

PROPOSAL PENGABDIAN KEPADA MASYARAKAT



REVIEW DESAIN TUNNEL NO. 5 (PEMODELAN FEM MENGGUNAKAN PLAXIS 2D) KERETA CEPAT JAKARTA BANDUNG

Ketua Tim :

Dr. techn. Indra Noer Hamdhan

Anggota:

Ahmad Faisal Amri (22-2015-225)

**PROGRAM STUDI TEKNIK SIPIL
FAKULTAS TEKNIK SIPIL DAN PERENCANAAN
INSTITUT TEKNOLOGI NASIONAL
BANDUNG
2018**

HALAMAN PENGESAHAN

1. Judul : Review Desain Tunnel No. 5 (Pemodelan Fem Menggunakan Plaxis 2d)
Kereta Cepat Jakarta Bandung
2. Pelaksana : Dr. tech. Indra Noer Hamdan, ST., MT.

NIP : 120030105
Pangkat/Golongan : Lektor/III D
Jurusan : Teknik Sipil
Bidang Keahlian : Geoteknik
3. Bentuk Kegiatan : Pelatihan
4. Waktu Kegiatan : 1 November - 31 Desember 2018
5. Sumber Dana : ASEA-UNINET dan RKAT Jurusan Teknik Sipil
6. Jumlah Dana : Rp. 20.000.000

Bandung, 6 September 2018

Pelaksana

Ketua Jurusan Teknik Sipil



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



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

Mengetahui

Kepala LP2M Itenas



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

DAFTAR ISI

1.	Informasi Umum Pekerjaan Kereta Cepat Jakarta-Bandung	1
A.	Lokasi Pekerjaan Kereta Cepat Jakarta-Bandung	1
B.	Lingkup Pekerjaan Terowongan	1
2.	Informasi Teknis	2
A.	Standar-Standar yang digunakan	2
B.	Kriteria Deformasi	2
C.	Metode Konstruksi Terowongan	4
D.	Tipe Struktur Lining.....	4
3.	Pengumpulan Data-Data	6
A.	Data Umum Terowongan No.5	6
B.	Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan.....	6
C.	Stratigrafi Tanah dan Data Borlog.....	7
D.	Hasil Pengujian Laboratorium.....	7
E.	Material Terowongan dan Referensi Penentuan Parameter Tanah/Batuan.....	7

1. Informasi Umum Pekerjaan Kereta Cepat Jakarta-Bandung

A. Lokasi Pekerjaan Kereta 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 Seismic Design of Railway Engineering
- GB50111-2005 : Code for Design on Railway Tunnel
- GB50010-2010 : Code for 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 Construction
- TB/T 3275-2011 : Concrete for Railway Construction
- GB/T 8077-2012 : Methods for Testing Uniformity of Concrete 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 Test.
- SNI 2052:2017 : Indonesian concrete 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: $\leq 20\text{mm}$; Settlement rate: $\leq 2\text{mm/d}$. For risk sensitive point, the control values shall be determined according to the specific situation.
2	Light rail	Accumulative abutment settlement: $\leq 16\text{mm}$; Settlement rate: $\leq 1.5\text{mm/d}$; Accumulative differential settlement of adjacent abutments: $\leq 4\text{mm}$; Differential settlement of single abutment (lateral direction) : $\leq 3\text{mm}$; Absolute rotation angle of beam end: $\leq 0.8 \times 10^{-3}/\text{rad}$; Relative rotation angle of beam end: $\leq 1.6 \times 10^{-3}/\text{rad}$; Concrete crack width: $\leq 0.2\text{mm}$.

No.	Monitoring objects	Monitoring items and its control values
3	Frame pier of Light rail bridge	Accumulative abutment settlement: $\leq 16\text{mm}$; Settlement rate: $\leq 1.5\text{mm/d}$; Accumulative differential settlement of adjacent frame pier: $\leq 4\text{mm}$ (longitudinal direction) ; Differential settlement of single frame pier: $\leq 6\text{mm}$; Concrete crack width: $\leq 0.2\text{mm}$ (for pre-stressed structure, cracking is forbidden) .
4	Pedestrian overbridge	Accumulative abutment settlement: $\leq 30\text{mm}$; Differential settlement of adjacent abutment of simple supported beam (longitudinal direction) : $\leq 8\text{mm}$; Differential settlement of abutment under stairs structure: $\leq 3\text{mm}$; Differential settlement of single abutment (lateral direction) : $\leq 4\text{mm}$; Horizontal displacement of pier cap: $\leq 4\text{mm}$; Settlement rate: $\leq 3\text{mm/d}$; Concrete cracking width: $\leq 0.2\text{mm}$.
5	Surface buildings	Structure inclination rate: $\leq 1/1000$; Accumulative settlement amount: $\leq 20\text{mm}$; Structure differential settlement amount: $\leq 1\%L$ (Where L denotes the centre spacing of adjacent base) ; Structure deformation rate: $\leq 1.5\text{mm/d}$; Maximum concrete crack width: $\leq 0.2\text{mm}$.
6	Highway interchange bridge	Accumulative abutment settlement amount: $\leq 20\text{mm}$; Settlement rate: $\leq 1.5\text{mm/d}$; Accumulative differential settlement of adjacent abutments (longitudinal direction) : $\leq 6\text{mm}$; Differential settlement of single abutment: $\leq 3\text{mm}$; Absolute rotation angle of beam end: $\leq 0.8 \times 10^{-3} // \text{rad}$; Relative rotation angle of beam end: $\leq 1.6 \times 10^{-3} // \text{rad}$; Concrete crack width: $\leq 0.2\text{mm}$ (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 penurunan 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

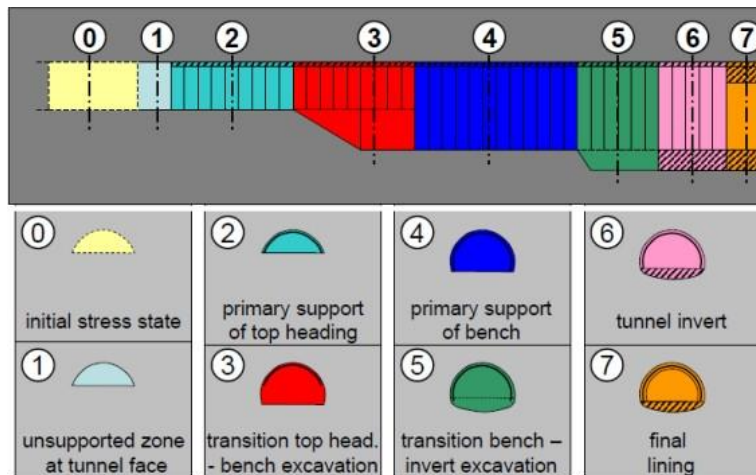
Pada masa operasional, deformasi izin pada *track* kereta cepat mengacu pada QCR9230-2016 dimana besar deformasi izinnnya sebesar 15 mm. Sedangkan pada konstruksi, deformasi izin pada terowongan dapat dilihat pada **Tabel 5**.

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		$0.04\%L_s$	—
Tunnel clearance convergence		$0.2\%D$	3
Notes: Ls denotes the longitudinal spacing of monitoring points along the tunnel D denotes the diameter of the tunnel excavation contour			

C. Metode Konstruksi Terowongan

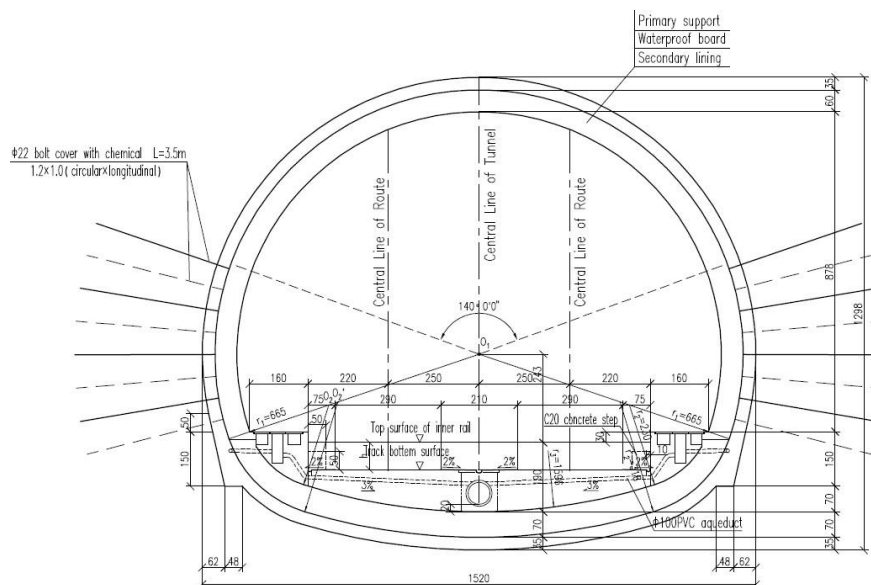
New Austrian Tunneling Method (NATM) : NATM merupakan metode *excavation* pada terowongan yang dilakukan secara manual dan bertahap. Tahapan pertama dalam metode ini adalah proses *excavation* pada area *tunnel* yang dapat dilakukan dengan menggunakan alat *twin header* dan *excavator*. Pembuangan tanah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



Gambar 1 Metode konstruksi terowongan dengan NATM

D. Tipe Struktur Lining

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



Gambar 2 Contoh model terowongan Tunnel No.5

Table 6 Pemilihan tipe lining berdasarkan jenis tanah/batuan

Surrounding rock	Lining type	Applicable conditions
II	II _a	II surrounding rock area
III	III _a	III surrounding rock area
	III _b	III surrounding rock of horizontal stratification area (Strata dip Angle $\leq 15^{\circ}$) 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 wall 15	—	—	—	—	—	—	—	—	—	35*	35*	3~5
2	III _a	arch wall 12	arch wall	Φ6	25×25	arch wall	3	1.2×1.5	—	—	—	40*	50*	5~8
3	III _b	arch wall 23	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 wall 25 invert 10	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 wall 25 invert 25	arch wall	Φ6	20×20	arch wall	3.5	1.2×1.2	I18shape steel	ring	1	45*	55*	8~10
6	IV _p	ring 28	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}	ring 28	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}	ring 28	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}	ring 30	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}	ring 35	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}	ring 30	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}	ring 35	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}	ring 35	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}	ring 35	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	ring 35	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	ring 35	arch wall	Φ8	20×20	arch wall	3.5	1.2×1.0	I25b shape steel	ring	0.6	60*	70*	20~25

3. Pengumpulan Data-Data

A. Data Umum Terowongan No.5

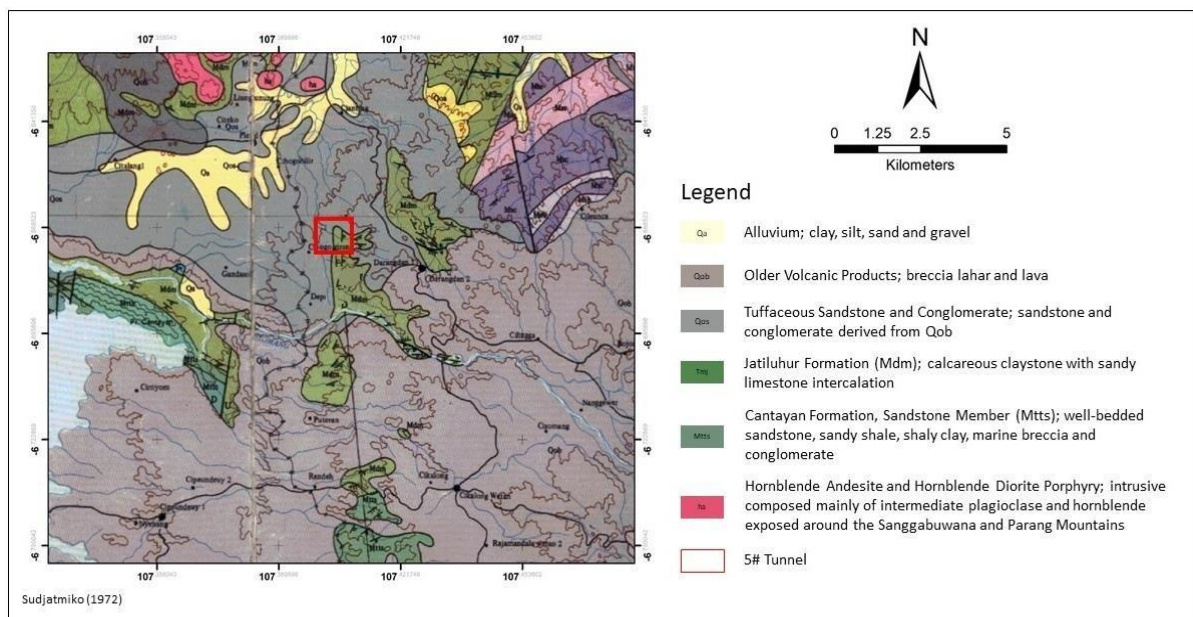
Terowongan No.5 Kereta Cepat Jakarta Bandung Jakarta, berlokasi di Purwakarta yang bertepatan di sebelah Timur Laut Waduk Jangari. Kondisi tanah disekitar lokasi terowongan mayoritas adalah Clay, Silty Clay dan sebagian Gravel. Metode konstruksi yang diterapkan pada Tunnel No.5 ini adalah metode galian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



Gambar 3 Lokasi *Soil Inestigastion* Terowongan No.5

B. Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan

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



Gambar 4 Peta Geologi (Sudjarmiko, 1972)

The map displays the Bandung region with a topographic overlay. Key features include:

- Railway Track Plan:** Indicated by a red line and arrow pointing to the location of Tunnel 5# and Tunnel Walini.
- Tunnel 5# and Tunnel Walini:** Marked with red pins on the railway track.
- IFSAR 5M DATA:** A red arrow points to the topographic data area.
- Geographical Features:** Various towns and locations are labeled, including Ciparahu, Ciamepa, Semplak, BOGOR, Gunungmejan, Ciawi, Brujul, Cipanas, Pasirkalong, Bojongkole, Cikalongkulan, Wanayasa, Sangalaberang, Cisalak, Ciater, Lembang, Padalarang, Cimahi, BANDUNG, Ujungberung, Cicalengka, Cigombong, Ubrug, Cibadak, Parungkuda, Cipetir, Cicurug, Ciantenherang, Ciurug, Cigaru, Ciemas, Waluran, Jampangkulon, Cimahi, Cibirang, Sagaranten, Kiragil, Kedupandak, Cibinong, Cigarendeng, Tonjongkarang, Pagelaran, Babakan Jampang, Ciwidey, Cianjur, Marujung, Majalaya, Ciparai, Banjaran, Soreang, Gununghalu, Campaka, Sukanegara, Sempur, Pelabuhanratu, and Cigombong.
- Coordinates:** The map is bounded by latitude from 6°35'0"S to 7°20'0"S and longitude from 106°35'0"E to 107°50'0"E.

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

Detail stratigrafi tanah di area Terowongan No.5 dapat dilihat pada **Lampiran A** dan untuk Data hasil penyelidikan tanah (SPT) dapat dilihat pada **Lampiran D**.

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

Spesifikasi material yang digunakan pada Terowongan No.5 dapat dilihat dibawah ini:

7

LAPORAN KEGIATAN PENGABDIAN KEPADA MASYARAKAT



REVIEW DESAIN TUNNEL NO. 5 (PEMODELAN FEM MENGGUNAKAN PLAXIS 2D) KERETA CEPAT JAKARTA BANDUNG

Ketua Tim :

Dr. techn. Indra Noer Hamdhan

Anggota:

Ahmad Faisal Amri (22-2015-225)

**Program Studi Teknik Sipil
Fakultas Teknik Sipil dan Perencanaan
INSTITUT TEKNOLOGI NASIONAL BANDUNG
2019**

HALAMAN PENGESAHAN

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

Bandung, 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



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

DAFTAR ISI

1.	Informasi Umum Pekerjaan Kereta Cepat Jakarta-Bandung	1
A.	Lokasi Pekerjaan Kereta Cepat Jakarta-Bandung	1
B.	Lingkup Pekerjaan Terowongan	1
2.	Informasi Teknis	2
A.	Standar-Standar yang digunakan	2
B.	Kriteria Deformasi	2
C.	Metode Konstruksi Terowongan	4
D.	Tipe Struktur Lining.....	4
3.	Pengumpulan Data-Data	6
A.	Data Umum Terowongan No.5	6
B.	Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan.....	6
C.	Stratigrafi Tanah dan Data Borlog.....	7
D.	Hasil Pengujian Laboratorium.....	7
E.	Material Terowongan dan Referensi Penentuan Parameter Tanah/Batuan	7
4.	Pemodelan Terowongan No.5.....	11
A.	Layout Geometri	11
B.	Parameter-Parameter Pemodelan Terowongan No.5	14
1.	Cross Section DK 86+640	14
2.	Cross Section DK 86+890	15
3.	Cross Section DK 86+905	16
C.	Perhitungan Beban Gempa di Area Terowongan No. 5	17
1.	Perhitungan NSPT desain rata-rata.....	19
2.	Penentuan Klasifikasi Situs berdasarkan NSPT rata-rata	19
3.	Faktor Amplifikasi	19
4.	Percepatan Puncak	20
D.	Kondisi Elemen Mesh dan <i>Initial Condition</i>	20
E.	Tahapan Konstruksi Pemodelan Terowongan	21
F.	Hasil Pemodelan (Deformasi, <i>Volume loss</i> , Gaya Dalam, dan Tegangan Tanah)....	23
1.	Perhitungan Volume Loss	23
2.	Deformasi <i>Tunnel</i>	23
3.	Gaya Dalam pada Lining Terowongan	34
4.	Tegangan Dalam Tanah.....	38

1. Informasi Umum Pekerjaan Kereta Cepat Jakarta-Bandung

A. Lokasi Pekerjaan Kereta 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 Seismic Design of Railway Engineering
- GB50111-2005 : Code for Design on Railway Tunnel
- GB50010-2010 : Code for 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 Construction
- TB/T 3275-2011 : Concrete for Railway Construction
- GB/T 8077-2012 : Methods for Testing Uniformity of Concrete 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 Test.
- SNI 2052:2017 : Indonesian concrete 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: $\leq 20\text{mm}$; Settlement rate: $\leq 2\text{mm/d}$. For risk sensitive point, the control values shall be determined according to the specific situation.
2	Light rail	Accumulative abutment settlement: $\leq 16\text{mm}$; Settlement rate: $\leq 1.5\text{mm/d}$; Accumulative differential settlement of adjacent abutments: $\leq 4\text{mm}$; Differential settlement of single abutment (lateral direction) : $\leq 3\text{mm}$; Absolute rotation angle of beam end: $\leq 0.8 \times 10^{-3}/\text{rad}$; Relative rotation angle of beam end: $\leq 1.6 \times 10^{-3}/\text{rad}$; Concrete crack width: $\leq 0.2\text{mm}$.

No.	Monitoring objects	Monitoring items and its control values
3	Frame pier of Light rail bridge	Accumulative abutment settlement: $\leq 16\text{mm}$; Settlement rate: $\leq 1.5\text{mm/d}$; Accumulative differential settlement of adjacent frame pier: $\leq 4\text{mm}$ (longitudinal direction) ; Differential settlement of single frame pier: $\leq 6\text{mm}$; Concrete crack width: $\leq 0.2\text{mm}$ (for pre-stressed structure, cracking is forbidden) .
4	Pedestrian overbridge	Accumulative abutment settlement: $\leq 30\text{mm}$; Differential settlement of adjacent abutment of simple supported beam (longitudinal direction) : $\leq 8\text{mm}$; Differential settlement of abutment under stairs structure: $\leq 3\text{mm}$; Differential settlement of single abutment (lateral direction) : $\leq 4\text{mm}$; Horizontal displacement of pier cap: $\leq 4\text{mm}$; Settlement rate: $\leq 3\text{mm/d}$; Concrete cracking width: $\leq 0.2\text{mm}$.
5	Surface buildings	Structure inclination rate: $\leq 1/1000$; Accumulative settlement amount: $\leq 20\text{mm}$; Structure differential settlement amount: $\leq 1\%L$ (Where L denotes the centre spacing of adjacent base) ; Structure deformation rate: $\leq 1.5\text{mm/d}$; Maximum concrete crack width: $\leq 0.2\text{mm}$.
6	Highway interchange bridge	Accumulative abutment settlement amount: $\leq 20\text{mm}$; Settlement rate: $\leq 1.5\text{mm/d}$; Accumulative differential settlement of adjacent abutments (longitudinal direction) : $\leq 6\text{mm}$; Differential settlement of single abutment: $\leq 3\text{mm}$; Absolute rotation angle of beam end: $\leq 0.8 \times 10^{-3}/\text{rad}$; Relative rotation angle of beam end: $\leq 1.6 \times 10^{-3}/\text{rad}$; Concrete crack width: $\leq 0.2\text{mm}$ (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 penurunan 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

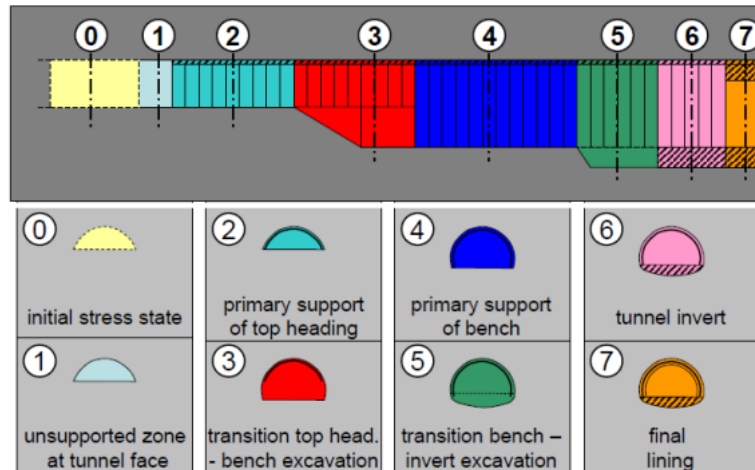
Pada masa operasional, deformasi izin pada *track* kereta cepat mengacu pada QCR9230-2016 dimana besar deformasi izinnnya sebesar 15 mm. Sedangkan pada konstruksi, deformasi izin pada terowongan dapat dilihat pada **Tabel 5**.

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

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

C. Metode Konstruksi Terowongan

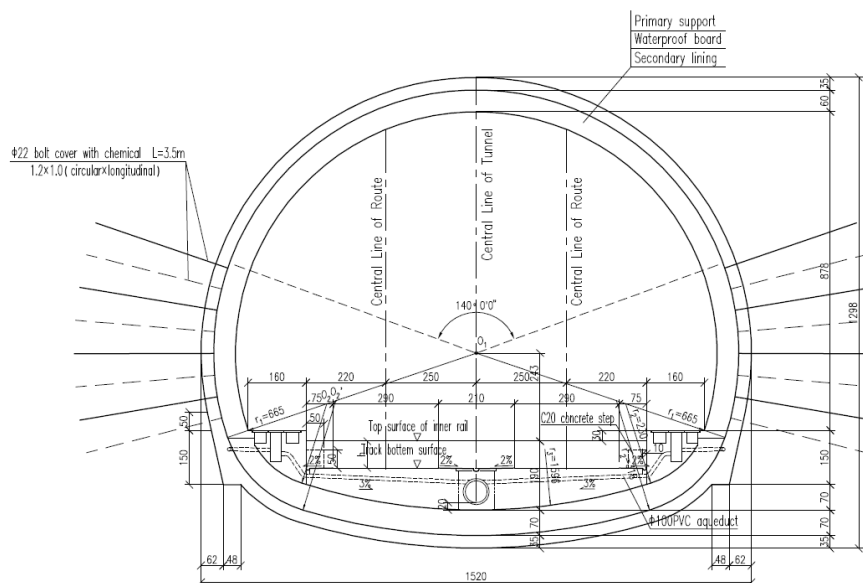
New Austrian Tunneling Method (NATM) : NATM merupakan metode *excavation* pada terowongan yang dilakukan secara manual dan bertahap. Tahapan pertama dalam metode ini adalah proses *excavation* pada area *tunnel* yang dapat dilakukan dengan menggunakan alat *twin header* dan *excavator*. Pembuangan tanah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



Gambar 1 Metode konstruksi terowongan dengan NATM

D. Tipe Struktur Lining

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



Gambar 2 Contoh model terowongan Tunnel No.5

Table 6 Pemilihan tipe lining berdasarkan jenis tanah/batuan

Surrounding rock	Lining type	Applicable conditions
II	II _a	II surrounding rock area
III	III _a	III surrounding rock area
	III _b	III surrounding rock of horizontal stratification area (Strata dip Angle $\leq 15^{\circ}$) 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 wall 5	—	—	—	—	—	—	—	—	—	35*	35*	3~5
2	III _a	arch wall 12	arch wall	Φ6	25x25	arch wall	3	1.2x1.5	—	—	—	40*	50*	5~8
3	III _b	arch wall 23	arch wall	Φ6	25x25	arch wall	3	1.2x1.5	150grid Φ22	arch wall	1.5	40*	50*	5~8
4	IV _a	arch wall 25 invert 10	arch wall	Φ6	20x20	arch wall	3.5	1.2x1.2	180grid Φ22	arch wall	1	45*	55*	8~10
5	IV _b	arch wall 25 invert 25	arch wall	Φ6	20x20	arch wall	3.5	1.2x1.2	I18shape steel	ring	1	45*	55*	8~10
6	IV _p	ring 28	arch wall	Φ8	20x20	arch wall	4	1.2x1.0	I20a shape steel	ring	0.8	45*	55*	8~10
7	V _{r-a}	ring 28	arch wall	Φ8	20x20	arch wall	4	1.2x1.0	I20a shape steel	ring	0.8	50*	60*	10~15
8	V _{r-b}	ring 28	arch wall	Φ8	20x20	arch wall	4	1.2x1.0	I20a shape steel	ring	0.6	50*	60*	10~15
9	V _{r-c}	ring 30	arch wall	Φ8	20x20	arch wall	4	1.2x1.0	I22a shape steel	ring	0.6	55*	65*	10~15
10	V _{r-p}	ring 35	arch wall	Φ8	20x20	arch wall	4	1.2x1.0	I25a shape steel	ring	0.6	55*	65*	15~20
11	V _{s-a}	ring 30	arch wall	Φ8	20x20	arch wall	3.5	1.2x1.0	I22a shape steel	ring	0.6	50*	60*	10~15
12	V _{s-b}	ring 35	arch wall	Φ8	20x20	arch wall	3.5	1.2x1.0	I25a shape steel	ring	0.6	55*	65*	15~20
13	V _{s-p-1}	ring 35	arch wall	Φ8	20x20	arch wall	3.5	1.2x1.0	I25b shape steel	ring	0.6	60*	70*	20~25
14	V _{s-p-2}	ring 35	arch wall	Φ8	20x20	arch wall	3.5	1.2x1.0	I25b shape steel	ring	0.6	60*	70*	20~25
15	VI _a	ring 35	arch wall	Φ8	20x20	arch wall	3.5	1.2x1.0	I25b shape steel	ring	0.6	60*	70*	20~25
16	VI _b	ring 35	arch wall	Φ8	20x20	arch wall	3.5	1.2x1.0	I25b shape steel	ring	0.6	60*	70*	20~25

3. Pengumpulan Data-Data

A. Data Umum Terowongan No.5

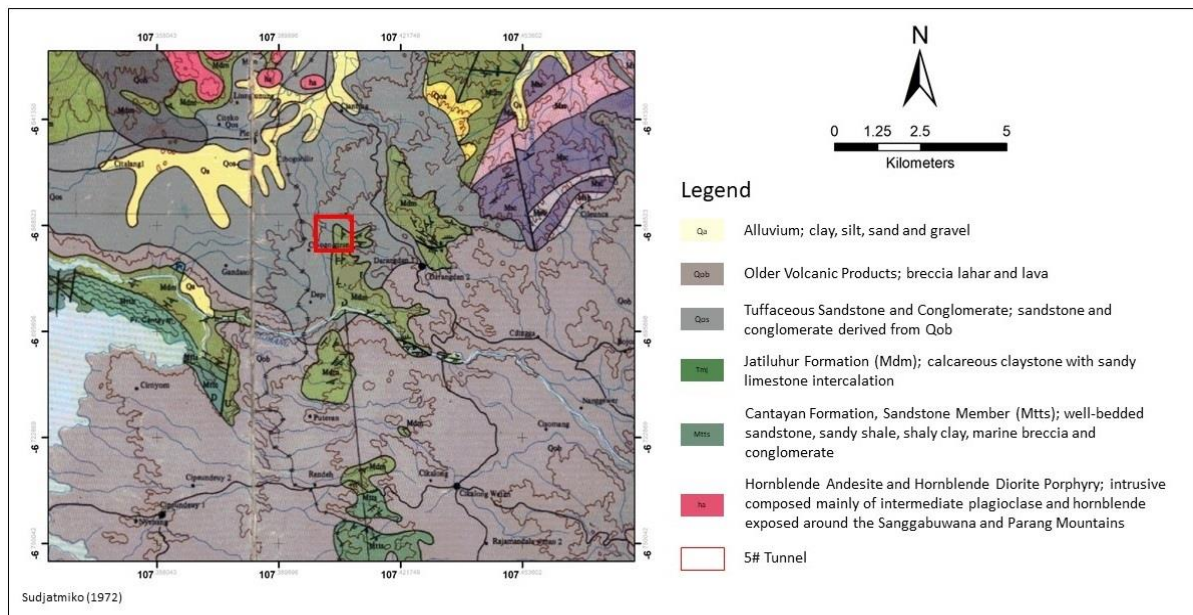
Terowongan No.5 Kereta Cepat Jakarta Bandung Jakarta, berlokasi di Purwakarta yang bertepatan di sebelah Timur Laut Waduk Jangari. Kondisi tanah disekitar lokasi terowongan mayoritas adalah Clay, Silty Clay dan sebagian Gravel. Metode konstruksi yang diterapkan pada Tunnel No.5 ini adalah metode galian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



Gambar 3 Lokasi *Soil Inestigation* Terowongan No.5

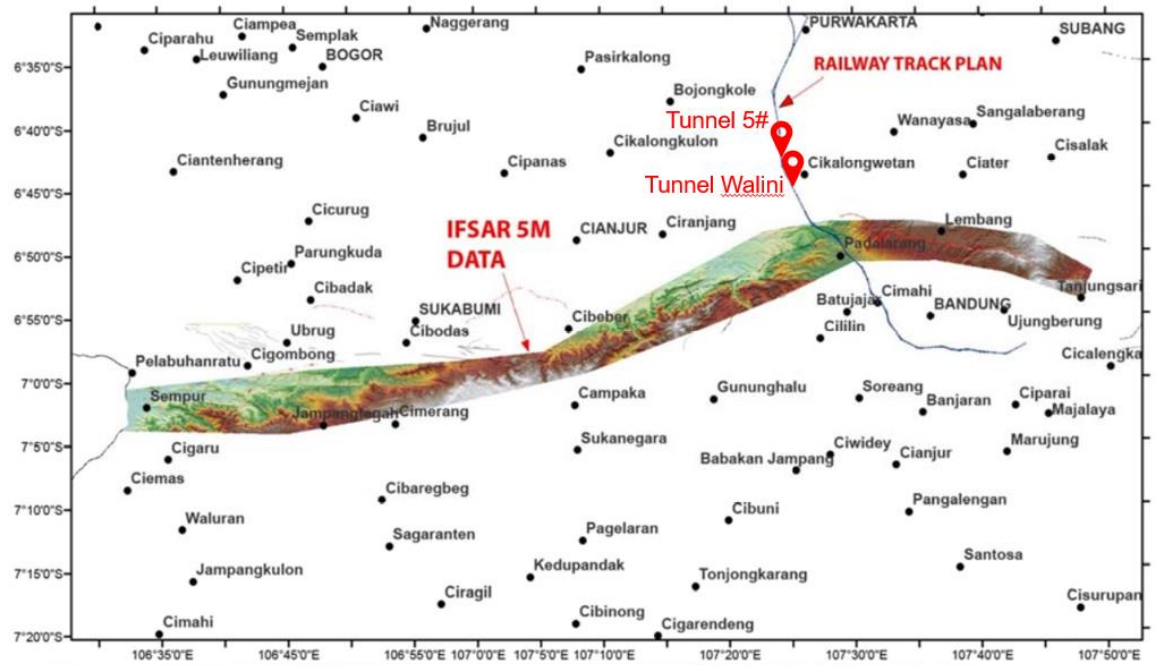
B. Kondisi Tanah/Geologi di Lokasi Konstruksi Terowongan

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



Gambar 4 Peta Geologi (Sudjtmiko, 1972)

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



Gambar 5 Hasil Analisis Geologi

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

C. Stratigrafi Tanah dan Data Borlog

Detail stratigrafi tanah di area Terowongan No.5 dapat dilihat pada **Lampiran A** dan untuk Data hasil penyelidikan tanah (SPT) dapat dilihat pada **Lampiran D**.

