In House Training Bidang Rekayasa Struktur Jalan Rel dan Jembatan

Yogyakarta, 9 – 13 Mei 2016

Direktorat Keselamatan Perkeretaapian Dirjen Perkeretaapian Kementerian Perhubungan bekerjasama dengan

Universitas Muhammadiyah Yogyakarta

Agenda Training:

- Day 1: Geo-track & Slab-Track
- Day 2 : Geoteknik & Penyelidikan Tanah
- Day 3 : Geoteknologi, Mekanika Bahan dan Jembatan
- Day 4: Risk Assessment
- Day 5: Lab Works

Review Problematika Struktur Jalan Rel di Indonesia

Sri Atmaja P. Rosyidi

Department of Civil Engineering

Universitas Muhammadiyah Yogyakarta

Sri Atmaja P. Rosyidi

Associate Professor
Ir., ST., M.Sc.Eng., Ph.D., P.Eng
MIACMAG, MIRDA, MISGE, MIABI, MIEI(PII), GA.Certf.

- Universitas Muhammadiyah Yogyakarta (UMY):
  - Profesor Madya (Lektor Kepala)
  - Pangkat/Gol: IVa/Pembina
- Pendidikan:
  - S1 – UMY 1999
  - S2 – the National Univ of Malaysia, 2004
  - Grad Certf of Earthquake Eng, NCREE Taiwan, 2007
  - S3 – the National Univ of Malaysia, 2009
  - Postgraduate Certf – Univ of Salerno, Italy 2008
  - Postdoctoral, – the National Univ of Malaysia, 2009 - 2011
- Email: atmaja_sri@umy.ac.id & atmaja.sri@gmail.com
- Telp. : 0815 790 9887
- Website: atmaja.staff.umy.ac.id

OUTLINE PAPARAN

- PENDAHULUAN
- PENGEMBANGAN INFRASTRUKTUR
- REVIEW PRASARANA DI INDONESIA:
  - STRUKTUR JALAN KERETA API: DISAIN DAN KONSTRUKSI
  - GEOTRACK DAN GEOHAZARDS: ANALISIS DAN MITIGASI
  - INSPEKSI DAN EVALUASI: PENGEMBANGAN TEKNOLOGI
  - RAILWAY SAFETY AND RISK ASSESSMENT (RASRIS): SISTEM TEKNOLOGI INFORMASI

PERAN TRANSPORTASI KERETA API

MENDUKUNG SISTEM TRANSPORTASI NASIONAL - TERINTEGRASI DALAM KONSEP MOBILISASI, LOGISTIK DAN KONEKSITAS

SISTEM TRANSPORTASI NASIONAL

- **MOBILISASI PENUMPANG**
- **SISTEM LOGISTIK TRANSPORTASI BARANG**
- **KONEKSITAS NASIONAL-REGIONAL**

KERETA API SEBAGAI MODA TRANSPORTASI UMUM YANG MAMPU MENGANGKUT DALAM JUMLAH BESAR (MASSAL), EFISIEN, MURAH, TERATUR, TERJADWAL, ANDAL, AMAN DAN BERDAMPAK LINGKUNGAN RENDAH

PENGUATAN DAYA SAING DALAM PEMBANGUNAN EKONOMI BERKELANJUTAN

Peran Transportasi Perkeretaapian:
RENCANA INDUK PERKERETAAPIAN (RIPNAS 2030)

VISI :

"Perkeretaapian yang berdaya saing, berintegrasi, berteknologi, bersinergi dengan industri, terjangkau dan mampu menjawab tantangan perkembangan".

ARAH PENGEMBANGAN :

1. **Pelayanan prasarana** dan **sarana perkeretaapian yang handal (prima), mengutamakan keamanan dan keselamatan (*security and safety first*),** terintegrasi dengan moda lain, terjangkau oleh seluruh lapisan masyarakat serta tersebar di pulau-pulau besar seperti Jawa, Sumatera, Kalimantan, Sulawesi, dan Papua.
2. **Teknologi perkeretaapian yang modern, ramah lingkungan, daya angkut besar dan berkecepatan tinggi.**
3. **Penyelenggaraan perkeretaapian nasional yang mandiri dan berdaya saing**, menerapkan prinsip-prinsip "*good governance*" serta didukung oleh SDM yang unggul, industri yang tangguh, iklim investasi yang kondusif, pendanaan yang kuat dengan melibatkan peran swasta.

RENCANA INDUK PERKERETAAPIAN (RIPNAS 2030)
5 dari 7 Target RIPNAS → Infrastruktur

TARGET RIPNAS 2030 :

1. **Share angkutan penumpang 11 – 13 % dan angkutan barang 15 – 17 %**
2. **Jaringan KA 10.000 km, double track dan elektrifikasi pada lintas utama → Infrastruktur**
3. **Jaringan perkeretaapian "Trans Sumatera" → Infrastruktur**
4. **Sebagai tulang punggung transportasi perkotaan → Infrastruktur**
5. **Pengoperasian "Argo Cahaya" (Kereta Api Cepat) di Pulau Jawa**
6. **Perkeretaapian sebagai tulang punggung angkutan barang di Kalimantan, Sulawesi dan Papua → Infrastruktur**
7. **Pelayanan yang terintegrasi, aman, nyaman, handal dan terjangkau → Infrastruktur**

PROYEKSI ANGKUTAN PENUMPANG (ORANG/TAHUN)

	2006	2010	2015	2020	2025
Jawa	127.519.723	155.158.347	184.299.294	214.417.082	244.673.991
Sumatera	2.566.924	4.366.143	6.401.799	8.653.562	11.103.851
Kalimantan	-	-	479.468	781.226	1.120.520
Sulawesi	-	-	2.483.369	3.902.371	5.406.375
TOTAL	130.086.647	159.524.490	193.663.930	227.754.241	262.304.737

SOURCES : RAILWAYS MASTER PLAN 2009

- **PADA TH. 2025 INDONESIA MEMILIKI PENDUDUK 273.6 JUTA ORANG.**
- **PENDUDUK KOTA IN JAWA MENCAPAI 82.2% SEKITAR 120 JUTA.**
- **PADA GDP PER KAPITA US$ 13,000-16,000 MOBILITAS MENINGKAT TAJAM.**

Pengembangan Infrastruktur untuk Jaringan Transportasi Kereta Api di Indonesia

BAGIAN – 2

ANGKUTAN JARAK JAUH UNGGULAN

ANGKUTAN PENUMPANG DENGAN MENUJU SUSTAINABLE TRANSPORT

ANGKUTAN KOMUTER /REGIONAL & KOTA

1 ANGKUTAN PENUMPANG JARAK JAUH

EKONOMI

2 ANGKUTAN PENUMPANG JARAK JAUH

EKSEKUTIF

3 ANGKUTAN KOMUTER/ REGIONAL

EKONOMI

4 ANGKUTAN PERKOTAAN

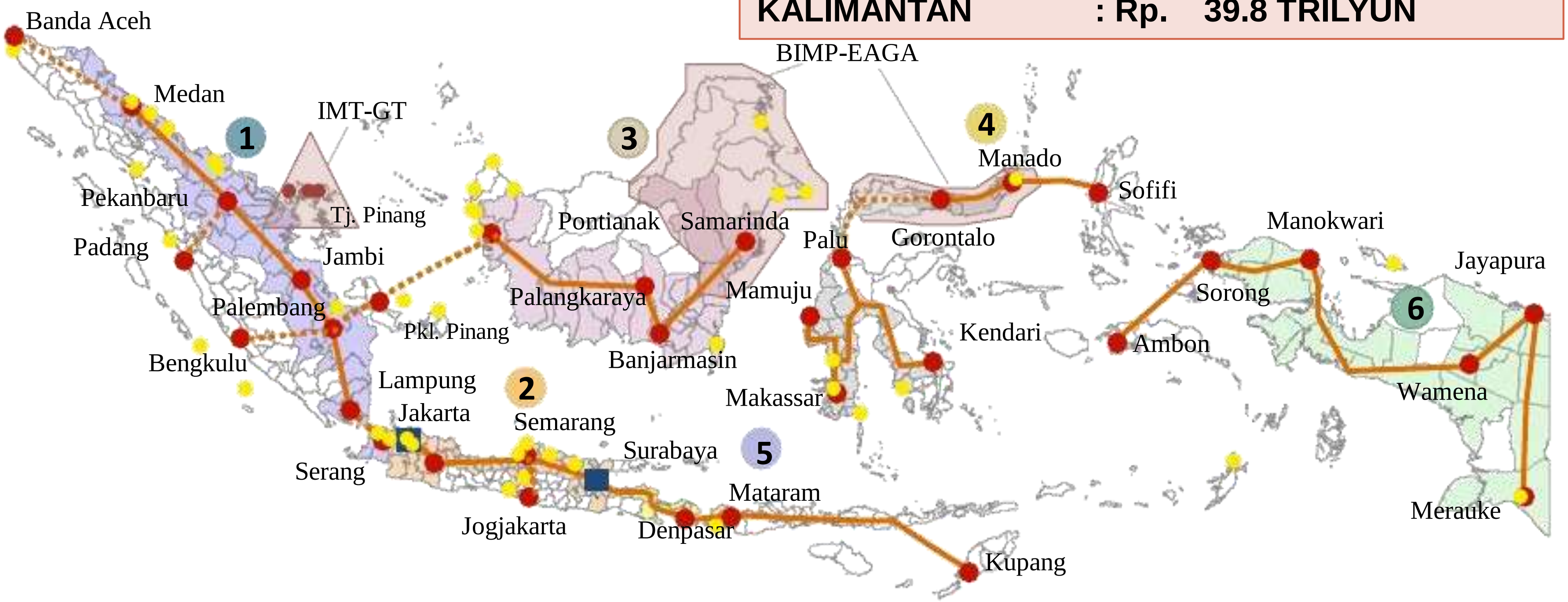
EKONOMI

KOMITMEN DALAM MP3EI – PERKERETAAPIAN

► RENCANA NILAI INVESTASI KERETA API Rp. 305.2 TRILYUN

INVESTASI INFRASTRUKTUR PERKERETAAPIAN

SUMATERA	: Rp. 43.2 TRILYUN
JAWA	: Rp. 222.2 TRILYUN
KALIMANTAN	: Rp. 39.8 TRILYUN



■ Pusat ekonomi mega ● Pusat ekonomi ● Usulan lokasi KEK ● Usulan lokasi KEK yang merupakan FTZ

1 **KE Sumatera** 3 **KE Kalimantan** 5 **KE Bali – Nusa Tenggara**

2 **KE Jawa** 4 **KE Sulawesi** 6 **KE Papua – Maluku**

- MINYAK SAWIT (NO. 1 DUNIA)
- BATUBARA (NO. 2 DUNIA)

ANGKUTAN KOMODITAS UNGGULAN

PERUBAHAN BISNIS ANGKUTAN BARANG DENGAN SOLUSI TERPADU

ANGKUTAN MULTIMODAL LOGISTIK NASIONAL

1. **ANGKUTAN BARANG CURAH PADAT**

BATUBARA

2. **ANGKUTAN BARANG CURAH CAIR**

MINYAK SAWIT

3. **ANGKUTAN BARANG INTERMODA**

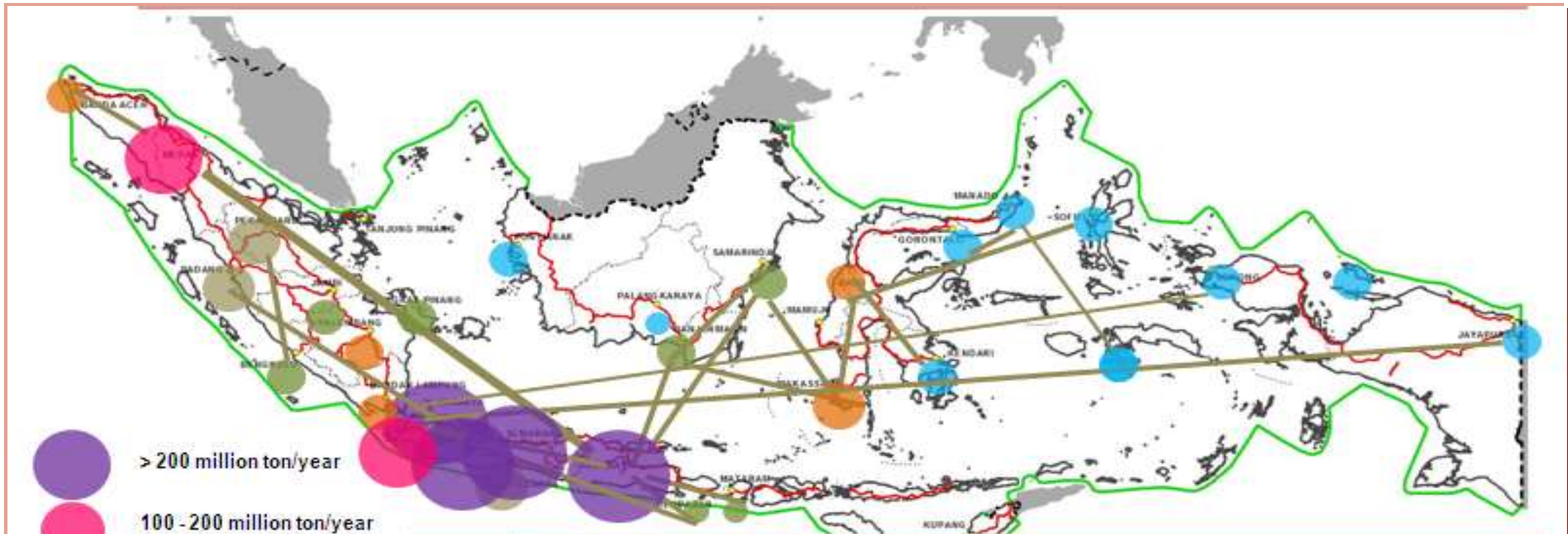
KONTENER, SEMEN

4. **ANGKUTAN GENERAL CARGO CEPAT**

ELEKTRONIK, CONSUMER GOODS

JARINGAN LOGISTIK NASIONAL PERKERETAAPIAN

PENGEMBANGAN SISTEM LOGISTIK NASIONAL KHUSUS UNTUK KORIDOR EKONOMI JAWA SEBAGAI ZONA ARUS BARANG TERPADAT DIBUTUHKAN JALUR KERETA API



No	Cargo Transportation (Volume)	Strategic Corridor
1	> 50 million ton/year	Bandung-Jakarta, Surbaya-Semarang
2	40-50 million ton/year	Jakarta-Surabaya
3	30-40 million ton/year	Jakarta-Cilegon/Merak, Yogyakarta-Semarang, Medan-Surabaya, Bandung-Surabaya
4	20-30 million ton/year	Medan, Banda Aceh, Pekanbaru/Dumai-Padang, Jakarta-Semarang, Bandung-Semarang, Makassar-Palu, Bandung-Cilegon/Merak, Surabaya-Cilegon/Merak
5	10-20 million ton/year	Medan-Pangkal Pinang, Medan-Pakanbaru/Dumai

Source:
Study of Intermode Transportation Development in Indonesia, Dephub-2004

KEBUTUHAN JARINGAN KA SUMATERA

CONTOH: PENGEMBANGAN KA TRANS SUMATERA TERKAIT DENGAN KONEKTIVITAS ASEAN

KONEKTIVITAS REGIONAL ASEAN

Tantangan Pengembangan Infrastruktur untuk Jaringan Transportasi Kereta Api di Indonesia

BAGIAN – 3

Tantangan Perkeretaapian di Indonesia

#Tantangan 1#
Keselamatan Perjalanan Perkeretaapian → “Zero Accident” → Menurunkan Risiko Kecelakaan

#Tantangan 2#
Pelayanan Perjalananan → “Kenyamanan & Keamanan “

#Tantangan 3#
Kesiapan Infrastruktur (Prasarana) → Updating Teknologi, Inspeksi dan Pemeliharaan

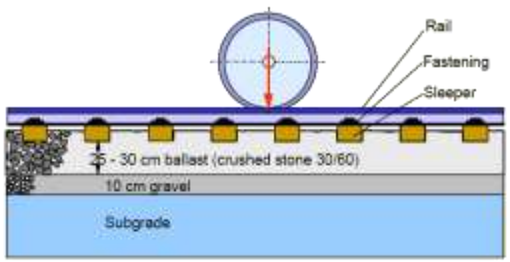
Tantangan Perkeretaapian di Indonesia

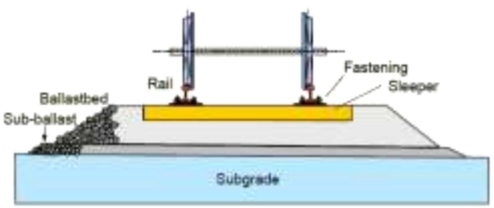
#Tantangan 4#
Kereta Cepat → Teknologi Sarana dan Prasarana

#Tantangan 5#
Inspeksi Prasarana Perkeretaapian

#Tantangan 6#
Risiko Bencana

Mempersiapkan pengembangan infrastruktur





Struktur Jalan Rel
- Superstructure
- Sub-structure
- Bangunan Pendukung

→ Pemodelan Struktur Jalan Rel; Sistem Disain Jalan Rel

Disain → ?
- Peningkatan daya angkut
- Peningkatan kecepatan
- Peningkatan struktur

Geotrack dan Geohazards
- Permasalahan Geoteknik
- Bencana Geologi

→ Disain Badan Jalan; Advanced Geotrack Technology; Analisis dan Mitigasi

Disain → ?
- Antisipasi variasi perilaku tanah dan bencana geologi

Sistem Inspeksi dan Audit Keselamatan
- Sistem Evaluasi
- Teknologi

→ Advanced Geotrack Technology

Sistem inspeksi dan pengembangan teknologi

Risk Assessment

Filosofi – Trilogi Struktur Jalan Rel

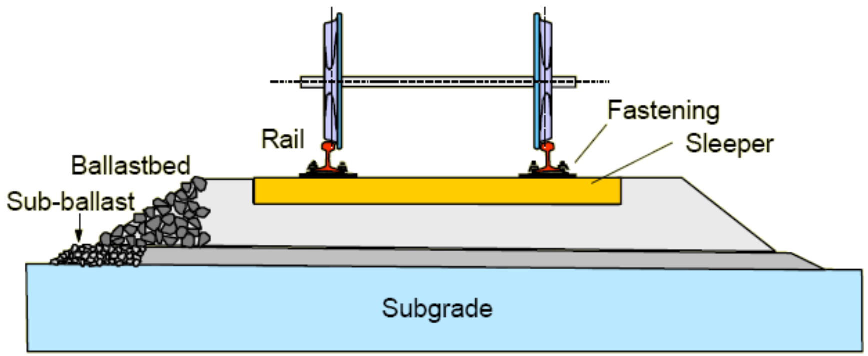
Konstruksi
- Mutu bahan
- Mutu pelaksanaan
- Mutu inspeksi

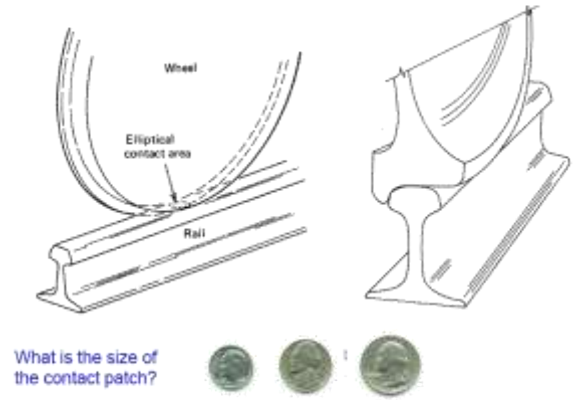
Disain Struktur (Pembebanan)
- Tepat metode
- Komponen yang sesuai
- Verifikasi disain

Perawatan/ Pemeliharaan
- Berkala
- Penanganan Spesifik
- Monitoring terintegasi

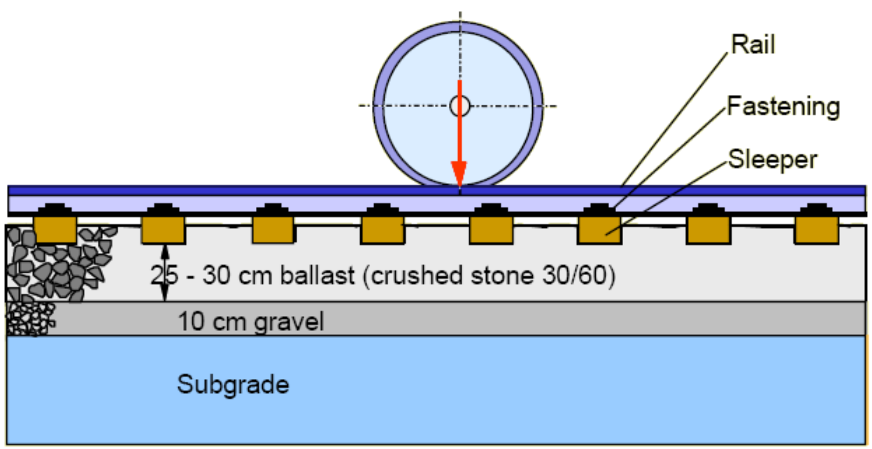
Jalan Rel

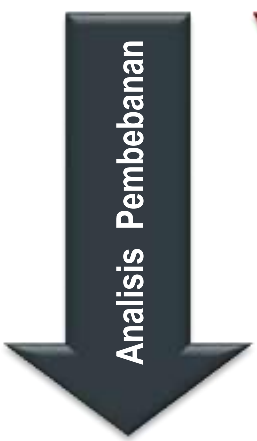
I. Disan Struktur Jalan Rel - Pembebanan





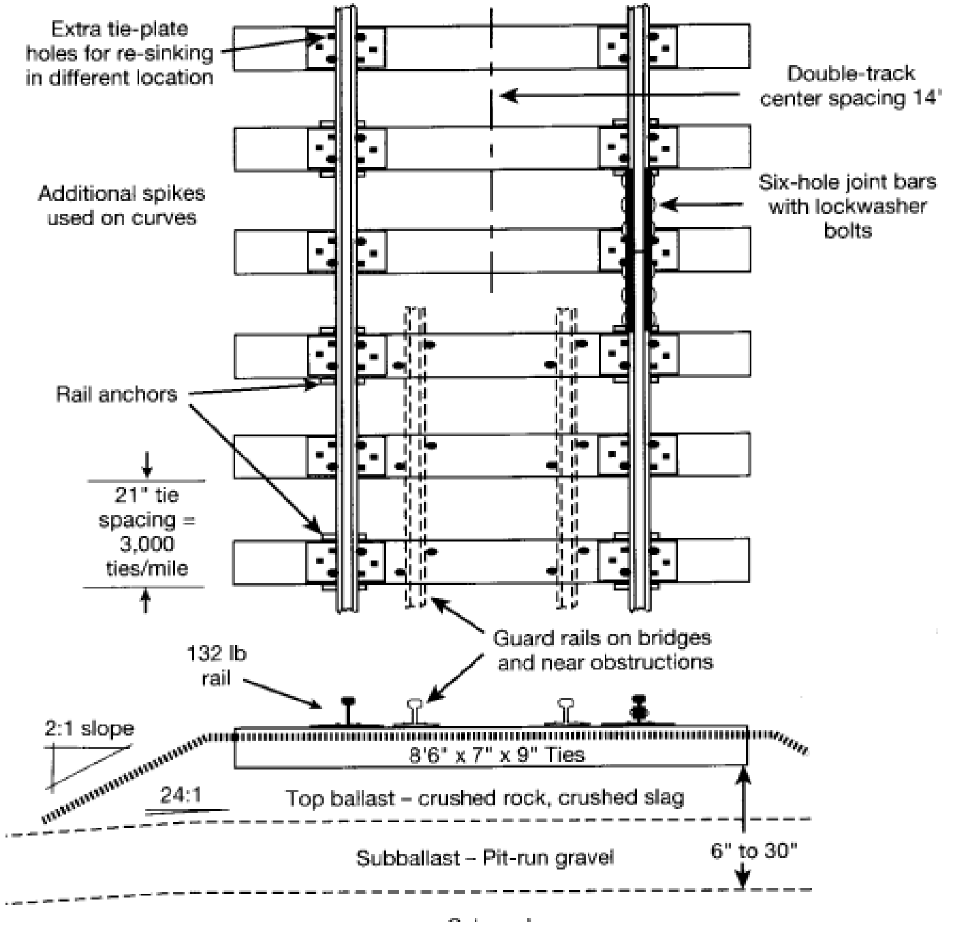
Konsep Pembebanan pada Struktur Jalan Rel – Sistem Kompleks dan merupakan Sistem Terintegrasi





Jalan Rel (**Track**) adalah sistem dinamik komponen-komponen yang saling berhubungan (*interacting*) yang mampu mendistribusikan beban dan menyediakan jalur untuk kereta api berjalan dengan lancar, nyaman dan stabil.

