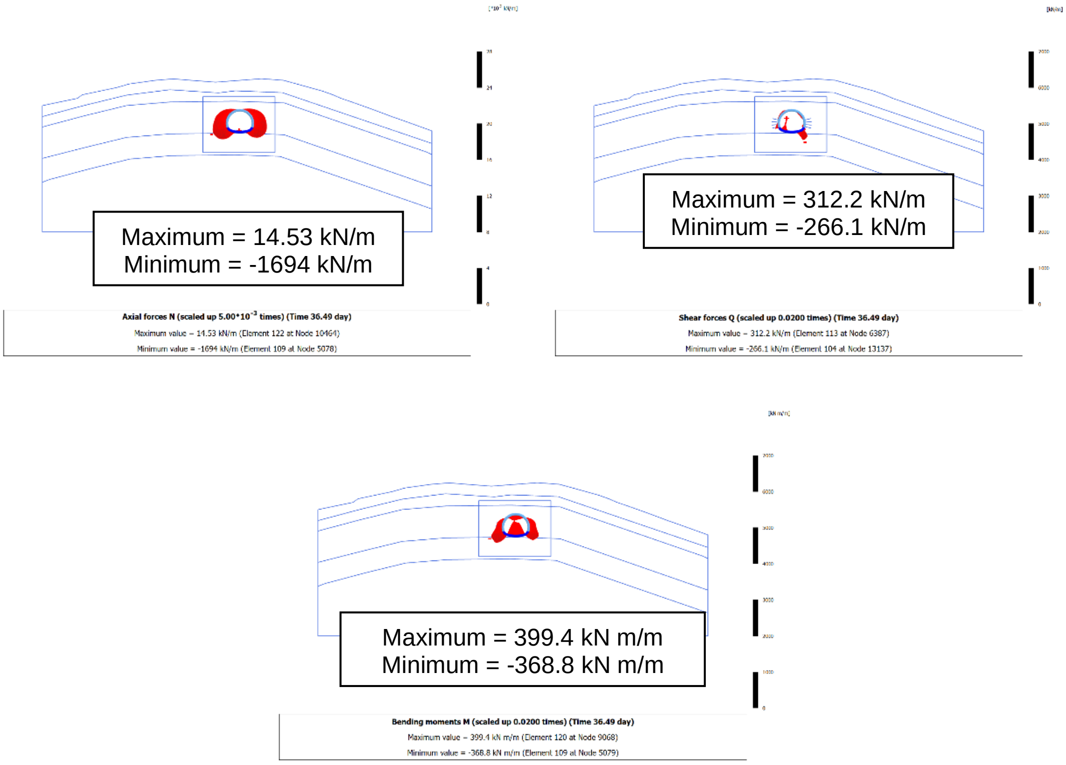


Gambar 28 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel No.5 (DK 86+890)

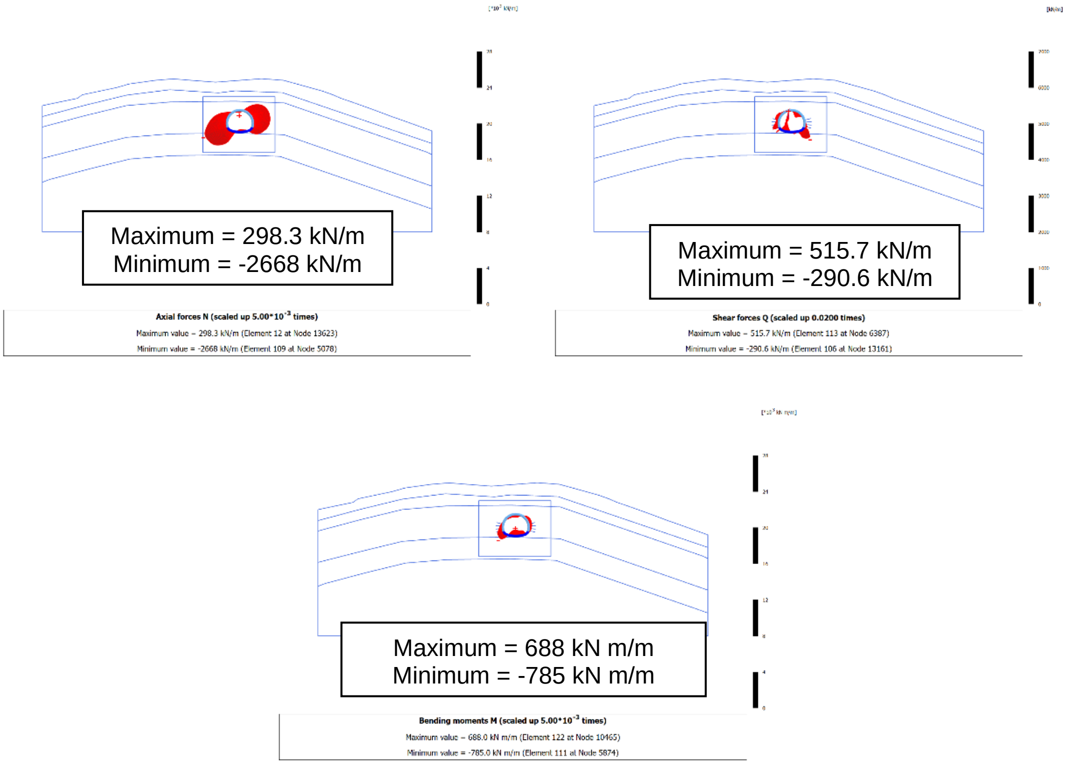


Gambar 29 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No.5 (DK 86+890)

c) *Cross Section DK 86+905*



Gambar 30 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel No.5 (DK 86+905)

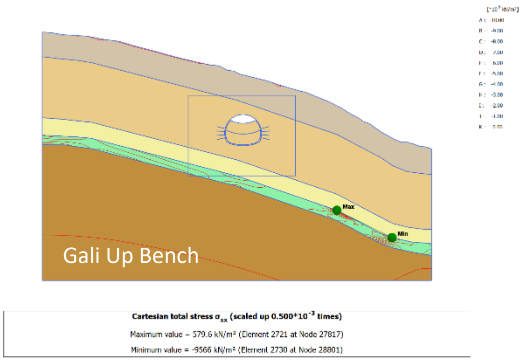


Gambar 31 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No.5 (DK 86+905)

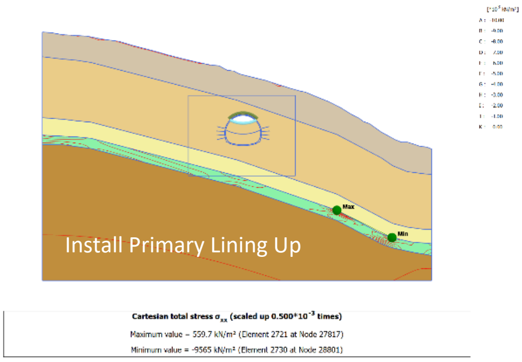
4. Tegangan Dalam Tanah

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 32** s/d **Gambar 61**.

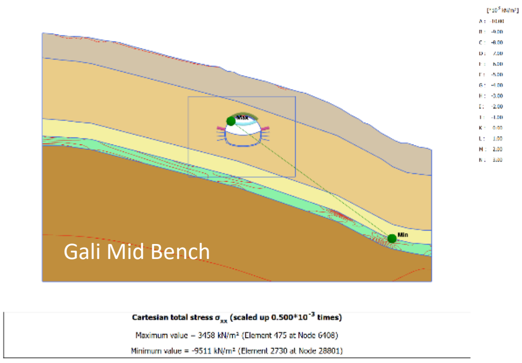
a) *Cross Section DK 86+640*



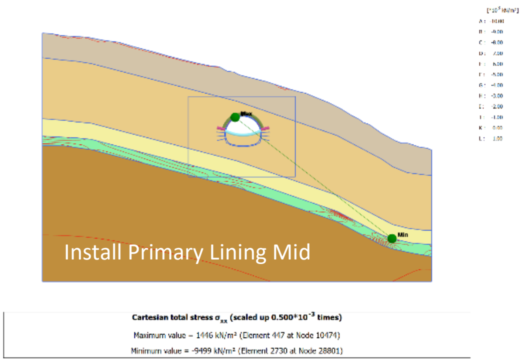
Maximum = 579.6 kN/m^2
Minimum = -9566 kN/m^2



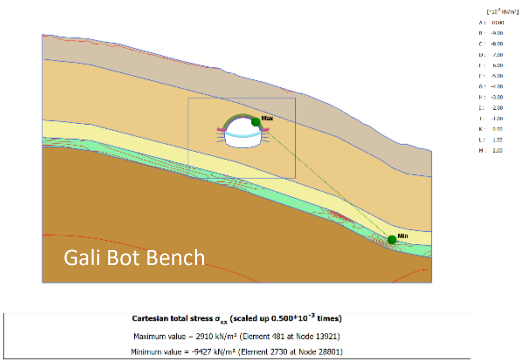
Maximum = 559.7 kN/m^2
Minimum = -9565 kN/m^2



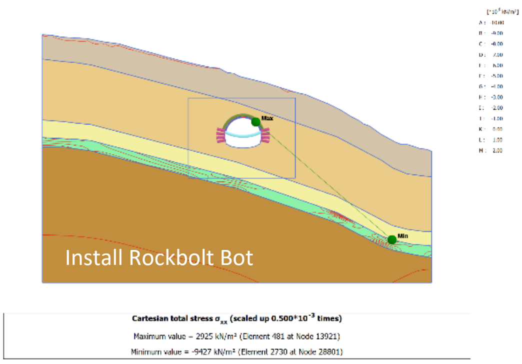
Maximum = 3458 kN/m^2
Minimum = -9511 kN/m^2



Maximum = 1446 kN/m^2
Minimum = -9499 kN/m^2

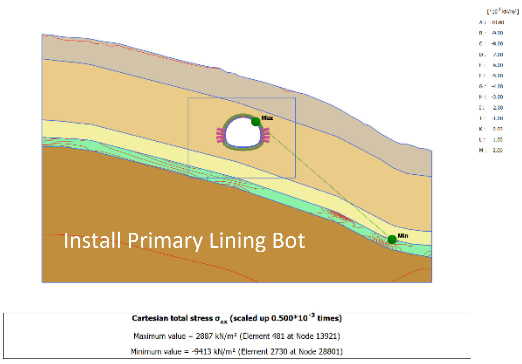


Maximum = 2910 kN/m^2
Minimum = -9427 kN/m^2

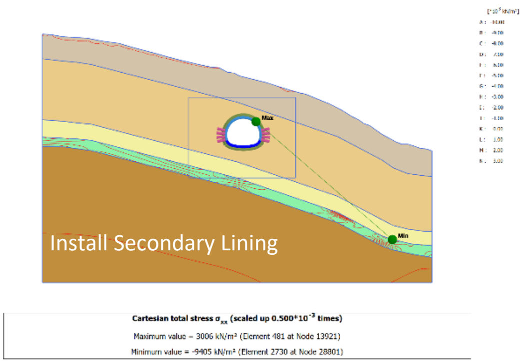


Maximum = 2925 kN/m^2
Minimum = -9427 kN/m^2

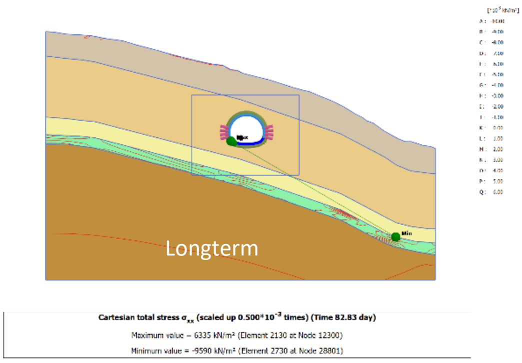
Gambar 32 Hasil analisis tegangan horizontal (σ_x) pada Tunnel No.5 (DK 86+640)



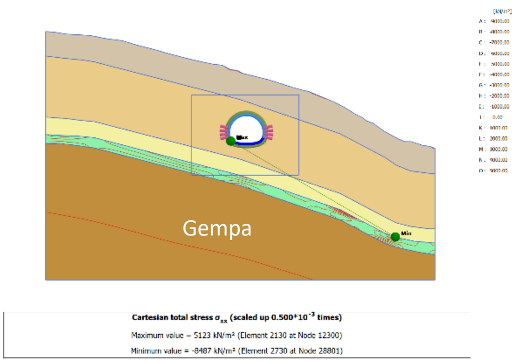
Maksimum = 2887 kN/m^2
Minimum = -9413 kN/m^2



Maximum = 3006 kN/m^2
Minimum = -9405 kN/m^2

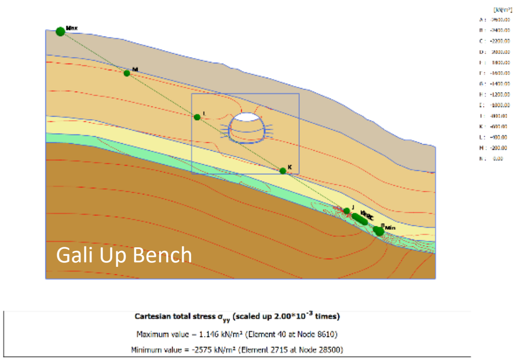


Maximum = 6335 kN/m^2
Minimum = -9590 kN/m^2

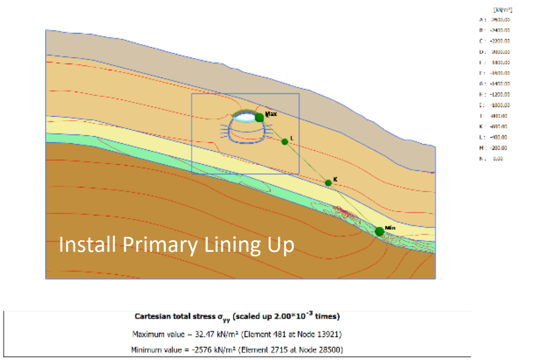


Maximum = 5123 kN/m^2
Minimum = -8487 kN/m^2

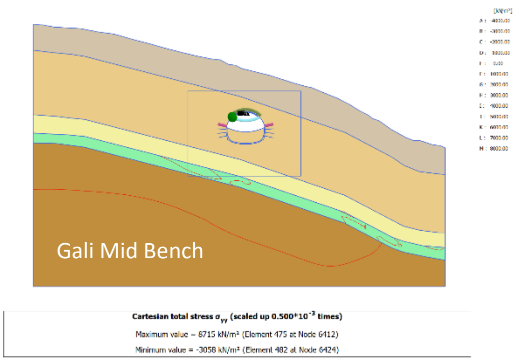
Gambar 33 Hasil analisis tegangan horizontal (σ_x) pada Tunnel No.5 (DK 86+640) (lanjutan)