D. Hasil Pengujian Laboratorium

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

E. Material Terowongan dan Referensi Penentuan Parameter Tanah/Batuan

Spesifikasi material yang digunakan pada Terowongan No.5 dapat dilihat dibawah ini:

Dimensi Terowongan

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

Ketebalan

Primary lining (Shotcrete) : 0.35 m

Secondary lining (Reinforced Concrete)

Invert Arch : 0.7 m

Wall Arch : 0.6 m

Material Terowongan

Shotcrete : C30

Reinforced Concrete : C35 dengan tulangan

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

Fill inverted arch : Beton C20

Ditch and cable duct : Beton C30

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

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

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

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

	Texture			
	Coarse	Medium	Fine	Very fine
Sedimentary	Conglomerates	Sandstones	Siltstones	Claystones
	300–400	200–350	350–400	200–300
	Breccias		Greywackes	Shales
	230–350		350	150–250 ^a
				Marls
				150–200
	Crystalline limestone	Sparitic limestone	Micritic limestone	Dolomite
	400–600	600–800	800–1000	350–500
		Gypsum	Anhydrite	Chalk
		(350) ^c	(350) ^c	1000+
Metamorphic	Marble	Hornfels	Quartzite	
	700–1000	400–700	300–450	
		Metasandstone		
		200–300		
	Migmatite	Amphibolites	Gneiss	
	350–400	400–500	300–750 ^a	
		Schists	Phyllites/Mica Schist	Slates
Igneous		250–1100 ^a	300–800 ^a	400–600 ^a
	Granite ^b	Diorite ^b		
	300–550	300–350		
	Granodiorite			
	400–450			
	Gabbro	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)

^aHighly 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

^bFelsic Granitoids: Coarse grained or altered (High modulus ratio), fine grained (low modulus ratio)

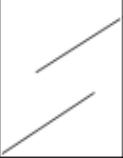
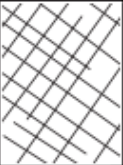
^cNo data available; Estimated on the basis of geological logic

Table 10 Lithology classification (*m*) (Brinkgreve, 2018)

Rock type	Class	Group	Texture			
			Coarse	Medium	Fine	Very fine
SEDIMENTARY	Clastic		Conglomerates (21±3)	Sandstones 17±4	Siltstones 7±2	Claystones 4±2
			Breccias (19±5)		Greywackes (18±3)	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	Diorite 25±5 Granodiorite (29±3)		
		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) (Brinkgreve, 2018)

Rock type:

		SURFACE CONDITIONS				
STRUCTURE		VERY GOOD Very rough, fresh unweathered surfaces.	GOOD Rough, slightly weathered, iron stained surfaces.	FAIR Smooth, moderately weathered and altered surfaces.	POOR Slackensided, highly weathered surfaces with compact coatings or fillings with angular fragments.	VERY POOR Slackensided, highly weathered
	INTACT OR MASSIVE Intact rock specimens or massive in situ rock with few widely spaced discontinuities.	90			N/A	N/A
	BLOCKY Well interlocked undisturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets.	80	70			
	VERY BLOCKY Interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets.		60	50		
	BLOCKY DISTURBED/SEAMY Folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity.			40	30	
	DISINTEGRATED Poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces.				20	
	LAMINATED/SHEARED Lack of blockiness due to close spacing of weak schistosity or shear planes.	N/A	N/A			10

4. Pemodelan Terowongan No.5

A. Layout Geometri

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

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

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

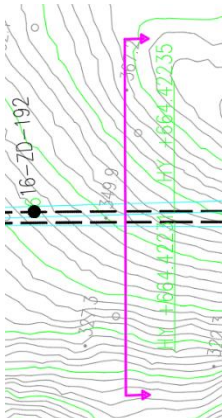
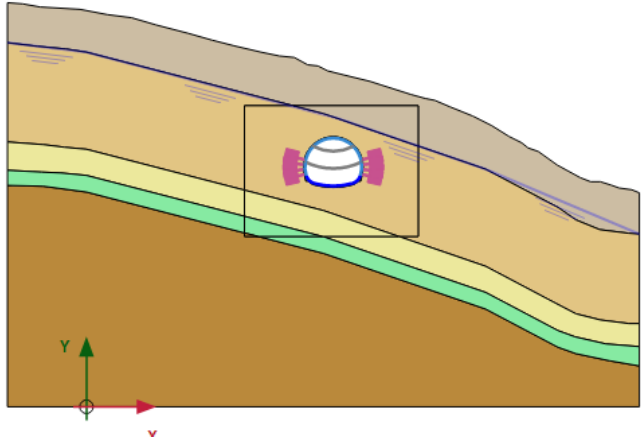
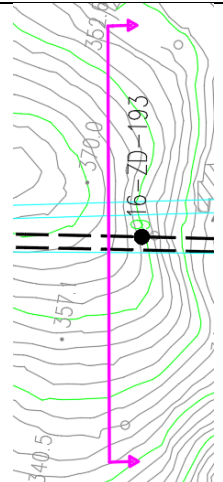
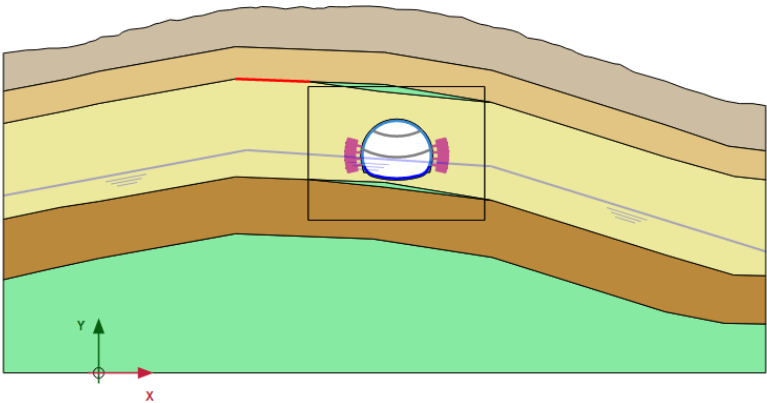
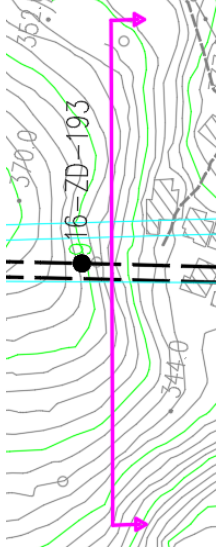
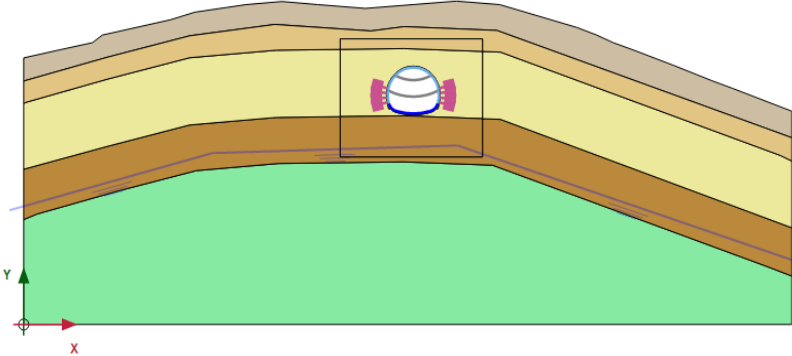
No. Potongan	Layout	Potongan Melintang	Keterangan
TUNNEL 5 (DK86+640)			Tidak ada beban jalan dan bangunan pada permukaan
TUNNEL 5 (DK86+890)			Tidak ada beban jalan dan bangunan pada permukaan

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

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

B. Parameter-Parameter Pemodelan Terowongan No.5

1. Cross Section DK 86+640

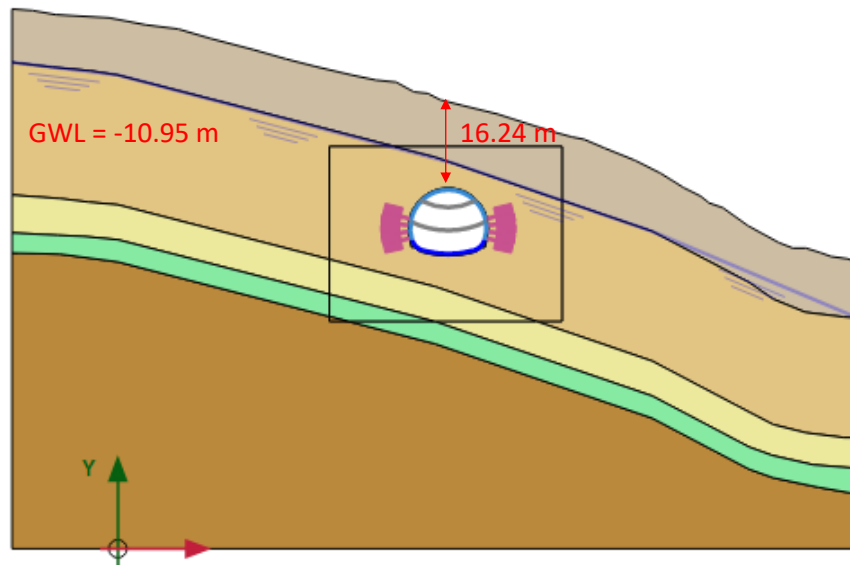


Table 14 Parameter Tanah Tunnel No.5 (DK 86 +640)

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

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

Lapis	Jenis Tanah	N SPT	E' (kN/m ²)	E_{50} (kN/m ²)	E_{oed} (kN/m ²)	E_{ur} (kN/m ²)
1	Clay	7	5250	5250	4200	15750
2	Silty Clay	47	70500	70500	56400	211500
3	Clay	45	67500	67500	54000	202500
5	Clay	50	75000	75000	60000	225000

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

Lapis	Jenis Tanah	N SPT	σ_{ci} (kPa) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 212	(Modulus Ratio) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 214	E_{rm} (kPa) Tomlinson, (2001)	m_i	GSI
4	Andesit	50	50000	300	12×10^6	25	30

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

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

Table 18 Parameter Secondary Lining Tunnel No.5 (DK 86 +640)

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

Table 19 Parameter Grouting Anchor (Rockbolt)

ID	Value	Unit
Material (Embedded Beam)	M10 Mortar	-
Diameter	22	mm
Unit weight (γ)	24	kN/m ³
Easticity modulus (E)	1.33×10^7	kPa
Spasi	1	m
Panjang	3.5	m

2. Cross Section DK 86+890

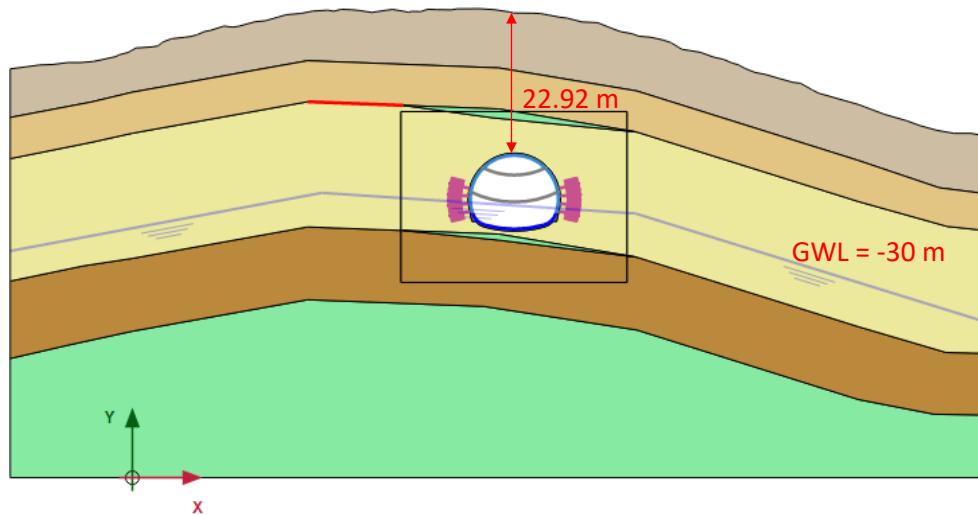


Table 20 Parameter Tanah Tunnel No.5 (DK 86 +890)

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

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

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

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

Lapis	Jenis Tanah	N SPT	σ_{ci} (kPa) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 212	(Modulus Ratio) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 214	E_{rm} (kPa) Tomlinson, (2001)	m_i	GSI
5	Andesit	50	50000	300	12×10^6	25	30

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

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

Table 24 Parameter Secondary Lining Tunnel No.5 (DK 86 +890)

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

Table 25 Parameter Grouting Anchor (Rockbolt)

ID	Value	Unit
Material (Embedded Beam)	M10 Mortar	-
Diameter	22	mm
Unit weight (γ)	24	kN/m ³
Easticity modulus (E)	1.33×10^7	kPa
Spasi	1	m
Panjang	3.5	m

3. Cross Section DK 86+905

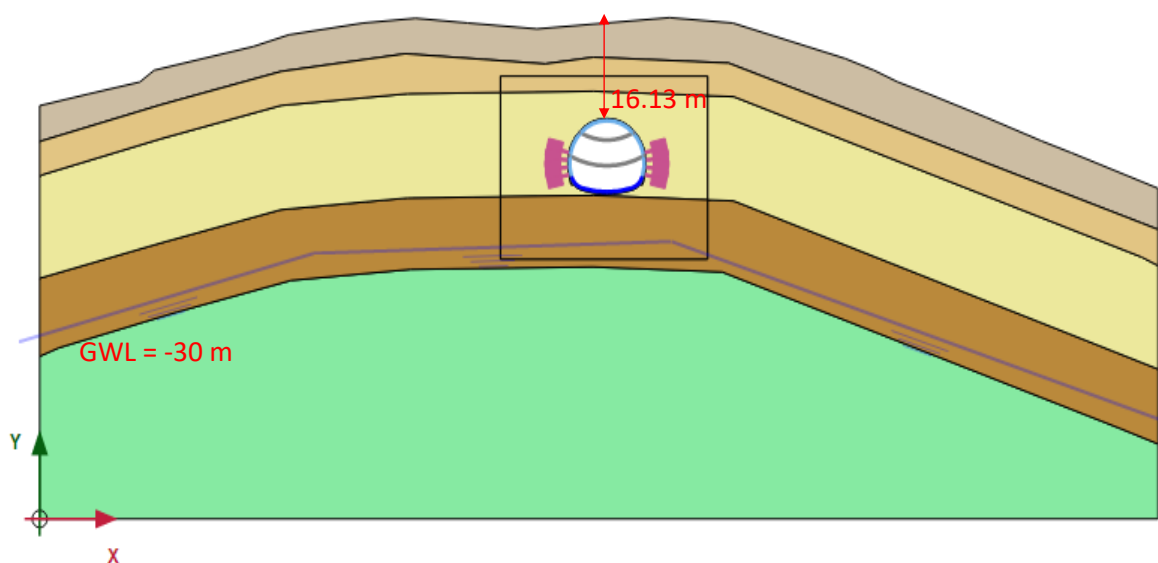


Table 26 Parameter Tanah Tunnel No.5 (DK 86 +905)

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

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

Lapis	Jenis Tanah	N SPT	E' (kN/m ²)	E ₅₀ (kN/m ²)	E _{oed} (kN/m ²)	E _{ur} (kN/m ²)
1	Silty Clay	10	7500	7500	6000	22500
2	Silty Clay	23	23000	23000	18400	69000
3	Silty Clay	50	75000	75000	60000	225000
4	Clay	50	75000	75000	60000	225000

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

Lapis	Jenis Tanah	N SPT	σ_{ci} (kPa) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 212	(Modulus Ratio) Correlations of soil and rock properties in geotechnical engineering (2016), hal: 214	E _{rm} (kPa) Tomlinson, (2001)	m _i	GSI
5	Andesit	50	50000	300	12 x 10 ⁶	25	30

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

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

Table 30 Parameter Secondary Lining Tunnel No.5 (DK 86 +905)

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

Table 31 Parameter Grouting Anchor (Rockbolt)

ID	Value	Unit
Material (Embedded Beam)	M10 Mortar	-
Diameter	22	mm
Unit weight (γ)	24	kN/m ³
Elasticity modulus (E)	1.33 x 10 ⁷	kPa
Spasi	1	m
Panjang	3.5	m

C. Perhitungan Beban Gempa di Area Terowongan No. 5

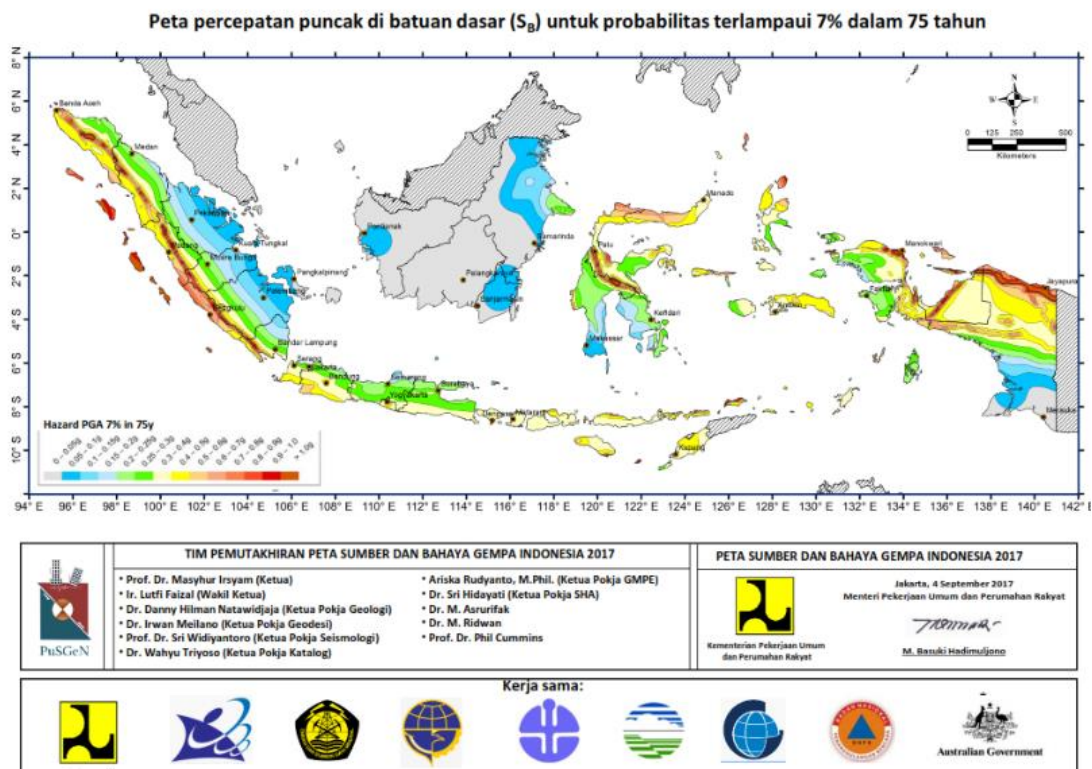
Analisis deformasi aksial dilakukan dengan menambahkan beban gempa berdasarkan peta gempa 2017. Percepatan tanah puncak gempa maksimum yang dipertimbangkan untuk bangunan bawah seperti yang tertera dalam SNI 8460 tahun 2017 (Bab 12), percepatan tanah puncak dengan 7% kemungkinan terlampaui dalam kurun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



Gambar 6 Lokasi jalur kereta cepat Bandung – Jakarta

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

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



Gambar 7 Peta gempa 2017 untuk periode ulang 1000 tahun.

1. Perhitungan NSPT desain rata-rata

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

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

Table 32 Desain untuk Menentukan SPT Rata-rata di Tunnel No.5 (DK86+890)

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

$$\overline{N}_{60} = \frac{43.5}{1.37} = 32$$

2. Penentuan Klasifikasi Situs berdasarkan NSPT rata-rata

Table 33 Klasifikasi situs berdasarkan SNI 8460

Klasifikasi Situs	$\overline{v}_s$ (m/detik)	$\overline{N}_{SPT}$ atau $\overline{N}_{SPT_{Ch}}$	$\overline{s}_u$ (kPa)
SA (batuan keras)	>1.500	N/A	N/A
SB (batuan dasar)	750 sampai 1.500	N/A	N/A
SC (tanah keras, sangat padat, dan batuan lunak)	350 sampai 750	>50	≥ 100
SD (tanah sedang)	175 sampai 350	15 sampai 50	50 sampai 100
SE (tanah lunak)	<175	<15	<50
	Atau setiap profil tanah yang mengandung lebih dari 3 m dengan karakteristik sebagai berikut: 1. Indeks Plastisitas, $PI > 20$, 2. Kadar air, $(w) \geq 40\%$, dan 3. Kuat geser niralir, $\overline{s}_u < 25$ 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 Plastisitas, $PI > 75$) - Lapisan lempung lunak/setengah teguh dengan ketebalan $H > 35$ m dengan $\overline{s}_u < 50$ kPa		

Keterangan: N/A = tidak dapat dipakai

3. Faktor Amplifikasi

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

Table 34 Faktor amplifikasi berdasarkan SNI 8460

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

Keterangan: Untuk nilai-nilai antara dapat dilakukan interpolasi linear

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

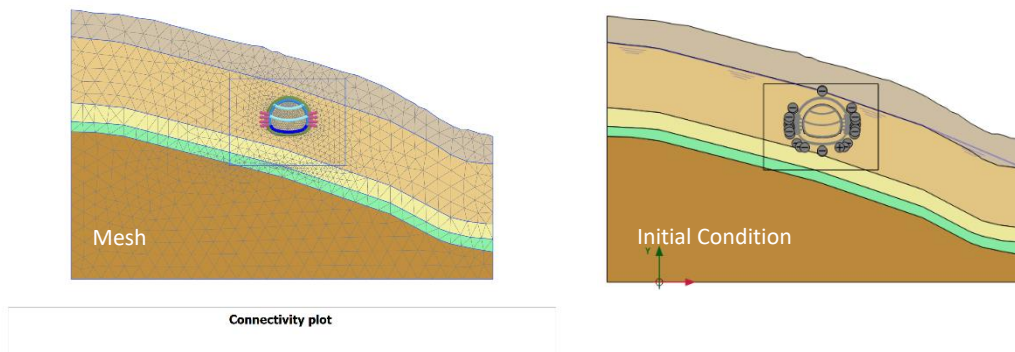
4. Percepatan Puncak

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

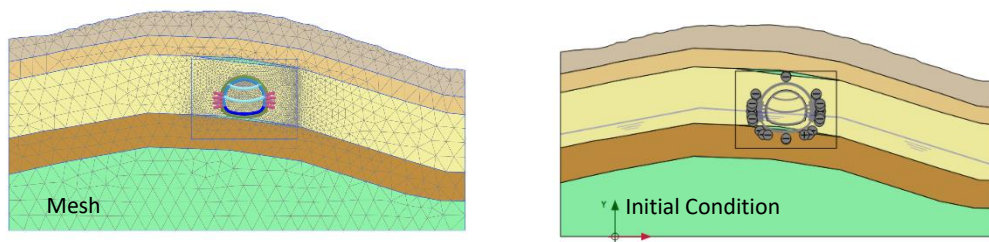
$$\text{Untuk } PGA \text{ 0.3} \rightarrow a = 0.3 \times 1.2 \times ((1.45 - 0.3) \times 0.3) = \mathbf{0.1242 \text{ g}}$$

D. Kondisi Elemen Mesh dan Initial Condition

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

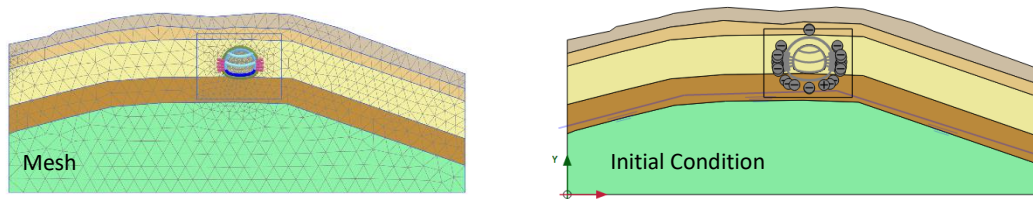


Gambar 8 Meshing dan initial condition Tunnel No.5 (DK 86+640)



Connectivity plot

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

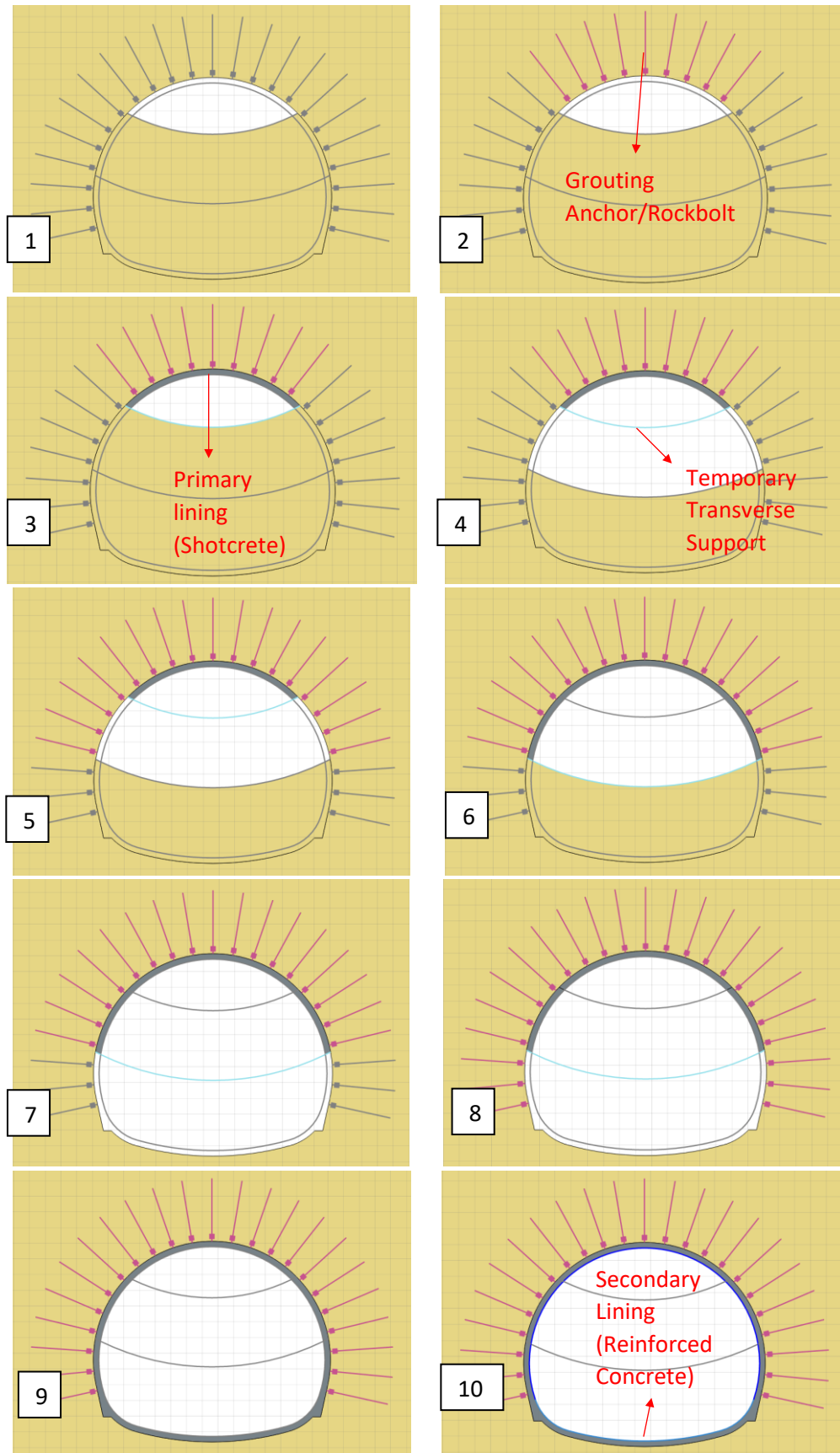


Connectivity plot

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

E. Tahapan Konstruksi Pemodelan Terowongan

Analisis galian terowongan yang dilakukan pada program numerik 2D terdiri dari 10 tahap konstruksi. Tahap pemodelan terowongan diawali dengan galian pada bagian upper bench **Gambar 11(1)**, Pemasangan grouting anchor/rockbolt (dimodelkan menggunakan Embedded Beam) bagian atas **Gambar 11(2)**, Pemasangan primary lining dan upper bench temporary transverse support **Gambar 11(3)**, galian pada bagian middle bench **Gambar 11(4)**, Pemasangan grouting anchor/rockbolt bagian mid **Gambar 11(5)**, Pemasangan primary lining dan middle bench temporary transverse support **Gambar 11(6)**, galian pada bagian lower bench **Gambar 11(7)**, Pemasangan grouting anchor/rockbolt bagian mid **Gambar 11(8)**, Pemasangan primary lining pada bagian lower bench **Gambar 11(9)**, pemasangan secondary lining (dimodelkan menggunakan plate) **Gambar 11(10)**, dan dilanjutkan analisis pada kondisi minimum excess pore pressure serta dilanjutkan analisis terhadap beban gempa.