Sistem harus **stabil** dalam arah **vertikal**, **lateral** dan **longitudinal**.



Derivatif Filosofi = Kriteria Struktur

Stiffness
Resiliency
Resistance to Permanent Deformation
Stability
Adjustability

Disain Struktur

- Metode/pendekatan untuk mendisain struktur:
  - Coba-Coba (Trial and Error)
  - Empirik – based on trial and error
  - Empirik/Rasional – menentukan beban dan sifat material
  - Rasional – analisis tegangan-regangan (stress/strain) dan berdasarkan pengukuran (mekanistik-empirik)

- Trackbed (landasan struktur jalan rel) bukan struktur jalan yang permanen (permanent way) – sangat bervariasi dan memerlukan disain yang tepat → perlu perawatan secara reguler dan berkelanjutan → sistem pengelolaan (manajemen) jalan rel
- Disain trackbed tidak bisa digeneralisasi dan perawatannya pun harus disesuaikan dengan problematic setempat.

Disain Pembebanan

Trackbed (landasan) sangat bergantung kepada variasi beban dan tegangan:

- Beban mati (dead loads)
- Beban hidup (live loads)
- Beban dinamik (dynamic loads)
- Gaya sentrifugal (centrifugal loads)
- Beban lateral (lateral loads)
- Beban termal (thermal loads) – CWR
- Beban longitudinal (longitudinal loads)
- Gerak rangkaian/wave action

Kondisi aktual bahan dan material penyusun struktur jalan rel, khususnya juga untuk landasan jalan rel (tanah dasar dan struktur geologi)

Belum terakomodasi dalam **PM 60 tahun 2012** dan **Peraturan Dinas No. 10 tahun 1986**

Masih mengacu pada persamaan empirik dan pola pembebanan (koefisien empirik) lama

Perilaku tegangan-regangan, dinamik dan pengaliran pada tanah dasar tidak mendapatkan perhatian yang detil.

1435 mm

b. Lebar Jalan Rel 1435 mm

Kelas Jalan	Daya Angkut Lintas (ton/tahun)	V maks (km/jam)	P maks gandar (ton)	Tipe Rel	Jenis Bantalan / Jarak antar sumbu bantalan (cm)	Jenis Penambat	Tebal Balas Atas (cm)	Lebar Bahu Balas (cm)
I	$> 20.10^6$	160	22,5	R.60	Beton / 60	Elastis Ganda	30	60
II	$10.10^6 – 20.10^6$	140	22,5	R.60	Beton / 60	Elastis Ganda	30	50
III	$5.10^6 – 10.10^6$	120	22,5	R.60/R.54	Beton / 60	Elastis Ganda	30	40
IV	$< 5.10^6$	100	22,5	R.60/R.54	Beton / 60	Elastis Ganda	30	40

Apakah tebal balas 30 cm masih mencukupi untuk mereduksi tegangan ke tanah dasar ?

Analisis Reaksi
(Beban, Gaya, Momen, Defleksi)

TRACK ANALYSIS:

- Ditentukan beban ijin/allowable loads dan deformasinya
- Ditentukan beban aktual/actual loads dan deformasinya
- Dibandingkan dan disesuaikan (bahan komponen dan tebal)
  - Riset awal : A.N. Talbot
  - Pengembangan sistem – Winkler, Westergaard, Boussineq, etc.
  - Sistem komputasi /computer systems (layered analysis)
  - Talbot treated track as a continuous and elastically supported beam

TRACK STIFFNESS:

- Gerak up and down (pumping) akibat beban berulang pada jalan rel merupakan sumber utama kerusakan.
- Disain struktur harus tetap memperhitungkan defeleksi minimum.
- Turunan dari gerak ini menyebabkan keausan komponen jalan rel.
- Parameter penting: pengukuran modulus → belum menjadi parameter utama dalam disain struktur jalan rel.

Beban dan Reaksi Tegangan pada Rel dan Bantalan

Kecepatan (km/jam)	120		
Beban gandar (ton)	18		
Beban dinamis	Talbot	Area	Eisnmen
Pd (kg)	16940.3	15922.74	10478.57

Perbandingan beban dinamis menurut teori Talbot (88,23%), AREA (76.91%) dan Eisenmann (16,42 %) lebih besar dari beban statis dengan beban gandar 18 ton.

Kecepatan (km/jam)	120		
Beban Gandar (ton)	18		
Beban dinamis	Talbot	Area	Eisenmen
σx (kg/cm2)	1196.027	1124.184	739.8125
Sbase (kg/cm2)	1150.705	1081.584	711.7783

Tipe rel R54 dengan kecepatan 120 km/jam, beban gandar 18 ton, beban dinamis menurut Talbot, Area Eisenmann telah memenuhi syarat tegangan ijin sebesar 1325 kg/cm^2 dan tahanan momen dasar sebesar 1176,8 kg/cm^2.

Kecepatan (km/jam)	120		
Beban gandar (ton)	18		
Beban dinamis	Talbot	Area	Eisnmen
Q (kg)	9944.236	9346.907	6151.093

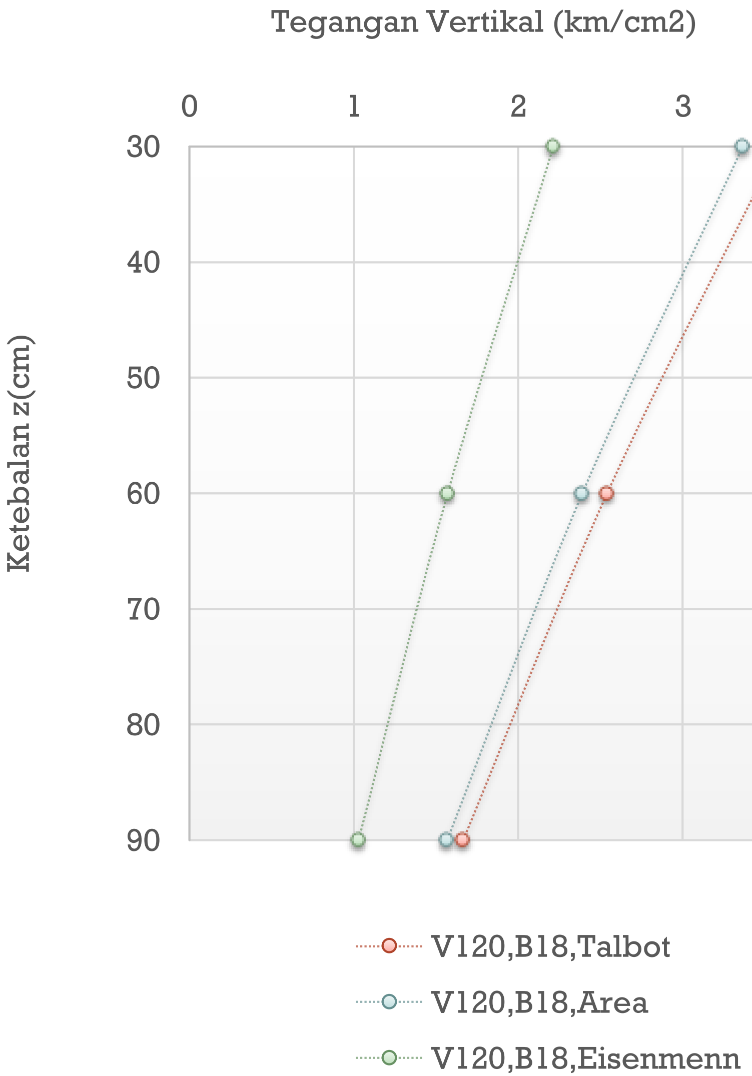
Beban yang di distribusikan rel ke bantalan

Reaksi Tegangan pada Balas

Kecepatan (km/jam)		120		
Beban (ton)		18		
Beban dinamis		Talbot	Area	Eisnmen
σz (kg/cm2) dengan z (cm)	30	3.57897	3.36399	2.21380
σz (kg/cm2) dengan z (cm)	60	2.54087	2.38825	1.57168
σz (kg/cm2) dengan z (cm)	90	1.66640	1.56631	1.03077

Tegangan Vertikal yang diterima balas dengan Teori Boussinesq

Semakin tebal, balas yang digunakan tegangan vertikal diterima balas semakin kecil.



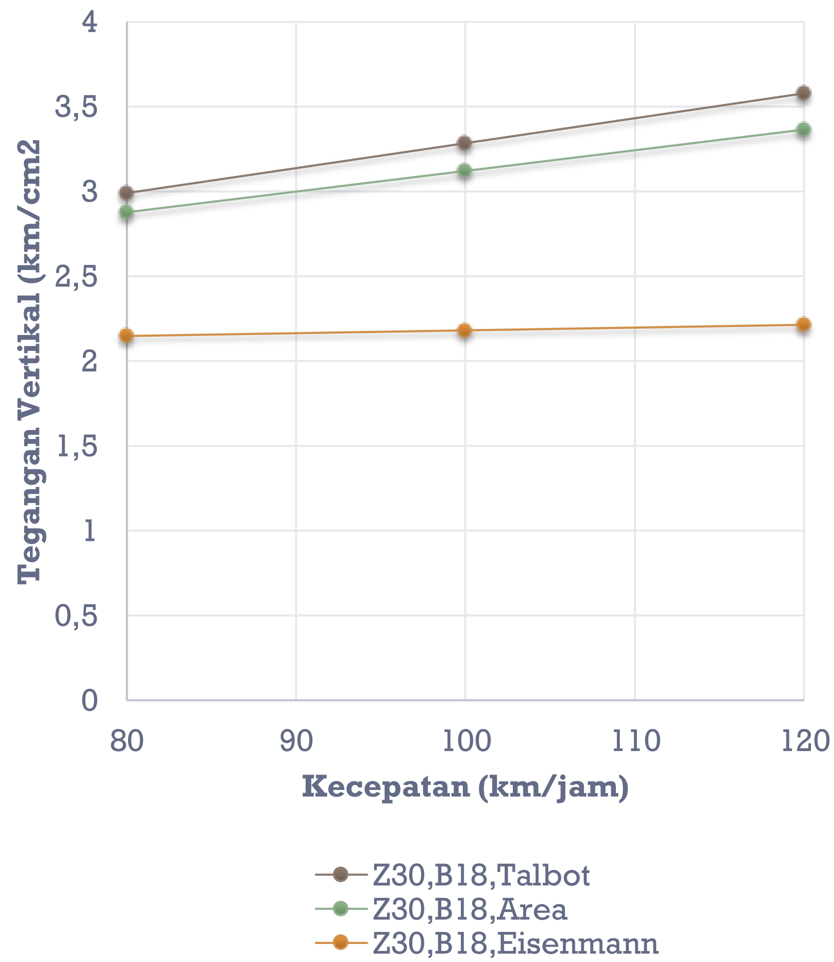
Pengaruh tegangan vertikal dengan ketebalan balas model sederhana teori Boussinesq dengan kecepatan 120 km/jam dengan variasi ketebalan balas 30,60,90 cm

Kecepatan (km/jam)		120		
Beban (ton)		18		
Beban dinamis		Talbot	Area	Eisnmen
σz (kg/cm2) dengan z (cm)	30	3.578	3.363	2.213
Kecepatan (km/jam)		100		
Beban (ton)		18		
Beban dinamis		Talbot	Area	Eisnmen
σz (kg/cm2) dengan z (cm)	30	3.283	3.120	2.179
Kecepatan (km/jam)		80		
Beban (ton)		18		
Beban dinamis		Talbot	Area	Eisnmen
σz (kg/cm2) dengan z (cm)	30	2.988	2.87	2.145

Pengaruh tegangan vertikal dengan variasi kecepatan model sederhana teori Boussinesq dengan kedalaman 30 cm

Semakin tinggi kecepatan semakin besar tegangan vertikal yang diterima.

Reaksi tegangan balas dengan variasi kecepatan



Reaksi tegangan pada ketebalan balas 30cm dengan variasi kecepatan 80,100 dan 120km/jam

Reaksi Tanah Dasar (Tanah Residu Lampung)

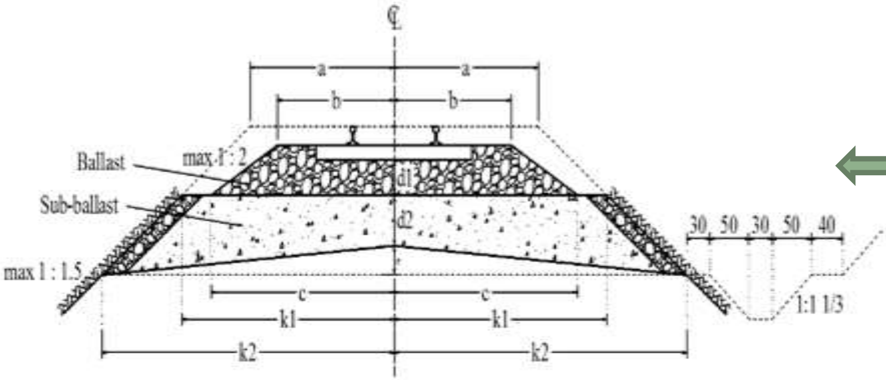
Hasil perhitungan tegangan vertikal yang diterima tanah dasar menurut teori BoEf(*Beam on Elastic Fondation*) dan JNR (*Japanese National Railways*) dengan kecepatan 120 km/jam beban dinamis menggunakan teori Talbot, Area dan Eissenmann, beban gandar 18 ton ketebalan keseluruhan balas dan sub-balas 80 cm

Kecepatan (km/jam)	**120**		
Beban (ton)	18		
Beban dinamis	Talbot	Area	Eisnmen
σ_2 (kg/cm^2)	0.635876	0.59768	0.39332

Dibandingkan dengan tegangan (daya dukung) tanah ijin setempat sebesar 1,014 kg/cm^2.

Pemodelan Numerik dan Parameter Material

- Tahap geometri model

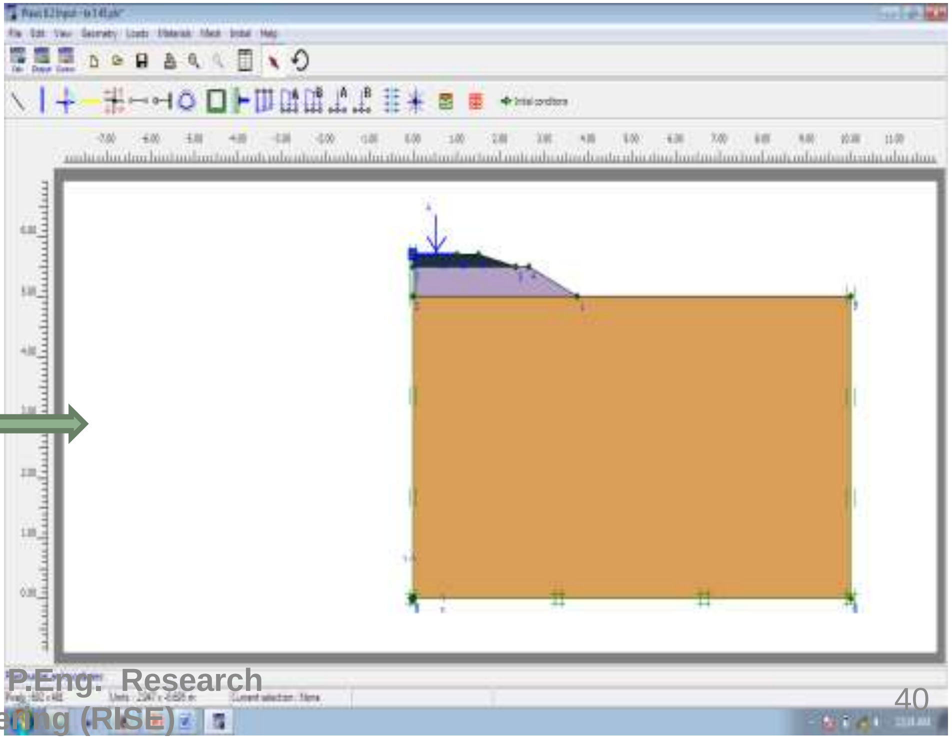


Penampang melintang struktur jalan rel dengan lebar jalan 1067 cm

KELAS JALAN	V Maks (km/jam)	d1 (cm)	b (cm)	c (cm)	k1 (cm)	d2 (cm)	e (cm)	k2 (cm)
I	120	30	150	235	265	15 – 50	25	375
II	110	30	150	235	265	15 – 50	25	375
III	100	30	140	225	240	15 – 50	22	325
IV	90	25	140	215	240	15 – 35	20	300
V	80	25	135	210	240	15 – 35	20	300

Sumber : PM No. 60 tahun 2012

Geometri model pada PLAXIS

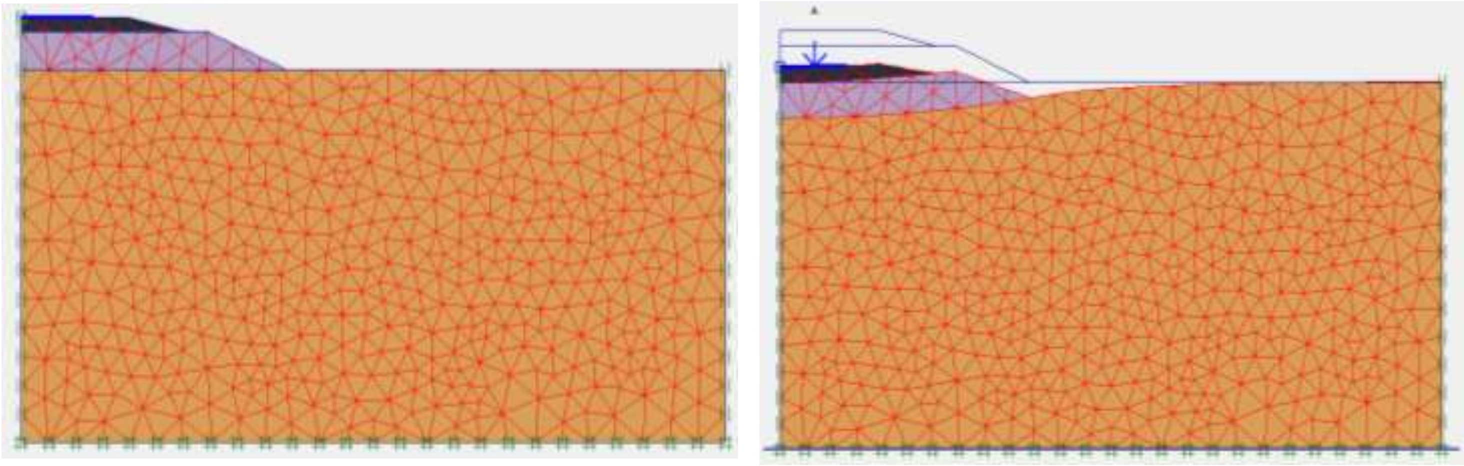


Untuk input dimensi tebal lapisan balas, digunakan variasi tebal lapisan balas 20 cm, 30 cm, 40 cm, 50 cm, dan 60 cm

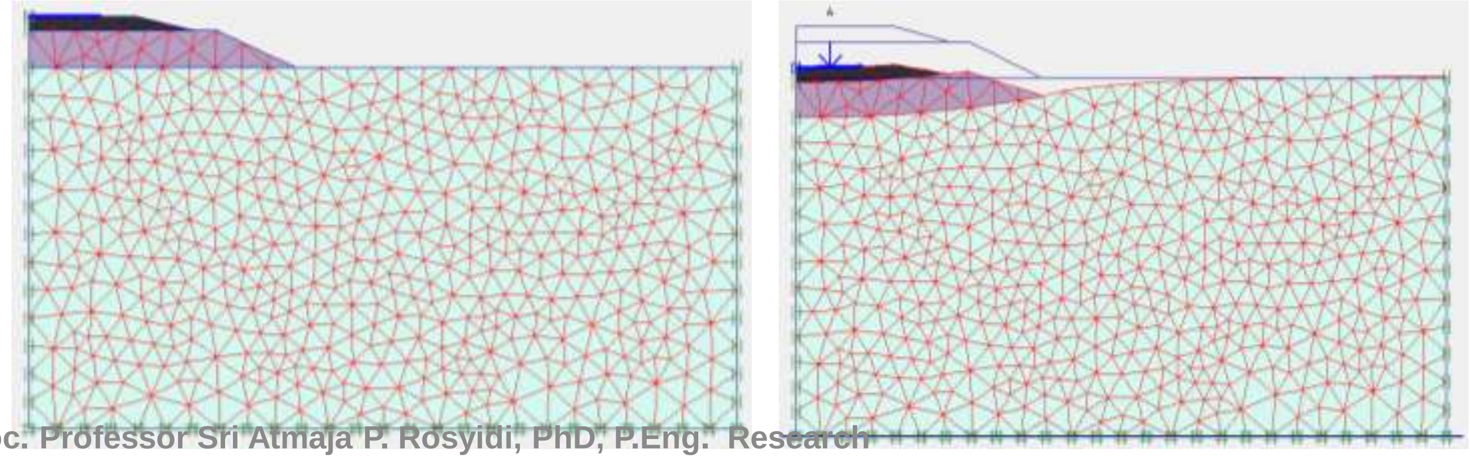
1. Besar Deformasi Akibat Beban Pada Lapis Jalan Rel

- Deformasi vertikal terkecil

Pola deformasi pada KM.117+600 dengan tebal balas 20 cm

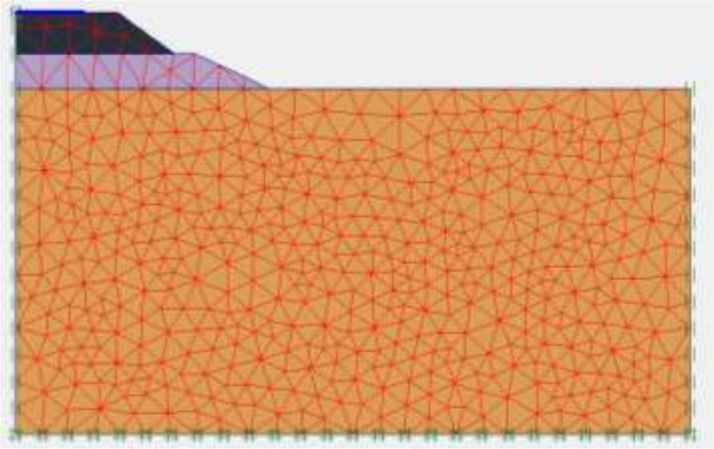


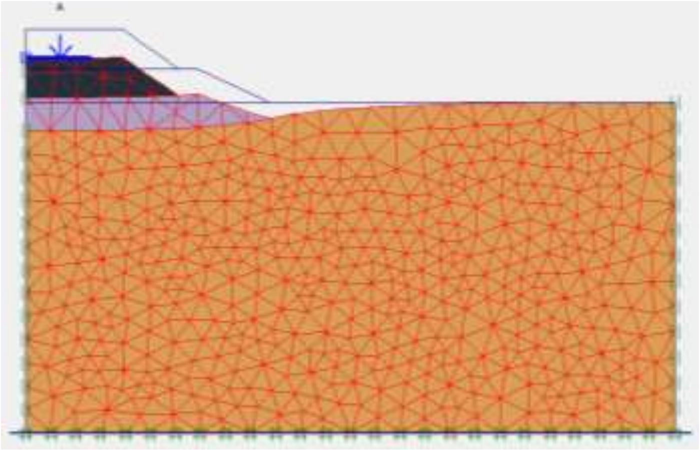
Pola deformasi pada KM.117+800 dengan tebal balas 20 cm