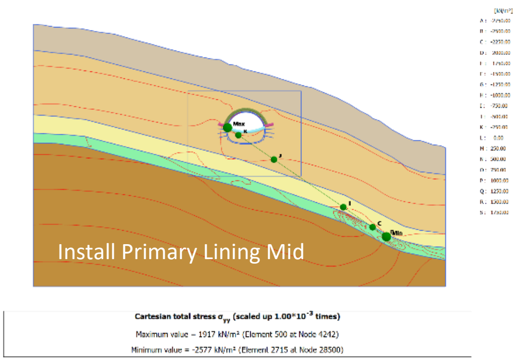
Maximum = 1.146 kN/m^2
Minimum = -2575 kN/m^2



Maximum = 32.47 kN/m^2
Minimum = -2576 kN/m^2

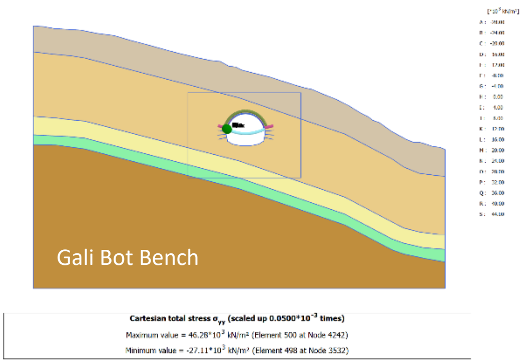


Maximum = 8715 kN/m^2
Minimum = -3058 kN/m^2

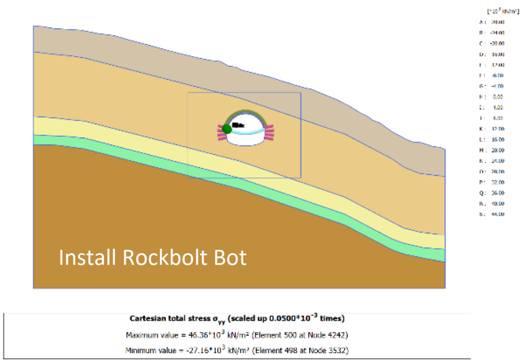


Maximum = 1917 kN/m^2
Minimum = -2577 kN/m^2

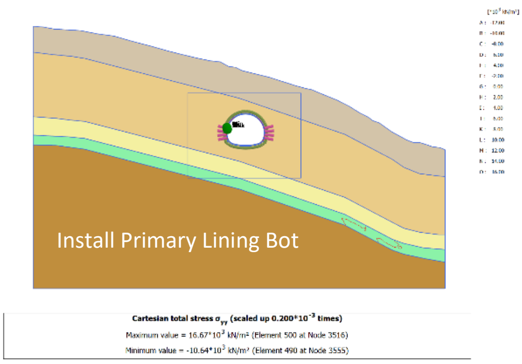
Gambar 34 Hasil analisis tegangan vertikal (σ_y) pada Tunnel No.5 (DK 86+640)



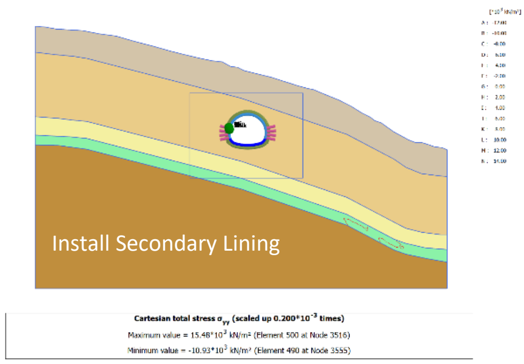
Maximum = 46.28 x 10^3 kN/m^2
Minimum = -27.11 x 10^3 kN/m^2



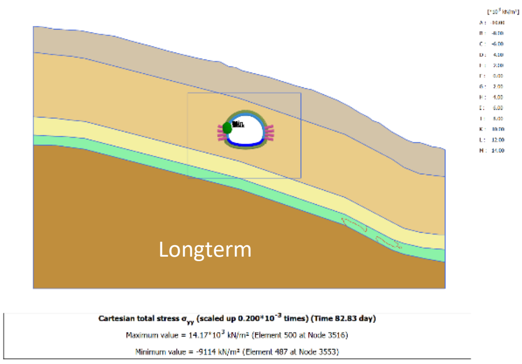
Maximum = 46.36 x 10^3 kN/m^2
Minimum = -27.16 x 10^3 kN/m^2



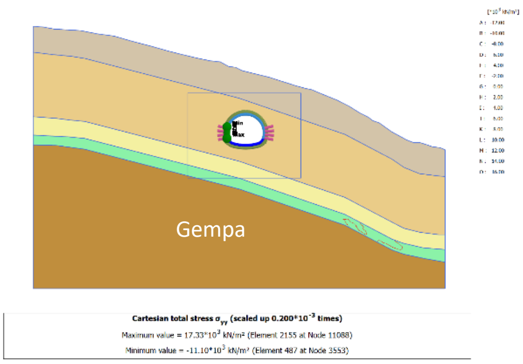
Maksimum = 16.67 x 10^3 kN/m^2
Minimum = -10.64 x 10^3 kN/m^2



Maximum = 15.48 x 10^3 kN/m^2
Minimum = -10.93 x 10^3 kN/m^2

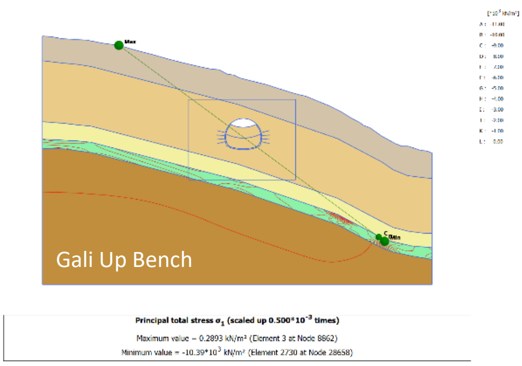


Maximum = 14.17 x 10^3 kN/m^2
Minimum = -9114 kN/m^2

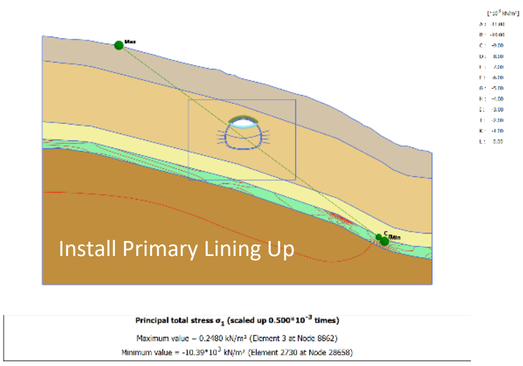


Maximum = 17.33 x 10^3 kN/m^2
Minimum = -11.10 x 10^3 kN/m^2

Gambar 35 Hasil analisis tegangan vertikal (σy) pada Tunnel No.5 (DK 86+640) (lanjutan)

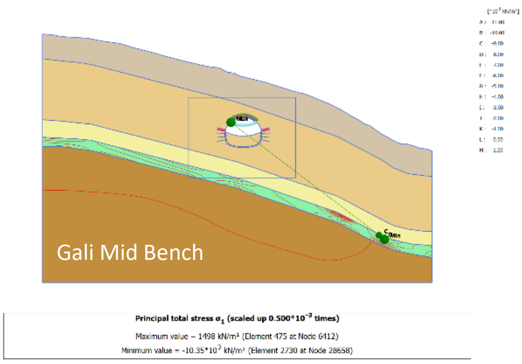


Maximum = 0.2893 kN/m^2
Minimum = -10.39 x 10^3 kN/m^2

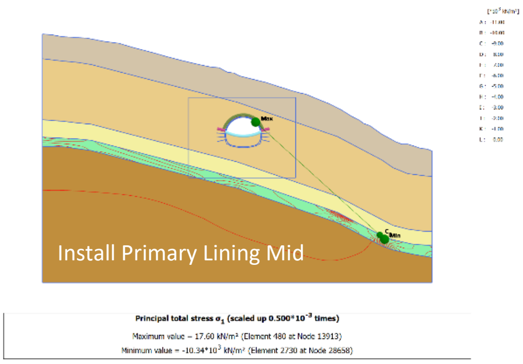


Maximum = 0.2480 kN/m^2
Minimum = -10.39 x 10^3 kN/m^2

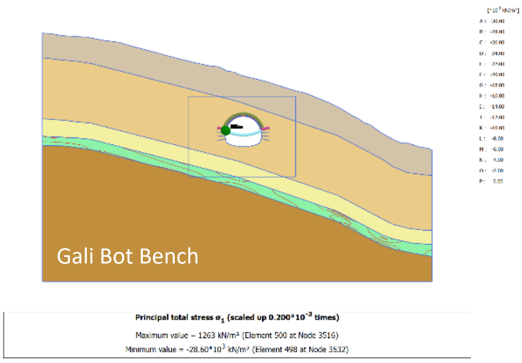
Gambar 36 Hasil analisis tegangan maksimum (σ1) pada Tunnel No.5 (DK 86+640)



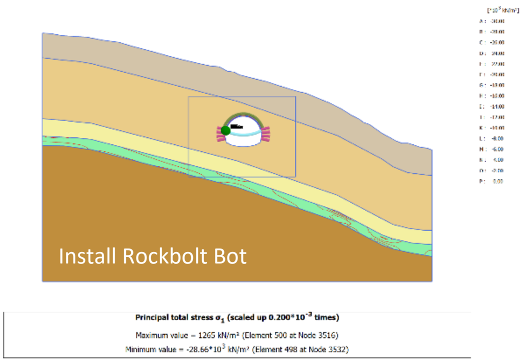
Maximum = 1498 kN/m^2
Minimum = -10.35 x 10^3 kN/m^2



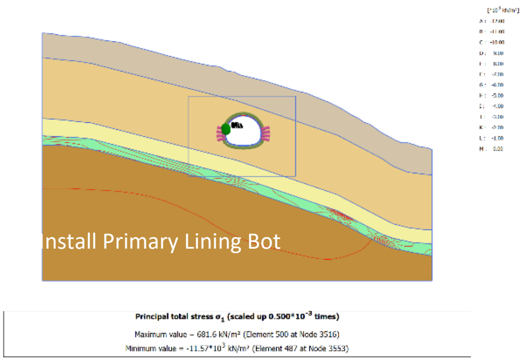
Maximum = 17.60 kN/m^2
Minimum = -10.34 x 10^3 kN/m^2



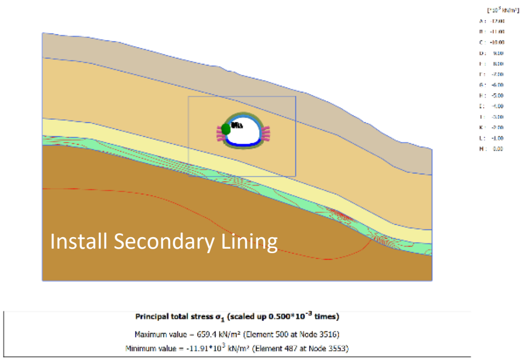
Maximum = 1263 kN/m^2
Minimum = -28.60 x 10^3 kN/m^2



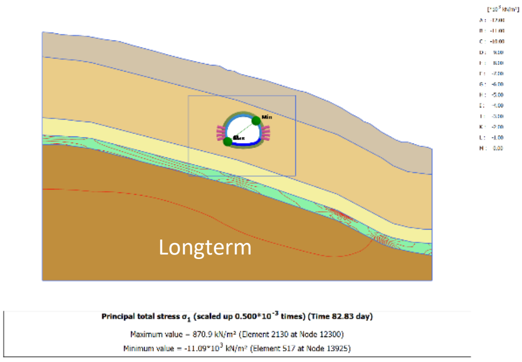
Maximum = 1265 kN/m^2
Minimum = -28.66 x 10^3 kN/m^2



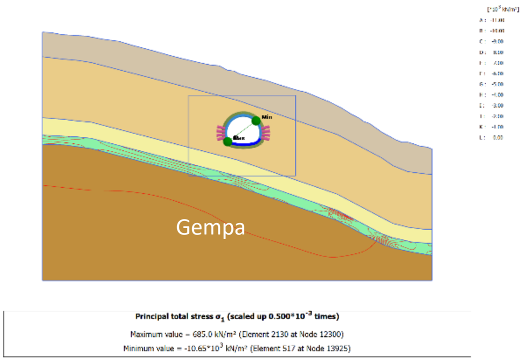
Maksimum = 681.6 kN/m^2
Minimum = -11.57 x 10^3 kN/m^2



Maximum = 659.4 kN/m^2
Minimum = -11.91 x 10^3 kN/m^2

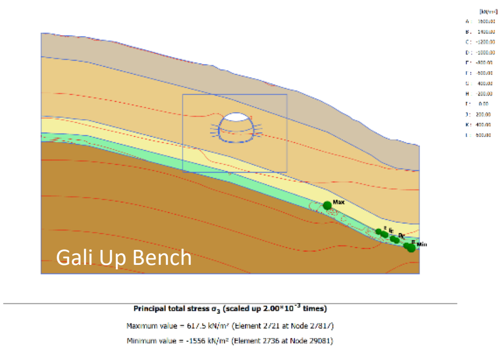


Maximum = 870.9 kN/m^2
Minimum = -11.09 x 10^3 kN/m^2

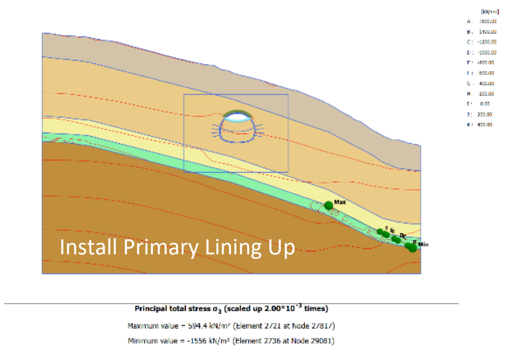


Maximum = 685.0 kN/m^2
Minimum = -10.65 x 10^3 kN/m^2

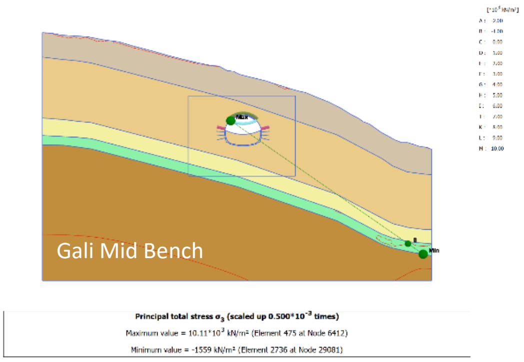
Gambar 37 Hasil analisis tegangan maksimum (σ1) pada Tunnel No.5 (DK 86+640) (lanjutan)



