PROPOSAL PENGABDIAN KEPADA MASYARAKAT

REVIEW DESAIN TUNNEL NO. 6

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

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HALAMAN PENGESAHAN

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DAFTAR ISI

1. Informasi Umum Pekerjaan Kereta Cepat Jakarta-Bandung

A. Lokasi Pekerjaan Kererta Cepat Jakarta-Bandung

Rute pekerjaan berawal dari stasiun Halim menuju ke arah selatan jalan, dan kemudian berlanjut menuju Kawasan Industri Karawang, Pusat administrasi perencanaan kabupaten Walini, Padalarang, kemudian diarahkan secara paralel menuju kota Bandung, diakhiri menuju Gedebage yang merupakan jalur dari terminal.

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.

B. Lingkup Pekerjaan Terowongan

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
2	NO.2 Tunnel	DK74+020	DK75+050	DK74+535.0	1030
3	NO.3 Tunnel	DK75+540	DK76+275	DK75+907.5	735
4	NO.4 Tunnel	DK76+935	DK78+250	DK77+592.5	1315
5	DIK81～DIK82 Tunnel	DK81+915	DK82+065	DK81+990	150
6	NO.5 Tunnel	DK86+535	DK86+957	DK86+746.0	422
7	NO.6 Tunnel	DK88+867	DK93+345	DK91+106.0	4478
8	NO.7 Tunnel	DK93+640	DK94+895	DK94+267.5	1255
9	Walini Tunnel	DK95+472	DK96+080	DK95+776.0	608
10	NO.8 Tunnel	DK97+320	DK99+510	DK98+415.0	2190
11	DK99～DK100 Tunnel	DK99+842	DK100+050	DK99+946.0	208
12	NO.10 Tunnel	DK107+070	DK108+300	DK107+685.0	1230
13	NO.11 Tunnel	DK113+390	DK114+491	DK113+940.5	1101

Table 2 Panjang Terowongan

Section	Tunnel length	Double-tracked tunnel length and number	
		Length（m）	Number
Main Line	L≤1000	2123	5
	1000<L≤2000	7816	6
	2000<L≤3000	2190	1
	3000<L≤5000	4478	1
	Total	16607	13

2. Informasi Teknis

A. Standar-Standar yang digunakan

Standar yang digunakan dalam pengujian material desain terowongan adalah sebagai berikut:

- TB1000005-2010 : Code for Durability Design on Concrete Structure of Railway
- TB10621-2014 : Code for Design of High Speed Railway
- GB50111-2006 : Code for Seimic Design of Railway Engineering
- GB50111-2005 : Code for Design on Railway Tunnel
- GB50010-2010 : Code fo Design of Concrete Structure
- TB10068-2010 : Code for Design of Ventilation in Operation of Railway Tunnels Operation
- TB10020-2017 : Code for Design of Railway Tunnel Disaster Prevention and Rescue Engineering
- TB10063-2016 : Code for Fire Protection Design of Railway Engineering
- TB10089-2015 : Code for Design of Railway Lighting
- GB/T 8074-2008 : Testing Method for Specific Surface of Cement-Blaine Method
- GB/T 1346-2011 : Test Methods for Water Requirement of Normal Consistency, Setting Time and Soundness of The Portland Cement
- GB/T 17671-1999 : Method of Testing Cements--Determination of Strength
- GB/T 176-2017 : Methods for Chemical Analysis of Cement
- GB/T 21372-2008 : Portland Cement Clinker
- GB/T 14684-2011 : Sand for Construction
- 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

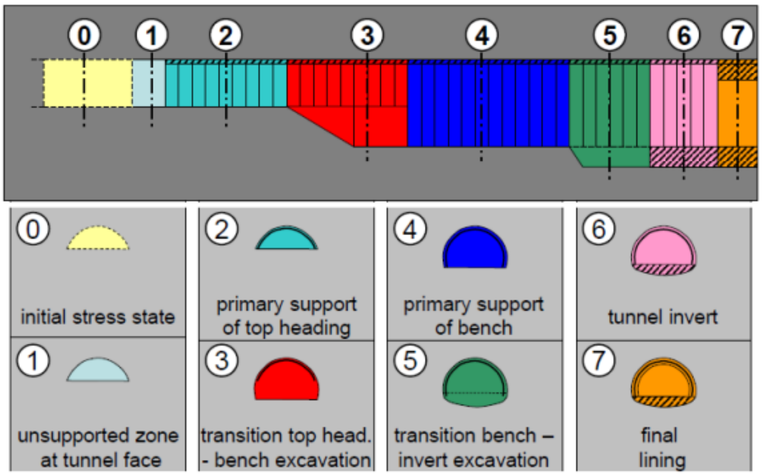
Pada masa operasional, deformasi izin pada *track* kereta cepat mengacu pada QCR9230-2016 dimana besar deformasi izinnya sebesar 15 mm. Sedangkan pada konstruksi, deformasi izin pada terowongan dapat dilihat pada **Tabel 5**.

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

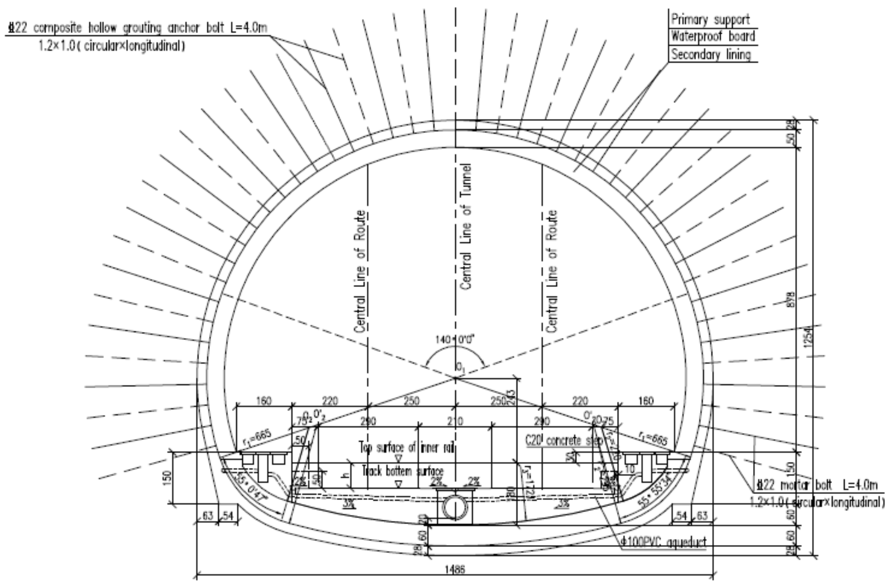
New Austrian Tunneling Method (NATM) : NATM merupakan metode *excavation* pada terowongan yang dilakukan secara manual dan bertahap. Tahapan pertama dalam metode ini adalah proses *excavation* pada area *tunnel* yang dapat dilakukan dengan menggunakan alat *twin header* dan *excavator*. Pembuangan tanah 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 14.86 m dan diameter vertikal 12.54 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.6

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)

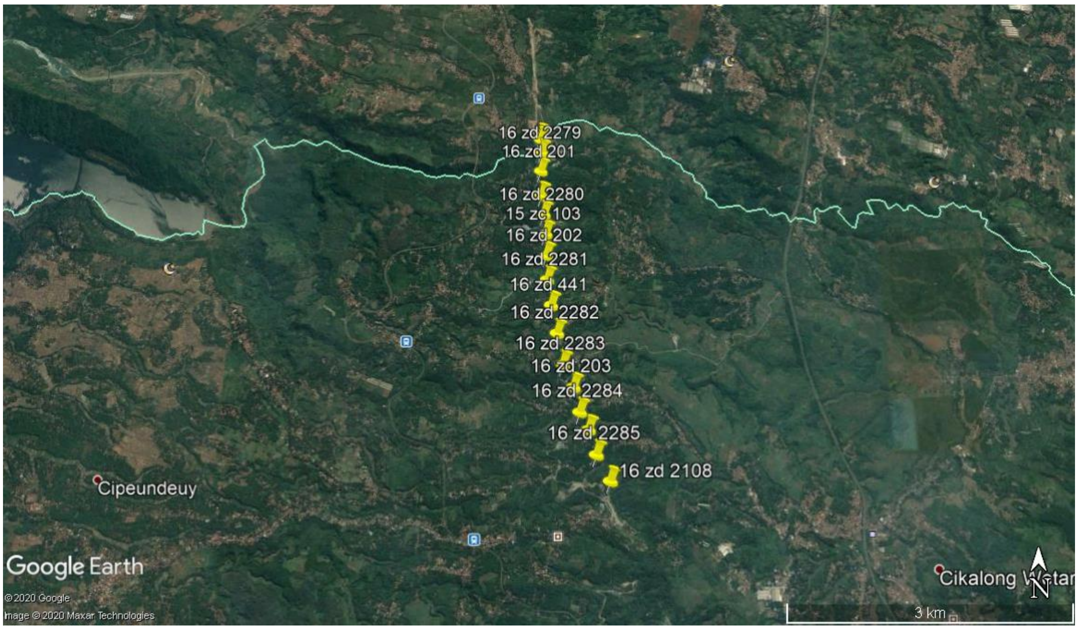
Table 7 Desain tebal lining berdasarkan kategori batuan

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. 6

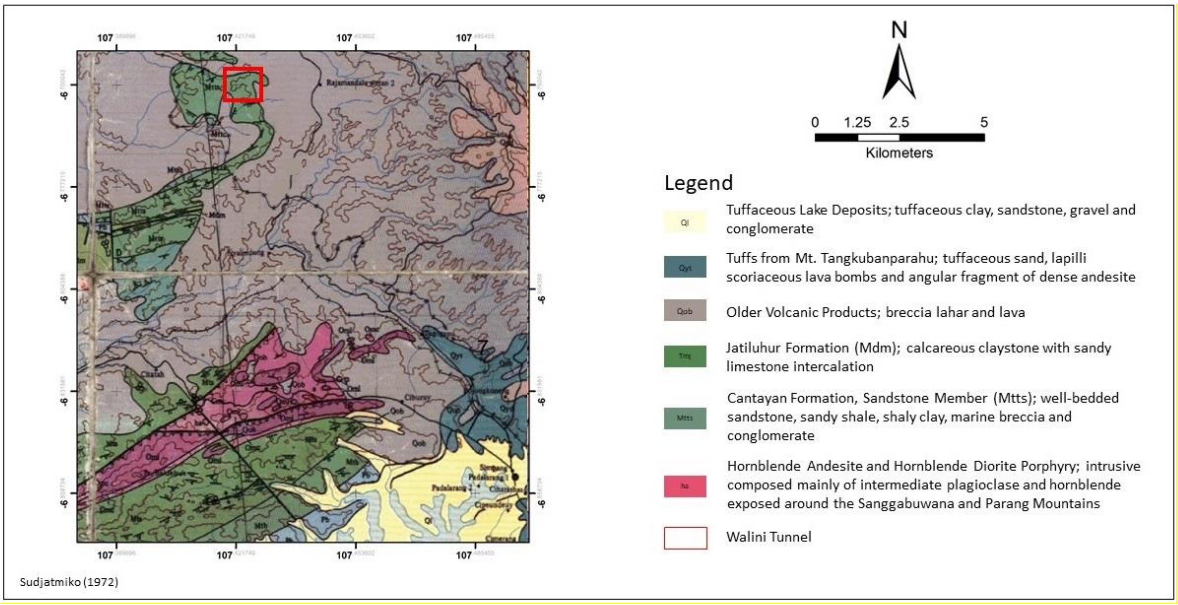
Terowongan No. 6 Kereta Cepat Jakarta Bandung Jakarta, berlokasi di Purwakarta yang bertepatan di Barat Daya. Metode konstruksi yang diterapkan pada Tunnel No. 6 ini adalah metode galian NATM (New Austrian Tunneling Method). Titik awal terowongan berada pada DK88+867 dan titik akhir terowongan pada DK93+345, sehingga total panjang terowongan, yaitu 4478m.



Gambar 3 Lokasi *Soil Inestigastion* Terowongan No.6

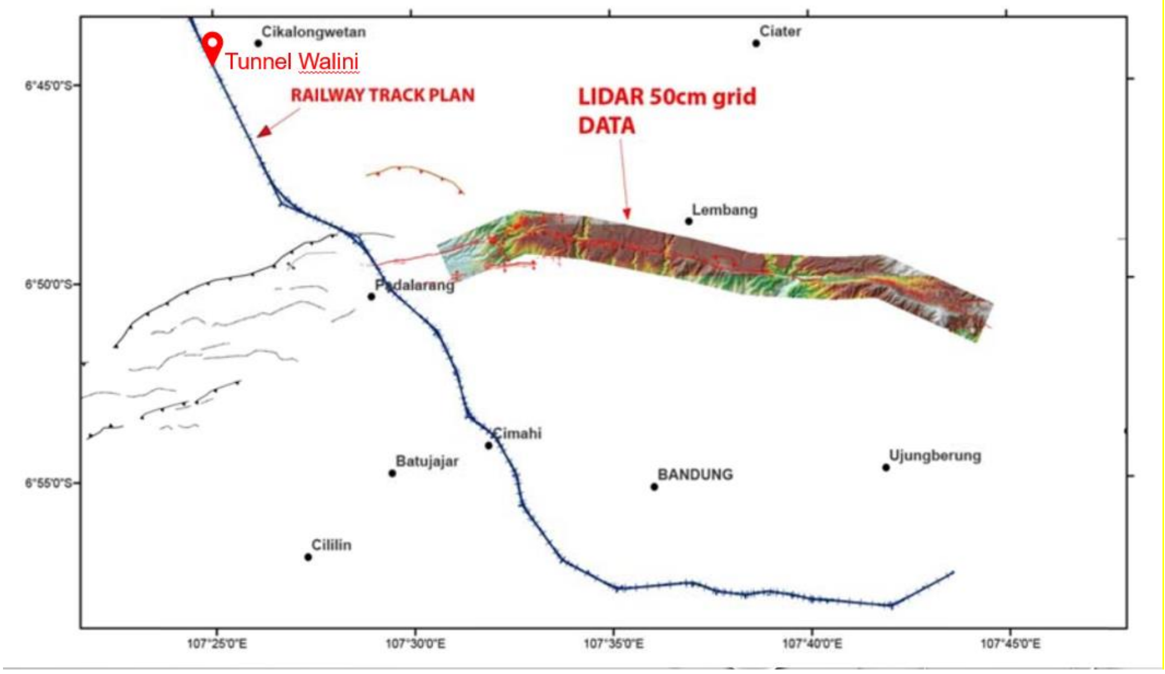
B. Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan

Berdasarkan Peta Geologi (Sudjatmiko, 1972) Terowongan DK 99-100 berada pada Formasi Cantayan, dengan sandstone member (Mtts) yang memiliki tebal 2700 m. Peta Geologi disajikan pada **Gambar 4.**



Gambar 4 Peta Geologi (Sudjatmiko, 1972)

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



Gambar 5 Hasil Analisis Geologi

Berdasarkan data geologi pada **Gambar 5** disebutkan bahwa pada Terowongan DK 99-100 tidak terdapat *fault zone*.

C. Stratigrafi Tanah dan Data Borlog

Detail stratigrafi tanah di area Terowongan No.6 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.6 dapat dilihat dibawah ini:

Dimensi Terowongan

Tipe Lining terowongan	: $V_{r\text{-}P}$
Diameter	: 15.1 m

Ketebalan

Primary lining (Shotcrete)	: 0.35 m

Secondary lining (Reinforced Concrete)

Invert Arch	: 0.65 m
Wall Arch	: 0.55 m

Material Terowongan

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

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)

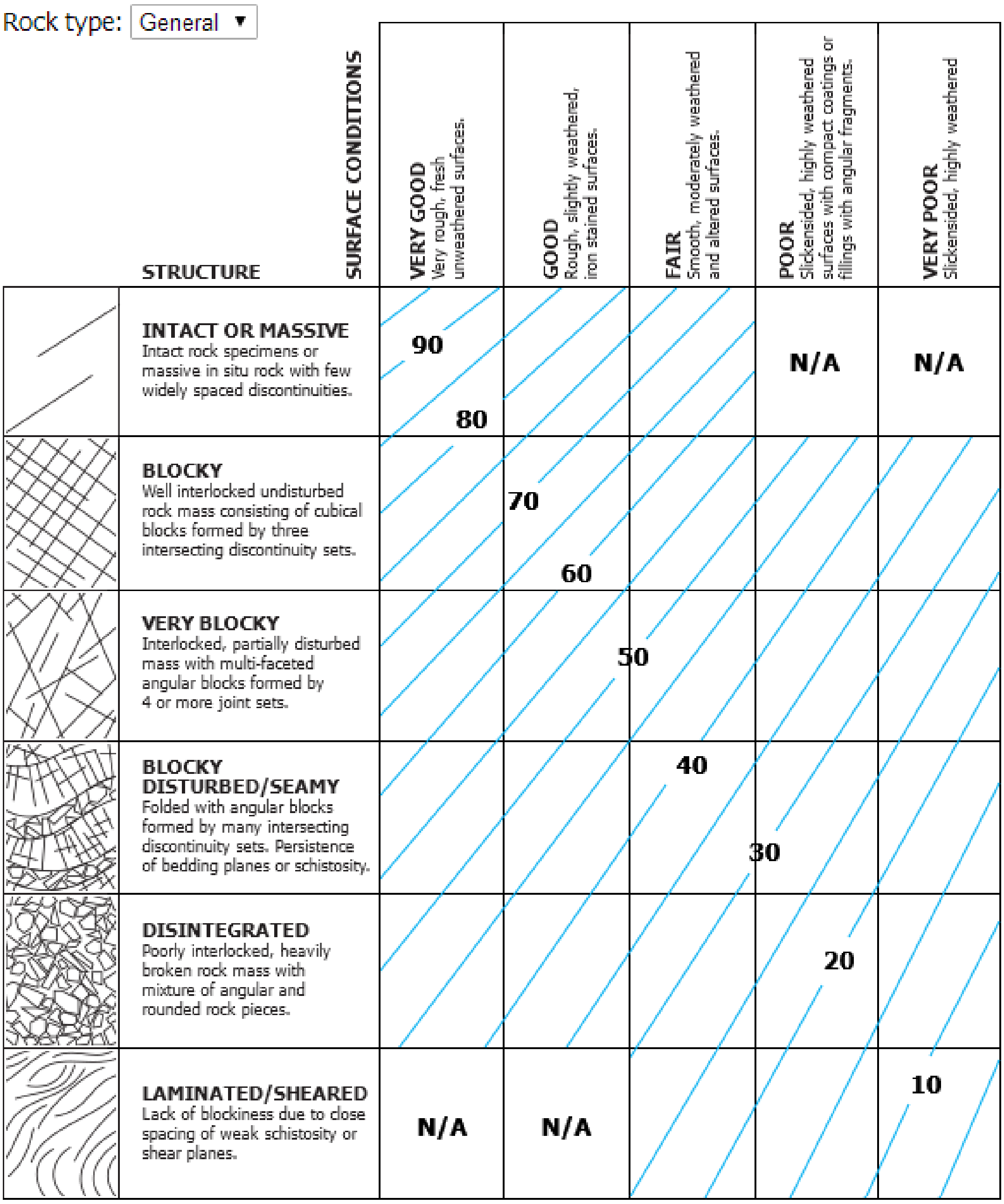
	Texture			
	Coarse	Medium	Fine	Very fine
Sedimentary	Conglomerates	Sandstones	Siltstones	Claystones
	300–400	200–350	350–400	200–300
	Breccias		Greywackes	Shales
	230–350		350	150–250[a]
				Marls
				150–200
	Crystalline limestone	Sparitic limestone	Micritic limestone	Dolomite
	400–600	600–800	800–1000	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	Medium	Fine	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)
	Non-Clastic	Carbonates	Crystalline Limestone (12±3)	Sparitic Limestones (10±2)	Micritic Limestones (9±2)	Dolomites (9±3)
		Evaporites		Gypsum 8±2	Anhydrite 12±2	
		Organic				Chalk 7±2
METAMORPHIC	Non foliated		Marble 9±3	Hornfels (19±4) Metasandstone (19±3)	Quartzites 20±3	
	Slightly foliated		Migmatite (29±3)	Amphibolites 26±6	Gneiss 28±5	
	Foliated*			Schists 12±3	Phyllites (7±3)	Slates 7±4
IGNEOUS	Plutonic	Light	Granite 32±3 Granodiorite (29±3)	Diorite 25±5		
		Dark	Gabbro 27±3 Norite 20±5	Dolerite (16±5)		
	Hypabyssal		Porphyries (20±5)		Diabase (15±5)	Peridotite (25±5)
	Volcanic	Lava		Rhyolite (25±5) Andesite 25±5	Dacite (25±3) Basalt (25±5)	Obsidian (19±3)
		Pyroclastic	Agglomerate (19±3)	Breccia (19±5)	Tuff (13±5)	

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



LAPORAN KEGIATAN PENGABDIAN KEPADA MASYARAKAT

REVIEW DESAIN TUNNEL NO. 6 (PEMODELAN FEM MENGGUNAKAN PLAXIS 2D) KERETA CEPAT JAKARTA BANDUNG

Ketua Tim :

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Anggota:

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Program Studi Teknik Sipil Fakultas Teknik Sipil dan Perencanaan INSTITUT TEKNOLOGI NASIONAL BANDUNG

2020

HALAMAN PENGESAHAN

1.	Judul	: Review Desain Tunnel No. 6 (Pemodelan Fem Menggunakan Plaxis 2d Kereta Cepat Jakarta Bandung)
2.	Pelaksana	: Dr. techn. Indra Noer Hamdhan, ST., MT.
	NIP	: 120030105
	Pangkat/Golongan	: Lektor /III D
	Jurusan	: Teknik Sipil
	Bidang Keahlian	: Geoteknik
3.	Bentuk Kegiatan	: Analisis
4.	Waktu Kegiatan	: 1 November – 31 Desember 2020
5.	Sumber Dana	: ASEA UNINET
6.	Jumlah Dana	: Rp. 20.000.000

Bandung, 8 Januari 2019

Pelaksana	Ketua Jurusan Teknik Sipil
(Dr. techn. Indra Noer Hamdhan, ST., MT.)	(Dr. techn. Indra Noer Hamdhan, ST., MT.)

Mengetahui

Kepala LP2M Itenas

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DAFTAR ISI

1. Informasi Umum Pekerjaan Kereta Cepat Jakarta-Bandung

A. Lokasi Pekerjaan Kererta Cepat Jakarta-Bandung

Rute pekerjaan berawal dari stasiun Halim menuju ke arah selatan jalan, dan kemudian berlanjut menuju Kawasan Industri Karawang, Pusat administrasi perencanaan kabupaten Walini, Padalarang, kemudian diarahkan secara paralel menuju kota Bandung, diakhiri menuju Gedebage yang merupakan jalur dari terminal.

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.

B. Lingkup Pekerjaan Terowongan

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	
		Entrance	Exit		
1	NO.1 Tunnel	DK2+540	DK4+425	DK3+482.5	1885
2	NO.2 Tunnel	DK74+020	DK75+050	DK74+535.0	1030
3	NO.3 Tunnel	DK75+540	DK76+275	DK75+907.5	735
4	NO.4 Tunnel	DK76+935	DK78+250	DK77+592.5	1315
5	DIK81〜DIK82 Tunnel	DK81+915	DK82+065	DK81+990	150
6	NO.5 Tunnel	DK86+535	DK86+957	DK86+746.0	422
7	NO.6 Tunnel	DK88+867	DK93+345	DK91+106.0	4478
8	NO.7 Tunnel	DK93+640	DK94+895	DK94+267.5	1255
9	Walini Tunnel	DK95+472	DK96+080	DK95+776.0	608
10	NO.8 Tunnel	DK97+320	DK99+510	DK98+415.0	2190
11	DK99〜DK100 Tunnel	DK99+842	DK100+050	DK99+946.0	208
12	NO.10 Tunnel	DK107+070	DK108+300	DK107+685.0	1230
13	NO.11 Tunnel	DK113+390	DK114+491	DK113+940.5	1101

Table 2 Panjang Terowongan

Section	Tunnel length	Double-tracked tunnel length and number	
		Length（m）	Number
Main Line	L≤1000	2123	5
	1000<L≤2000	7816	6
	2000<L≤3000	2190	1
	3000<L≤5000	4478	1
	Total	16607	13

2. Informasi Teknis

A. Standar-Standar yang digunakan

Standar yang digunakan dalam pengujian material desain terowongan adalah sebagai berikut:

TB1000005-2010 : Code for Durability Design on Concrete Structure of Railway
TB10621-2014 : Code for Design of High Speed Railway
GB50111-2006 : Code for Seimic Design of Railway Engineering
GB50111-2005 : Code for Design on Railway Tunnel
GB50010-2010 : Code fo Design of Concrete Structure
TB10068-2010 : Code for Design of Ventilation in Operation of Railway Tunnels Operation
TB10020-2017 : Code for Design of Railway Tunnel Disaster Prevention and Rescue Engineering
TB10063-2016 : Code for Fire Protection Design of Railway Engineering
TB10089-2015 : Code for Design of Railway Lighting
GB/T 8074-2008 : Testing Method for Specific Surface of Cement-Blaine Method
GB/T 1346-2011 : Test Methods for Water Requirement of Normal Consistency, Setting Time and Soundness of The Portland Cement
GB/T 17671-1999 : Method of Testing Cements--Determination of Strength
GB/T 176-2017 : Methods for Chemical Analysis of Cement
GB/T 21372-2008 : Portland Cement Clinker
GB/T 14684-2011 : Sand for Construction
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

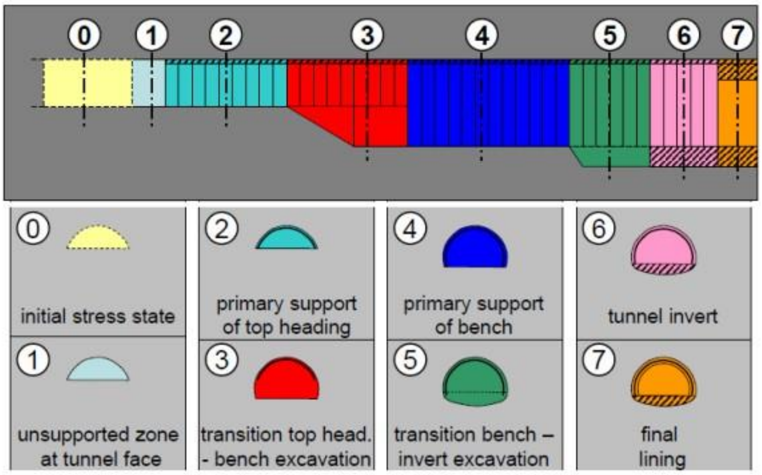
Pada masa operasional, deformasi izin pada *track* kereta cepat mengacu pada QCR9230-2016 dimana besar deformasi izinnya sebesar 15 mm. Sedangkan pada konstruksi, deformasi izin pada terowongan dapat dilihat pada **Tabel 5**.

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

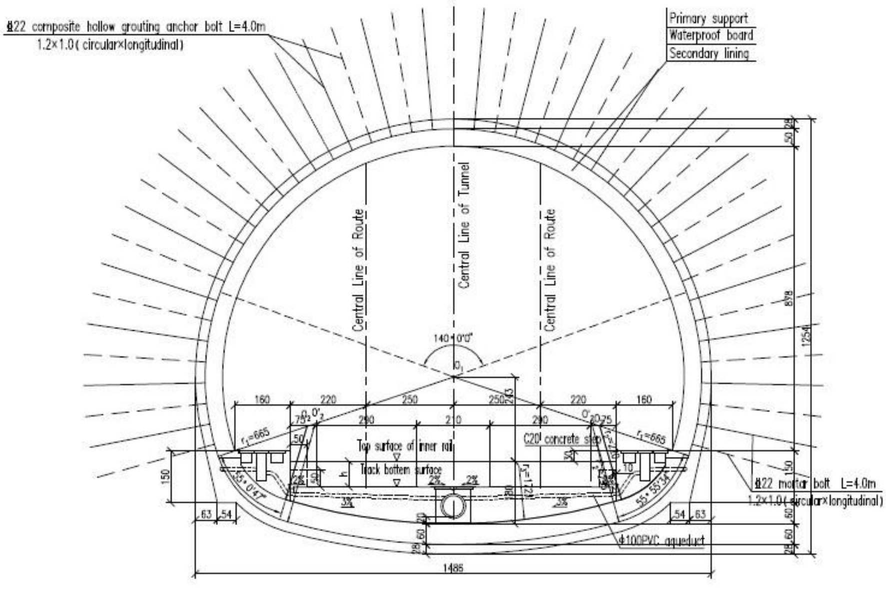
New Austrian Tunneling Method (NATM) : NATM merupakan metode *excavation* pada terowongan yang dilakukan secara manual dan bertahap. Tahapan pertama dalam metode ini adalah proses *excavation* pada area *tunnel* yang dapat dilakukan dengan menggunakan alat *twin header* dan *excavator*. Pembuangan tanah 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 14.86 m dan diameter vertikal 12.54 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.6

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)

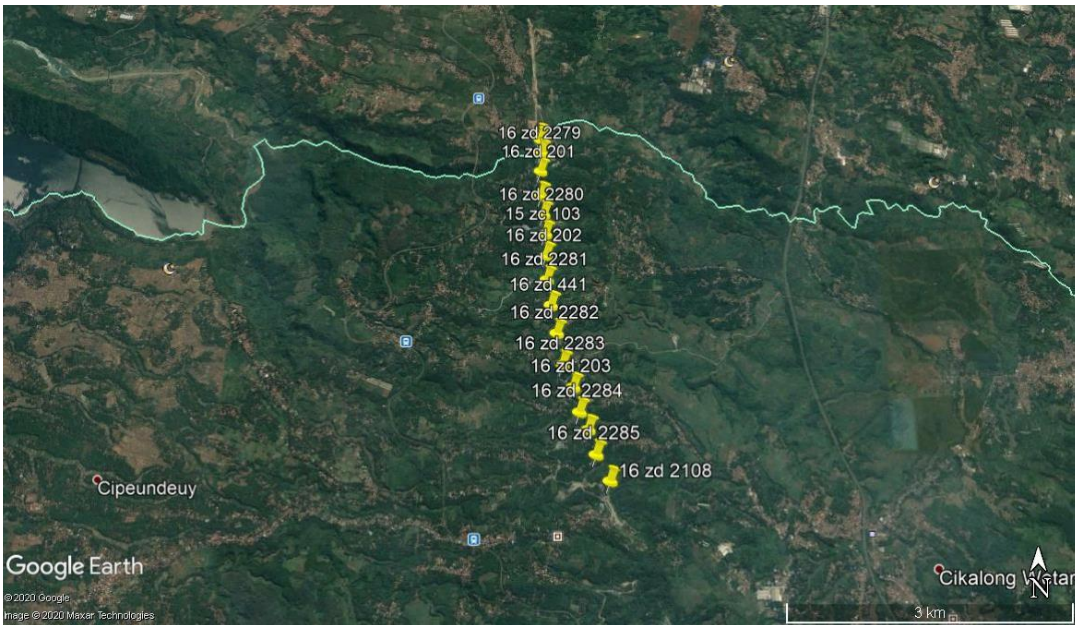
Table 7 Desain tebal lining berdasarkan kategori batuan

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. 6

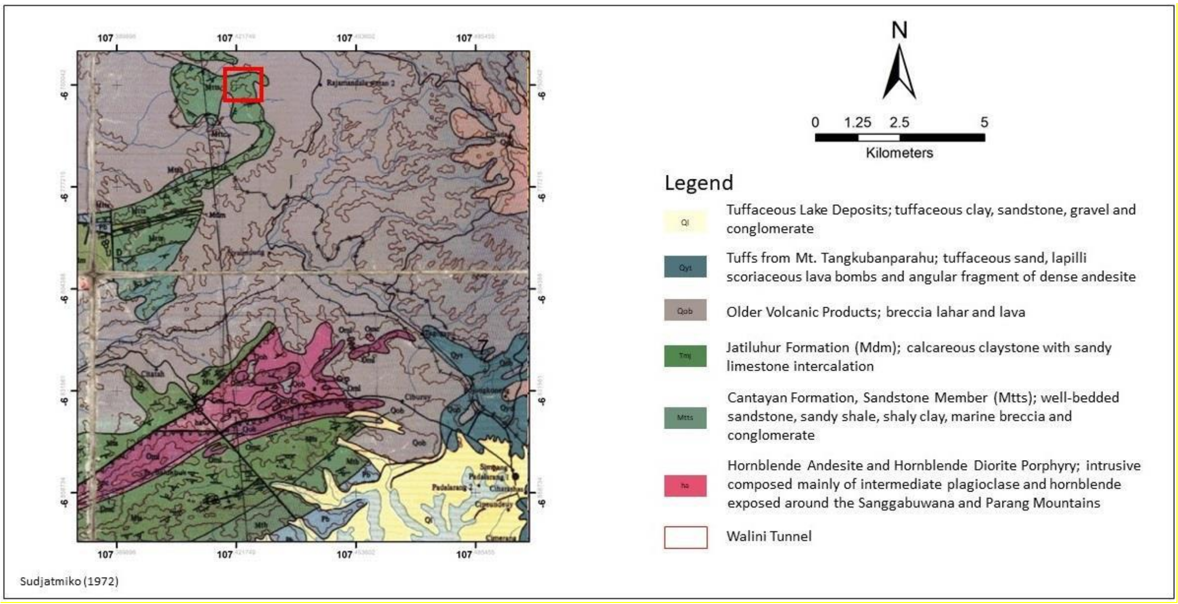
Terowongan No. 6 Kereta Cepat Jakarta Bandung Jakarta, berlokasi di Purwakarta yang bertepatan di Barat Daya. Metode konstruksi yang diterapkan pada Tunnel No. 6 ini adalah metode galian NATM (New Austrian Tunneling Method). Titik awal terowongan berada pada DK88+867 dan titik akhir terowongan pada DK93+345, sehingga total panjang terowongan, yaitu 4478m.



Gambar 3 Lokasi *Soil Inestigastion* Terowongan No.6

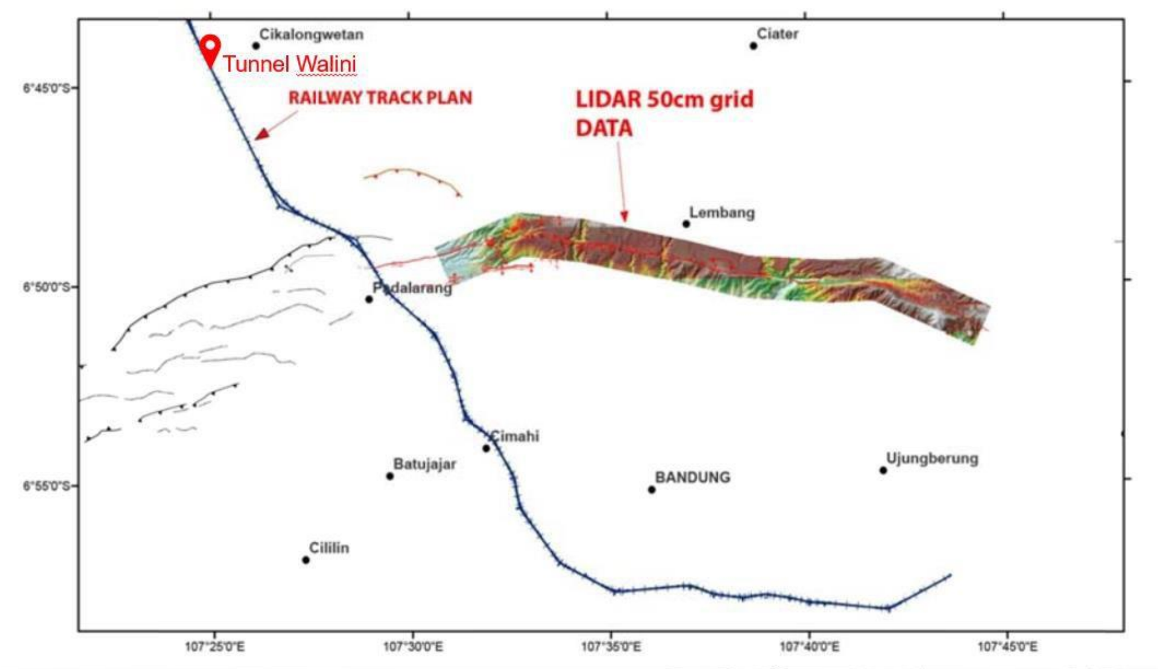
B. Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan

Berdasarkan Peta Geologi (Sudjatmiko, 1972) Terowongan DK 99-100 berada pada Formasi Cantayan, dengan sandstone member (Mtts) yang memiliki tebal 2700 m. Peta Geologi disajikan pada **Gambar 4.**



Gambar 4 Peta Geologi (Sudjatmiko, 1972)

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



Gambar 5 Hasil Analisis Geologi

Berdasarkan data geologi pada **Gambar 5** disebutkan bahwa pada Terowongan DK 99-100 tidak terdapat *fault zone*.