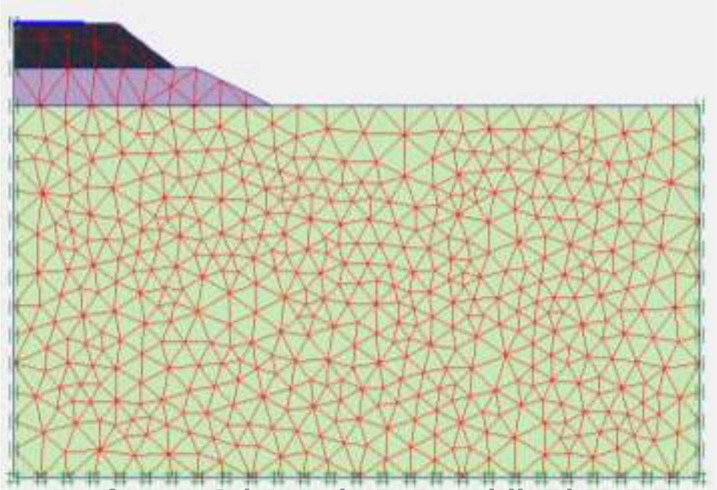
- Deformasi vertikal terbesar

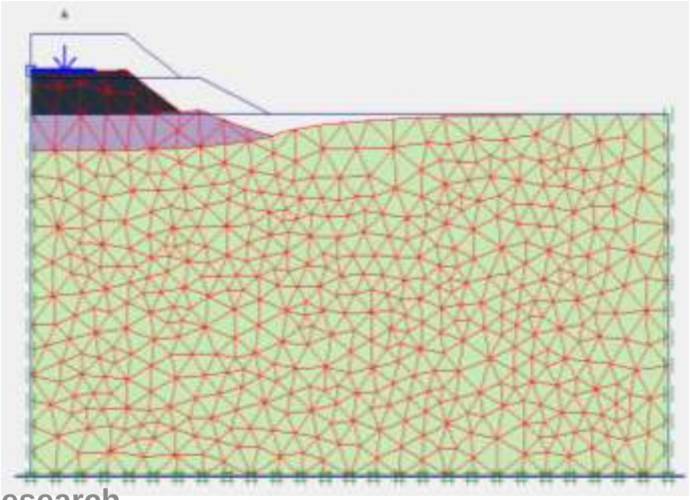
Pola deformasi pada KM.117+600 dengan tebal balas 60 cm



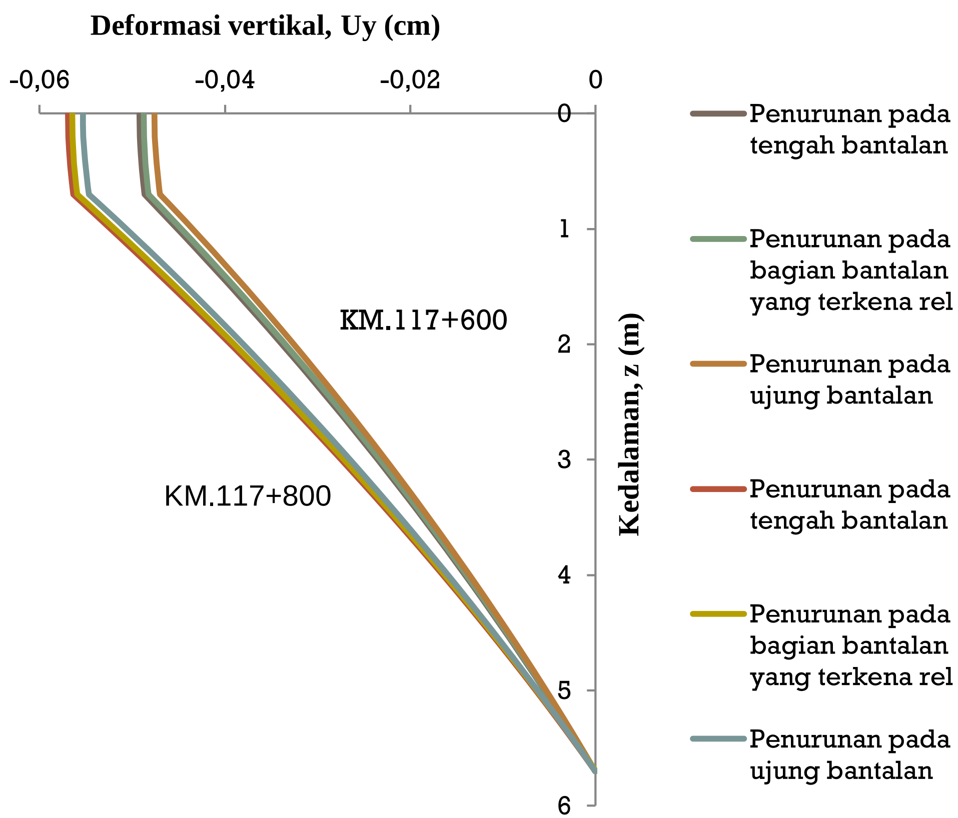


Pola deformasi pada KM.117+800 dengan tebal balas 60 cm

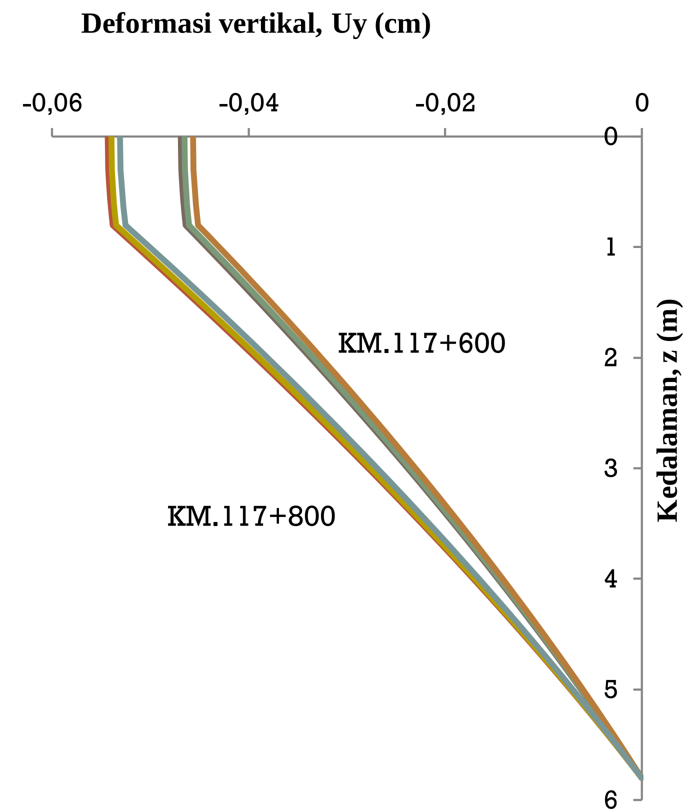




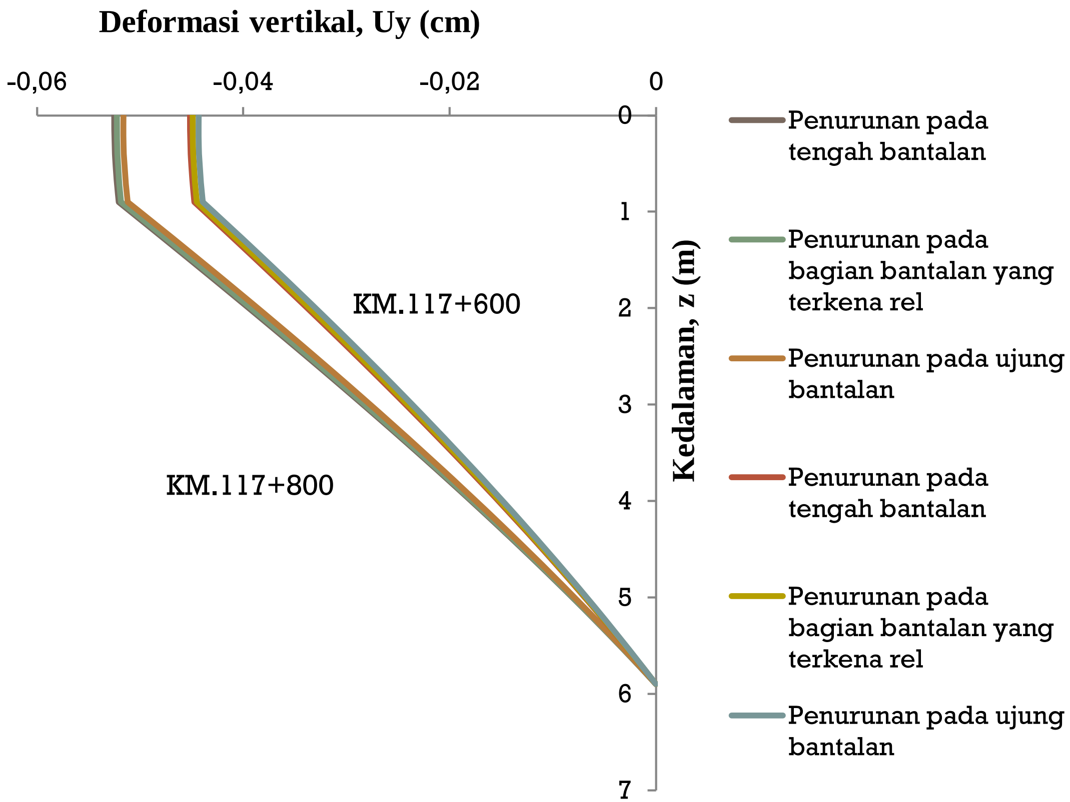
- # Grafik deformasi vertikal dengan ketebalan lapisan jalan rel



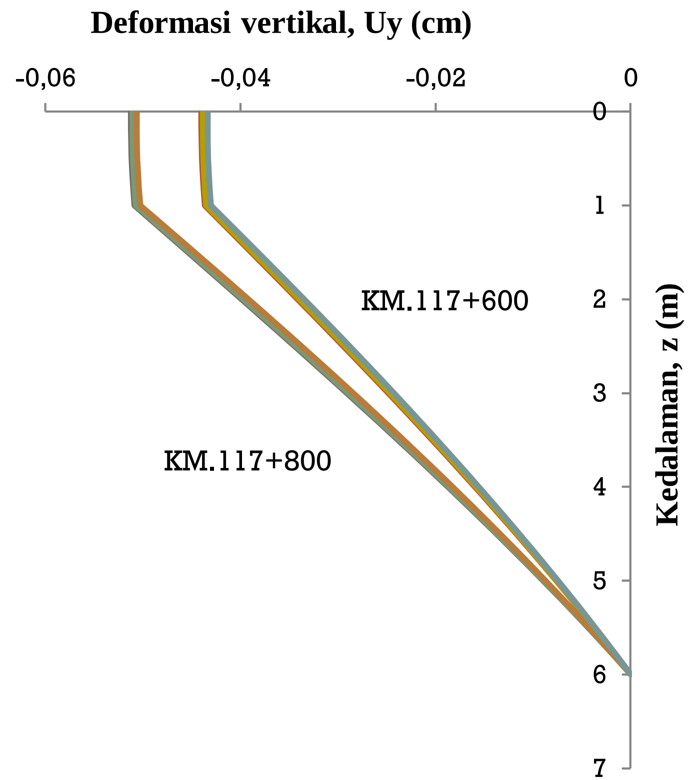
Grafik deformasi vertikal dengan ketebalan balas 20 cm



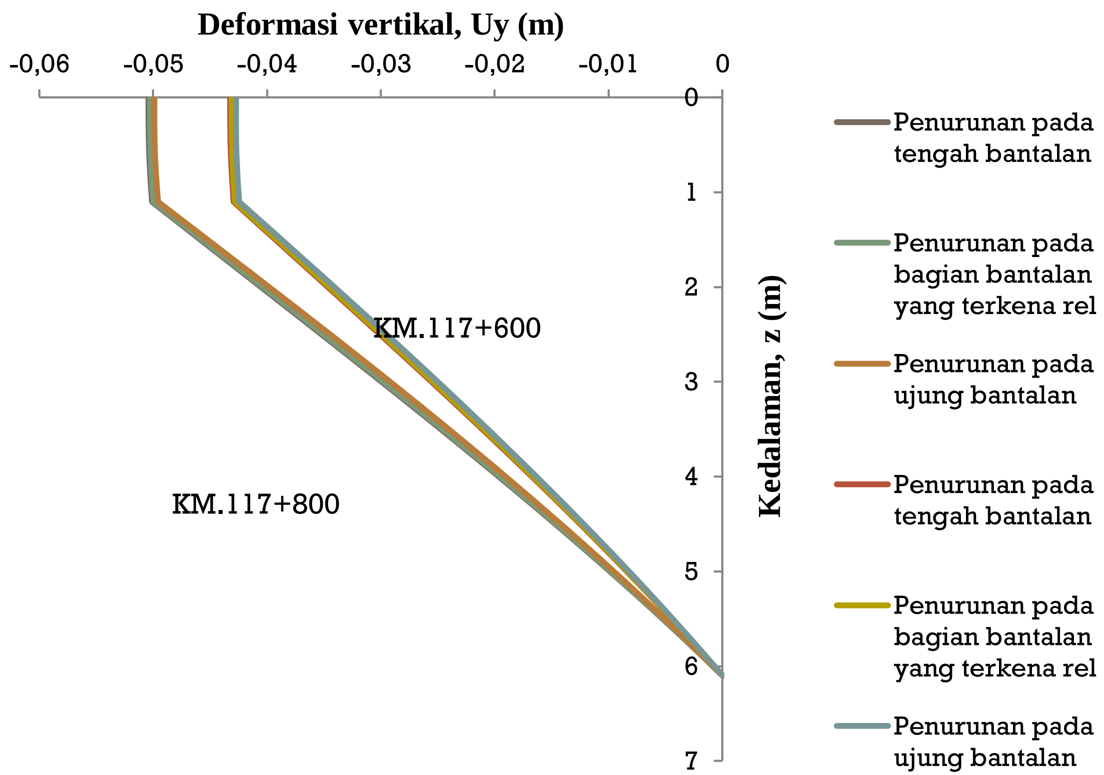
Grafik deformasi vertikal dengan ketebalan balas 30 cm



Grafik deformasi vertikal dengan ketebalan balas 30 cm



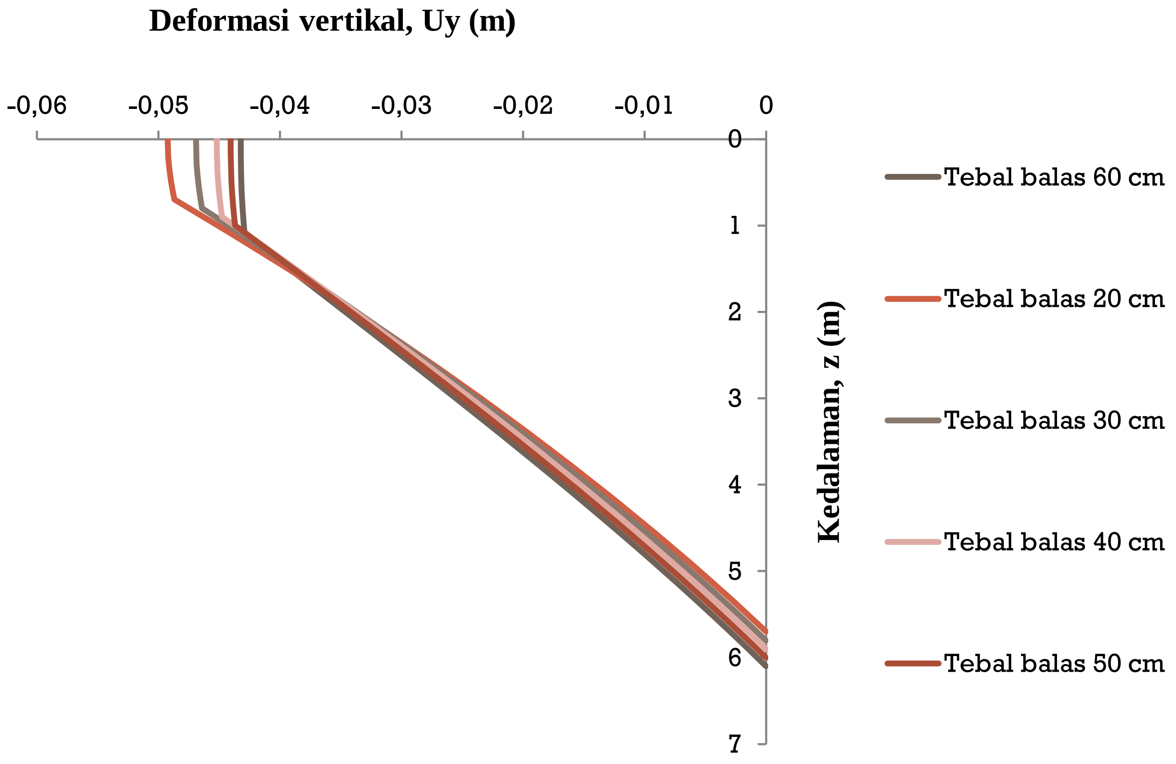
Grafik deformasi vertikal dengan ketebalan balas 40 cm



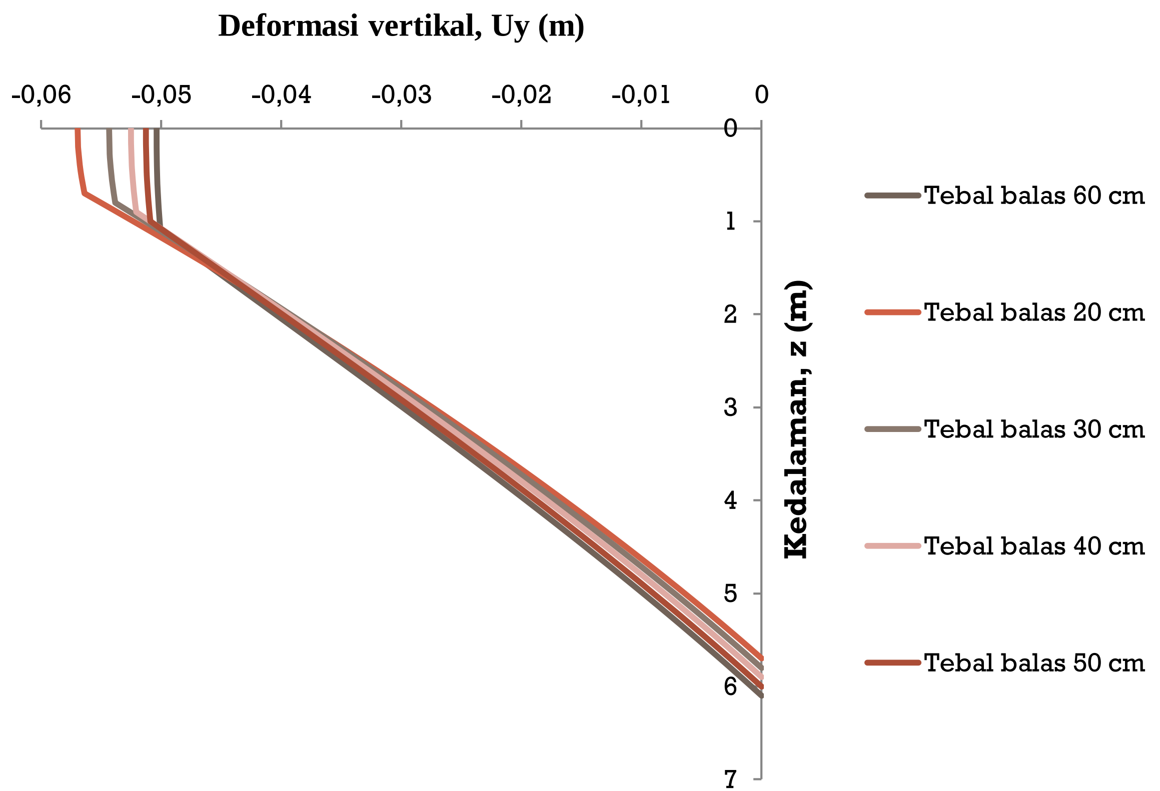
Grafik deformasi vertikal dengan ketebalan balas 60 cm

2. Pengaruh Tebal Lapisan Balas (*ballast*) Pada Lapis Jalan Rel Terhadap Deformasi Vertikal

- **Grafik Hubungan antara tebal lapisan balas dengan nilai deformasi vertikal**



Grafik deformasi vertikal pada KM. 117+600



Grafik deformasi vertikal pada KM. 117+800

Subgrade Damage Analysis

- Excessive permanent deformation controls failure
- Deformation is governed by the vertical compressive stress on the top of the subgrade
- Based on Highway experience
- The number of allowable repetitions before failure

$$N_d = 4.837 \times 10^{-5} \sigma_c^{-3.734} E_s^{+3.583}$$

Service Life Prediction

Damage Analysis

Subgrade

- Excessive permanent deformation controls failure
- Deformation is governed by the vertical compressive stress on the top of the subgrade
- $N_d = 4.837 \times 10^{-5} \sigma_c{}^{-3.734} E_s{}^{3.583}$

Asphalt

- Fatigue cracking controls failure
- Fatigue cracking is governed by the tensile strain in the bottom of the asphalt
- $N_a = 0.0795 \times \varepsilon_a{}^{-3.291} E_a{}^{-0.853}$