Gambar 11 Tahapan konstruksi tunnel NATM di Tunnel Walini (DK 95+602)

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

1. Perhitungan Volume Loss

Perhitungan volume loss pada permukaan biasanya dilakukan dengan mengasumsikan kurva penurunan Gauss, pengukuran deformasi maksimum yang terjadi di permukaan, mengukur kedalaman terhadap terowongan dan memperkirakan parameter K. Perhitungan volume loss dilakukan dengan menggunakan *spreadsheet* berdasarkan hasil analisis yang dilakukan pada program Plaxis. Untuk hasil rekapitulasi dapat dilihat pada **Tabel 35 s/d Tabel 37**. Untuk hasil perhitungan lebih lengkapnya dapat dilihat pada **Lampiran C**.

2. Deformasi Tunnel

Berdasarkan hasil analisis numerik dengan menggunakan program Plaxis 2D, didapatkan hasil berupa penurunan. Deformasi dicatat dengan mengambil nilai deformasi aksial dan lateral terbesar di sekeliling lining terowongan. Deformasi aksial global dicatat pada seluruh tahap konstruksi serta deformasi aksial dan lateral pada lining terowongan dicatat pada tahap ketika seluruh *lining* terpasang, kondisi *longterm* dan setelah gempa yang dapat dilihat pada **Gambar 12 s/d Gambar 25**. Rekapitulasi hasil deformasi dan gaya dalam yang dihasilkan dalam pemodelan PLAXIS 2D pada setiap tahapan konstruksi dapat dilihat pada **Tabel 35 s/d Tabel 37**.

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

Staged Construction	Deformasi Aksial Global (m)	Volume Loss (%)	Deformasi Lining Tunnel		Gaya Dalam Tunnel		
			Axial (m)	Lateral (m)	Axial (kN/m)	Shear (kN/m)	Momen (kNm/m)
Gali up bench	-0.01489	-	-	-	-	-	-
Install Primary lining up	-0.01561	-	-	-	-	-	-
Gali mid bench	-0.05795	-	-	-	-	-	-
Install Primary lining mid	-0.05730	-	-	-	-	-	-
Gali bot bench	-0.09053	-	-	-	-	-	-
Install Rockbolt bot	-0.09075	-	-	-	-	-	-
Install Primary lining bot	-0.09074	-	-	-	-	-	-
Install Secondary lining	-0.09409	1.23	-0.09132	0.05348	-1587	294.6	-435.0
Longterm	-0.02045	-	-0.00853	0.01405	-2519	508.8	830.3
Gempa	0.02287	-	0.00284	-0.01462	-2273	468.6	807.6

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

Staged Construction	Deformasi Aksial Global (m)	Volume Loss (%)	Deformasi Lining Tunnel		Gaya Dalam Tunnel		
			Axial (m)	Lateral (m)	Axial (kN/m)	Shear (kN/m)	Momen (kNm/m)
Gali up bench	-9.141 x 10 ⁻³	-	-	-	-	-	-
Install Primary lining up	-9.425 x 10 ⁻³	-	-	-	-	-	-
Gali mid bench	-0.02044	-	-	-	-	-	-
Install Primary lining mid	-0.02059	-	-	-	-	-	-
Gali bot bench	-0.02630	-	-	-	-	-	-
Install Rockbolt bot	-0.02699	-	-	-	-	-	-
Install Primary lining bot	-0.02693	-	-	-	-	-	-
Install Secondary lining	-0.03017	0.32	-0.02976	0.006381	-1500	240.9	-256.3
Longterm	-0.02264	-	-0.01760	0.00907	-2730	544.2	710.5
Gempa	-0.1493	-	-0.00708	0.01832	-3385	668.8	-901.9

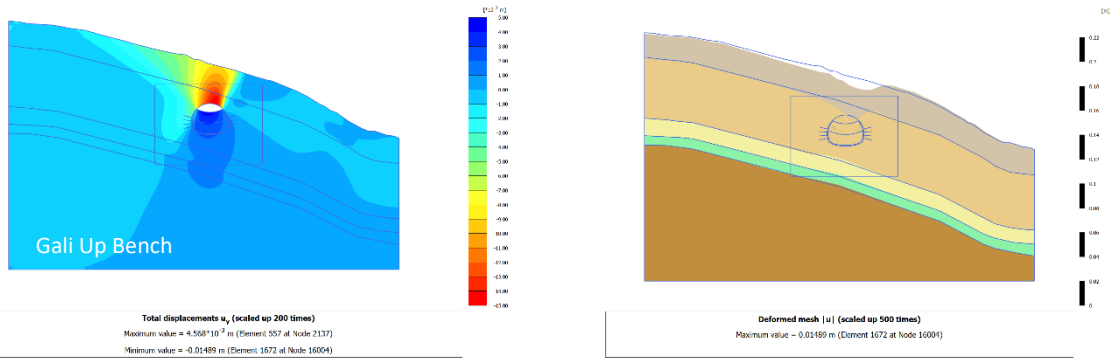
Table 37 Hasil Rekapitulasi Deformasi pada Tunnel No.5 (DK86+905)

Staged Construction	Deformasi Aksial Global (m)	Volume Loss (%)	Deformasi Lining Tunnel		Gaya Dalam Tunnel		
			Axial (m)	Lateral (m)	Axial (kN/m)	Shear (kN/m)	Momen (kNm/m)
Gali up bench	-8.686 x 10 ⁻³	-	-	-	-	-	-
Install Primary lining up	-9.037 x 10 ⁻³	-	-	-	-	-	-
Gali mid bench	-0.01989	-	-	-	-	-	-
Install Primary lining mid	-0.01999	-	-	-	-	-	-
Gali bot bench	-0.02548	-	-	-	-	-	-
Install Rockbolt bot	-0.02605	-	-	-	-	-	-
Install Primary lining bot	-0.02594	-	-	-	-	-	-
Install Secondary lining	-0.02919	0.31	-0.02911	0.005653	-1179	199.5	-221.5
Longterm	-0.01078	-	-0.00511	0.00414	-1694	312.2	399.4
Gempa	-0.3662	-	-0.00945	0.02556	-2668	515.7	-785.0

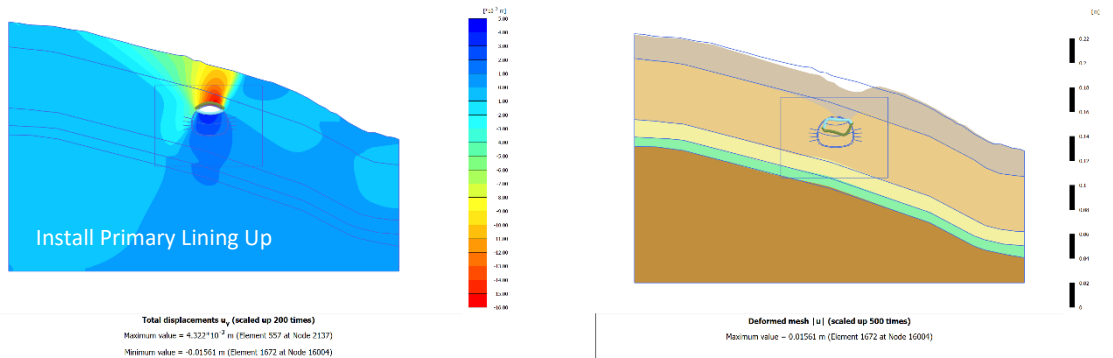
Dari hasil rekapitulasi deformasi menunjukkan bahwa selisih atau Δ deformasi dari potongan DK 86+890 dengan DK 86+905 terbesar adalah **±1 cm pada kondisi longterm** dengan syarat izin differential settlement 0.04%(15 m)= 0.006 m atau sebesar 0.6 cm. Hasil tersebut tidak memenuhi kedalam syarat izin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

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

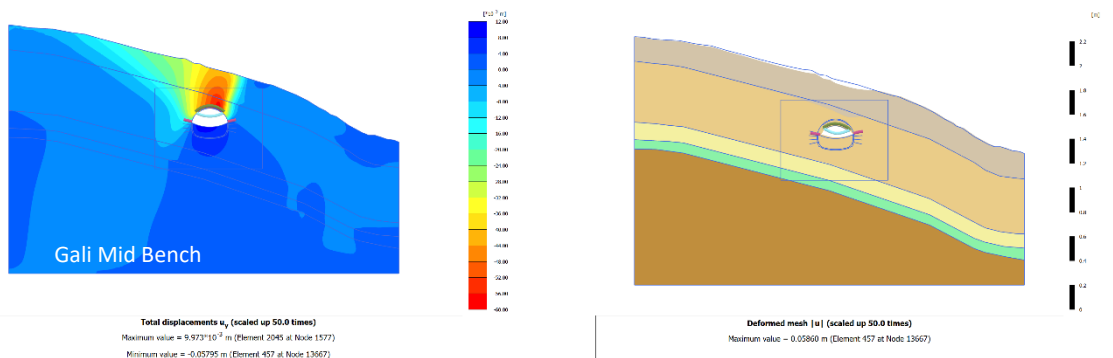
a) Cross Section DK 86+640



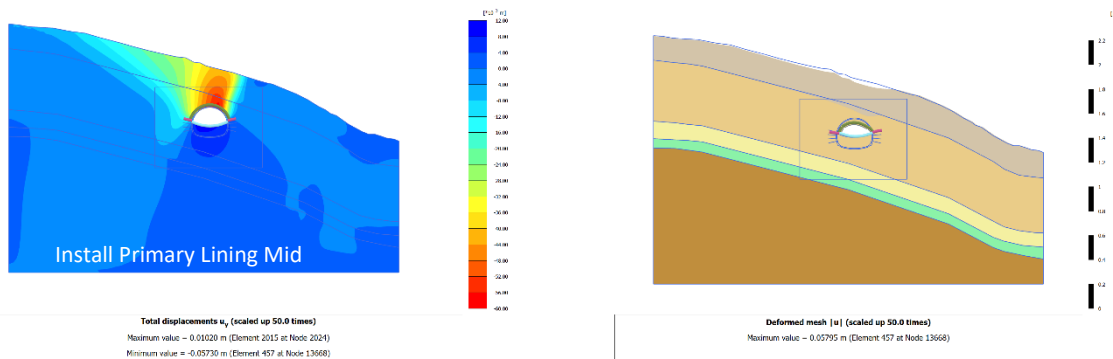
Maximum = 4.568×10^{-3} m
 Minimum = -0.01489 m



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

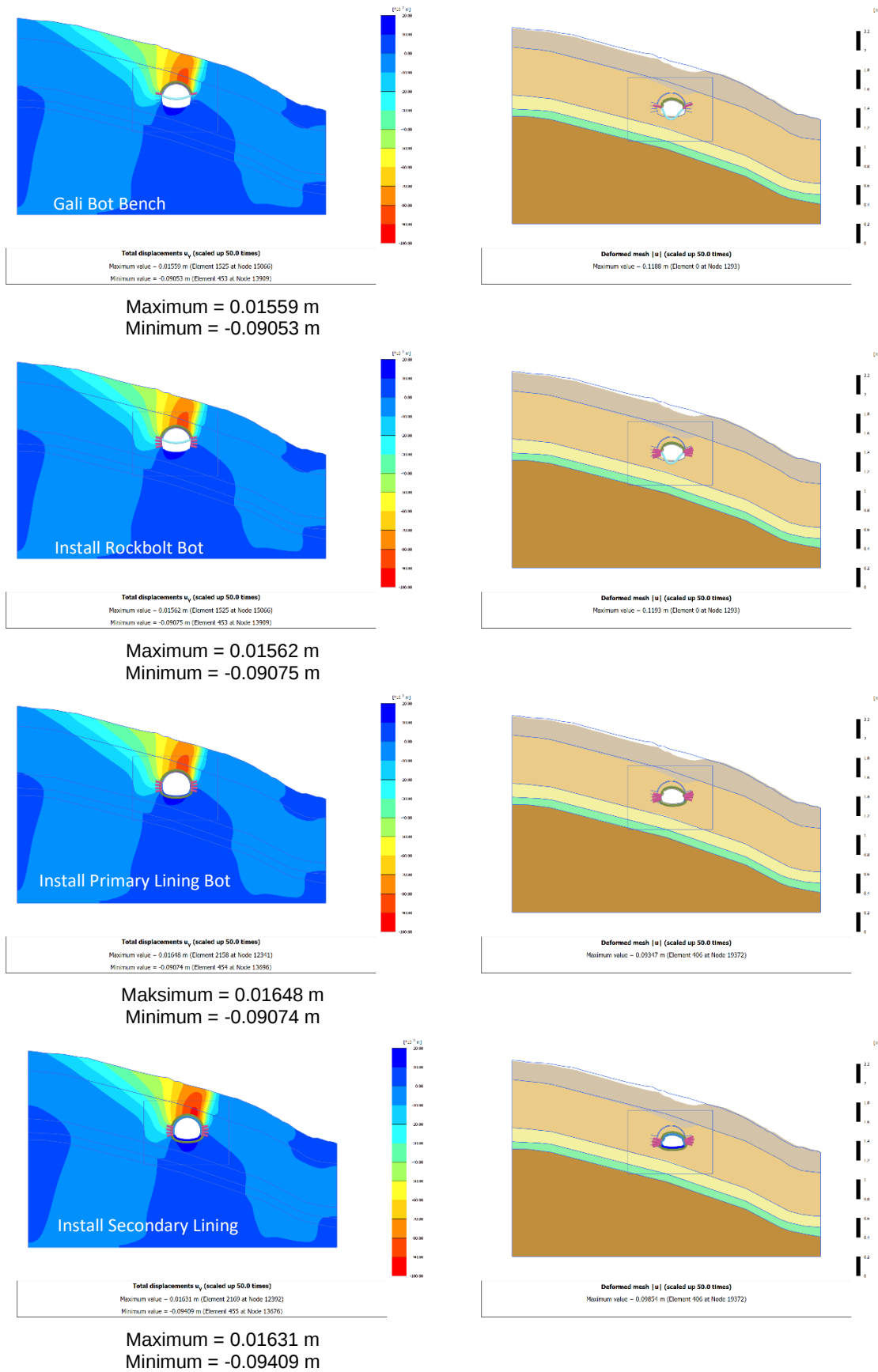


Maximum = 9.973×10^{-3} m
 Minimum = -0.05795 m

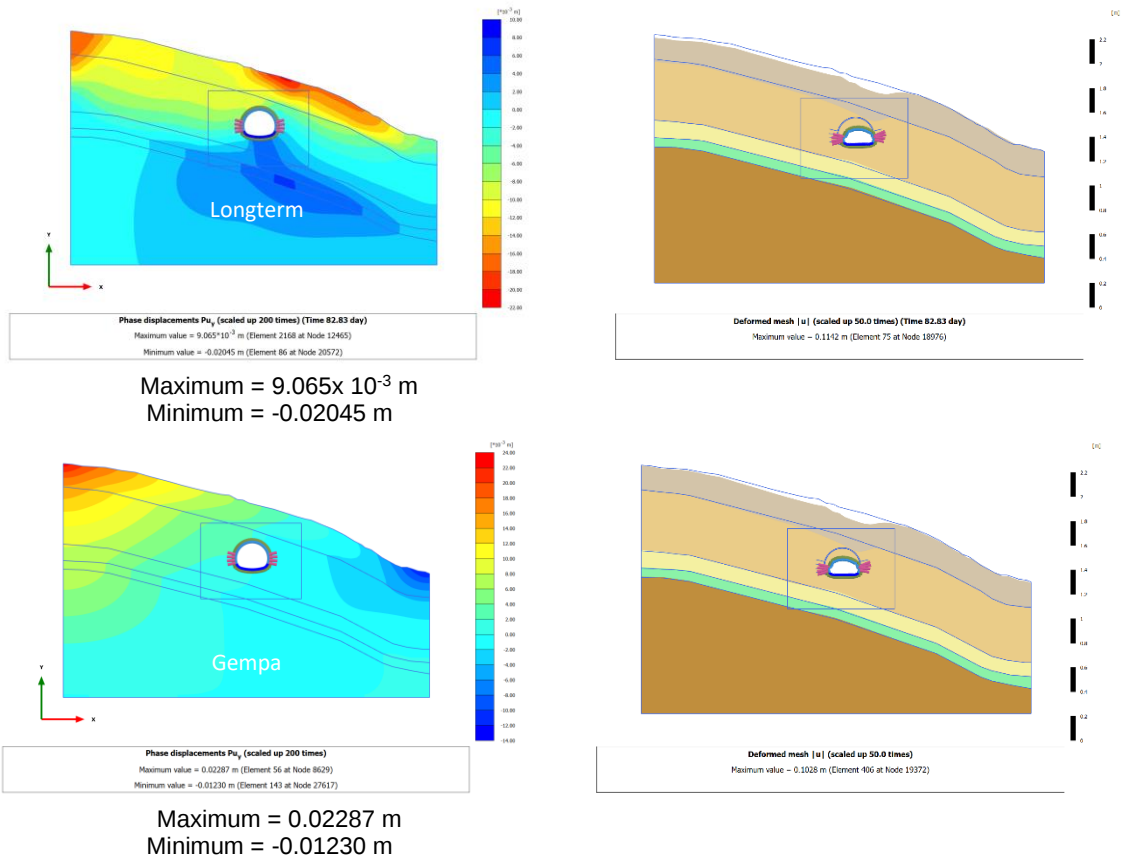


Maximum = 0.01020 m
 Minimum = -0.05730 m

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

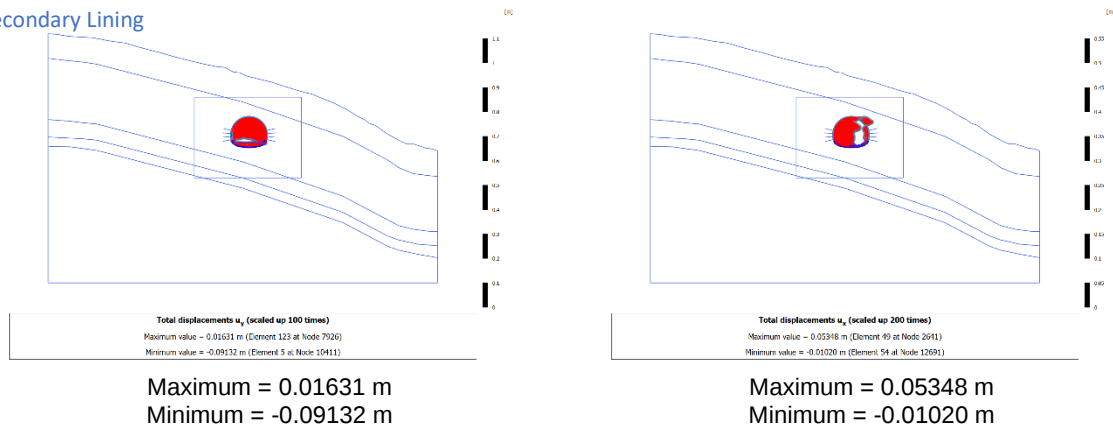


Gambar 13 Hasil analisis deformasi terowongan aksial global Tunnel No.5 (DK 86+640) (lanjutan)

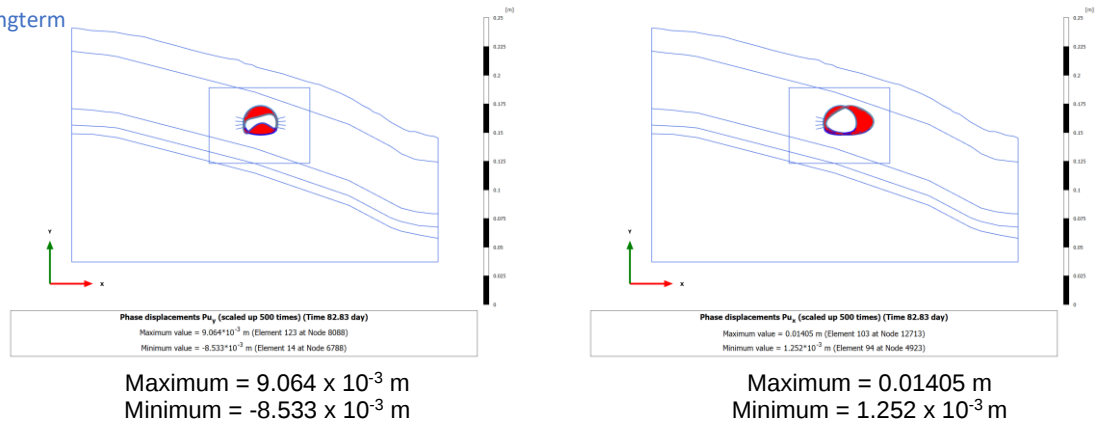


Gambar 14 Hasil analisis deformasi terowongan aksial global Tunnel No.5 (DK 86+640) (lanjutan)

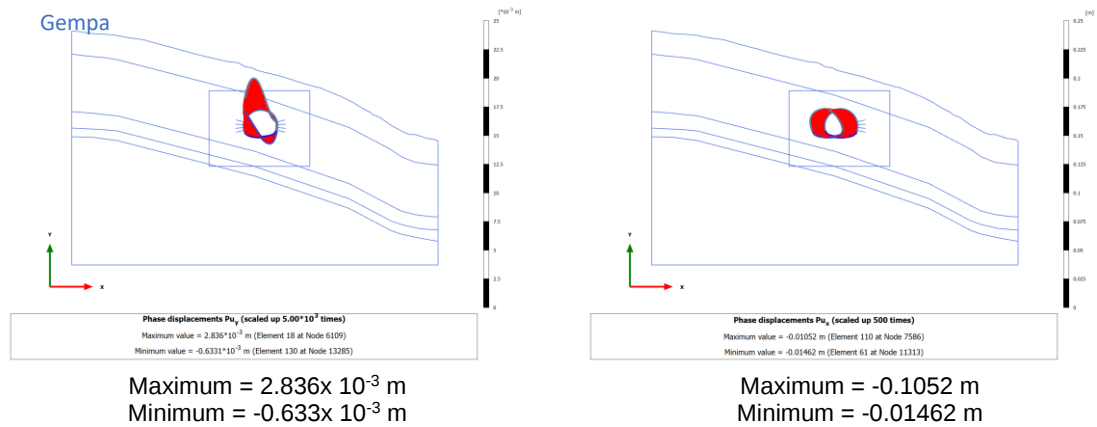
Secondary Lining



Longterm

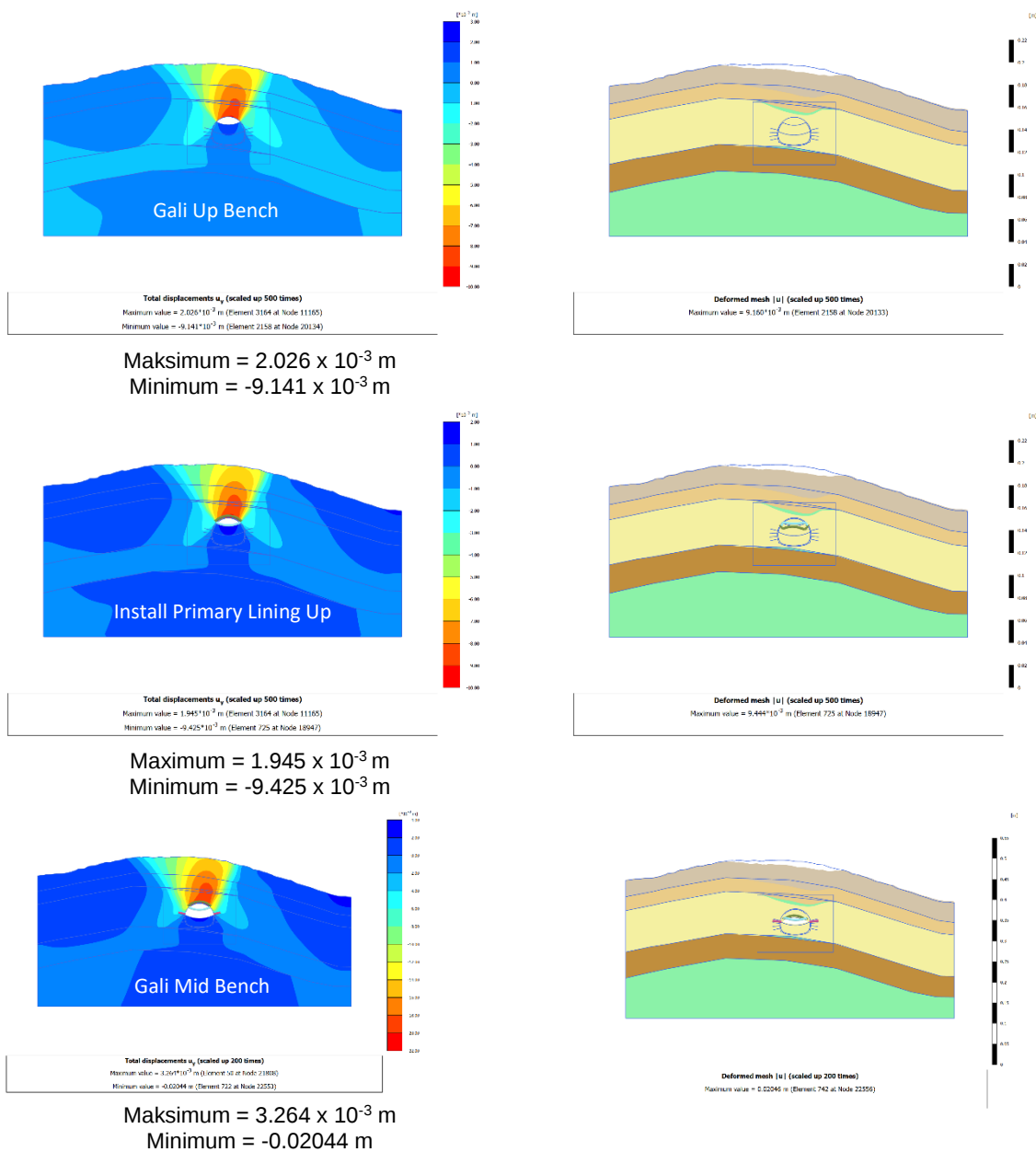


Gambar 15 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+640)

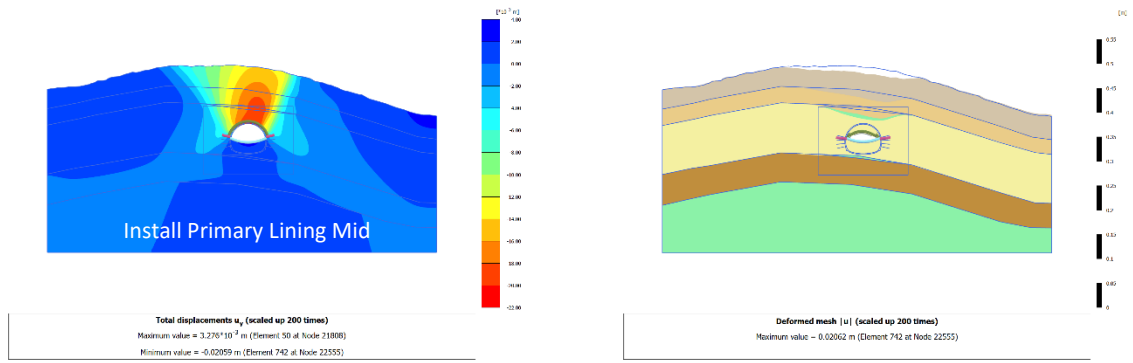


Gambar 16 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+640) (lanjutan)

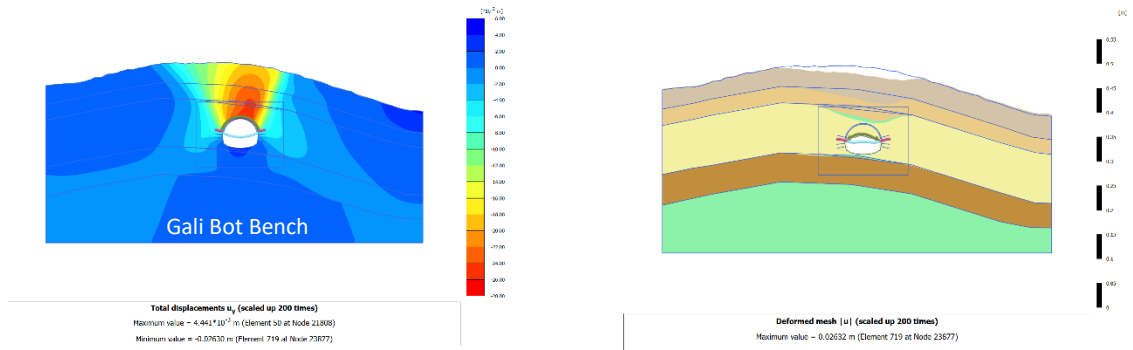
b) Cross Section DK 86+890



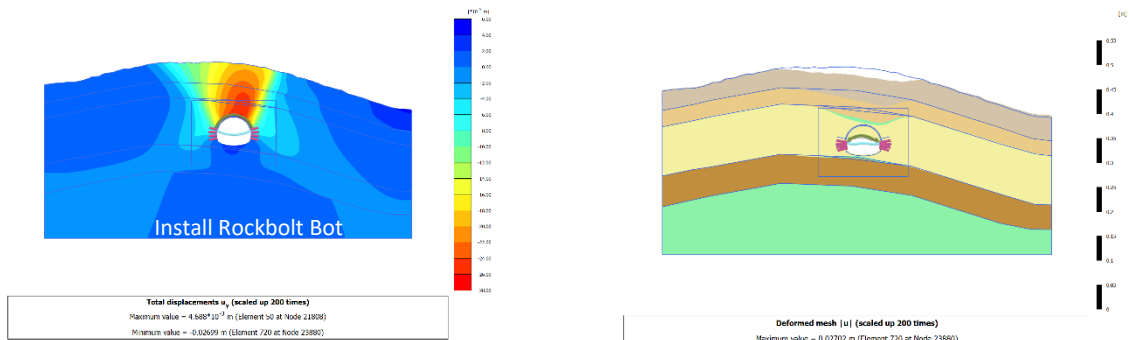
Gambar 17 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+890)