C. Stratigrafi Tanah dan Data Borlog

Detail stratigrafi tanah di area Terowongan No.6 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.6 dapat dilihat dibawah ini:

Dimensi Terowongan

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

Material Terowongan

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

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 ($_{ci}$), (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

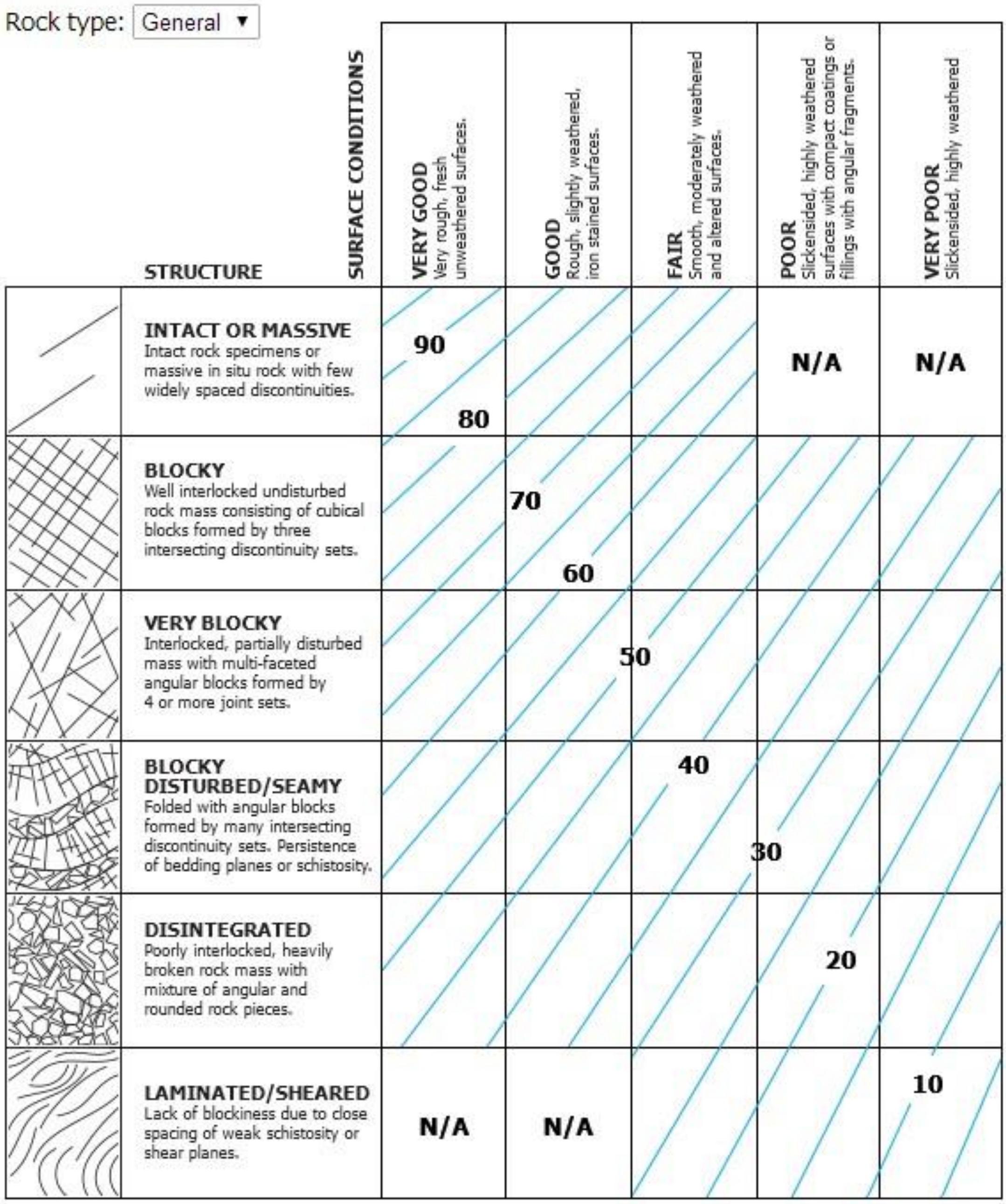
[b]Felsic Granitoids: Coarse grained or altered (High modulus ratio), fine grained (low modulus ratio)

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

Table 10 Lithology classification ($\boldsymbol{m_i}$) (Brinkgreeve, 2018)

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

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



4. Pemodelan Terowongan No. 6

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

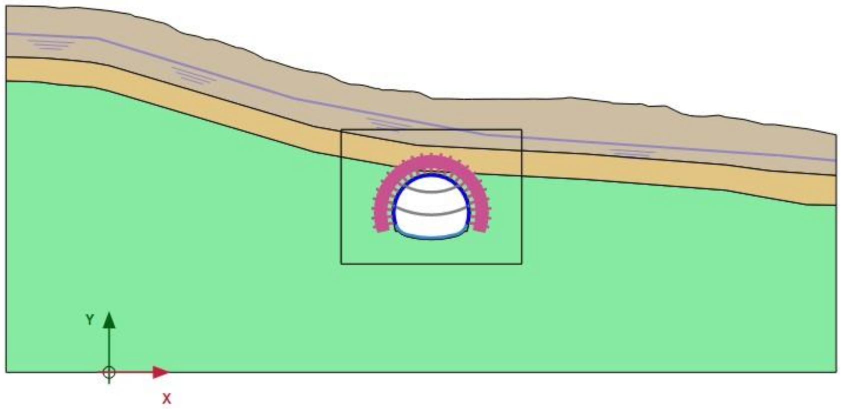
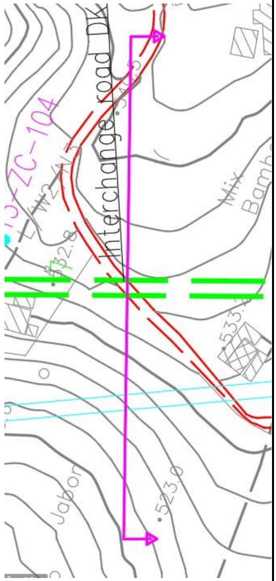
No. Potongan	Layout	Potongan Melintang	Keterangan
TUNNEL NO. 6 (DK89+360)			Tidak ada beban jalan dan bangunan pada permukaan
TUNNEL NO. 6 (DK90+916)		15 kPa 15 kPa	Pada bagian permukaan terdapat beban lalu lintas sebesar 15 kPa.

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

No. Potongan	Layout	Potongan Melintang	Keterangan
TUNNEL NO. 6 (DK92+720)		15 kPa 15 kPa	Pada bagian permukaan terdapat beban lalu lintas sebesar 15 kPa

B. Parameter-Parameter Pemodelan Terowongan No. 6

1. Cross Section DK 89 + 360

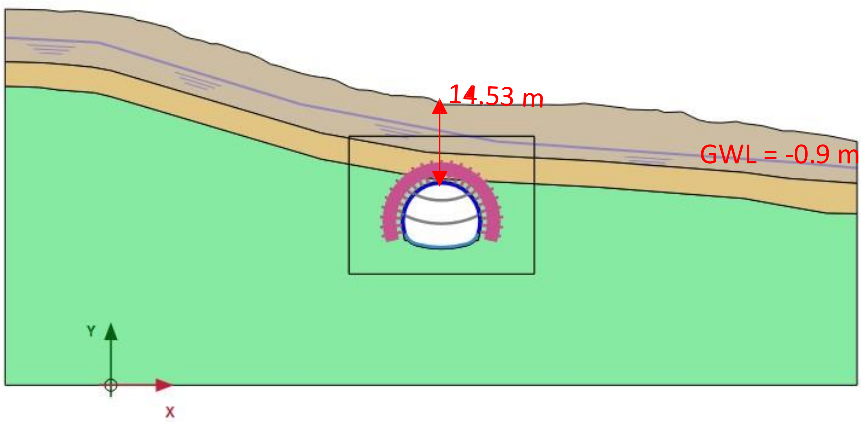


Table 14 Parameter Tanah di Tunnel No. 6 (DK 89 + 360)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	unsat (kN/m3)	sat (kN/m3)		c' (kPa)	' (degrees)	k (m/day)
1	0-8.5	8.5	14.5	Clay	15	16	0.5	15	27	0.00864
2	8.5-13.4	4.9	37	Clay	16	17	0.5	30	35	0.00864
3	13.4-40	26.6	50	Mudstone	19	20	0.35	-	-	-

Table 15 Nilai Modulus Elastisas di Tunnel No. 6 (DK 89 + 360)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Clay	14.5	7500	7500	6000	22500
2	Clay	37	35000	35000	28000	105000

Table 16 Paramater Hoek Brown untuk Batuan di Tunnel No. 6 (DK 89 + 360)

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

Table 17 Parameter Primary Linning Tunnel No. 6 (DK 89 + 360)

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

Table 18 Parameter Secondary Linning Tunnel No. 6 (DK 89 + 360)

ID	Value		Unit
	Invert	Arch	
Material Type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.65	0.55	m
Unit weight (��)	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 (��)	24	kN/m^3
Easticity modulus (E)	1.33×10^7	kPa
Spasi	1	m
Panjang	4	m

2. Cross Section DK 90 + 916

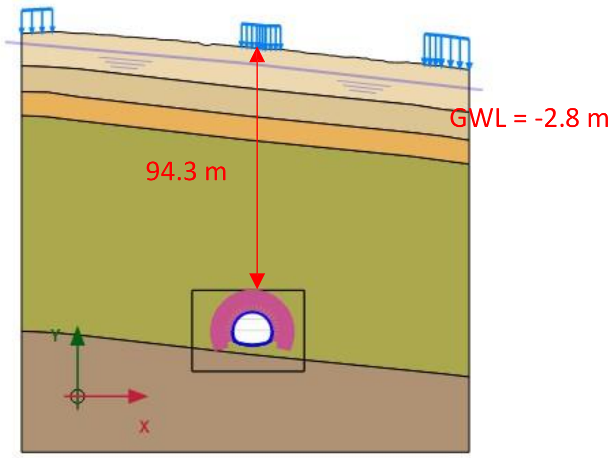


Table 20 Parameter Tanah di Tunnel No. 6 (DK 90 + 916)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	unsat (kN/m3)	sat (kN/m3)		c' (kPa)	' (degrees)	k (m/day)
1	0-7.5	7.5	6.333333	Clay	15	16	0.5	13	28	0.000864
2	7.5-11.5	4	26	Silty Clay	17	18	0.35	30	30	0.0005184
3	11.5-23	11.5	44.66667	Silty Clay	17	18	0.3	35	31	0.0005184
4	23-73	50	50	Mudstone	19	20	0.3			
5	73-80	7	50	Volcanic breksi	21	22	0.3			

Table 21 Nilai Modulus Elastisas di Tunnel No. 6 (DK 90 + 916)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Clay	6	4500	4500	3600	13500
2	Silty Clay	26	32500	32500	26000	97500
3	Silty Clay	45	67500	67500	54000	202500

Table 22 Paramater Hoek Brown untuk Batuan di Tunnel No. 6 (DK 90 + 916)

Lapis	Jenis Tanah	N SPT	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	Mudstone	50	3000	150	225000	6	10
5	Mudstone	50	4000	150	300000	6	10

Table 23 Parameter Primary Linning Tunnel No. 6 (DK 90 + 916)

ID	Value	Unit
Material	C30 Shotcrete	-
Tebal Lining	0.28	m
Unit weight (��)	24	kN/m^3
Easticity modulus (E)	2.575×10^7	kPa

Table 24 Parameter Secondary Linning Tunnel No. 6 (DK 90 + 916)

ID	Value		Unit
	Invert	Arch	
Materialn type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.55	0.45	m
Unit weight (��)	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 (��)	24	kN/m^3
Easticity modulus (E)	1.33×10^7	kPa
Spasi	1	m
Panjang	3.5	m

3. Cross Section DK 92 + 720

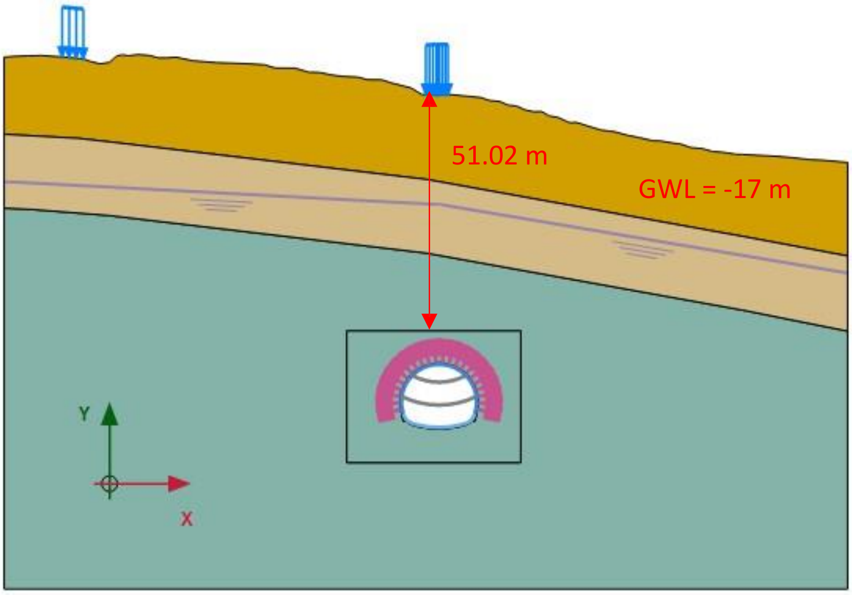


Table 26 Parameter Tanah di Tunnel No. 6 (DK 92 + 720)

Lapis	Kedalaman	Tebal	N SPT	Jenis Tanah	unsat (kN/m3)	sat (kN/m3)		c' (kPa)	' (degrees)	k (m/day)
1	0-19	19	9	Clay	15	16	0.5	15	29	0.00864
2	19-30	11	32	Clay	17	18	0.35	30	30	0.00864
3	30-50	20	50	Sandstone	19	20	0.3	-	-	-

Table 27 Nilai Modulus Elastisas di Tunnel No. 6 (DK 92 + 720)

Lapis	Jenis Tanah	N SPT	E' (kN/m2)	E50 (kN/m2)	Eoed (kN/m2)	Eur (kN/m2)
1	Clay	9	6750	6750	5400	20250
2	Clay	32	40000	40000	32000	120000

Table 28 Paramater Hoek Brown untuk Batuan di Tunnel No. 6 (DK 92 + 720)

Lapis	Jenis Tanah	N SPT	ci (kPa) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 212	(Modulus Ratio) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 214	E_{rm} (kPa) Tomlinson, (2001)	m_i	GSI
2	Sandstone	50	4000	150	300000	6	10

Table 29 Parameter Primary Linning Tunnel No. 6 (DK 92 + 720)

ID	Value	Unit
Material	C30 Shotcrete	-
Tebal Lining	0.28	m
Unit weight (��)	24	kN/m^3
Easticity modulus (E)	2.575×10^7	kPa

Table 30 Parameter Secondary Linning Tunnel No. 6 (DK 92 + 720)

ID	Value		Unit
	Invert	Arch	
Materialn type (Plate)	C35 Reinforced Concrete	C35 Reinforced Concrete	-
Tebal Lining	0.6	0.5	m
Unit weight (��)	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 (��)	24	kN/m^3
Easticity modulus (E)	1.33×10^7	kPa
Spasi	1	m
Panjang	3.5	m

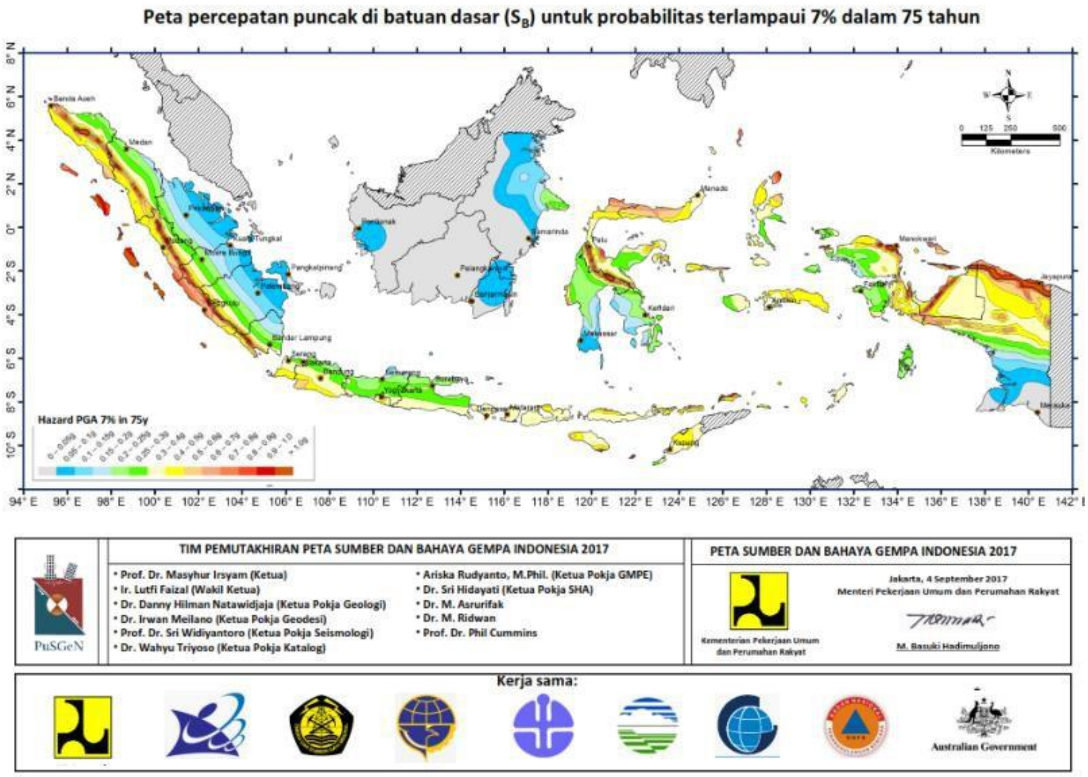
C. Perhitungan Beban Gempa di Area Terowongan No. 6

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

$$\bar{N} = \frac{\sum di}{\sum \frac{di}{N}}$$

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

Table 32 Desain untuk Menentukan SPT Rata-rata di Tunnel DK 99-100 (DK99+978)

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

$$\bar{N} = \frac{[illegible]}{[illegible]} =$$

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
[redacted]	175 sampai 350	[redacted]	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
[redacted]	1,6	1,4	[redacted]	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)

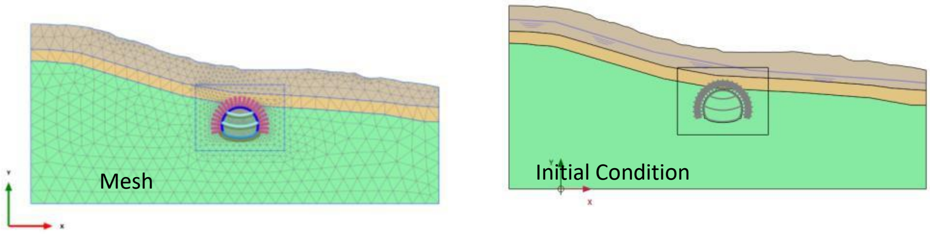
4. Percepatan Puncak

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

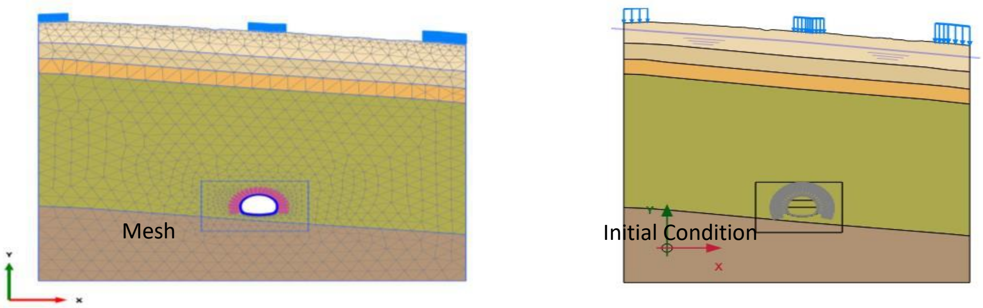
Untuk PGA 0.3 → $a = 0.3 \times 1.2 \times ((1.45 - 0.3) \times 0.3) =$ �. ���� g

D. Kondisi Elemen Mesh dan *Initial Condition*

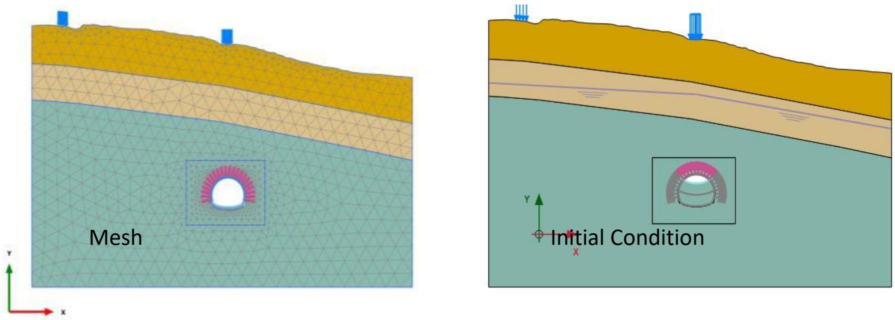
Meshing merupakan proses membagi komponen yang akan dianalisis menjadi elemen-elemen kecil yang menjadi dasar dalam perhitungan/iterasi dalam pemodelan FEM (PLAXIS 2D). *Meshing* yang digunakan dalam pemodelan ini menggunakan mesh *very fine. Initial condition* merupakan kondisi awal pemodelan pada analisis 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. 6 (DK 89+360)



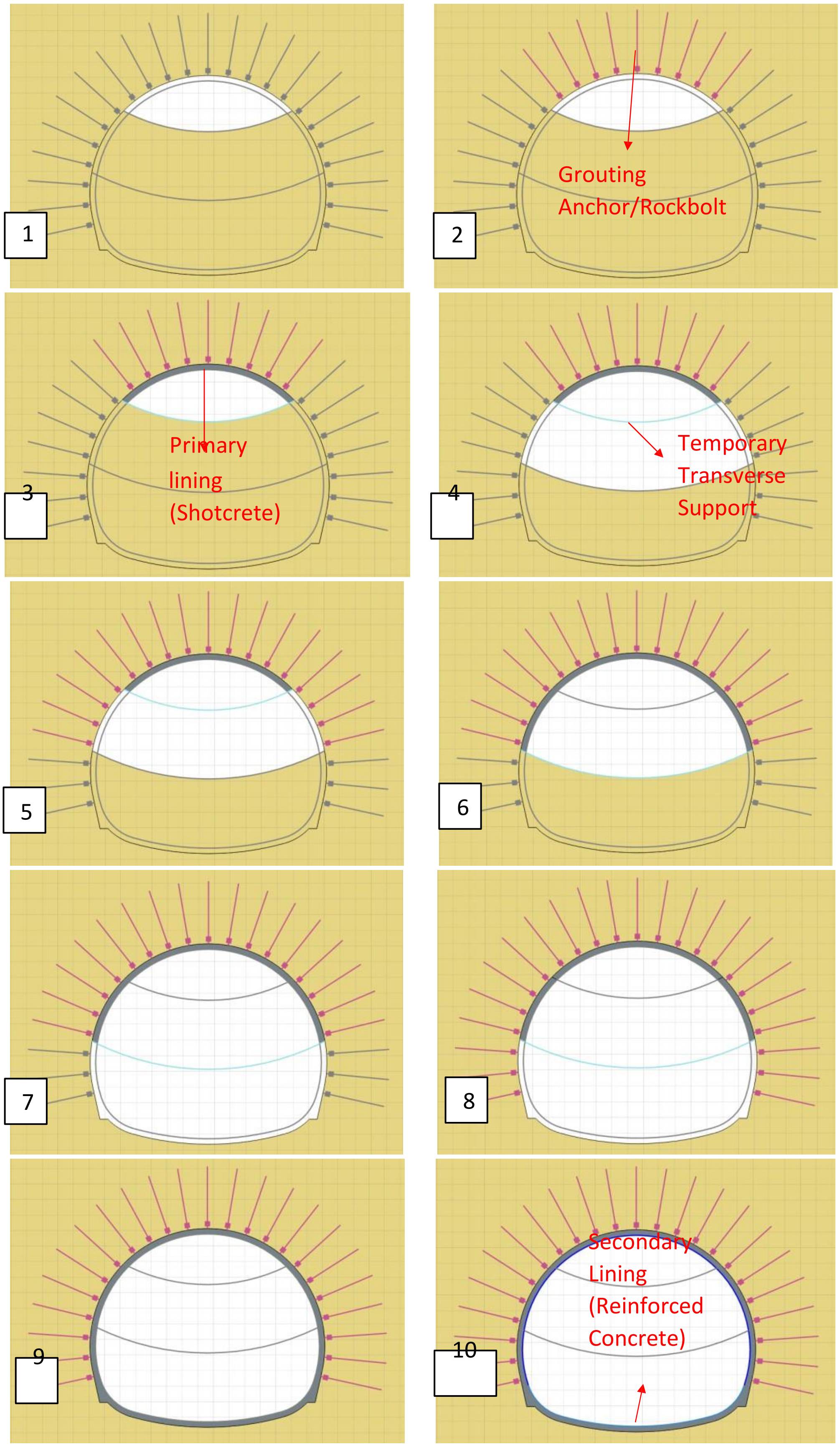
Gambar 9 *Meshing* dan *initial condition* Tunnel No. 6 (DK 90+916)



Gambar 10 *Meshing* dan *initial condition* Tunnel No. 6 (DK 92+720)

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. 6 (DK 89 + 360)

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	-7.893x10^3	-	-	-	-	-	-
Install rockbolt up	-8.739x10^3	-	-	-	-	-	-
Install Primary lining up	-9.134x10^3	-	-	-	-	-	-
Gali mid bench	-0.02851	-	-	-	-	-	-
Install rockbolt mid	-0.02855	-	-	-	-	-	-
Install Primary lining mid	-0.02841	-	-	-	-	-	-
Gali bot bench	-0.04945	-	-	-	-	-	-
Install rockbolt bot	-0.04976	-	-	-	-	-	-
Install Primary lining bot	-0.04934	-	-	-	-	-	-
Install Secondary lining	-0.05033		-0.05033	7.982x10^3	-224.1	373.7	345.6
Longterm	-0.05087	-	-0.01787	0.1937x10^3	-2032	376.9	357.7
Gempa	-0.3644	-	-0.3386	5.151x10^3	1.983	625.5	586.1

Table 36 Hasil Rekapitulasi Deformasi pada Tunnel No. 6 (DK 90 + 916)

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	-0.03135	-	-	-	-	-	-
Install rockbolt up	-0.03335	-	-	-	-	-	-
Install Primary lining up	-0.03360	-	-	-	-	-	-
Gali mid bench	-0.05681	-	-	-	-	-	-
Install rockbolt mid	-0.05919	-	-	-	-	-	-
Install Primary lining mid	-0.05932	-	-	-	-	-	-
Gali bot bench	-0.07708	-	-	-	-	-	-
Install rockbolt bot	-0.07886	-	-	-	-	-	-
Install Primary lining bot	-0.07903	-	-	-	-	-	-
Install Secondary lining	-0.09501		-0.01886	0.04123	-6764	1023	841.5
Longterm	-0.01898	-	-1.526x10^3	1.581x10^3	-7008	1063	937.7
Gempa	-0.3747	-	-0.01480	7.719x10^3	-9167	1440	1237

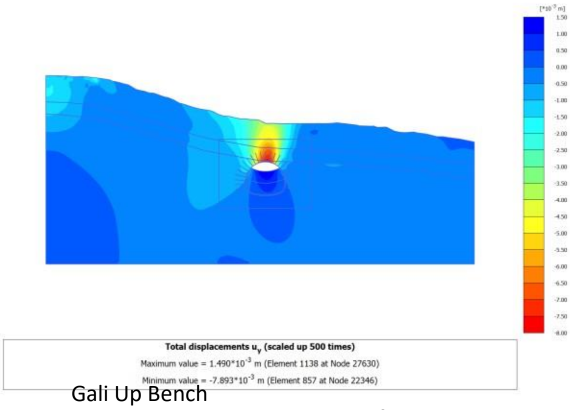
Table 37 Hasil Rekapitulasi Deformasi pada Tunnel No. 6 (DK 92 + 720)

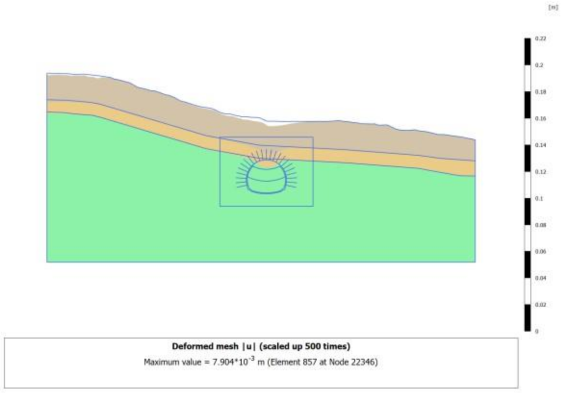
Staged Construction	Deformasi Aksial Global (m)	Volume Loss (%)	Deformasi Lining Tunnel		Gaya Dalam Tunnel		
			Axial (m)	Lateral (m)	Axial (kN/m)	Shear (kN/m)	Momen (kNm/m)
Gali up bench	$-3.495x10^3$	-	-	-	-	-	-
Install rockbolt up	$-3.534x10^3$	-	-	-	-	-	-
Install Primary lining up	$-3.690x10^3$	-	-	-	-	-	-
Gali mid bench	$-8.606x10^3$	-	-	-	-	-	-
Install rockbolt mid	$-8.857x10^3$	-	-	-	-	-	-
Install Primary lining mid	$-7.972x10^3$	-	-	-	-	-	-
Gali bot bench	-0.01123	-	-	-	-	-	-
Install rockbolt bot	-0.01161	-	-	-	-	-	-
Install Primary lining bot	-0.01007	-	-	-	-	-	-
Install Secondary lining	-0.02333		-0.01328	$9.405x10^{-3}$	-3690	706.8	633.1
Longterm	-0.01046	-	$-0.764x10^3$	$0.2430x10^{-3}$	-3741	721.5	646.1
Gempa	-0.2543	-	$-3.589x10^3$	0.01322	-4349	818.7	697.9

Dari hasil rekapitulasi deformasi menunjukkan bahwa selisih atau ∆deformasi dari potongan DK 89+360 dengan DK 90+916 terbesar adalah **±3 cm pada install secondary lining** dengan syarat izin diferential settlement 0.04%(1556 m)= 0.6224 m atau sebesar 62.24 cm. Hasil tersebut telah memenuhi syarat izin yaitu 0.04%(Ls).