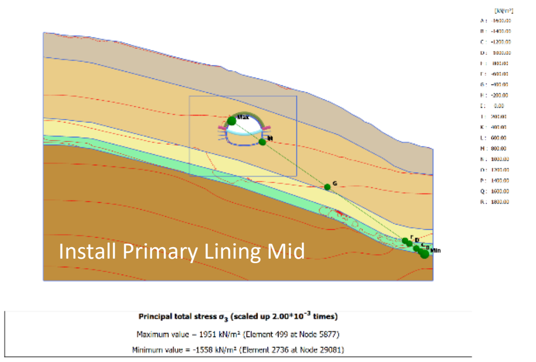
Maximum = 617.5 kN/m^2
Minimum = -1556 kN/m^2



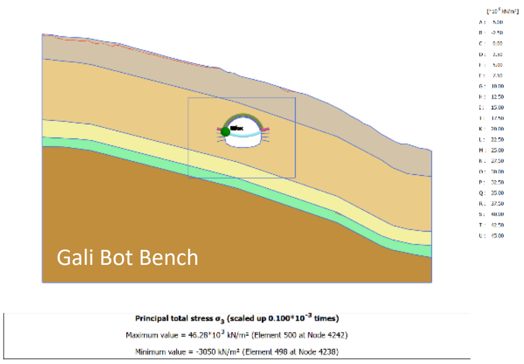
Maximum = 594.4 kN/m^2
Minimum = -1556 kN/m^2



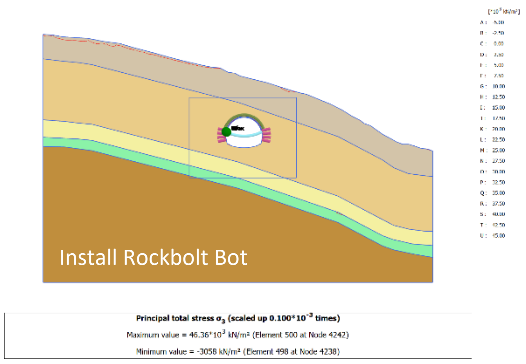
Maximum = 10.11 x 10^3 kN/m^2
Minimum = -1559 kN/m^2



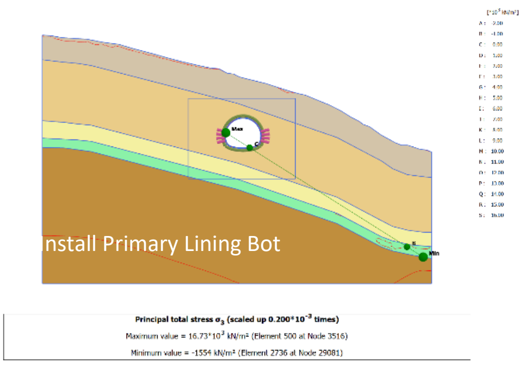
Maximum = 1951 kN/m^2
Minimum = -1558 kN/m^2



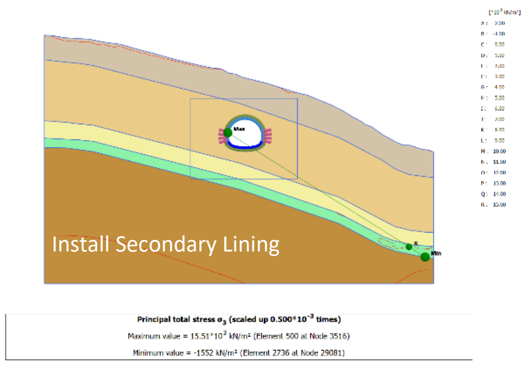
Maximum = 46.28 x 10^3 kN/m^2
Minimum = -3050 kN/m^2



Maximum = 46.36 x 10^3 kN/m^2
Minimum = -3058 kN/m^2

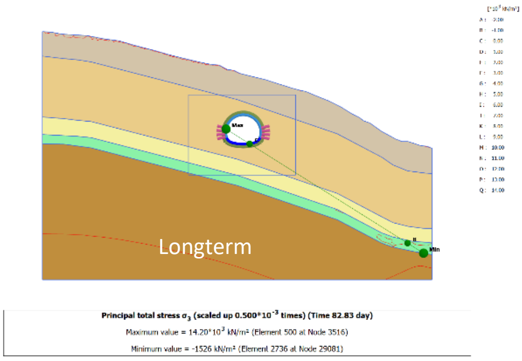


Maksimum = 16.73 x 10^3 kN/m^2
Minimum = -1554 kN/m^2

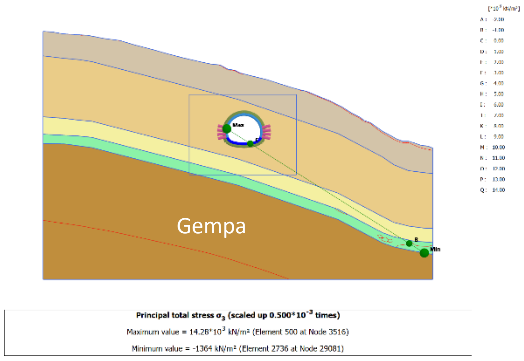


Maximum = 15.51 x 10^3 kN/m^2
Minimum = -1552 kN/m^2

Gambar 38 Hasil analisis tegangan minimum ($\sigma 3$) pada Tunnel No.5 (DK 86+640)

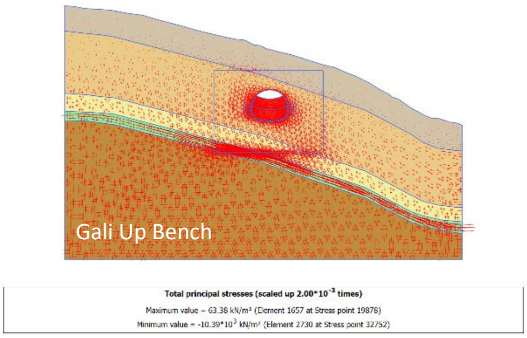


Maximum = 14.20 x 10^3 kN/m^2
Minimum = -1526 kN/m^2

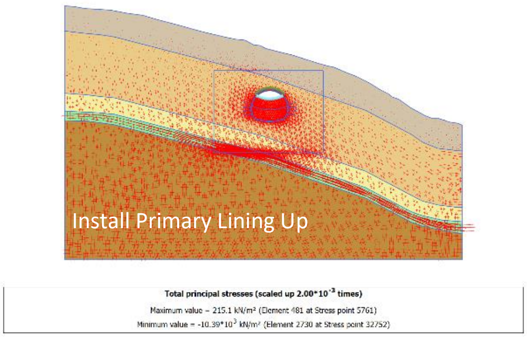


Maximum = 14.28 x 10^3 kN/m^2
Minimum = -1364 kN/m^2

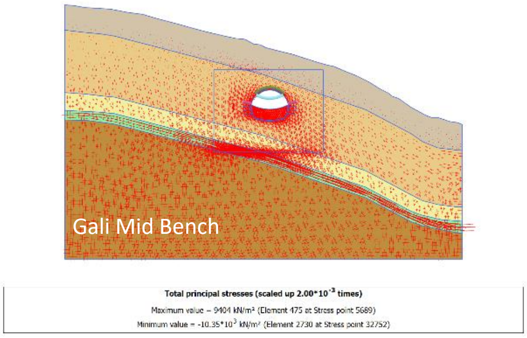
Gambar 39 Hasil analisis tegangan minimum ($\sigma 3$) pada Tunnel No.5 (DK 86+640) (lanjutan)



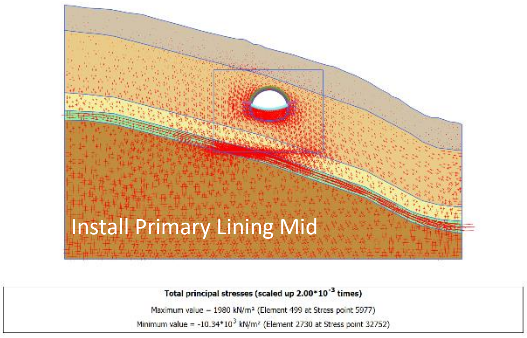
Maximum = 63.38 kN/m^2
Minimum = -10.39 x 10^3 kN/m^2



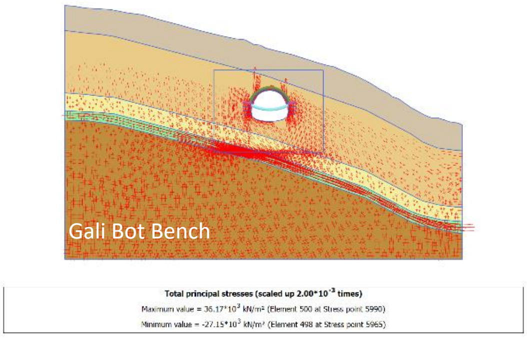
Maximum = 215.1 kN/m^2
Minimum = -10.39 x 10^3 kN/m^2



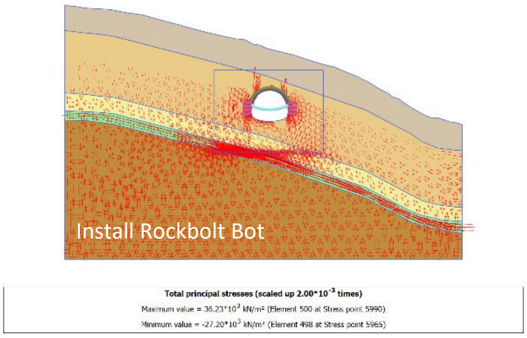
Maximum = 9404 kN/m^2
Minimum = -10.35 x 10^3 kN/m^2



Maximum = 1980 kN/m^2
Minimum = -10.34 x 10^3 kN/m^2

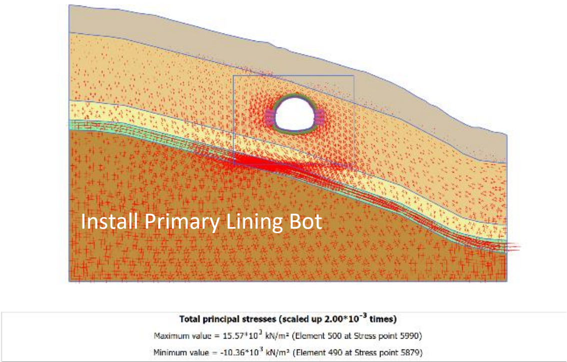


Maximum = 36.17 x 10^3 kN/m^2
Minimum = -27.15 x 10^3 kN/m^2

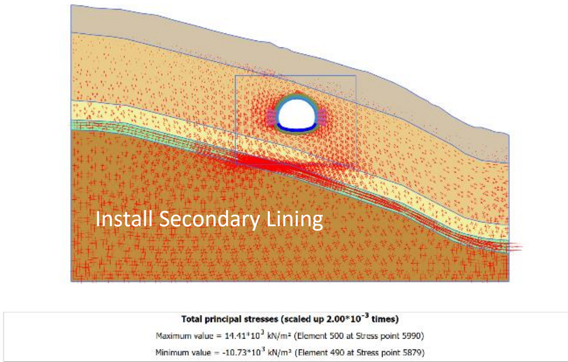


Maximum = 36.23 x 10^3 kN/m^2
Minimum = -27.20 x 10^3 kN/m^2

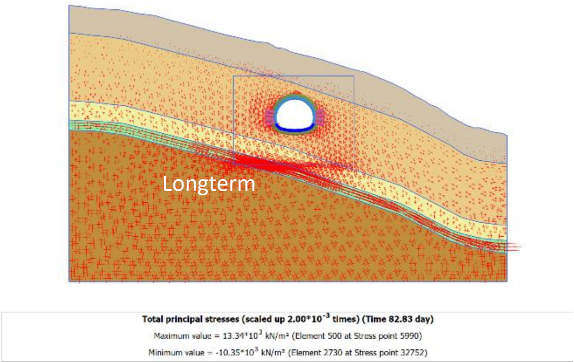
Gambar 40 Hasil analisis Total Principal Stresses pada Tunnel No.5 (DK 86+640)



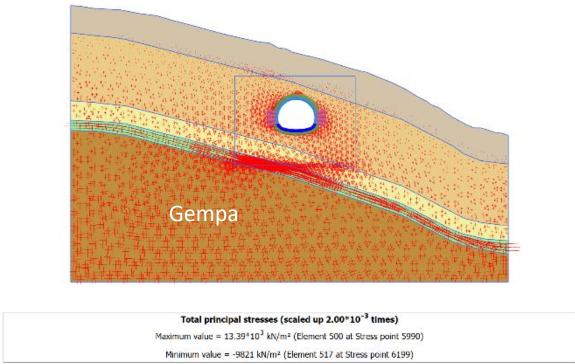
Maksimum = 15.57 x 10^3 kN/m^2
Minimum = -10.36 x 10^3 kN/m^2



Maximum = 14.41 x 10^3 kN/m^2
Minimum = -10.73 x 10^3 kN/m^2



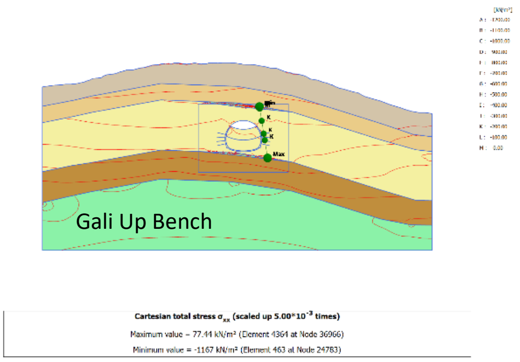
Maximum = 13.34 x 10^3 kN/m^2
Minimum = -10.35 x 10^3 kN/m^2