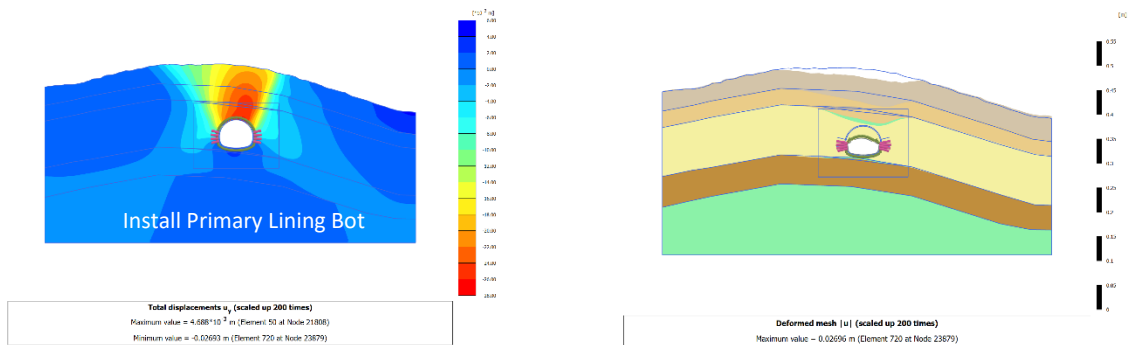
Maksimum = 3.276×10^{-3} m
Minimum = -0.02059 m



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

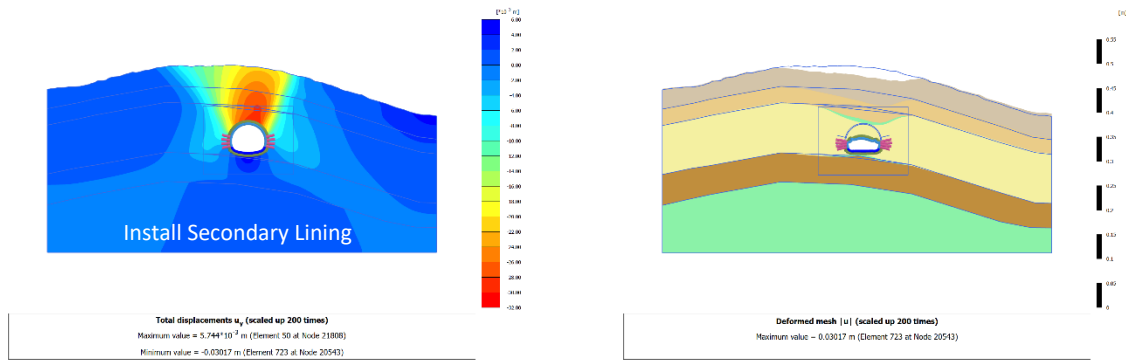


Maximum = 4.688×10^{-3} m
Minimum = -0.02699 m

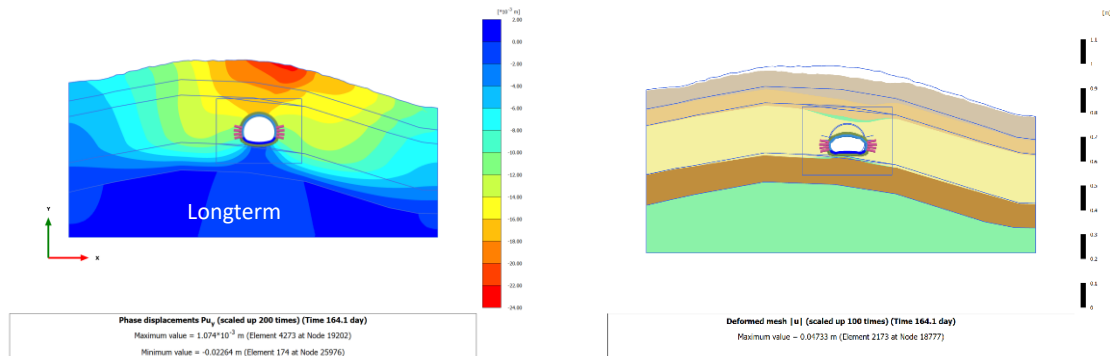


Maksimum = 4.688×10^{-3} m
Minimum = -0.02693 m

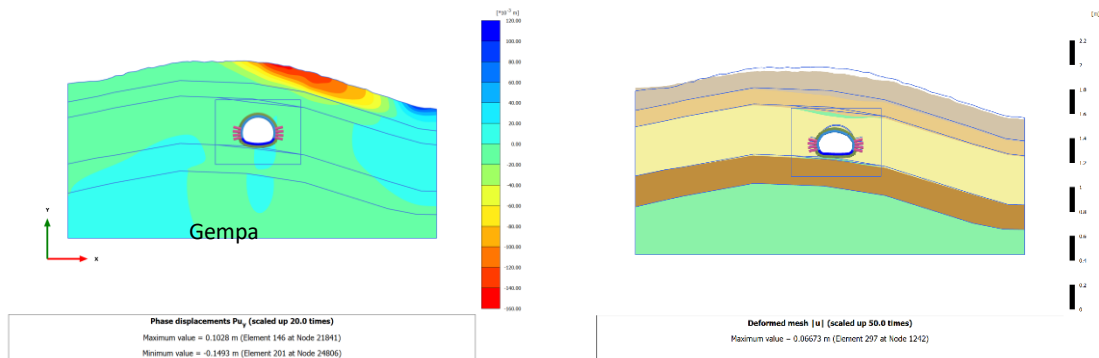
Gambar 18 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+890) (lanjutan)



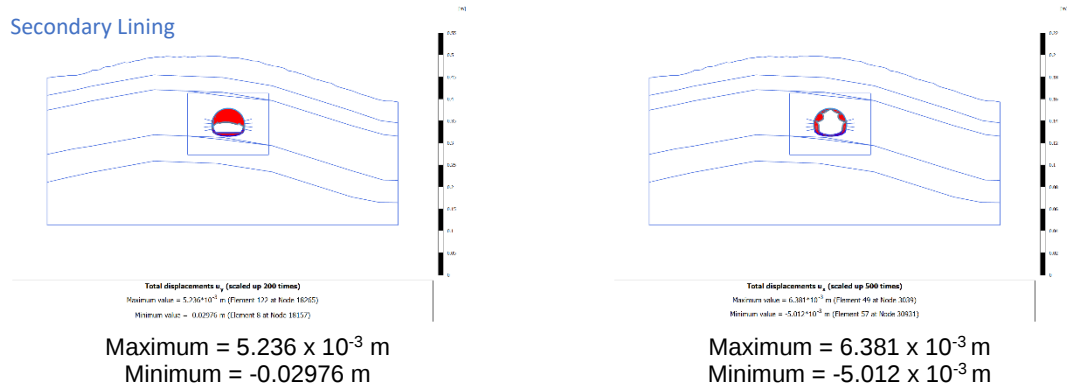
Maximum = 5.744×10^{-3} m
 Minimum = -0.03017 m



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



Maximum = 0.1028 m
 Minimum = -0.1493 m
 Gambar 19 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+890) (lanjutan)

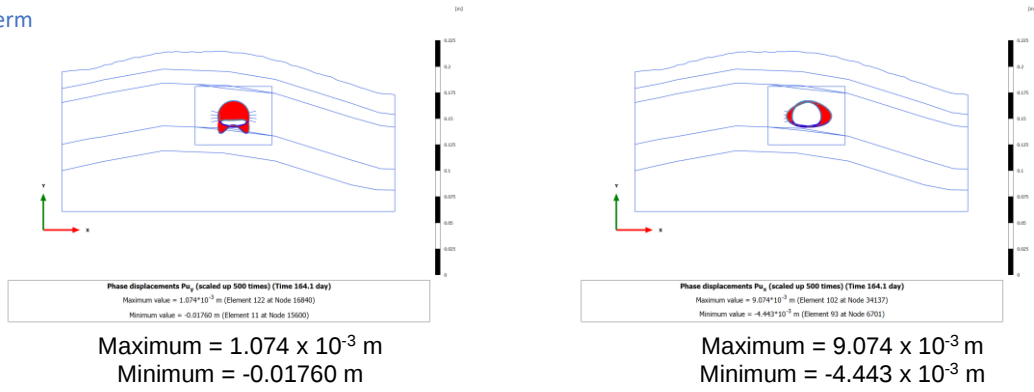


Maximum = 5.236×10^{-3} m
 Minimum = -0.02976 m

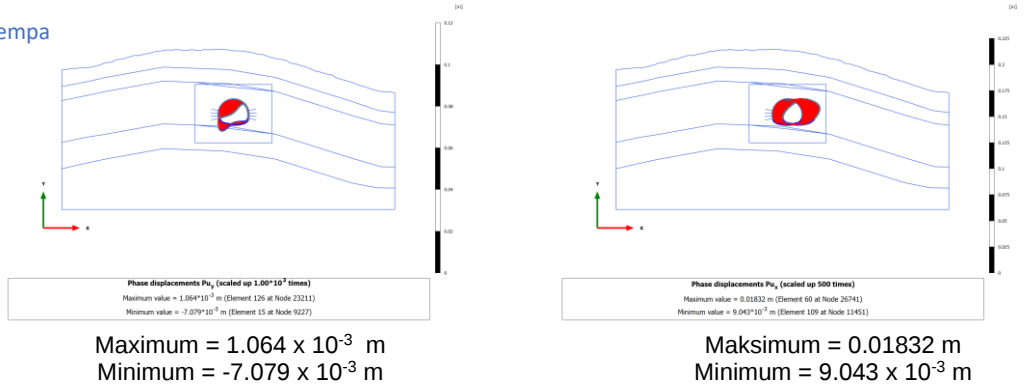
Maximum = 6.381×10^{-3} m
 Minimum = -5.012×10^{-3} m

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

Longterm

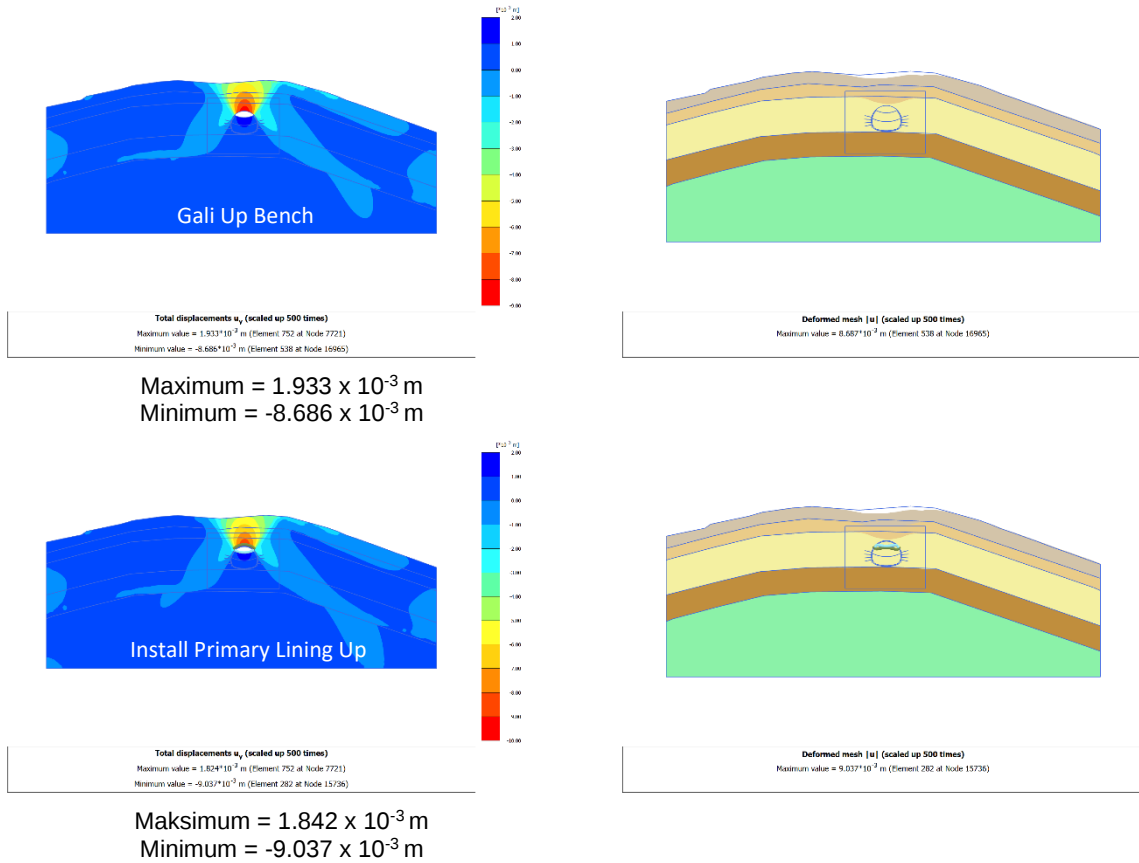


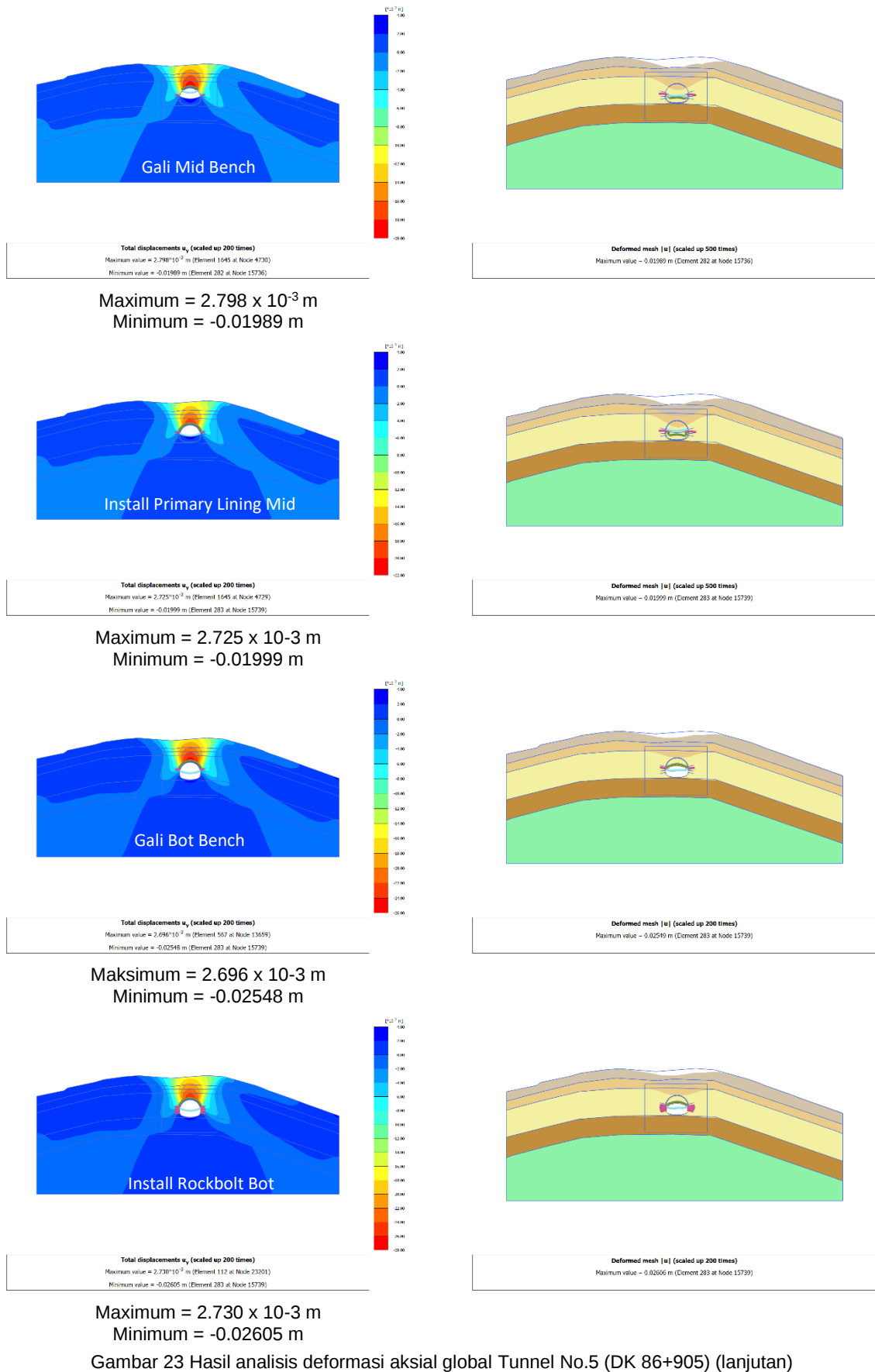
Gempa



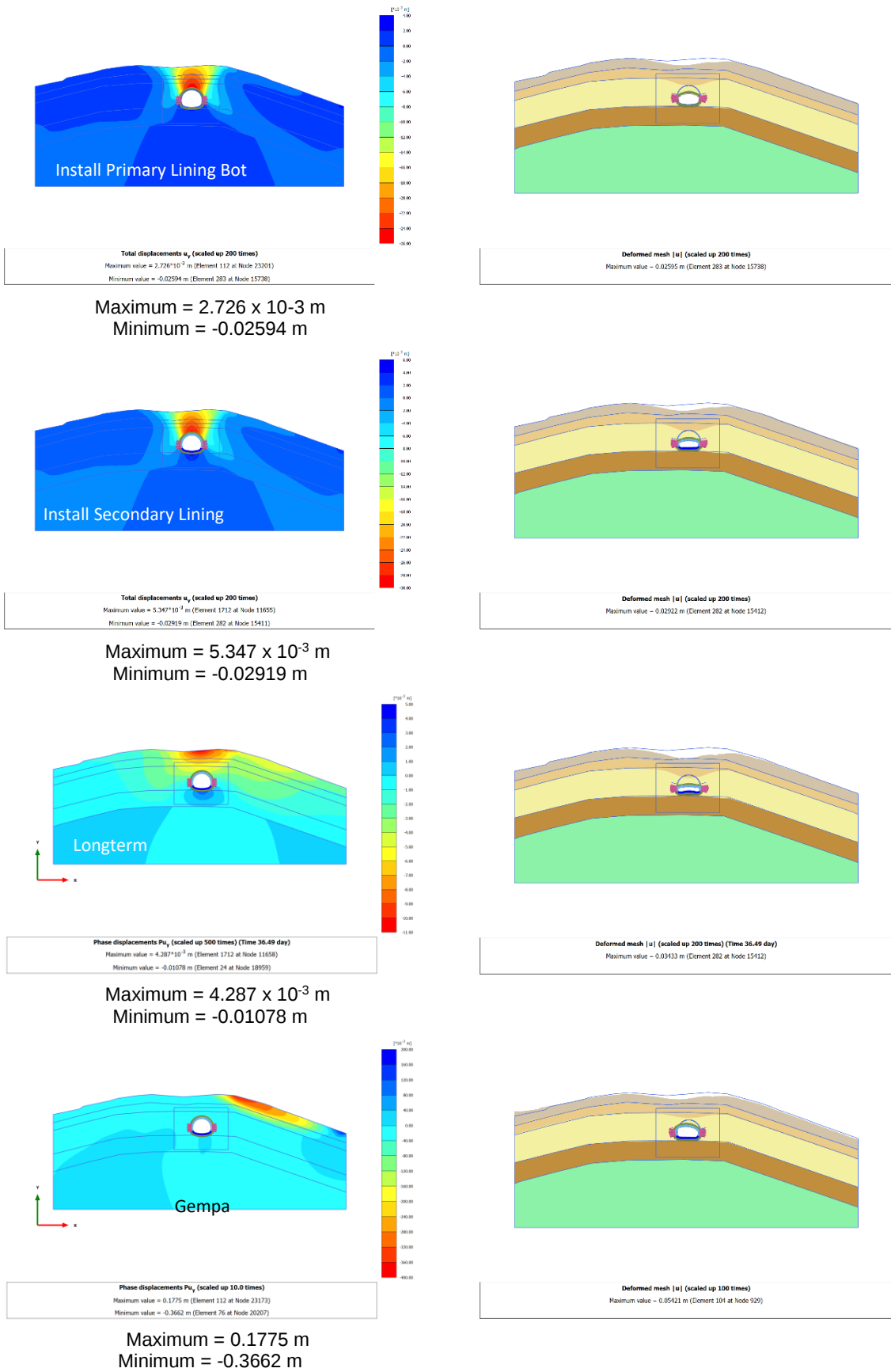
Gambar 21 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+890) (lanjutan)

c) Cross Section DK 86+905



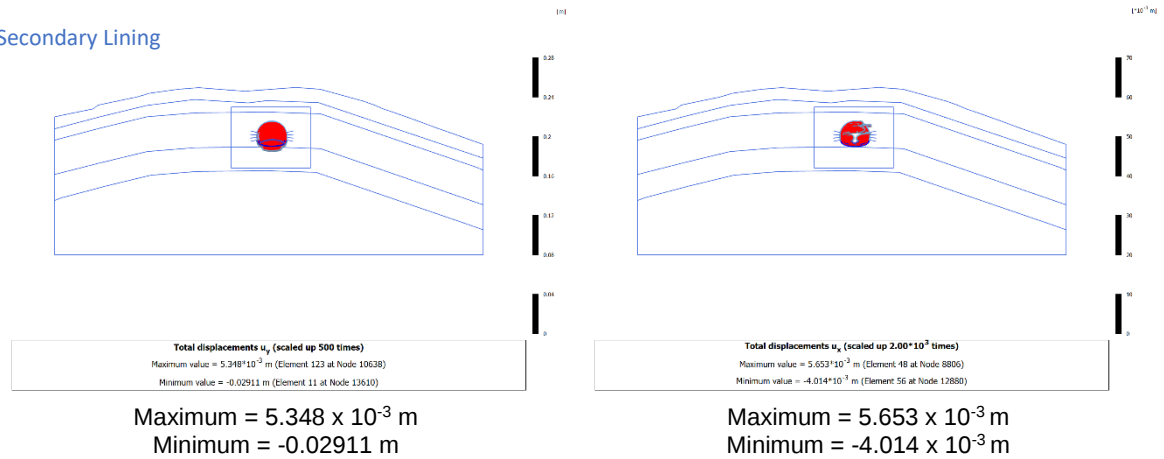


Gambar 23 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+905) (lanjutan)

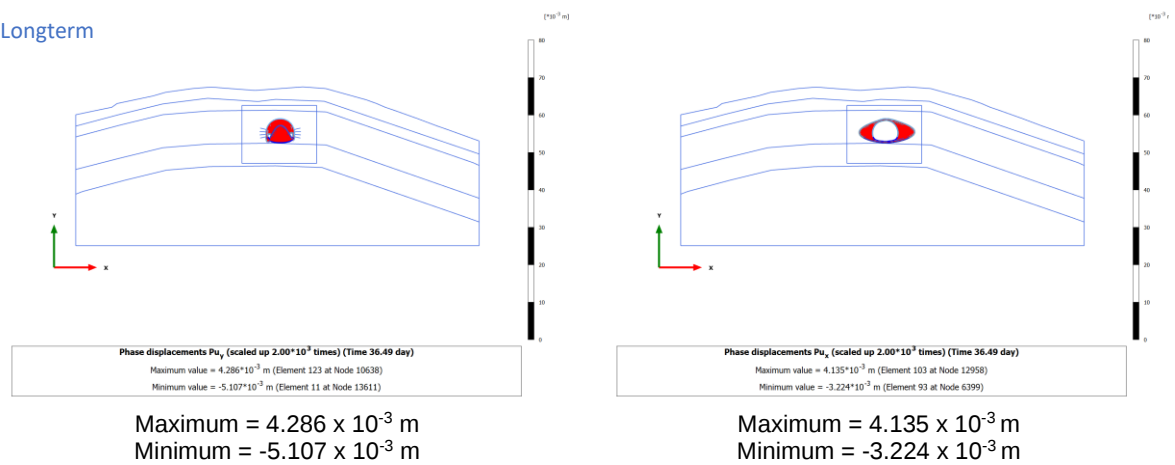


Gambar 24 Hasil analisis deformasi aksial global Tunnel No.5 (DK 86+905) (lanjutan)

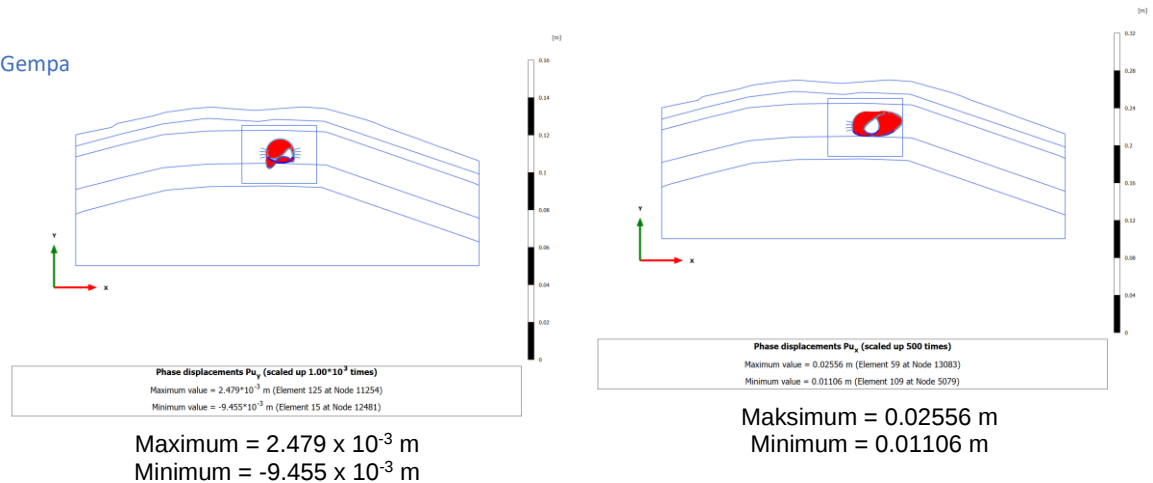
Secondary Lining



Longterm



Gempa

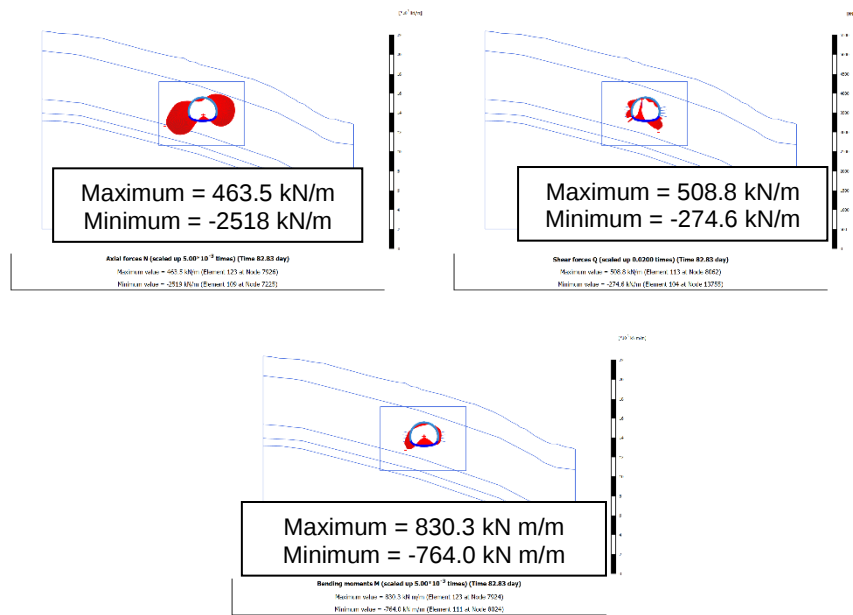


Gambar 25 Hasil analisis deformasi aksial(kiri) dan lateral(kanan) pada lining Tunnel No.5 (DK 86+905)

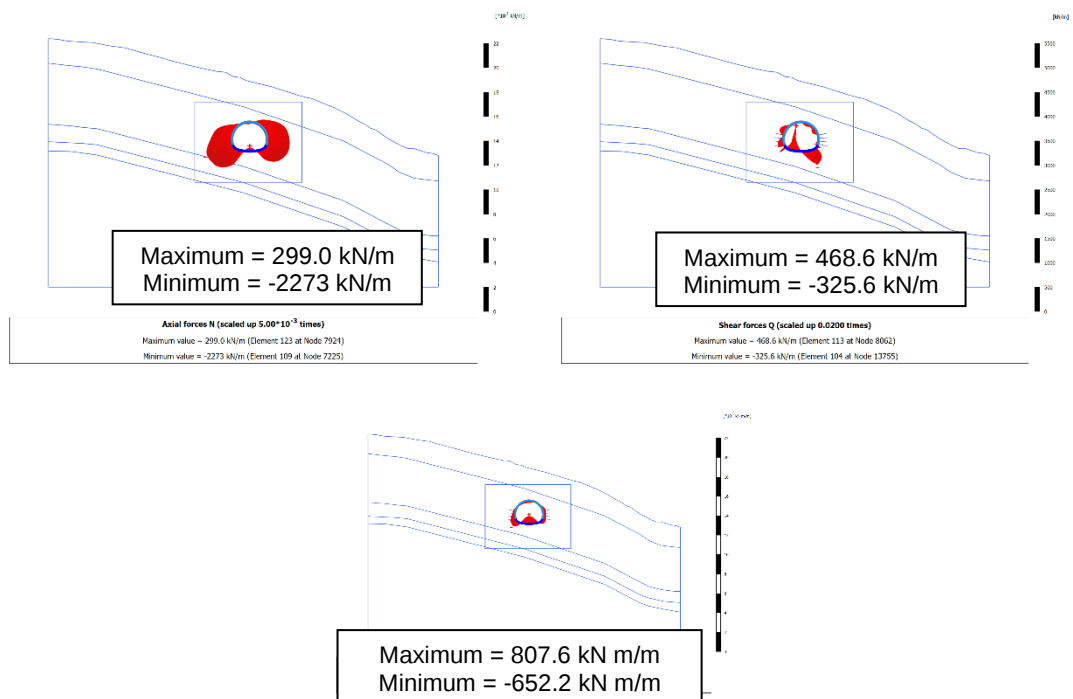
3. Gaya Dalam pada Lining Terowongan

Berdasarkan hasil analisis yang dilakukan dengan model numerik, gaya dalam yang bekerja pada lining terowongan dapat diperiksa. Gaya yang bekerja pada lining terowongan diantaranya gaya aksial, gaya geser dan momen lentur. Nilai gaya dalam yang dicantumkan merupakan nilai gaya dalam pada kondisi *longterm* dan kondisi setelah gempa. Gaya-gaya yang bekerja pada hasil analisis pemodelan dapat dilihat pada **Gambar 26 s/d Gambar 31**.