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

a) *Cross Section DK 89 + 360*

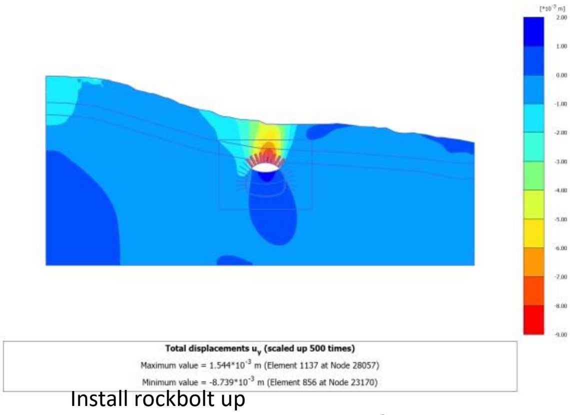


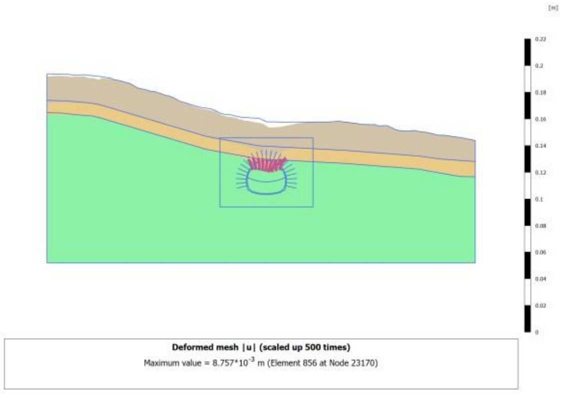


Gali Up Bench

Maximum = 1.490×10^{-3} m

Minimum = -7.893×10^{-3} m

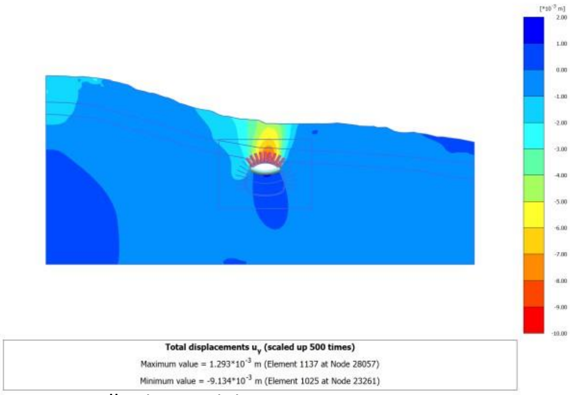


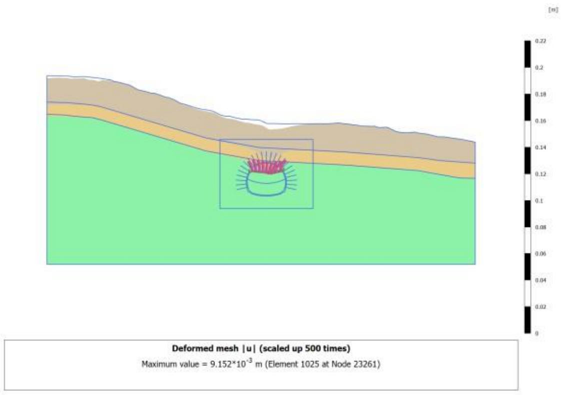


Install rockbolt up

Maximum = 1.544×10^{-3} m

Minimum = -8.739×10^{-3} m



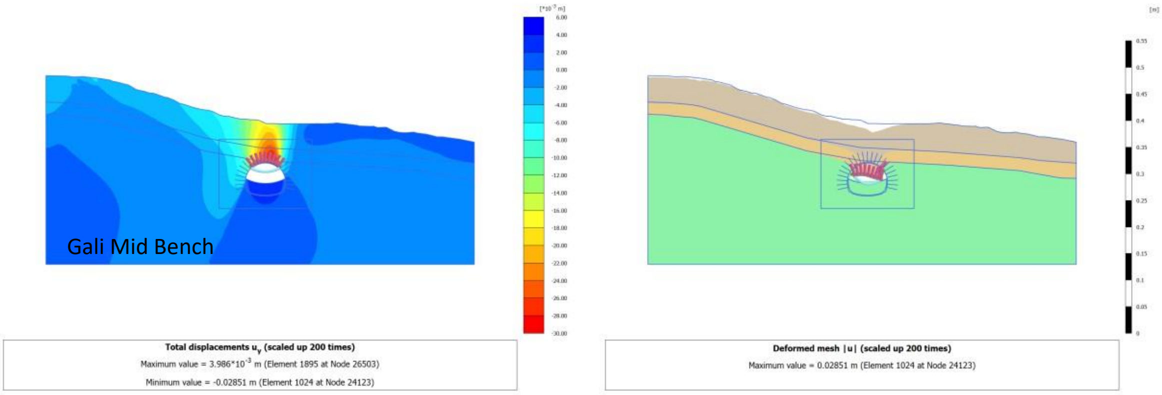


Install Primary Lining Up

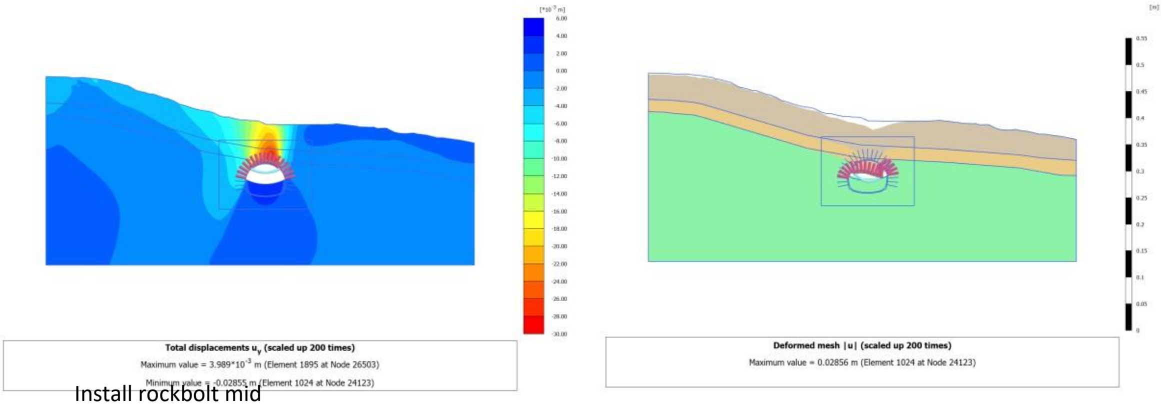
Maximum = 1.293×10^{-3} m

Minimum = -9.134×10^{-3} m

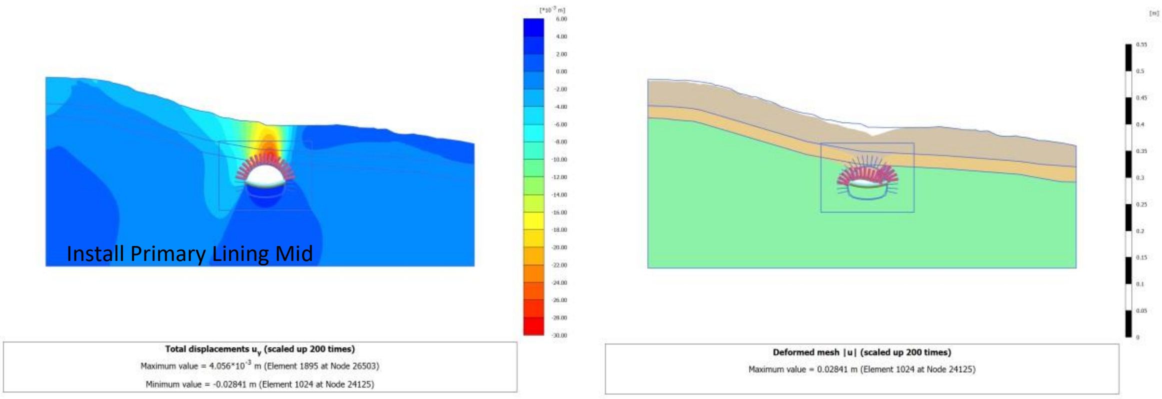
Gambar 12 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 89+360)



Maximum = $3.986x10^{-3}$ m
Minimum = -0.02851 m

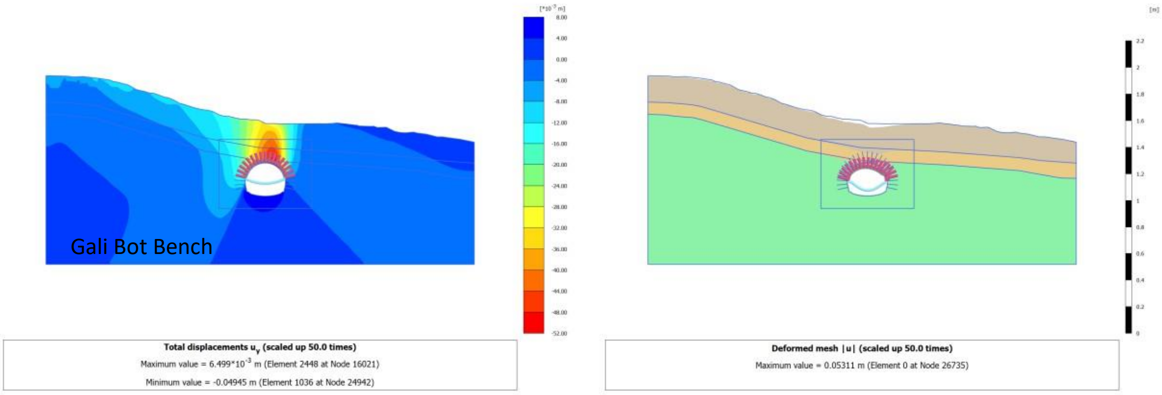


Install rockbolt mid
Maximum = $3.989x10^{-3}$ m
Minimum = -0.02885 m

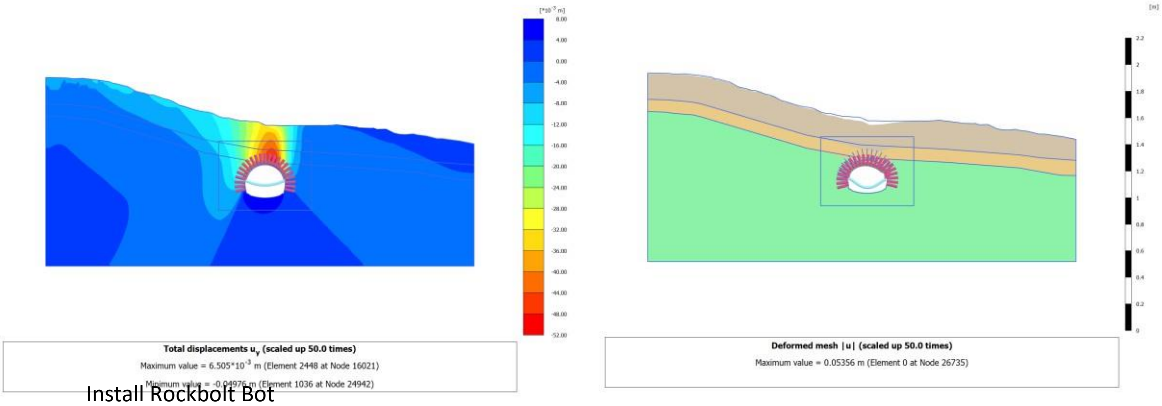


Maximum = $4.056x10^{-3}$ m
Minimum = -0.02841 m

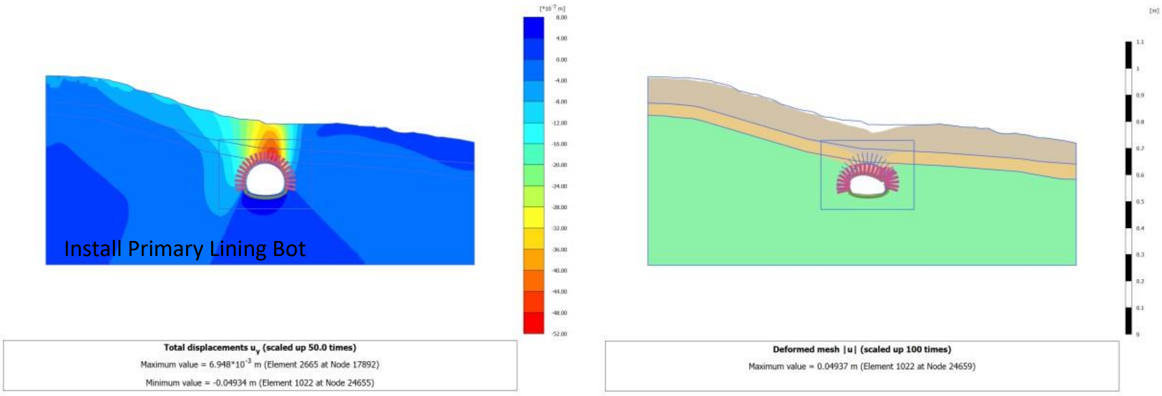
Gambar 13 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 89+360) (lanjutan)



Maximum = 6.499×10^{-3} m
Minimum = -0.04945 m

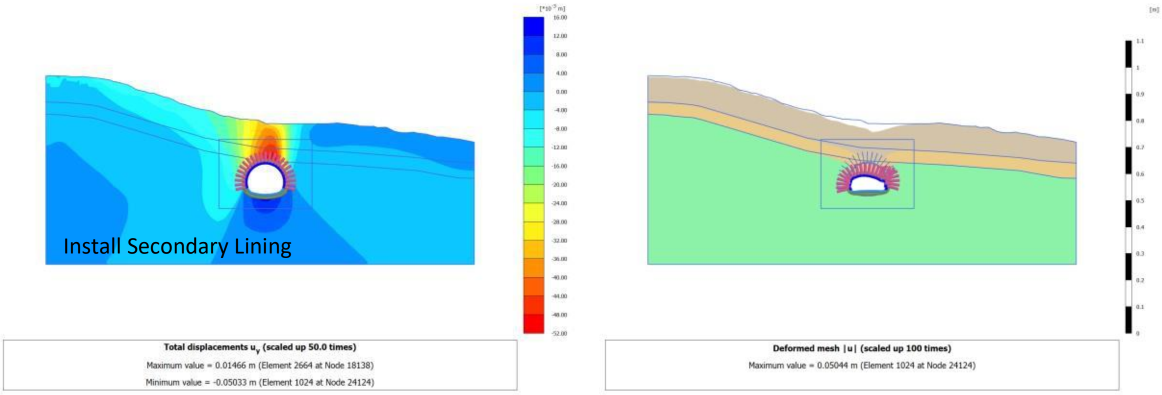


Maximum = 6.505×10^{-3} m
Minimum = -0.04976 m

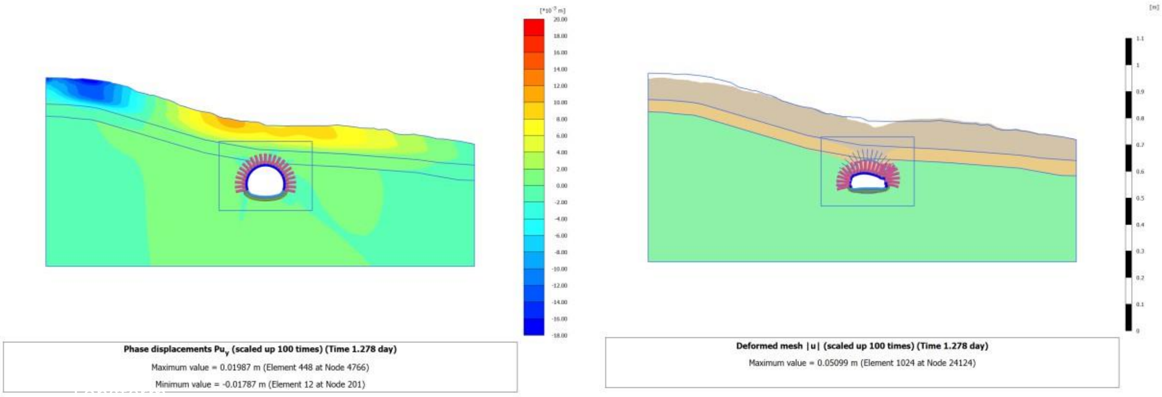


Maximum = 6.948×10^{-3} m
Minimum = -0.04934 m

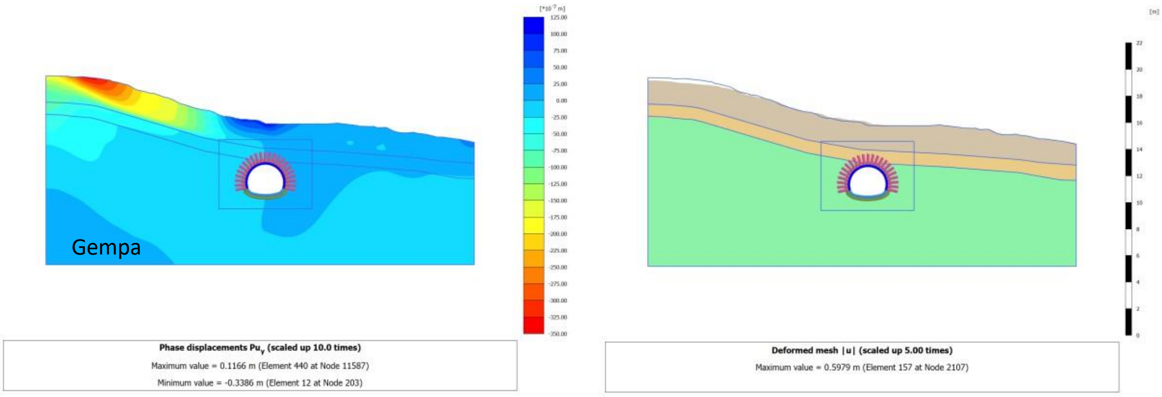
Gambar 14 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 89+360) (lanjutan)



Maximum = 0.01466 m
Minimum = -0.05033 m

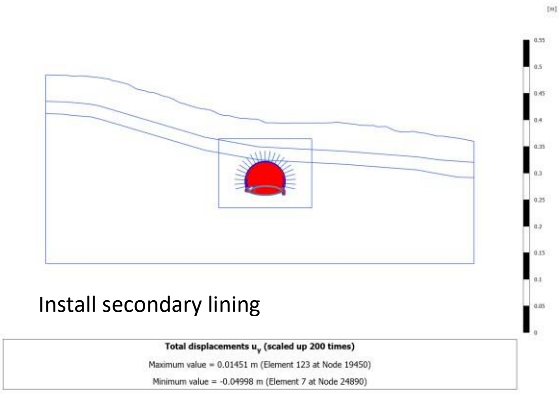


Maximum = 0.01987 m
Minimum = -0.01787 m

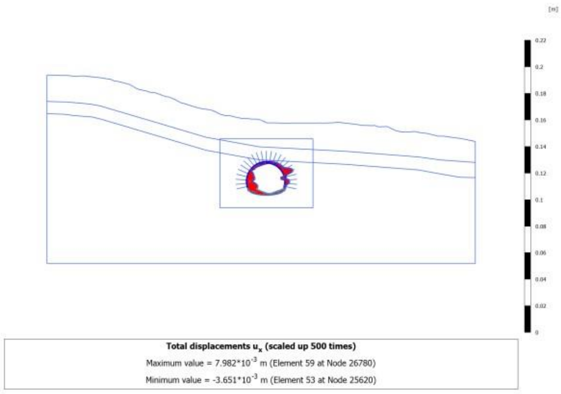


Maximum = 0.1166 m
Minimum = -0.03386 m

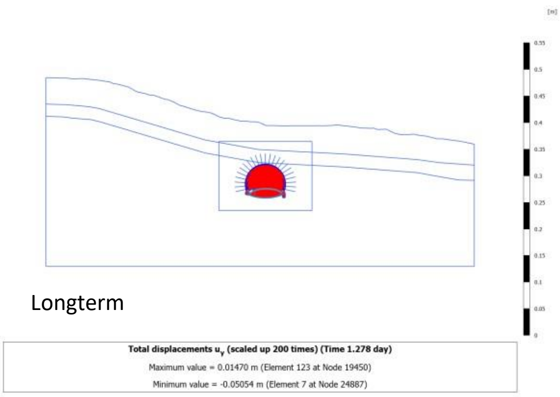
Gambar 15 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 89+360) (lanjutan)



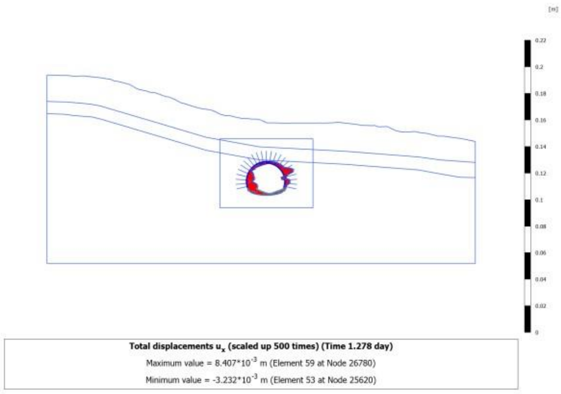
Maximum = 0.01451 m
Minimum = -0.04998 m



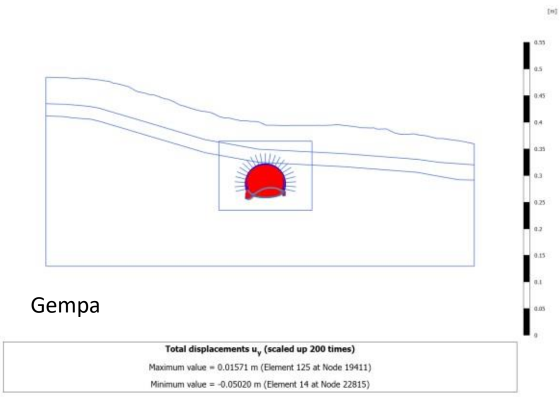
Maximum = 7.982×10^{-3} m
Minimum = -3.651×10^{-3} m



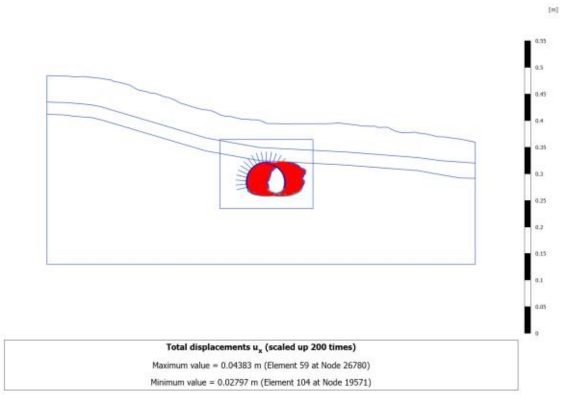
Maximum = 0.01470 m
Minimum = -0.05054 m



Maximum = 8.407×10^{-3} m
Minimum = -3.232×10^{-3} m



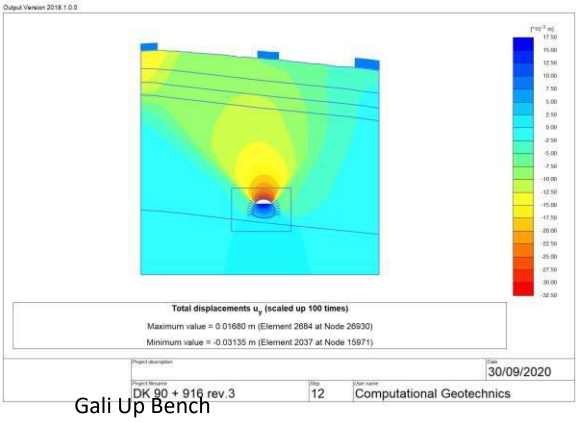
Maximum = 0.01571 m
Minimum = -0.05020 m

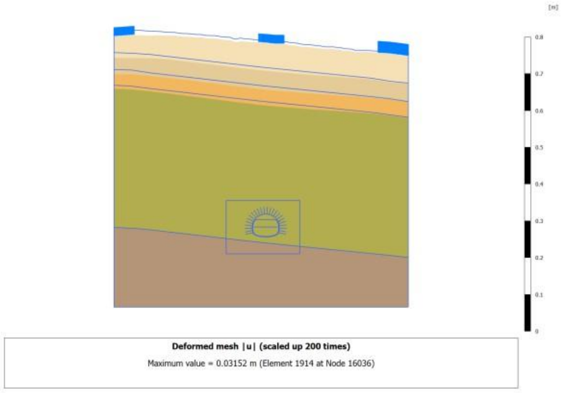


Maximum = 0.04383 m
Minimum = -0.02797 m

Gambar 16 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No. 6 (DK 89+360)

b) *Cross Section DK 90 + 916*

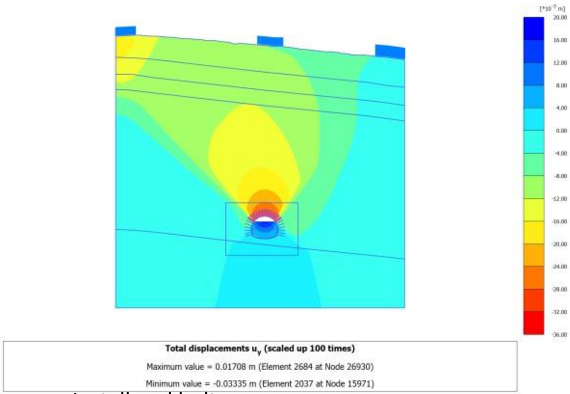


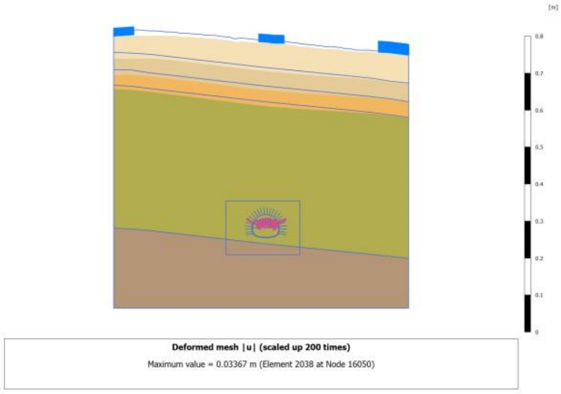


Gali Up Bench

Maximum = 0.01680 m

Minimum = -0.03135 m

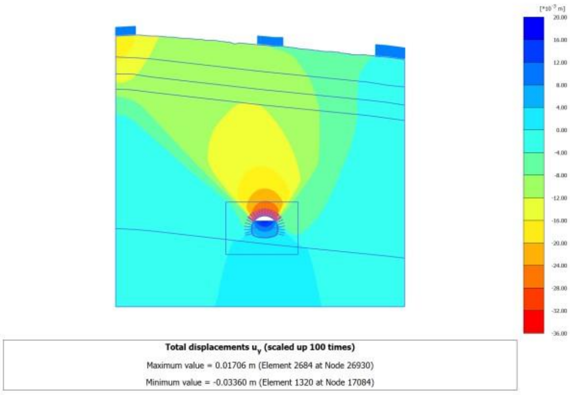


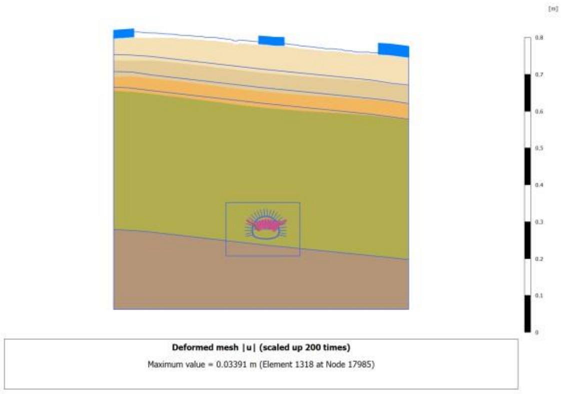


Install rockbolt up

Maximum = 0.01708 m

Minimum = -0.03335 m



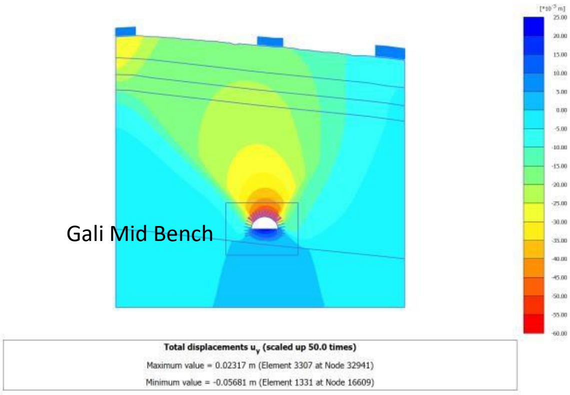


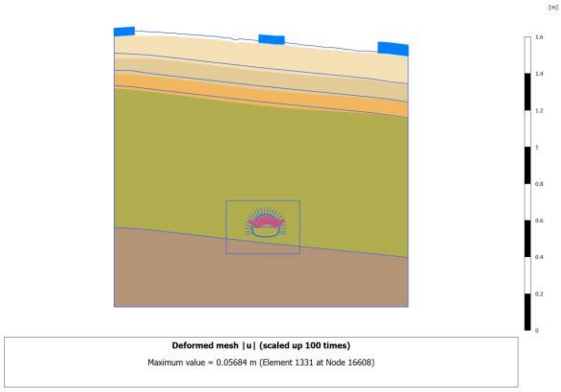
Install Primary Lining Up

Maximum = 0.01706 m

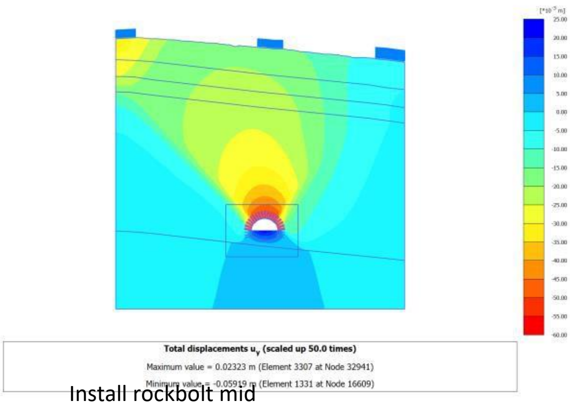
Minimum = -0.03360 m

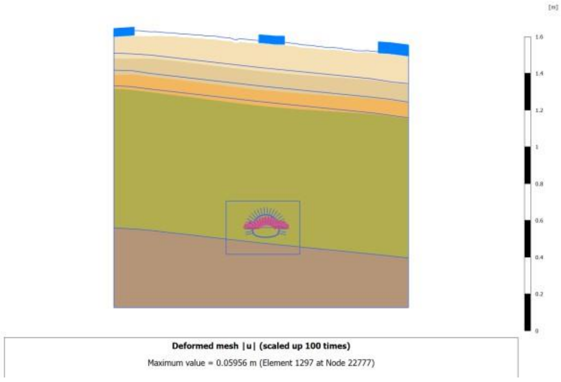
Gambar 17 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 90+916)



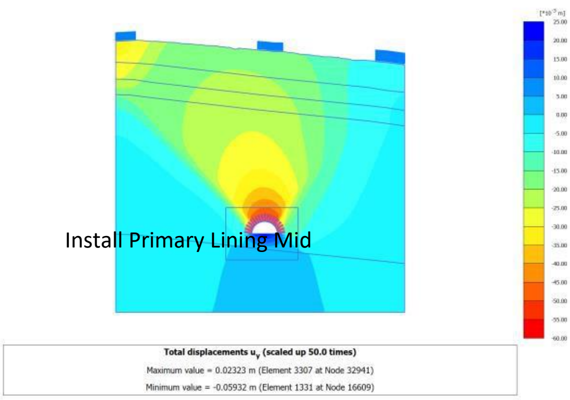


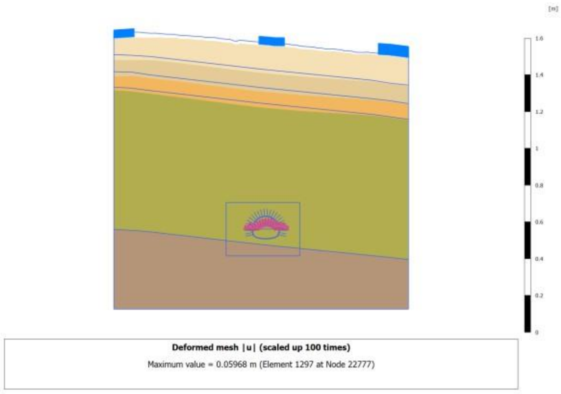
Maximum = 0.02317 m
Minimum = -0. 05681 m





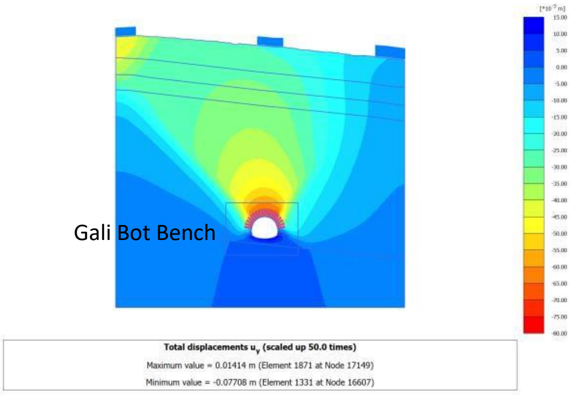
Maximum = 0.02323 m
Minimum = -0.05919 m

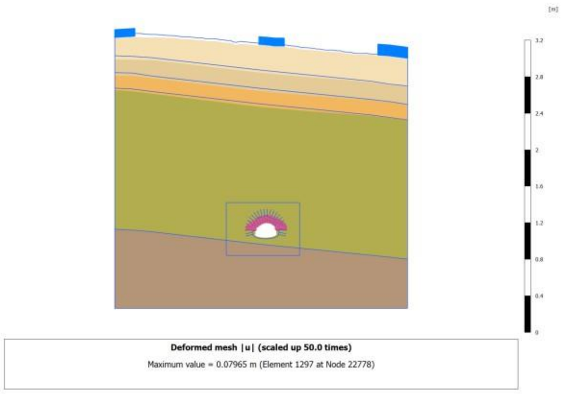




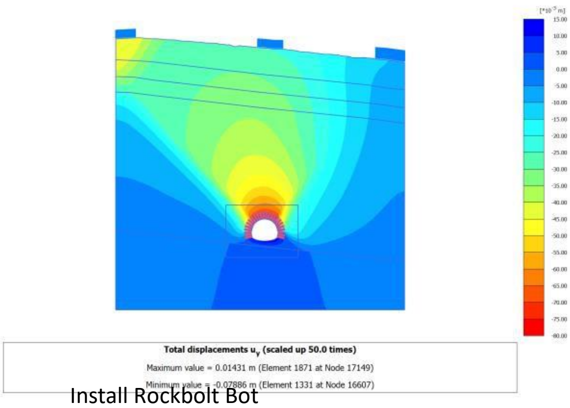
Maximum = 0.02323 m
Minimum = -0.05932 m

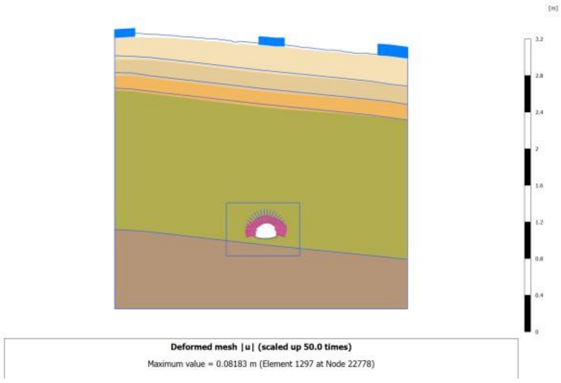
Gambar 18 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 90+916) (lanjutan)





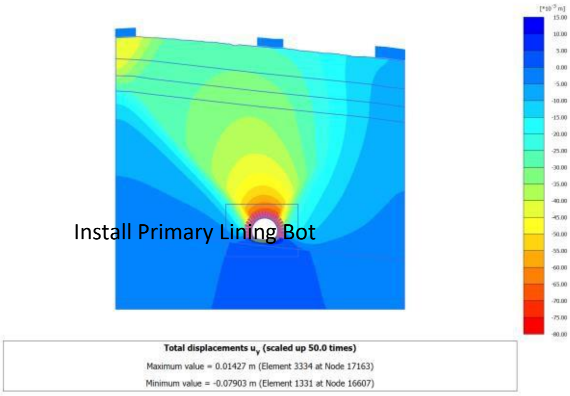
Maximum = 0.01414 m
Minimum = -0.07708 m

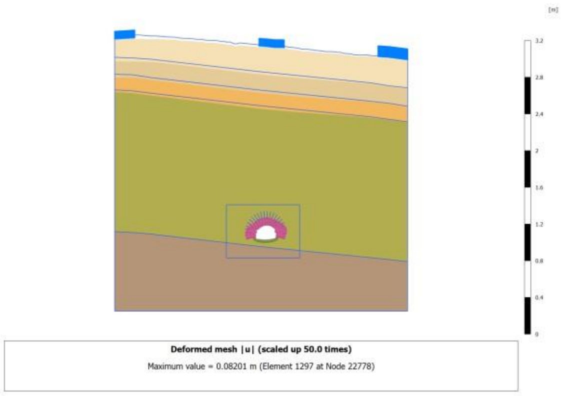




Install Rockbolt Bot

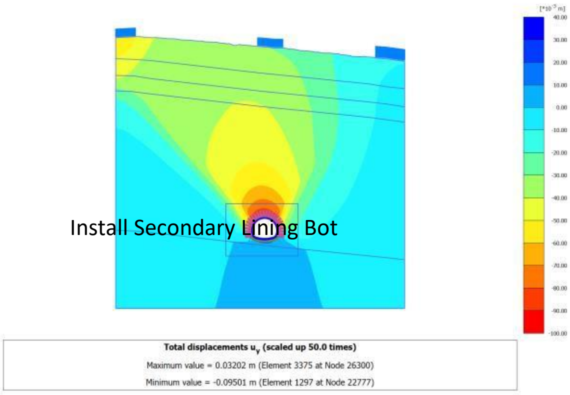
Maximum = 0.01431 m
Minimum = -0.07886 m

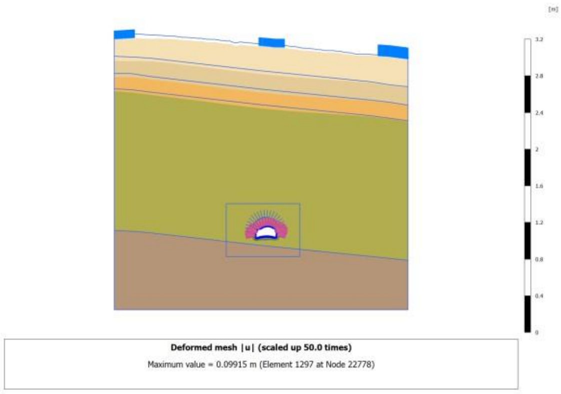




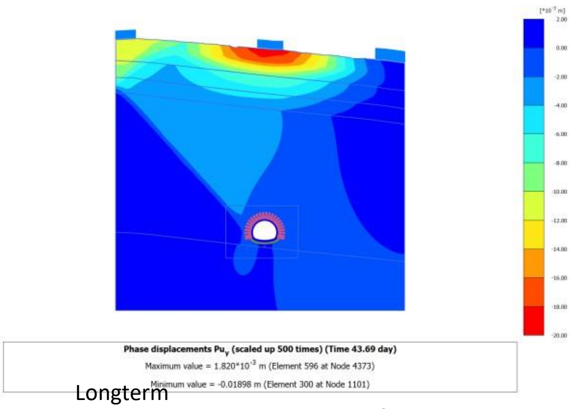
Maximum = 0.01427 m
Minimum = -0.07903 m