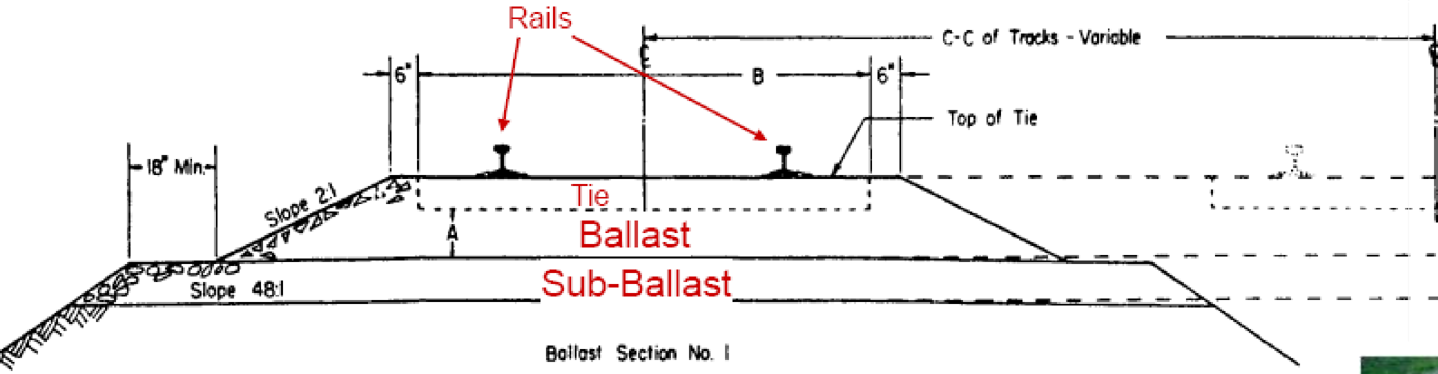
Service Life Prediction

$$L = \frac{1}{\sum_{i=1}^{n} \frac{N_p}{N_a \, or N_d}}$$

Subgrade Service Life

Asphalt Service Life

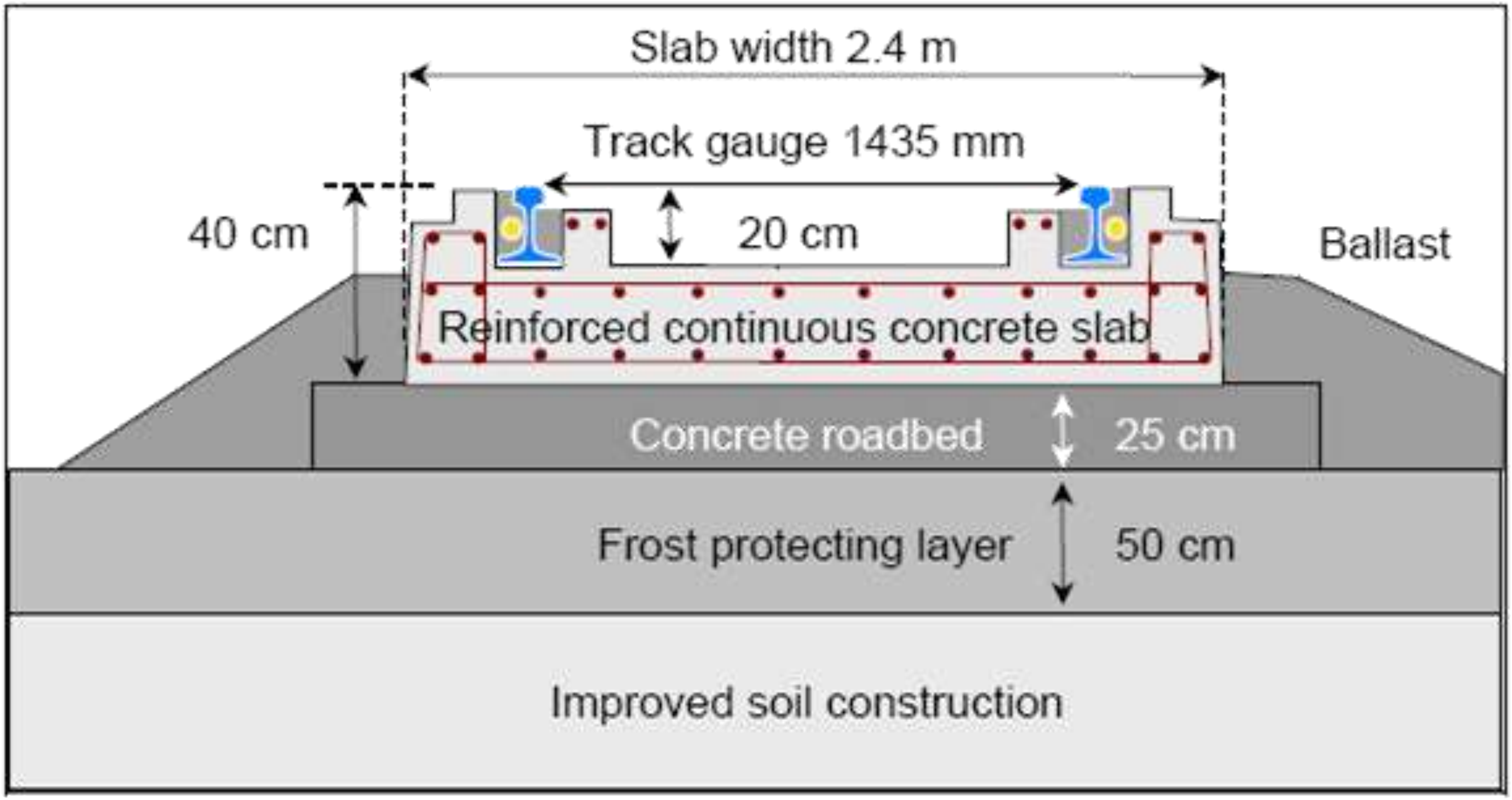
Ballast & sub-ballast cross-section*



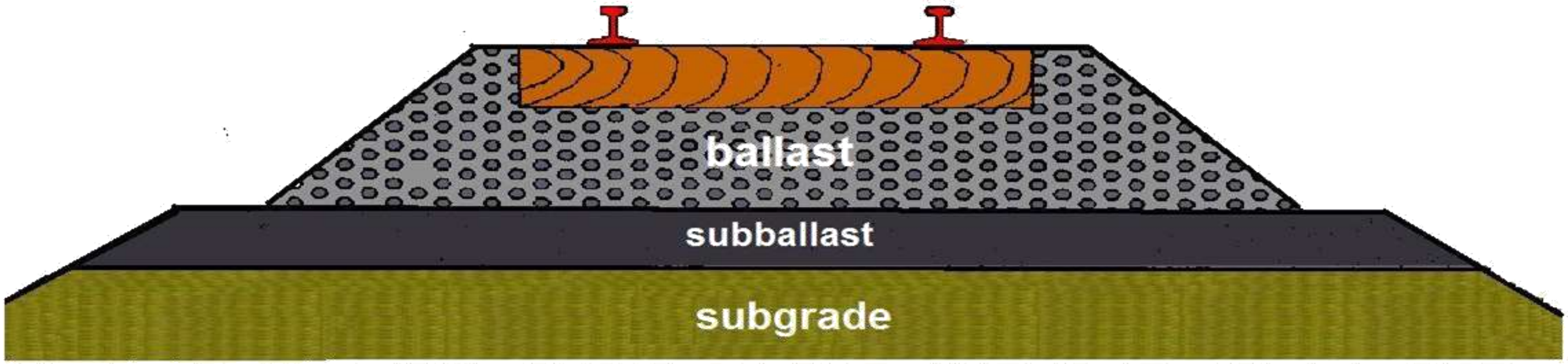
- Ballast and sub-ballast are the final stages in load distribution
- In addition to distributing vertical loads, ballast has a critical role maintaining longitudinal and lateral stability of track.
- Ballast and sub-ballast must provide adequate drainage.
- Ballast is subject to pulverization from loading and unloading as trains pass over, thereby generating fine particles that clog the ballast

Kualitas tanah (geoteknik) sangat bervariasi dan sangat penting !

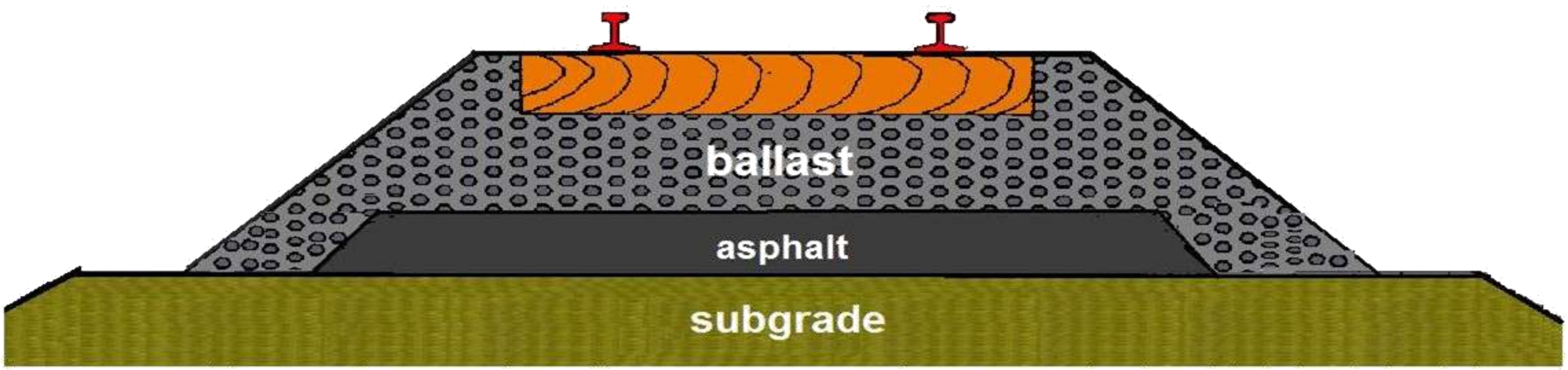
Innovation in Rail Track



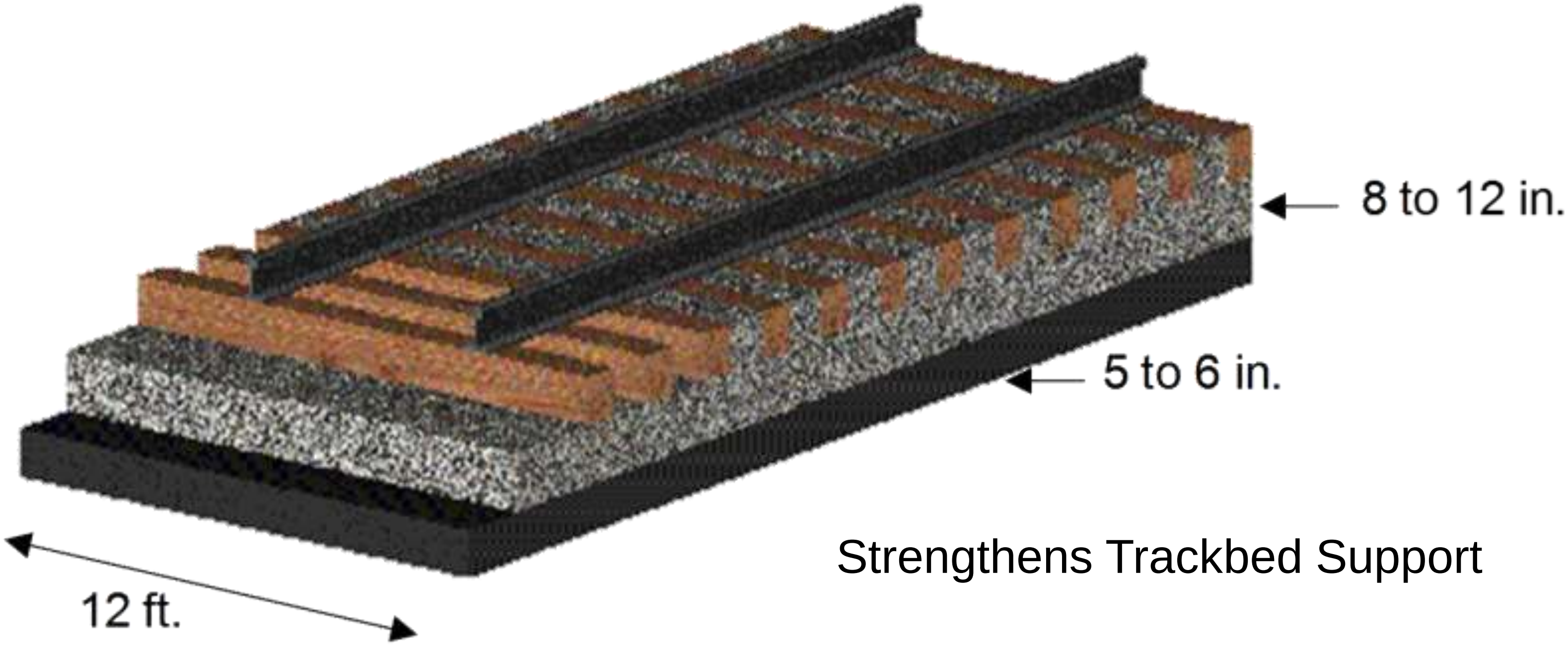
TRACKBEDS



BALLASTED TRACKBED



ASPHALT TRACKBED

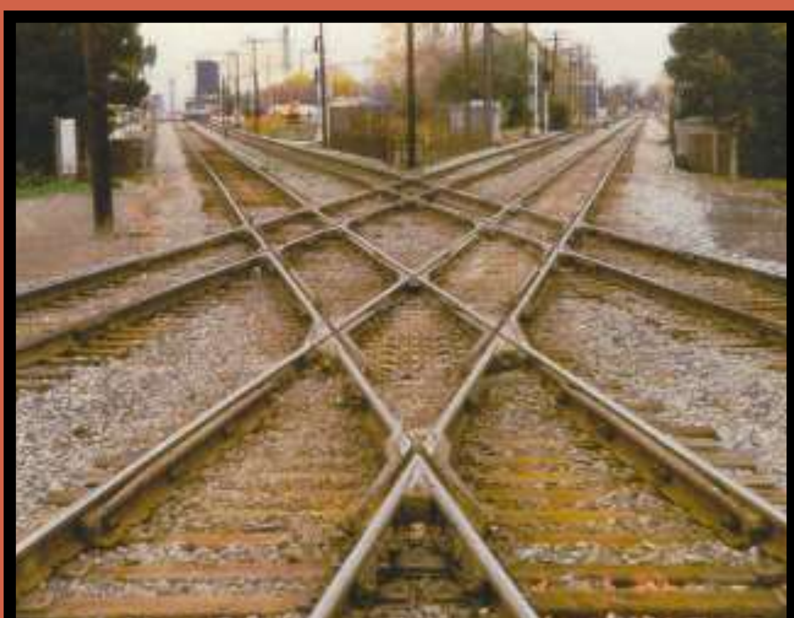


Strengthens Trackbed Support

Waterproofs Underlying Roadbed

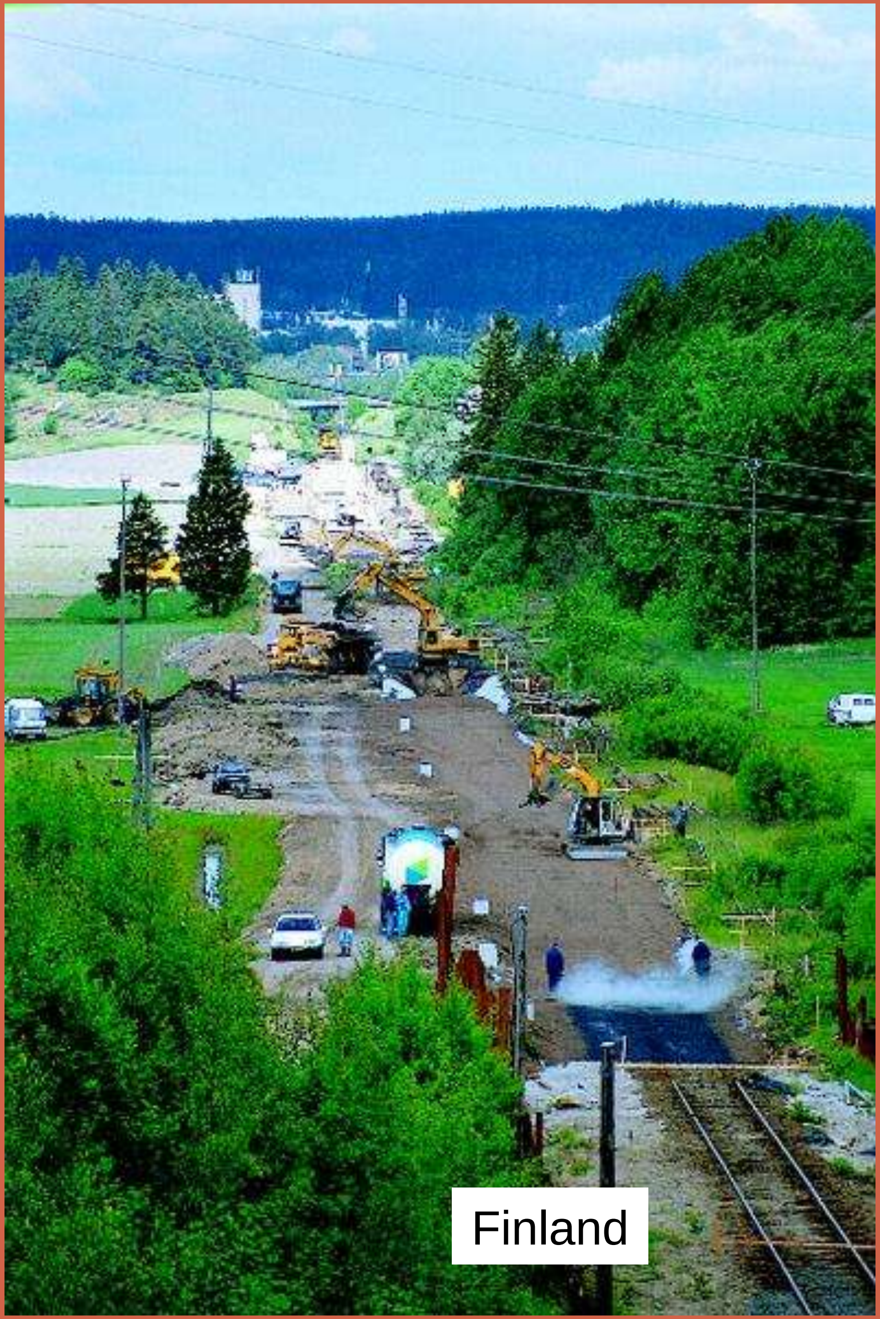
Confines Ballast and Track







Italy

Germany

Finland







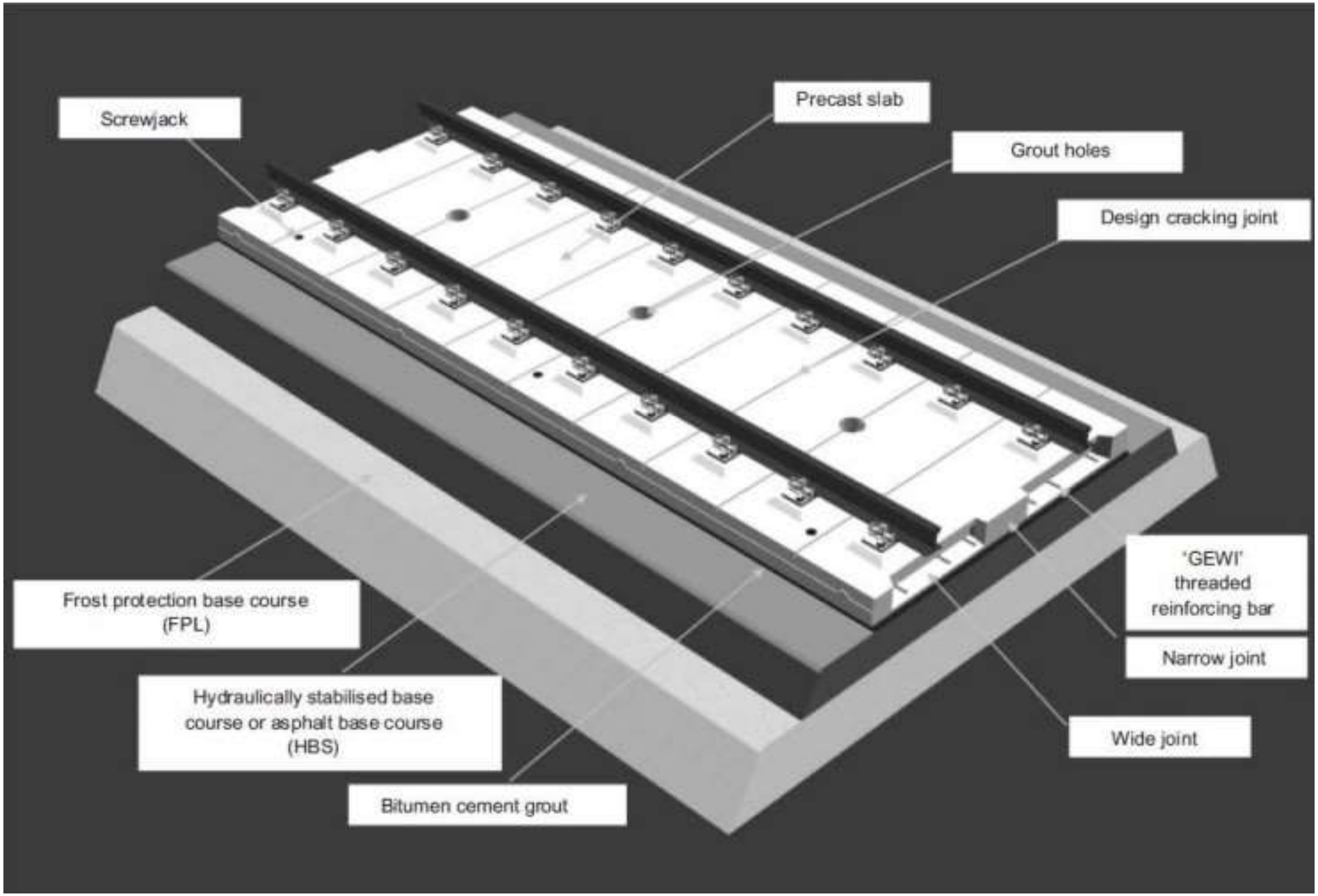



• Ballastless (Slab) Track System

Slab Track Design	Country of Design	Total Construction (km)
Bögl	Germany	4391
Shinkansen	Japan	3044
Rheda	**Germany**	**2205**
Sonnevile-LVT	Swiss	1031
Züblin	Germany	606
Stedef	France	334
Infundo-Edilon	Netherlands	211
ÖBB-Porr	Austria	122.2
IPA	Italy	100
PACT	UK	95.4
SATO	Germany	35.8
FFYS	Germany	33.1
???????	INDONESIA	0

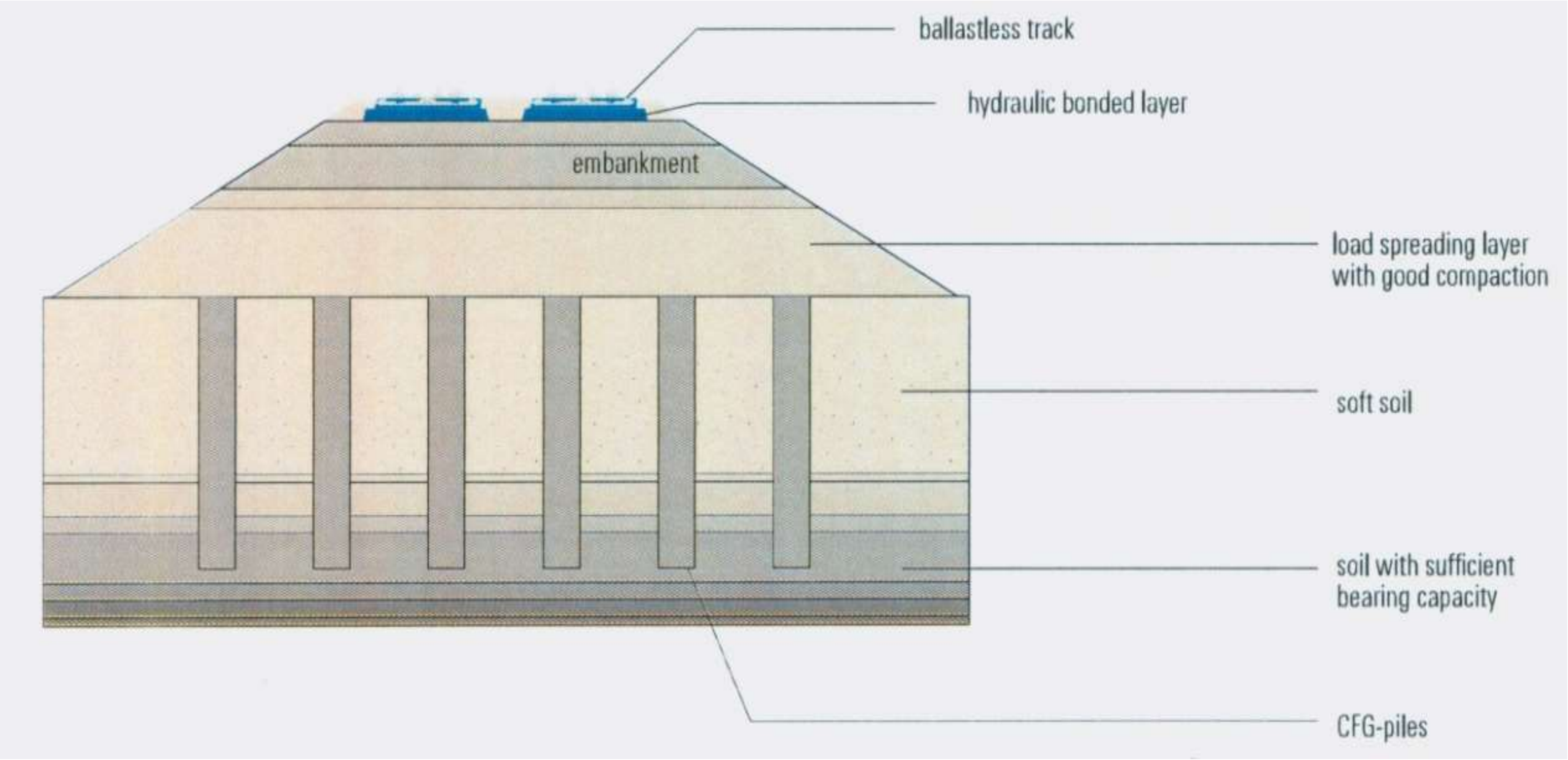
The current lengths (km) of constructed slab track designs worldwide according to the available references (Michas, 2012).