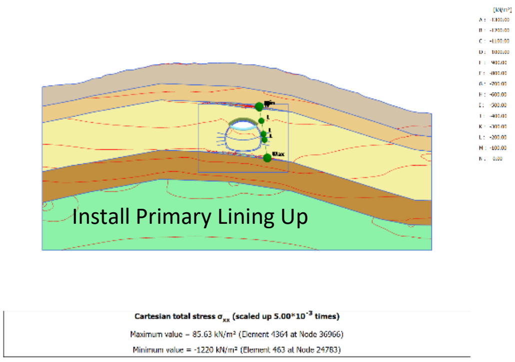
Maximum = 13.39 x 10^3 kN/m^2
Minimum = -9821 kN/m^2

Gambar 41 Hasil analisis Total Principal Stresses pada Tunnel No.5 (DK 86+640) (lanjutan)

b) *Cross Section DK 86+890*

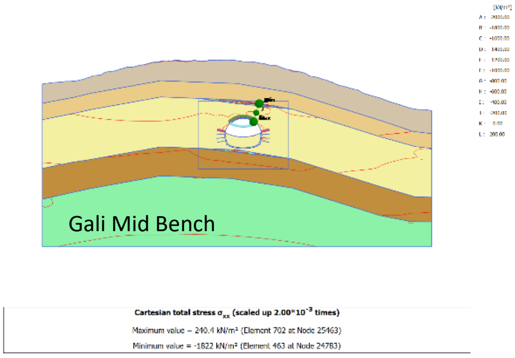


Maximum = 77.44 kN/m^2
Minimum = -1167 kN/m^2

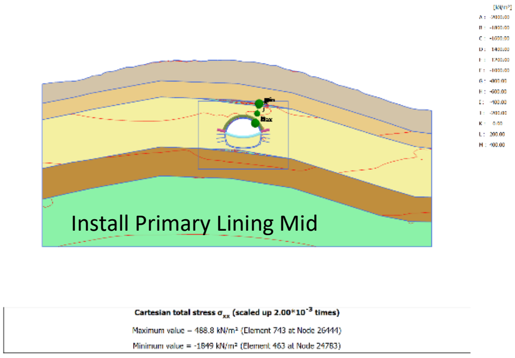


Maximum = 85.63 kN/m^2
Minimum = -1220 kN/m^2

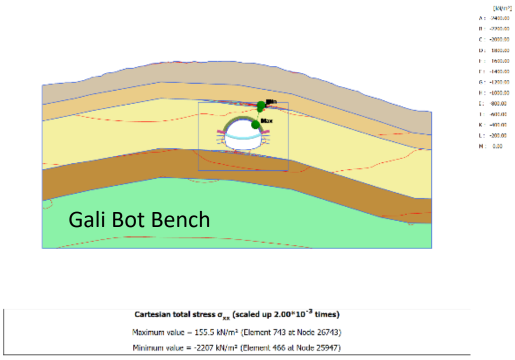
Gambar 42 Hasil analisis tegangan horizontal (σx) pada Tunnel No.5 (DK 86+890)



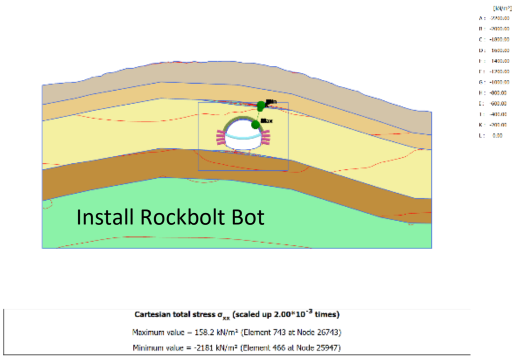
Maximum = 240.4 kN/m^2
Minimum = -1822 kN/m^2



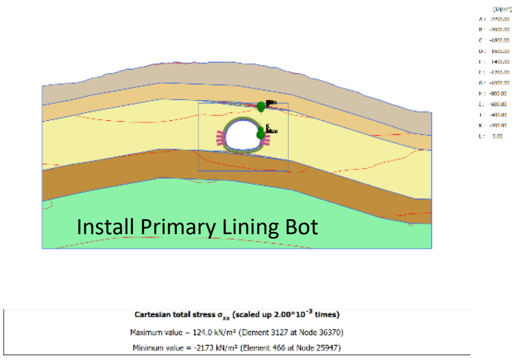
Maximum = 488.8 kN/m^2
Minimum = -1849 kN/m^2



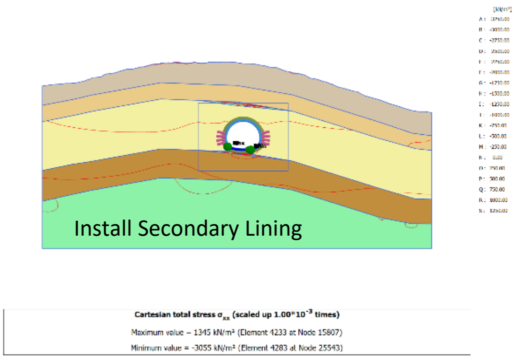
Maximum = 0155.5 kN/m^2
Minimum = -2207 kN/m^2



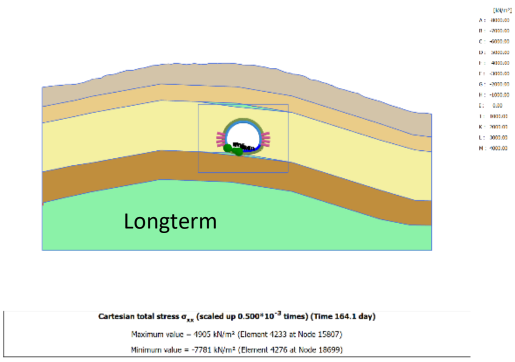
Maximum = 158.2 kN/m^2
Minimum = -2181 kN/m^2



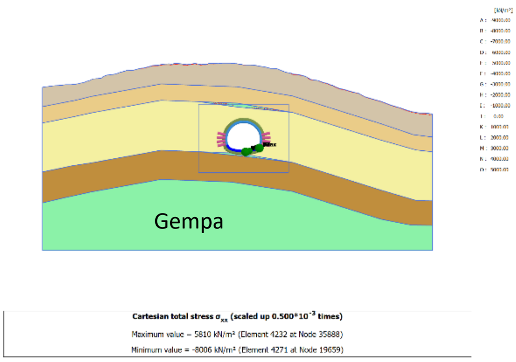
Maksimum = 124.0 kN/m^2
Minimum = -2173 kN/m^2



Maximum = 1345 kN/m^2
Minimum = -3055 kN/m^2

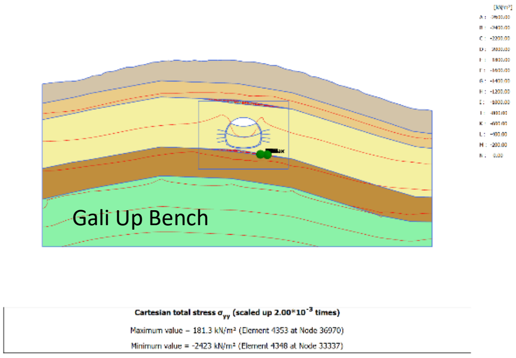


Maximum = 4905 kN/m^2
Minimum = -7781 kN/m^2

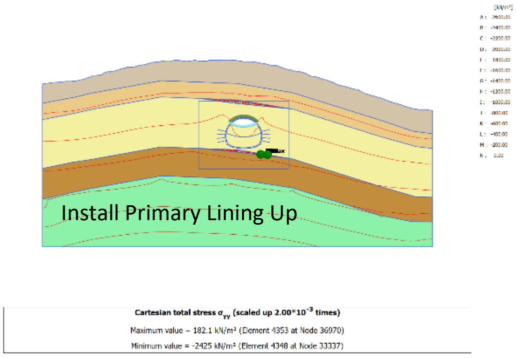


Maximum = 5810 kN/m^2
Minimum = -8006 kN/m^2

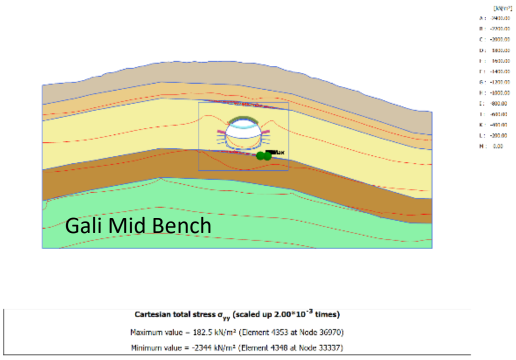
Gambar 43 Hasil analisis tegangan horizontal (σx) pada Tunnel No.5 (DK 86+890) (lanjutan)



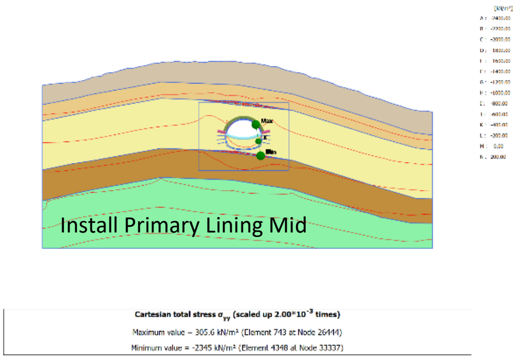
Maximum = 181.3 kN/m^2
Minimum = -2423 kN/m^2



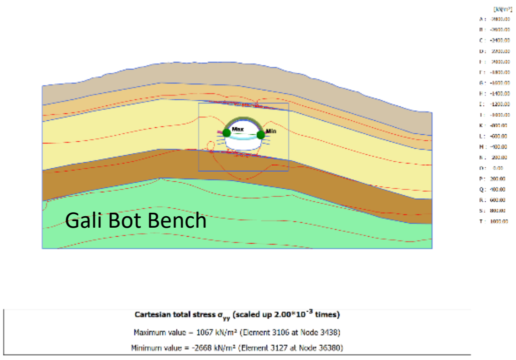
Maximum = 182.1 kN/m^2
Minimum = -2425 kN/m^2



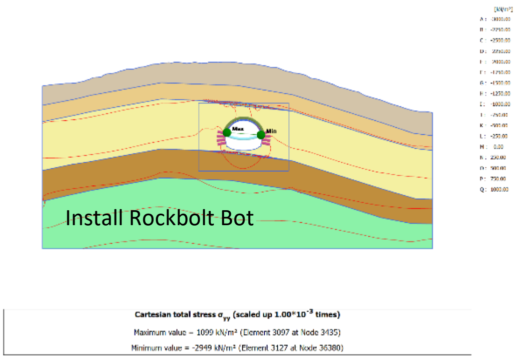
Maximum = 182.5 kN/m^2
Minimum = -2344 kN/m^2



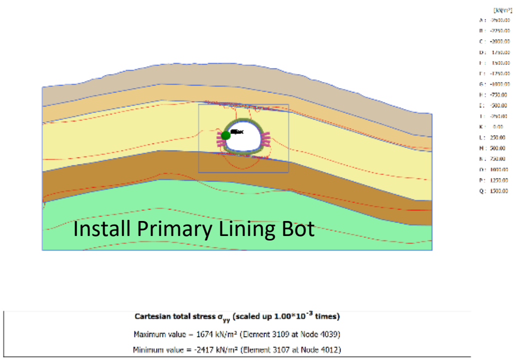
Maximum = 305.6 kN/m^2
Minimum = -2345 kN/m^2



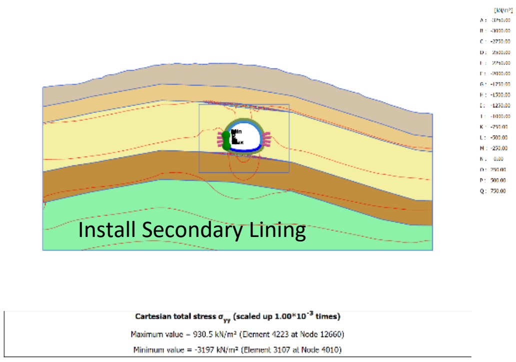
Maximum = 1067 kN/m^2
Minimum = -2668 kN/m^2



Maximum = 1099 kN/m^2
Minimum = -2949 kN/m^2

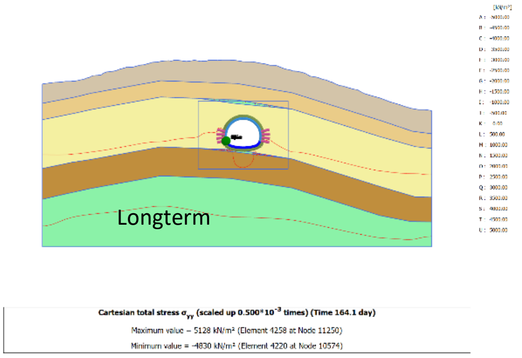


Maksimum = 1674 kN/m^2
Minimum = -2417 kN/m^2

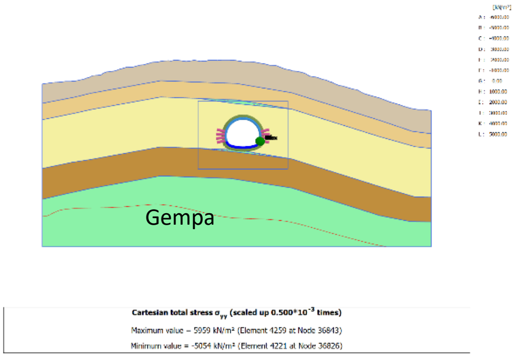


Maximum = 930.5 kN/m^2
Minimum = -3197 kN/m^2

Gambar 44 Hasil analisis tegangan vertikal (σy) pada Tunnel No.5 (DK 86+890)