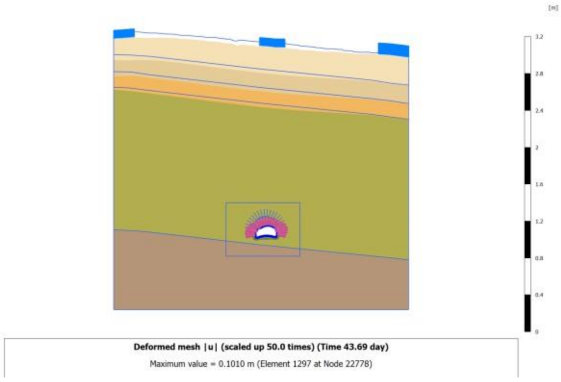
Gambar 19 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 90+916) (lanjutan)



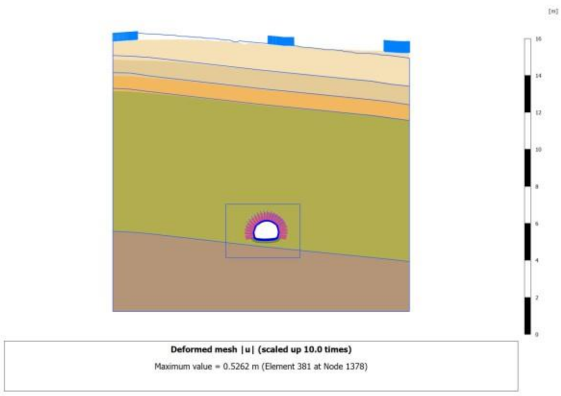


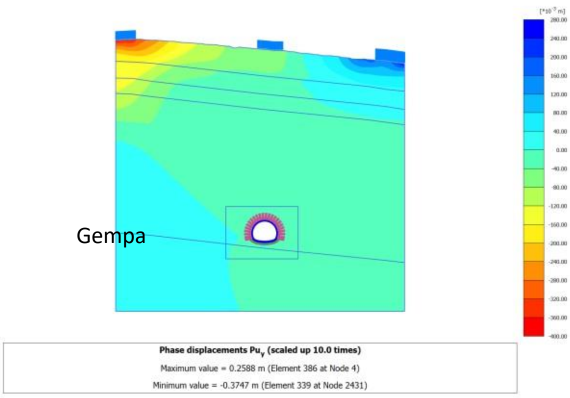
Maximum = 0.03202 m
Minimum = -0.09501 m





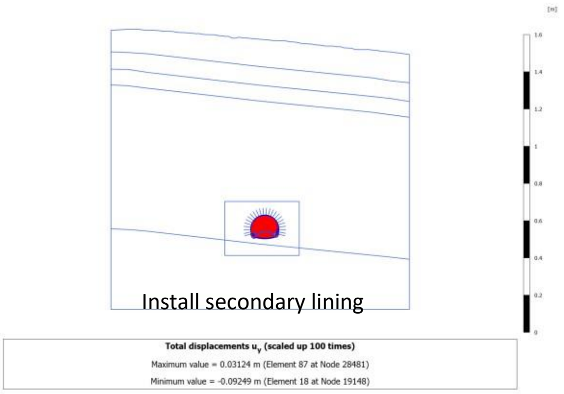
Maximum = 1.820×10^{-3} m
Minimum = -0.01898 m



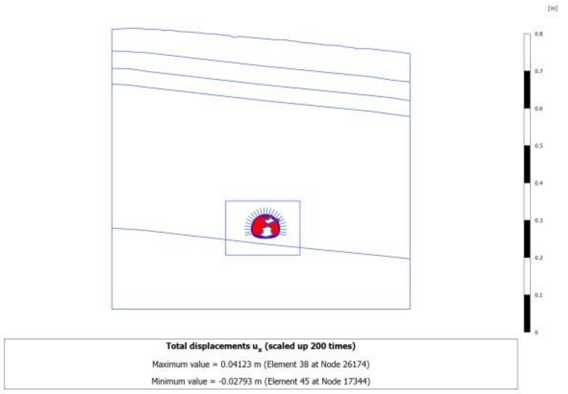


Maximum = 0.2588 m
Minimum = -0.3747 m

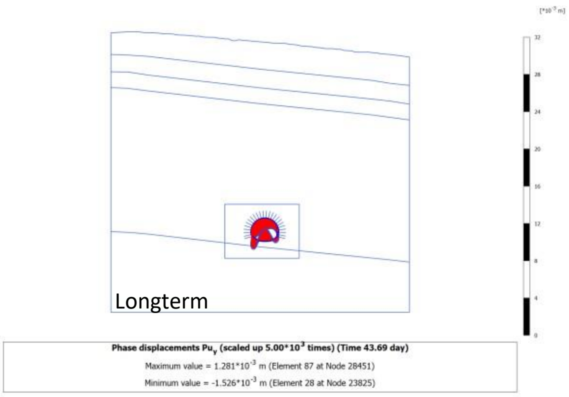
Gambar 20 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 90+916) (lanjutan)



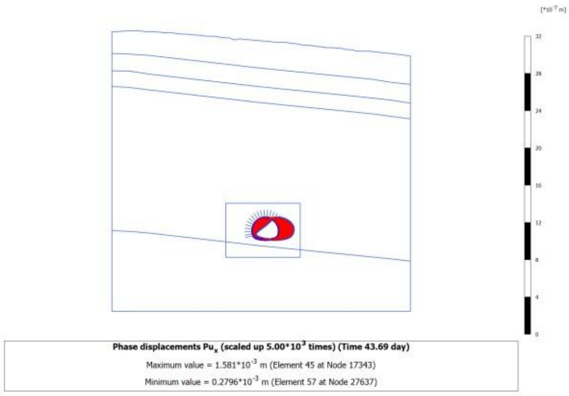
Maximum = 0.03124 m
Minimum = -0.09249 m



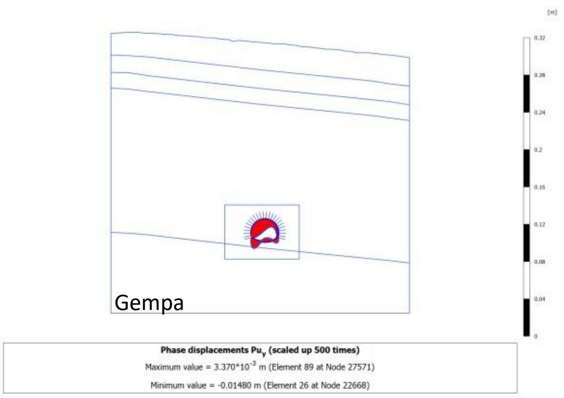
Maximum = 0.04123 m
Minimum = -0.02793 m



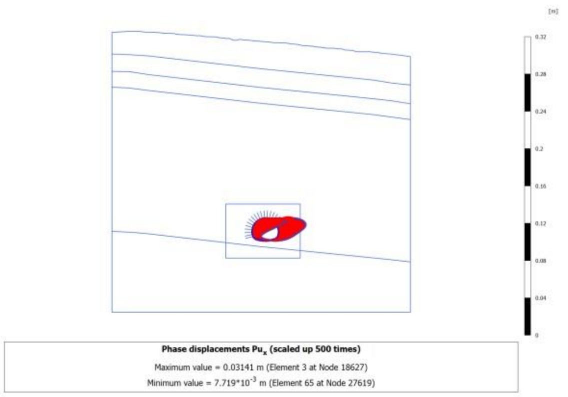
Maximum = 1.281×10^{-3} m
Minimum = -1.526×10^{-3} m



Maximum = 1.581×10^{-3} m
Minimum = -0.2796×10^{-3} m



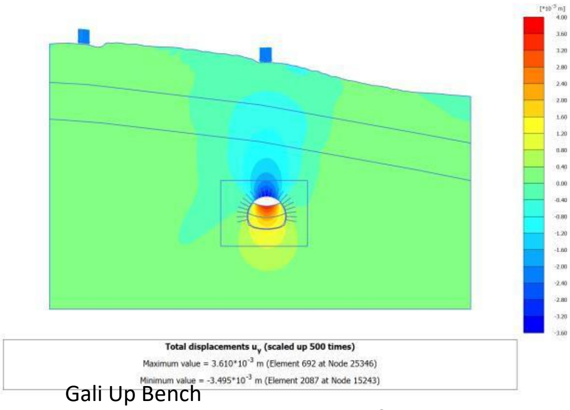
Maximum = 3.370×10^{-3} m
Minimum = -0.01480 m

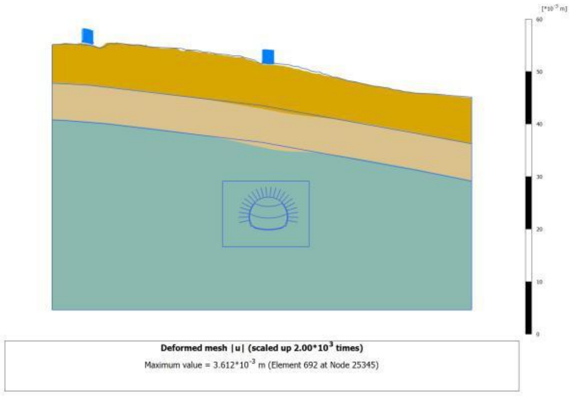


Maximum = 0.03141 m
Minimum = 7.719×10^{-3} m

Gambar 21 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No. 6 (DK 90+916)

c) *Cross Section DK 92 + 720*

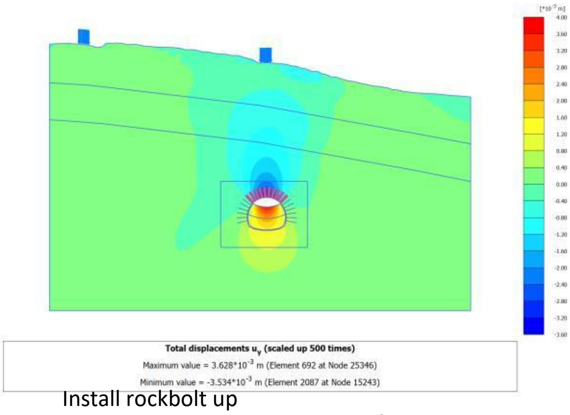


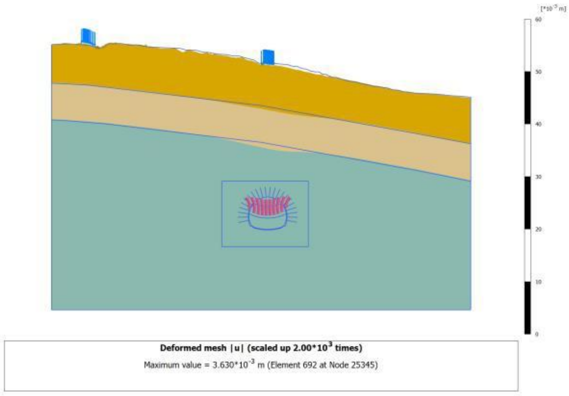


Gali Up Bench

Maximum = 3.610×10^{-3} m

Minimum = -3.495×10^{-3} m

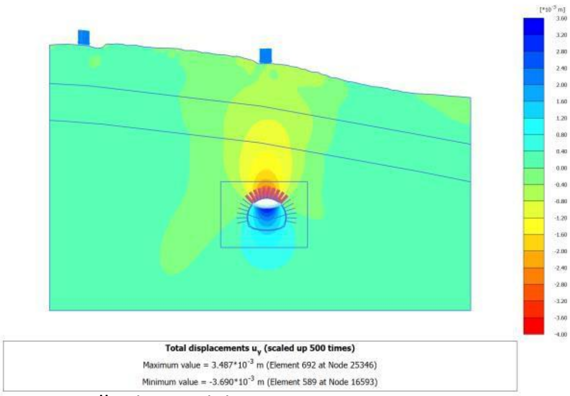


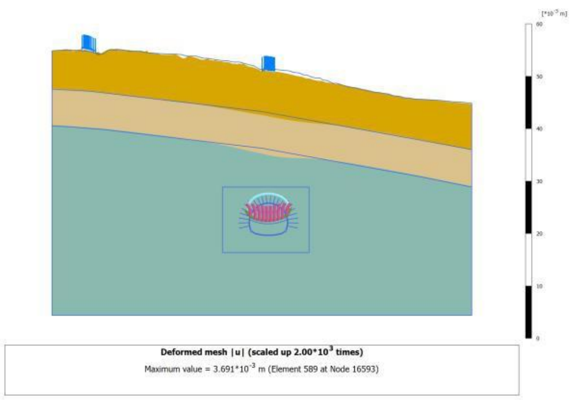


Install rockbolt up

Maximum = 3.628×10^{-3} m

Minimum = -3.534×10^{-3} m



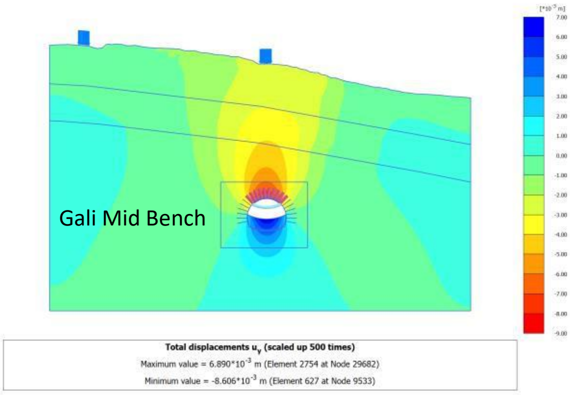


Install Primary Lining Up

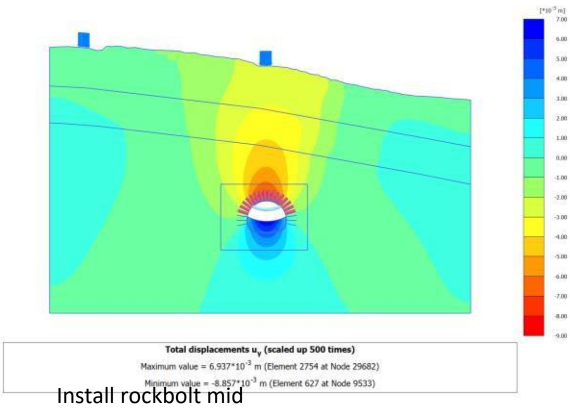
Maximum = 3.487×10^{-3} m

Minimum = -3.690×10^{-3} m

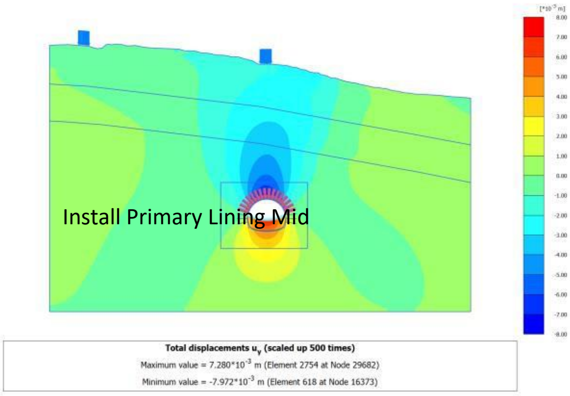
Gambar 22 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 92+720)



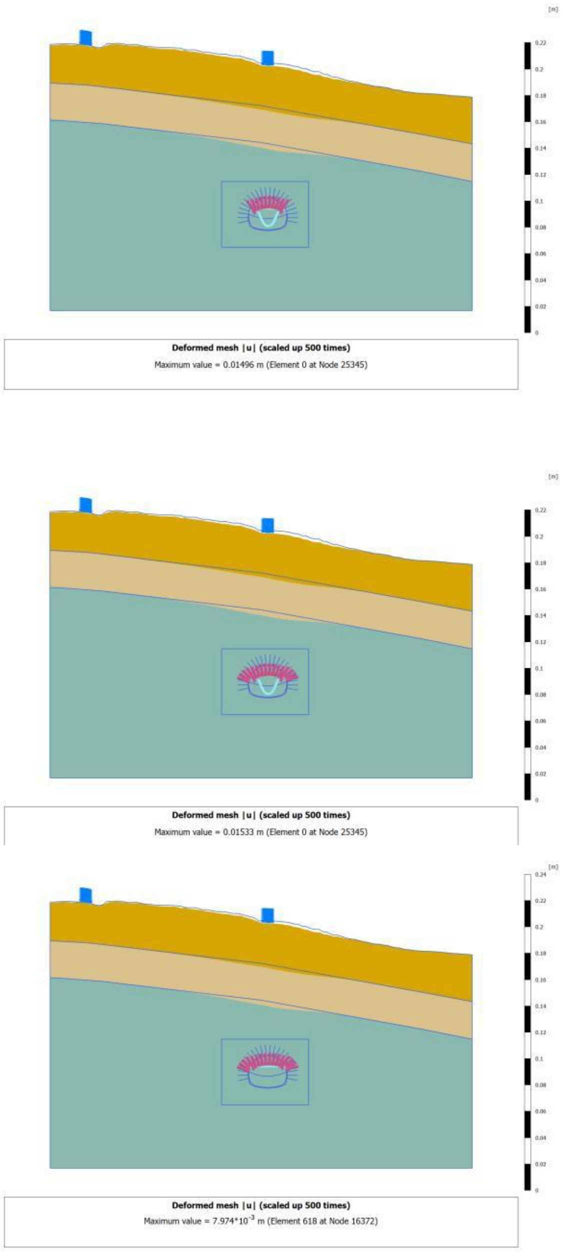
Maximum = 6.890x10^{-3} m
Minimum = -8.606x10^{-3} m



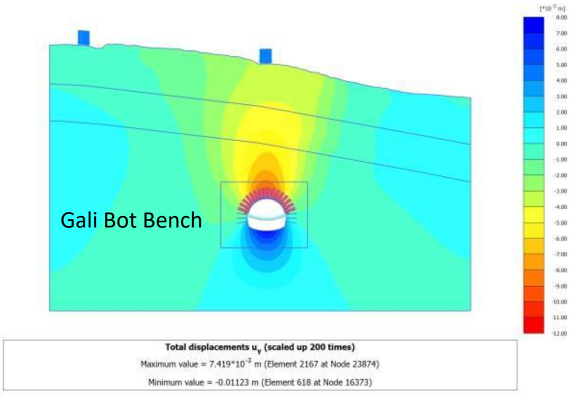
Maximum = 6.937x10^{-3} m
Minimum = -8.857x10^{-3} m

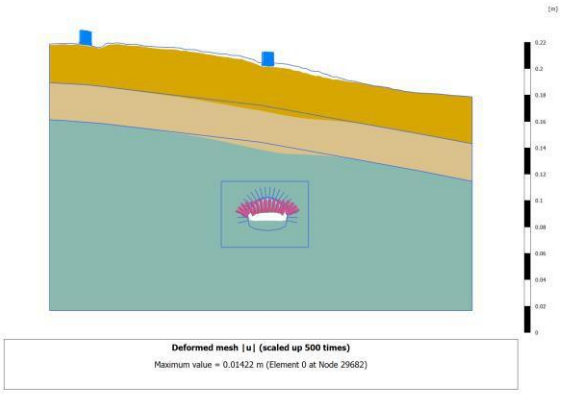


Maximum = 7.280x10^{-3} m
Minimum = -7972x10^{-3} m

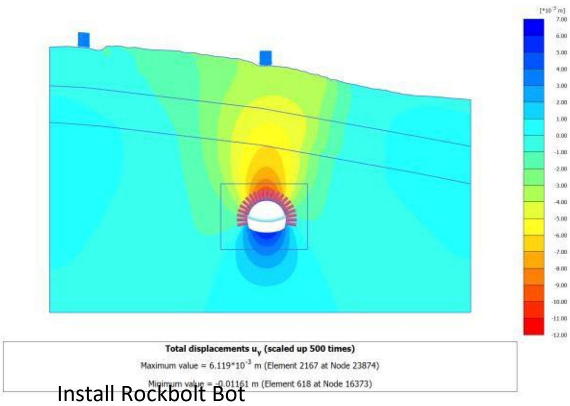


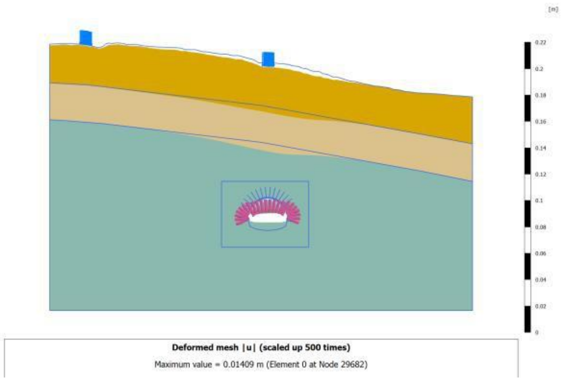
Gambar 23 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 92+720) (lanjutan)



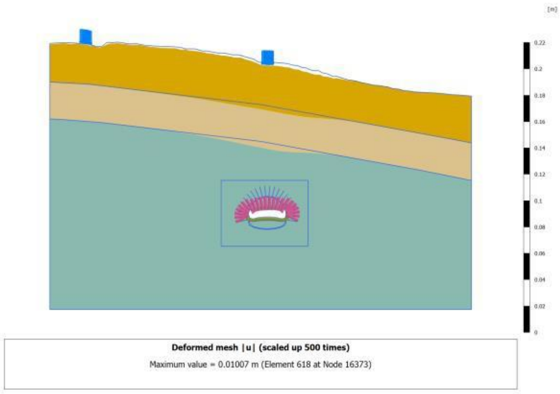


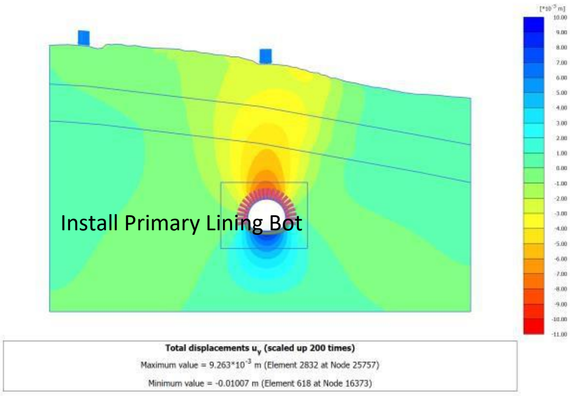
Maximum = 7.419×10^{-3} m
Minimum = -0.01123 m





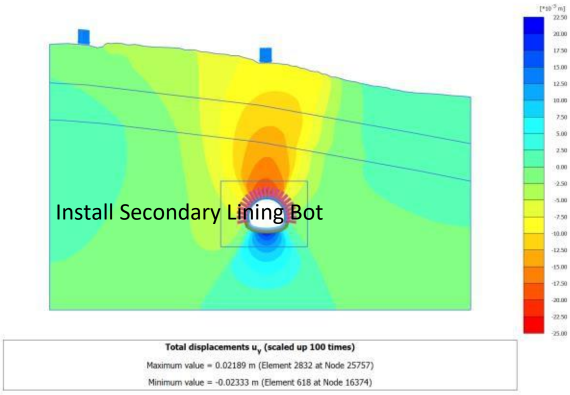
Maximum = 6.119×10^{-3} m
Minimum = -0.01161 m

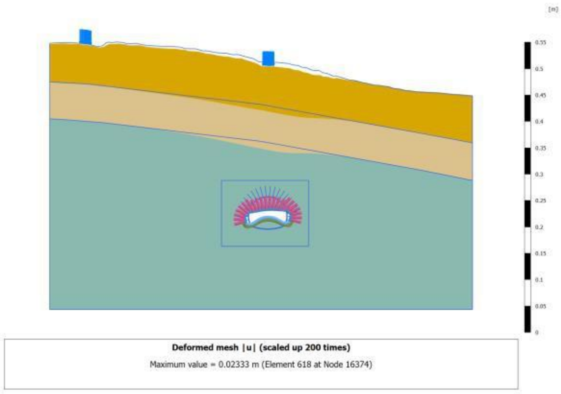




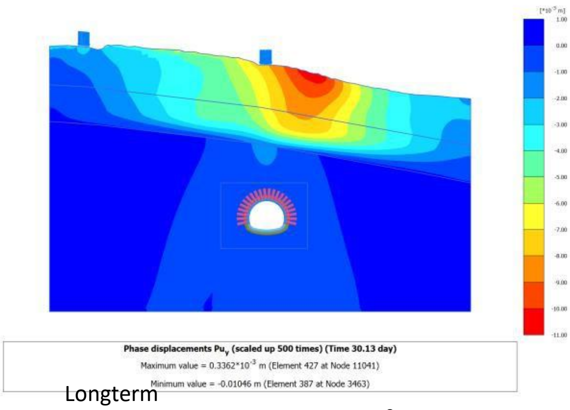
Maximum = 9.263×10^{-3} m
Minimum = -0.01007 m

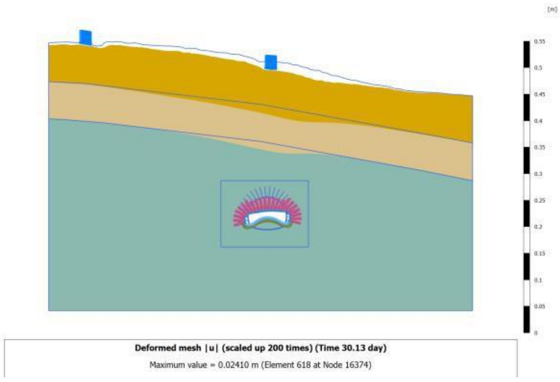
Gambar 24 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 92+720) (lanjutan)





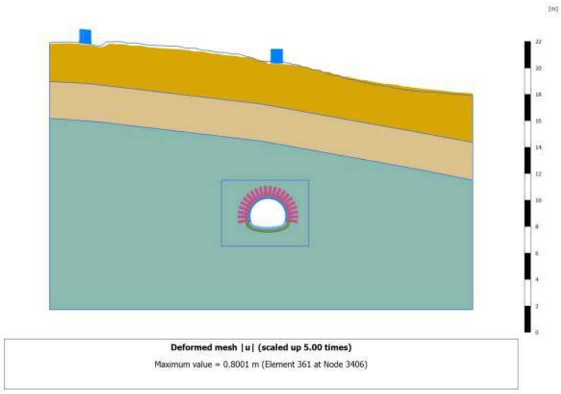
Maximum = 0.02189 m
Minimum = -0.02333 m

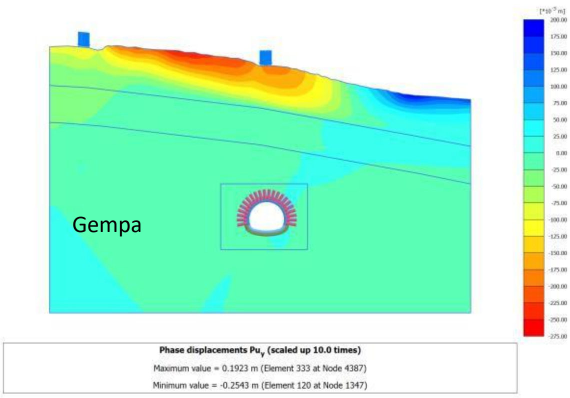




Longterm

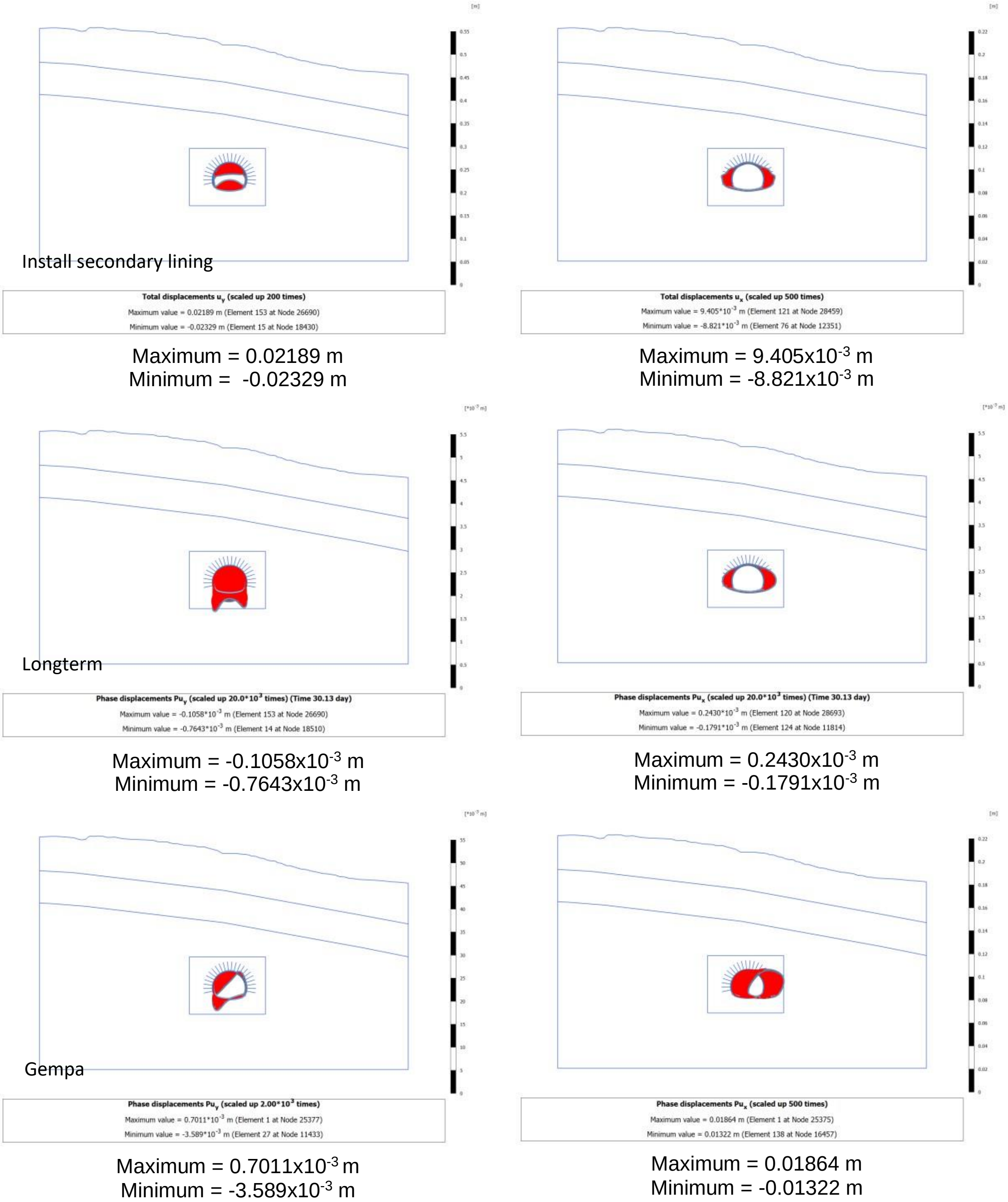
Maximum = 0.3362×10^{-3} m
Minimum = -0.01046×10^{-3} m





Maximum = 0.1923 m
Minimum = -0.2543 m

Gambar 25 Hasil analisis deformasi aksial global Tunnel No. 6 (DK 92+720) (lanjutan)

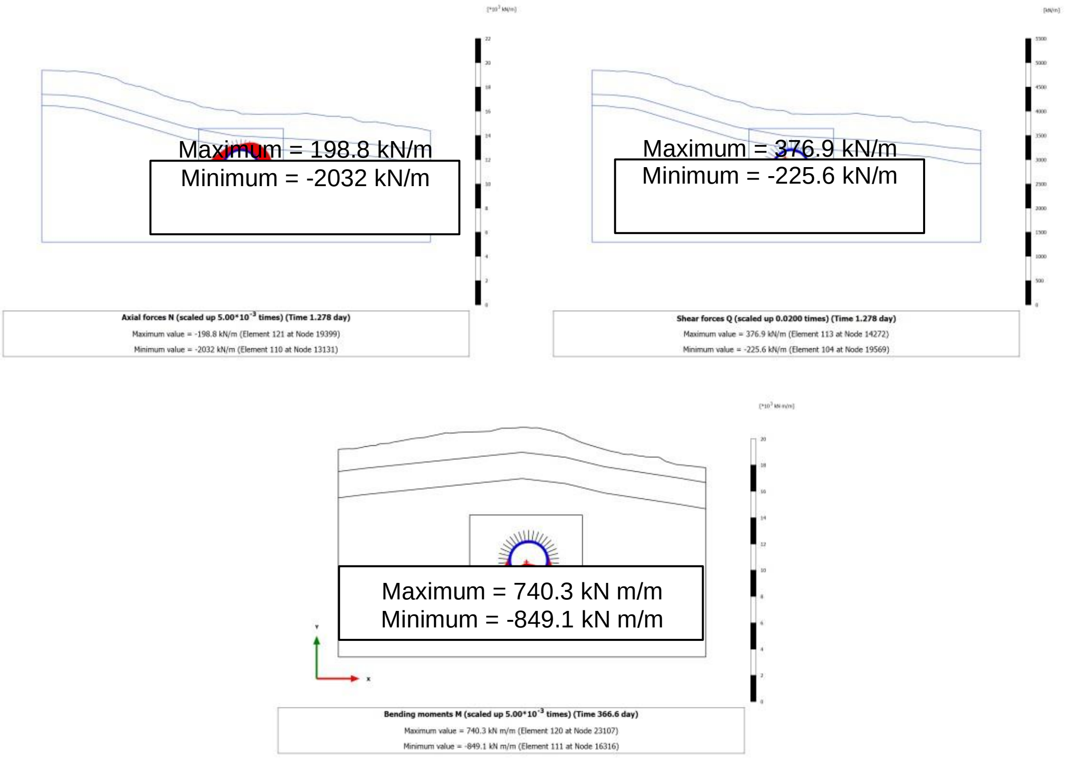


Gambar 26 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No. 6 (DK 92+720)