► Bogl Systems (GERMANY) (Prefabricated)



- **Shinkansen Systems (JAPAN) (Prefabricated)**

Components of Ballastless (Slab) Track Systems



The typical cross section of embankment and Cement Fly-ash Gravel (CFG) piles compaction method Piles for subsoil improvement (SSF Ingenieure, 2010)

Components of Ballastless (Slab) Track Systems

The construction of Concrete Bearing Layer (CBL) & Hydraulically Bearing Layer (HBL)

Conventional Track vs Slab Track

Conventional Track	Rheda (Slab) Track
Rails: - R 54 (UIC 54) - Standard rail (25 m) - Conventional jointed rails (Fishplates)	**Rails**: - R 60 (UIC 60) - Short rail (100 m) - Continuous welded rails
Rail Fastenings and pads: - Pandrol (spring-type elastic) fastenings - Rubber pads 5 mm	**Rail Fastenings and pads**: - Vossloh 300 fastening - Soft elastic pads 10 – 12 mm
Rail Support by Sleepers: - Monoblock pre-tensioned sleepers	**Rail Support**: - Modified twin-block sleepers
Ballast Thickness = 50 cm E = 30 MPa	**Concrete Bearing Layer** Thickness = 24 cm The cement content = 350 to 370 kg/m^3

Conventional Track vs Slab Track

Conventional Track	Rheda (Slab) Track
Subballast Thickness = 40 cm E = 15MPa	**Hydraulically Bonded Bearing Layer** Thickness = 30 cm The portland cement content =110 kg/m^3
Overall Thickness = 104 cm	**Overall Thickness = 71 cm**
Embankment Thickness = 3 to 6 m E = 10 Mpa	**Embankment** Thickness = 3 to 6 m E = > 60 Mpa
Subgrade E = 8.2 MPa Soil reinforcement : Geotextiles	**Subgrade** E = 60 MPa Soil reinforcement method: CFG piles

Conventional Track

+

- Much lower construction cost.
- A better solution in earth structures.
- Possibility to rectify easily track defects or differential settlements.
- High flexibility of the track.
- Emission of lower levels of noise compared to slab track.

–

- Higher maintenance costs.
- Limited availability of suitable ballast material.
- Lower speeds in curves.
- The flying of ballast particles due to the passing high speed trains resulting in damaging of the rails and wheels.
- In case of viaducts and bridges, conventional track system is heavier and higher structure demanding stronger structures and larger foundations.

Ballastless (Slab) Track

+	–
Lower maintenance costs	Higher investment costs
Higher serviceability life (50 years)	Requires homogeneous sublayers with minor or no settlements
Higher structural track stability	Longer manufacture and installation time needed for its construction.
Lower structural height,economically efficient when used in bridges&tunnels	Limited options in adjustments after construction.
Allows a smaller cross-section and facilities maintenance	Special attention should be given in the foundation preparations.

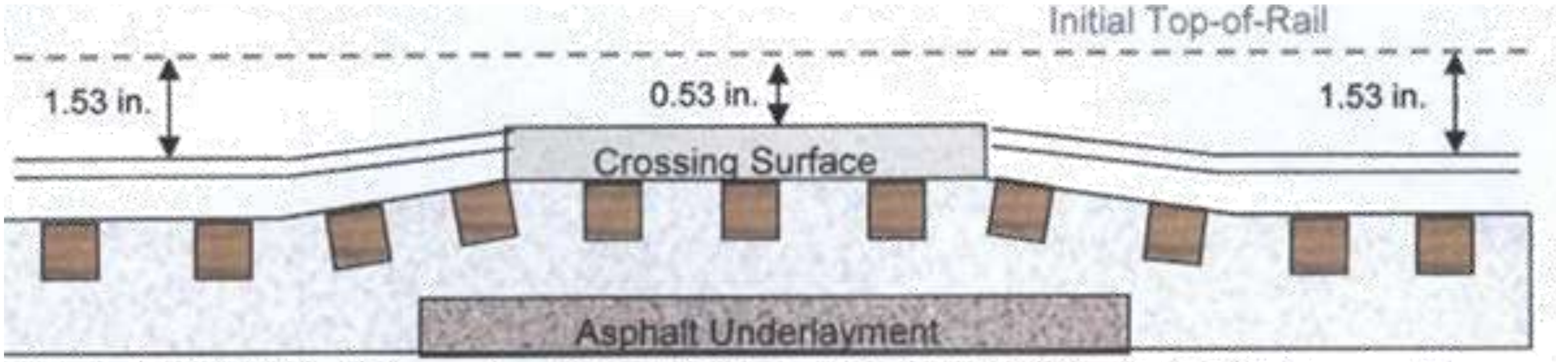
Permasalahan Geoteknik

- Kondisi geografis → Iklim Tropis
  - Pengaruh curah hujan dan pergerakan angin
  - Kondisi geologi

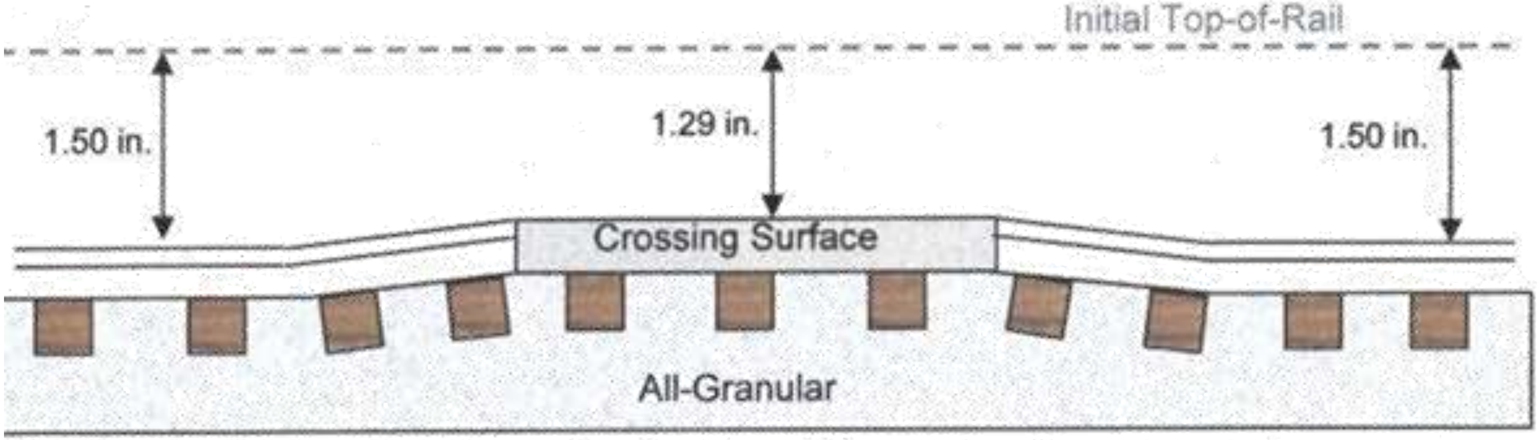
Variabilitas Jenis Tanah

Letak Astronomis Indonesia

- Daya dukung tanah yang rendah → salah analisis/disain
- Badan jalan pada konstruksi timbunan
- Muka air (pengaliran) dangkal
- Seepage (rembesan)
- Konstruksi di atas tanah lunak
  - Primary settlement dan long-term settlement
  - Pengaliran
  - Expansive soil → daya dukung rendah
- Perilaku dinamik → beban gempa
  - Penurunan
  - Likuifaksi – alivium/endapan
  - Retak/geser
- Tanah bergerak

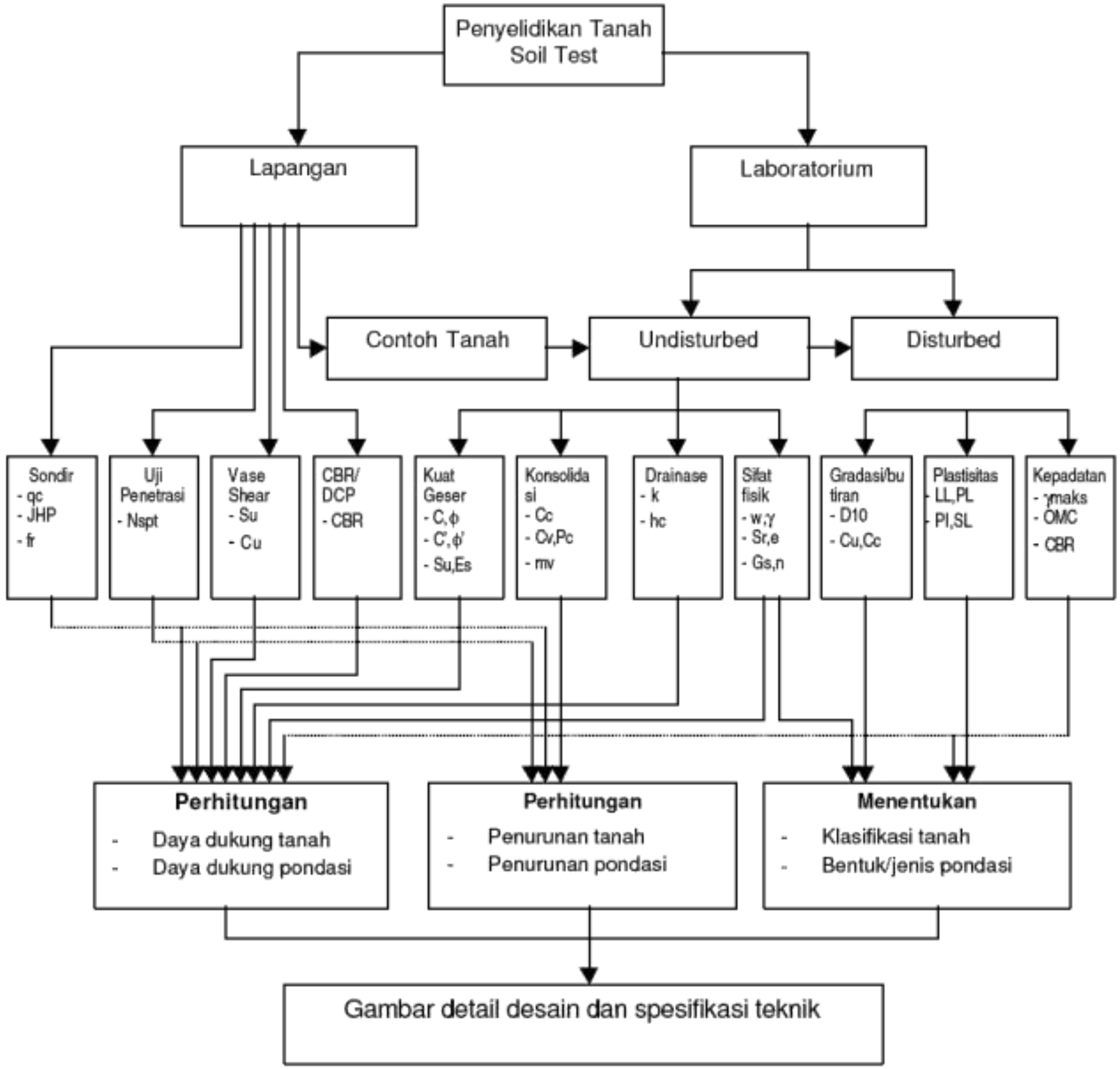


(42 Months in service)



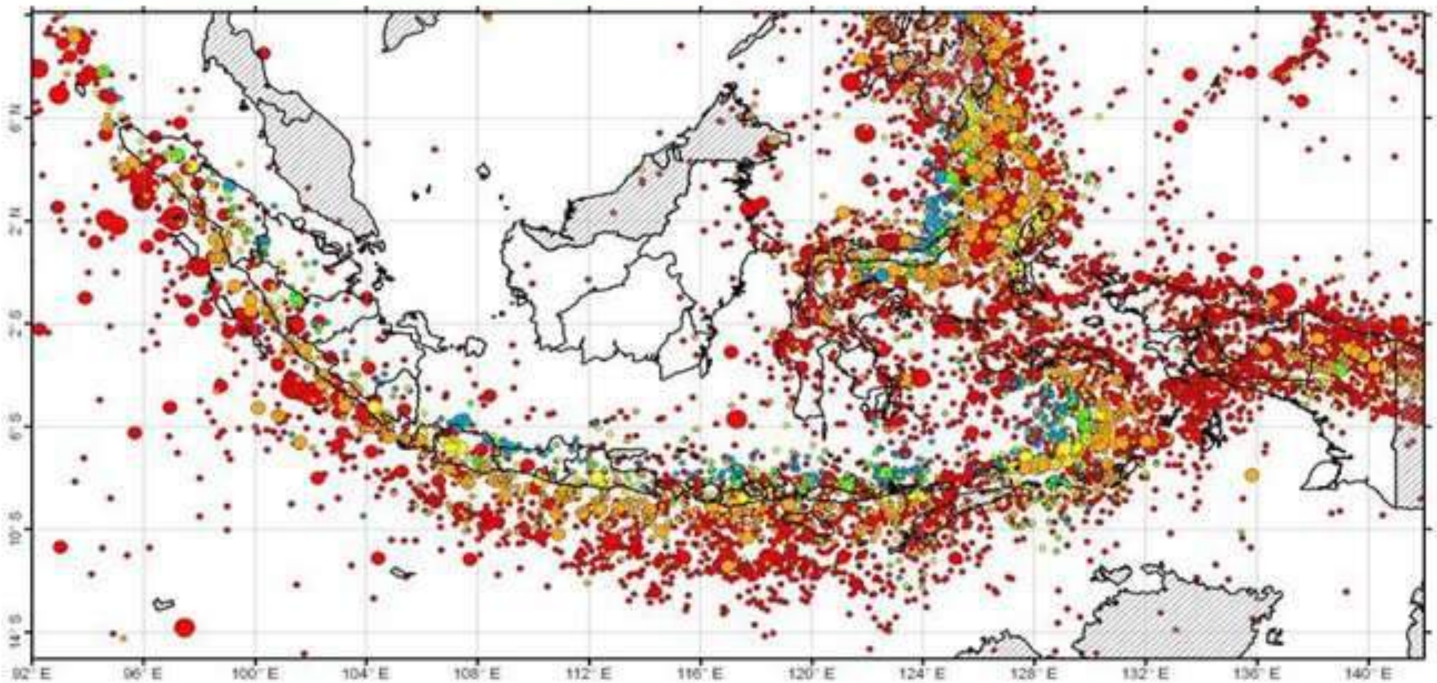
(33 Months in service)

1.0 in. = 25.4 mm


Penyelidikan Tanah
Soil Test
Lapangan
Laboratorium
Contoh Tanah
Undisturbed
Disturbed
Sondir
- qc
- JHP
- fr
Uji Penetrasi
- Nspt
Vase Shear
- Su
- Cu
CBR/ DCP
- CBR
Kuat Geser
- C,ϕ
- C',ϕ'
- Su,Es
Konsolidasi
- Cc
- Cv,Pc
- mv
Drainase
- k
- hc
Sifat fisik
- w,γ
- Sr,e
- Gs,n
Gradasi/butiran
- D10
- Cu,Cc
Plastisitas
- LL,PL
- PI,SL
Kepadatan
- γmaks
- OMC
- CBR
Perhitungan
- Daya dukung tanah
- Daya dukung pondasi
Perhitungan
- Penurunan tanah
- Penurunan pondasi
Menentukan
- Klasifikasi tanah
- Bentuk/jenis pondasi
Gambar detail desain dan spesifikasi teknik

Seismicity of Indonesia

Indonesia is one of the most seismically active countries in the world, it is situated in South-east Asia tectonic regime.



Main shocks only

Irsyam et al., 2010

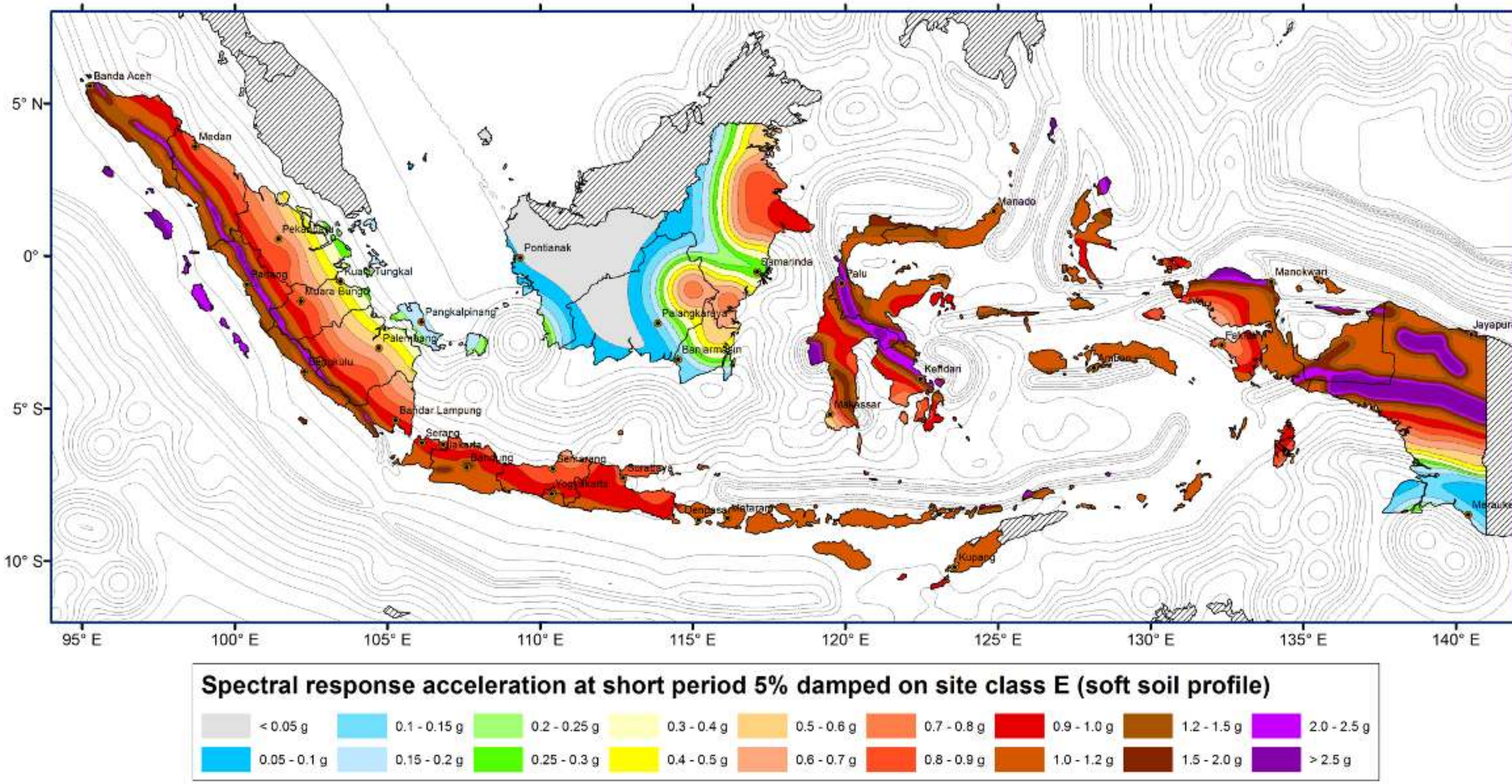
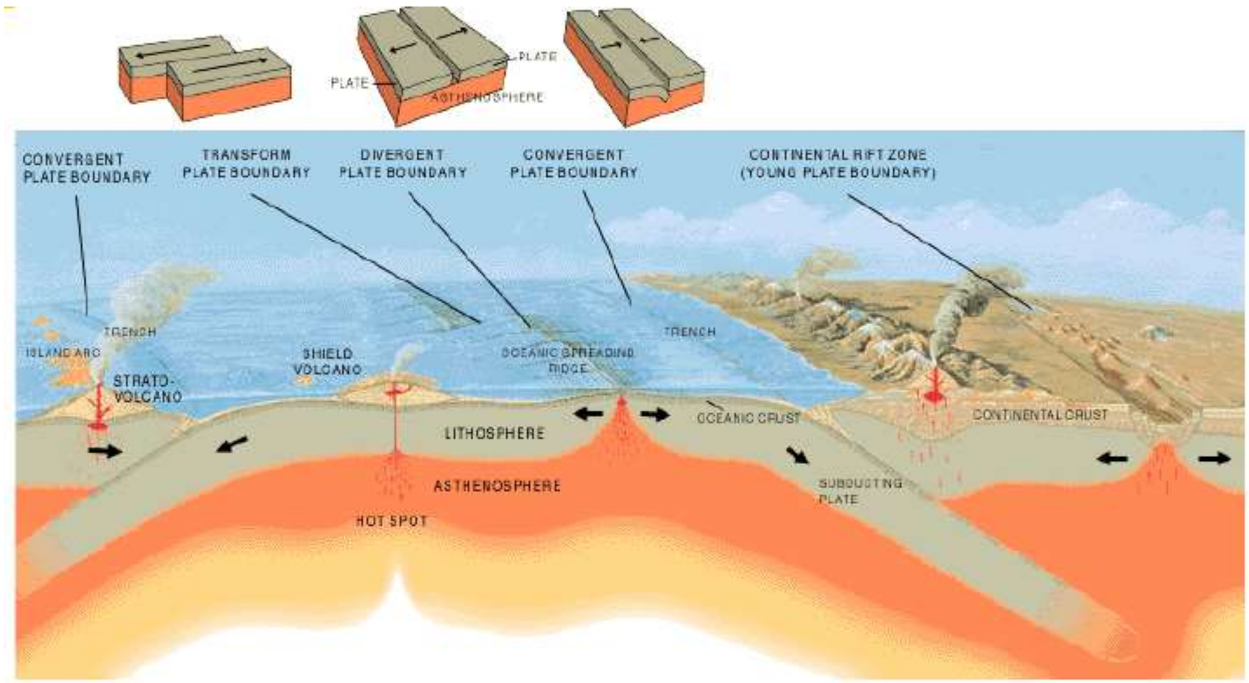
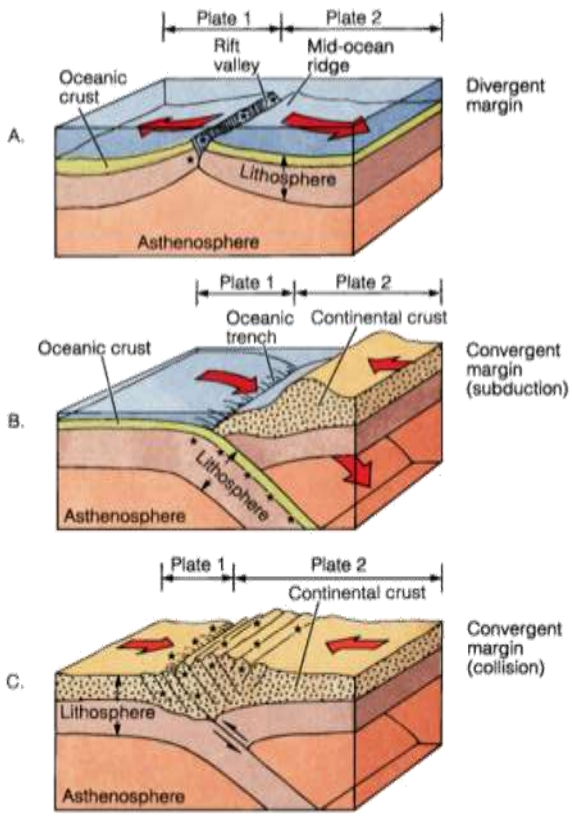

Spectral response acceleration at short period 5% damped on site class E (soft soil profile)
< 0.05 g
0.05 - 0.1 g
0.1 - 0.15 g
0.15 - 0.2 g
0.2 - 0.25 g
0.25 - 0.3 g
0.3 - 0.4 g
0.4 - 0.5 g
0.5 - 0.6 g
0.6 - 0.7 g
0.7 - 0.8 g
0.8 - 0.9 g
0.9 - 1.0 g
1.0 - 1.2 g
1.2 - 1.5 g
1.5 - 2.0 g
2.0 - 2.5 g
> 2.5 g
5° N
0°
5° S
10° S
95° E
100° E
105° E
110° E
115° E
120° E
125° E
130° E
135° E
140° E
Banda Aceh
Medan
Pontianak
Samarinda
Manado
Palu
Manokwari
Jayapura
Pangkalpinang
Palangkaraya
Kendari
Bengkulu
Bandar Lampung
Makassar
Merauke
Kupang
Yogyakarta
Denpasar
Mataram
Semarang
Bandung
Serang
Jakarta
Surabaya

