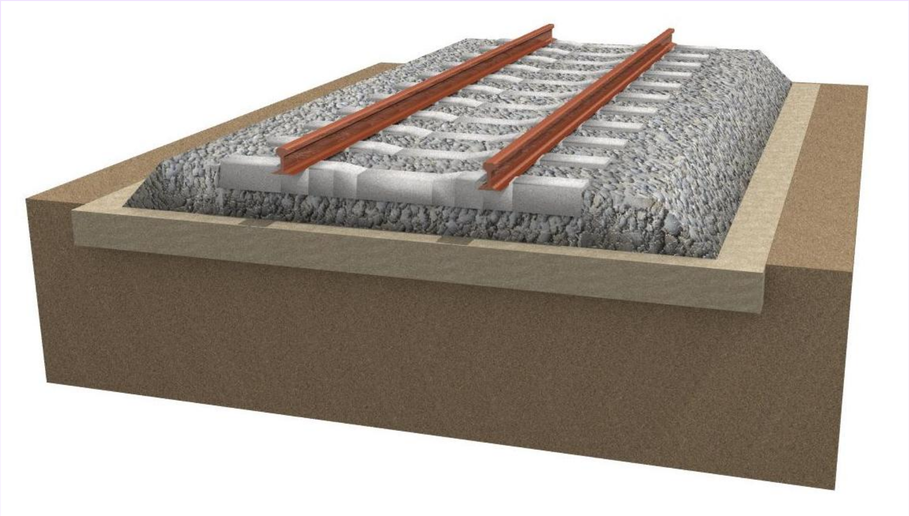
Geotechnical issues around ballasted track and slab track in Japan



Railway Technical Research Institute

Yoshitsugu Momoya

Contents

- Introduction
- Ballasted tracks in existing line
- Asphalt roadbed in design standard
- Slab track on earth structure

Ballasted track and slab track

Ballasted track

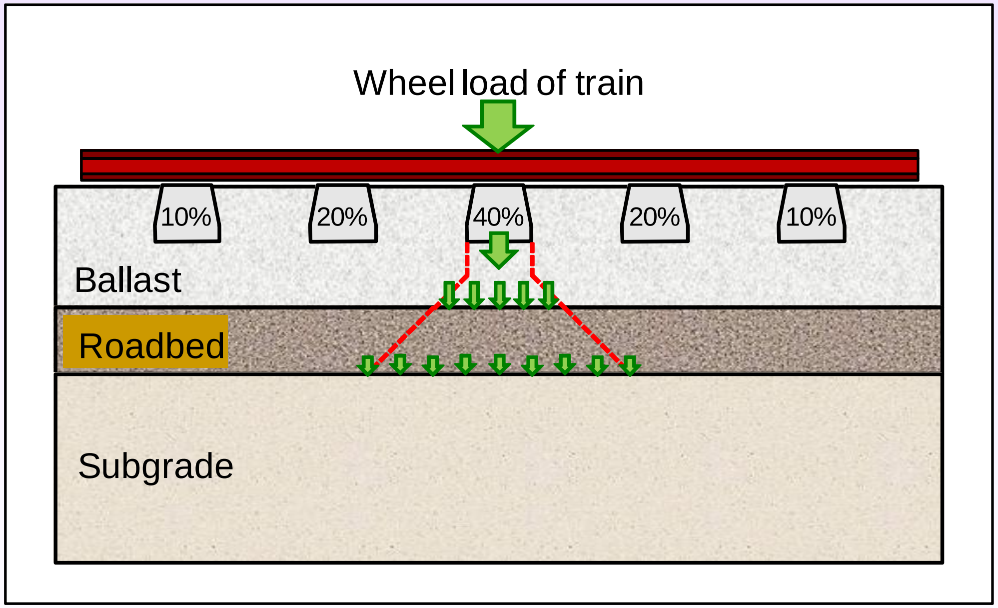
- Periodical maintenance work is necessary.
- Easy to correct track irregularity.
- Construction cost is relatively low.

Slab track

- Low maintenance work.
- Difficult to correct track irregularity.
- Construction cost is relatively high.

Requirement for ballasted track

- Supporting sleepers stably and uniformly.
- Distribute train load applied on roadbed.



Requirement for ballasted track

- Easy to correct track irregularity by tamping.
- Good drainage.