a) Cross Section DK 86+640

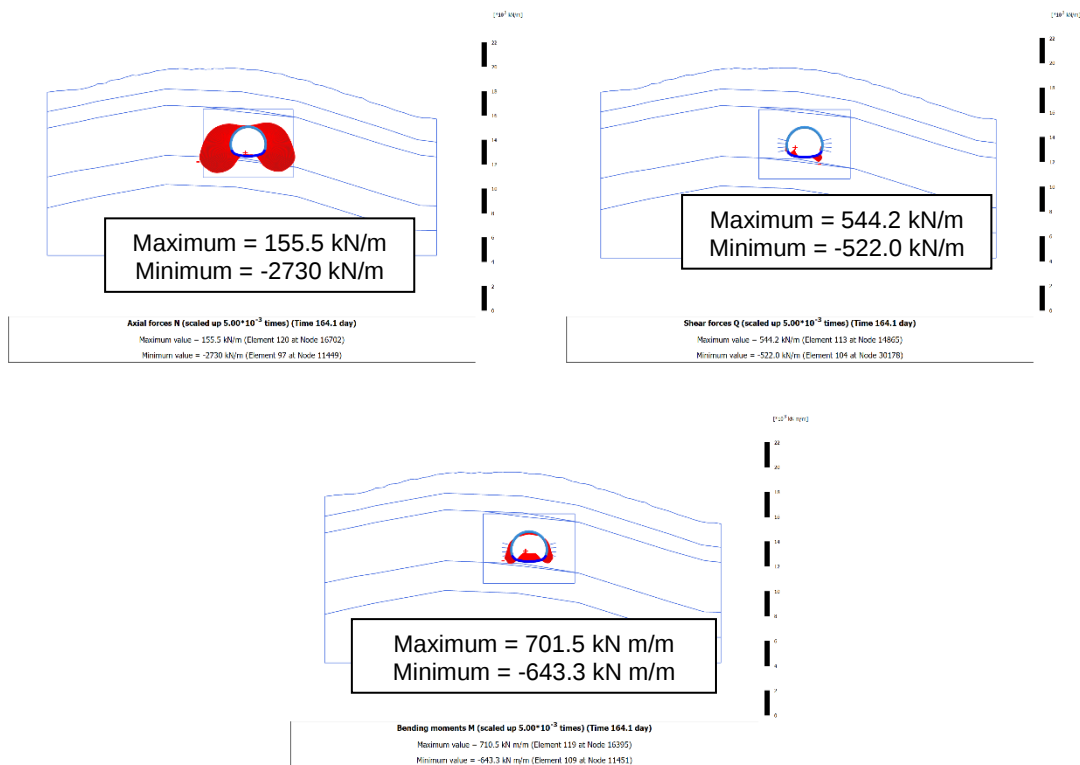


Gambar 26 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel No.5 (DK 86+640)

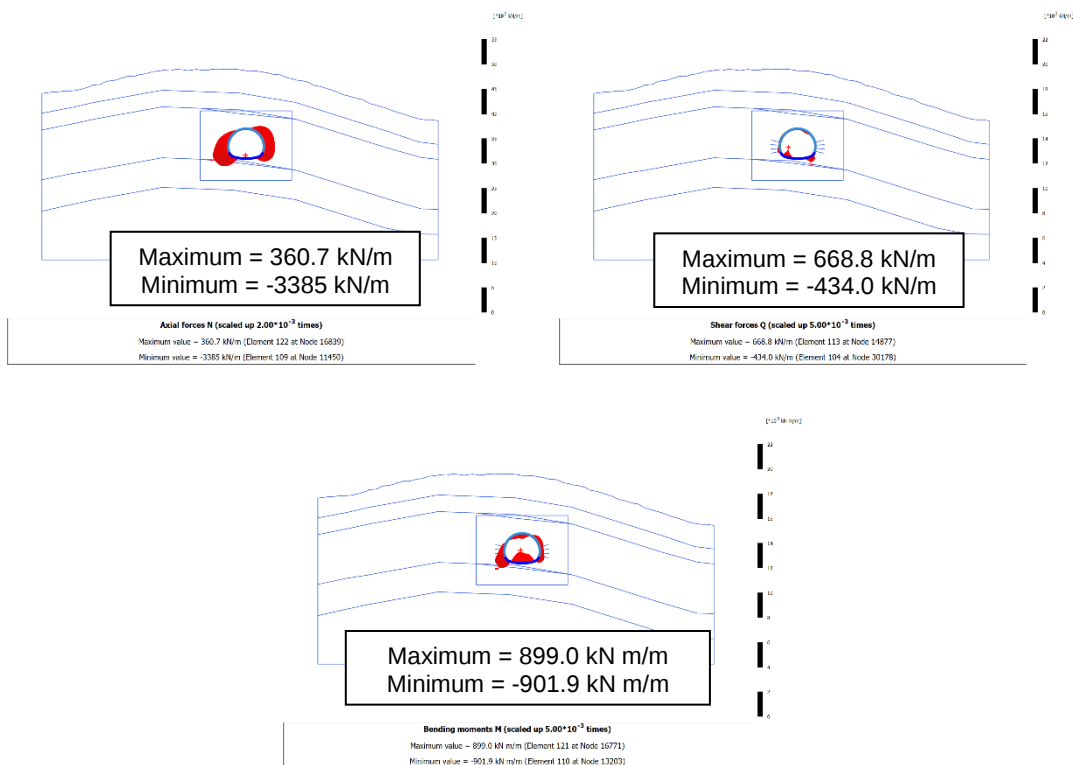


Gambar 27 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No.5 (DK 86+640)

b) Cross Section DK 86+890

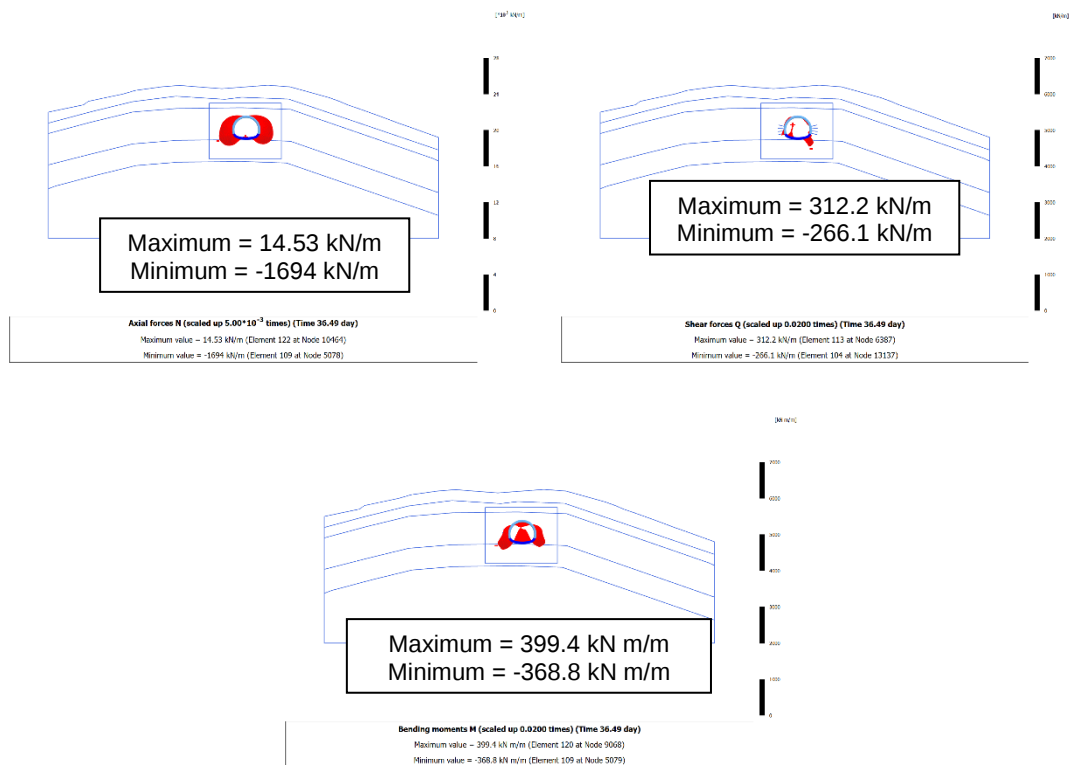


Gambar 28 Hasil analisis gaya dalam terowongan kondisi longterm di Tunnel No.5 (DK 86+890)

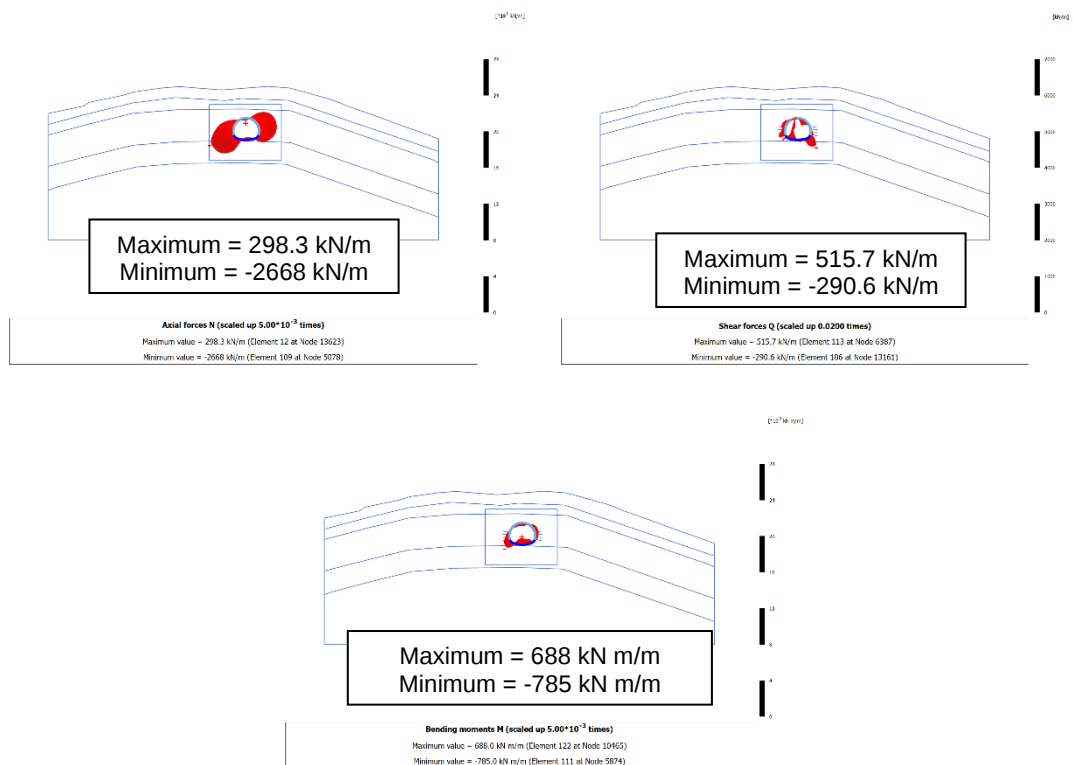


Gambar 29 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No.5 (DK 86+890)

c) Cross Section DK 86+905



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

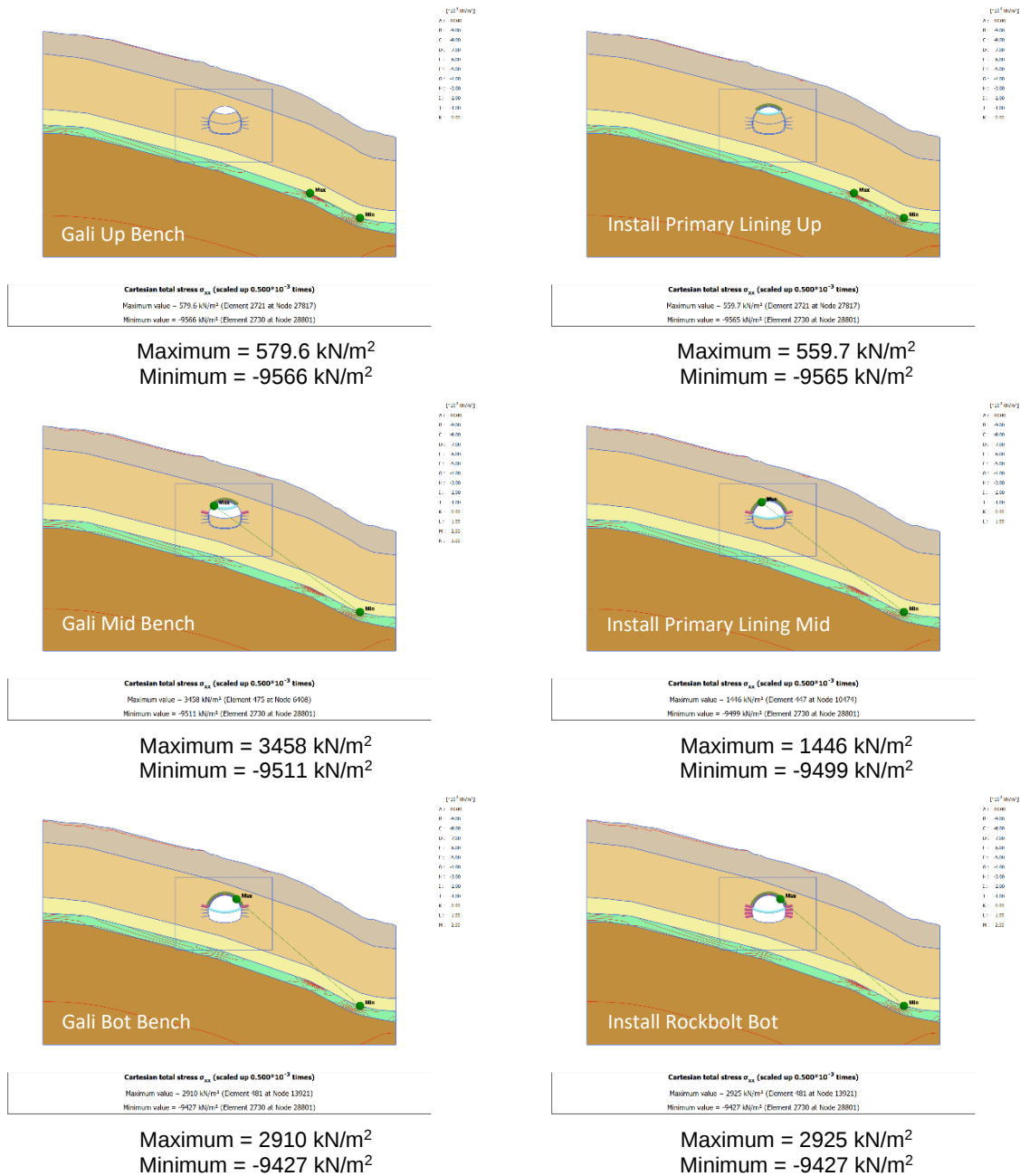


Gambar 31 Hasil analisis gaya dalam terowongan kondisi gempa di Tunnel No.5 (DK 86+905)

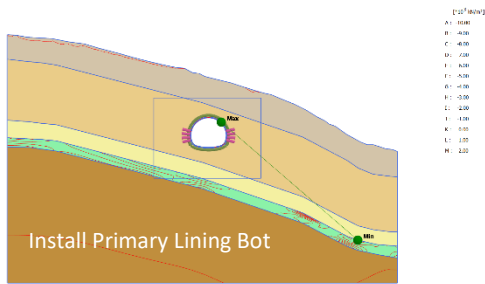
4. Tegangan Dalam Tanah

Berdasarkan hasil analisis yang dilakukan pada model numerik PLAXIS 2D, tegangan-tegangan dalam tanah yang dihasilkan dapat diperiksa. Tegangan dalam tanah berupa distribusi tegangan vertikal/ σ_y , horizontal/ σ_x , maksimum/ σ_1 , minimum/ σ_3 . Nilai tegangan dalam tanah yang dicantumkan merupakan besaran tegangan pada semua kondisi tahap galian. Tegangan-tegangan yang dihasilkan pada analisis pemodelan dapat dilihat pada **Gambar 32 s/d Gambar 61**.

a) Cross Section DK 86+640



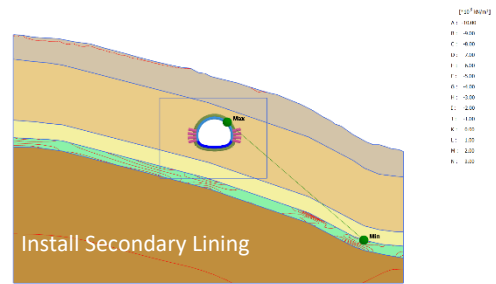
Gambar 32 Hasil analisis tegangan horizontal (σ_x) pada Tunnel No.5 (DK 86+640)



Install Primary Lining Bot

Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times)
Maximum value = 2887 kN/m² (Element 481 at Node 13921)
Minimum value = -9413 kN/m² (Element 2730 at Node 28801)

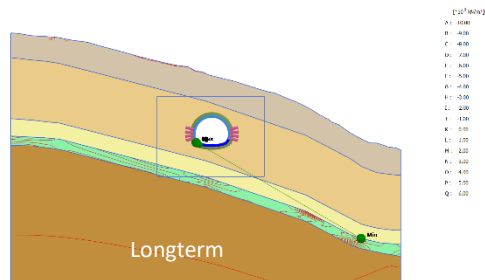
Maksimum = 2887 kN/m²
Minimum = -9413 kN/m²



Install Secondary Lining

Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times)
Maximum value = 3006 kN/m² (Element 481 at Node 13921)
Minimum value = -9405 kN/m² (Element 2730 at Node 28801)

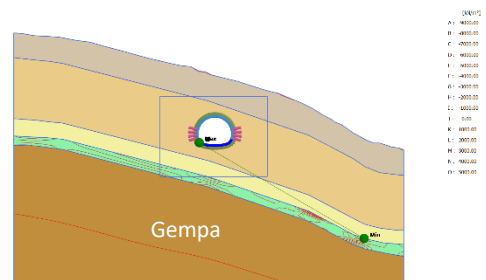
Maximum = 3006 kN/m²
Minimum = -9405 kN/m²



Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times) (Time 82.83 day)
Maximum value = 6335 kN/m² (Element 2130 at Node 12300)
Minimum value = -9590 kN/m² (Element 2730 at Node 28801)

Maximum = 6335 kN/m²
Minimum = -9590 kN/m²

Longterm

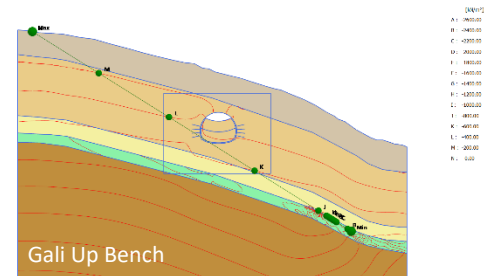


Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times)
Maximum value = 5123 kN/m² (Element 2130 at Node 12300)
Minimum value = -8487 kN/m² (Element 2730 at Node 28801)

Maximum = 5123 kN/m²
Minimum = -8487 kN/m²

Gempa

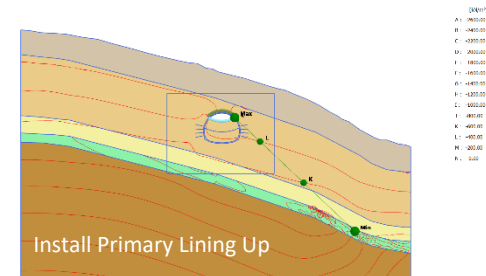
Gambar 33 Hasil analisis tegangan horizontal (σ_x) pada Tunnel No.5 (DK 86+640) (lanjutan)



Gali Up Bench

Cartesian total stress σ_{yy} (scaled up 2.00×10^{-3} times)
Maximum value = 1.146 kN/m² (Element 40 at Node 6410)
Minimum value = -2575 kN/m² (Element 2715 at Node 28500)

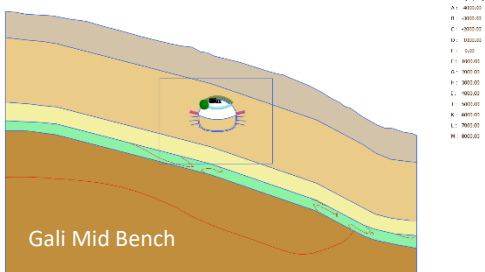
Maximum = 1.146 kN/m²
Minimum = -2575 kN/m²



Install Primary Lining Up

Cartesian total stress σ_{yy} (scaled up 2.00×10^{-3} times)
Maximum value = 32.47 kN/m² (Element 481 at Node 13921)
Minimum value = -2576 kN/m² (Element 2715 at Node 28500)

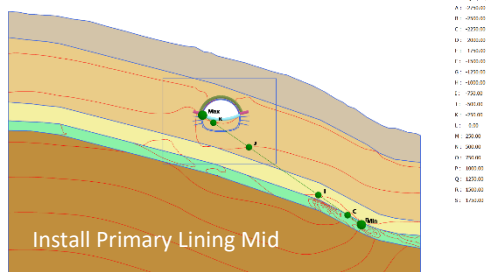
Maximum = 32.47 kN/m²
Minimum = -2576 kN/m²



Gali Mid Bench

Cartesian total stress σ_{yy} (scaled up 0.500×10^{-3} times)
Maximum value = 8715 kN/m² (Element 475 at Node 6412)
Minimum value = -3058 kN/m² (Element 482 at Node 6424)

Maximum = 8715 kN/m²
Minimum = -3058 kN/m²

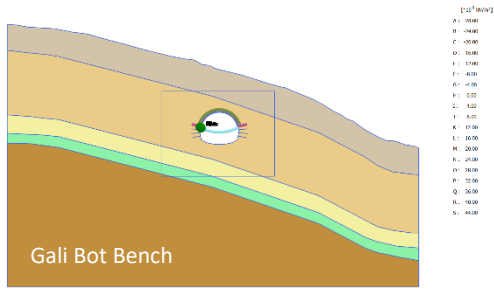


Install Primary Lining Mid

Cartesian total stress σ_{yy} (scaled up 1.00×10^{-3} times)
Maximum value = 1917 kN/m² (Element 500 at Node 4242)
Minimum value = -2577 kN/m² (Element 2715 at Node 28500)

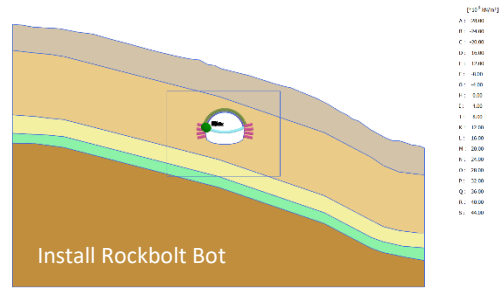
Maximum = 1917 kN/m²
Minimum = -2577 kN/m²

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



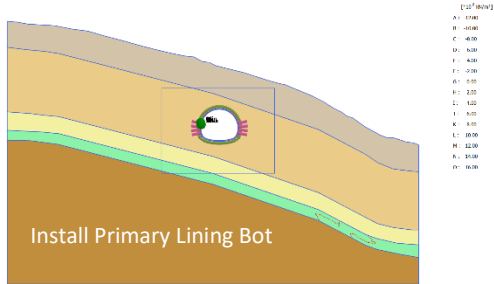
Cartesian total stress σ_{yy} (scaled up 0.0500*10⁻³ times)
 Maximum value = 46.28*10³ kN/m² (Element 500 at Node 4242)
 Minimum value = -27.11*10³ kN/m² (Element 498 at Node 3532)

Maximum = 46.28 x 10³ kN/m²
 Minimum = -27.11 x 10³ kN/m²



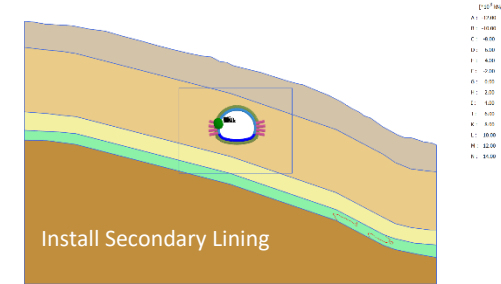
Cartesian total stress σ_{yy} (scaled up 0.0500*10⁻³ times)
 Maximum value = 46.36*10³ kN/m² (Element 500 at Node 4242)
 Minimum value = -27.16*10³ kN/m² (Element 498 at Node 3532)

Maximum = 46.36 x 10³ kN/m²
 Minimum = -27.16 x 10³ kN/m²



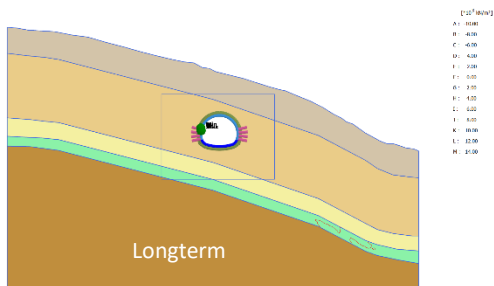
Cartesian total stress σ_{yy} (scaled up 0.200*10⁻³ times)
 Maximum value = 16.67*10³ kN/m² (Element 500 at Node 3516)
 Minimum value = -10.64*10³ kN/m² (Element 490 at Node 3535)

Maksimum = 16.67 x 10³ kN/m²
 Minimum = -10.64 x 10³ kN/m²



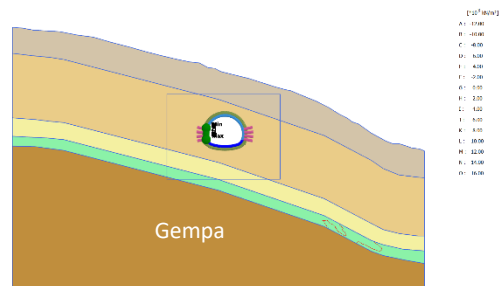
Cartesian total stress σ_{yy} (scaled up 0.200*10⁻³ times)
 Maximum value = 15.48*10³ kN/m² (Element 500 at Node 3516)
 Minimum value = -10.93*10³ kN/m² (Element 490 at Node 3535)

Maximum = 15.48 x 10³ kN/m²
 Minimum = -10.93 x 10³ kN/m²



Cartesian total stress σ_{yy} (scaled up 0.200*10⁻³ times) (Time 82.83 day)
 Maximum value = 14.17*10³ kN/m² (Element 500 at Node 3516)
 Minimum value = -9114 kN/m² (Element 487 at Node 3533)

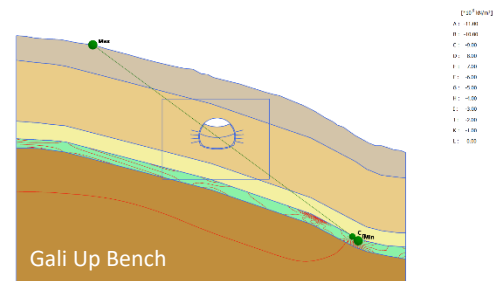
Maximum = 14.17 x 10³ kN/m²
 Minimum = -9114 kN/m²



Cartesian total stress σ_{yy} (scaled up 0.200*10⁻³ times)
 Maximum value = 17.33*10³ kN/m² (Element 2155 at Node 11088)
 Minimum value = -11.10*10³ kN/m² (Element 487 at Node 3533)

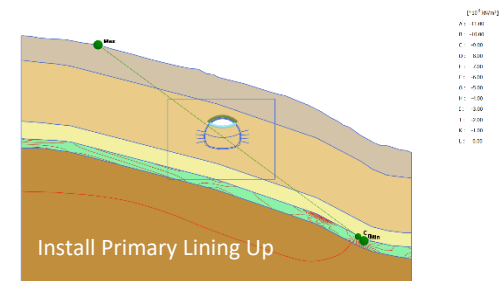
Maximum = 17.33 x 10³ kN/m²
 Minimum = -11.10 x 10³ kN/m²

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



Principal total stress σ_1 (scaled up 0.500*10⁻³ times)
 Maximum value = 0.2893 kN/m² (Element 3 at Node 8862)
 Minimum value = -10.39*10³ kN/m² (Element 2730 at Node 28638)

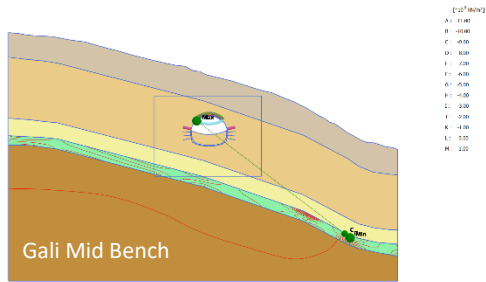
Maximum = 0.2893 kN/m²
 Minimum = -10.39 x 10³ kN/m²



Principal total stress σ_1 (scaled up 0.500*10⁻³ times)
 Maximum value = 0.2480 kN/m² (Element 3 at Node 8862)
 Minimum value = -10.39*10³ kN/m² (Element 2730 at Node 28638)

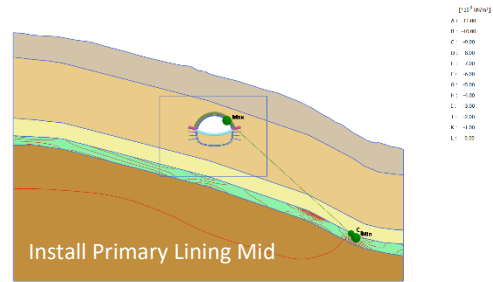
Maximum = 0.2480 kN/m²
 Minimum = -10.39 x 10³ kN/m²

Gambar 36 Hasil analisis tegangan maksimum (σ_1) pada Tunnel No.5 (DK 86+640)