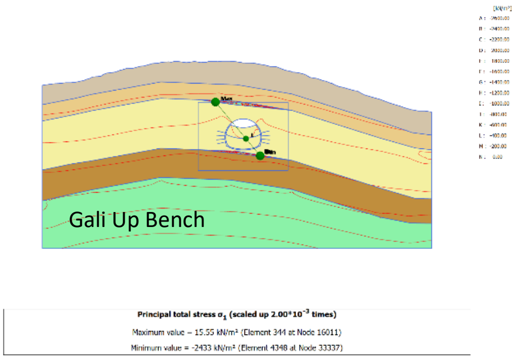


Maximum = 5128 kN/m^2
Minimum = -4830 kN/m^2

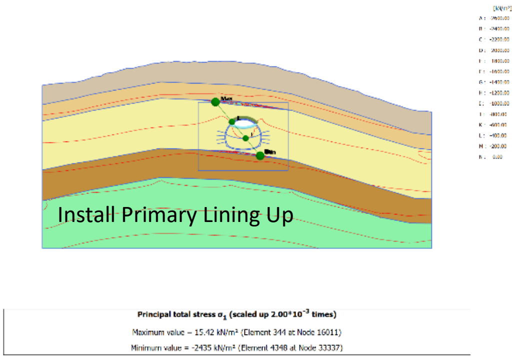


Maximum = 5959 kN/m^2
Minimum = -5054 kN/m^2

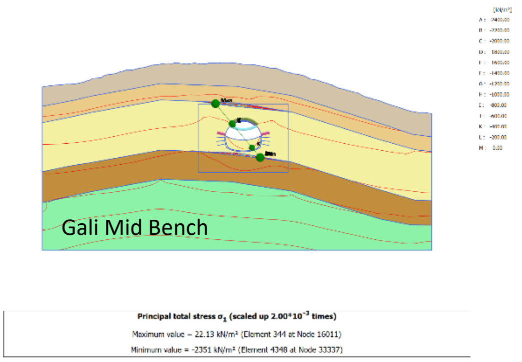
Gambar 45 Hasil analisis tegangan vertikal (σy) pada Tunnel No.5 (DK 86+890) (lanjutan)



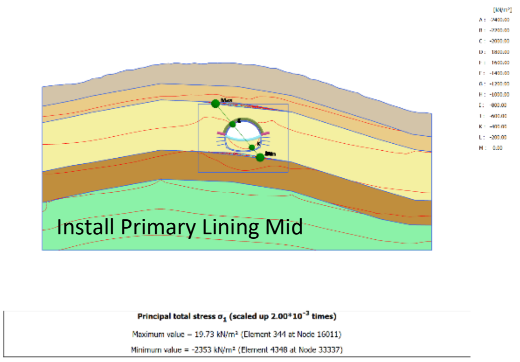
Maximum = 15.55 kN/m^2
Minimum = -2433 kN/m^2



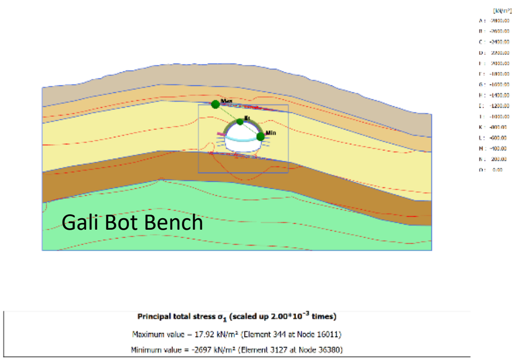
Maximum = 15.42 kN/m^2
Minimum = -2435 kN/m^2



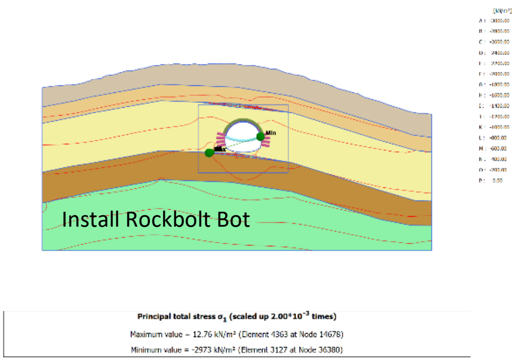
Maximum = 22.13 kN/m^2
Minimum = -2351 kN/m^2



Maximum = 19.73 kN/m^2
Minimum = -2353 kN/m^2

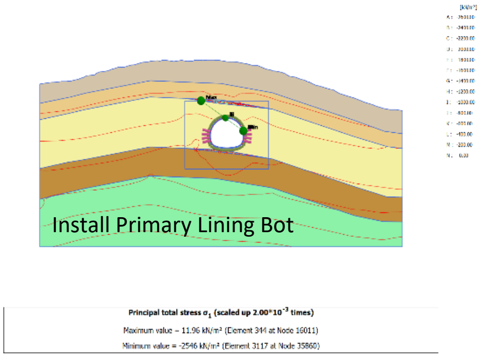


Maximum = 17.92 kN/m^2
Minimum = -2697 kN/m^2

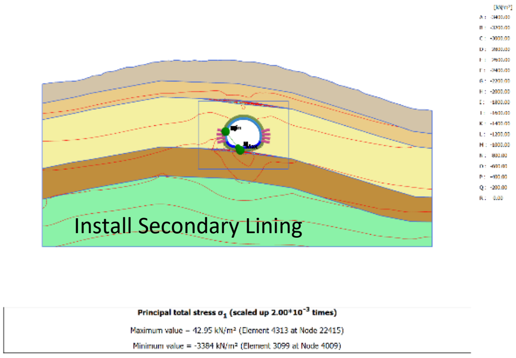


Maximum = 12.76 kN/m^2
Minimum = -2973 kN/m^2

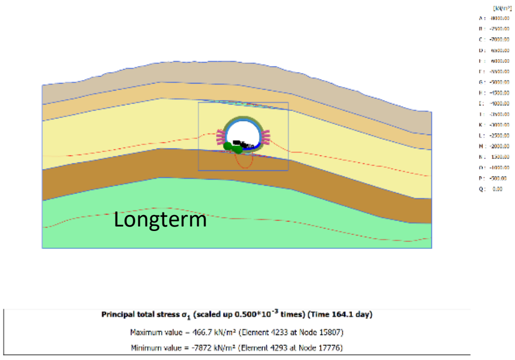
Gambar 46 Hasil analisis tegangan maksimum (σ1) pada Tunnel No.5 (DK 86+890)



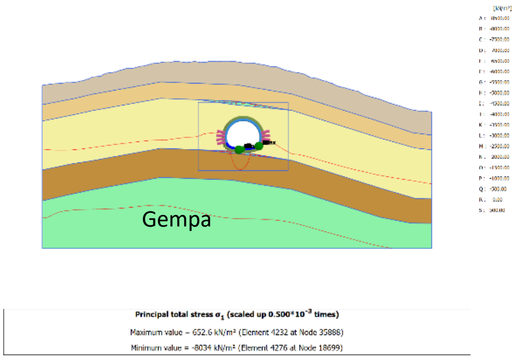
Maksimum = 11.96 kN/m^2
Minimum = -2546 kN/m^2



Maximum = 24.95 kN/m^2
Minimum = -3384 kN/m^2

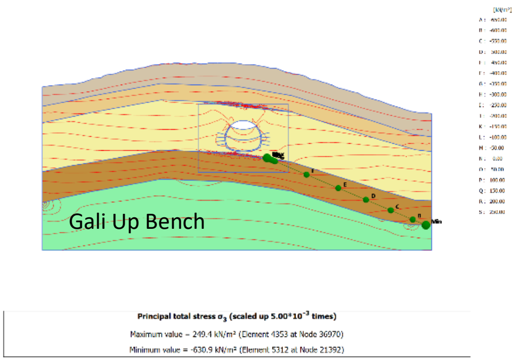


Maximum = 466.7 kN/m^2
Minimum = -7872 kN/m^2

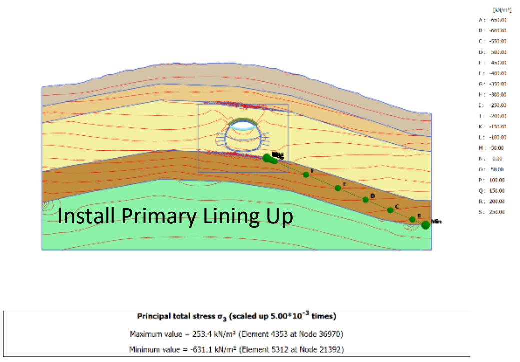


Maximum = 652.6 kN/m^2
Minimum = -8034 kN/m^2

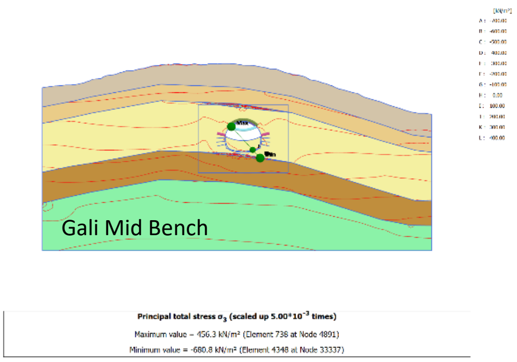
Gambar 47 Hasil analisis tegangan maksimum (σ1) pada Tunnel No.5 (DK 86+890) (lanjutan)



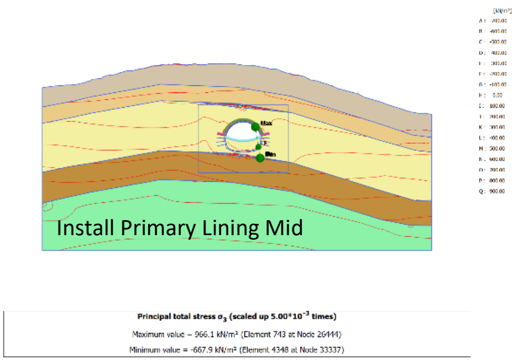
Maximum = 249.4 kN/m^2
Minimum = -630.9 kN/m^2



Maximum = 253.4 kN/m^2
Minimum = -631.1 kN/m^2

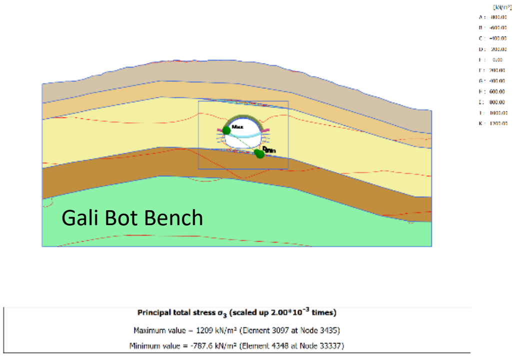


Maximum = 456.3 kN/m^2
Minimum = -680.8 kN/m^2

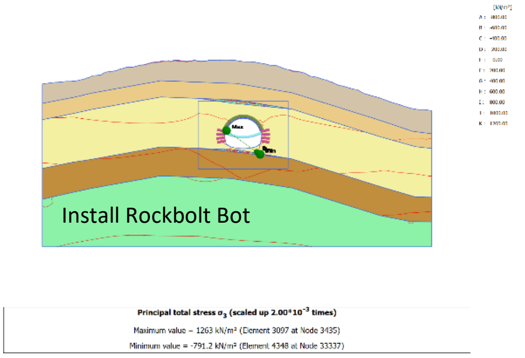


Maximum = 966.1 kN/m^2
Minimum = -667.9 kN/m^2

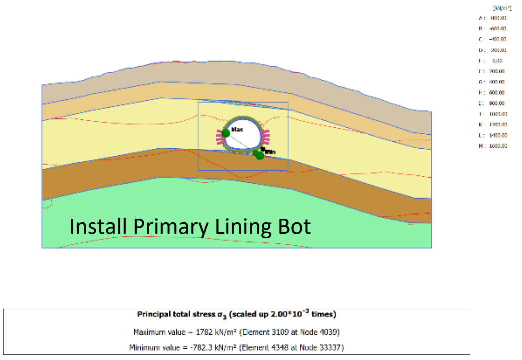
Gambar 48 Hasil analisis tegangan minimum (σ3) pada Tunnel No.5 (DK 86+890)



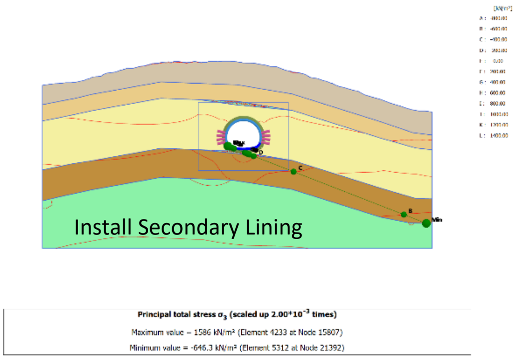
Maximum = 1209 kN/m^2
Minimum = -787.6 kN/m^2



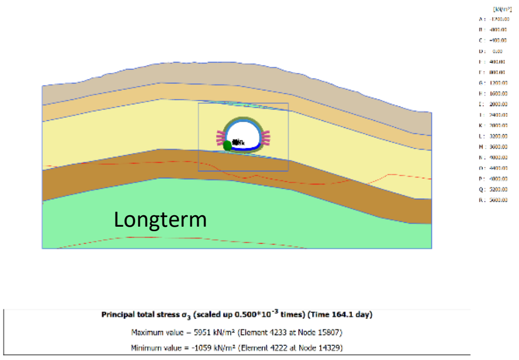
Maximum = 1263 kN/m^2
Minimum = -791.2 kN/m^2



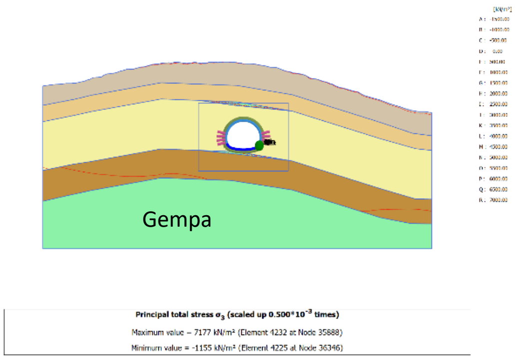
Maksimum = 1782 kN/m^2
Minimum = -782.3 kN/m^2