■ Requirement for ballasted track

- ◆ Lateral resistance against lateral train load and rail buckling.
- ◆ Apply adequate elasticity on track (especially on bridge or viaduct)

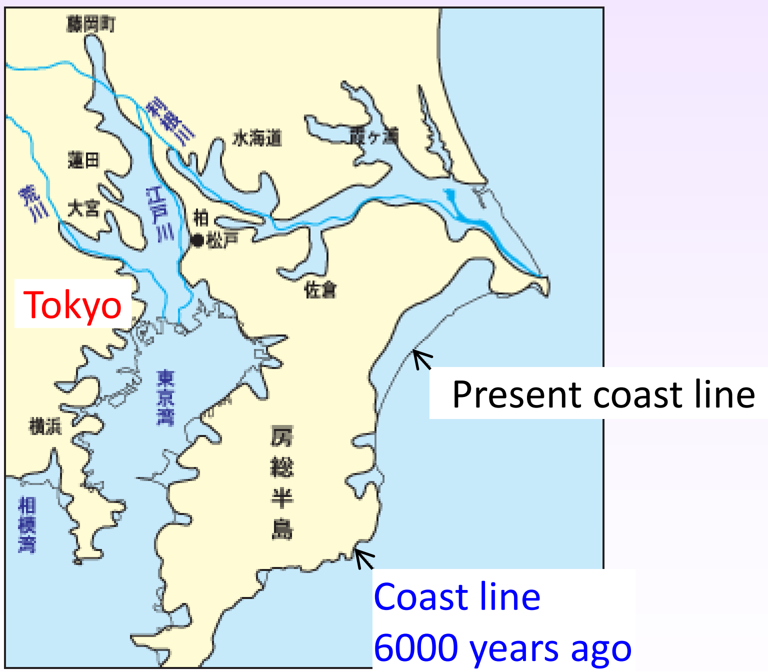
Requirement for slab track

- Maintenance free.
- Not high construction cost.

Difficult circumstance for railway track in Japan

◆ Soft ground.

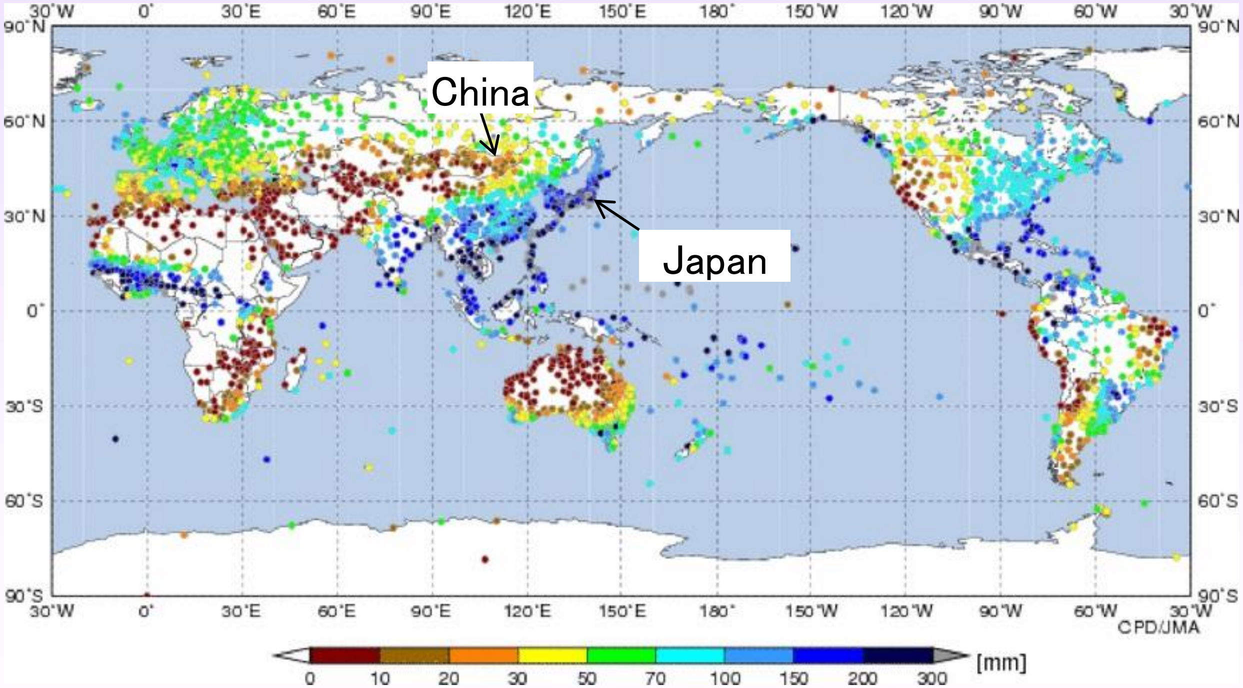
Alluvial clays are deposited at plains.
Geological ages are young.
(younger than 6000 years)

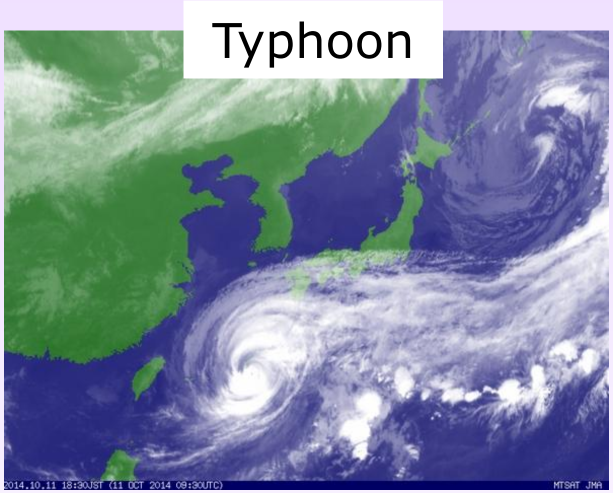


Difficult circumstance for railway track in Japan

◆ Heavy rain.