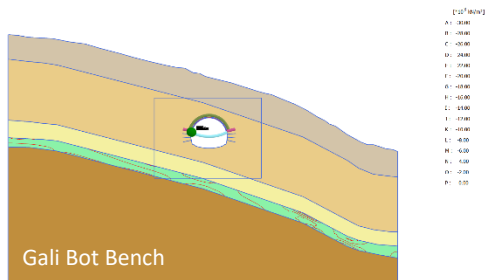
Principal total stress σ_1 (scaled up 0.500×10^{-3} times)
 Maximum value = 1498 kN/m² (Element 475 at Node 6412)
 Minimum value = -10.35×10^3 kN/m² (Element 2730 at Node 28658)

Maximum = 1498 kN/m²
 Minimum = -10.35×10^3 kN/m²



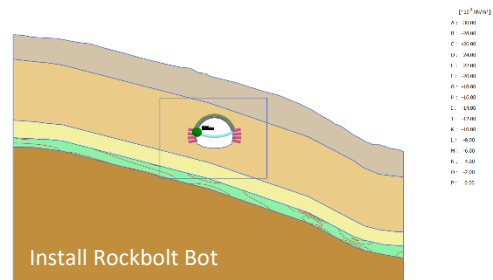
Principal total stress σ_1 (scaled up 0.500×10^{-3} times)
 Maximum value = 17.60 kN/m² (Element 480 at Node 13913)
 Minimum value = -10.34×10^3 kN/m² (Element 2730 at Node 28658)

Maximum = 17.60 kN/m²
 Minimum = -10.34×10^3 kN/m²



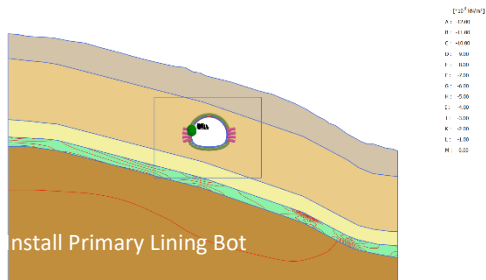
Principal total stress σ_1 (scaled up 0.200×10^{-3} times)
 Maximum value = 1263 kN/m² (Element 500 at Node 3516)
 Minimum value = -28.66×10^3 kN/m² (Element 498 at Node 3532)

Maximum = 1263 kN/m²
 Minimum = -28.66×10^3 kN/m²



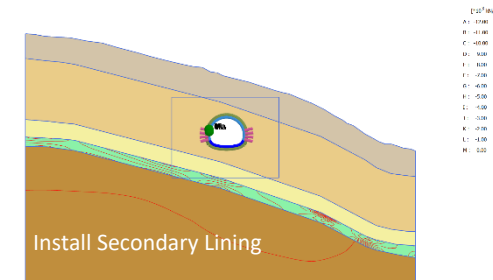
Principal total stress σ_1 (scaled up 0.200×10^{-3} times)
 Maximum value = 1265 kN/m² (Element 500 at Node 3516)
 Minimum value = -28.66×10^3 kN/m² (Element 498 at Node 3532)

Maximum = 1265 kN/m²
 Minimum = -28.66×10^3 kN/m²



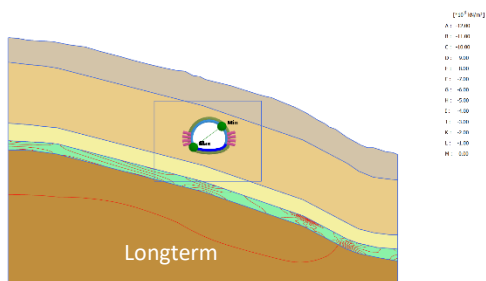
Principal total stress σ_1 (scaled up 0.500×10^{-3} times)
 Maximum value = 681.6 kN/m² (Element 500 at Node 3516)
 Minimum value = -11.57×10^3 kN/m² (Element 487 at Node 3553)

Maksimum = 681.6 kN/m²
 Minimum = -11.57×10^3 kN/m²



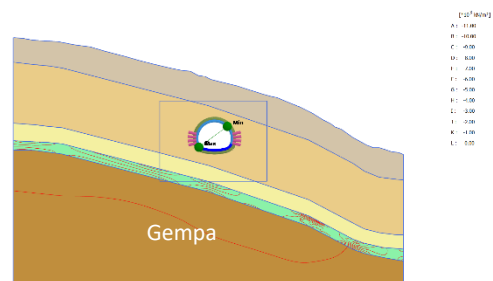
Principal total stress σ_1 (scaled up 0.500×10^{-3} times)
 Maximum value = 659.4 kN/m² (Element 500 at Node 3516)
 Minimum value = -11.91×10^3 kN/m² (Element 487 at Node 3553)

Maximum = 659.4 kN/m²
 Minimum = -11.91×10^3 kN/m²



Principal total stress σ_1 (scaled up 0.500×10^{-3} times) (Time 82.83 day)
 Maximum value = 870.9 kN/m² (Element 2130 at Node 12300)
 Minimum value = -11.09×10^3 kN/m² (Element 517 at Node 13925)

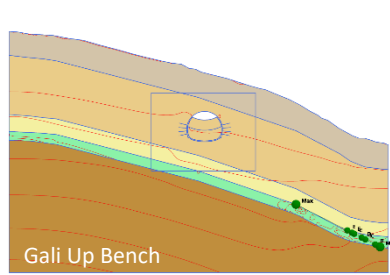
Maximum = 870.9 kN/m²
 Minimum = -11.09×10^3 kN/m²



Principal total stress σ_1 (scaled up 0.500×10^{-3} times)
 Maximum value = 685.0 kN/m² (Element 2130 at Node 12300)
 Minimum value = -10.65×10^3 kN/m² (Element 517 at Node 13925)

Maximum = 685.0 kN/m²
 Minimum = -10.65×10^3 kN/m²

Gambar 37 Hasil analisis tegangan maksimum (σ_1) pada Tunnel No.5 (DK 86+640) (lanjutan)

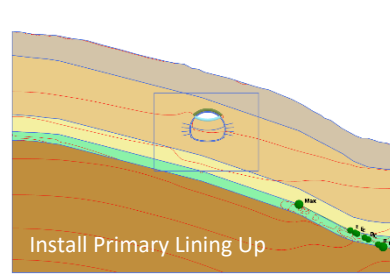


300000
 A: 1000.00
 B: 1000.00
 C: 1000.00
 D: 1000.00
 E: 1000.00
 F: 1000.00
 G: 1000.00
 H: 1000.00
 I: 1000.00
 J: 1000.00
 K: 1000.00
 L: 1000.00
 M: 1000.00
 N: 1000.00
 O: 1000.00
 P: 1000.00
 Q: 1000.00
 R: 1000.00
 S: 1000.00
 T: 1000.00
 U: 1000.00
 V: 1000.00
 W: 1000.00
 X: 1000.00
 Y: 1000.00
 Z: 1000.00

Gali Up Bench

Principal total stress σ_3 (scaled up 2.00×10^{-3} times)
 Maximum value = 617.5 kN/m^2 (Element 2/21 at Node 2/81)
 Minimum value = -1556 kN/m^2 (Element 2736 at Node 29081)

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

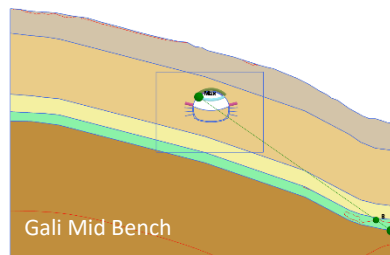


300000
 A: 1000.00
 B: 1000.00
 C: 1000.00
 D: 1000.00
 E: 1000.00
 F: 1000.00
 G: 1000.00
 H: 1000.00
 I: 1000.00
 J: 1000.00
 K: 1000.00
 L: 1000.00
 M: 1000.00
 N: 1000.00
 O: 1000.00
 P: 1000.00
 Q: 1000.00
 R: 1000.00
 S: 1000.00
 T: 1000.00
 U: 1000.00
 V: 1000.00
 W: 1000.00
 X: 1000.00
 Y: 1000.00
 Z: 1000.00

Install Primary Lining Up

Principal total stress σ_3 (scaled up 2.00×10^{-3} times)
 Maximum value = 594.4 kN/m^2 (Element 2/21 at Node 2/81)
 Minimum value = -1556 kN/m^2 (Element 2736 at Node 29081)

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

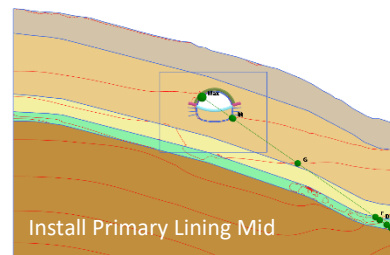


300000
 A: 1000.00
 B: 1000.00
 C: 1000.00
 D: 1000.00
 E: 1000.00
 F: 1000.00
 G: 1000.00
 H: 1000.00
 I: 1000.00
 J: 1000.00
 K: 1000.00
 L: 1000.00
 M: 1000.00
 N: 1000.00
 O: 1000.00
 P: 1000.00
 Q: 1000.00
 R: 1000.00
 S: 1000.00
 T: 1000.00
 U: 1000.00
 V: 1000.00
 W: 1000.00
 X: 1000.00
 Y: 1000.00
 Z: 1000.00

Gali Mid Bench

Principal total stress σ_3 (scaled up 0.500×10^{-3} times)
 Maximum value = $10.11 \times 10^3 \text{ kN/m}^2$ (Element 475 at Node 6412)
 Minimum value = -1559 kN/m^2 (Element 2736 at Node 29081)

Maximum = $10.11 \times 10^3 \text{ kN/m}^2$
 Minimum = -1559 kN/m^2

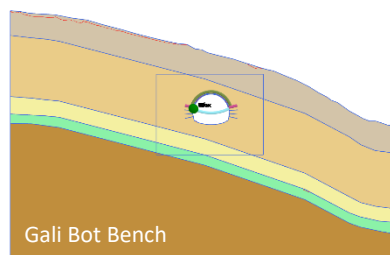


300000
 A: 1000.00
 B: 1000.00
 C: 1000.00
 D: 1000.00
 E: 1000.00
 F: 1000.00
 G: 1000.00
 H: 1000.00
 I: 1000.00
 J: 1000.00
 K: 1000.00
 L: 1000.00
 M: 1000.00
 N: 1000.00
 O: 1000.00
 P: 1000.00
 Q: 1000.00
 R: 1000.00
 S: 1000.00
 T: 1000.00
 U: 1000.00
 V: 1000.00
 W: 1000.00
 X: 1000.00
 Y: 1000.00
 Z: 1000.00

Install Primary Lining Mid

Principal total stress σ_3 (scaled up 2.00×10^{-3} times)
 Maximum value = 1951 kN/m^2 (Element 499 at Node 5877)
 Minimum value = -1558 kN/m^2 (Element 2736 at Node 29081)

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

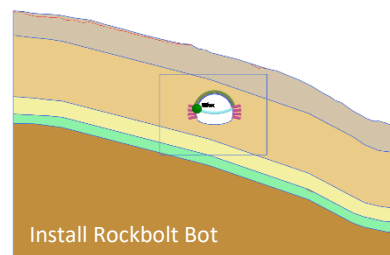


300000
 A: 1000.00
 B: 1000.00
 C: 1000.00
 D: 1000.00
 E: 1000.00
 F: 1000.00
 G: 1000.00
 H: 1000.00
 I: 1000.00
 J: 1000.00
 K: 1000.00
 L: 1000.00
 M: 1000.00
 N: 1000.00
 O: 1000.00
 P: 1000.00
 Q: 1000.00
 R: 1000.00
 S: 1000.00
 T: 1000.00
 U: 1000.00
 V: 1000.00
 W: 1000.00
 X: 1000.00
 Y: 1000.00
 Z: 1000.00

Gali Bot Bench

Principal total stress σ_3 (scaled up 0.100×10^{-3} times)
 Maximum value = $46.28 \times 10^3 \text{ kN/m}^2$ (Element 500 at Node 4242)
 Minimum value = -3050 kN/m^2 (Element 498 at Node 4238)

Maximum = $46.28 \times 10^3 \text{ kN/m}^2$
 Minimum = -3050 kN/m^2

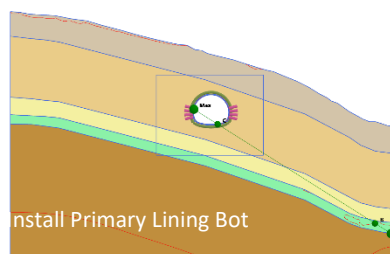


300000
 A: 1000.00
 B: 1000.00
 C: 1000.00
 D: 1000.00
 E: 1000.00
 F: 1000.00
 G: 1000.00
 H: 1000.00
 I: 1000.00
 J: 1000.00
 K: 1000.00
 L: 1000.00
 M: 1000.00
 N: 1000.00
 O: 1000.00
 P: 1000.00
 Q: 1000.00
 R: 1000.00
 S: 1000.00
 T: 1000.00
 U: 1000.00
 V: 1000.00
 W: 1000.00
 X: 1000.00
 Y: 1000.00
 Z: 1000.00

Install Rockbolt Bot

Principal total stress σ_3 (scaled up 0.100×10^{-3} times)
 Maximum value = $46.35 \times 10^3 \text{ kN/m}^2$ (Element 500 at Node 4242)
 Minimum value = -3058 kN/m^2 (Element 498 at Node 4238)

Maximum = $46.35 \times 10^3 \text{ kN/m}^2$
 Minimum = -3058 kN/m^2

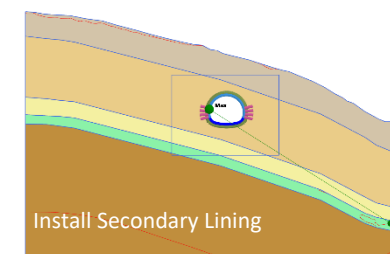


300000
 A: 1000.00
 B: 1000.00
 C: 1000.00
 D: 1000.00
 E: 1000.00
 F: 1000.00
 G: 1000.00
 H: 1000.00
 I: 1000.00
 J: 1000.00
 K: 1000.00
 L: 1000.00
 M: 1000.00
 N: 1000.00
 O: 1000.00
 P: 1000.00
 Q: 1000.00
 R: 1000.00
 S: 1000.00
 T: 1000.00
 U: 1000.00
 V: 1000.00
 W: 1000.00
 X: 1000.00
 Y: 1000.00
 Z: 1000.00

Install Primary Lining Bot

Principal total stress σ_3 (scaled up 0.200×10^{-3} times)
 Maximum value = $16.73 \times 10^3 \text{ kN/m}^2$ (Element 500 at Node 3516)
 Minimum value = -1554 kN/m^2 (Element 2736 at Node 29081)

Maksimum = $16.73 \times 10^3 \text{ kN/m}^2$
 Minimum = -1554 kN/m^2



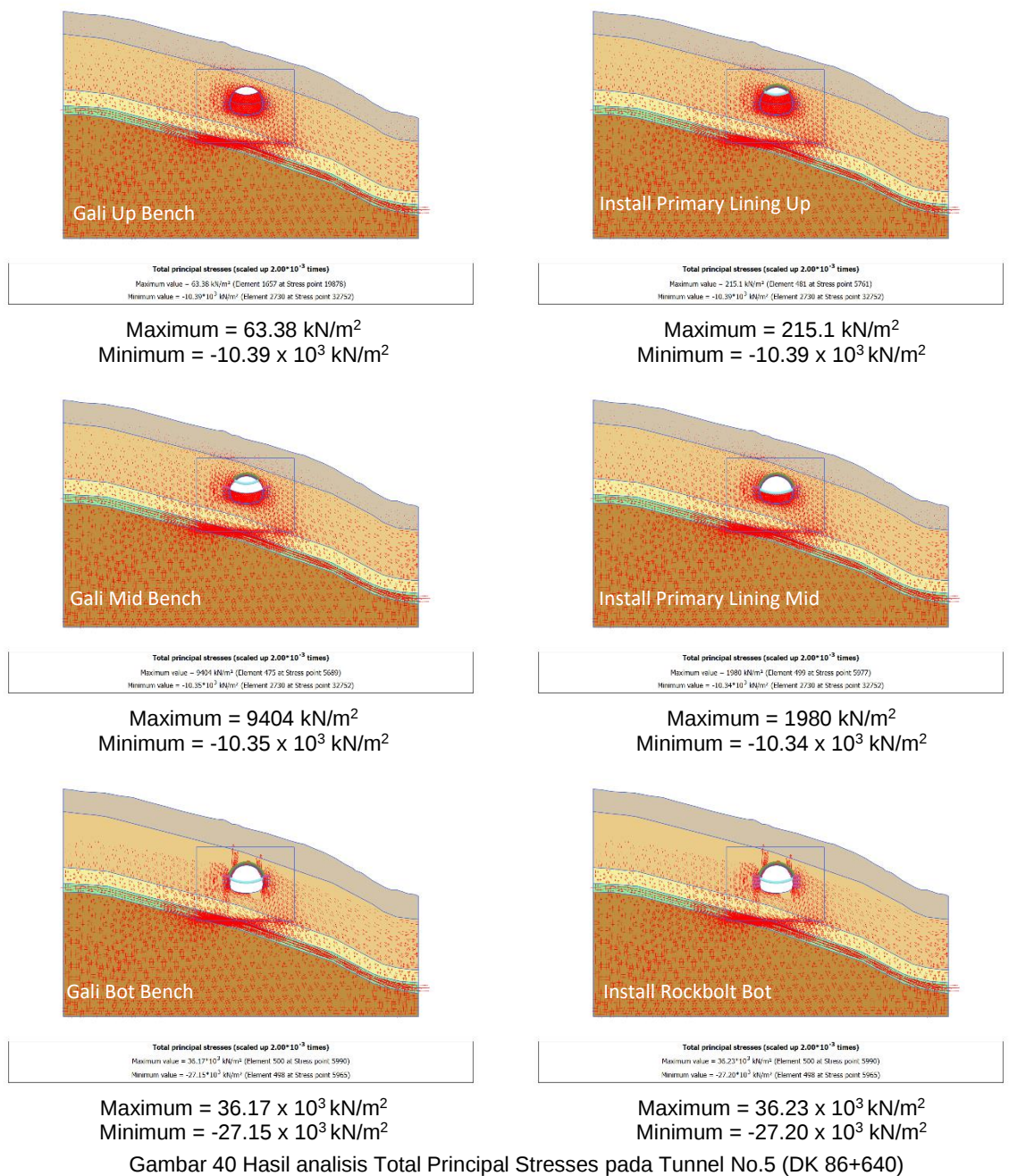
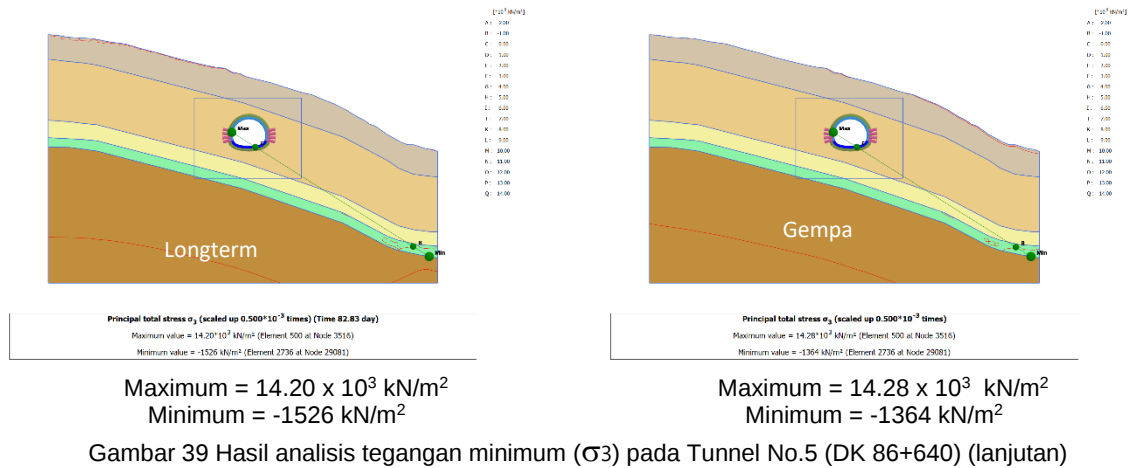
300000
 A: 1000.00
 B: 1000.00
 C: 1000.00
 D: 1000.00
 E: 1000.00
 F: 1000.00
 G: 1000.00
 H: 1000.00
 I: 1000.00
 J: 1000.00
 K: 1000.00
 L: 1000.00
 M: 1000.00
 N: 1000.00
 O: 1000.00
 P: 1000.00
 Q: 1000.00
 R: 1000.00
 S: 1000.00
 T: 1000.00
 U: 1000.00
 V: 1000.00
 W: 1000.00
 X: 1000.00
 Y: 1000.00
 Z: 1000.00

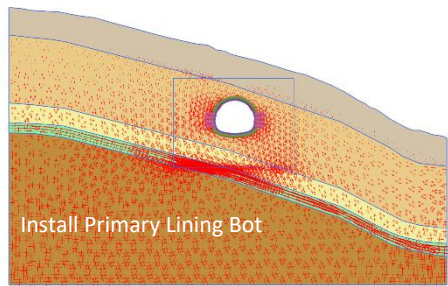
Install Secondary Lining

Principal total stress σ_3 (scaled up 0.500×10^{-3} times)
 Maximum value = $15.51 \times 10^3 \text{ kN/m}^2$ (Element 500 at Node 3516)
 Minimum value = -1552 kN/m^2 (Element 2736 at Node 29081)

Maximum = $15.51 \times 10^3 \text{ kN/m}^2$
 Minimum = -1552 kN/m^2

Gambar 38 Hasil analisis tegangan minimum (σ_3) pada Tunnel No.5 (DK 86+640)

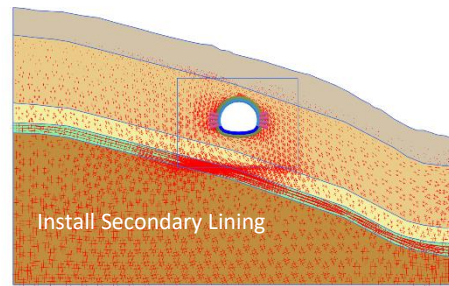




Install Primary Lining Bot

Total principal stresses (scaled up 2.00×10^{-3} times)
Maximum value = 15.57×10^3 kN/m² (Element 500 at Stress point 5990)
Minimum value = -10.36×10^3 kN/m² (Element 490 at Stress point 5879)

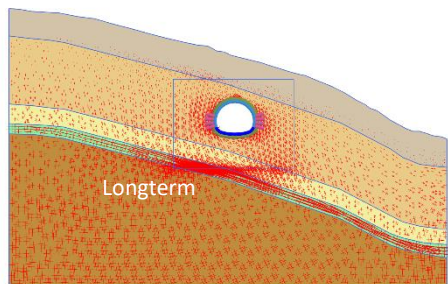
Maksimum = 15.57×10^3 kN/m²
Minimum = -10.36×10^3 kN/m²



Install Secondary Lining

Total principal stresses (scaled up 2.00×10^{-3} times)
Maximum value = 14.41×10^3 kN/m² (Element 500 at Stress point 5990)
Minimum value = -10.73×10^3 kN/m² (Element 490 at Stress point 5879)

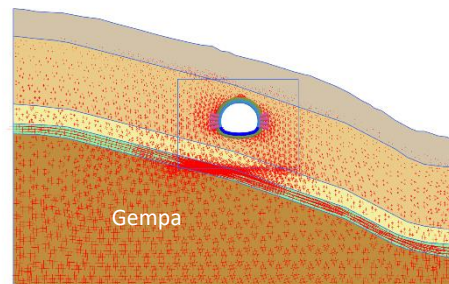
Maximum = 14.41×10^3 kN/m²
Minimum = -10.73×10^3 kN/m²



Longterm

Total principal stresses (scaled up 2.00×10^{-3} times) (Time 82.83 day)
Maximum value = 13.34×10^3 kN/m² (Element 500 at Stress point 5990)
Minimum value = -10.35×10^3 kN/m² (Element 2730 at Stress point 32752)

Maximum = 13.34×10^3 kN/m²
Minimum = -10.35×10^3 kN/m²



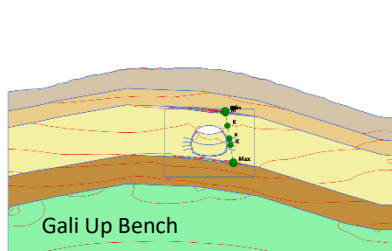
Gempa

Total principal stresses (scaled up 2.00×10^{-3} times)
Maximum value = 13.39×10^3 kN/m² (Element 500 at Stress point 5990)
Minimum value = -9821 kN/m² (Element 517 at Stress point 6199)

Maximum = 13.39×10^3 kN/m²
Minimum = -9821 kN/m²

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

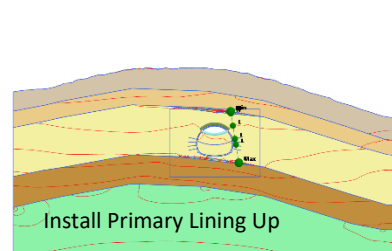
b) Cross Section DK 86+890



Gali Up Bench

Cartesian total stress σ_{xx} (scaled up 5.00×10^{-3} times)
Maximum value = 77.44 kN/m² (Element 4364 at Node 36966)
Minimum value = -1167 kN/m² (Element 463 at Node 24783)

Maximum = 77.44 kN/m²
Minimum = -1167 kN/m²

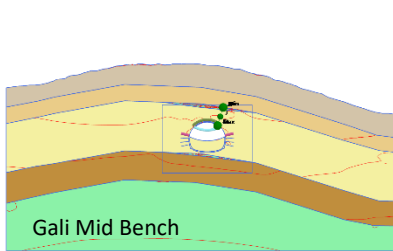


Install Primary Lining Up

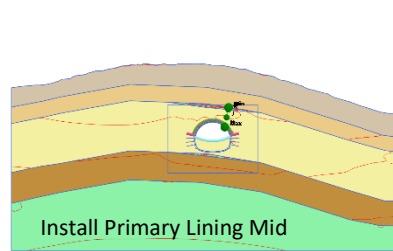
Cartesian total stress σ_{xx} (scaled up 5.00×10^{-3} times)
Maximum value = 85.63 kN/m² (Element 4364 at Node 36966)
Minimum value = -1220 kN/m² (Element 463 at Node 24783)

Maximum = 85.63 kN/m²
Minimum = -1220 kN/m²

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



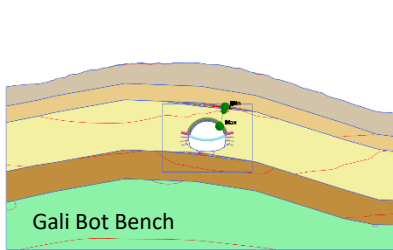
Cartesian total stress σ_{xx} (scaled up 2.00×10^{-3} times)
 Maximum value = 240.4 kN/m² (Element 702 at Node 25433)
 Minimum value = -1822 kN/m² (Element 463 at Node 24783)



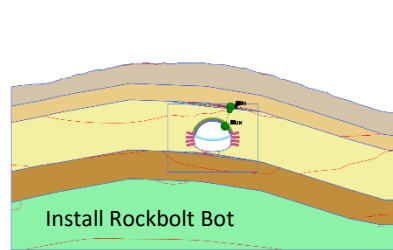
Cartesian total stress σ_{xx} (scaled up 2.00×10^{-3} times)
 Maximum value = 488.8 kN/m² (Element 743 at Node 26444)
 Minimum value = -1849 kN/m² (Element 463 at Node 24783)

Maximum = 240.4 kN/m²
 Minimum = -1822 kN/m²

Maximum = 488.8 kN/m²
 Minimum = -1849 kN/m²



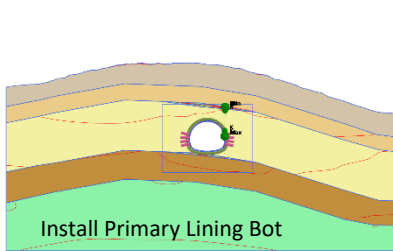
Cartesian total stress σ_{xx} (scaled up 2.00×10^{-3} times)
 Maximum value = 155.5 kN/m² (Element 743 at Node 26743)
 Minimum value = -2207 kN/m² (Element 466 at Node 25947)



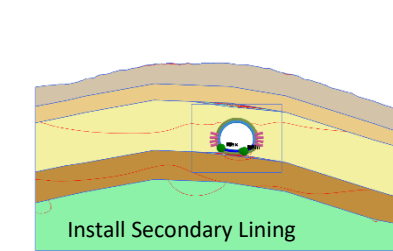
Cartesian total stress σ_{xx} (scaled up 2.00×10^{-3} times)
 Maximum value = 158.2 kN/m² (Element 743 at Node 26743)
 Minimum value = -2181 kN/m² (Element 466 at Node 25947)

Maximum = 0155.5 kN/m²
 Minimum = -2207 kN/m²

Maximum = 158.2 kN/m²
 Minimum = -2181 kN/m²



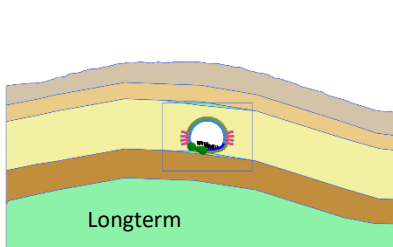
Cartesian total stress σ_{xx} (scaled up 2.00×10^{-3} times)
 Maximum value = 124.0 kN/m² (Element 3127 at Node 36370)
 Minimum value = -2173 kN/m² (Element 466 at Node 25947)



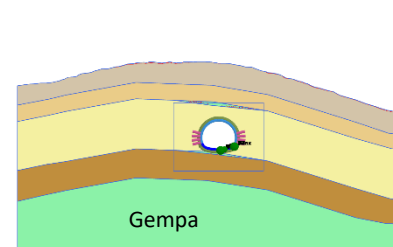
Cartesian total stress σ_{xx} (scaled up 1.00×10^{-3} times)
 Maximum value = 1345 kN/m² (Element 4233 at Node 15807)
 Minimum value = -3055 kN/m² (Element 4283 at Node 25543)

Maksimum = 124.0 kN/m²
 Minimum = -2173 kN/m²

Maximum = 1345 kN/m²
 Minimum = -3055 kN/m²



Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times) (Time 164.1 day)
 Maximum value = 4905 kN/m² (Element 4233 at Node 15807)
 Minimum value = -7781 kN/m² (Element 4278 at Node 18699)