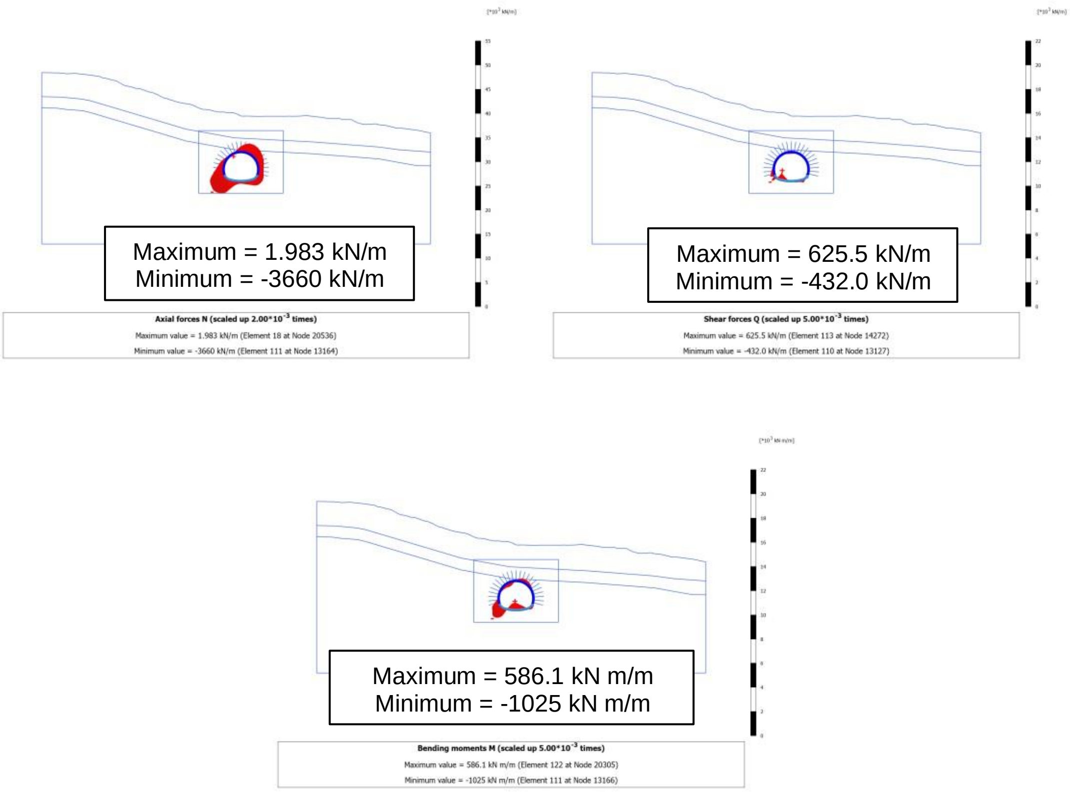
3. Gaya Dalam pada Lining Terowongan

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 27** s/d **Gambar 32**.

a) Cross Section DK 89+360

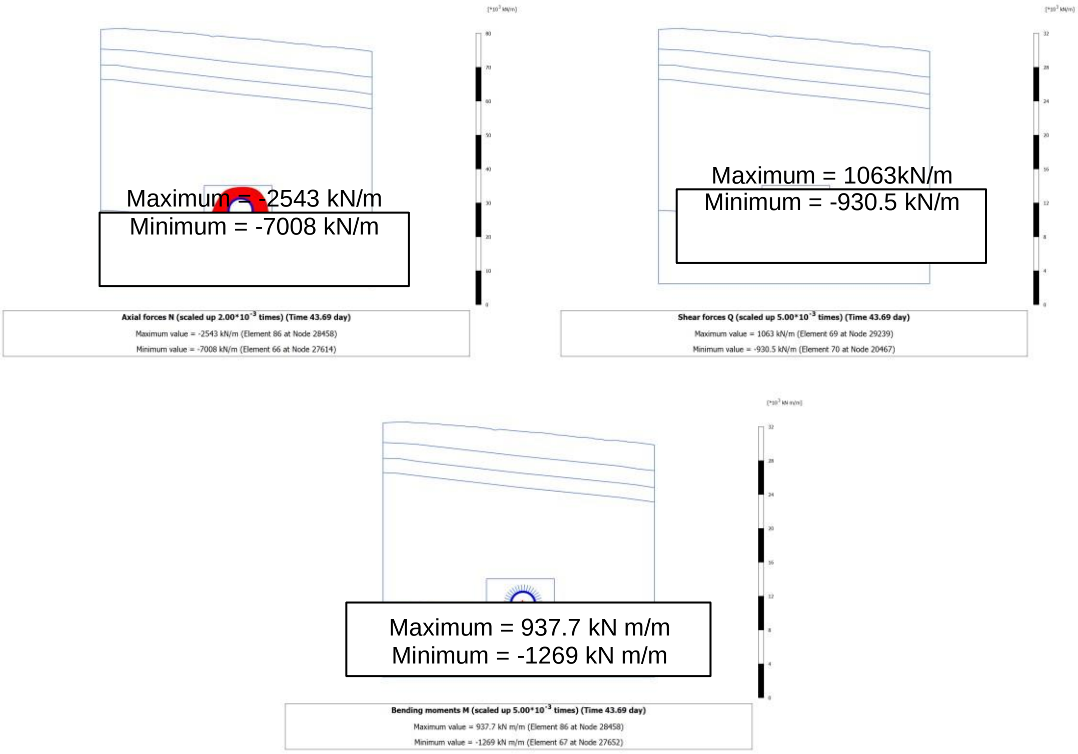


Gambar 27 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel No. 6 (DK 89+360)

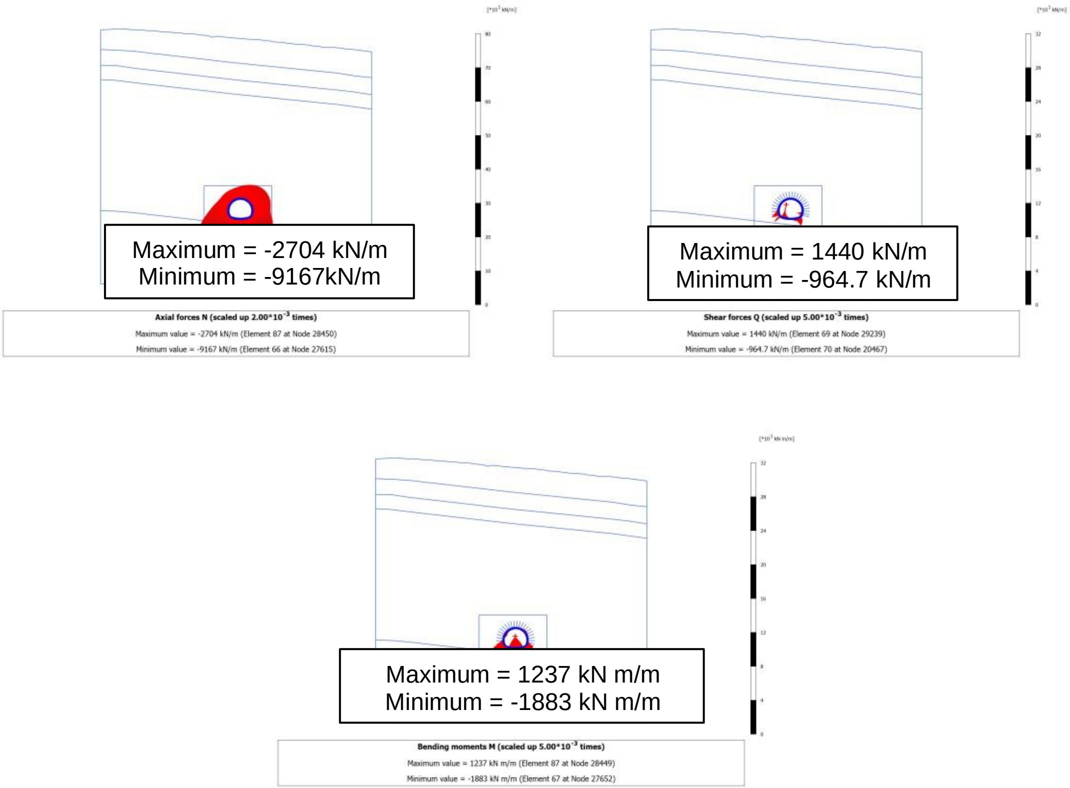


Gambar 28 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No. 6 (DK 89+360)

b) Cross Section DK 90+916

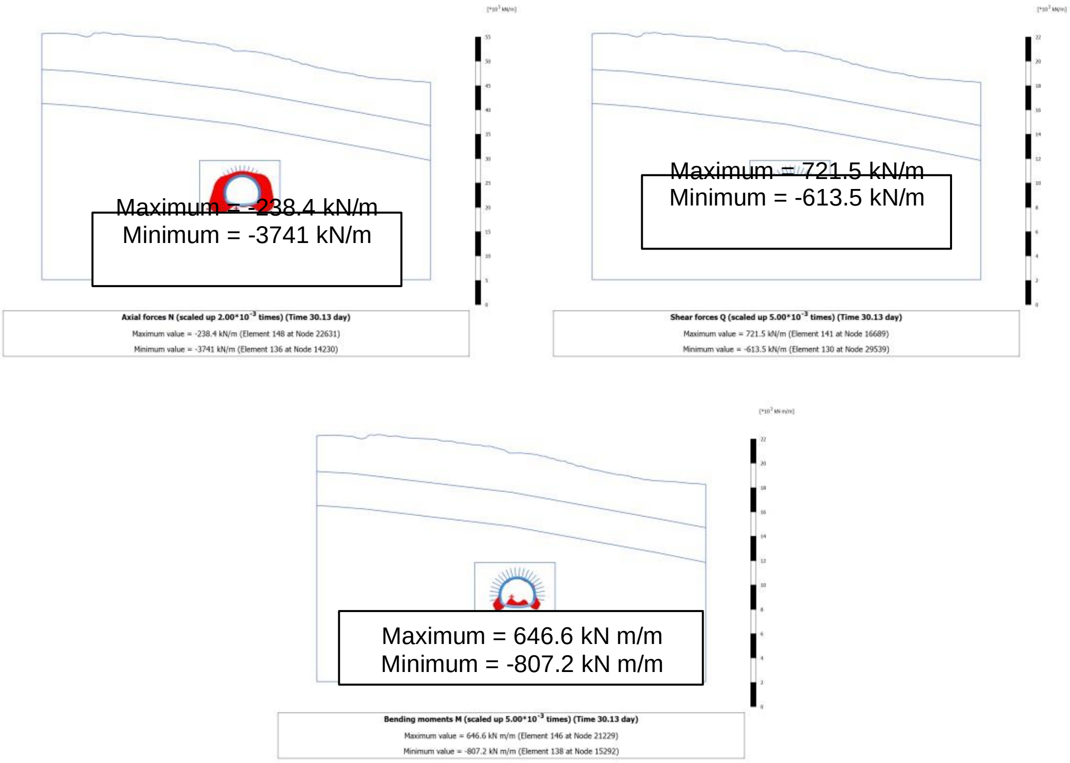


Gambar 29 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel No. 6 (DK 90+916)

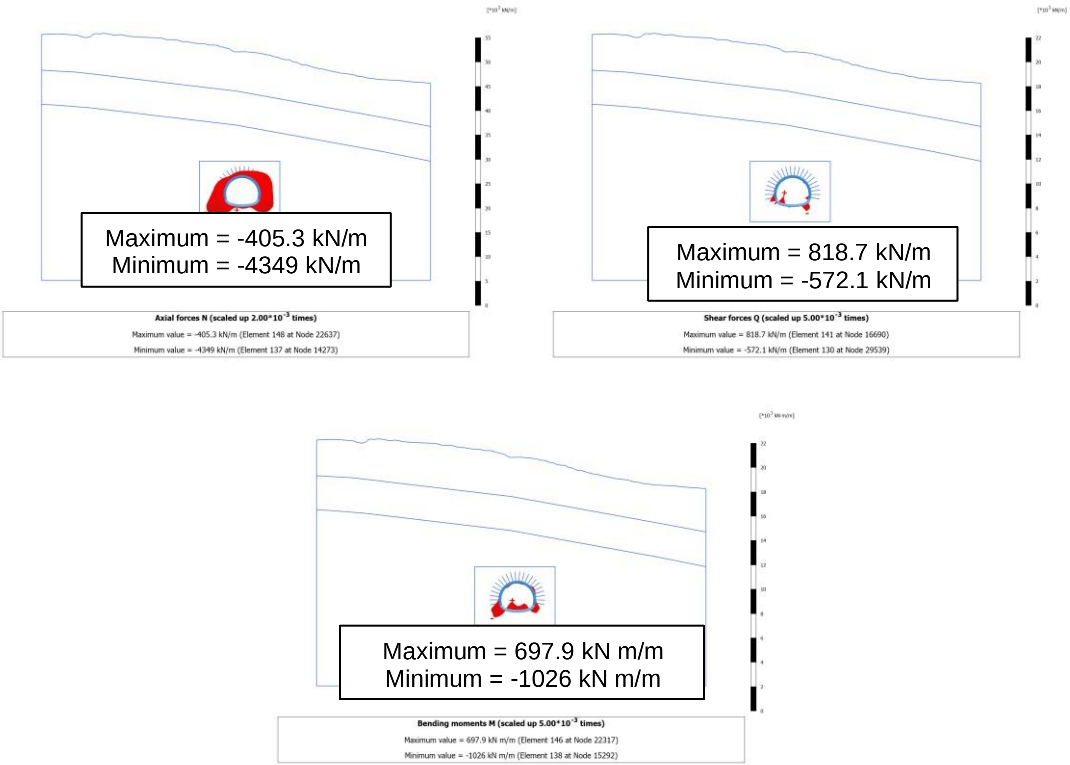


Gambar 30 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No. 6 (DK 90+916)

c) Cross Section DK 92+720



Gambar 31 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel No. 6 (DK 92+720)

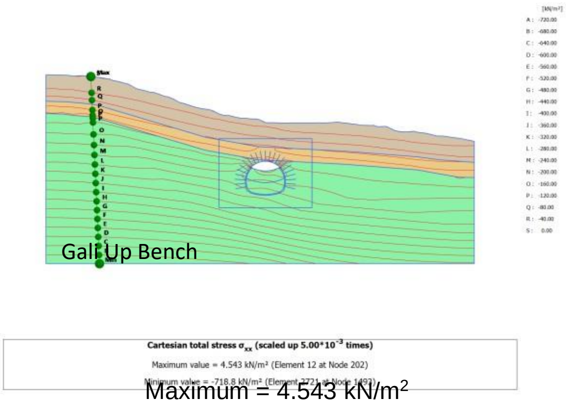


Gambar 32 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No. 6 (DK 92+720)

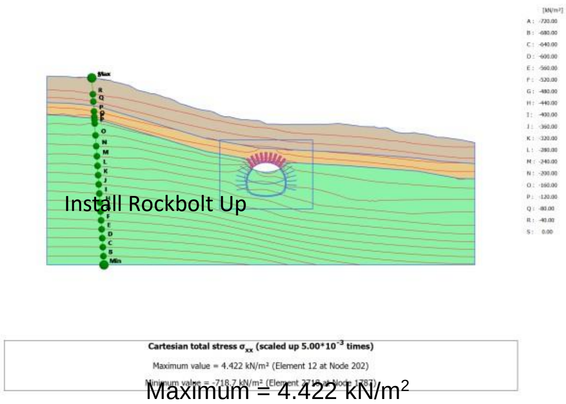
4. Tegangan Dalam Tanah

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/y, horizontal/x, maksimum/1, minimum/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 33** s/d **Gambar 62**.

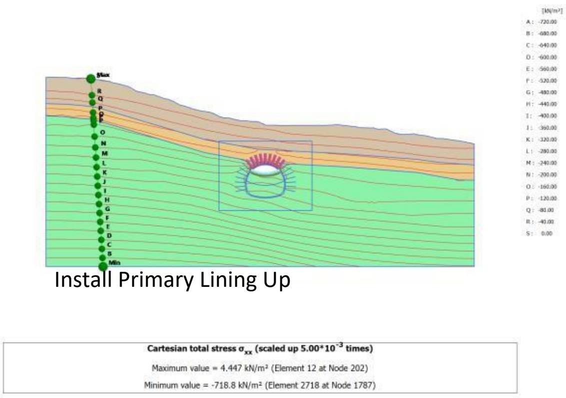
a) *Cross Section DK 89+360*



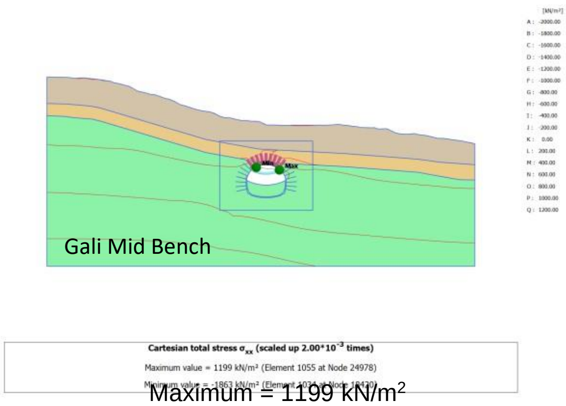
Maximum = 4.543 kN/m^2
Minimum = -718.8 kN/m^2



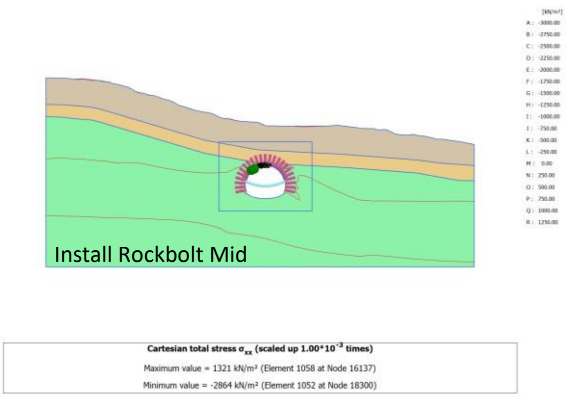
Maximum = 4.422 kN/m^2
Minimum = -718.7 kN/m^2



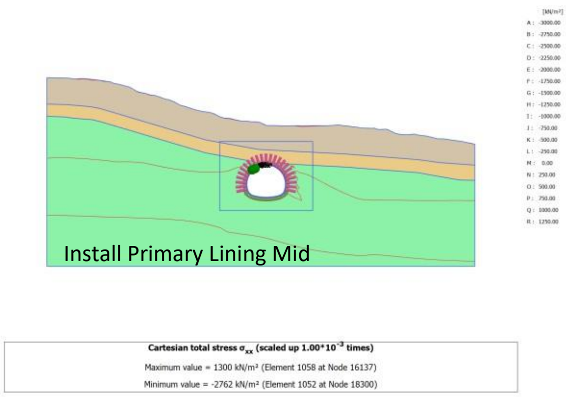
Maximum = 4.447 kN/m^2
Minimum = -718.8 kN/m^2



Maximum = 1199 kN/m^2
Minimum = -1863 kN/m^2

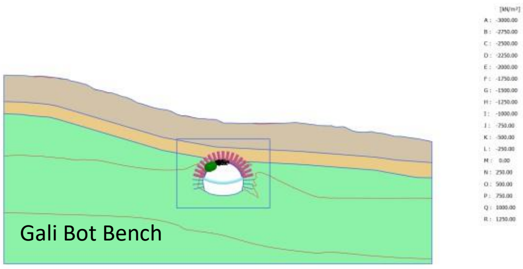


Maximum = 1321 kN/m^2
Minimum = -2864 kN/m^2

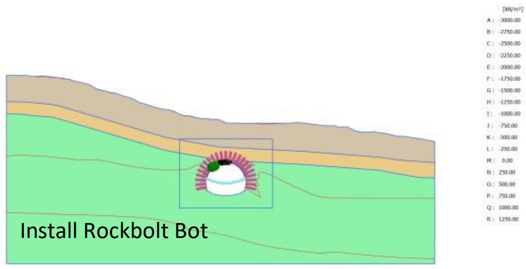


Maximum = 1300 kN/m^2
Minimum = -2762 kN/m^2

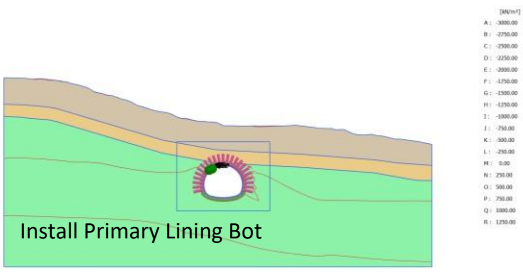
Gambar 33 Hasil analisis tegangan horizontal (x) pada Tunnel No. 6 (DK 89+360)



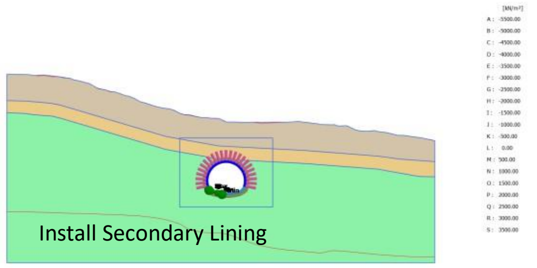
Maksimum = 1284 kN/m²
Minimum = -2849 kN/m²



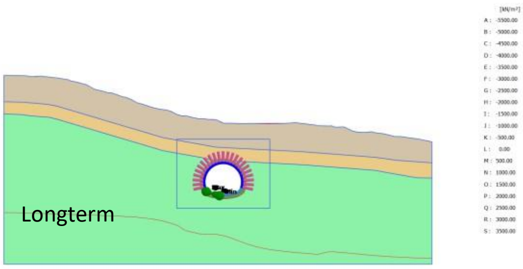
Maximum = 1321 kN/m²
Minimum = -2864 kN/m²



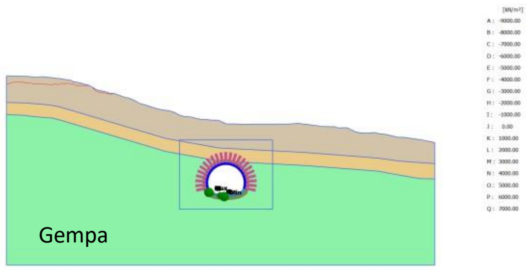
Maximum = 1300 kN/m²
Minimum = -2762 kN/m²



Maximum = 3680 kN/m²
Minimum = -5001 kN/m²

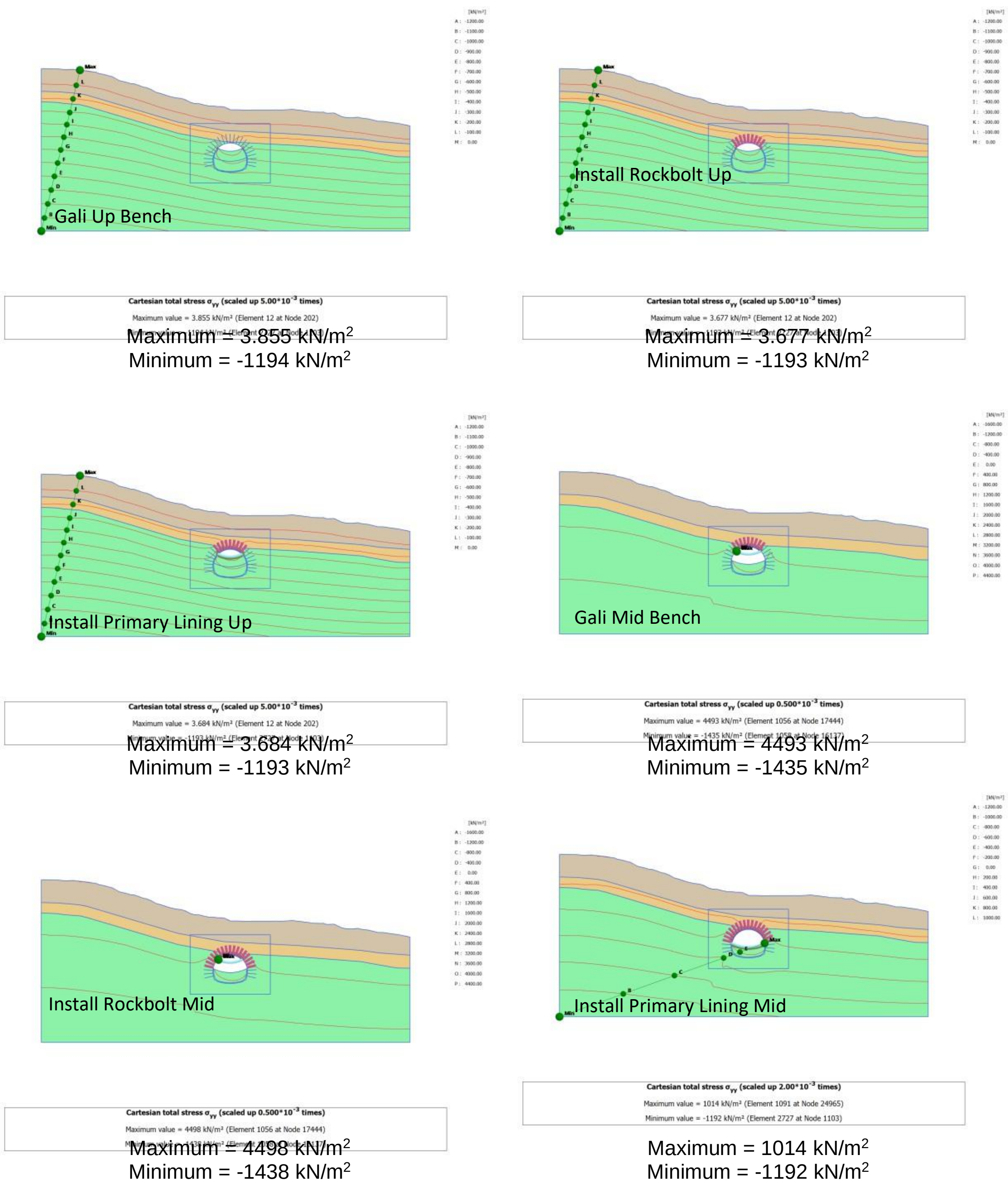


Maksimum = 3790 kN/m²
Minimum = -5132 kN/m²

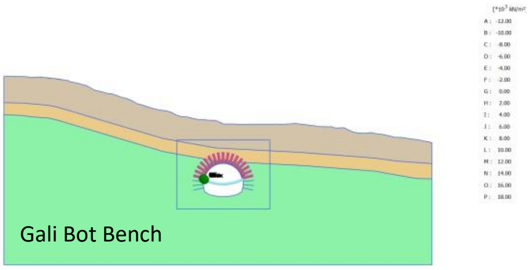


Maximum = 7764 kN/m²
Minimum = -8763kN/m²

Gambar 34 Hasil analisis tegangan horizontal (x) pada Tunnel No. 6 (DK 89+360) (lanjutan)

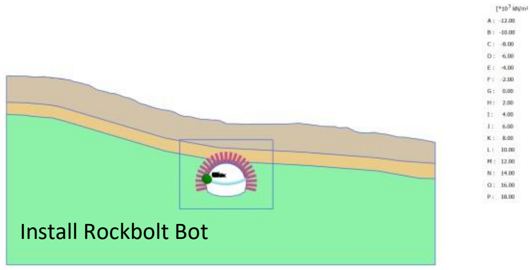


Gambar 35 Hasil analisis tegangan vertikal (y) pada Tunnel No. 6 (DK 89+360)



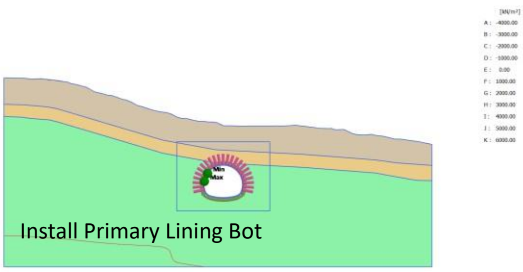
Cartesian total stress σ_{yy} (scaled up 0.200×10^{-3} times)

Maksimum = 18.66×10^{3} kN/m^2
Minimum = -10.08×10^{3} kN/m^2



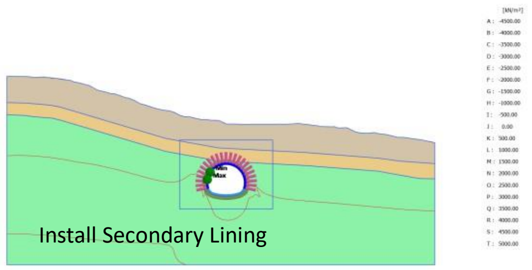
Cartesian total stress σ_{yy} (scaled up 0.200×10^{-3} times)

Maximum = 18.71×10^{3} kN/m^2
Minimum = -10.11×10^{3} kN/m^2



Cartesian total stress σ_{yy} (scaled up 0.500×10^{-3} times)

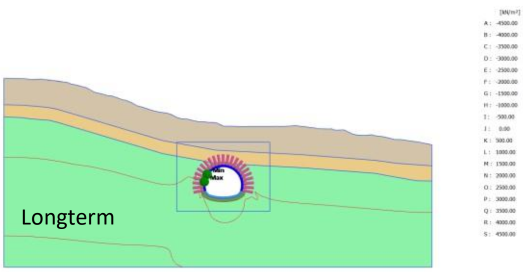
Maximum = 6801 kN/m^2
Minimum = -3591 kN/m^2



Cartesian total stress σ_{yy} (scaled up 0.500×10^{-3} times)

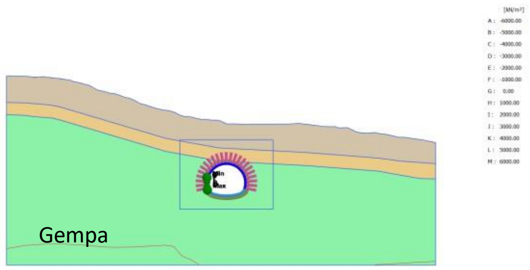
Maximum value = 5073 kN/m^2 (Element 1074 at Node 14398)

Maximum = 5073 kN/m^2
Minimum = -4290^3 kN/m^2



Cartesian total stress σ_{yy} (scaled up 0.500×10^{-3} times) (Time 1.278 day)

Maksimum = 4990 kN/m^2
Minimum = -4336 kN/m^2

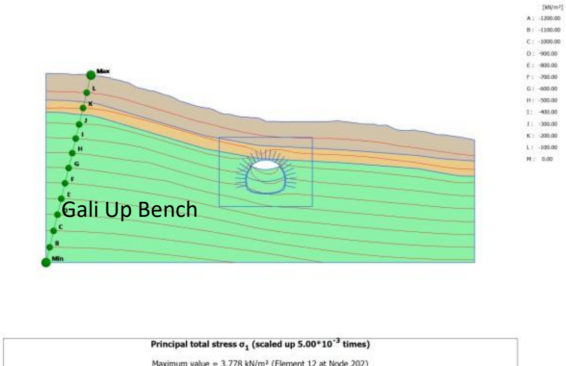


Cartesian total stress σ_{yy} (scaled up 0.500×10^{-3} times)

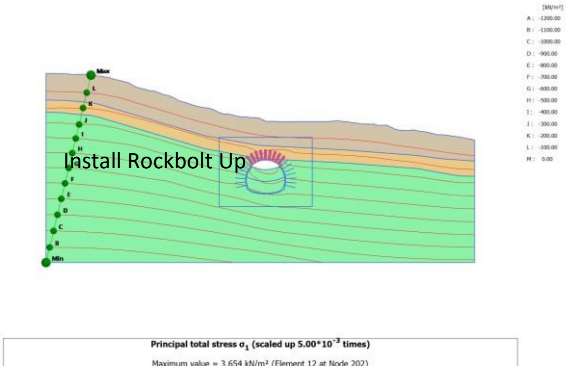
Maximum value = 6515 kN/m^2 (Element 2599 at Node 11058)

Maximum = 6515 kN/m^2
Minimum = 5777 kN/m^2

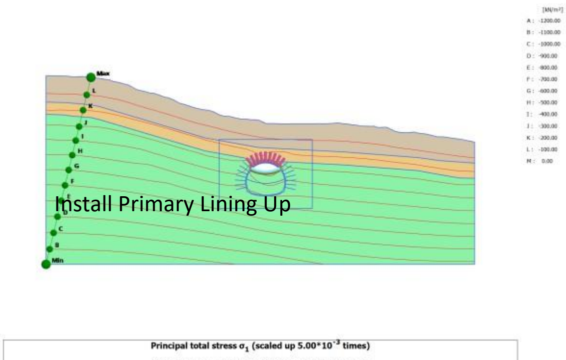
Gambar 36 Hasil analisis tegangan vertikal (y) pada Tunnel No. 6 (DK 89+360) (lanjutan)



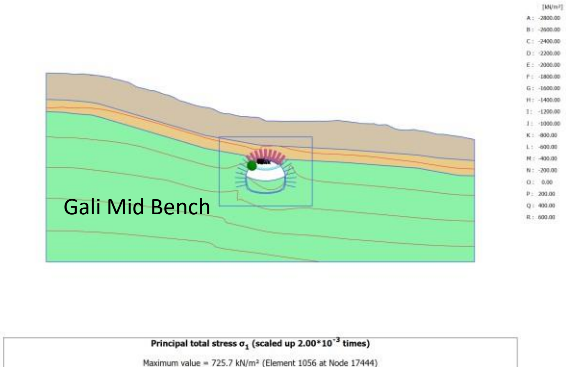
Maximum = 3.778 kN/m^2
Minimum = -1194 kN/m^2



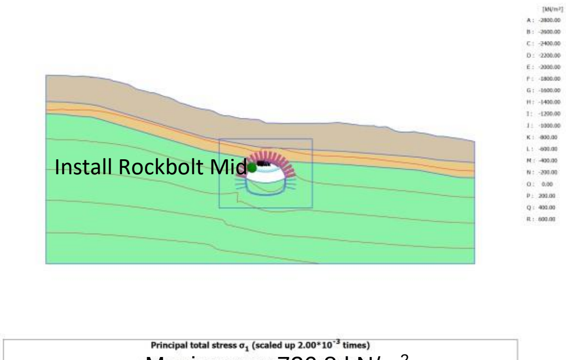
Maximum = 3.654 kN/m^2
Minimum = -1193 kN/m^2



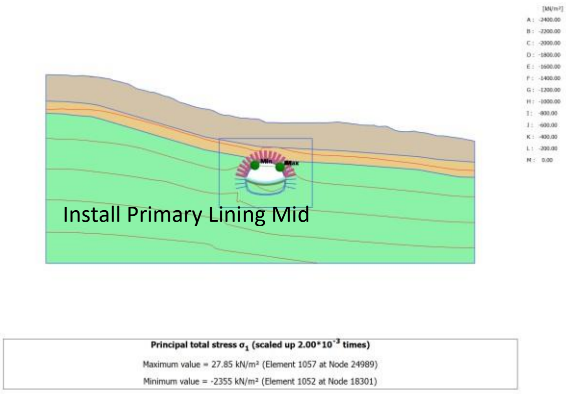
Maximum = 3.660 kN/m^2
Minimum = -1193 kN/m^2



Maximum = 725.7 kN/m^2
Minimum = -2737 kN/m^2

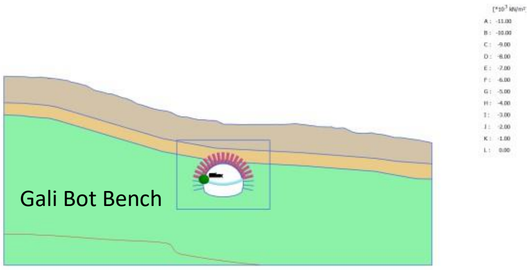


Maximum = 726.8 kN/m^2
Minimum = -2741 kN/m^2

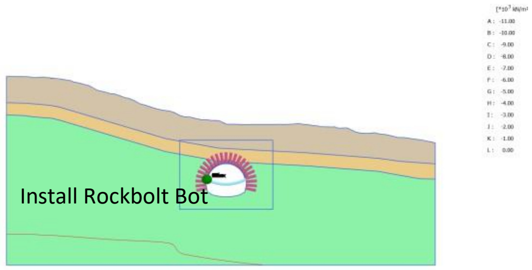


Maximum = 27.85 kN/m^2
Minimum = -2355 kN/m^2

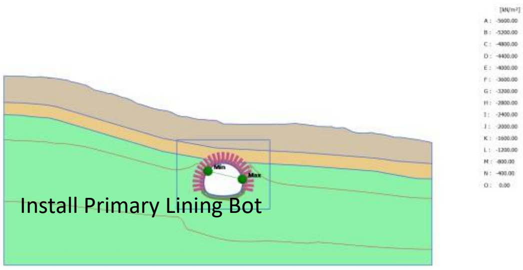
Gambar 37 Hasil analisis tegangan maksimum (1) pada Tunnel No. 6 (DK 74+300)