Rain fall in September (average)





Contents

- Introduction
- Ballasted tracks in existing line
- Asphalt roadbed in design standard
- Slab track on earth structure

■ Existing line and newly constructed line

◆ Existing line

- Constructed before 1960’s

  Design standard was not regulated.

◆ Newly constructed line

- Constructed after 1970’s

  Design standard was established in 1978

Most of railway lines in Japan were constructed before 1950’s

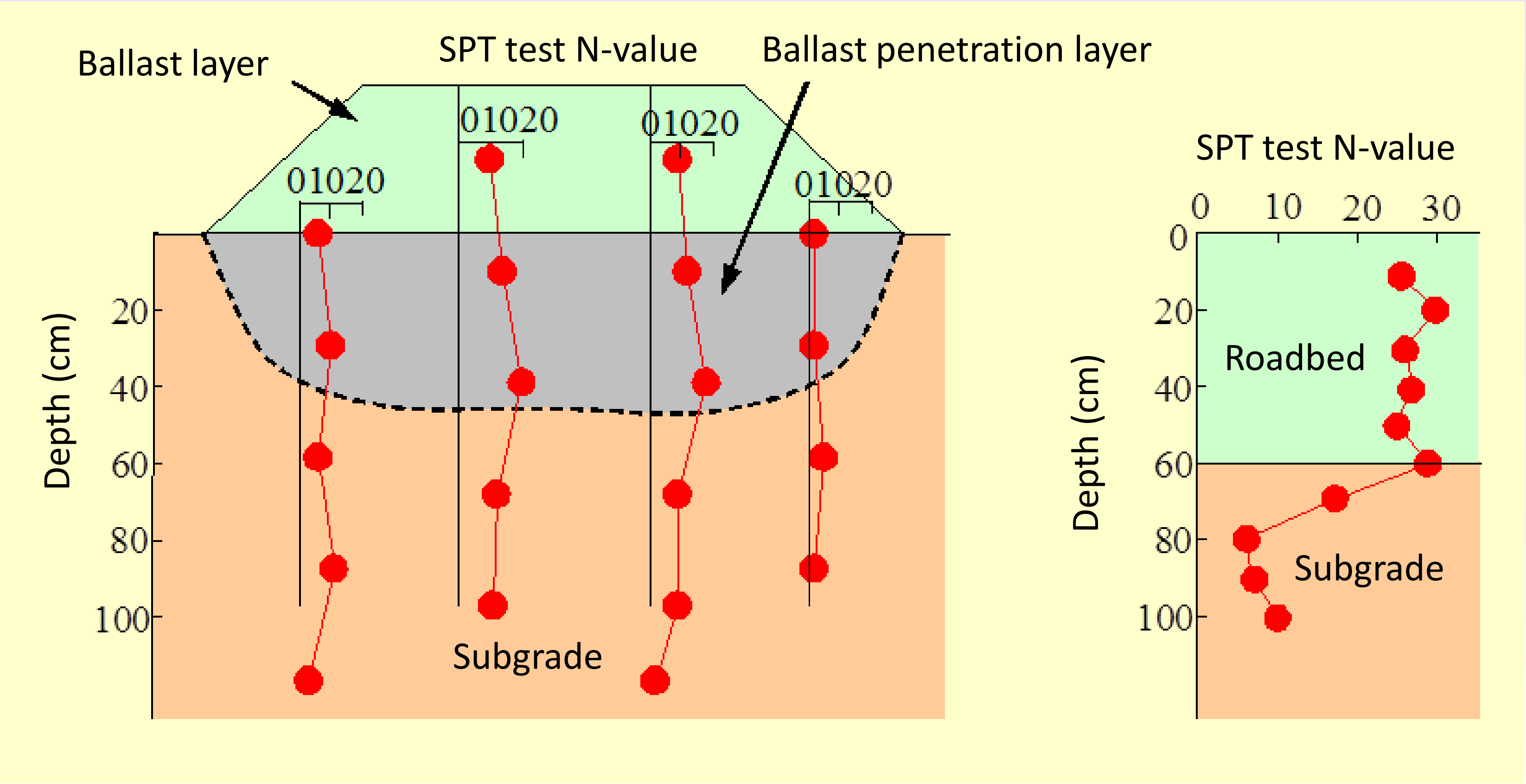
Roadbed and subgrade in existing line

- No specific roadbed layer
- Material is not regulated
- Insufficient drainage
- Low stiffness subgrade