Maximum = 1586 kN/m^2
Minimum = -646.3 kN/m^2

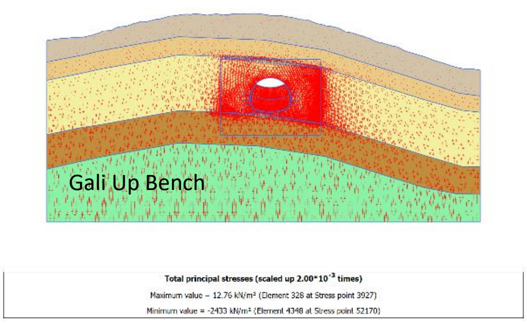


Maximum = 5951 kN/m^2
Minimum = -1059 kN/m^2

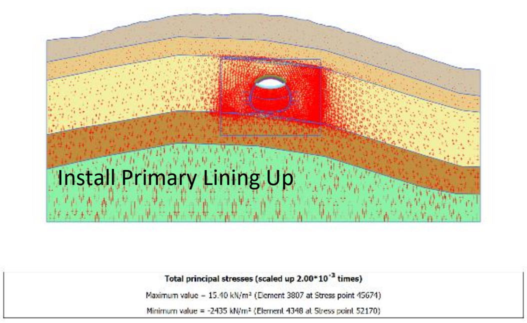


Maximum = 7177 kN/m^2
Minimum = -1155 kN/m^2

Gambar 49 Hasil analisis tegangan minimum (σ3) pada Tunnel No.5 (DK 86+890) (lanjutan)

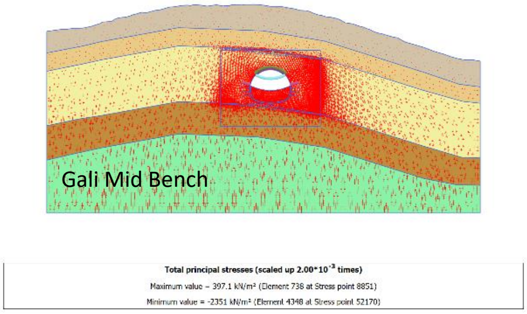


Maximum = 12.76 kN/m^2
Minimum = -2433 kN/m^2

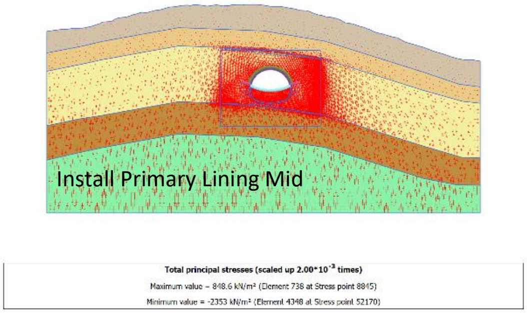


Maximum = 15.40 kN/m^2
Minimum = -2435 kN/m^2

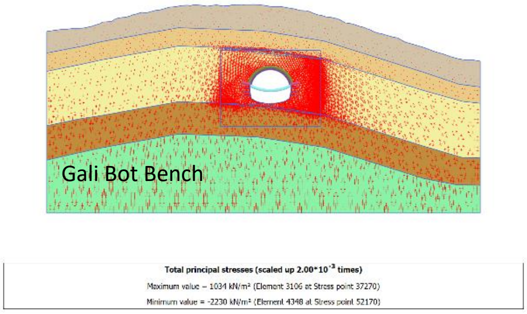
Gambar 50 Hasil analisis Total Principal Stresses pada Tunnel No.5 (DK 86+890)



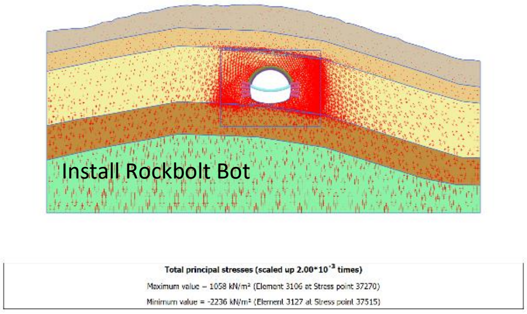
Maximum = 397.1 kN/m^2
Minimum = -2351 kN/m^2



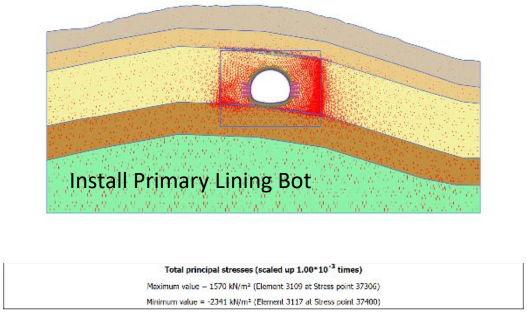
Maximum = 948.6 kN/m^2
Minimum = -2353 kN/m^2



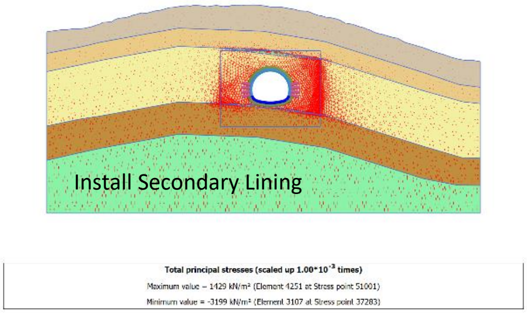
Maximum = 1034 kN/m^2
Minimum = -2230 kN/m^2



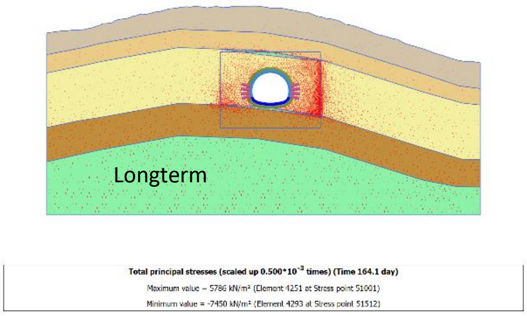
Maximum = 1058 kN/m^2
Minimum = -2236 kN/m^2



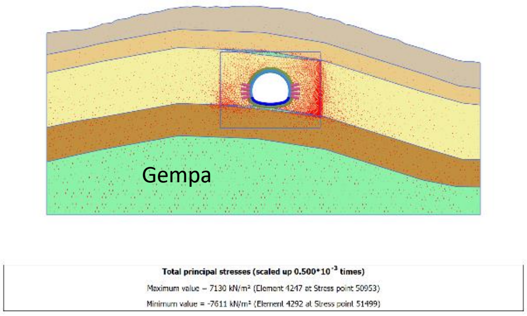
Maksimum = 1570 kN/m^2
Minimum = -2341 kN/m^2



Maximum = 1429 kN/m^2
Minimum = -3199 kN/m^2



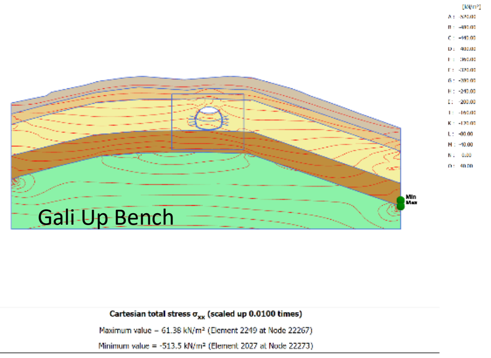
Maximum = 5786 kN/m^2
Minimum = -7450 kN/m^2



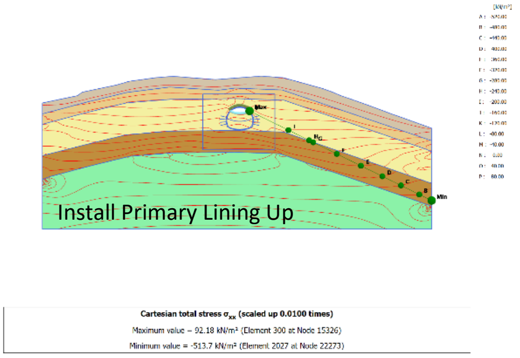
Maximum = 7130 kN/m^2
Minimum = -7611 kN/m^2

Gambar 51 Hasil analisis Total Principal Stresses pada Tunnel No.5 (DK 86+890) (lanjutan)

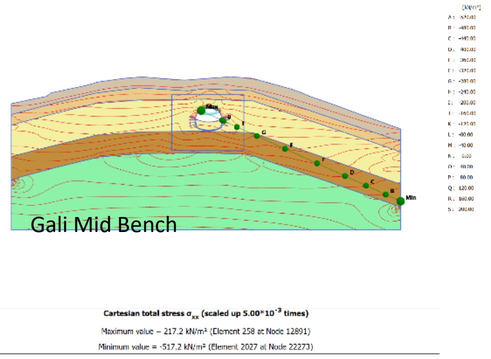
c) *Cross Section DK 86+905*



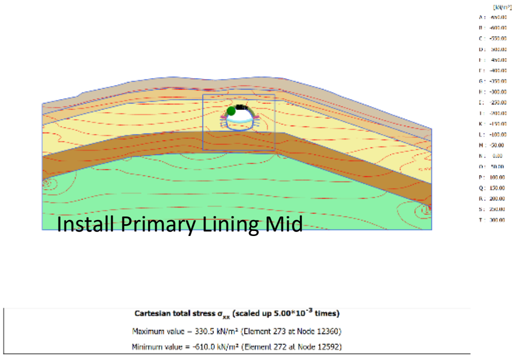
Maximum = 61.38 kN/m^2
Minimum = -513.5 kN/m^2



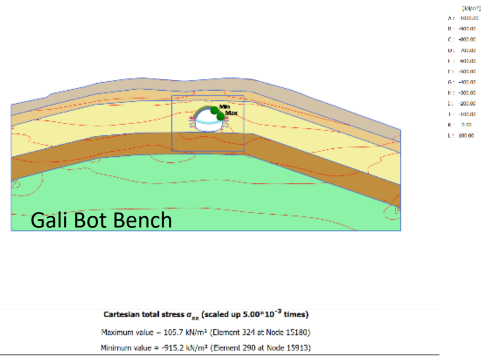
Maximum = 92.18 kN/m^2
Minimum = -513.7 kN/m^2



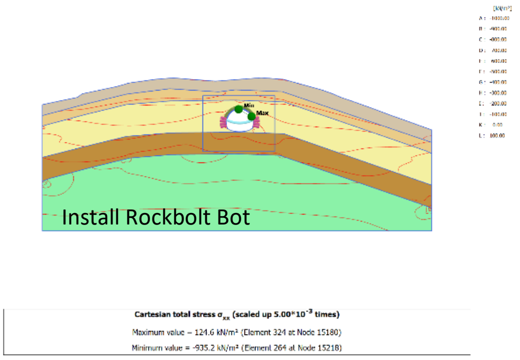
Maximum = 217.2 kN/m^2
Minimum = -517.2 kN/m^2



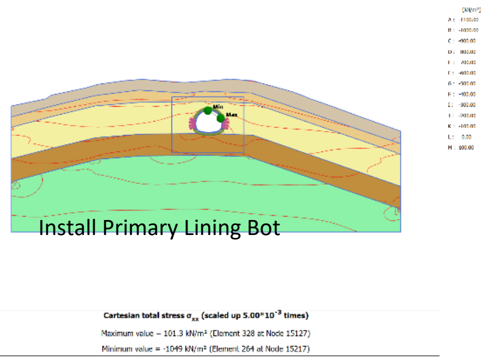
Maximum = 330.5 kN/m^2
Minimum = -610.0 kN/m^2



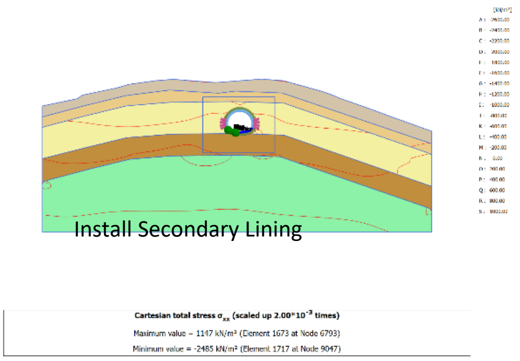
Maximum 105.7 kN/m^2
Minimum = -915.2 kN/m^2



Maximum = 124.6 kN/m^2
Minimum = -935.2 kN/m^2

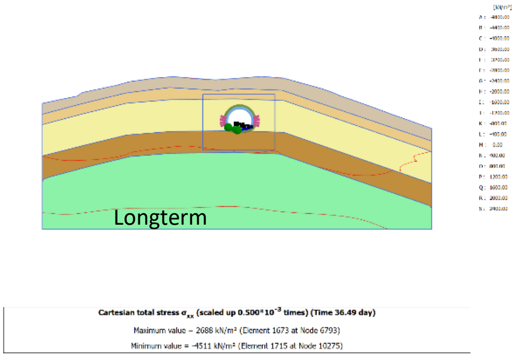


Maksimum = 101.3 kN/m^2
Minimum = -1049 kN/m^2

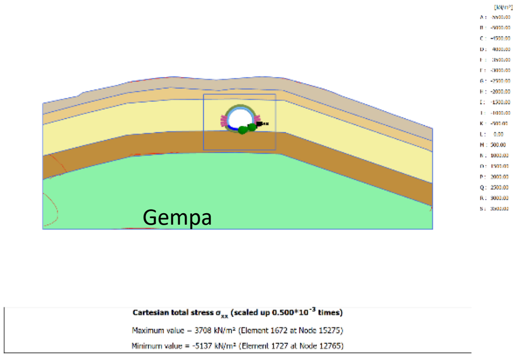


Maximum = 1147 kN/m^2
Minimum = -2485 kN/m^2

Gambar 52 Hasil analisis tegangan horizontal (σ_x) pada Tunnel No.5 (DK 86+905)