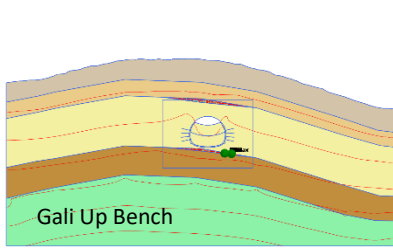


Cartesian total stress σ_{xx} (scaled up 0.500×10^{-3} times)
 Maximum value = 5810 kN/m² (Element 4232 at Node 35888)
 Minimum value = -8006 kN/m² (Element 4271 at Node 19659)

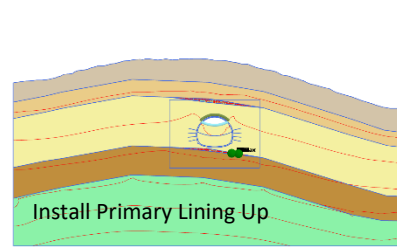
Maximum = 4905 kN/m²
 Minimum = -7781 kN/m²

Maximum = 5810 kN/m²
 Minimum = -8006 kN/m²

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



[N/m²]
A: -1800.00
B: -1800.00
C: -1800.00
D: -1800.00
E: -1800.00
F: -1800.00
G: -1800.00
H: -1800.00
I: -1800.00
J: -1800.00
K: -1800.00
L: -1800.00
M: -1800.00
N: 0.00



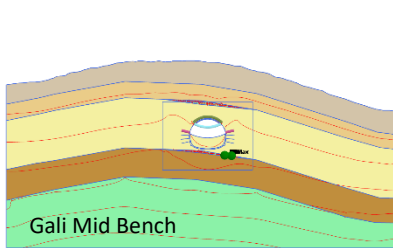
[N/m²]
A: -1800.00
B: -1800.00
C: -1800.00
D: -1800.00
E: -1800.00
F: -1800.00
G: -1800.00
H: -1800.00
I: -1800.00
J: -1800.00
K: -1800.00
L: -1800.00
M: -1800.00
N: 0.00

Cartesian total stress σ_{yy} (scaled up $2.00 \cdot 10^{-3}$ times)
Maximum value = 181.3 kN/m² (Element 4353 at Node 36970)
Minimum value = -2423 kN/m² (Element 4348 at Node 33337)

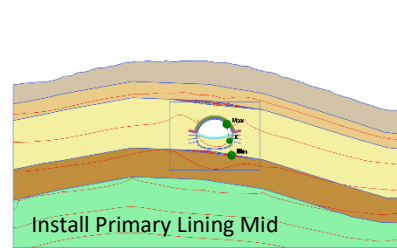
Maximum = 181.3 kN/m²
Minimum = -2423 kN/m²

Cartesian total stress σ_{yy} (scaled up $2.00 \cdot 10^{-3}$ times)
Maximum value = 182.1 kN/m² (Element 4353 at Node 36970)
Minimum value = -2425 kN/m² (Element 4348 at Node 33337)

Maximum = 182.1 kN/m²
Minimum = -2425 kN/m²



[N/m²]
A: -1800.00
B: -1800.00
C: -1800.00
D: -1800.00
E: -1800.00
F: -1800.00
G: -1800.00
H: -1800.00
I: -1800.00
J: -1800.00
K: -1800.00
L: -1800.00
M: 0.00



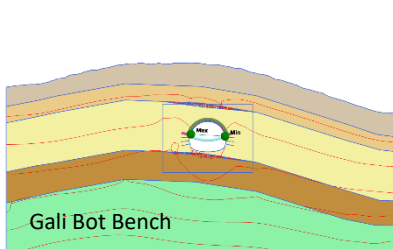
[N/m²]
A: -1800.00
B: -1800.00
C: -1800.00
D: -1800.00
E: -1800.00
F: -1800.00
G: -1800.00
H: -1800.00
I: -1800.00
J: -1800.00
K: -1800.00
L: -1800.00
M: 0.00

Cartesian total stress σ_{yy} (scaled up $2.00 \cdot 10^{-3}$ times)
Maximum value = 182.5 kN/m² (Element 4353 at Node 36970)
Minimum value = -2344 kN/m² (Element 4348 at Node 33337)

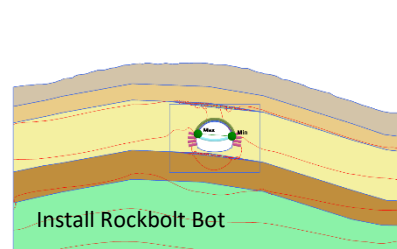
Maximum = 182.5 kN/m²
Minimum = -2344 kN/m²

Cartesian total stress σ_{yy} (scaled up $2.00 \cdot 10^{-3}$ times)
Maximum value = 305.6 kN/m² (Element 743 at Node 26414)
Minimum value = -2345 kN/m² (Element 4348 at Node 33337)

Maximum = 305.6 kN/m²
Minimum = -2345 kN/m²



[N/m²]
A: -1800.00
B: -1800.00
C: -1800.00
D: -1800.00
E: -1800.00
F: -1800.00
G: -1800.00
H: -1800.00
I: -1800.00
J: -1800.00
K: -1800.00
L: -1800.00
M: -1800.00
N: 0.00
O: -1800.00
P: -1800.00
Q: -1800.00
R: -1800.00
S: -1800.00
T: -1800.00



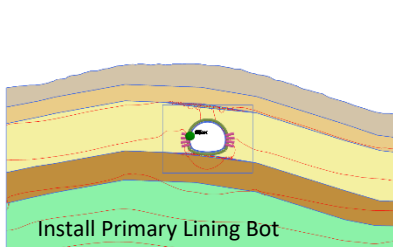
[N/m²]
A: -1800.00
B: -1800.00
C: -1800.00
D: -1800.00
E: -1800.00
F: -1800.00
G: -1800.00
H: -1800.00
I: -1800.00
J: -1800.00
K: -1800.00
L: -1800.00
M: -1800.00
N: -1800.00
O: -1800.00
P: -1800.00
Q: -1800.00

Cartesian total stress σ_{yy} (scaled up $2.00 \cdot 10^{-3}$ times)
Maximum value = 1067 kN/m² (Element 3106 at Node 3438)
Minimum value = -2668 kN/m² (Element 3127 at Node 36380)

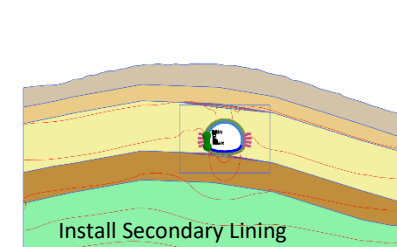
Maximum = 1067 kN/m²
Minimum = -2668 kN/m²

Cartesian total stress σ_{yy} (scaled up $1.00 \cdot 10^{-3}$ times)
Maximum value = 1099 kN/m² (Element 3097 at Node 3435)
Minimum value = -2949 kN/m² (Element 3127 at Node 36380)

Maximum = 1099 kN/m²
Minimum = -2949 kN/m²



[N/m²]
A: -1800.00
B: -1800.00
C: -1800.00
D: -1800.00
E: -1800.00
F: -1800.00
G: -1800.00
H: -1800.00
I: -1800.00
J: -1800.00
K: -1800.00
L: -1800.00
M: -1800.00
N: -1800.00
O: -1800.00
P: -1800.00
Q: -1800.00



[N/m²]
A: -1800.00
B: -1800.00
C: -1800.00
D: -1800.00
E: -1800.00
F: -1800.00
G: -1800.00
H: -1800.00
I: -1800.00
J: -1800.00
K: -1800.00
L: -1800.00
M: -1800.00
N: -1800.00
O: -1800.00
P: -1800.00
Q: -1800.00

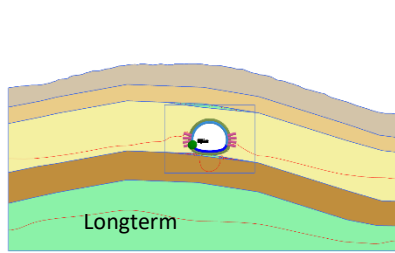
Cartesian total stress σ_{yy} (scaled up $1.00 \cdot 10^{-3}$ times)
Maximum value = 1674 kN/m² (Element 3109 at Node 4039)
Minimum value = -2417 kN/m² (Element 3107 at Node 4012)

Maksimum = 1674 kN/m²
Minimum = -2417 kN/m²

Cartesian total stress σ_{yy} (scaled up $1.00 \cdot 10^{-3}$ times)
Maximum value = 930.5 kN/m² (Element 4223 at Node 12660)
Minimum value = -3197 kN/m² (Element 3107 at Node 4012)

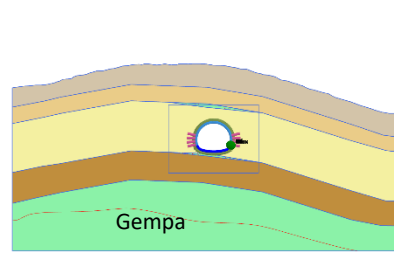
Maximum = 930.5 kN/m²
Minimum = -3197 kN/m²

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



Cartesian total stress σ_y (scaled up 0.500×10^{-3} times) (Time 164.1 day)
 Maximum value = 5128 kN/m² (Element 4258 at Node 11250)
 Minimum value = -4830 kN/m² (Element 4220 at Node 10574)

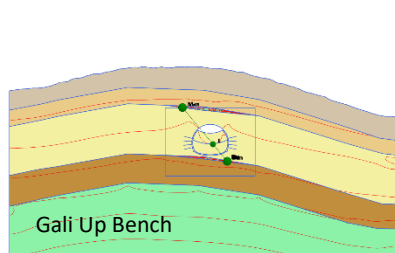
Maximum = 5128 kN/m²
 Minimum = -4830 kN/m²



Cartesian total stress σ_y (scaled up 0.500×10^{-3} times)
 Maximum value = 5959 kN/m² (Element 4259 at Node 36813)
 Minimum value = -5054 kN/m² (Element 4221 at Node 36826)

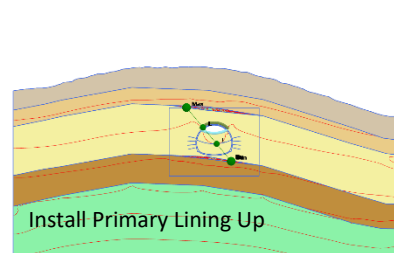
Maximum = 5959 kN/m²
 Minimum = -5054 kN/m²

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



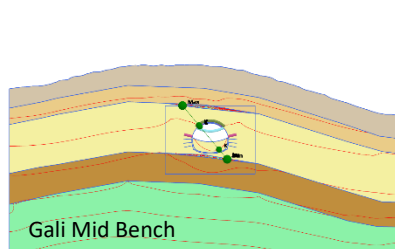
Principal total stress σ_1 (scaled up 2.00×10^{-3} times)
 Maximum value = 15.55 kN/m² (Element 344 at Node 16011)
 Minimum value = -2433 kN/m² (Element 4398 at Node 33337)

Maximum = 15.55 kN/m²
 Minimum = -2433 kN/m²



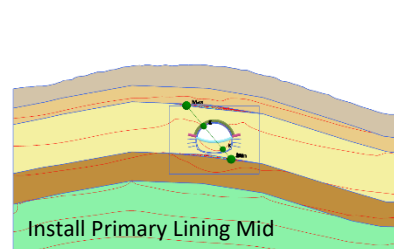
Principal total stress σ_1 (scaled up 2.00×10^{-3} times)
 Maximum value = 15.42 kN/m² (Element 344 at Node 16011)
 Minimum value = -2435 kN/m² (Element 4398 at Node 33337)

Maximum = 15.42 kN/m²
 Minimum = -2435 kN/m²



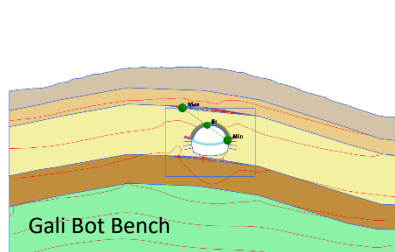
Principal total stress σ_1 (scaled up 2.00×10^{-3} times)
 Maximum value = 22.13 kN/m² (Element 344 at Node 16011)
 Minimum value = -2351 kN/m² (Element 4398 at Node 33337)

Maximum = 22.13 kN/m²
 Minimum = -2351 kN/m²



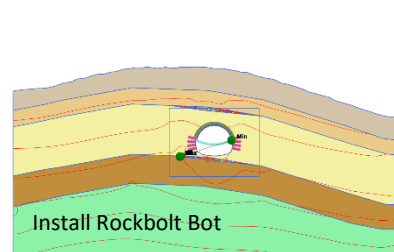
Principal total stress σ_1 (scaled up 2.00×10^{-3} times)
 Maximum value = 19.73 kN/m² (Element 344 at Node 16011)
 Minimum value = -2353 kN/m² (Element 4398 at Node 33337)

Maximum = 19.73 kN/m²
 Minimum = -2353 kN/m²



Principal total stress σ_1 (scaled up 2.00×10^{-3} times)
 Maximum value = 17.92 kN/m² (Element 344 at Node 16011)
 Minimum value = -2697 kN/m² (Element 3127 at Node 36380)

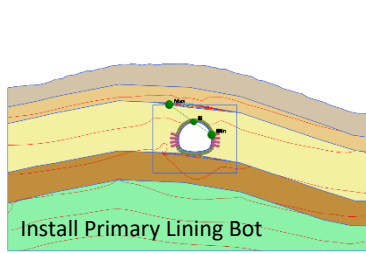
Maximum = 17.92 kN/m²
 Minimum = -2697 kN/m²



Principal total stress σ_1 (scaled up 2.00×10^{-3} times)
 Maximum value = 12.76 kN/m² (Element 4363 at Node 14678)
 Minimum value = -2973 kN/m² (Element 3127 at Node 36380)

Maximum = 12.76 kN/m²
 Minimum = -2973 kN/m²

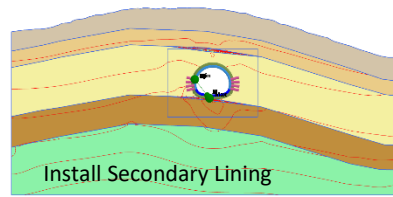
Gambar 46 Hasil analisis tegangan maksimum (σ_1) pada Tunnel No.5 (DK 86+890)



Principal total stress σ_1 (scaled up $2.00 \cdot 10^{-3}$ times)

Maximum value = 11.96 kN/m² (Element 341 at Node 15011)

Minimum value = -2546 kN/m² (Element 3117 at Node 35865)



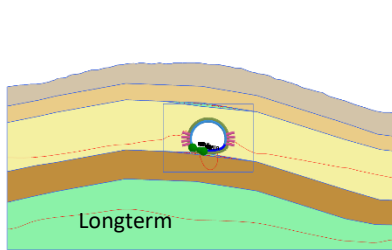
Principal total stress σ_1 (scaled up $2.00 \cdot 10^{-3}$ times)

Maximum value = 24.95 kN/m² (Element 4313 at Node 22115)

Minimum value = -3384 kN/m² (Element 3099 at Node 4009)

Maksimum = 11.96 kN/m²
Minimum = -2546 kN/m²

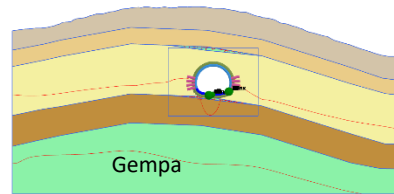
Maximum = 24.95 kN/m²
Minimum = -3384 kN/m²



Principal total stress σ_1 (scaled up $0.500 \cdot 10^{-3}$ times) (Time 164.1 day)

Maximum value = 466.7 kN/m² (Element 4233 at Node 15807)

Minimum value = -7872 kN/m² (Element 4293 at Node 17776)



Principal total stress σ_1 (scaled up $0.500 \cdot 10^{-3}$ times)

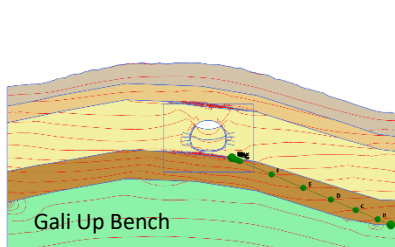
Maximum value = 652.6 kN/m² (Element 4232 at Node 35888)

Minimum value = -8034 kN/m² (Element 4276 at Node 18699)

Maximum = 466.7 kN/m²
Minimum = -7872 kN/m²

Maximum = 652.6 kN/m²
Minimum = -8034 kN/m²

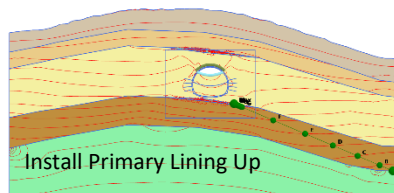
Gambar 47 Hasil analisis tegangan maksimum (σ_1) pada Tunnel No.5 (DK 86+890) (lanjutan)



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

Maximum value = 249.4 kN/m² (Element 4353 at Node 36970)

Minimum value = -630.9 kN/m² (Element 5312 at Node 21392)



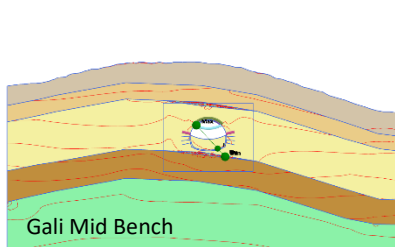
Principal total stress σ_3 (scaled up $5.00 \cdot 10^{-3}$ times)

Maximum value = 253.4 kN/m² (Element 4353 at Node 36970)

Minimum value = -631.1 kN/m² (Element 5312 at Node 21392)

Maximum = 249.4 kN/m²
Minimum = -630.9 kN/m²

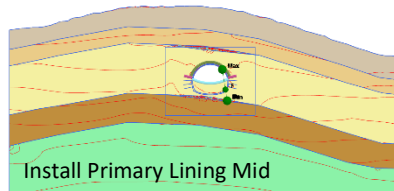
Maximum = 253.4 kN/m²
Minimum = -631.1 kN/m²



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

Maximum value = 456.3 kN/m² (Element 738 at Node 4891)

Minimum value = -680.8 kN/m² (Element 4348 at Node 33337)



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

Maximum value = 966.1 kN/m² (Element 743 at Node 26444)

Minimum value = -667.9 kN/m² (Element 4348 at Node 33337)

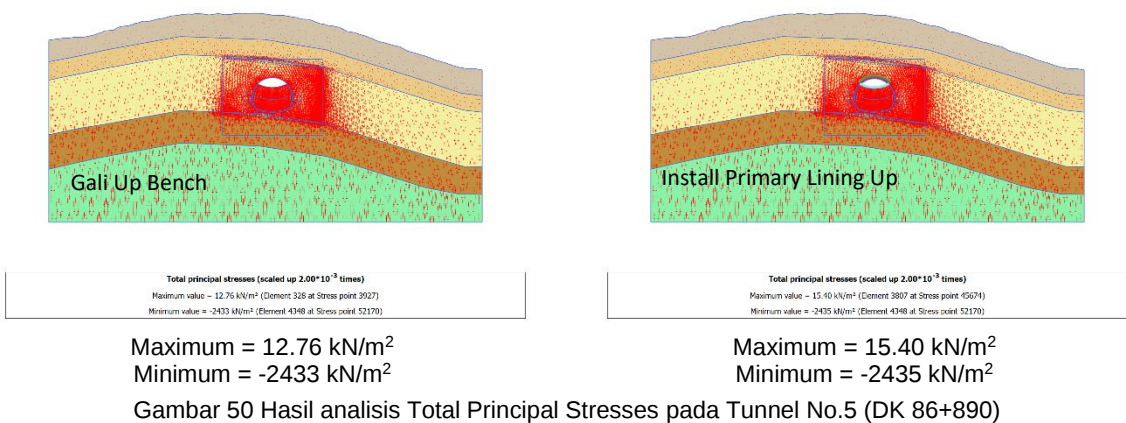
Maximum = 456.3 kN/m²
Minimum = -680.8 kN/m²

Maximum = 966.1 kN/m²
Minimum = -667.9 kN/m²

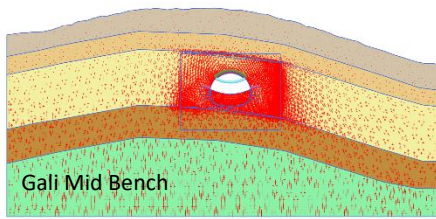
Gambar 48 Hasil analisis tegangan minimum (σ_3) pada Tunnel No.5 (DK 86+890)



Gambar 49 Hasil analisis tegangan minimum (σ_3) pada Tunnel No.5 (DK 86+890) (lanjutan)

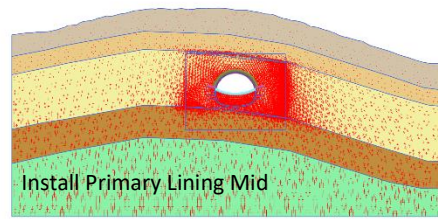


Gambar 50 Hasil analisis Total Principal Stresses pada Tunnel No.5 (DK 86+890)



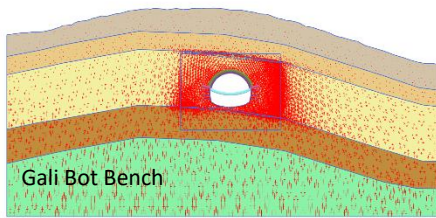
Total principal stresses (scaled up 2.00×10^{-3} times)
 Maximum value = 397.1 kN/m² (Element 738 at Stress point 8851)
 Minimum value = -2351 kN/m² (Element 4348 at Stress point 52170)

Maximum = 397.1 kN/m²
 Minimum = -2351 kN/m²



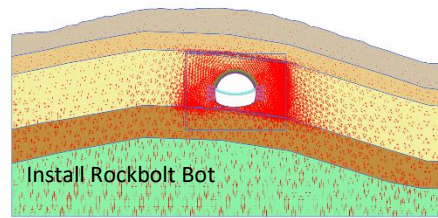
Total principal stresses (scaled up 2.00×10^{-3} times)
 Maximum value = 948.6 kN/m² (Element 738 at Stress point 8815)
 Minimum value = -2353 kN/m² (Element 4348 at Stress point 52170)

Maximum = 948.6 kN/m²
 Minimum = -2353 kN/m²



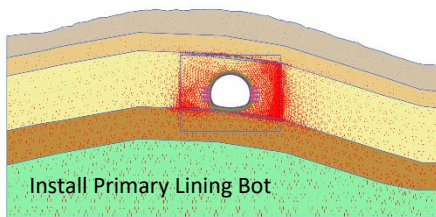
Total principal stresses (scaled up 2.00×10^{-3} times)
 Maximum value = 1034 kN/m² (Element 3106 at Stress point 37270)
 Minimum value = -2230 kN/m² (Element 4348 at Stress point 52170)

Maximum = 1034 kN/m²
 Minimum = -2230 kN/m²



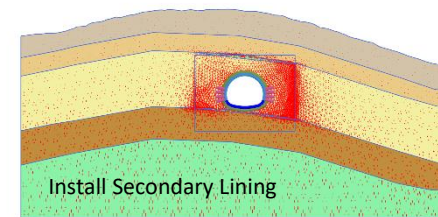
Total principal stresses (scaled up 2.00×10^{-3} times)
 Maximum value = 1058 kN/m² (Element 3106 at Stress point 37270)
 Minimum value = -2236 kN/m² (Element 3127 at Stress point 37515)

Maximum = 1058 kN/m²
 Minimum = -2236 kN/m²



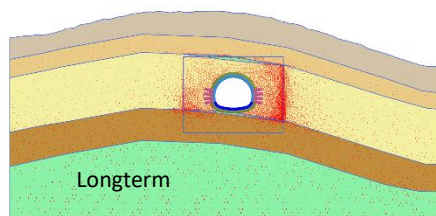
Total principal stresses (scaled up 1.00×10^{-3} times)
 Maximum value = 1570 kN/m² (Element 3109 at Stress point 37306)
 Minimum value = -2341 kN/m² (Element 3117 at Stress point 37400)

Maksimum = 1570 kN/m²
 Minimum = -2341 kN/m²



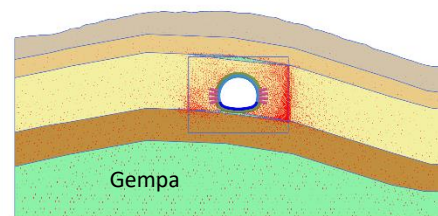
Total principal stresses (scaled up 1.00×10^{-3} times)
 Maximum value = 1429 kN/m² (Element 4251 at Stress point 51001)
 Minimum value = -3199 kN/m² (Element 3107 at Stress point 37283)

Maximum = 1429 kN/m²
 Minimum = -3199 kN/m²



Total principal stresses (scaled up 0.500×10^{-3} times) (Time 164.1 day)
 Maximum value = 5786 kN/m² (Element 4251 at Stress point 51001)
 Minimum value = -7450 kN/m² (Element 4293 at Stress point 51512)

Maximum = 5786 kN/m²
 Minimum = -7450 kN/m²

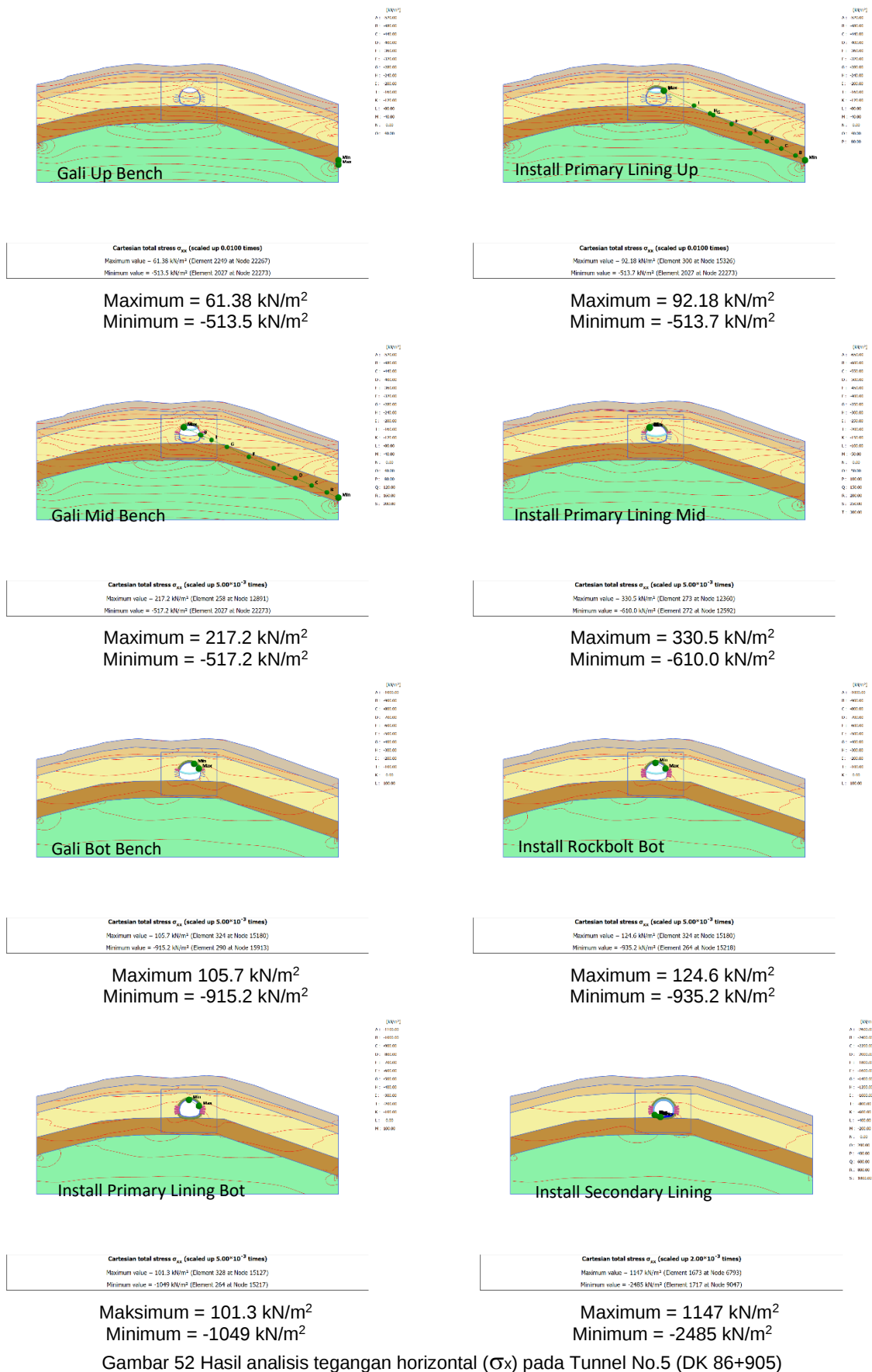


Total principal stresses (scaled up 0.500×10^{-3} times)
 Maximum value = 7130 kN/m² (Element 4247 at Stress point 50953)
 Minimum value = -7611 kN/m² (Element 4292 at Stress point 51499)

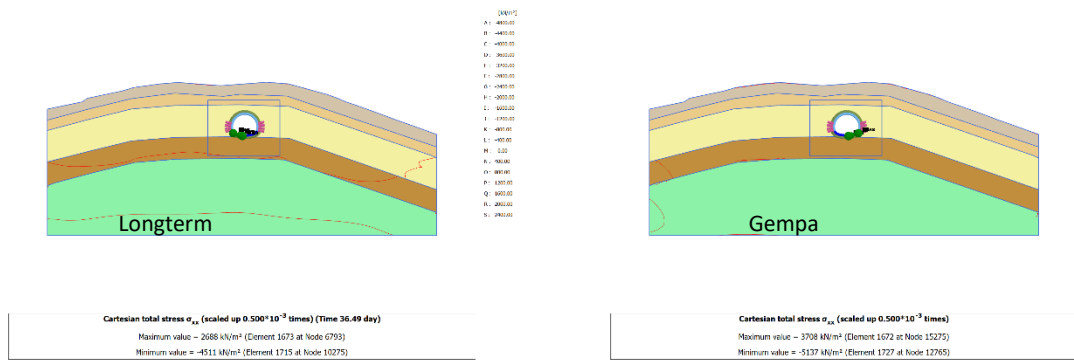
Maximum = 7130 kN/m²
 Minimum = -7611 kN/m²