↓

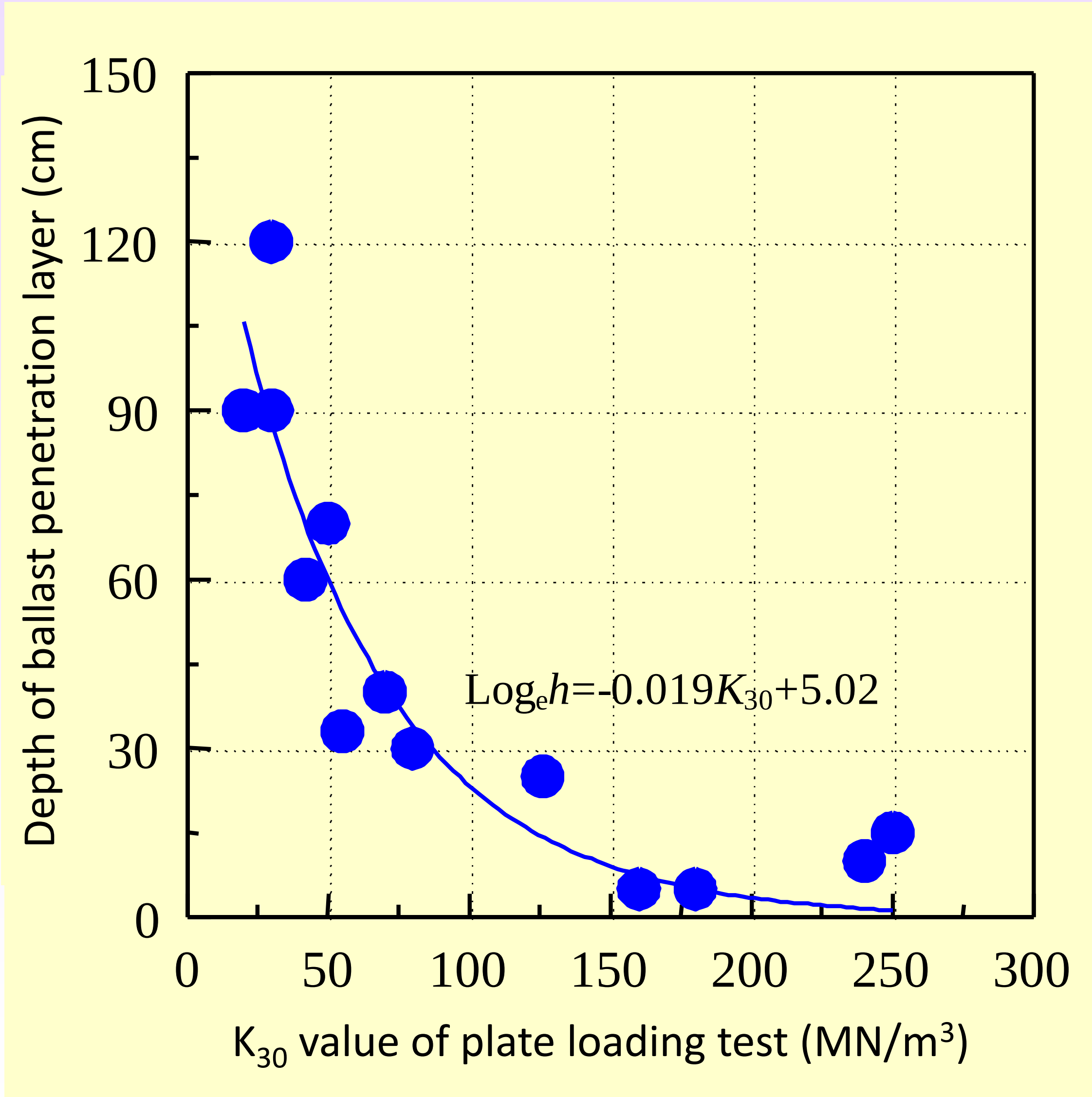
- Penetration of ballast into roadbed
- Mud pumping
- Large dynamic deformation
- Increase of maintenance work