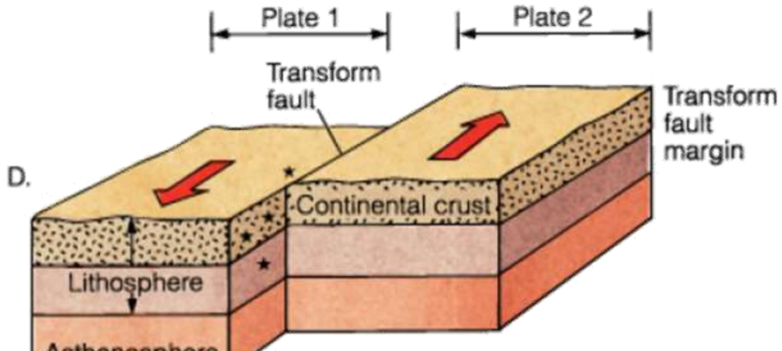
Plate Tectonics

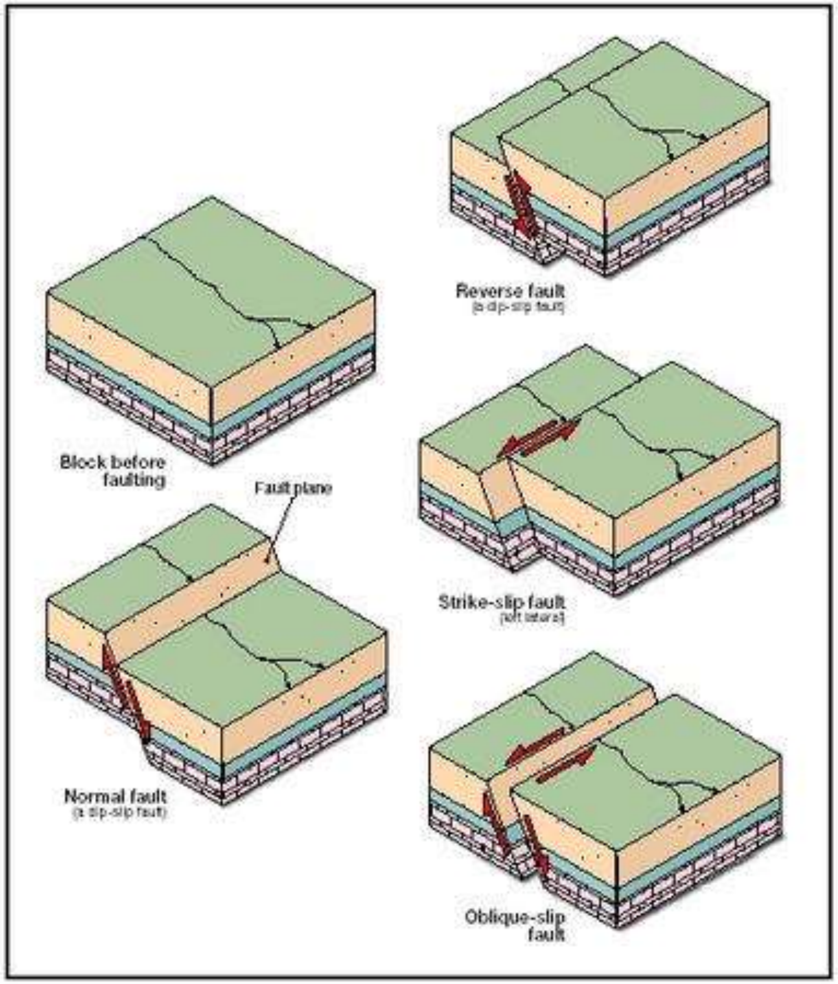




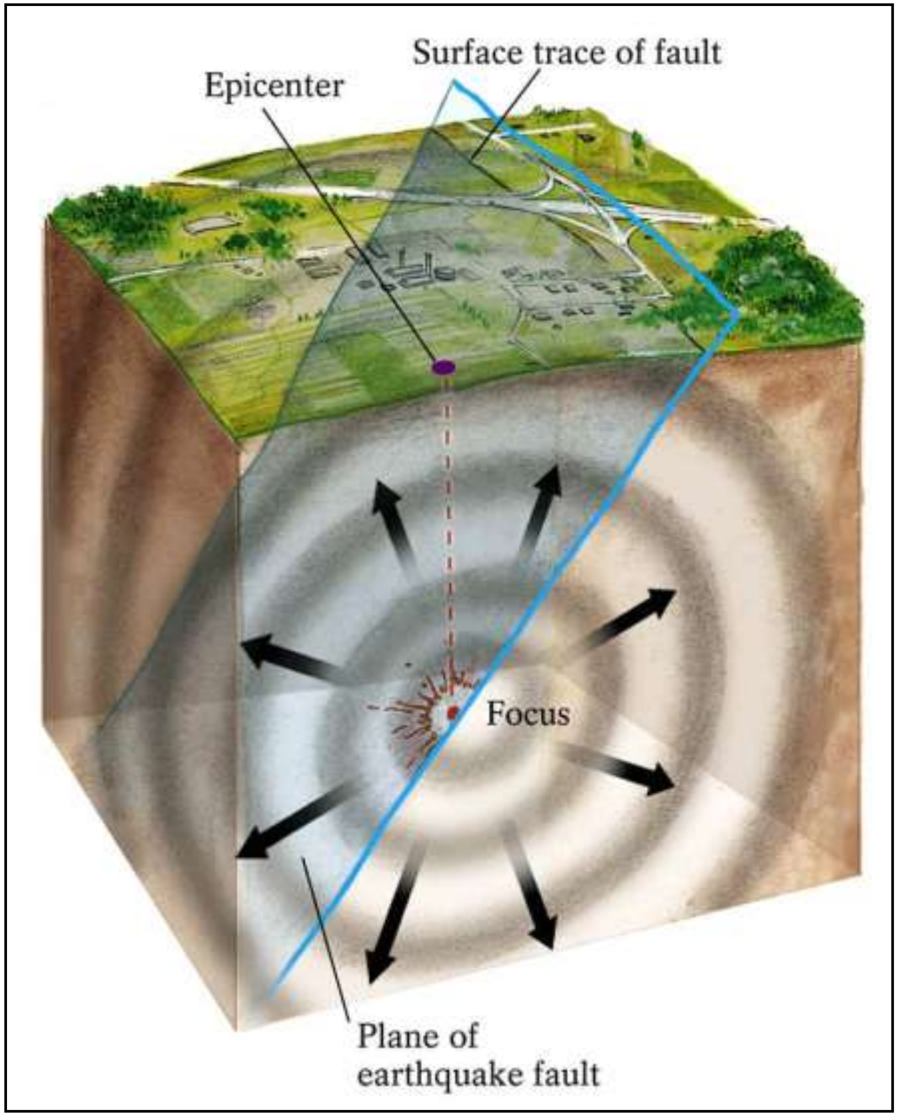
How does the EQ occur?

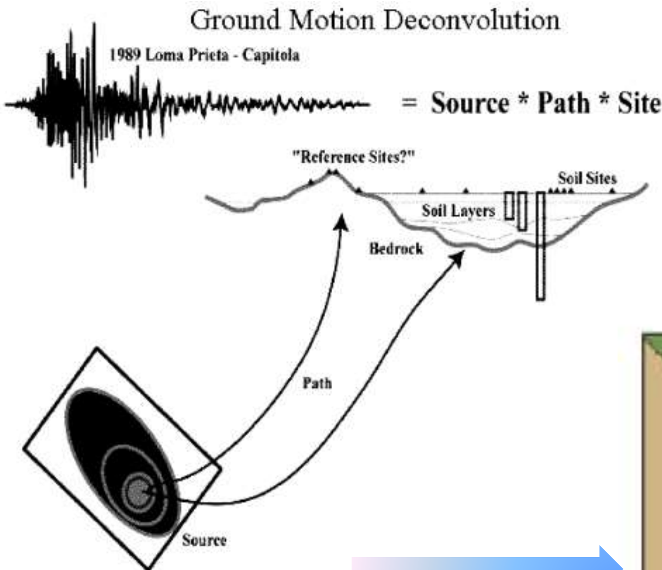
- Plates moving past each other do so along the TRANSFORM FAULTS.
- Earthquakes occur at **FAULTS.**
- Fault is a weak zone separating two geological blocks/plates.
- Tectonic forces cause the blocks to move relative one to another.

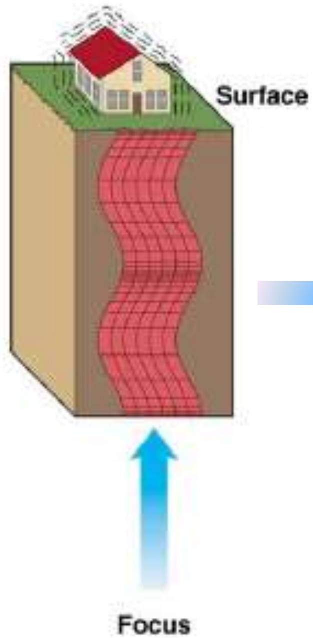




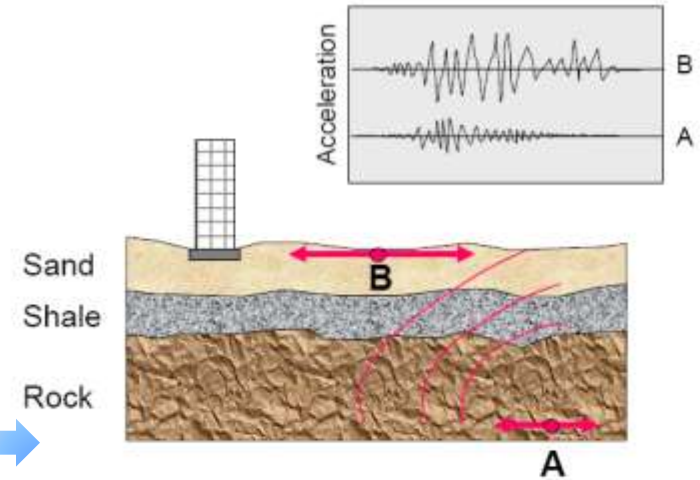
Anatomy of Earthquakes

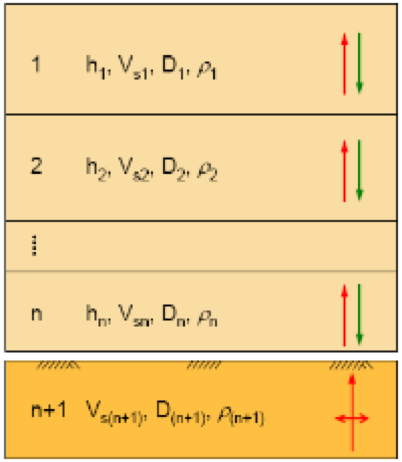






Site Amplification Is Common





Site Response Mechanisms

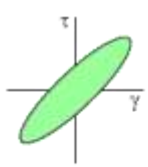
- Constant flux rate – impedance

  $\rho V_s \hat{u}^2$ = constant

- Resonances within the soil column

$$f_n = \frac{V_s}{4H}$$

- Low-strain damping and apparent attenuation in soil
- Nonlinear soil behavior

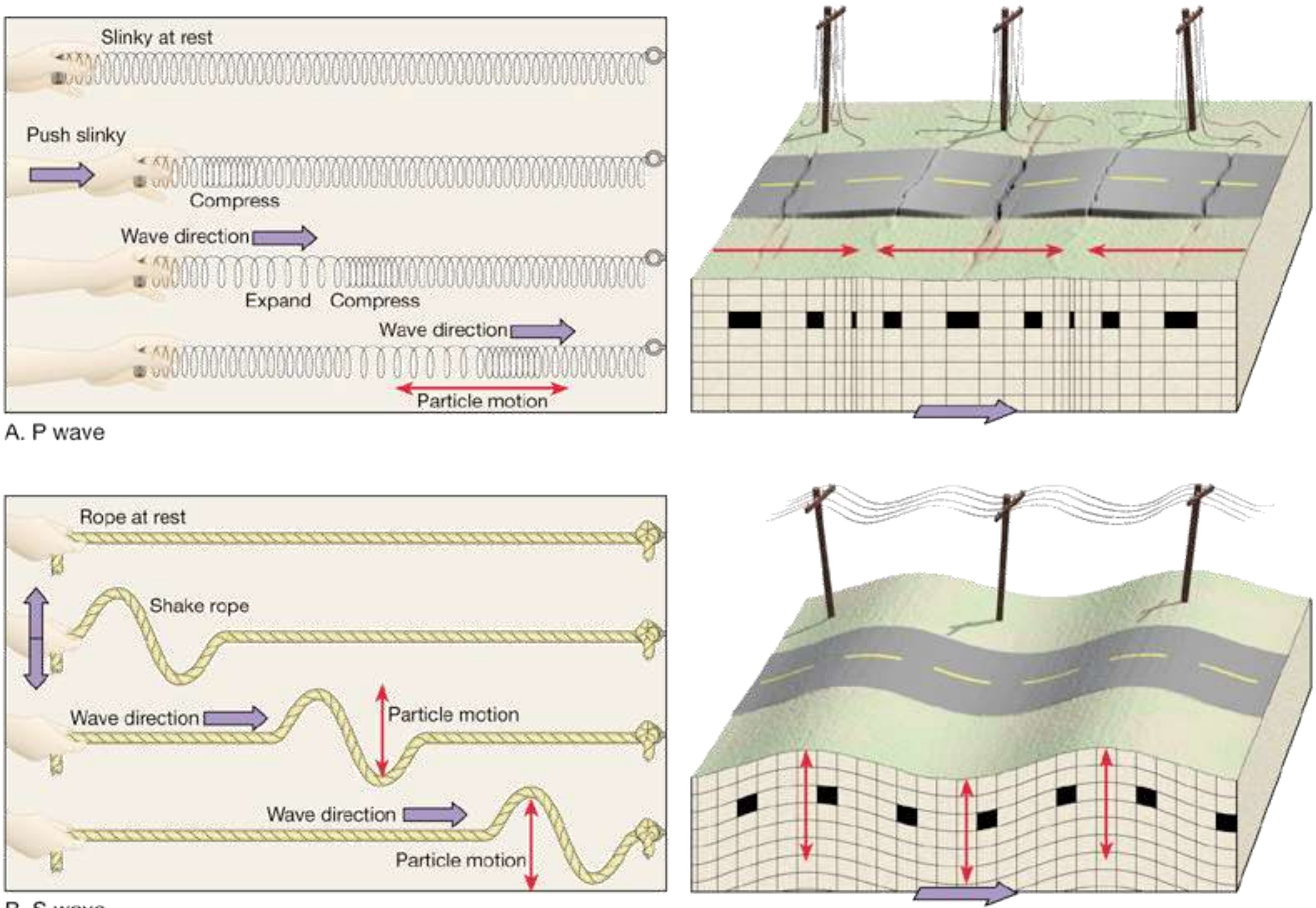


Amplification

Deamplification

Figure adapted from Rix, G. J., (2001)

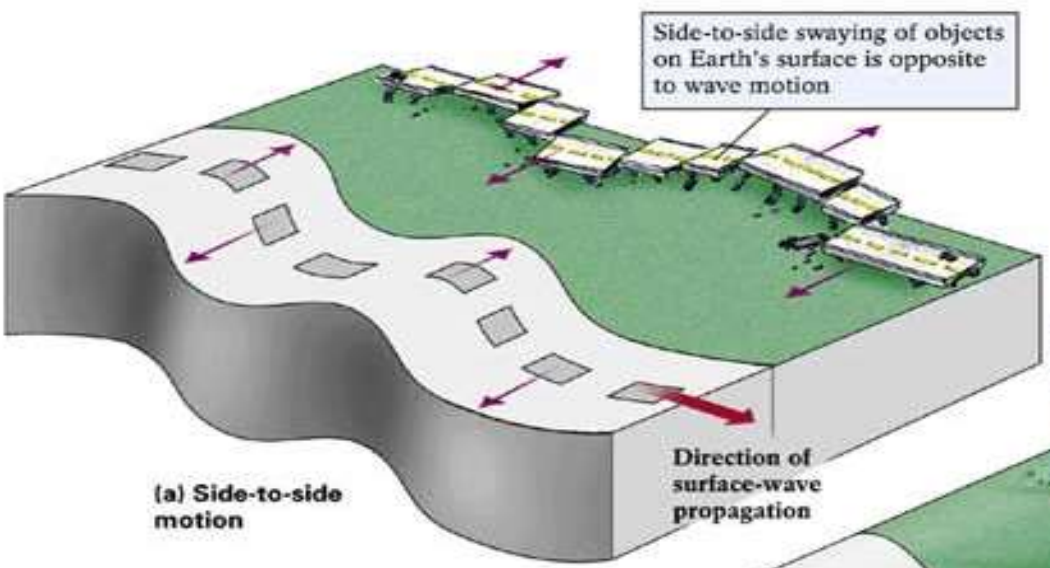
P and S waves

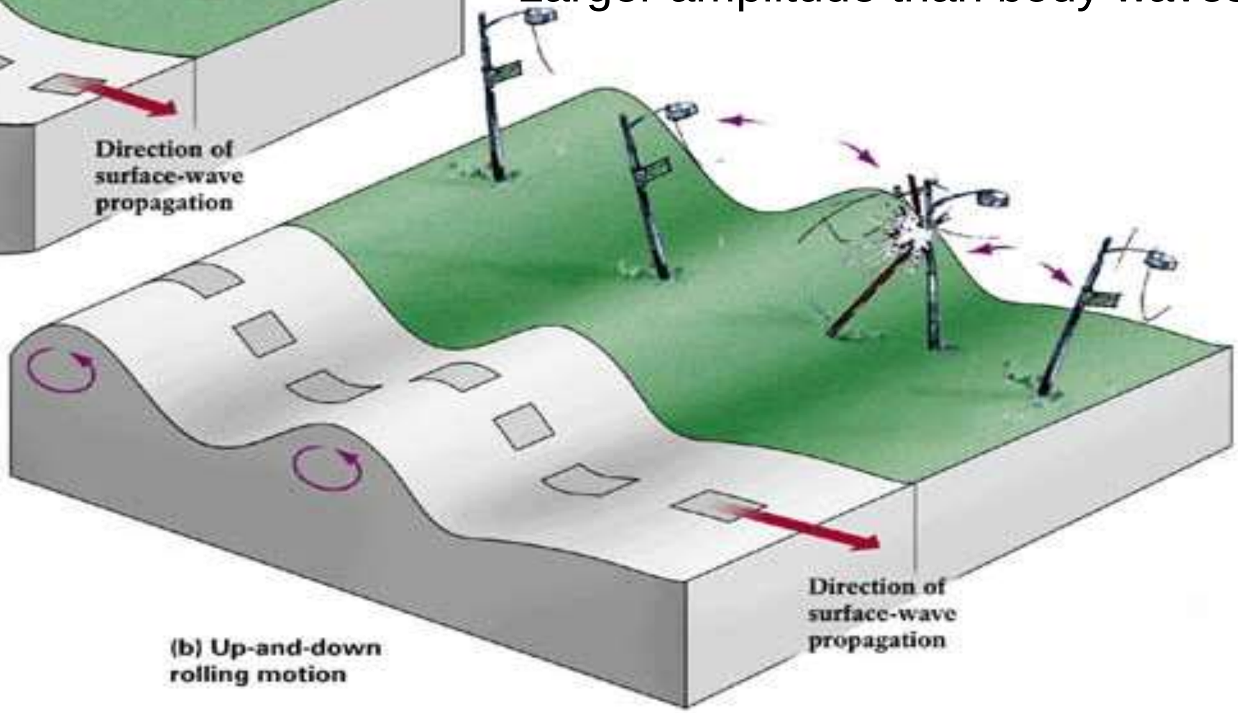


A. P wave

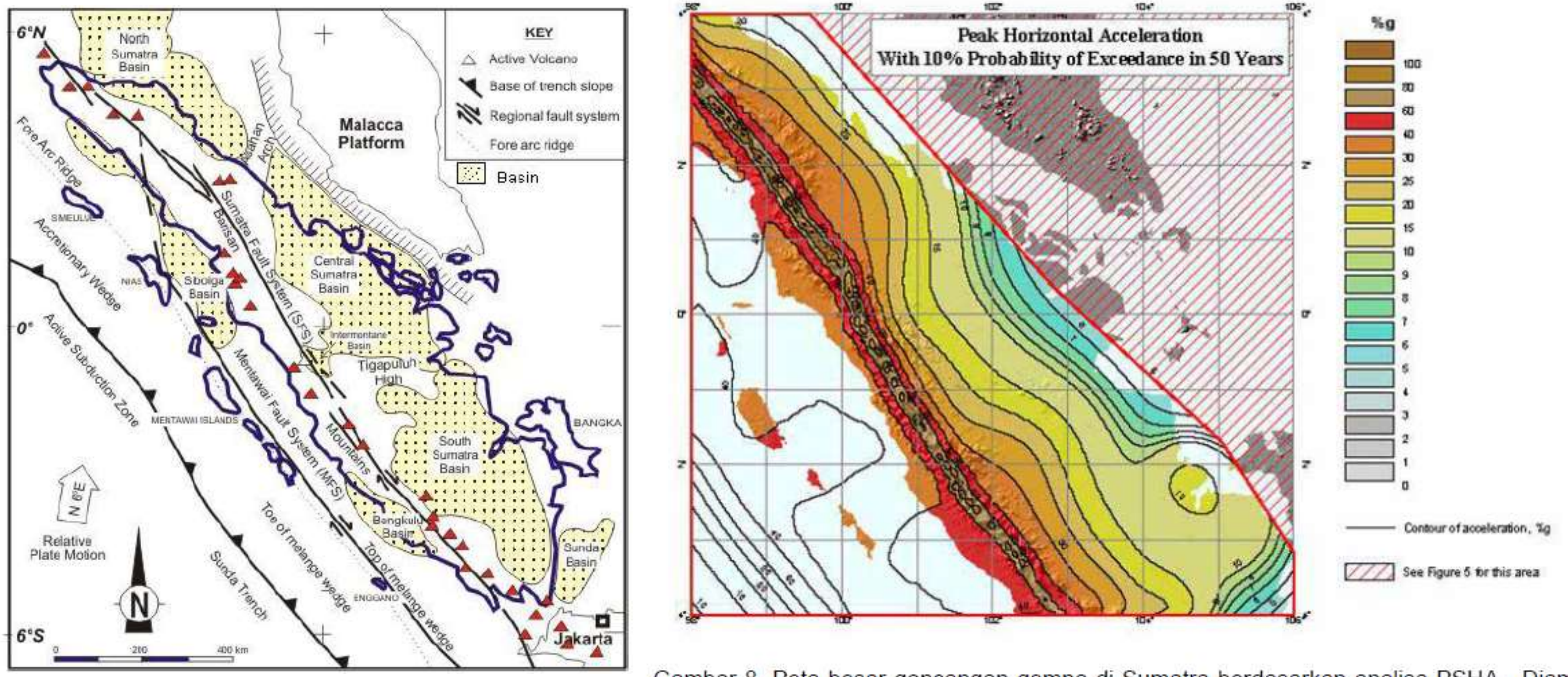
B. S wave

Smaller amplitude than surface (L) waves, but faster, P arrives first



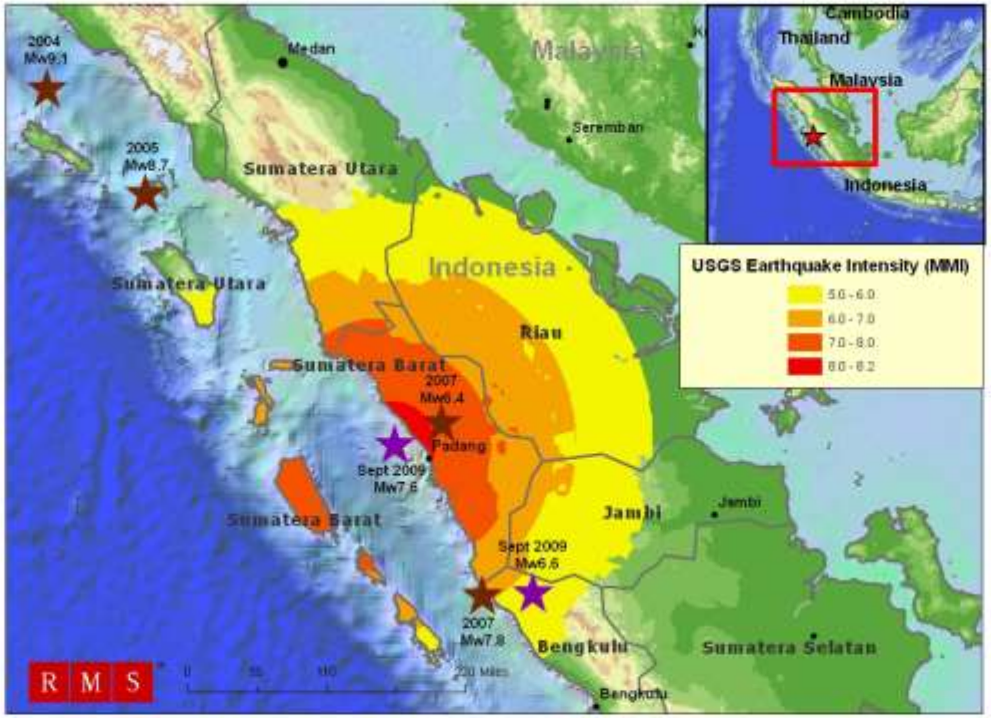


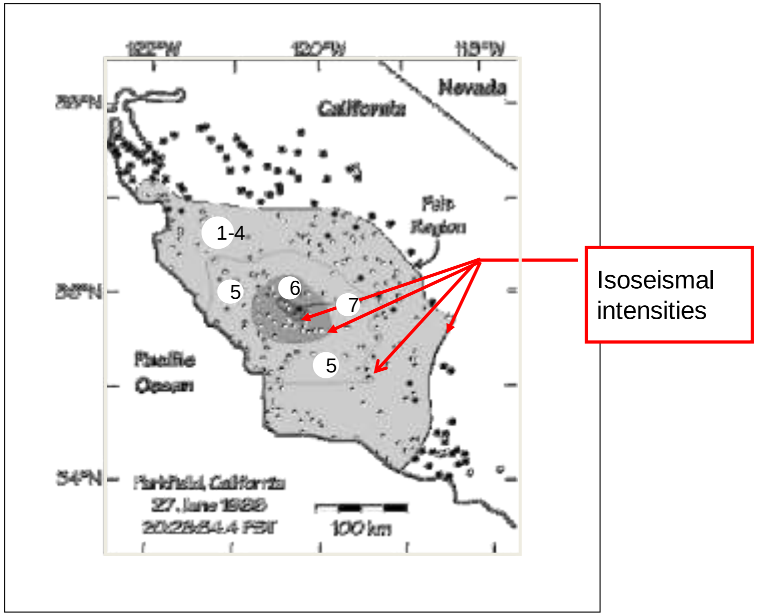
Most of the destruction
Larger amplitude than body waves



Gambar 8. Peta besar goncangan gempa di Sumatra berdasarkan analisa PSHA. Diambil nilai PGA untuk "10% probability of excedance" dalam 50 tahun.(dari *Petersen et al* [2004]).