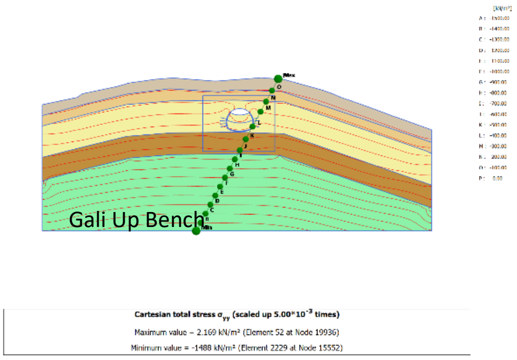


Maximum = 2688 kN/m^2
Minimum = -4511 kN/m^2

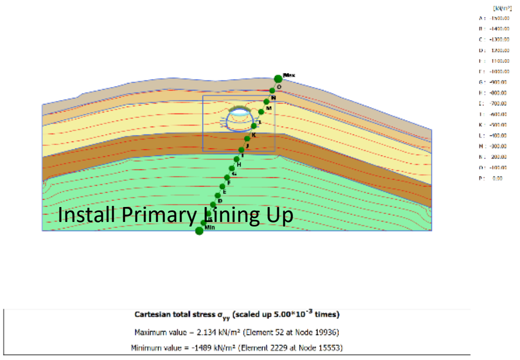


Maximum = 3708 kN/m^2
Minimum = -5137 kN/m^2

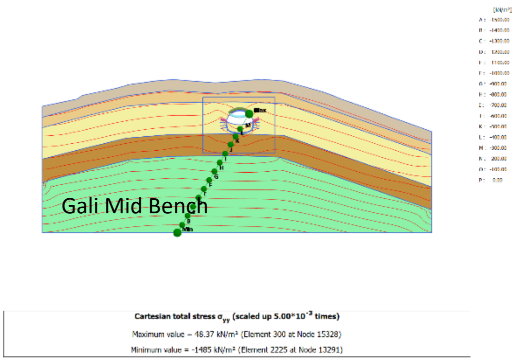
Gambar 53 Hasil analisis tegangan horizontal (σx) pada Tunnel No.5 (DK 86+905) (lanjutan)



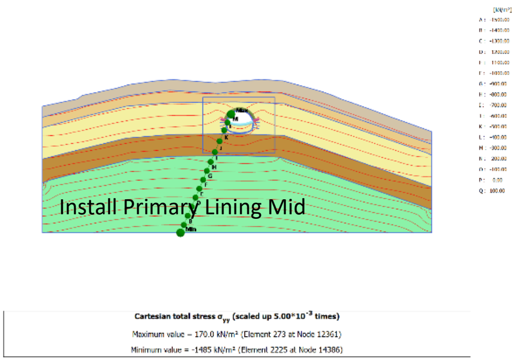
Maximum = 2.169 kN/m^2
Minimum = -1488 kN/m^2



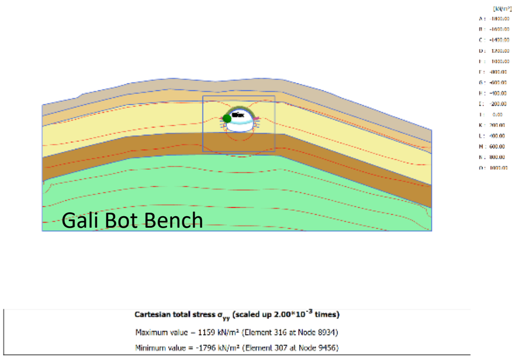
Maximum = 2.134 kN/m^2
Minimum = -1489 kN/m^2



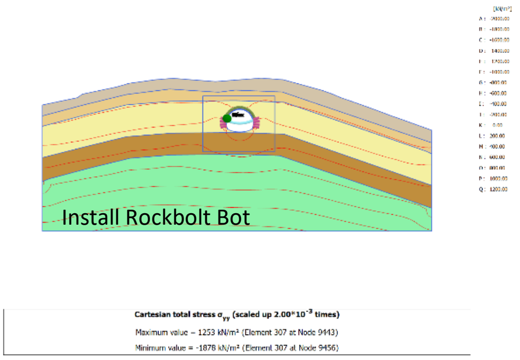
Maximum = 48.37 kN/m^2
Minimum = -1485 kN/m^2



Maximum = 170.0 kN/m^2
Minimum = -1485 kN/m^2

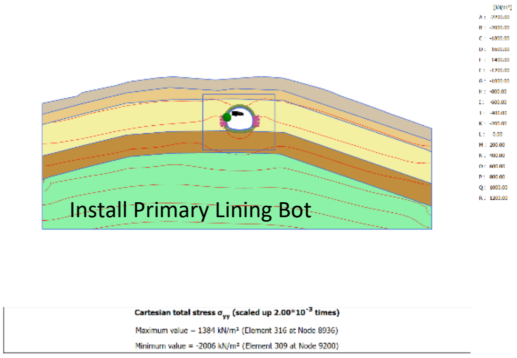


Maximum = 1159 kN/m^2
Minimum = -1796 kN/m^2

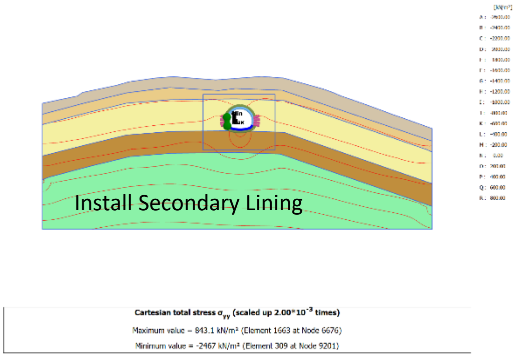


Maximum = 1253 kN/m^2
Minimum = -1878 kN/m^2

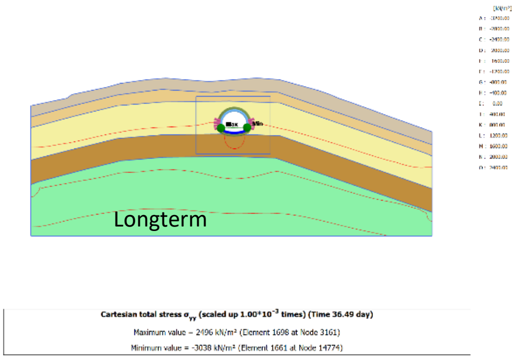
Gambar 54 Hasil analisis tegangan vertikal (σy) pada Tunnel No.5 (DK 86+905)



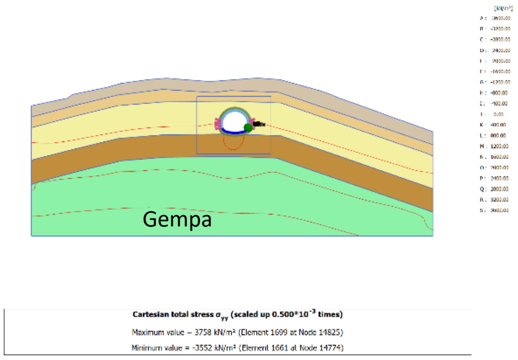
Maksimum = 1384 kN/m^2
Minimum = -2006 kN/m^2



Maximum = 843.1 kN/m^2
Minimum = -2467 kN/m^2

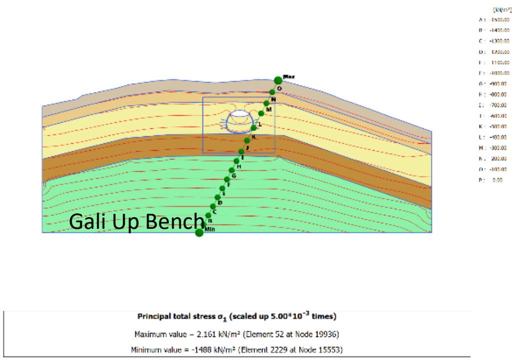


Maximum = 2496 kN/m^2
Minimum = -3038 kN/m^2

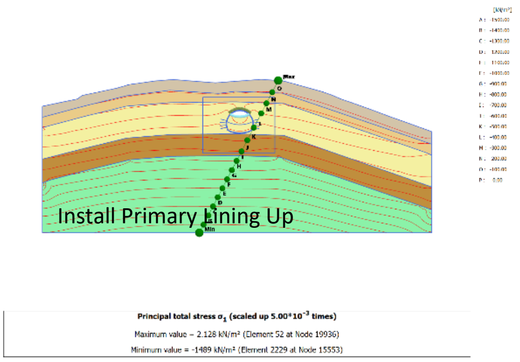


Maximum = 3758 kN/m^2
Minimum = -3552 kN/m^2

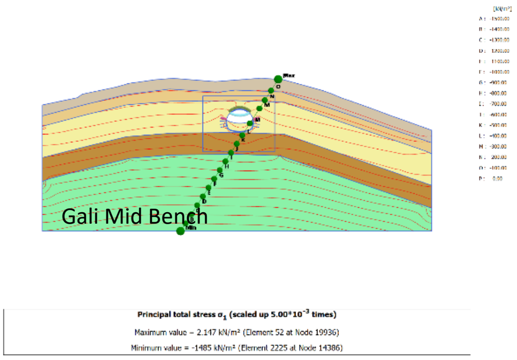
Gambar 55 Hasil analisis tegangan vertikal (σy) pada Tunnel No.5 (DK 86+905) (lanjutan)



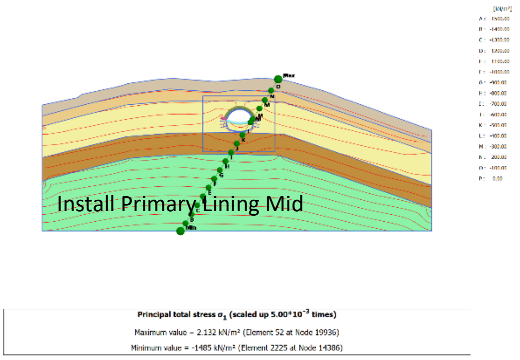
Maximum = 2.161 kN/m^2
Minimum = -1488 kN/m^2



Maximum = 2.128 kN/m^2
Minimum = -1489 kN/m^2

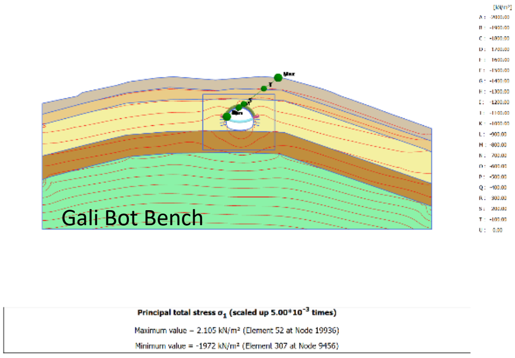


Maximum = 2.147 kN/m^2
Minimum = -1485 kN/m^2

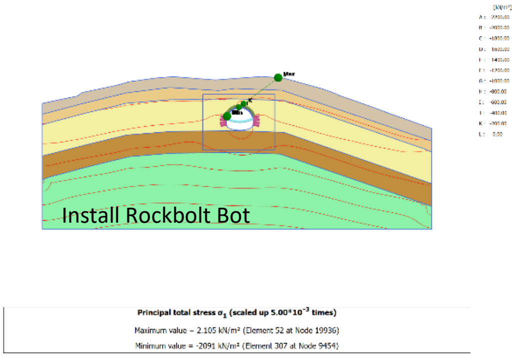


Maximum = 2.132 kN/m^2
Minimum = -1485 kN/m^2

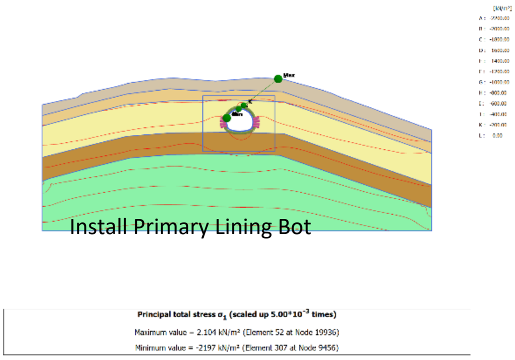
Gambar 56 Hasil analisis tegangan maksimum (σ1) pada Tunnel No.5 (DK 86+905)



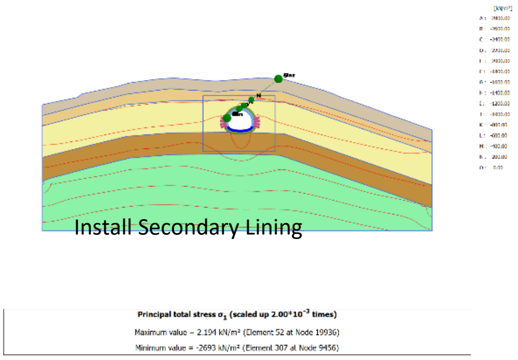
Maximum = 2.105 kN/m^2
Minimum = -1972 kN/m^2



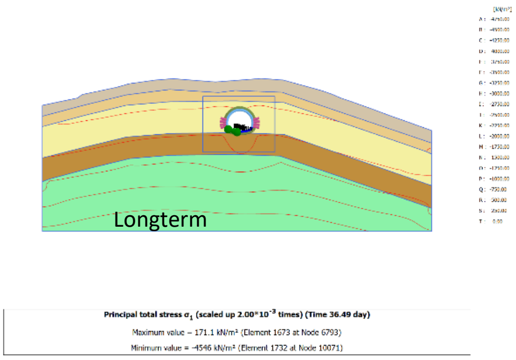
Maximum = 2.105 kN/m^2
Minimum = -2091 kN/m^2



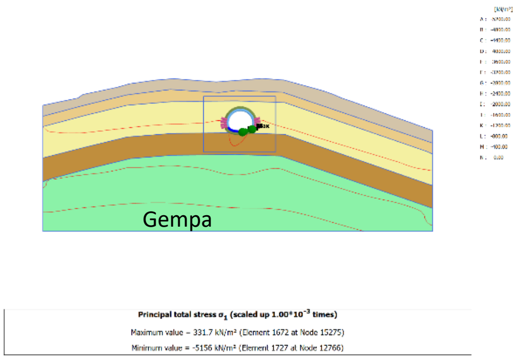
Maksimum = 2.104 kN/m^2
Minimum = -2197 kN/m^2