Penetration of ballast into roadbed

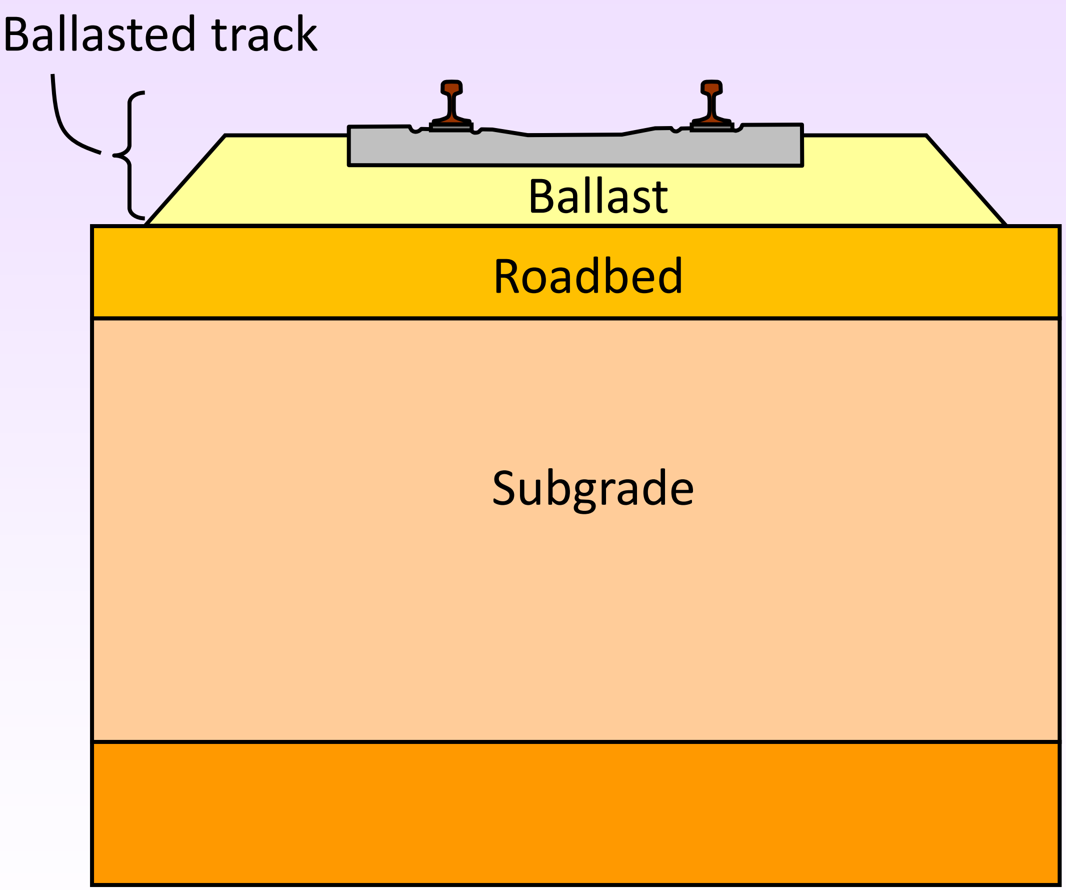


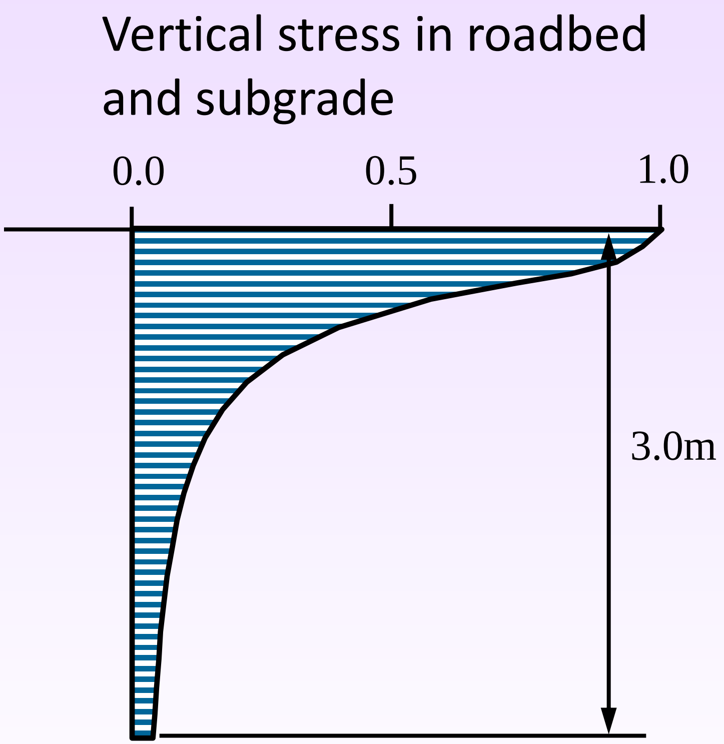
Existing line　　　Newly constructed line

Depth of ballast penetration layer



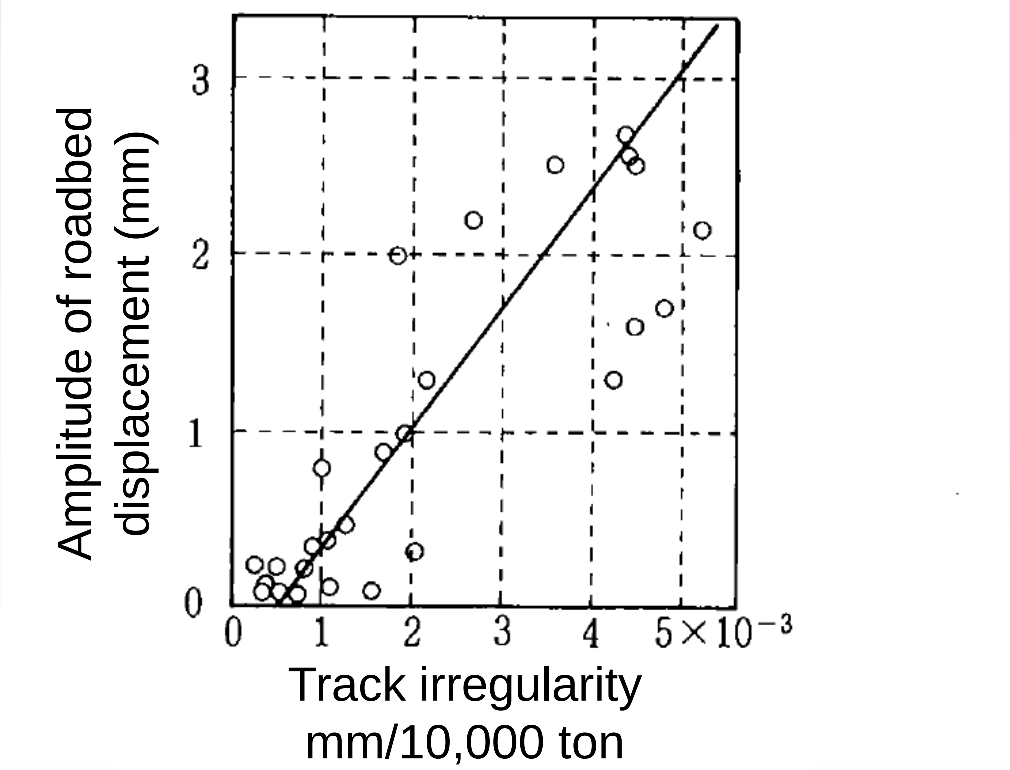
Vertical stress in roadbed and subgrade





■ Stiffness of roadbed and track irregularity

Settlement of ballasted tracks and track irregularity strongly depends on the stiffness of roadbed and subgrade.