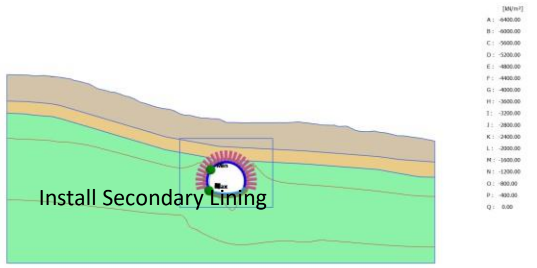
Maksimum = 391.6 kN/m²
Minimum = -10.73x10³ kN/m²



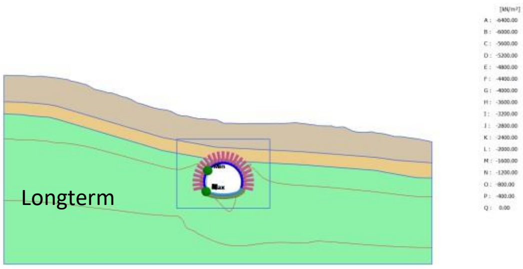
Maximum = 393.0 kN/m²
Minimum = -10.77x10³ kN/m²



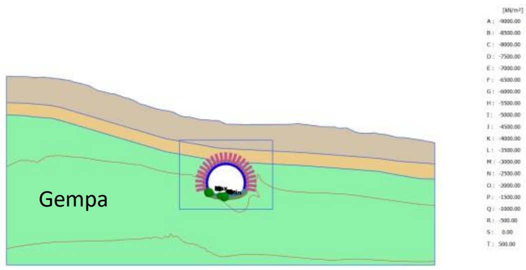
Maximum = 109.6 kN/m²
Minimum = -5263 kN/m²



Maximum = 366.7 kN/m²
Minimum = -6186 kN/m²

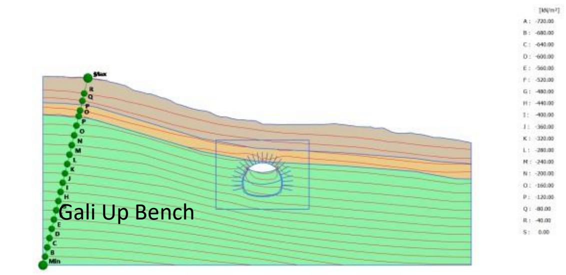


Maksimum = 386.4 kN/m²
Minimum = -6253 kN/m²



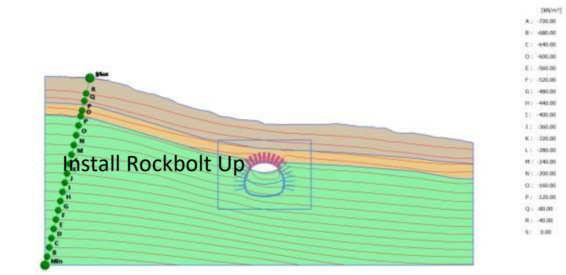
Maximum = 972.6 kN/m²
Minimum = -8782 kN/m²

Gambar 38 Hasil analisis tegangan maksimum (1) pada Tunnel No. 6 (DK 89+360) (lanjutan)



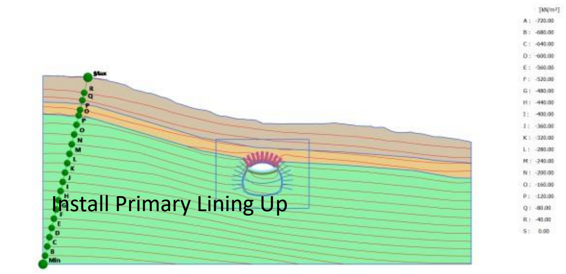
Principal total stress σ_3 (scaled up $5.00*10^{-3}$ times)

Maximum = 4.623 kN/m^2
Minimum = -717.6 kN/m^2



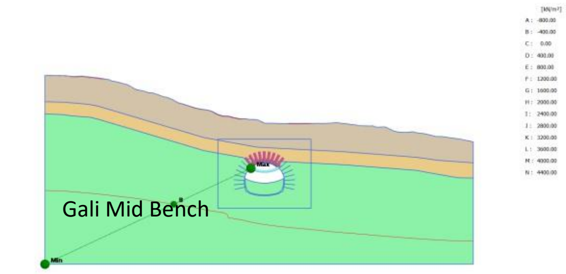
Principal total stress σ_3 (scaled up $5.00*10^{-3}$ times)

Maximum = 4.566kN/m^2
Minimum = -717.5kN/m^2



Principal total stress σ_3 (scaled up $5.00*10^{-3}$ times)

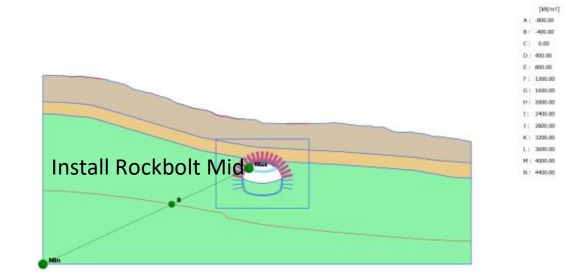
Maximum = 4.582 kN/m^2
Minimum = -717.5 kN/m^2



Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times)

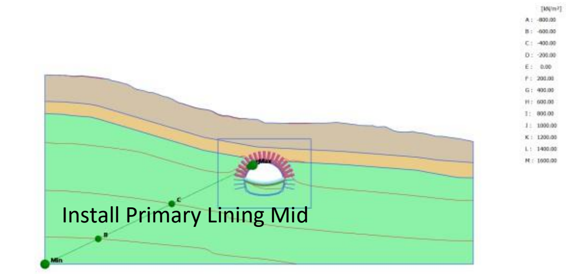
Maximum value = 4683 kN/m² (Element 1056 at Node 17444)

Maximum = 4683 kN/m^2
Minimum = -716.9 kN/m^2



Principal total stress σ_3 (scaled up $0.500*10^{-3}$ times)

Maximum = 4689 kN/m^2
Minimum = -716.9 kN/m^2



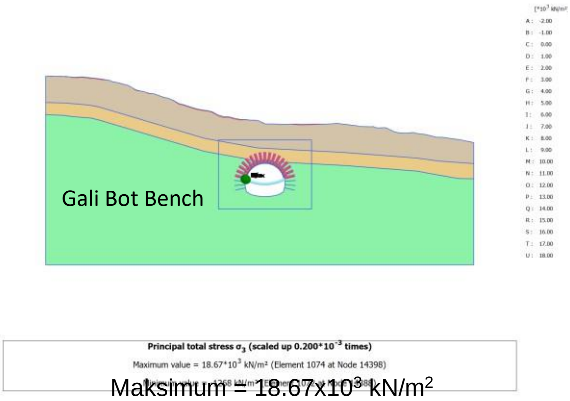
Principal total stress σ_3 (scaled up $2.00*10^{-3}$ times)

Maximum value = 1607 kN/m² (Element 1032 at Node 18182)

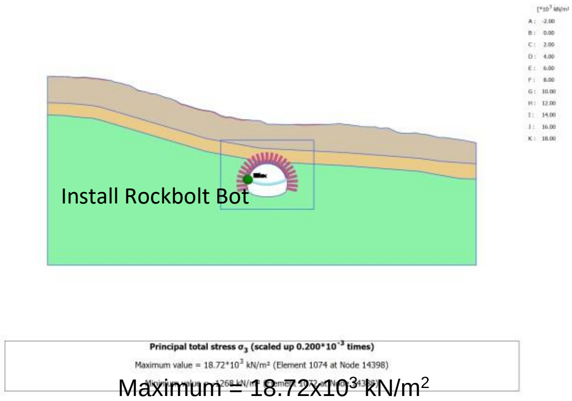
Minimum value = -717.0 kN/m² (Element 2727 at Node 1103)

Maximum = 1607 kN/m^2
Minimum = -717.0 kN/m^2

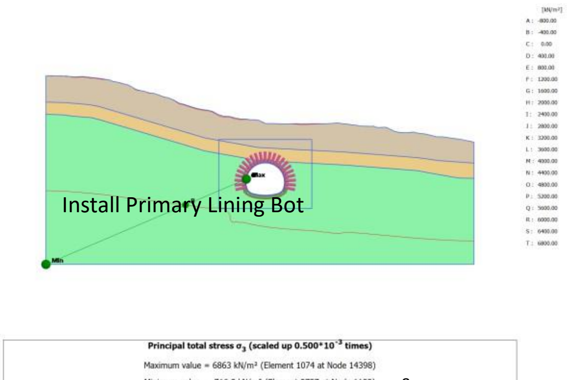
Gambar 39 Hasil analisis tegangan minimum (3) pada Tunnel No. 6 (DK 89+360)



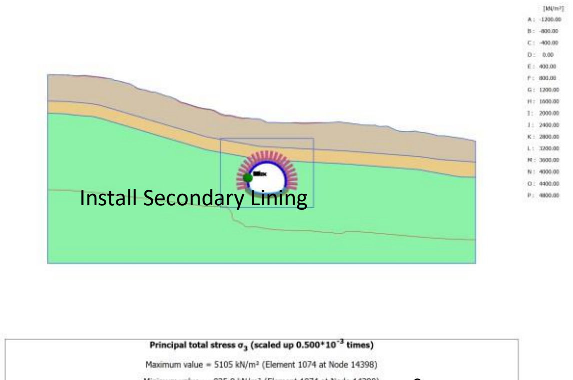
Maksimum = $18.67 x 10^3$ kN/m^2
Minimum = -1268 kN/m^2



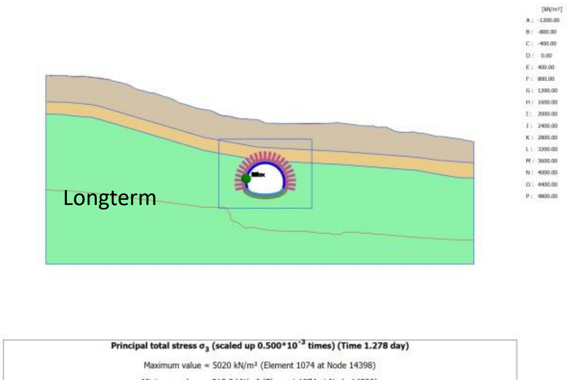
Maximum = $18.72 x 10^3$ kN/m^2
Minimum = -1268 kN/m^2



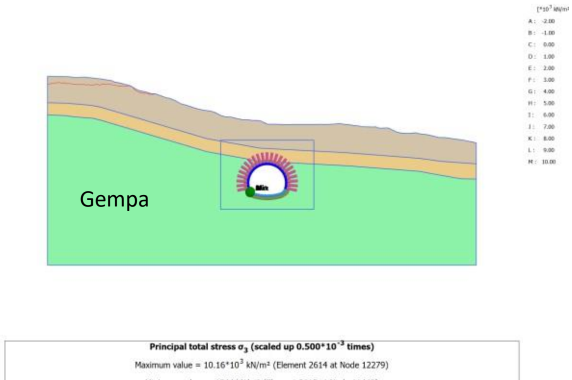
Maximum = 6863 kN/m^2
Minimum = -716.8kN/m^2



Maximum = 5105 kN/m^2
Minimum = -825.9 kN/m^2

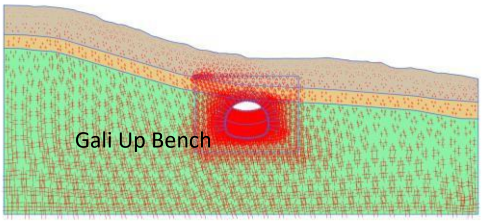


Maksimum = 5020 kN/m^2
Minimum = -818.9 kN/m^2



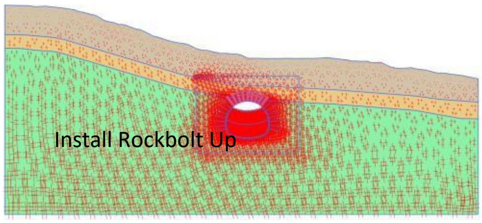
Maximum = $10.16 x 10^3$ kN/m^2
Minimum = -1344 kN/m^2

Gambar 40 Hasil analisis tegangan minimum (3) pada Tunnel No. 6 (DK 89+360) (lanjutan)



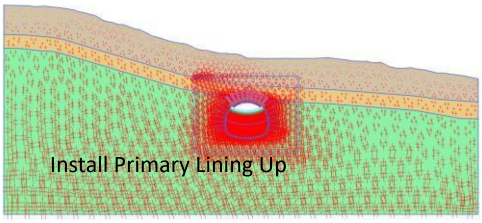
Total principal stresses (scaled up 5.00×10^{-3} times)

Maximum = -0.7846 kN/m^2
Minimum = -1189 kN/m^2



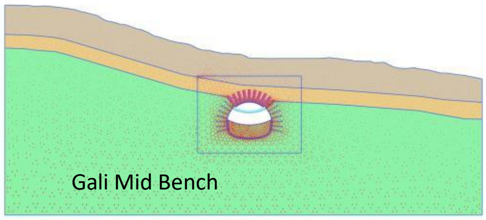
Total principal stresses (scaled up 5.00×10^{-3} times)

Maximum = -0.9149 kN/m^2
Minimum = -1189 kN/m^2



Total principal stresses (scaled up 5.00×10^{-3} times)

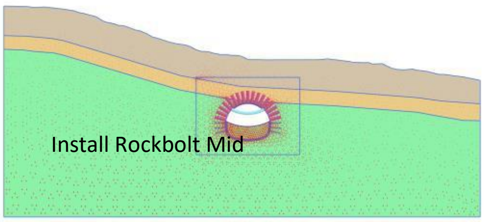
Maximum = -0.9302 kN/m^2
Minimum = -1189 kN/m^2



Total principal stresses (scaled up 0.500×10^{-3} times)

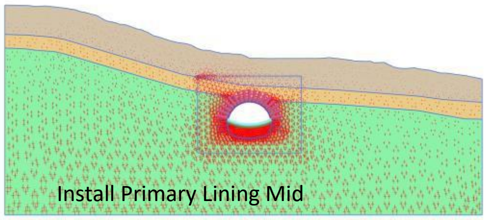
Maximum value = 4769 kN/m² (Element 1056 at Stress point 12661)

Maximum = 4769 kN/m^2
Minimum = -2528 kN/m^2



Total principal stresses (scaled up 0.500×10^{-3} times)

Maximum = 4776 kN/m^2
Minimum = -2532 kN/m^2



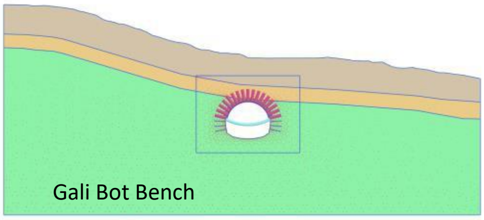
Total principal stresses (scaled up 2.00×10^{-3} times)

Maximum value = 1400 kN/m² (Element 1032 at Stress point 12381)

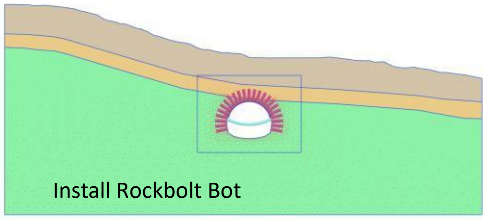
Minimum value = -2142 kN/m² (Element 1052 at Stress point 12619)

Maximum = 1400 kN/m^2
Minimum = -2142 kN/m^2

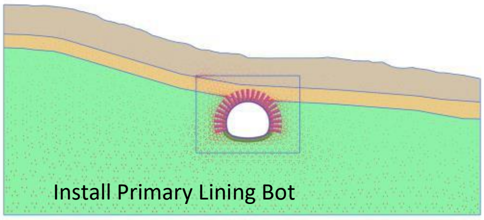
Gambar 41 Hasil analisis Total Principal Stresses pada Tunnel No. 6 (DK 89+360)



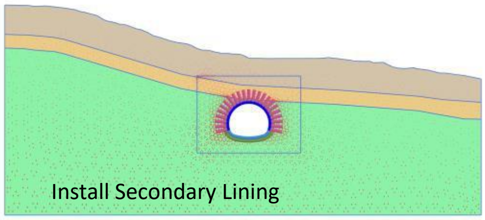
Maksimum = 14.43x10^3 kN/m^2
Minimum = -10.28 x10^3 kN/m^2



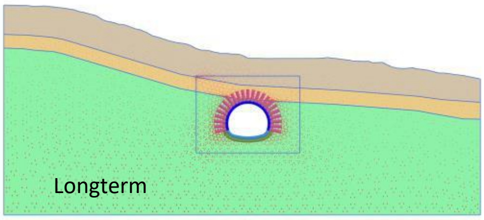
Maximum = 14.47x10^3 kN/m^2
Minimum = -10.10x10^3 kN/m^2



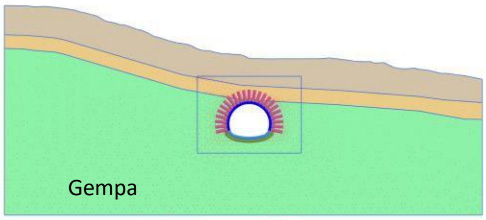
Maximum = 4994 kN/m^2
Minimum = -4792 kN/m^2



Maximum = 4648 kN/m^2
Minimum = -5801 kN/m^2



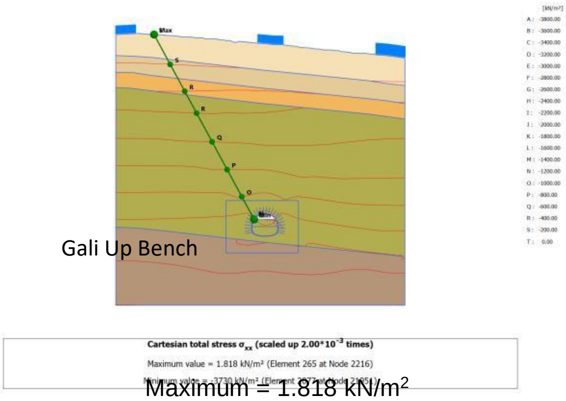
Maksimum = 4768 kN/m^2
Minimum = -5862 kN/m^2



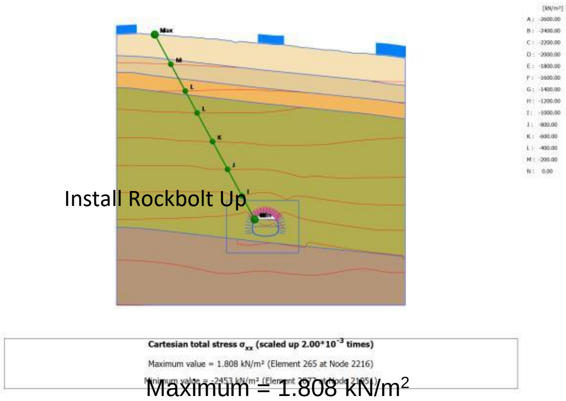
Maximum = 10.54 x10^3 kN/m^2
Minimum = -8358 kN/m^2

Gambar 42 Hasil analisis Total Principal Stresses pada Tunnel No. 6 (DK 89+360) (lanjutan)

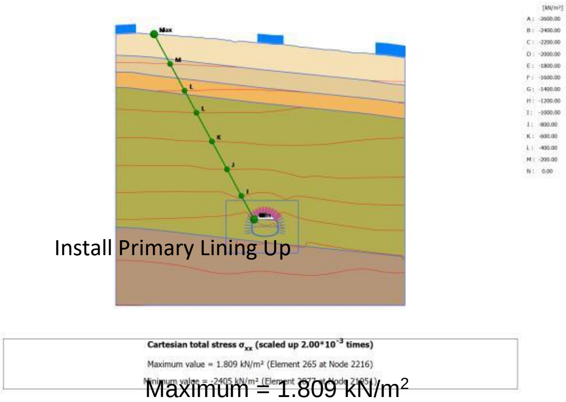
b) *Cross Section DK 90+916*



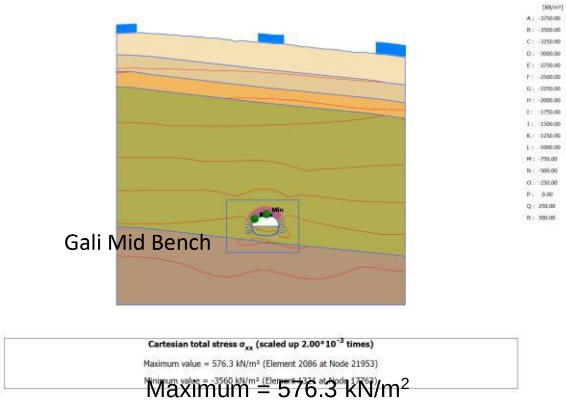
Maximum = 1.818 kN/m^2
Minimum = -3730 kN/m^2



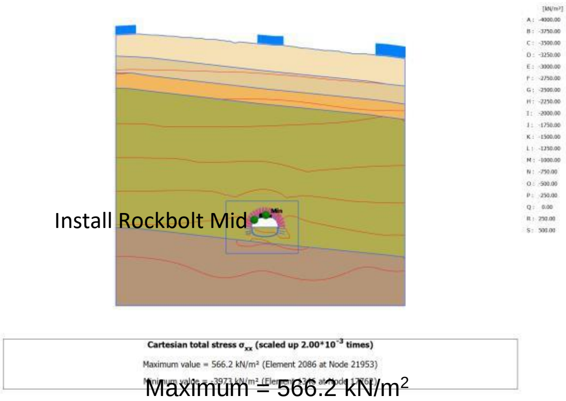
Maximum = 1.808 kN/m^2
Minimum = -2453 kN/m^2



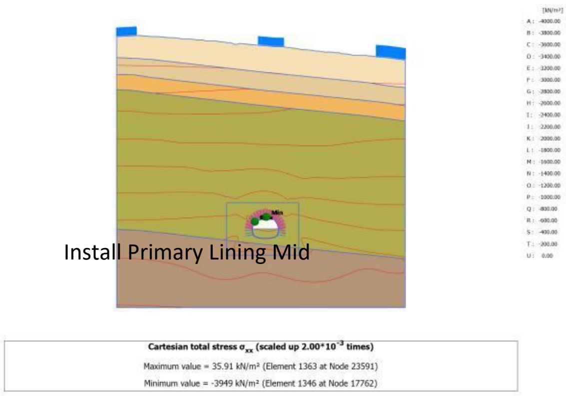
Maximum = 1.809 kN/m^2
Minimum = -2405 kN/m^2



Maximum = 576.3 kN/m^2
Minimum = -3560 kN/m^2

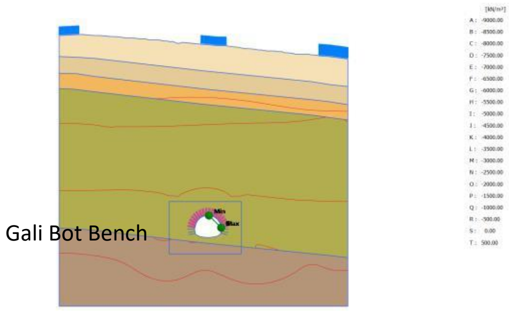


Maximum = 566.2 kN/m^2
Minimum = -3973 kN/m^2



Maximum = 35.91 kN/m^2
Minimum = -3949 kN/m^2

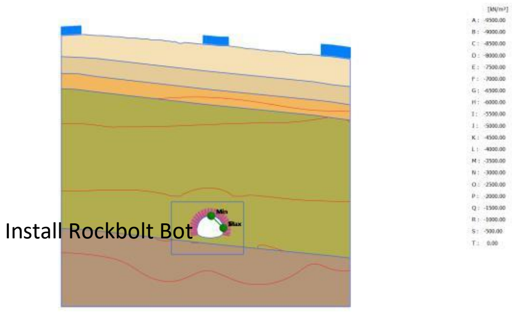
Gambar 43 Hasil analisis tegangan horizontal (x) pada Tunnel No. 6 (DK 90+916)



Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times)

Maksimum =629.5 kN/m^2

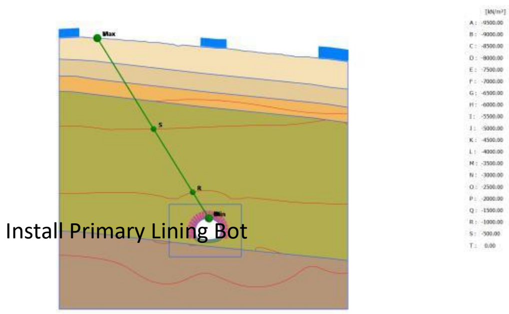
Minimum = -8912 kN/m^2



Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times)

Maximum =433.8 kN/m^2

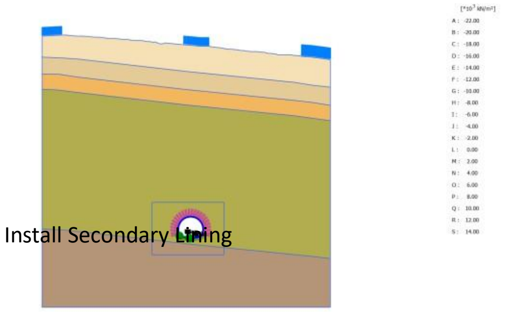
Minimum = -9175 kN/m^2



Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times)

Maximum = 1.756 kN/m^2

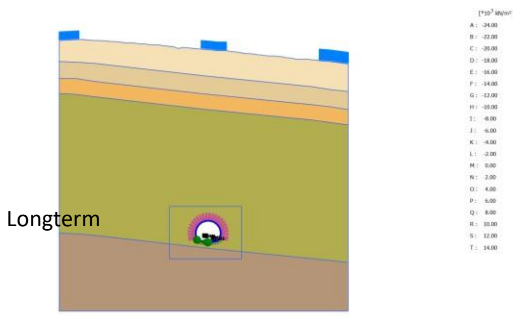
Minimum = -9166 kN/m^2



Cartesian total stress σ_{xx} (scaled up 0.200×10^{-3} times)

Maximum = 14.55X10^3 kN/m^2

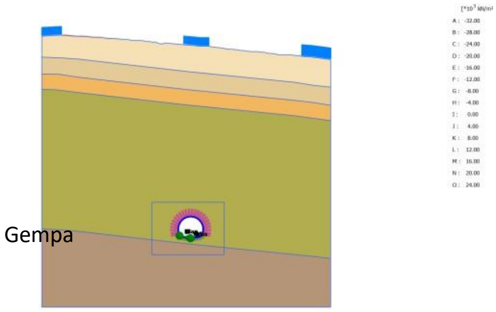
Minimum = -20.53 x10^3 kN/m^2



Cartesian total stress σ_{xx} (scaled up 0.200×10^{-3} times) (Time 43.69 day)

Maksimum = 15.78X10^3 kN/m^2

Minimum = -22.24 x10^3 kN/m^2

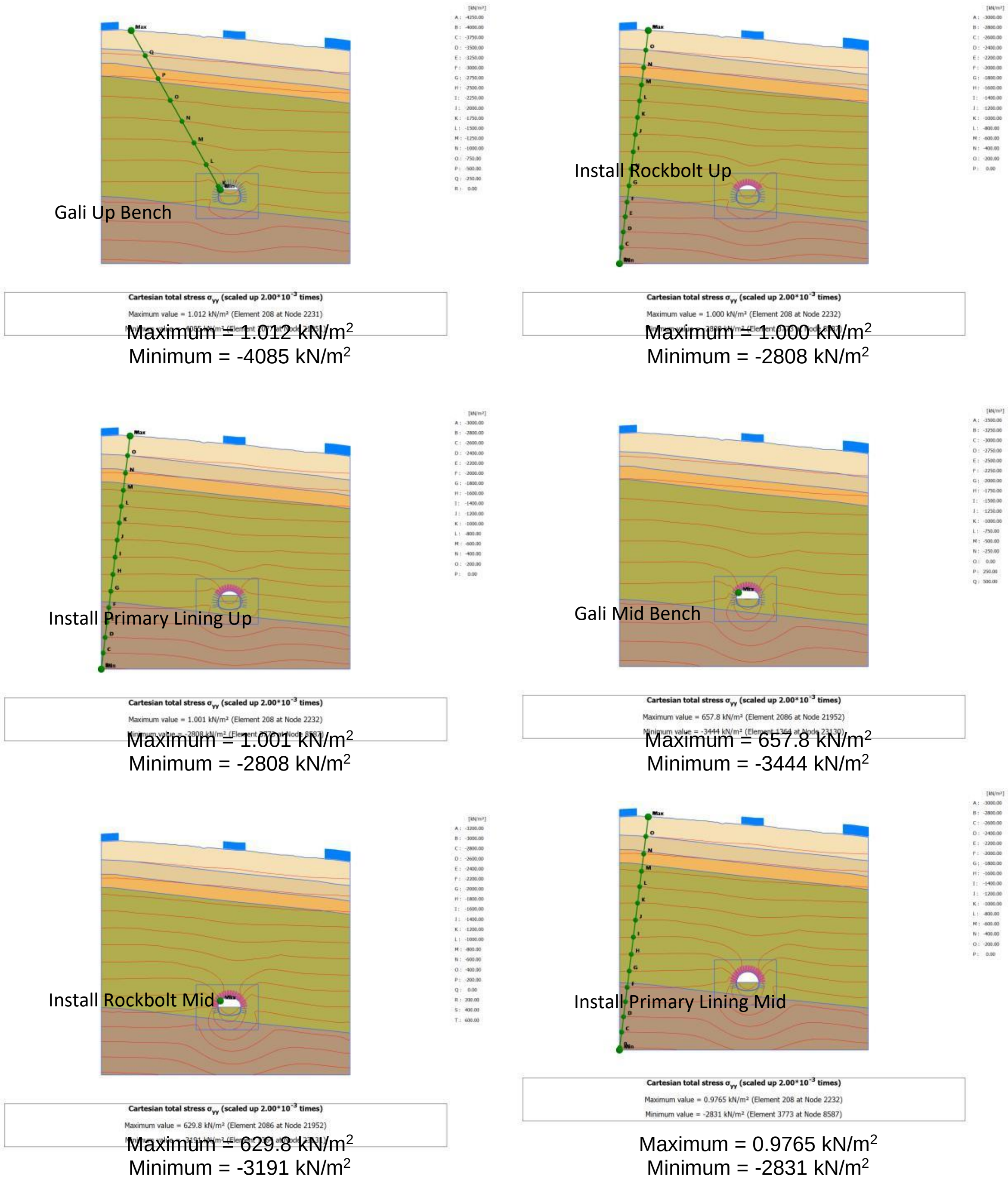


Cartesian total stress σ_{xx} (scaled up 0.100×10^{-3} times)

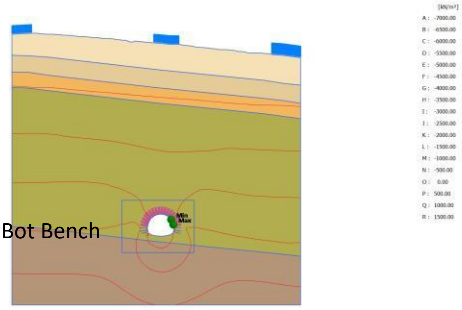
Maximum = 26.11x10^3 kN/m^2

Minimum = -27.95 x10^3 kN/m^2

Gambar 44 Hasil analisis tegangan horizontal (x) pada Tunnel No. 6 (DK 90+916) (lanjutan)

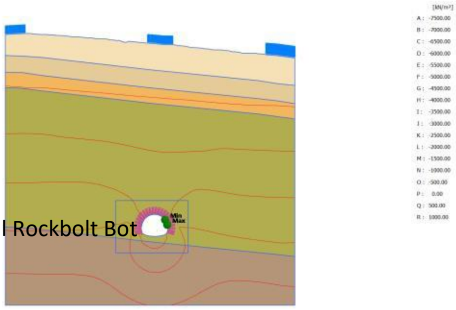


Gambar 45 Hasil analisis tegangan vertikal (y) pada Tunnel No. 6 (DK 90+916)



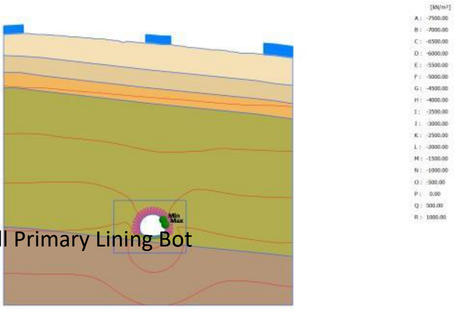
Gali Bot Bench

Maksimum = 1637 kN/m^2
Minimum = -6891 kN/m^2



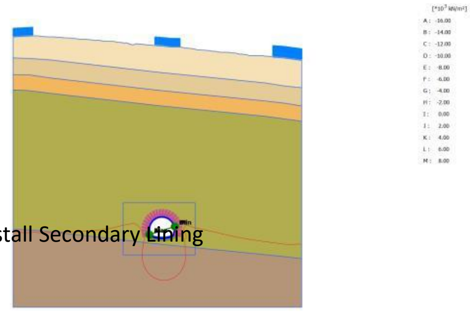
Install Rockbolt Bot

Maximum = 1325 kN/m^2
Minimum = -7361 kN/m^2



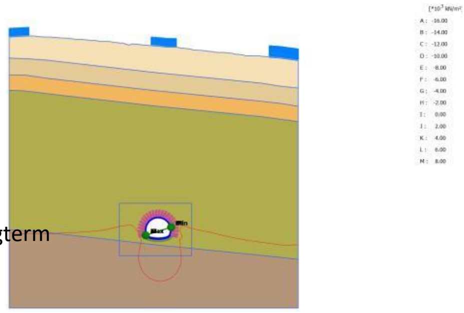
Install Primary Lining Bot

Maximum = 1266 kN/m^2
Minimum = -7344 kN/m^2



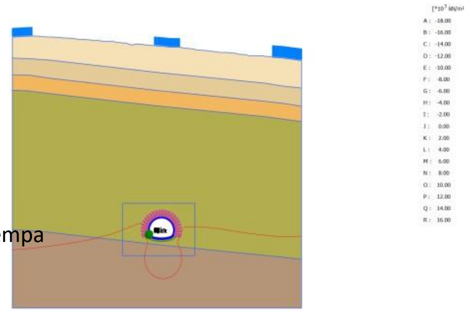
Install Secondary Lining

Maximum = 8388 kN/m^2
Minimum = -14.52 x10^3 kN/m^2



Longterm

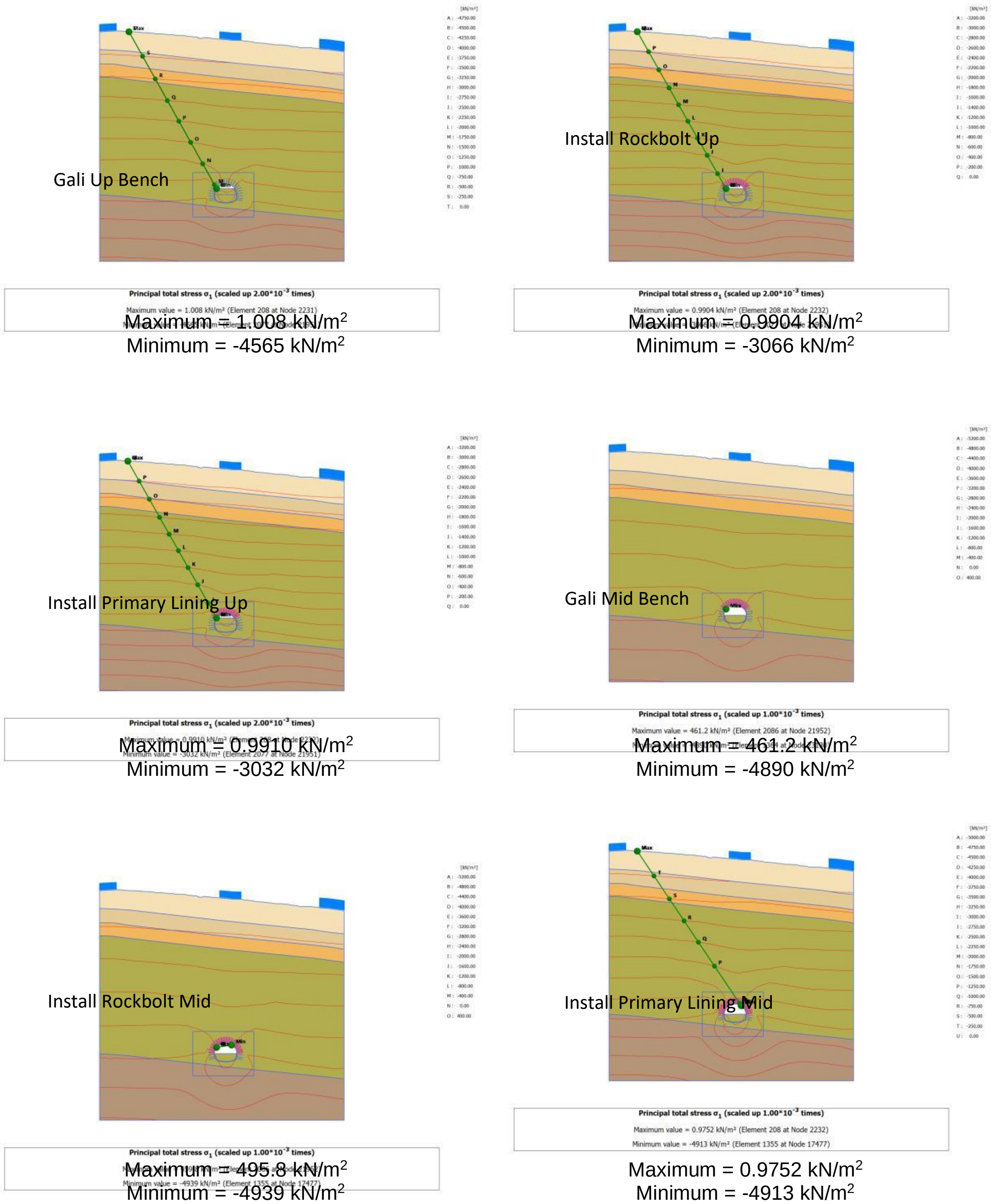
Maksimum = 9258 kN/m^2
Minimum = -14.59 x10^3 kN/m^2