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

c) Cross Section DK 86+905



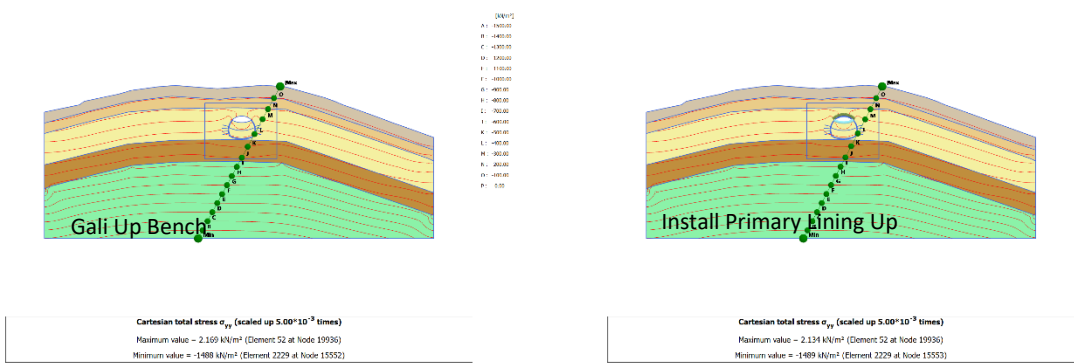
Gambar 52 Hasil analisis tegangan horizontal (σ_x) pada Tunnel No.5 (DK 86+905)



Maximum = 2688 kN/m²
 Minimum = -4511 kN/m²

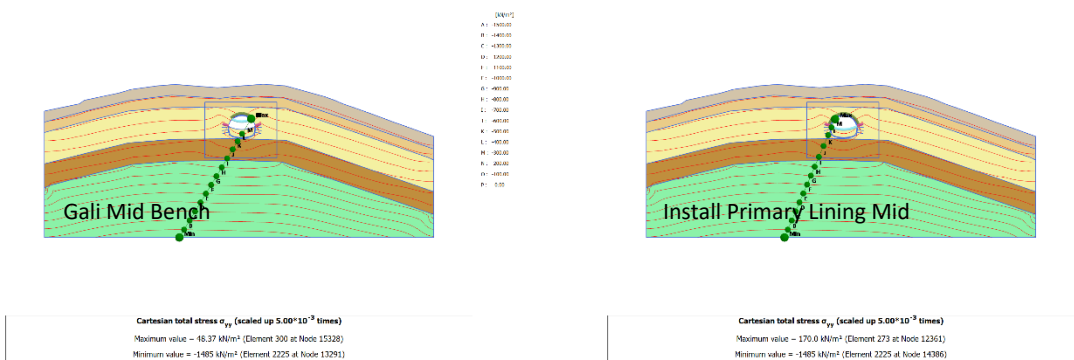
Maximum = 3708 kN/m²
 Minimum = -5137 kN/m²

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



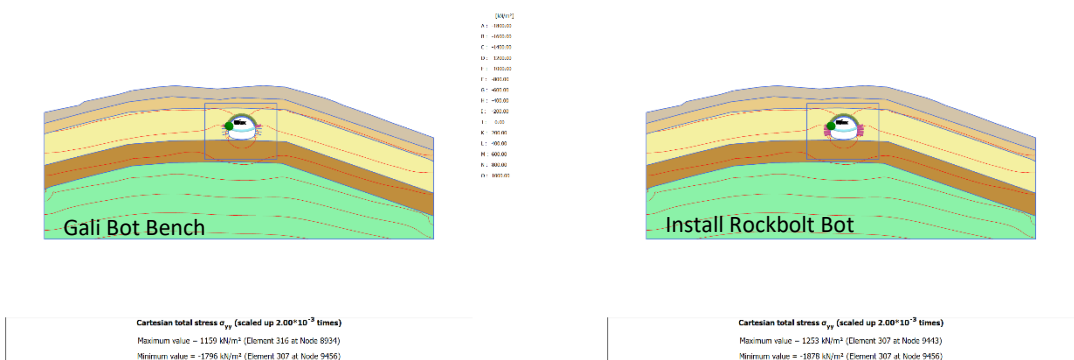
Maximum = 2.169 kN/m²
 Minimum = -1488 kN/m²

Maximum = 2.134 kN/m²
 Minimum = -1489 kN/m²



Maximum = 48.37 kN/m²
 Minimum = -1485 kN/m²

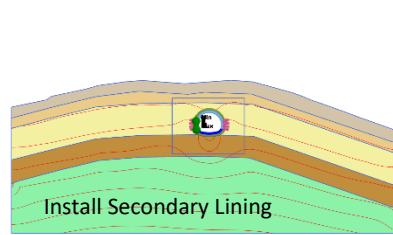
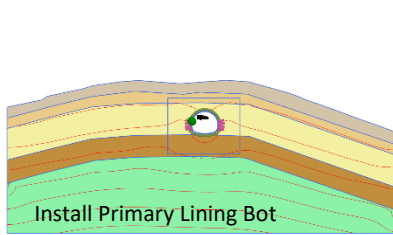
Maximum = 170.0 kN/m²
 Minimum = -1485 kN/m²



Maximum = 1159 kN/m²
 Minimum = -1796 kN/m²

Maximum = 1253 kN/m²
 Minimum = -1878 kN/m²

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

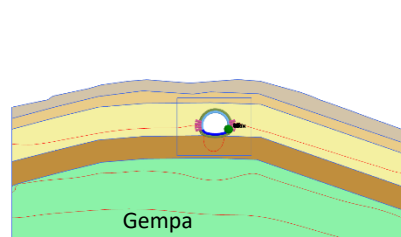
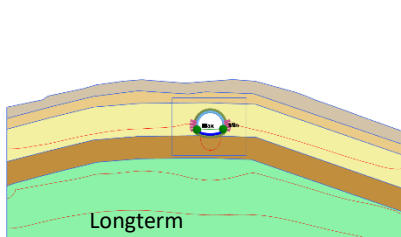


Cartesian total stress σ_{yy} (scaled up 2.00×10^{-3} times)
Maximum value = 1384 kN/m² (Element 316 at Node 8936)
Minimum value = -2006 kN/m² (Element 309 at Node 9200)

Cartesian total stress σ_{yy} (scaled up 2.00×10^{-3} times)
Maximum value = 843.1 kN/m² (Element 1663 at Node 6676)
Minimum value = -2467 kN/m² (Element 309 at Node 9201)

Maksimum = 1384 kN/m²
Minimum = -2006 kN/m²

Maximum = 843.1 kN/m²
Minimum = -2467 kN/m²



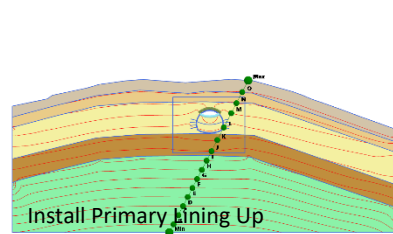
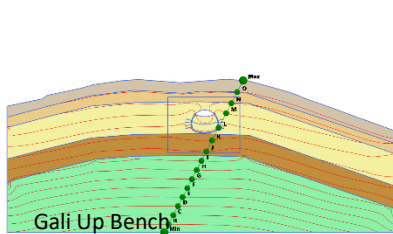
Cartesian total stress σ_{yy} (scaled up 1.00×10^{-3} times) (Time 36.49 day)
Maximum value = 2496 kN/m² (Element 1698 at Node 3161)
Minimum value = -3038 kN/m² (Element 1661 at Node 14774)

Cartesian total stress σ_{yy} (scaled up 0.500×10^{-3} times)
Maximum value = 3758 kN/m² (Element 1699 at Node 14825)
Minimum value = -3552 kN/m² (Element 1661 at Node 14774)

Maximum = 2496 kN/m²
Minimum = -3038 kN/m²

Maximum = 3758 kN/m²
Minimum = -3552 kN/m²

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

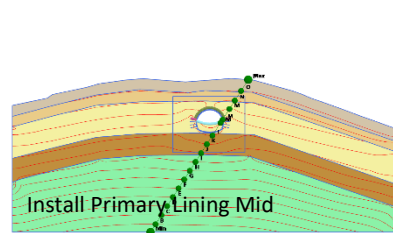
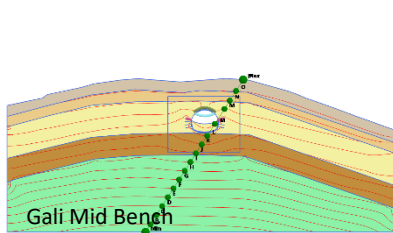


Principal total stress σ_1 (scaled up 5.00×10^{-3} times)
Maximum value = 2.161 kN/m² (Element 52 at Node 19936)
Minimum value = -1488 kN/m² (Element 2229 at Node 15553)

Principal total stress σ_1 (scaled up 5.00×10^{-3} times)
Maximum value = 2.128 kN/m² (Element 52 at Node 19936)
Minimum value = -1489 kN/m² (Element 2229 at Node 15553)

Maximum = 2.161 kN/m²
Minimum = -1488 kN/m²

Maximum = 2.128 kN/m²
Minimum = -1489 kN/m²



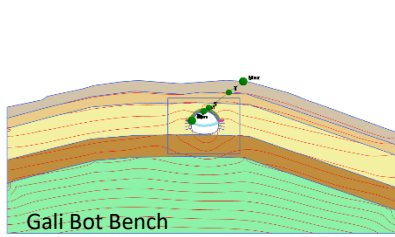
Principal total stress σ_1 (scaled up 5.00×10^{-3} times)
Maximum value = 2.147 kN/m² (Element 52 at Node 19936)
Minimum value = -1485 kN/m² (Element 2225 at Node 14386)

Principal total stress σ_1 (scaled up 5.00×10^{-3} times)
Maximum value = 2.132 kN/m² (Element 52 at Node 19936)
Minimum value = -1485 kN/m² (Element 2225 at Node 14386)

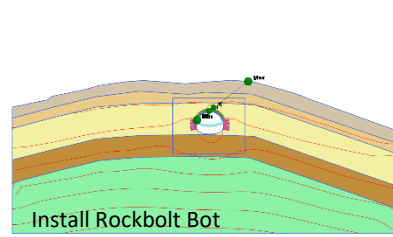
Maximum = 2.147 kN/m²
Minimum = -1485 kN/m²

Maximum = 2.132 kN/m²
Minimum = -1485 kN/m²

Gambar 56 Hasil analisis tegangan maksimum (σ_1) pada Tunnel No.5 (DK 86+905)



[kN/m²]
 A: 1700.00
 B: -4000.00
 C: -4000.00
 D: 1700.00
 E: 1940.00
 F: -4700.00
 G: -4000.00
 H: -4300.00
 I: 1400.00
 J: -1100.00
 K: -4000.00
 L: -4000.00
 M: -4000.00
 N: 1700.00
 O: -4000.00
 P: -4000.00
 Q: -4000.00
 R: 1700.00
 S: 1700.00
 T: -4000.00
 U: 0.00



[kN/m²]
 A: 1700.00
 B: -4000.00
 C: -4000.00
 D: 1700.00
 E: 1940.00
 F: -4700.00
 G: -4000.00
 H: -4300.00
 I: 1400.00
 J: -1100.00
 K: -4000.00
 L: -4000.00
 M: -4000.00
 N: 1700.00
 O: -4000.00
 P: -4000.00
 Q: -4000.00
 R: 1700.00
 S: 1700.00
 T: -4000.00
 U: 0.00

Principal total stress σ_1 (scaled up 5.00×10^{-3} times)

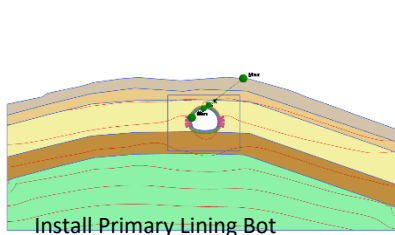
Maximum value = 2.105 kN/m² (Element 52 at Node 19936)
Minimum value = -1972 kN/m² (Element 307 at Node 9456)

Maximum = 2.105 kN/m²
Minimum = -1972 kN/m²

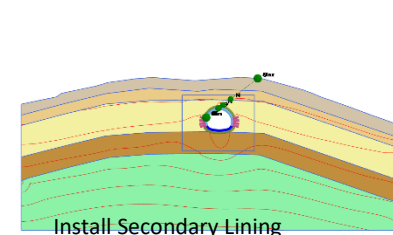
Principal total stress σ_1 (scaled up 5.00×10^{-3} times)

Maximum value = 2.105 kN/m² (Element 52 at Node 19936)
Minimum value = -2091 kN/m² (Element 307 at Node 9454)

Maximum = 2.105 kN/m²
Minimum = -2091 kN/m²



[kN/m²]
 A: 1700.00
 B: -4000.00
 C: -4000.00
 D: 1700.00
 E: 1940.00
 F: -4700.00
 G: -4000.00
 H: -4300.00
 I: 1400.00
 J: -1100.00
 K: -4000.00
 L: -4000.00
 M: -4000.00
 N: 1700.00
 O: -4000.00
 P: -4000.00
 Q: -4000.00
 R: 1700.00
 S: 1700.00
 T: -4000.00
 U: 0.00



[kN/m²]
 A: 1700.00
 B: -4000.00
 C: -4000.00
 D: 1700.00
 E: 1940.00
 F: -4700.00
 G: -4000.00
 H: -4300.00
 I: 1400.00
 J: -1100.00
 K: -4000.00
 L: -4000.00
 M: -4000.00
 N: 1700.00
 O: -4000.00
 P: -4000.00
 Q: -4000.00
 R: 1700.00
 S: 1700.00
 T: -4000.00
 U: 0.00

Principal total stress σ_1 (scaled up 5.00×10^{-3} times)

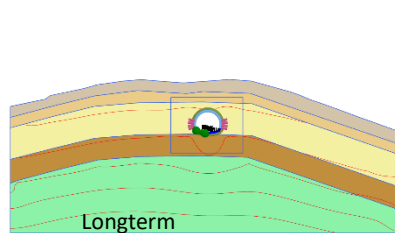
Maximum value = 2.104 kN/m² (Element 52 at Node 19936)
Minimum value = -2197 kN/m² (Element 307 at Node 9456)

Maksimum = 2.104 kN/m²
Minimum = -2197 kN/m²

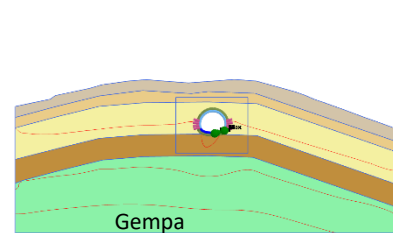
Principal total stress σ_1 (scaled up 3.00×10^{-3} times)

Maximum value = 2.194 kN/m² (Element 52 at Node 19936)
Minimum value = -2693 kN/m² (Element 307 at Node 9456)

Maximum = 2.194 kN/m²
Minimum = -2693 kN/m²



[kN/m²]
 A: 1700.00
 B: -4000.00
 C: -4000.00
 D: 1700.00
 E: 1940.00
 F: -4700.00
 G: -4000.00
 H: -4300.00
 I: 1400.00
 J: -1100.00
 K: -4000.00
 L: -4000.00
 M: -4000.00
 N: 1700.00
 O: -4000.00
 P: -4000.00
 Q: -4000.00
 R: 1700.00
 S: 1700.00
 T: -4000.00
 U: 0.00



[kN/m²]
 A: 1700.00
 B: -4000.00
 C: -4000.00
 D: 1700.00
 E: 1940.00
 F: -4700.00
 G: -4000.00
 H: -4300.00
 I: 1400.00
 J: -1100.00
 K: -4000.00
 L: -4000.00
 M: -4000.00
 N: 1700.00
 O: -4000.00
 P: -4000.00
 Q: -4000.00
 R: 1700.00
 S: 1700.00
 T: -4000.00
 U: 0.00

Principal total stress σ_1 (scaled up 2.00×10^{-3} times) (Time 36.49 day)

Maximum value = 171.1 kN/m² (Element 1673 at Node 6793)
Minimum value = -4546 kN/m² (Element 1732 at Node 10071)

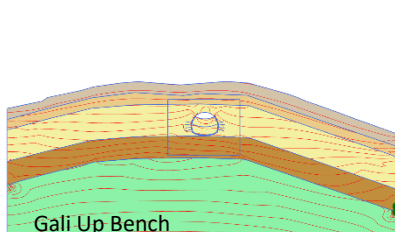
Maximum = 171.1 kN/m²
Minimum = -4546 kN/m²

Principal total stress σ_1 (scaled up 1.00×10^{-3} times)

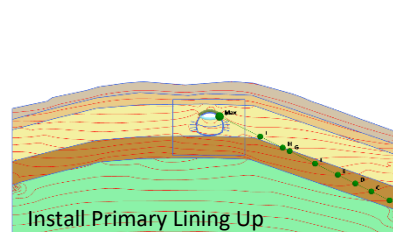
Maximum value = 331.7 kN/m² (Element 1672 at Node 15275)
Minimum value = -5156 kN/m² (Element 1727 at Node 12266)

Maximum = 331.7 kN/m²
Minimum = -5156 kN/m²

Gambar 57 Hasil analisis tegangan maksimum (σ_1) pada Tunnel No.5 (DK 86+905) (lanjutan)



[kN/m²]
 A: 1700.00
 B: -4000.00
 C: -4000.00
 D: 1700.00
 E: 1940.00
 F: -4700.00
 G: -4000.00
 H: -4300.00
 I: 1400.00
 J: -1100.00
 K: -4000.00
 L: -4000.00
 M: -4000.00
 N: 1700.00
 O: -4000.00
 P: -4000.00
 Q: -4000.00
 R: 1700.00
 S: 1700.00
 T: -4000.00
 U: 0.00



[kN/m²]
 A: 1700.00
 B: -4000.00
 C: -4000.00
 D: 1700.00
 E: 1940.00
 F: -4700.00
 G: -4000.00
 H: -4300.00
 I: 1400.00
 J: -1100.00
 K: -4000.00
 L: -4000.00
 M: -4000.00
 N: 1700.00
 O: -4000.00
 P: -4000.00
 Q: -4000.00
 R: 1700.00
 S: 1700.00
 T: -4000.00
 U: 0.00

Principal total stress σ_3 (scaled up 0.0100 times)

Maximum value = 62.12 kN/m² (Element 2219 at Node 22267)
Minimum value = -513.5 kN/m² (Element 2027 at Node 22273)

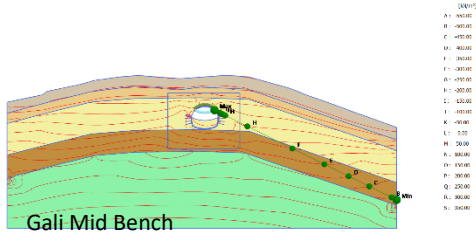
Maximum = 62.12 kN/m²
Minimum = -513.5 kN/m²

Principal total stress σ_3 (scaled up 0.0100 times)

Maximum value = 116.3 kN/m² (Element 300 at Node 15326)
Minimum value = -513.7 kN/m² (Element 2027 at Node 22273)

Maximum = 116.3 kN/m²
Minimum = -513.7 kN/m²

Gambar 58 Hasil analisis tegangan minimum (σ_3) pada Tunnel No.5 (DK 86+905)

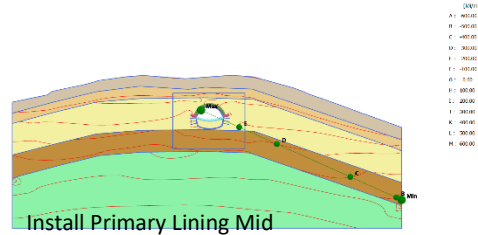


Gali Mid Bench

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

Maximum value = 361.3 kN/m² (Element 300 at Node 12326)
 Minimum value = -517.2 kN/m² (Element 2027 at Node 22273)

Maximum = 361.3 kN/m²
 Minimum = -517.2 kN/m²

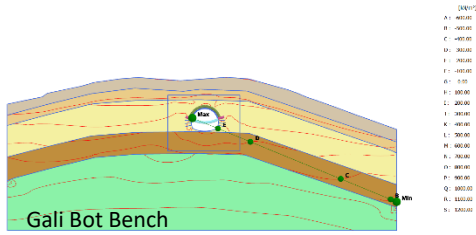


Install Primary Lining Mid

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

Maximum value = 627.6 kN/m² (Element 273 at Node 12361)
 Minimum value = -517.3 kN/m² (Element 2027 at Node 22273)

Maximum = 627.6 kN/m²
 Minimum = -517.3 kN/m²

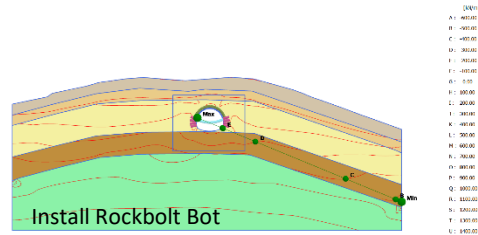


Gali Bot Bench

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

Maximum value = 1291 kN/m² (Element 316 at Node 8934)
 Minimum value = -519.4 kN/m² (Element 2027 at Node 22273)

Maximum = 1291 kN/m²
 Minimum = -519.4 kN/m²

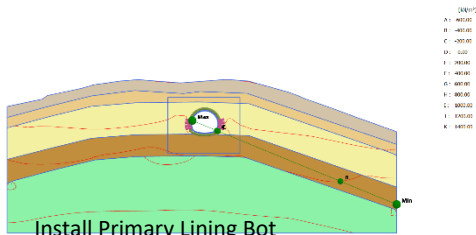


Install Rockbolt Bot

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

Maximum value = 1416 kN/m² (Element 307 at Node 9413)
 Minimum value = -519.8 kN/m² (Element 2027 at Node 22273)

Maximum = 1416 kN/m²
 Minimum = -519.8 kN/m²

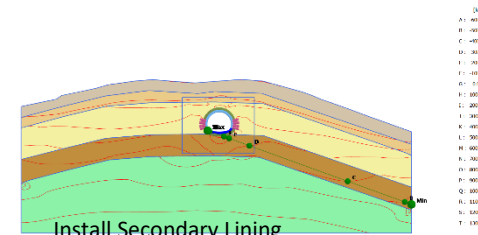


Install Primary Lining Bot

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

Maximum value = 1508 kN/m² (Element 316 at Node 8935)
 Minimum value = -519.7 kN/m² (Element 2027 at Node 22273)

Maksimum = 1508 kN/m²
 Minimum = -519.7 kN/m²

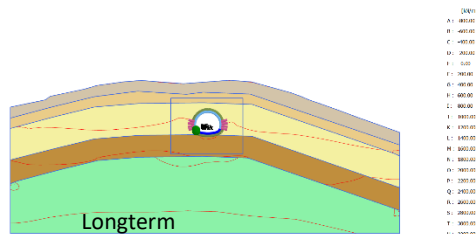


Install Secondary Lining

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

Maximum value = 1385 kN/m² (Element 1673 at Node 6793)
 Minimum value = -521.3 kN/m² (Element 2027 at Node 22273)

Maximum = 1385 kN/m²
 Minimum = -521.3 kN/m²

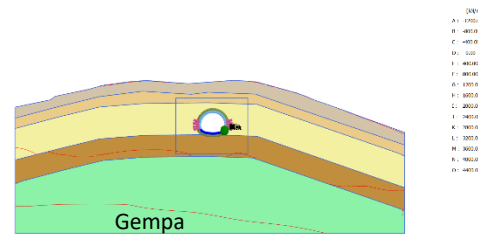


Longterm

Principal total stress σ_3 (scaled up 2.00×10^{-3} times) (Time 36.49 day)

Maximum value = 3241 kN/m² (Element 1673 at Node 6793)
 Minimum value = -666.2 kN/m² (Element 1562 at Node 15046)

Maximum = 3241 kN/m²
 Minimum = -666.2 kN/m²



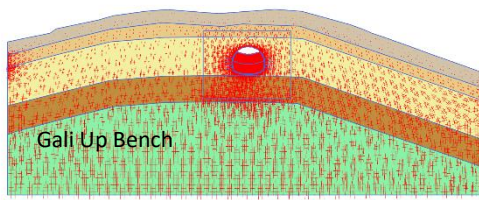
Gempa

Principal total stress σ_3 (scaled up 1.00×10^{-3} times)

Maximum value = 4580 kN/m² (Element 1672 at Node 15275)
 Minimum value = -800.9 kN/m² (Element 1565 at Node 15046)

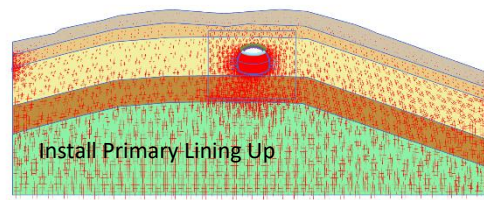
Maximum = 4580 kN/m²
 Minimum = -800.9 kN/m²

Gambar 59 Hasil analisis tegangan minimum (σ_3) pada Tunnel No.5 (DK 86+905) (lanjutan)



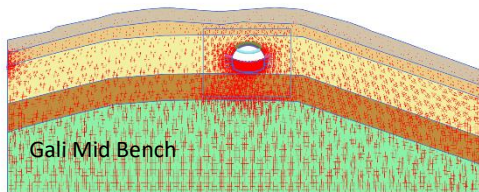
Total principal stresses (scaled up $5.00 \cdot 10^{-3}$ times)
 Maximum value = 2.257 kN/m² (Element 2565 at Stress point 30770)
 Minimum value = -1482 kN/m² (Element 2229 at Stress point 26745)

Maximum = 2.257 kN/m²
 Minimum = -1482 kN/m²



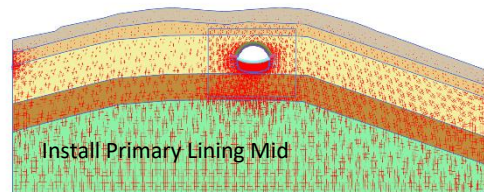
Total principal stresses (scaled up $5.00 \cdot 10^{-3}$ times)
 Maximum value = 70.93 kN/m² (Element 300 at Stress point 3589)
 Minimum value = -1483 kN/m² (Element 2229 at Stress point 26745)

Maximum = 70.93 kN/m²
 Minimum = -1483 kN/m²



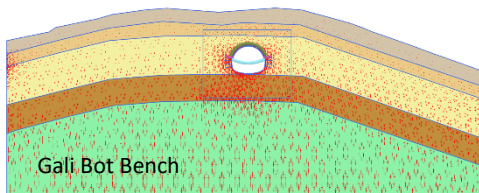
Total principal stresses (scaled up $5.00 \cdot 10^{-3}$ times)
 Maximum value = 315.6 kN/m² (Element 300 at Stress point 3590)
 Minimum value = -1478 kN/m² (Element 2229 at Stress point 26696)

Maximum = 315.6 kN/m²
 Minimum = -1478 kN/m²



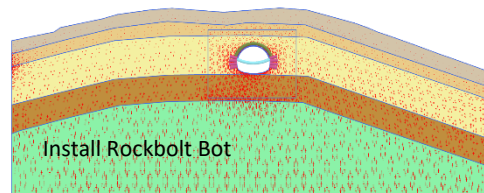
Total principal stresses (scaled up $5.00 \cdot 10^{-3}$ times)
 Maximum value = 548.0 kN/m² (Element 273 at Stress point 3271)
 Minimum value = -1479 kN/m² (Element 2229 at Stress point 26696)

Maximum = 548.0 kN/m²
 Minimum = -1479 kN/m²



Total principal stresses (scaled up $2.00 \cdot 10^{-3}$ times)
 Maximum value = 1122 kN/m² (Element 316 at Stress point 3790)
 Minimum value = -1796 kN/m² (Element 307 at Stress point 3682)

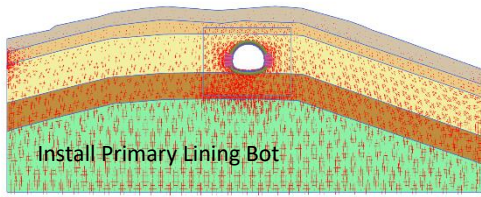
Maximum = 1122 kN/m²
 Minimum = -1796 kN/m²



Total principal stresses (scaled up $2.00 \cdot 10^{-3}$ times)
 Maximum value = 1218 kN/m² (Element 308 at Stress point 3695)
 Minimum value = -1909 kN/m² (Element 307 at Stress point 3681)

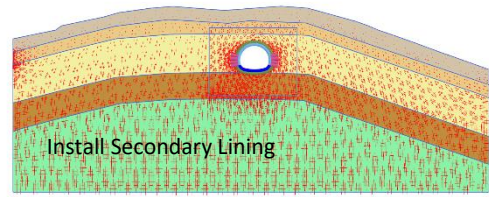
Maximum = 1218 kN/m²
 Minimum = -1909 kN/m²

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



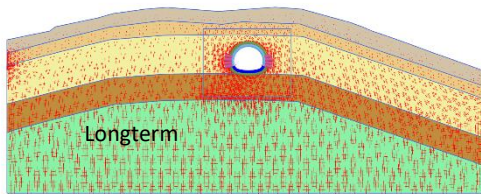
Total principal stresses (scaled up $4.00 \cdot 10^{-3}$ times)
 Maximum value = 1315 kN/m² (Element 316 at Stress point 3789)
 Minimum value = -1988 kN/m² (Element 309 at Stress point 3707)

Maksimum = 1315 kN/m²
 Minimum = -1988 kN/m²



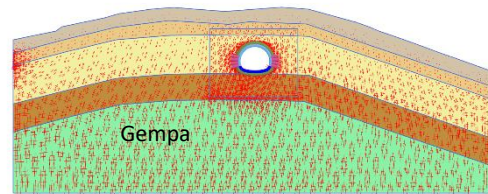
Total principal stresses (scaled up $4.00 \cdot 10^{-3}$ times)
 Maximum value = 1307 kN/m² (Element 1691 at Stress point 20281)
 Minimum value = -2535 kN/m² (Element 309 at Stress point 3707)

Maximum = 1307 kN/m²
 Minimum = -2535 kN/m²



Total principal stresses (scaled up $4.00 \cdot 10^{-3}$ times) (Time 36.49 day)
 Maximum value = 3136 kN/m² (Element 1691 at Stress point 20281)
 Minimum value = -4312 kN/m² (Element 1732 at Stress point 20779)

Maximum = 3136 kN/m²
 Minimum = -4312 kN/m²



Total principal stresses (scaled up $4.00 \cdot 10^{-3}$ times)
 Maximum value = 4559 kN/m² (Element 1687 at Stress point 20233)
 Minimum value = -4891 kN/m² (Element 1727 at Stress point 20720)

Maximum = 4559 kN/m²
 Minimum = -4891 kN/m²

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