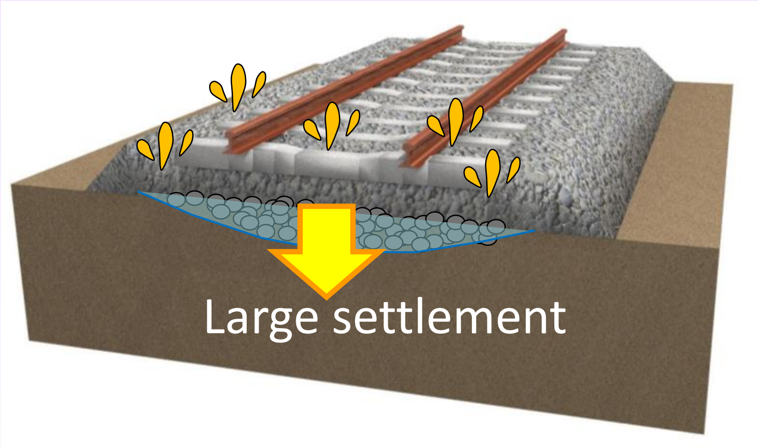


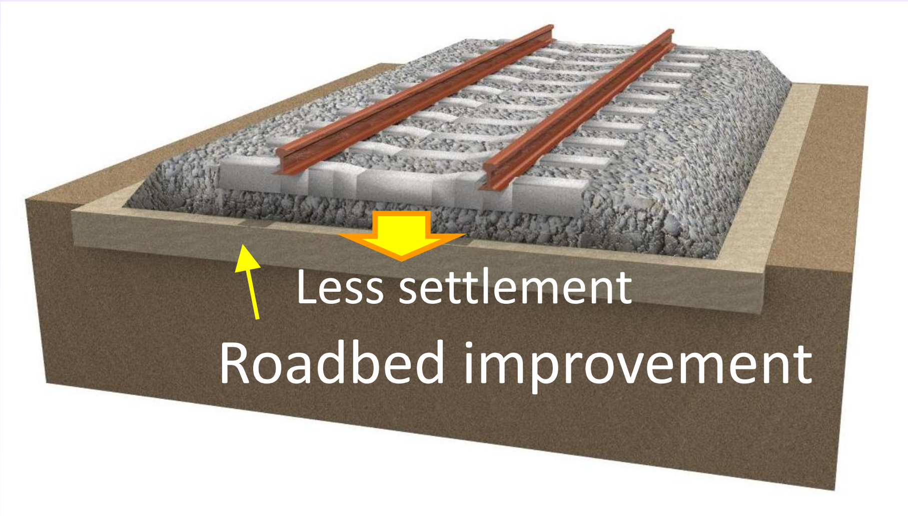
Roadbed improvement

- Most of the roadbeds constructed before 1960's do not have sufficient stiffness.

Without improvement

Roadbed improvement





- Settlement of ballasted track becomes less after roadbed improvement.

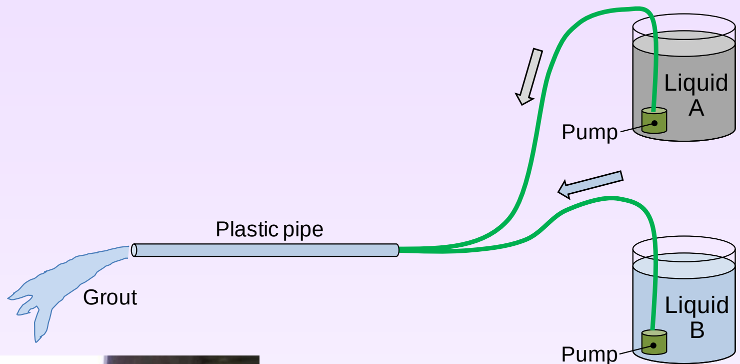
Conventional roadbed improvement

Conventional roadbed improvement method:
Crushed stone, steel slag, cement treated material.