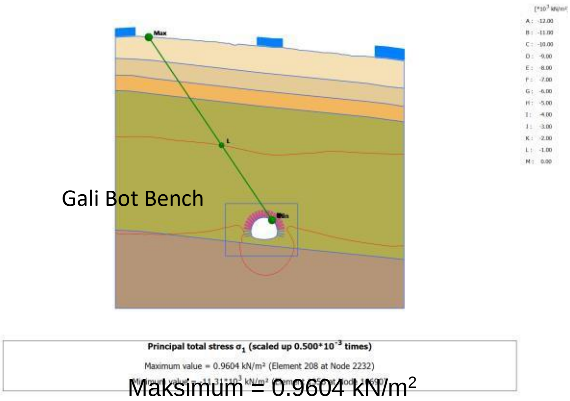
Gempa

Maximum = 16.44x10^3 kN/m^2
Minimum = -17.31x10^3 kN/m^2

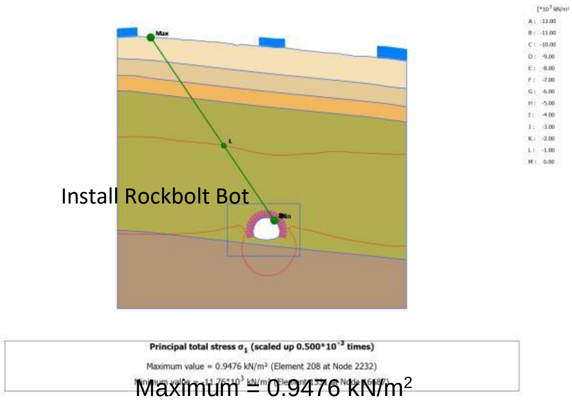
Gambar 46 Hasil analisis tegangan vertikal ($_y$) pada Tunnel No. 6 (DK 90+916) (lanjutan)



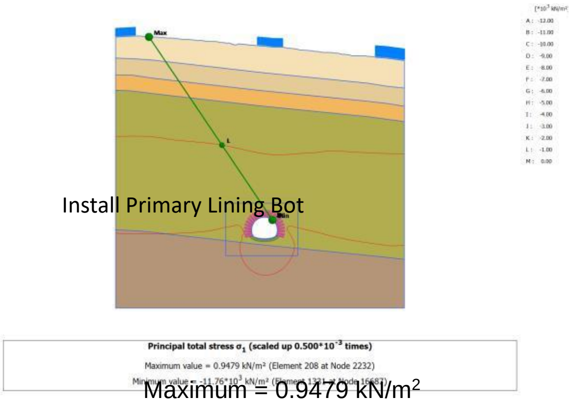
Gambar 47 Hasil analisis tegangan maksimum (1) pada Tunnel No. 6 (DK 90+916)



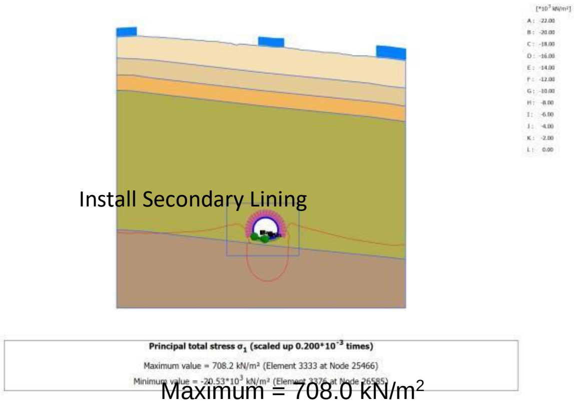
Maksimum = 0.9604 kN/m^2
Minimum = -11.31 x10^3 kN/m^2



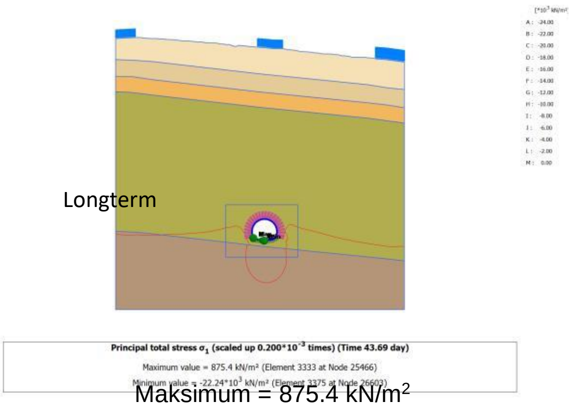
Maximum = 0.9476 kN/m^2
Minimum = -11.76 x10^3 kN/m^2



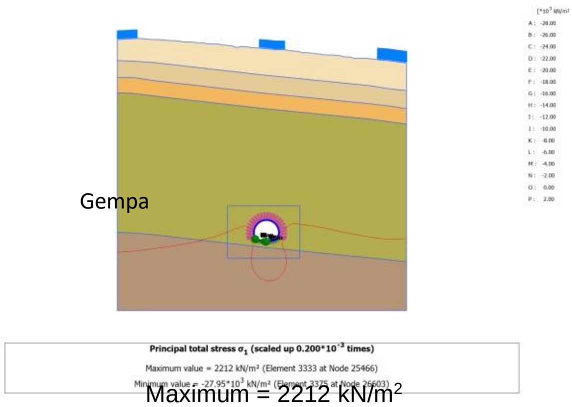
Maximum = 0.9479 kN/m^2
Minimum = -11.76 x10^3 kN/m^2



Maximum = 708.0 kN/m^2
Minimum = -20.53 x10^3 kN/m^2

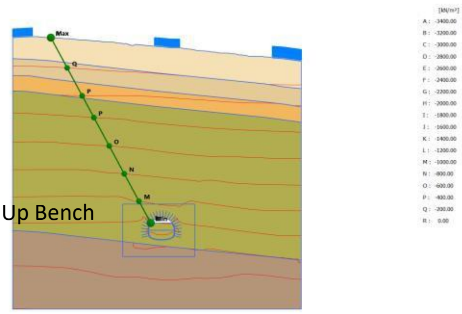


Maksimum = 875.4 kN/m^2
Minimum = -22.24 x10^3 kN/m^2



Maximum = 2212 kN/m^2
Minimum = -27.95 x10^3 kN/m^2

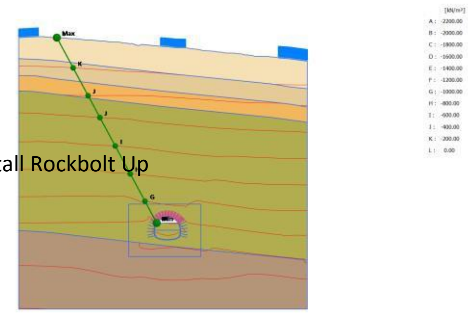
Gambar 48 Hasil analisis tegangan maksimum (1) pada Tunnel No. 6 (DK 90+916) (lanjutan)



Gali Up Bench

Principal total stress σ_3 (scaled up 2.00*10^{-3} times)

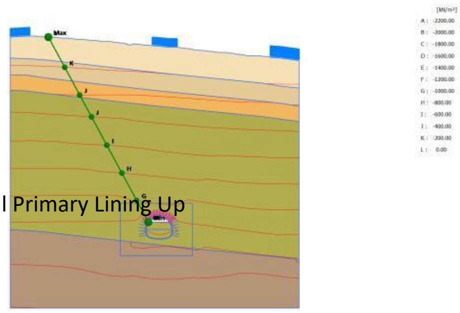
Maximum = 1.818 kN/m^2
Minimum = -3249 kN/m^2



Install Rockbolt Up

Principal total stress σ_3 (scaled up 5.00*10^{-3} times)

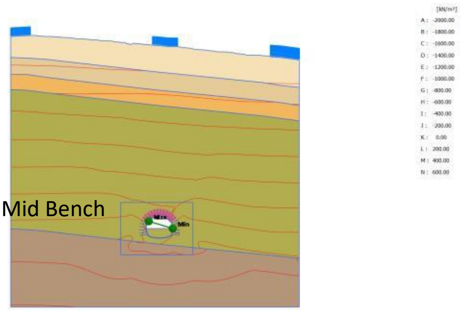
Maximum = 1.809 kN/m^2
Minimum = -2031 kN/m^2



Install Primary Lining Up

Principal total stress σ_3 (scaled up 5.00*10^{-3} times)

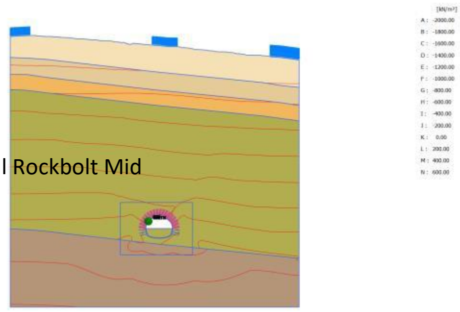
Maximum = 1.810 kN/m^2
Minimum = -2006 kN/m^2



Gali Mid Bench

Principal total stress σ_3 (scaled up 2.00*10^{-3} times)

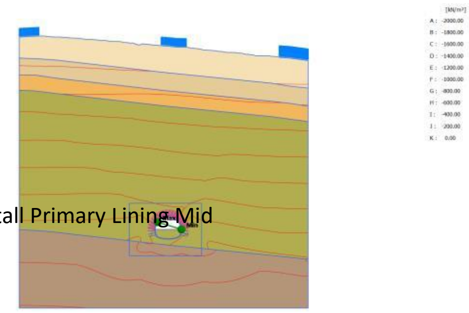
Maximum = 659.5 kN/m^2
Minimum = -1961 kN/m^2



Install Rockbolt Mid

Principal total stress σ_3 (scaled up 2.00*10^{-3} times)

Maximum = 641.0 kN/m^2
Minimum = -1915 kN/m^2



Install Primary Lining Mid

Principal total stress σ_3 (scaled up 5.00*10^{-3} times)

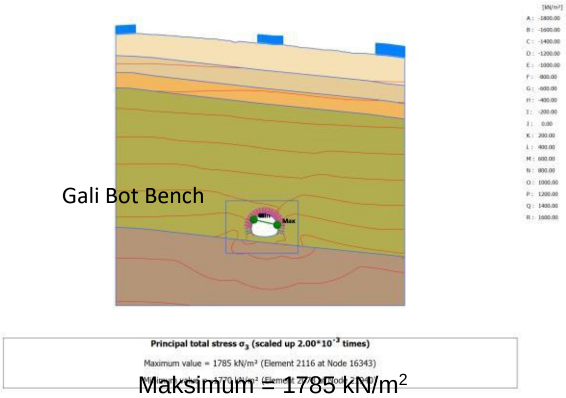
Maximum value = 98.93 kN/m² (Element 1363 at Node 23591)

Minimum value = -1909 kN/m² (Element 3428 at Node 17289)

Maximum = 98.93kN/m^2
Minimum = -1909 kN/m^2

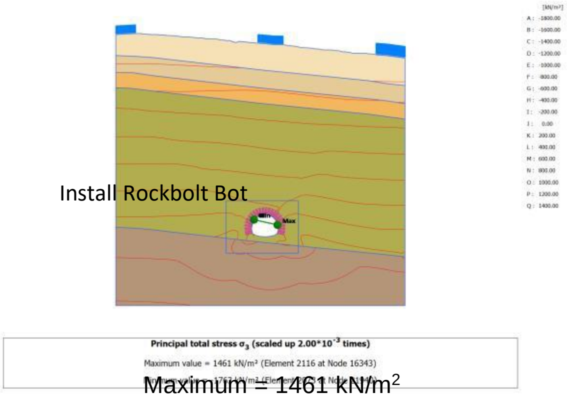
Gambar 49 Hasil analisis tegangan minimum (3) pada Tunnel No. 6 (DK 90+916)

Gali Bot Bench



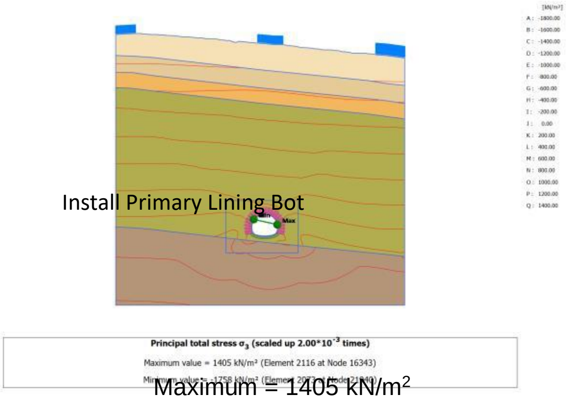
Maksimum = 1785 kN/m^2
Minimum = -1770 kN/m^2

Install Rockbolt Bot



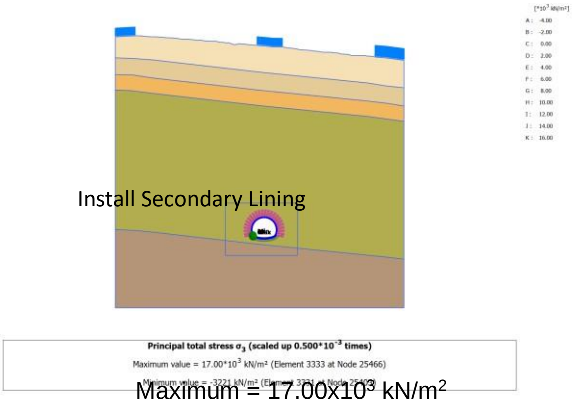
Maximum = 1461 kN/m^2
Minimum = -1763 kN/m^2

Install Primary Lining Bot



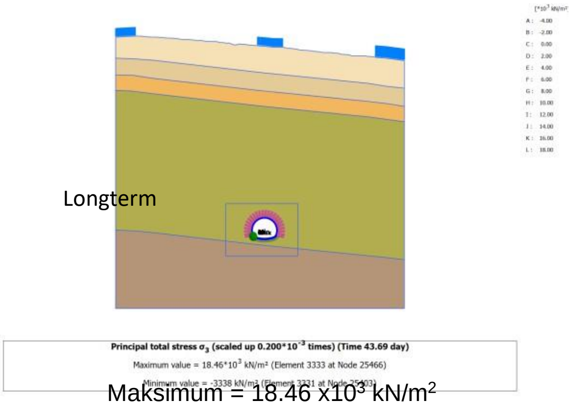
Maximum = 1405 kN/m^2
Minimum = -1758 kN/m^2

Install Secondary Lining



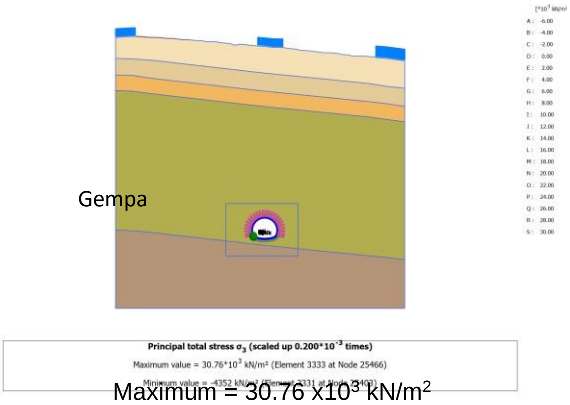
Maximum = 17.00x10^3 kN/m^2
Minimum = -3221 kN/m^2

Longterm



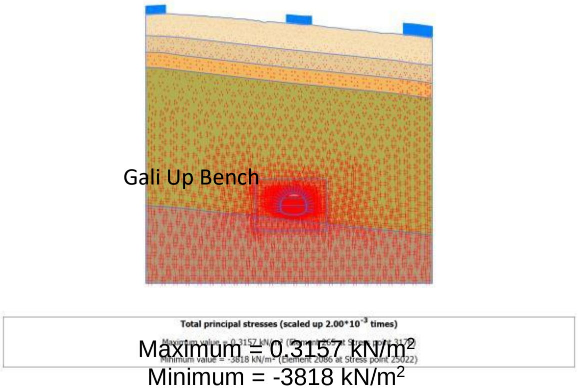
Maksimum = 18.46 x10^3 kN/m^2
Minimum = -3338 kN/m^2

Gempa



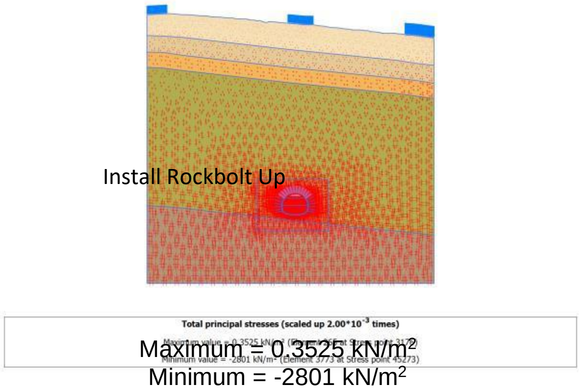
Maximum = 30.76 x10^3 kN/m^2
Minimum = -4352 kN/m^2

Gambar 50 Hasil analisis tegangan minimum (3) pada Tunnel No. 6 (DK 90+916) (lanjutan)



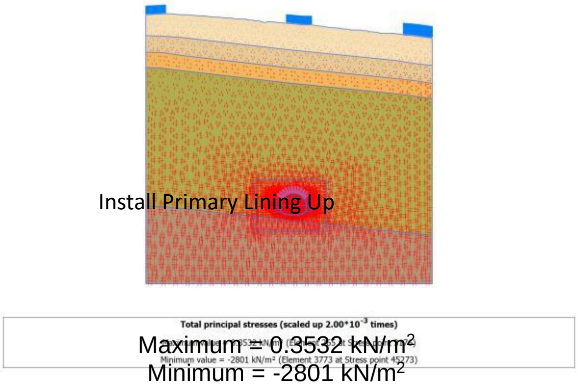
Gali Up Bench

Maximum = 0.3157 kN/m^2
Minimum = -3818 kN/m^2



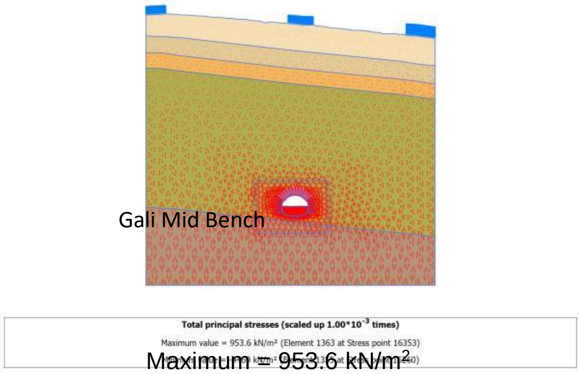
Install Rockbolt Up

Maximum = 0.3525 kN/m^2
Minimum = -2801 kN/m^2



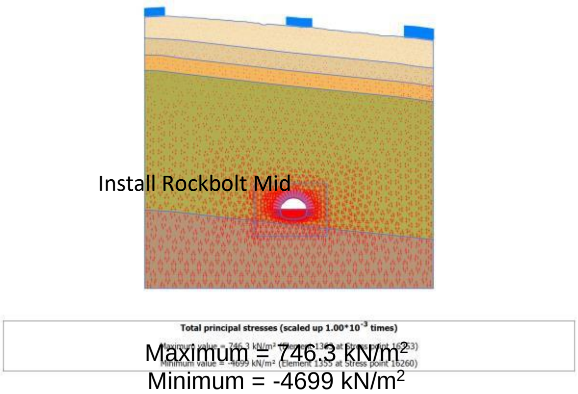
Install Primary Lining Up

Maximum = 0.3532 kN/m^2
Minimum = -2801 kN/m^2



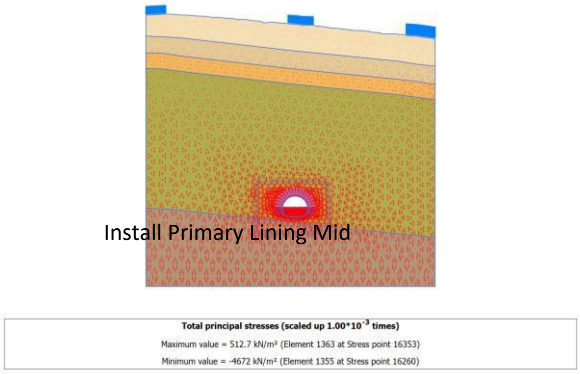
Gali Mid Bench

Maximum = 953.6 kN/m^2
Minimum = -4469 kN/m^2



Install Rockbolt Mid

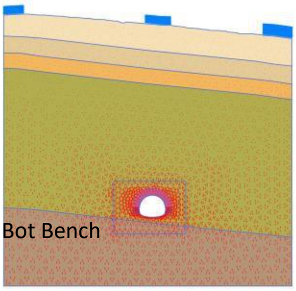
Maximum = 746.3 kN/m^2
Minimum = -4699 kN/m^2



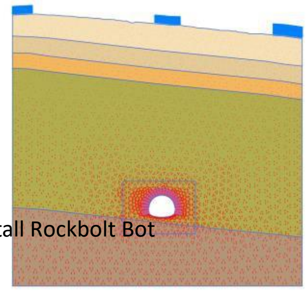
Install Primary Lining Mid

Maximum = 512.7 kN/m^2
Minimum = -4672 kN/m^2

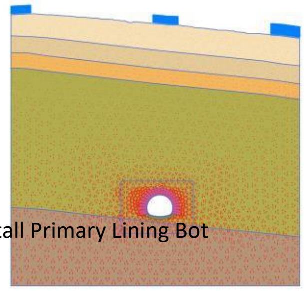
Gambar 51 Hasil analisis Total Principal Stresses pada Tunnel No. 6 (DK 90+916)



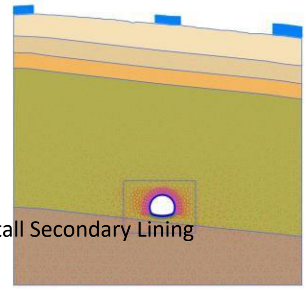
Maksimum = 1349 kN/m^2
Minimum = -10.80 x10^3 kN/m^2



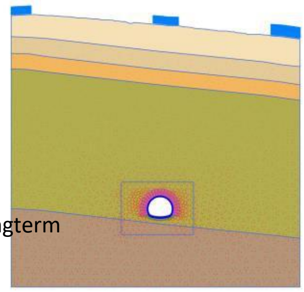
Maximum = 1071 kN/m^2
Minimum = -11.20 x10^3 kN/m^2



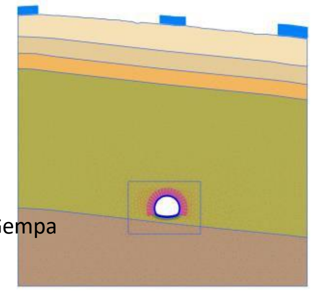
Maximum = 1018 kN/m^2
Minimum = -11.20 x10^3 kN/m^2



Maximum = 16.46 x10^3 kN/m^2
Minimum = -19.71 x10^3 kN/m^2



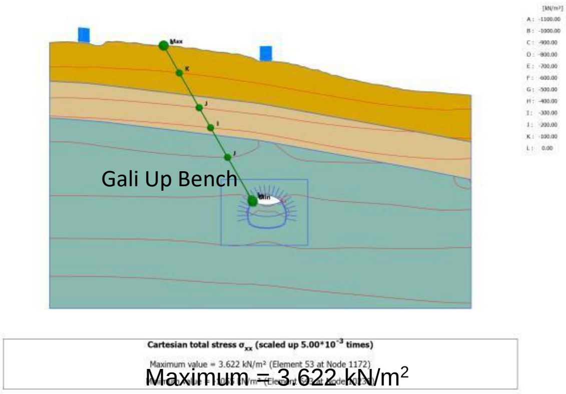
Maksimum = 17.92 x10^3 kN/m^2
Minimum = -21.30 x10^3 kN/m^2



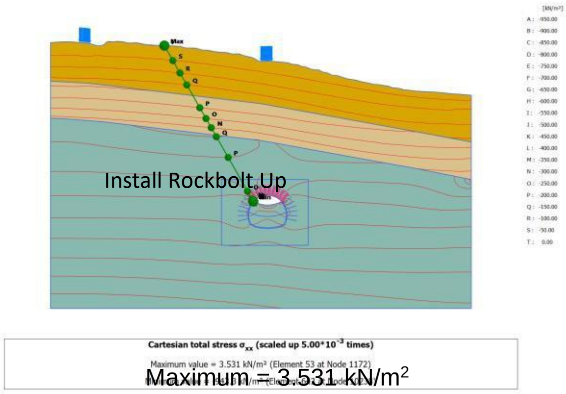
Maximum = 30.23 x10^3 kN/m^2
Minimum = -26.73 x10^3 kN/m^2

Gambar 52 Hasil analisis Total Principal Stresses pada Tunnel No. 6 (DK 90+916) (lanjutan)

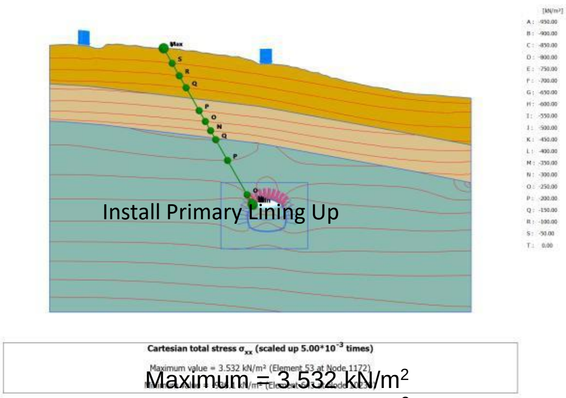
c) *Cross Section DK 92+720*



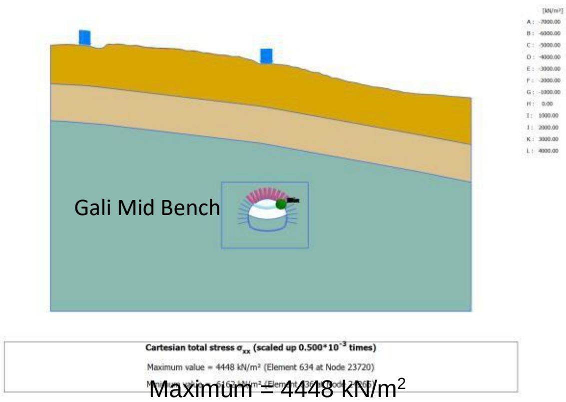
Maximum = 3.622 kN/m^2
Minimum = -1055 kN/m^2



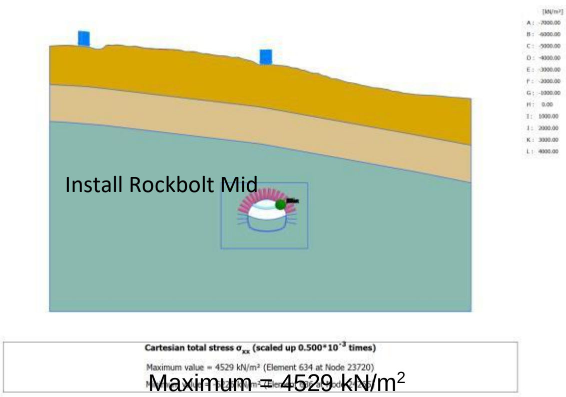
Maximum = 3.531 kN/m^2
Minimum = -943.3 kN/m^2



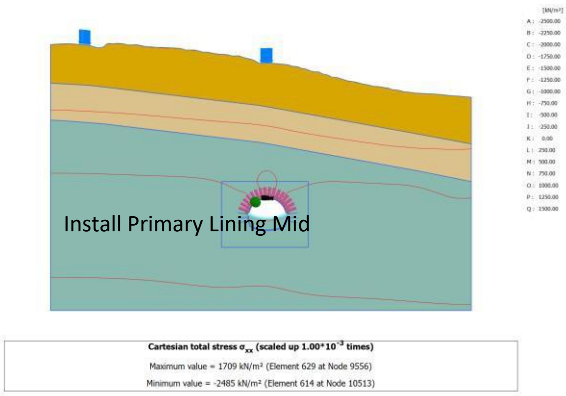
Maximum = 3.532 kN/m^2
Minimum = -936.1 kN/m^2



Maximum = 4448 kN/m^2
Minimum = -6162 kN/m^2

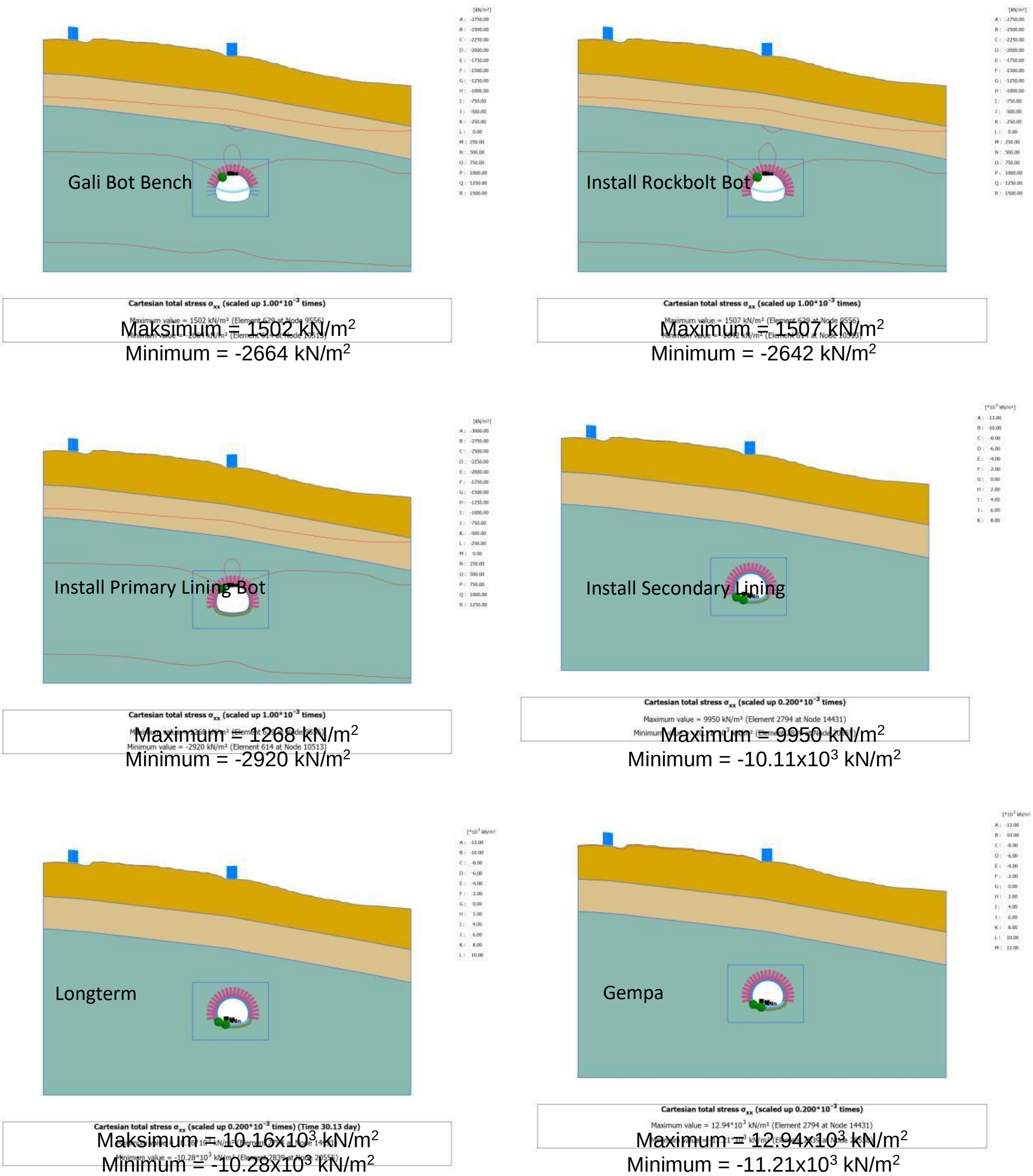


Maximum = 4529 kN/m^2
Minimum = -6226 kN/m^2

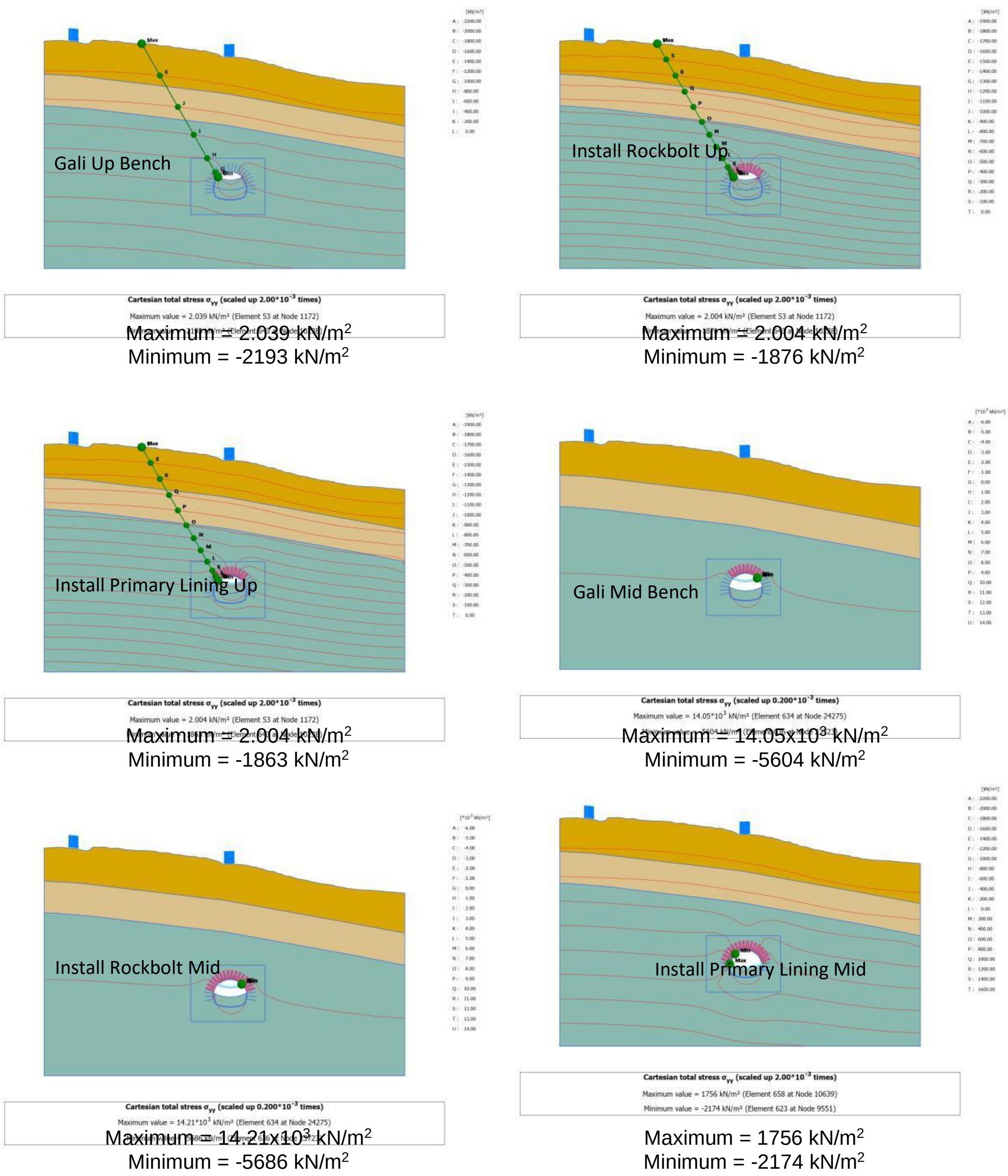


Maximum = 1709 kN/m^2
Minimum = -2485 kN/m^2

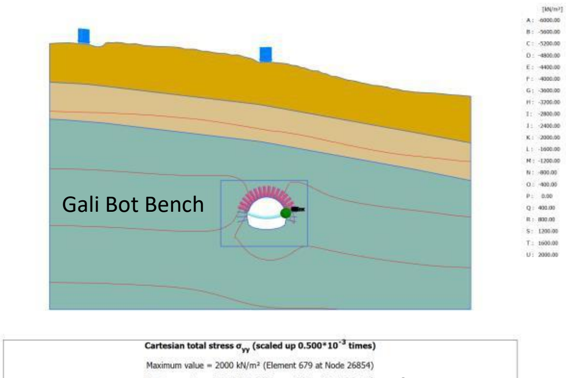
Gambar 53 Hasil analisis tegangan horizontal (x) pada Tunnel No. 6 (DK 92+720)