Maximum = 2.194 kN/m^2
Minimum = -2693 kN/m^2

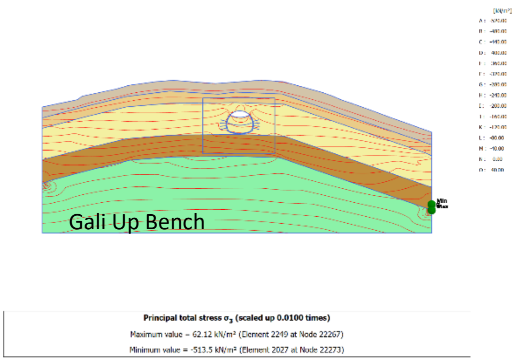


Maximum = 171.1 kN/m^2
Minimum = -4546 kN/m^2

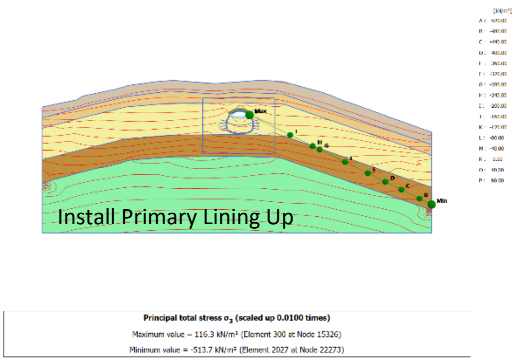


Maximum = 331.7 kN/m^2
Minimum = -5156 kN/m^2

Gambar 57 Hasil analisis tegangan maksimum (σ1) pada Tunnel No.5 (DK 86+905) (lanjutan)

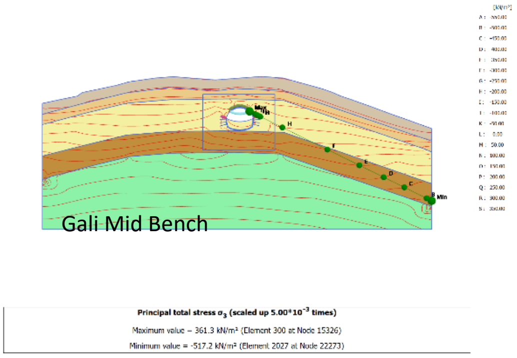


Maximum = 62.12 kN/m^2
Minimum = -513.5 kN/m^2

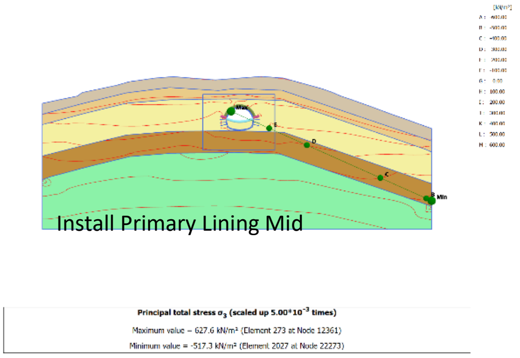


Maximum = 116.3 kN/m^2
Minimum = -513.7 kN/m^2

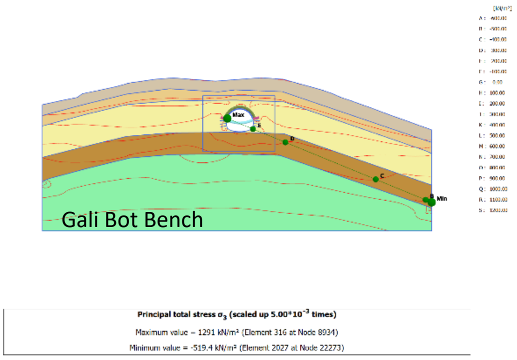
Gambar 58 Hasil analisis tegangan minimum (σ3) pada Tunnel No.5 (DK 86+905)



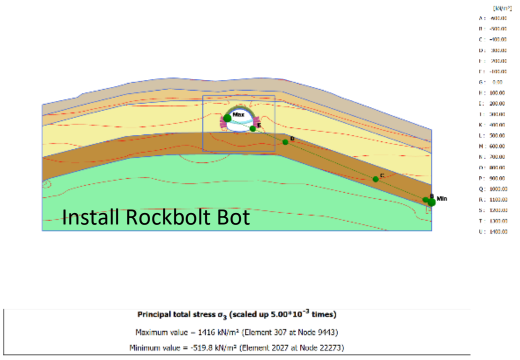
Maximum = 361.3 kN/m^2
Minimum = -517.2 kN/m^2



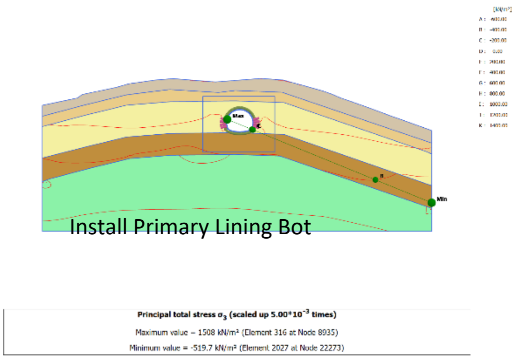
Maximum = 627.6 kN/m^2
Minimum = -517.3 kN/m^2



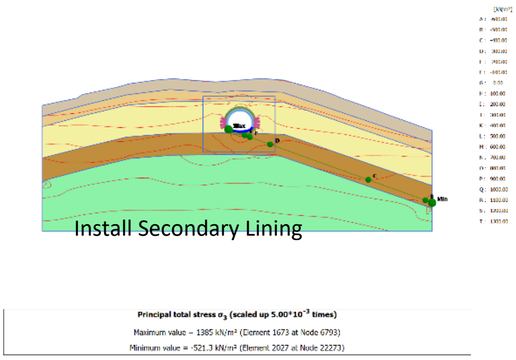
Maximum = 1291 kN/m^2
Minimum = -519.4 kN/m^2



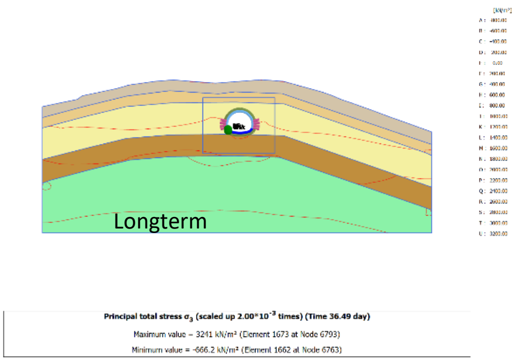
Maximum = 1416 kN/m^2
Minimum = -519.8 kN/m^2



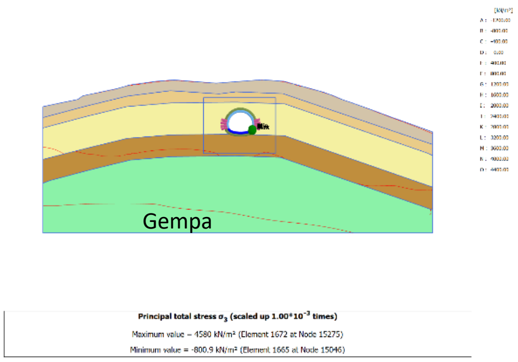
Maksimum = 1508 kN/m^2
Minimum = -519.7 kN/m^2



Maximum = 1385 kN/m^2
Minimum = -521.3 kN/m^2

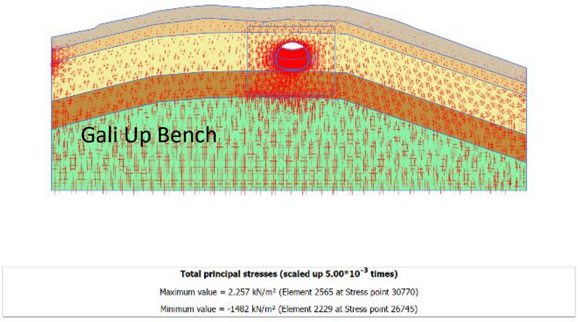


Maximum = 3241 kN/m^2
Minimum = -666.2 kN/m^2

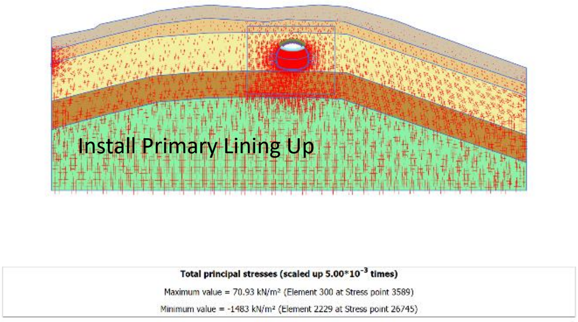


Maximum = 4580 kN/m^2
Minimum = -800.9 kN/m^2

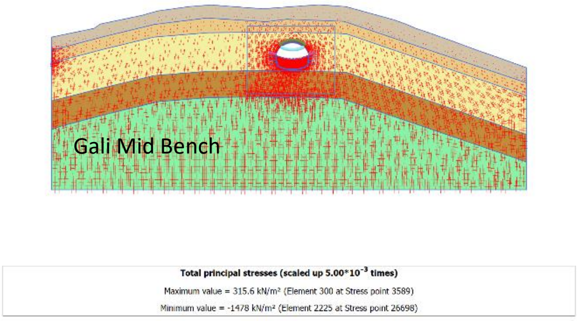
Gambar 59 Hasil analisis tegangan minimum ($\sigma 3$) pada Tunnel No.5 (DK 86+905) (lanjutan)



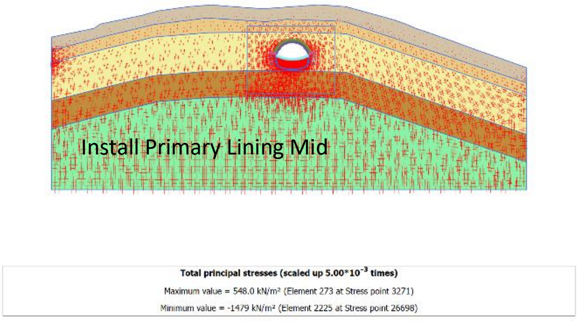
Maximum = 2.257 kN/m^2
Minimum = -1482 kN/m^2



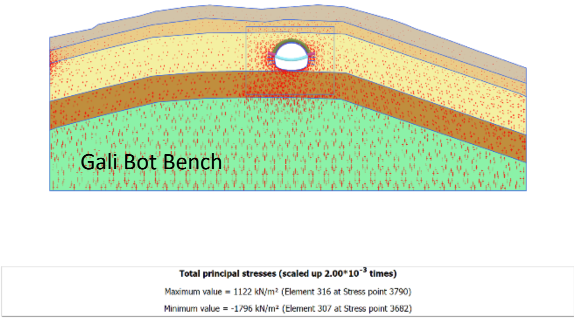
Maximum = 70.93 kN/m^2
Minimum = -1483 kN/m^2



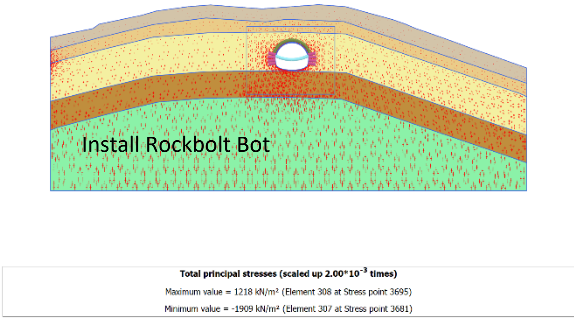
Maximum = 315.6 kN/m^2
Minimum = -1478 kN/m^2



Maximum = 548.0 kN/m^2
Minimum = -1479 kN/m^2

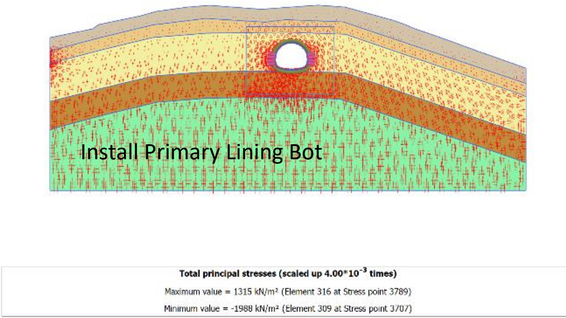


Maximum = 1122 kN/m^2
Minimum = -1796 kN/m^2

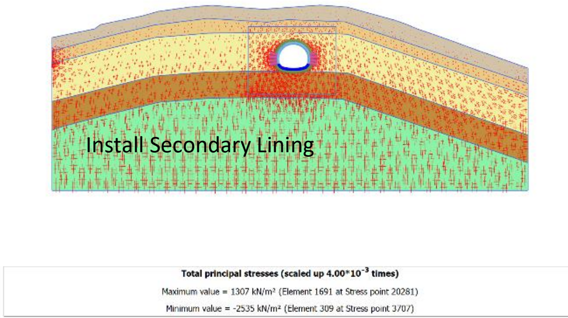


Maximum = 1218 kN/m^2
Minimum = -1909 kN/m^2

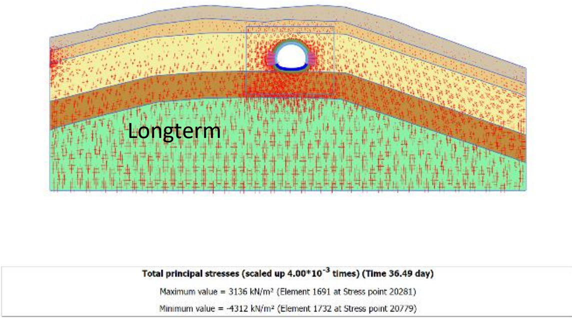
Gambar 60 Hasil analisis Total Principal Stresses pada Tunnel No.5 (DK 86+905)



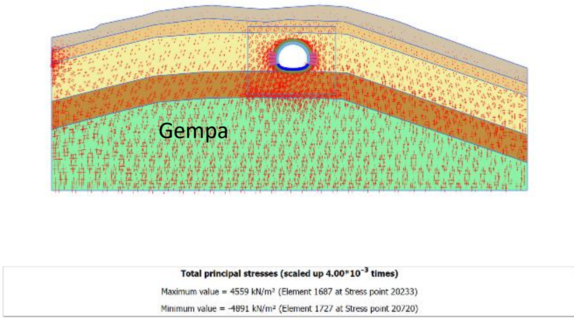
Maksimum = 1315 kN/m^2
Minimum = -1988 kN/m^2



Maximum = 1307 kN/m^2
Minimum = -2535 kN/m^2



Maximum = 3136 kN/m^2
Minimum = -4312 kN/m^2



Maximum = 4559 kN/m^2
Minimum = -4891 kN/m^2

Gambar 61 Hasil analisis Total Principal Stresses pada Tunnel No.5 (DK 86+905)