Sufficient compaction work was necessary.

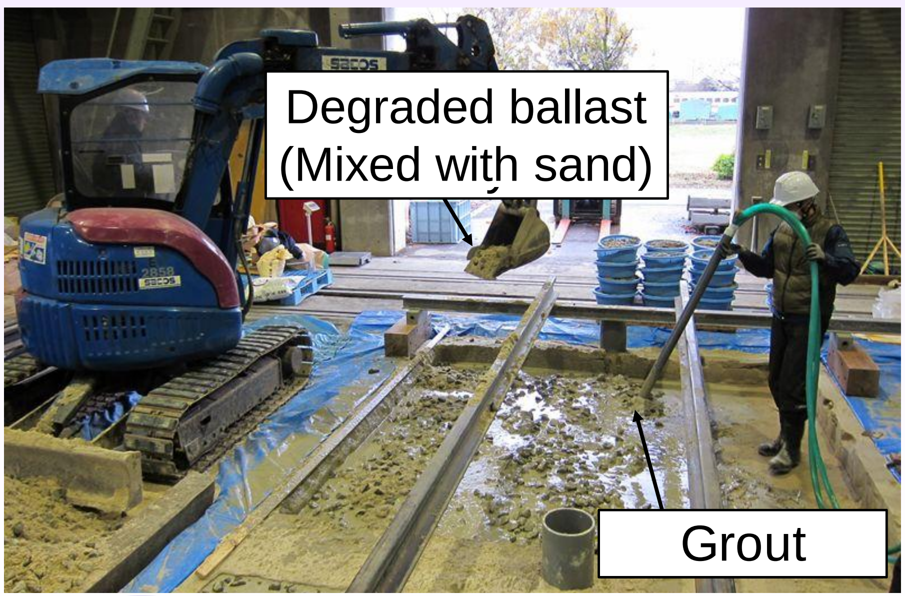
New roadbed improvement method

- Reusing degraded ballast mixed with cement grout.