Intensity Patterns and Maps





Liquefaction damage -Niigata, Japan 1964

Soil/Sand Boils

Surface Rupture

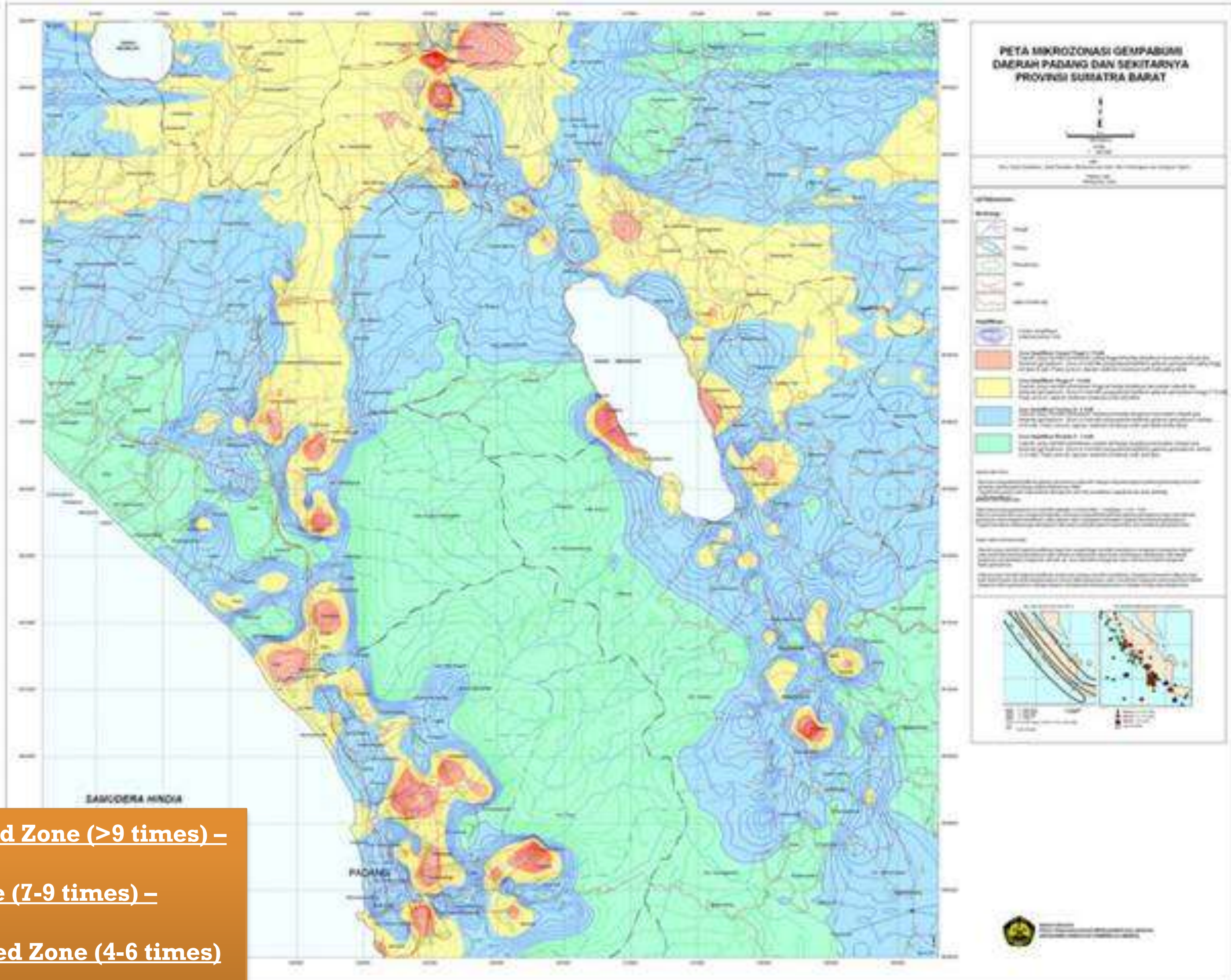
Landslide

El Salvador

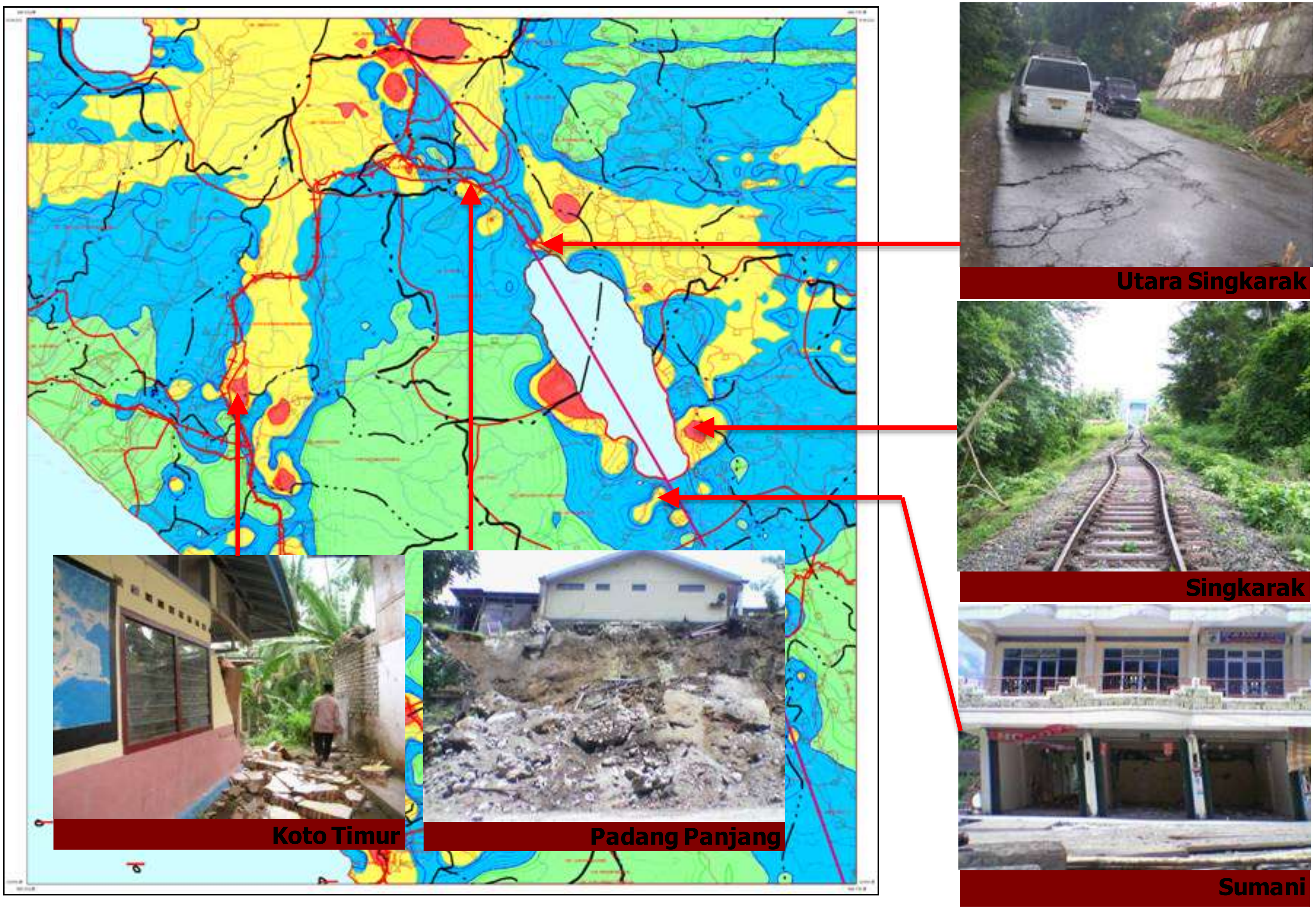
January 13, 2001

Magnitude 7.6

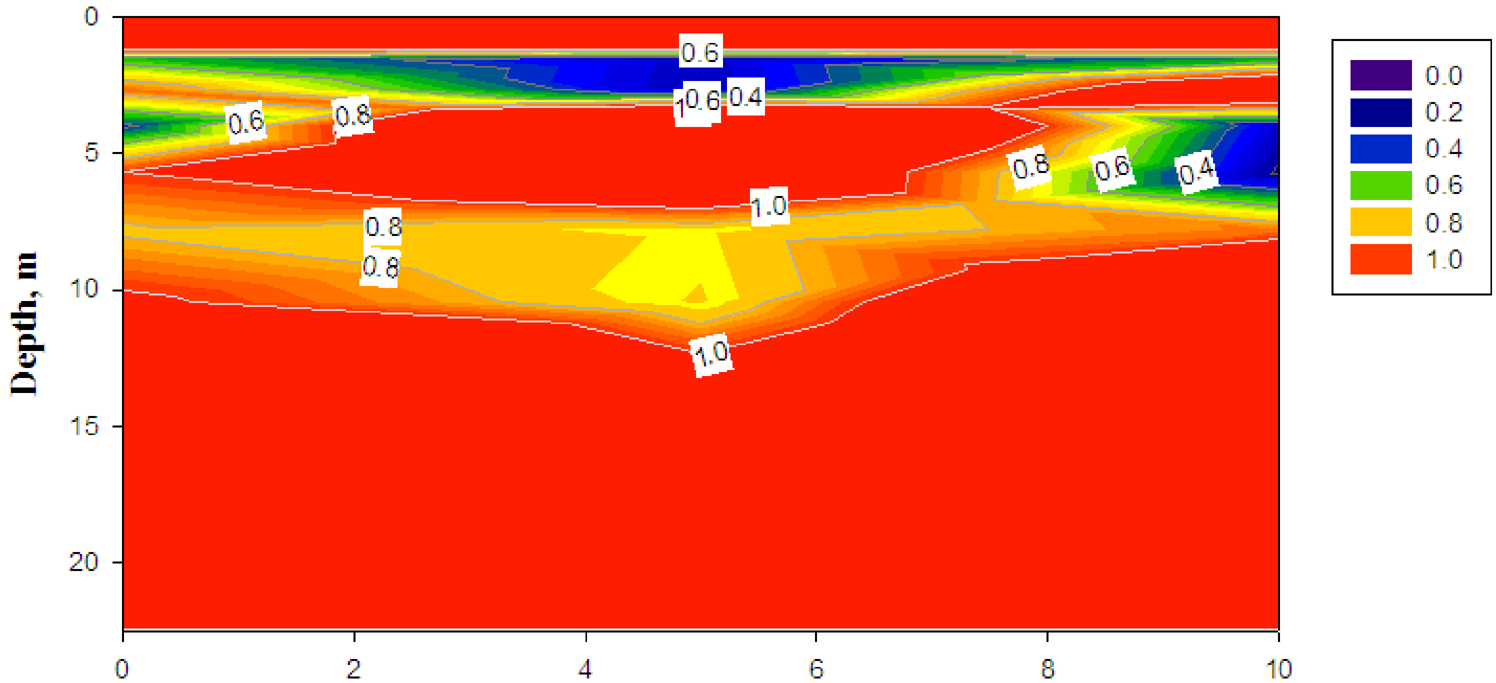
Photo Credit: USGS



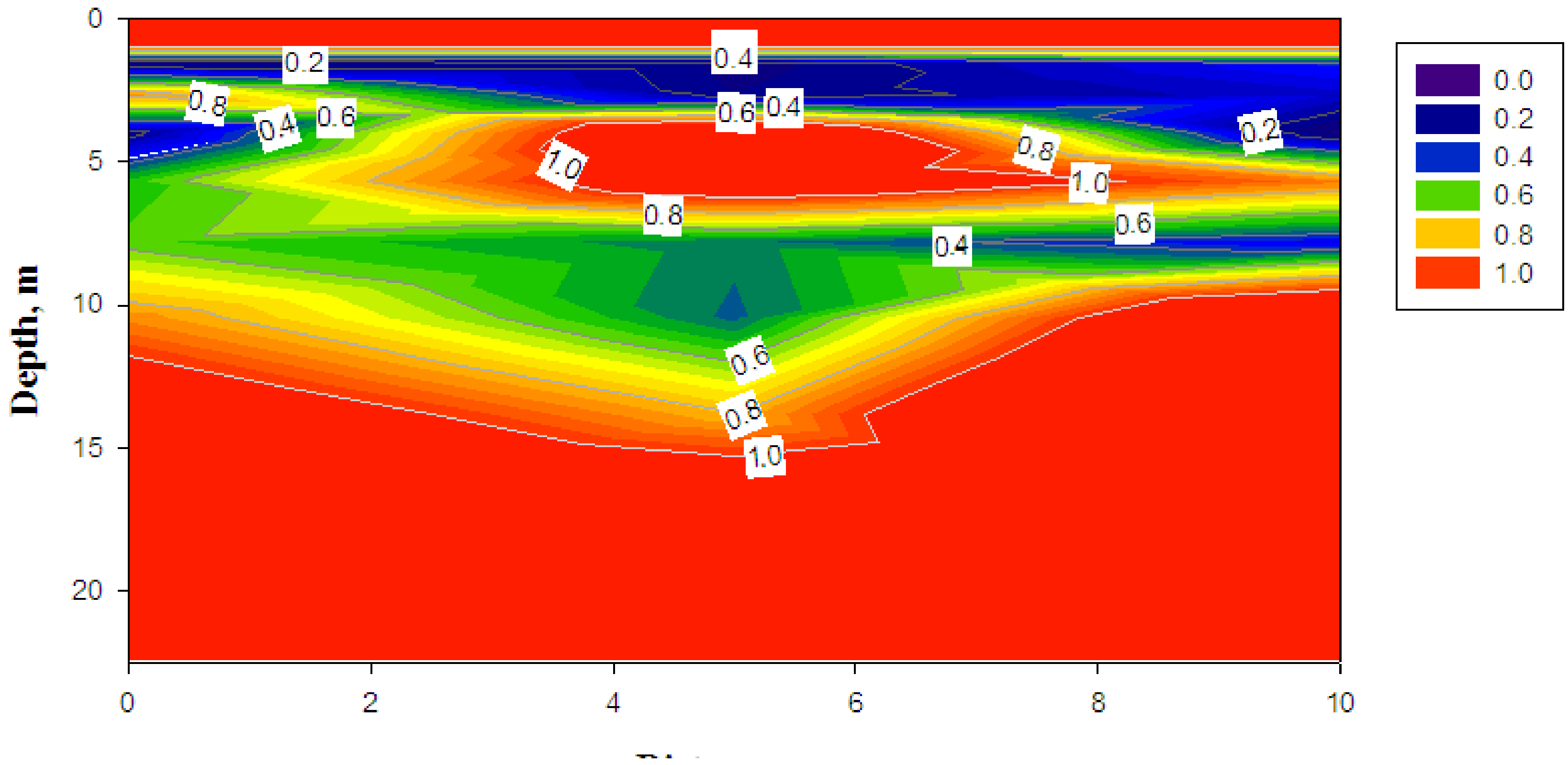
VERY HIGH Amplified Zone (>9 times) – RED
HIGH Amplified Zone (7-9 times) – YELLOW
MODERATE Amplified Zone (4-6 times) – BLUE
LOW Amplified Zone (1-3 times) – GREEN


Utara Singkarak
Singkarak
Sumani
Koto Timur
Padang Panjang

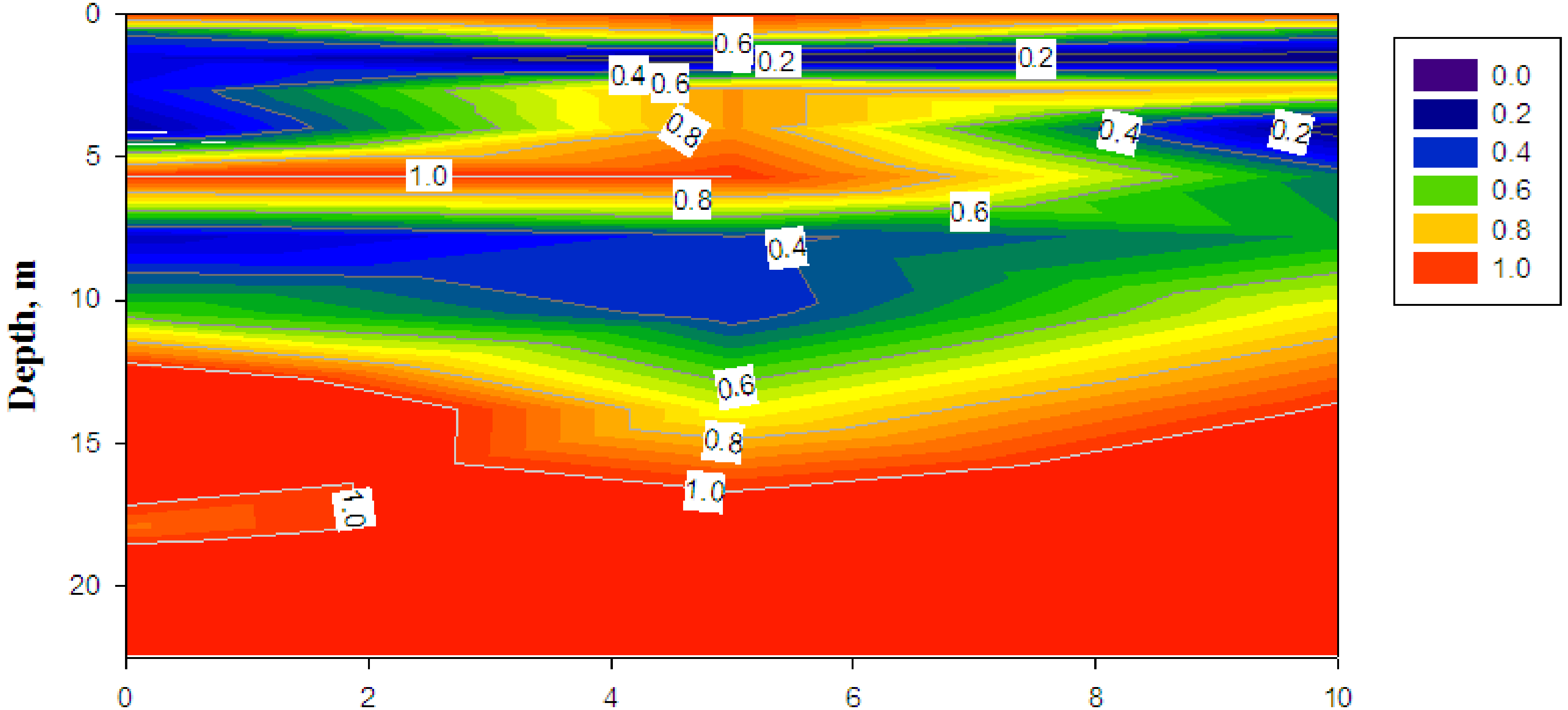
Earthquake scenario, 6.3 Mw



Earthquake Scenario 7.5 Mw



Earthquake Scenario, 8 Mw



Perawatan – Track Maintenance

Inspeksi – Track Inspection

FRA Regulations

"Transportation exists to conquer space and time -"

- **Hi-Rail Inspection**

– **Walking Inspection**

– **Train Inspection**

Inspection By Hi-rail

Hi-Rail

- The hi-rail is a versatile vehicle that allows the inspector to traverse the track in one direction and return by road
- Provides flexibility/versatility
- Most common method utilized for scheduled and special inspections
- Most often one, and sometimes two Inspectors observing the track
- Scheduled per regulatory requirement and/or company policy
- Visual detection of defects
- "Feel" and sound of the track that may indicate the presence of a substandard condition

- **Allows for a more detailed look at the track.**
- **Quantify defects with physical measurements**
- **Planned at various times of year,**
- **Regulatory requirement for inspecting turnouts, track crossings and lift rail assemblies or other transition devices on moveable bridges to be performed "on foot"**

- Provides a “feel” of the track under loaded conditions
- Frequency depends on amount and type of train traffic, anywhere from twice annually to monthly

Types of Track Inspection

- Normal or Scheduled (Routine)
- Special Inspection
  - Specific Planned (i.e. Culverts, Rail Wear etc)
  - Emergency (Weather related, Incidents/Accidents)
- Specialized Inspection Vehicles
  - Rail Flaw Detection Vehicles
  - Track Geometry Vehicle

- Kerusakan pada satu komponen pasti berimpak kepada komponen lainnya
- Penggantian setempat dan penggantian (rehabilitasi dan rekonstruksi) lengkap
- Aktivitas perawatan adalah sistem perputaran

http://www.ncports.com/userfiles/StemtoStern/091217RRTiesReplacement_0097.JPG

- Track disturbance can lead to buckling
  - Dynamic track stabilizer

http://www.struktonrail.com/en-us/RailInfraStructure/Pages/Stabilizers.aspx

- Rail grinding – grinding machines or trains equipped with grinding wheels

http://www.flashpointfire.com.au/images/gallery/WEB3_IMG.JPG

http://www.railroad.net/santucci/Grinding_the_weld.jpg

[Daytime]

[Night]

Rail Grinding

- Purpose: Remove Surface Imperfections in the Rail & Optimize Rail/Wheel Contact Area
- Out-of-Face & Switch Multiple Stone Grinders
- Grinds Main Track Based on Railroad Policy
- Grinds 6 to 15 MPH