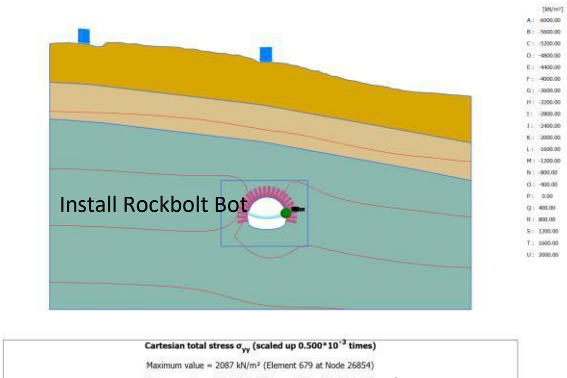
Gambar 54 Hasil analisis tegangan horizontal (x) pada Tunnel No. 6 (DK 92+720) (lanjutan)



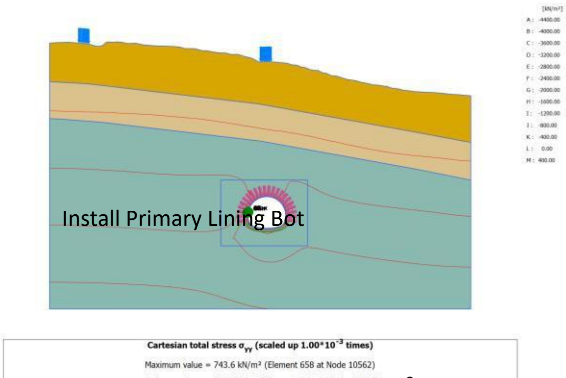
Gambar 55 Hasil analisis tegangan vertikal (y) pada Tunnel No. 6 (DK 92+720)



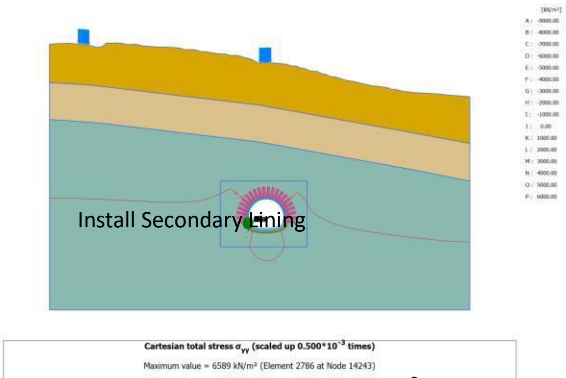
Maksimum = 2000 kN/m^2
Minimum = -5712 kN/m^2



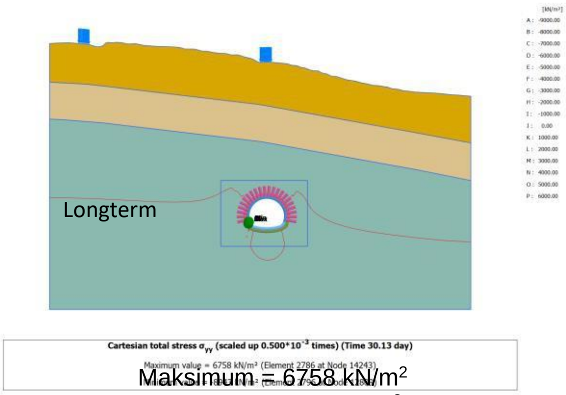
Maximum = 2087 kN/m^2
Minimum = -5872 kN/m^2



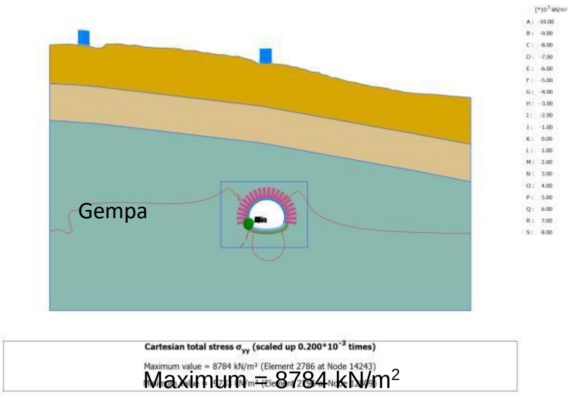
Maximum = 743.6 kN/m^2
Minimum = -4261 kN/m^2



Maximum = 6589 kN/m^2
Minimum = -8844 kN/m^2

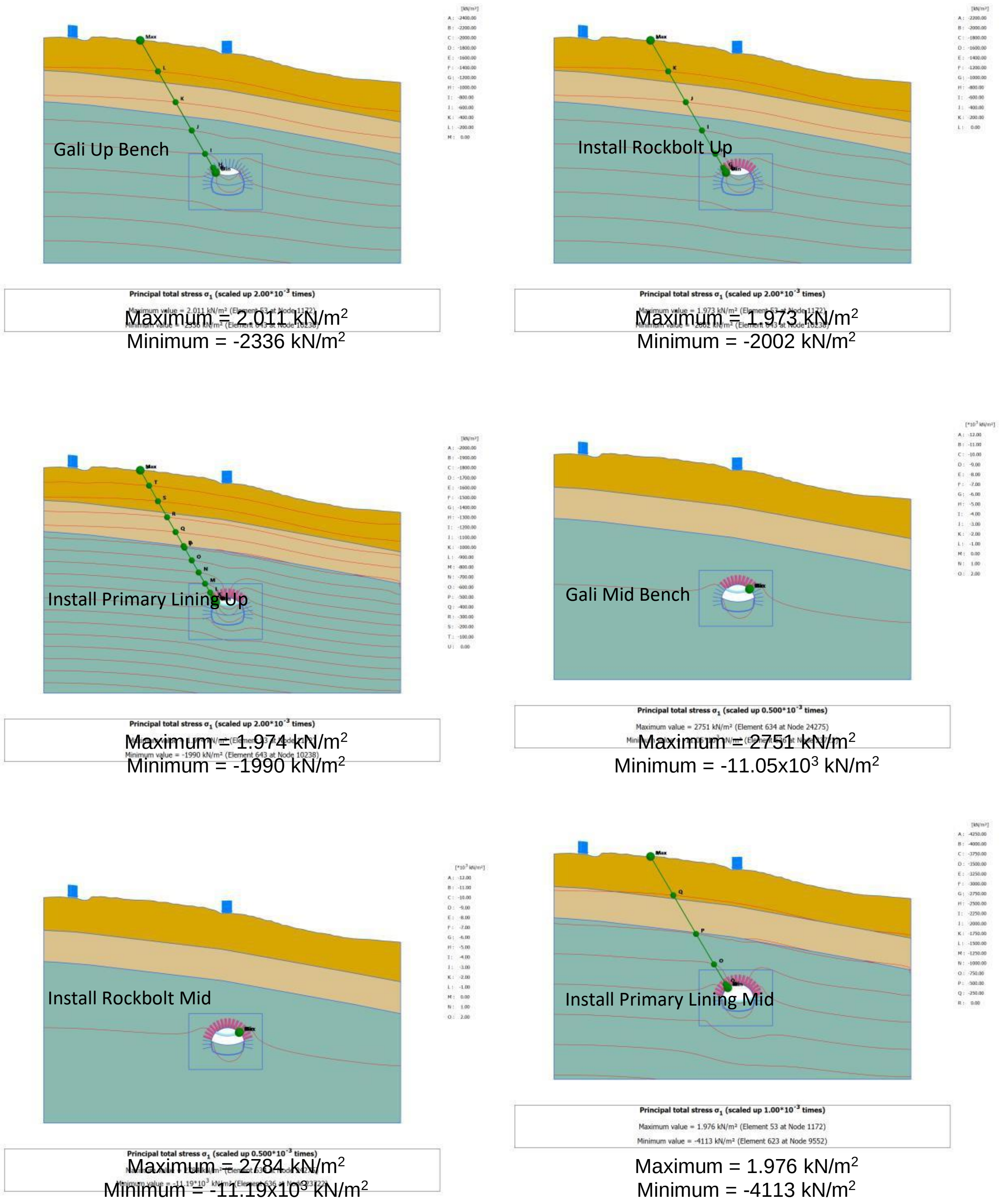


Maksimum = 6758 kN/m^2
Minimum = -8943 kN/m^2

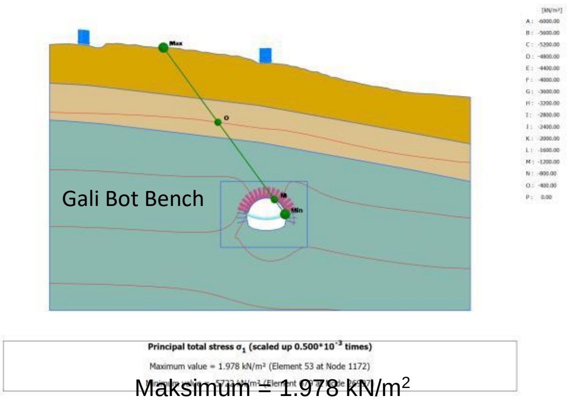


Maximum = 8784 kN/m^2
Minimum = -9733 kN/m^2

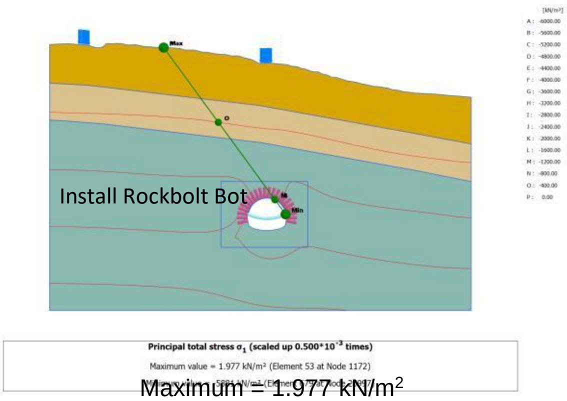
Gambar 56 Hasil analisis tegangan vertikal (y) pada Tunnel No. 6 (DK 92+720) (lanjutan)



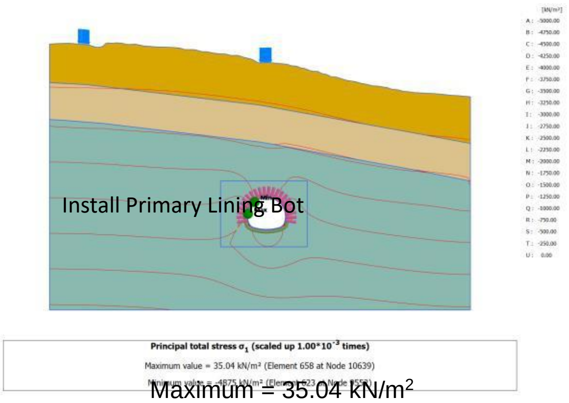
Gambar 57 Hasil analisis tegangan maksimum (1) pada Tunnel No. 6 (DK 92+720)



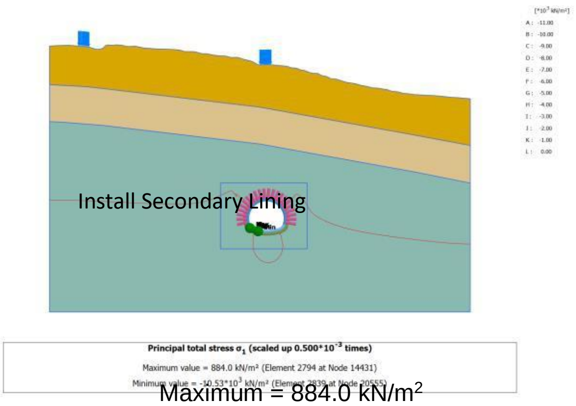
Maksimum = 1.978 kN/m²
Minimum = -5722 kN/m²



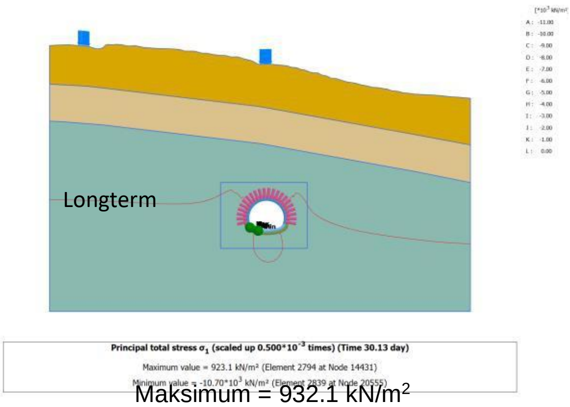
Maximum = 1.977 kN/m²
Minimum = -5881 kN/m²



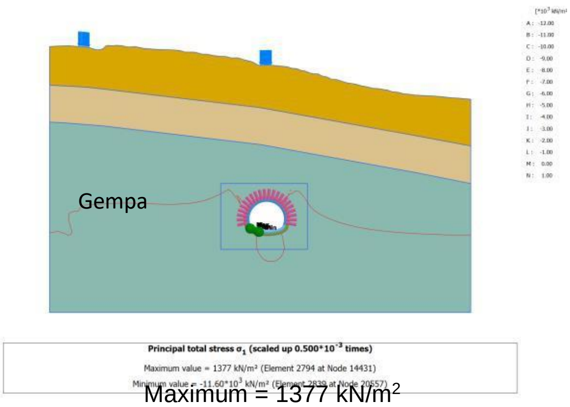
Maximum = 35.04 kN/m²
Minimum = -4875 kN/m²



Maximum = 884.0 kN/m²
Minimum = -10.53x10³ kN/m²

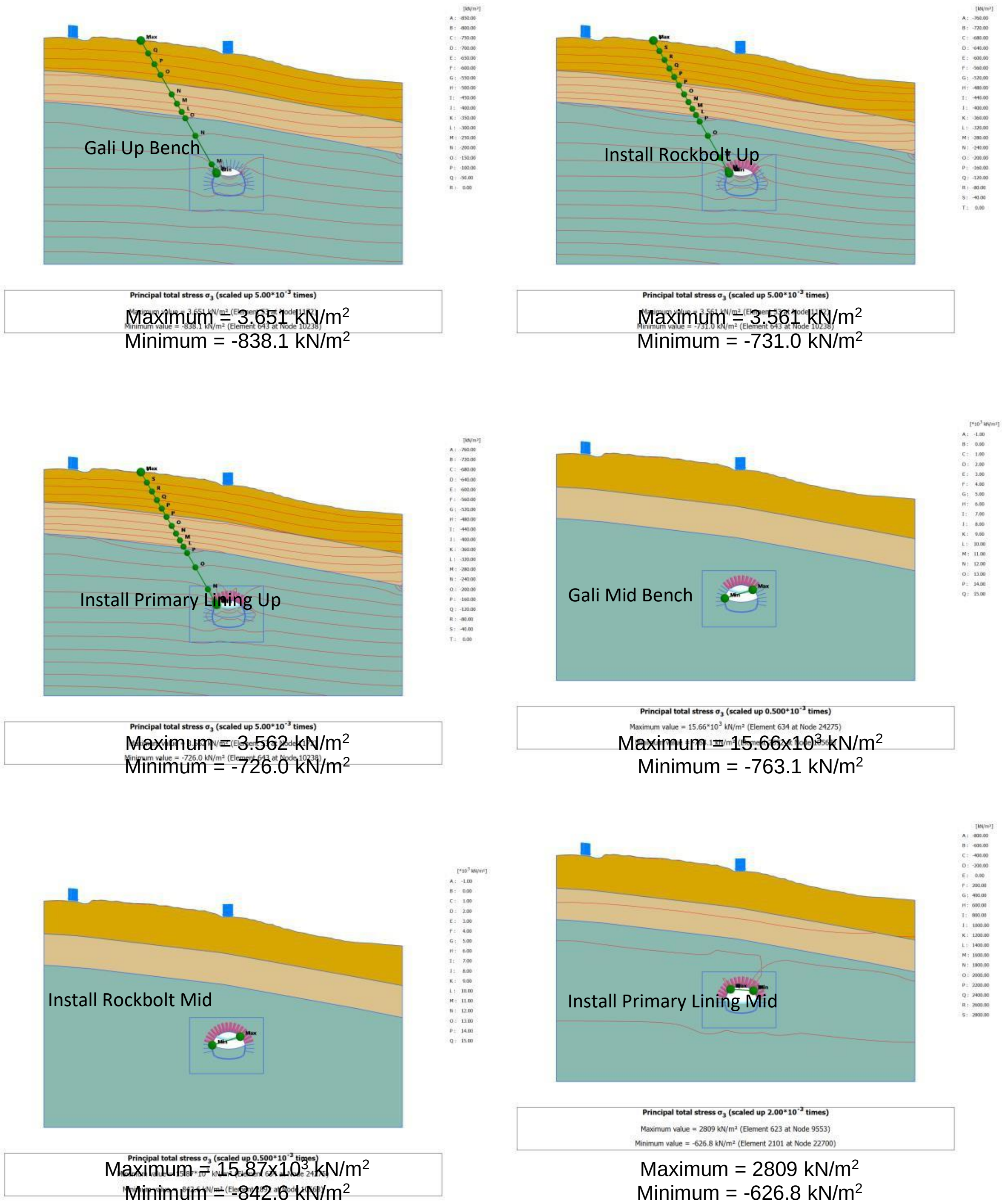


Maksimum = 932.1 kN/m²
Minimum = -10.70x10³ kN/m²

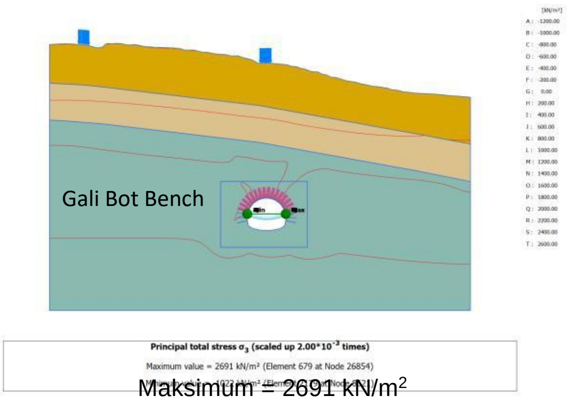


Maximum = 1377 kN/m²
Minimum = -11.60x10³ kN/m²

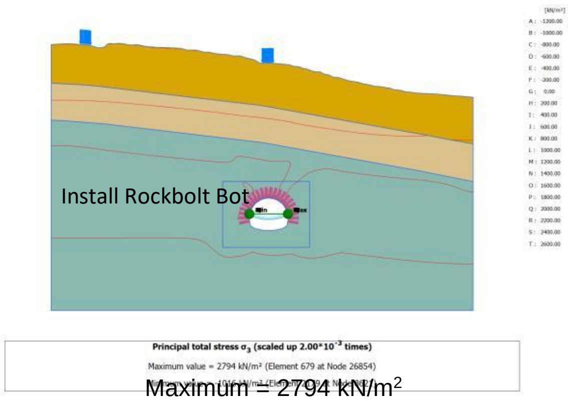
Gambar 58 Hasil analisis tegangan maksimum (1) pada Tunnel No. 6 (DK 92+720) (lanjutan)



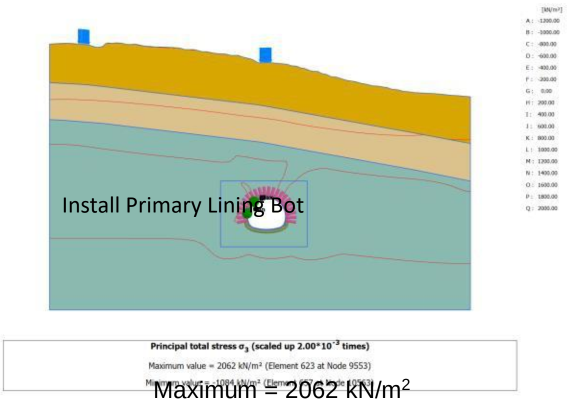
Gambar 59 Hasil analisis tegangan minimum (3) pada Tunnel No. 6 (DK 92+720)



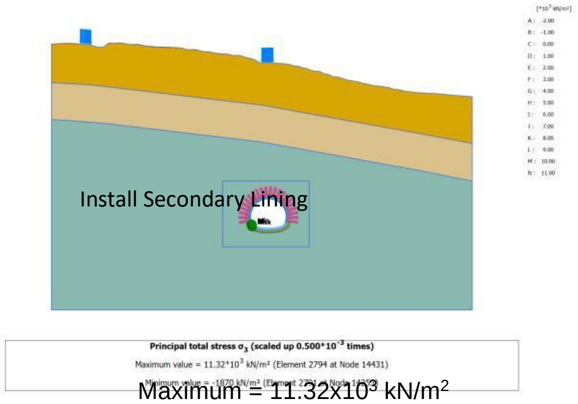
Maksimum = 2691 kN/m^2
Minimum = -1022 kN/m^2



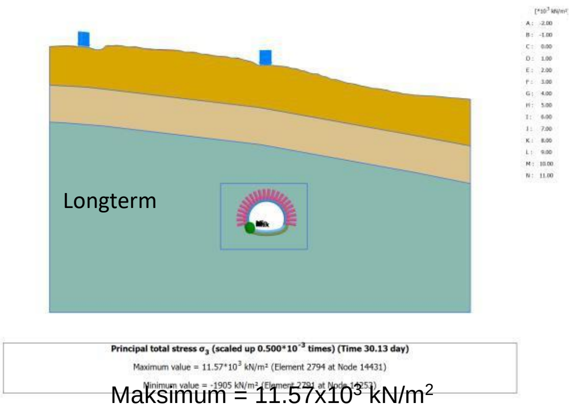
Maximum = 2794 kN/m^2
Minimum = -1016 kN/m^2



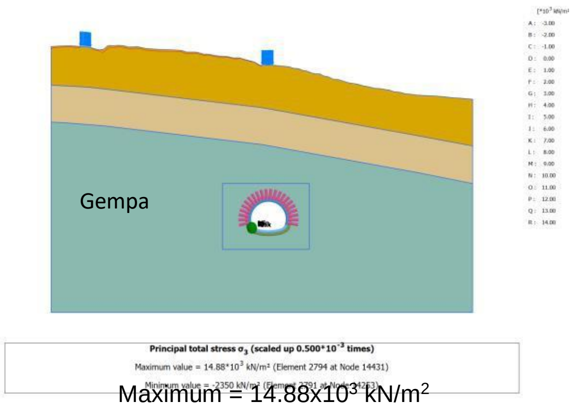
Maximum = 2062 kN/m^2
Minimum = -1084 kN/m^2



Maximum = 11.32x10^3 kN/m^2
Minimum = -1870 kN/m^2

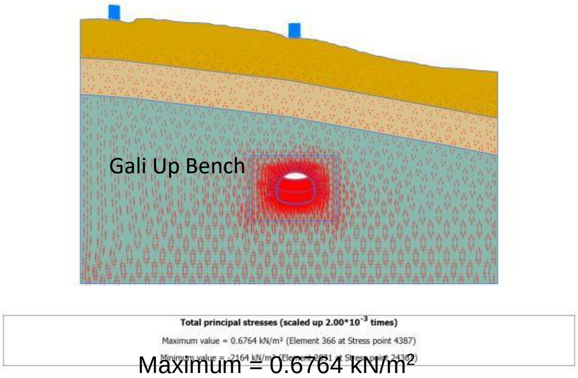


Maksimum = 11.57x10^3 kN/m^2
Minimum = -1905 kN/m^2

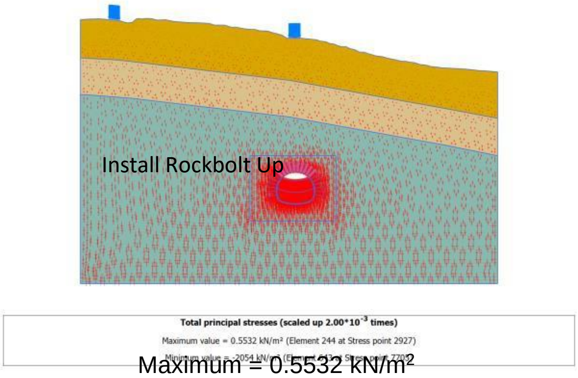


Maximum = 14.88x10^3 kN/m^2
Minimum = -2350 kN/m^2

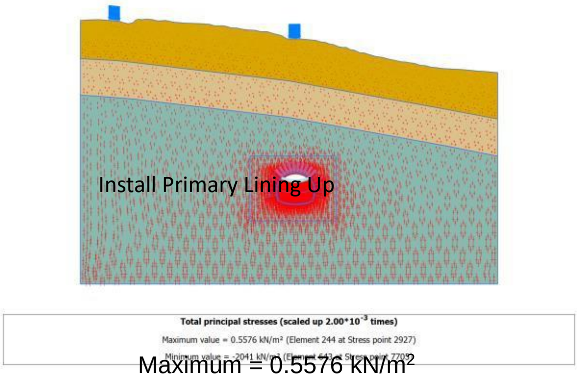
Gambar 60 Hasil analisis tegangan minimum (3) pada Tunnel No. 6 (DK 92+720) (lanjutan)



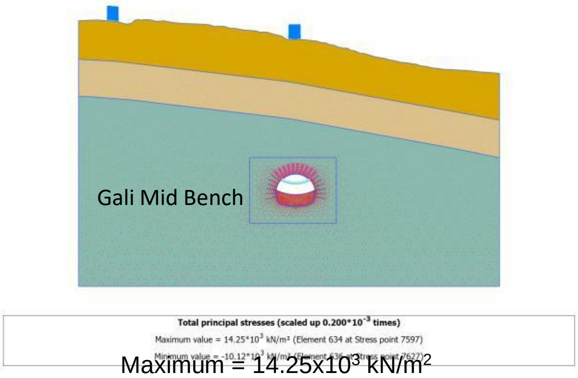
Maximum = 0.6764 kN/m^2
Minimum = -2164 kN/m^2



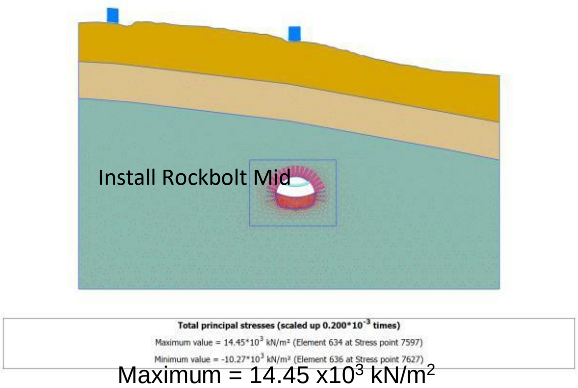
Maximum = 0.5532 kN/m^2
Minimum = -2054 kN/m^2



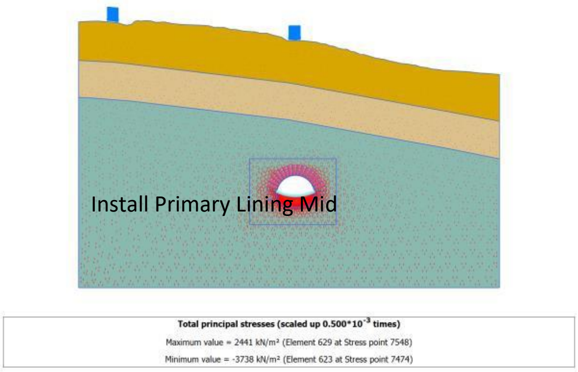
Maximum = 0.5576 kN/m^2
Minimum = -2041 kN/m^2



Maximum = 14.25x10^3 kN/m^2
Minimum = -10.12x10^3 kN/m^2

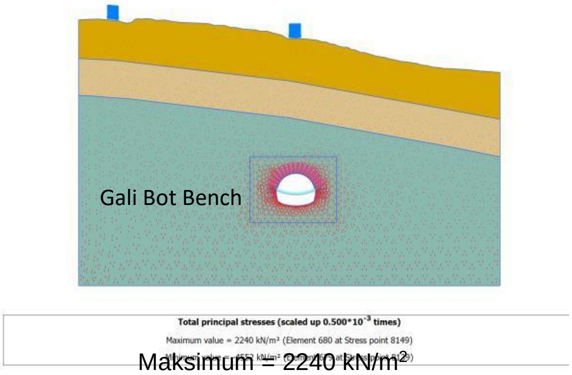


Maximum = 14.45 x10^3 kN/m^2
Minimum = -10.27x10^3 kN/m^2

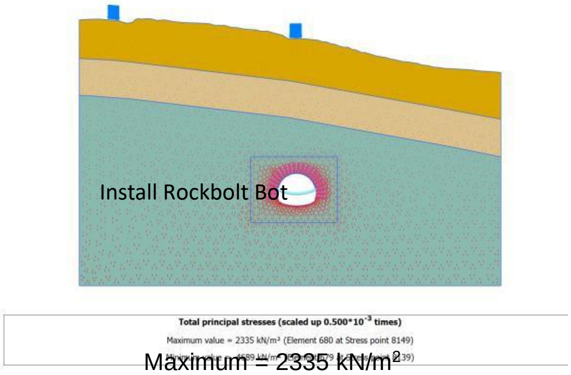


Maximum = 2441 kN/m^2
Minimum = -3738 kN/m^2

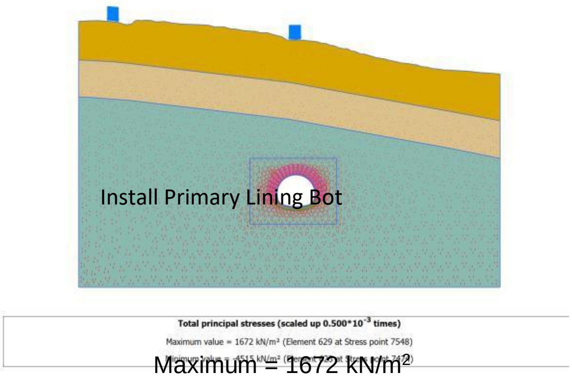
Gambar 61 Hasil analisis Total Principal Stresses pada Tunnel No. 6 (DK 92+720)



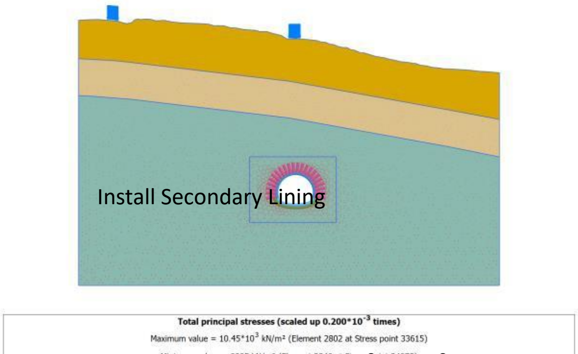
Maksimum = 2240 kN/m^2
Minimum = -4552 kN/m^2



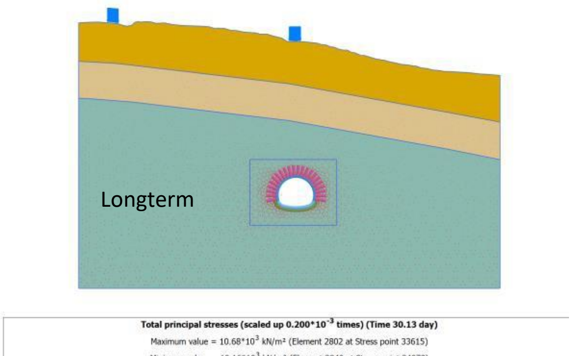
Maximum = 2335 kN/m^2
Minimum = -4689 kN/m^2



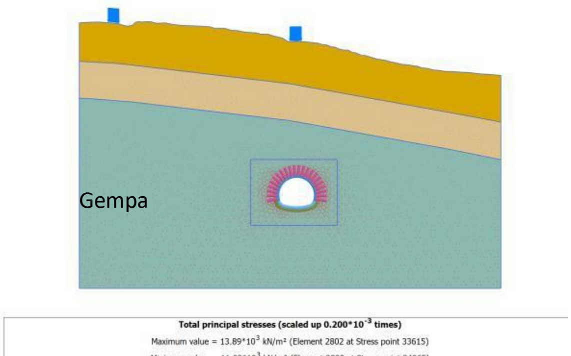
Maximum = 1672 kN/m^2
Minimum = -4515 kN/m^2



Maximum = 10.45x10^3 kN/m^2
Minimum = -9995 kN/m^2



Maksimum = 10.68x10^3 kN/m^2
Minimum = -10.16x10^3 kN/m^2



Maximum = 13.89x10^3 kN/m^2
Minimum = -11.03x10^3 kN/m^2

Gambar 62 Hasil analisis Total Principal Stresses pada Tunnel No. 6 (DK 92+720) (lanjutan)