- Vegetation Control – chemical and mechanical

http://www.homegrowntimber.com/indexrailways.html

- Stabilization and Drainage
- Welding

http://peer.berkeley.edu/publications/nisqually/geotech/liquefaction/lateralspread/index.html

http://www.railroad.net/santucci/Flash_Butt_Welding.jpg

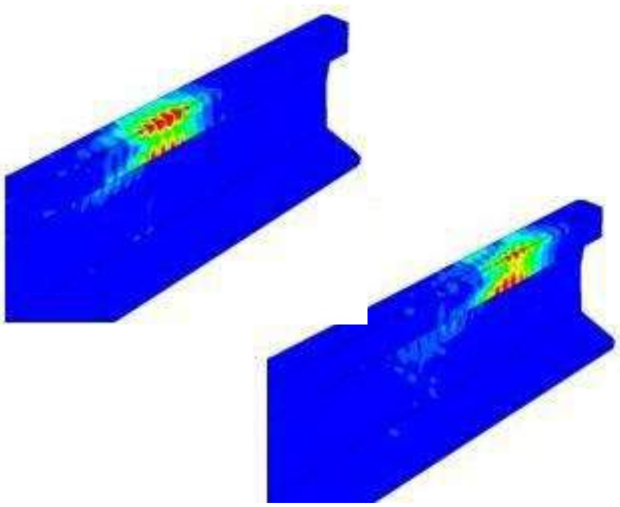
- Measures the condition of the track
- Determines where maintenance is needed
- Visual and specialized

http://www.ensco.com/index.cfm?page=318

[Inspector at Work]

http://www.ensco.com/index.cfm?page=318

- Rail Defect Testing – Ultrasonic vehicle



http://www.wins-ndt.com/ultrasonic_rail_flaw_detection.php

- Gage Compliance - Geometry Cars
- Gage Restraint Measuring Systems (GRMS)

http://www.northeast.railfan.net/images/co2.jpg

http://www.ensco.com/userfiles/file/Products_Services_PDF/07_Rail/Track-Inspection-Systems/04_0204_ENSCO_Rail_Deployable_Gage_Restraint_Measurement_System.pdf

Rail Gang Make-up

Tie Gang Make-up


Anchor Spreader


Tie Handler


Tie Inserter/Remover


Spiker

Production Surfacing

- Highly mechanized crews
- 4 to 20 employees
- Typical Equipment Includes:
  - Production Tamper
  - Jr. Tamper
  - Regulator
  - Stabilizer

Surfacing Gang Consist

MK IV Tamper

Ballast Regulator

Dynamic Track Stabilizer

Ballast Unloading

Undercutting

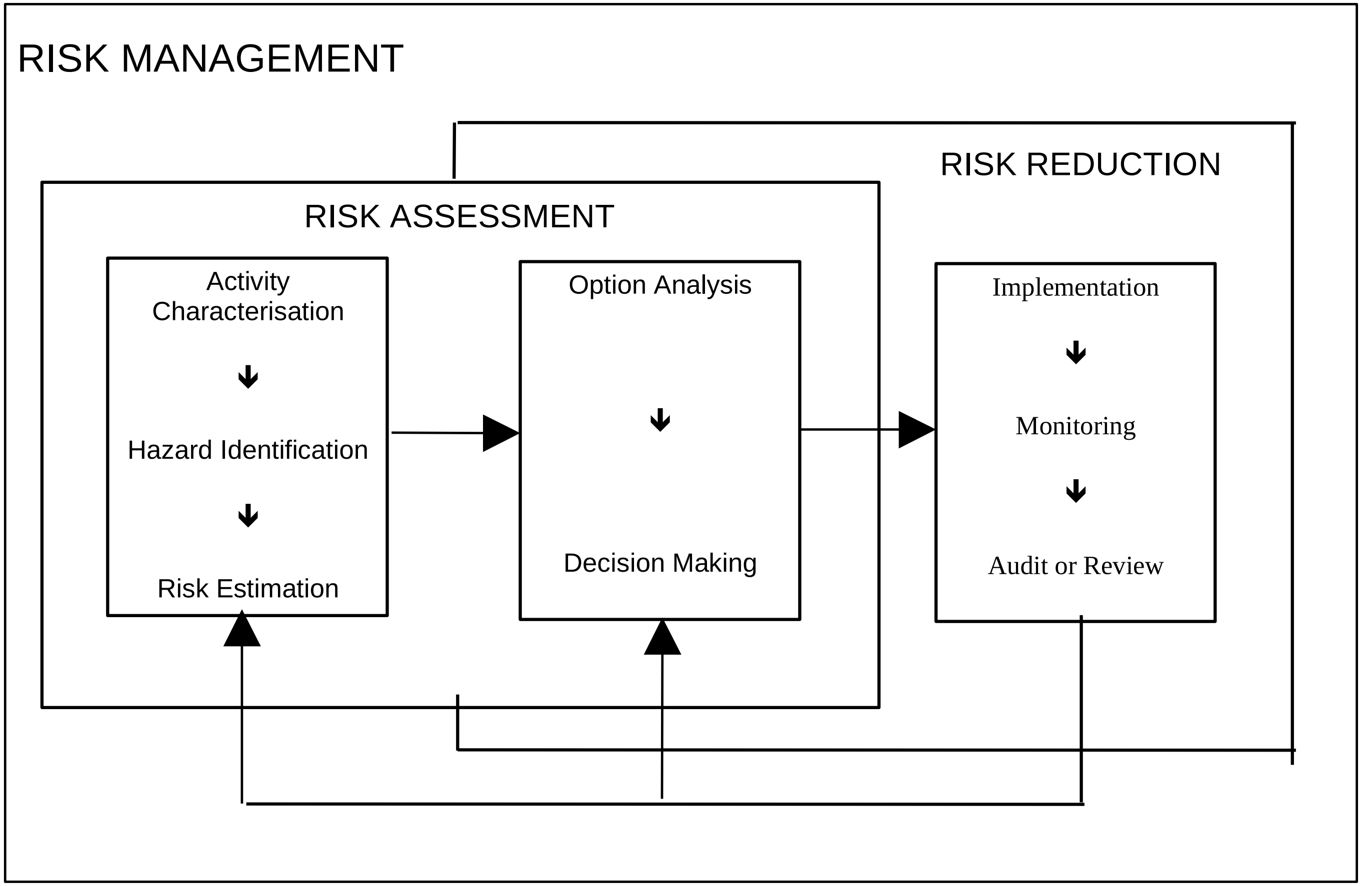
Prinsip: Risk Management

Risk management can be defined as:

The eradication or minimisation of the adverse affects of risks to which an organisation is exposed.

Stages in Risk Management

- Identifying the hazards.
- Evaluating the associated risks.
- Controlling the risks.


RISK MANAGEMENT
RISK REDUCTION
RISK ASSESSMENT
Activity Characterisation
Hazard Identification
Risk Estimation
Option Analysis
Decision Making
Implementation
Monitoring
Audit or Review

Risk assessment can be a

'*very straightforward process based on judgement requiring no specialist skills or complicated techniques*.'

This approach is commonly known as **qualitative or subjective risk assessment.**

Major Hazards

- Major hazards associated with complex chemical or nuclear plants, may '*warrant the need of such techniques as Quantitative Risk Assessment*'.
- In Quantitative Risk Assessment **(QRA)** a numerical estimate is made of the probability that a defined harm will result from the occurrence of a particular event.

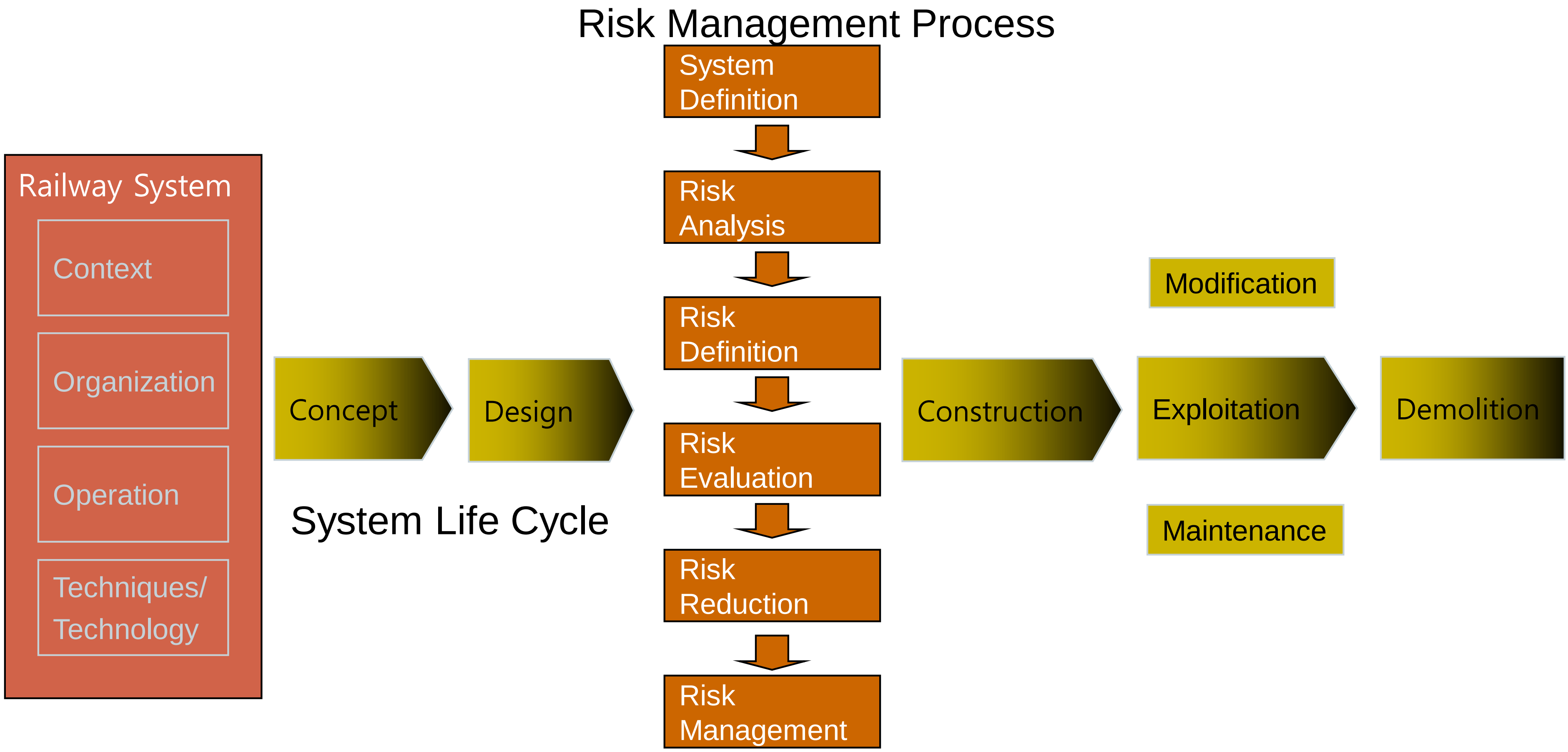
The Risk Management Process

Hazard Identification

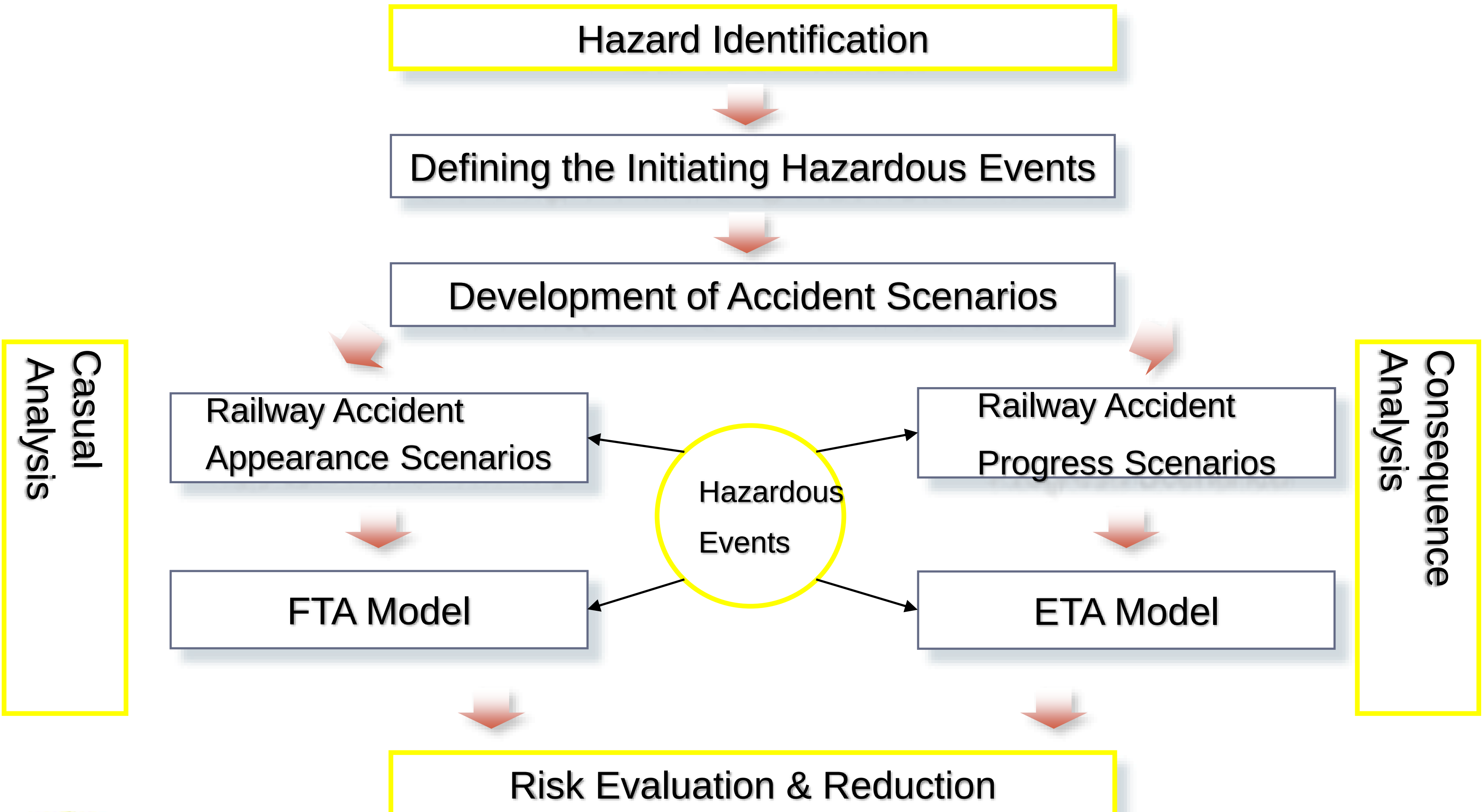
Hazard :

The potential to cause harm. Harm including ill health and injury, damage to property, plant, products or the environment, production losses or increased liabilities.

Common Approach Risk Management



Railway Risk Assessment Procedure

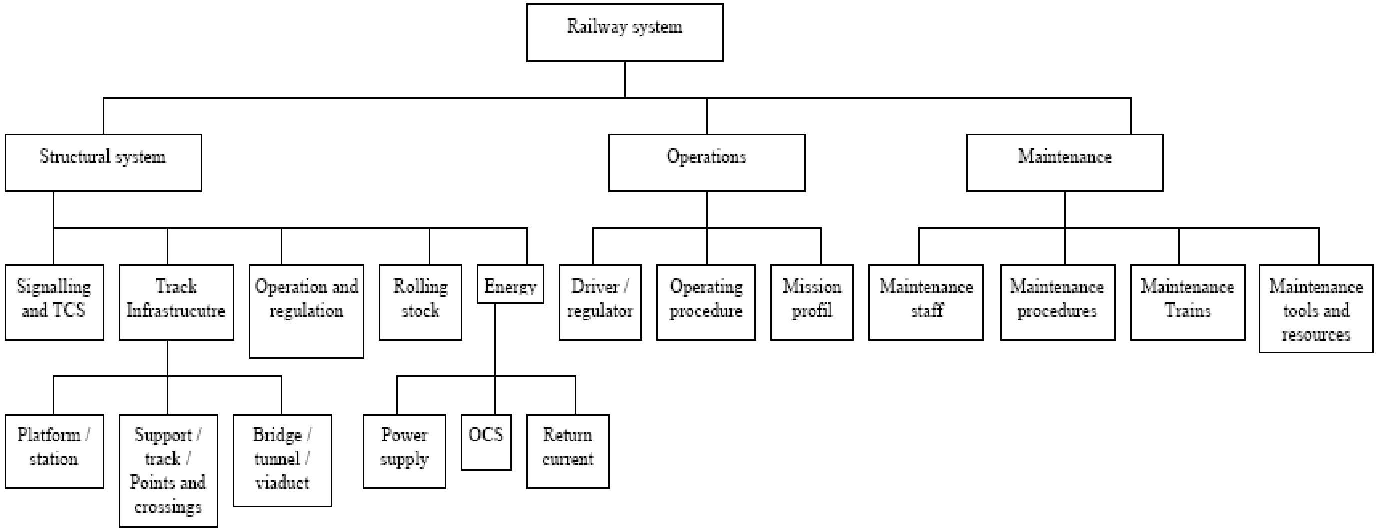


Hazard Identification Procedure

System definition and boundary setting	Setting up objective of hazard identification & its boundary
↓	
Identifying hazardous events/ hazards/ barriers	Including the definition of measures which stops the increases of accident
↓	
Developing accident appearance scenarios	Defining relationships among hazardous events, hazards and barriers.
↓	
Developing accident progress scenarios	Considering the relevant key influential factors.
↓	
Accident scenario management	Drawing up hazard log.

System & Boundary Definition

Typical railway system configuration proposed in SAMRAIL project, South Korea



According to the accident classification of "Railway Accident Report Regulation",

The scenarios were divided into the five main areas

1) Train collision accident,
2) Train derailment accident,
3) Train fire accident,
4) Level crossing accident,
5) Railway (traffic/safety) casualty accident.

Hazardous Event Identification

Railway Category		Hazardous Events
Train Collision	Misrouted train	Mistaking in dealing points, point faults, mistaking in dealing blockage, interlocking system faults
	Faults in driving	Signal/direction violation, signal fault, mistaking in dealing braking system, braking system fault, over speeding
	Abnormal train	Train separation, car rolling, train stop, backward moving
	Obstacles on the track	External obstacles, parts from train/freight falling, infrastructure collapsing/obstruction
Level Crossing Accident	Being trapped in level crossing	-Engine stop -Deviation of pathway -Gangway blocking -Lack of propulsion/braking -Violation entry -Limit interference -Breaking or detour
	Crossing during warning signal	
	Breaking through or detour the barrier	
Railway Traffic Casualty Accident	People struck/crushed	Striking with train, Striking with objects
	Trip/Slip	Trip/slip during train boarding/alighting, Trip/slip by train emergency braking/emergency start
	Falling	Falling from train, Falling from platform during train boarding/alighting
	Caught/Dragged	Caught in a train door, Caught between platform and train
	Others	Electric Shock, Burn, Suffocation

Railway Accident Appearance Scenario

Accident type	→	Hazardous Event	→	Immediate Causes	
Traffic casualty accident		Falling from train		Inside station premises	Unauthorized door handling
					Door handling error/malfunction
				Outside station premises	door locking system faults
					Train running with opened door
					Holding / jump on to train
		Falling from platform during train boarding/alighting		Floor/slipperiness (freezing/oil),	
				Safety installations (handle/footing) faults	
				Interruption from floor obstruction	
				Carelessness	
Safety casualty accident		Falling from rolling stock		Jump down from train	
				door handling error/malfunction	
				door locking system faults	
				Train running with opened door	
				Holding / jump on to train	
				Carelessness	
		Falling from rolling stock roof		Falling from rolling stock roof	
				Falling from rolling stock roof after electric shock with catenary/overhead line	
		Falling during elevated work		Falling from a ladder	
				Falling from a scaffolding	
				Falling from a railway bridge	
				Falling to inspection pit	
				Falling during other elevated works	
		Falling from infrastructure		Falling from outside area (overpass/viaduct) to track	
				Falling from outside area (overpass/viaduct) to track of road vehicles	
				Falling from infrastructure inside station premises	
		Falling from platform		Floor/slipperiness (freezing/oil),	
				Safety installations (safety fence/footing) faults	
				Interruption from floor obstruction	
				carelessness	

→	Underlying Causes		
	Human Management Factors	Information recognition error	Alcohol
		Circumstantial judgment error	Disease
		Decision making error	Congestion
		Performance error	
		Miscommunication	Visible/ Audible handicap
		Procedure/Regulation violation	Others
	Technical Factors	Track/Structure defects	
		Signal control system defects	
		Telecommunication system defects	
		Catenary power systems defects	
		Train/rolling stock system defects	
		Level crossing installations defects	
		Work objects/equipment defects	
	External Factors	Illegal action	Trespass/action
			Suspected suicide
			Unauthorized construction /voluntary work
			Unauthorized installation/placement
			Terror
			Other train running interruption action
		Incomplete climate condition	
		Incomplete circumstance condition	

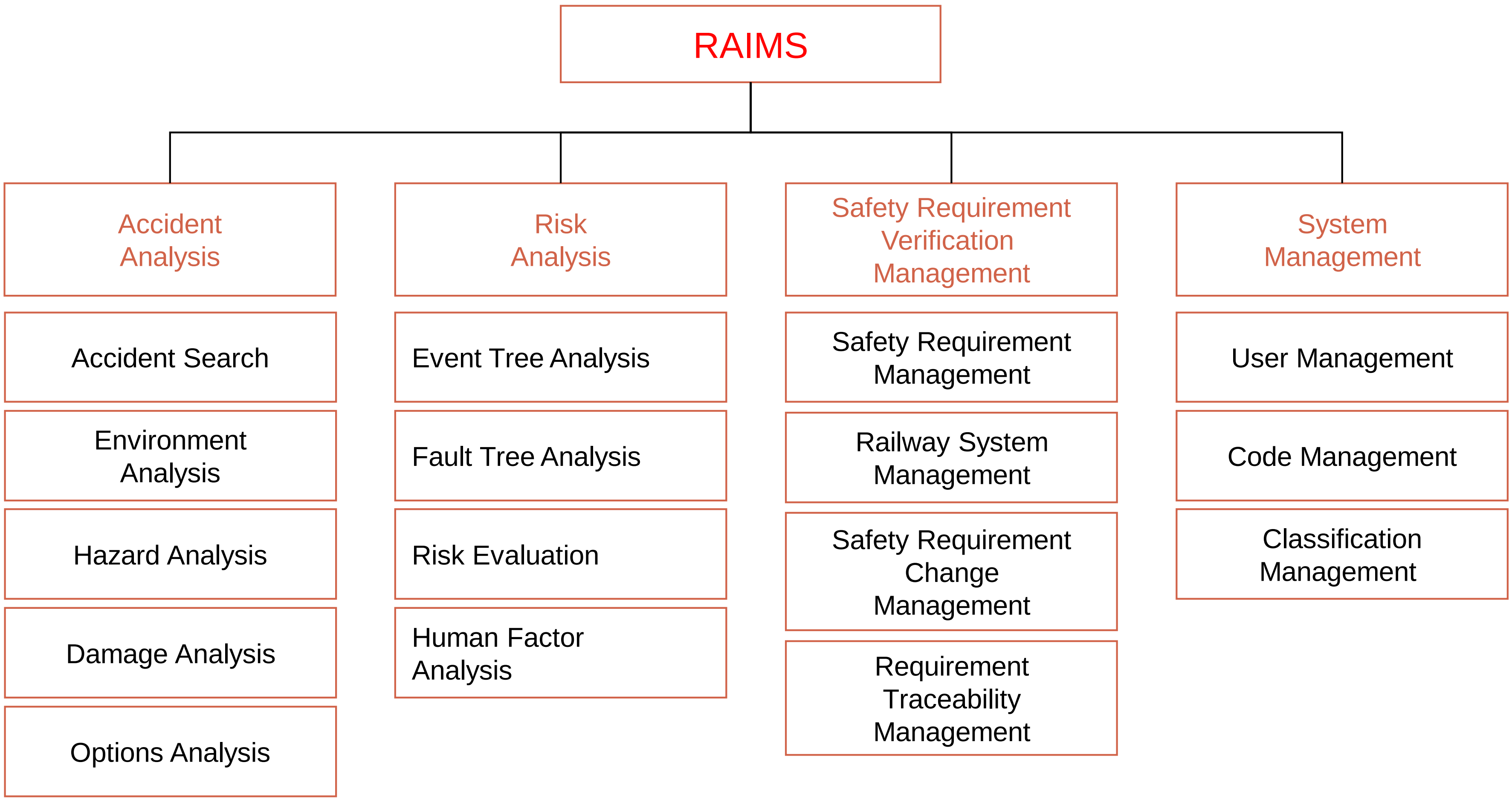
Risk Measure Method

Risk assessment model
: the form of a cause and consequence analysis
: using fault trees and event trees.

Collective Risk
(Average Number of FWI/year)
=
Frequency
(Average frequency at which the scenario sequence occurs)
X
Consequences
(the number of FWI/scenario sequence)

1 FWI = 1 fatality = 10 major injuries = 200 minor injuries

Railway Risk Assessment & Information Management System (RAIMS)



Ada Pertanyaan ?