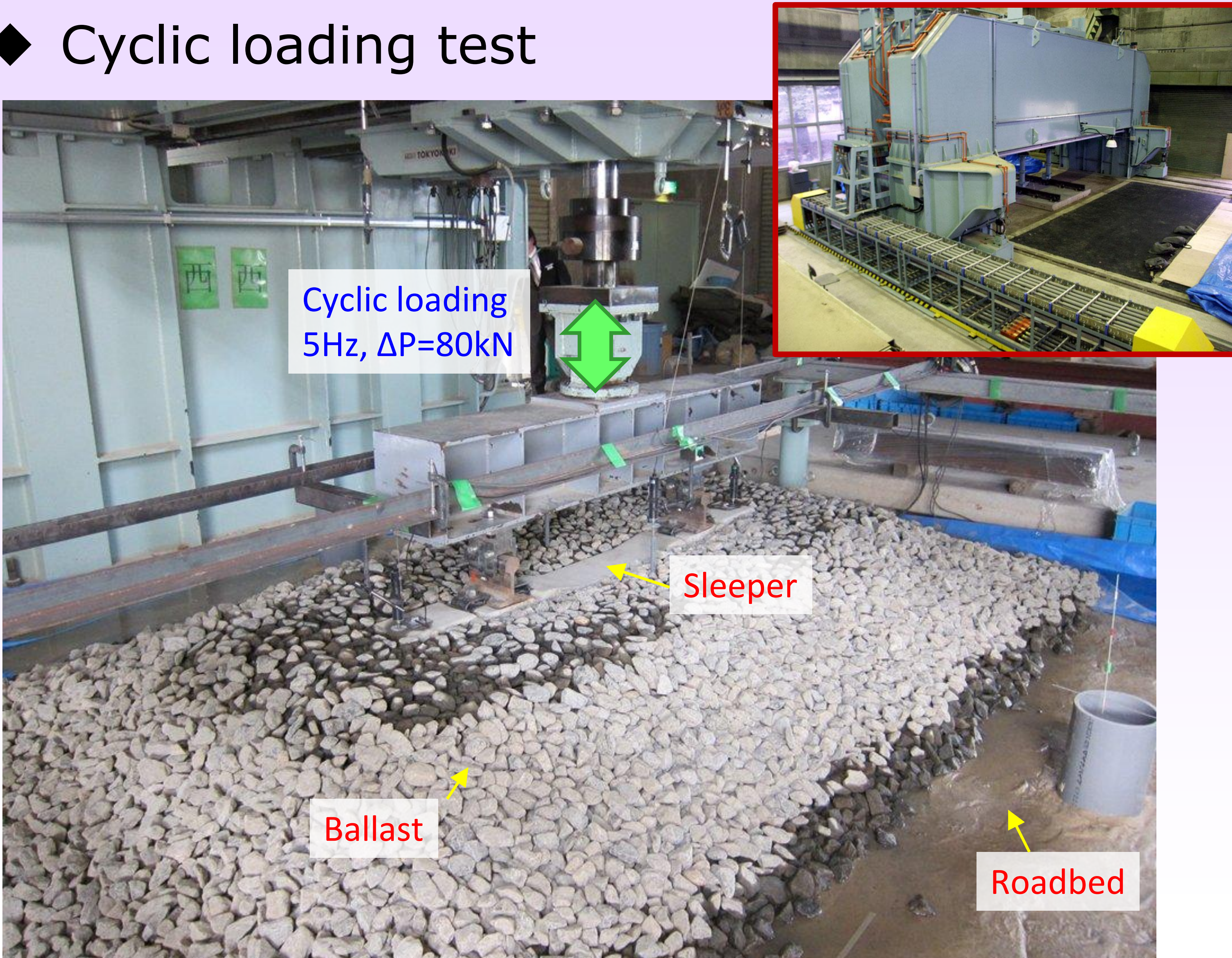


Slag cement
Setting accelerator
Water

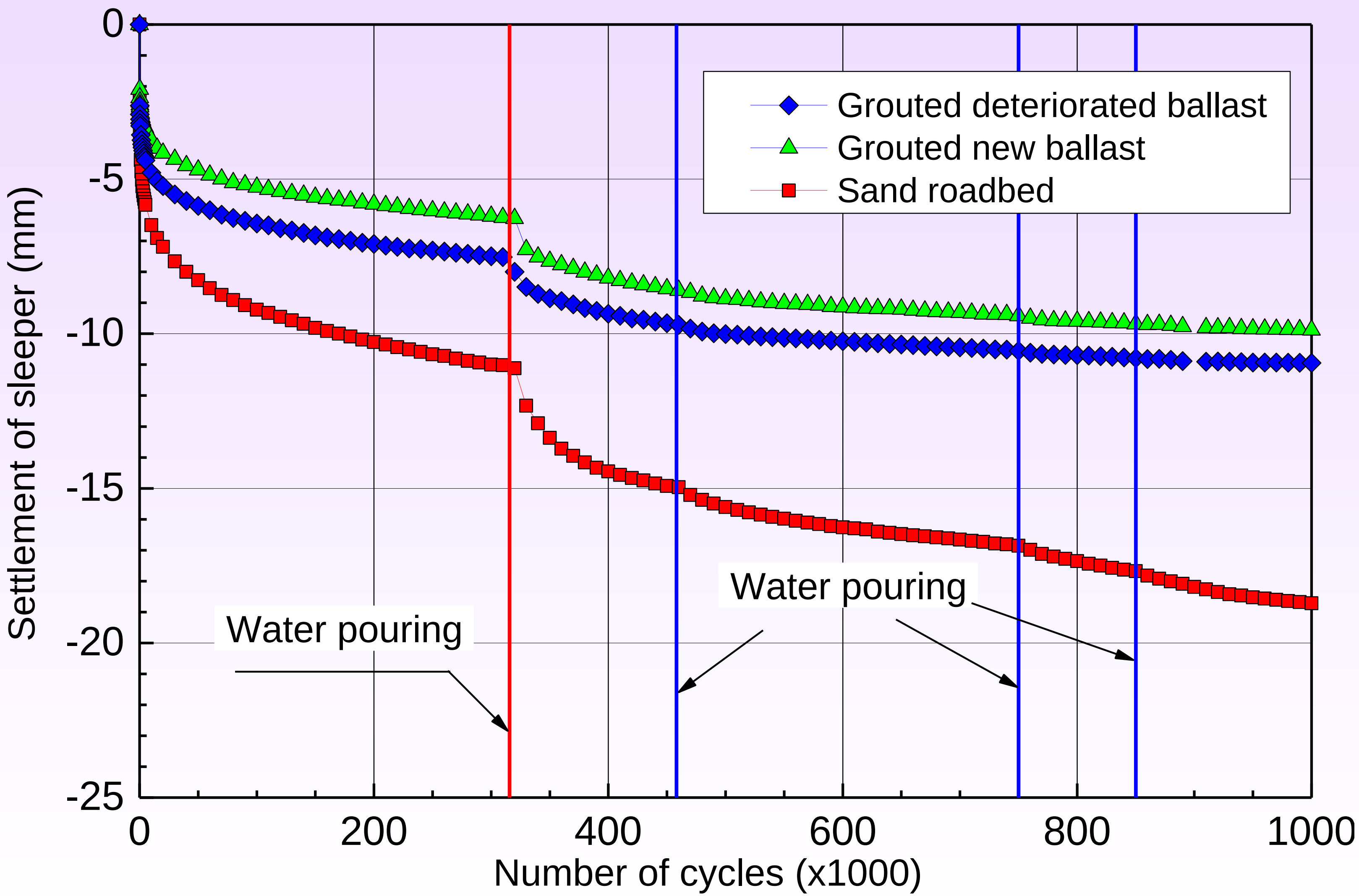
Hardening agent
Water



◆ Cyclic loading test

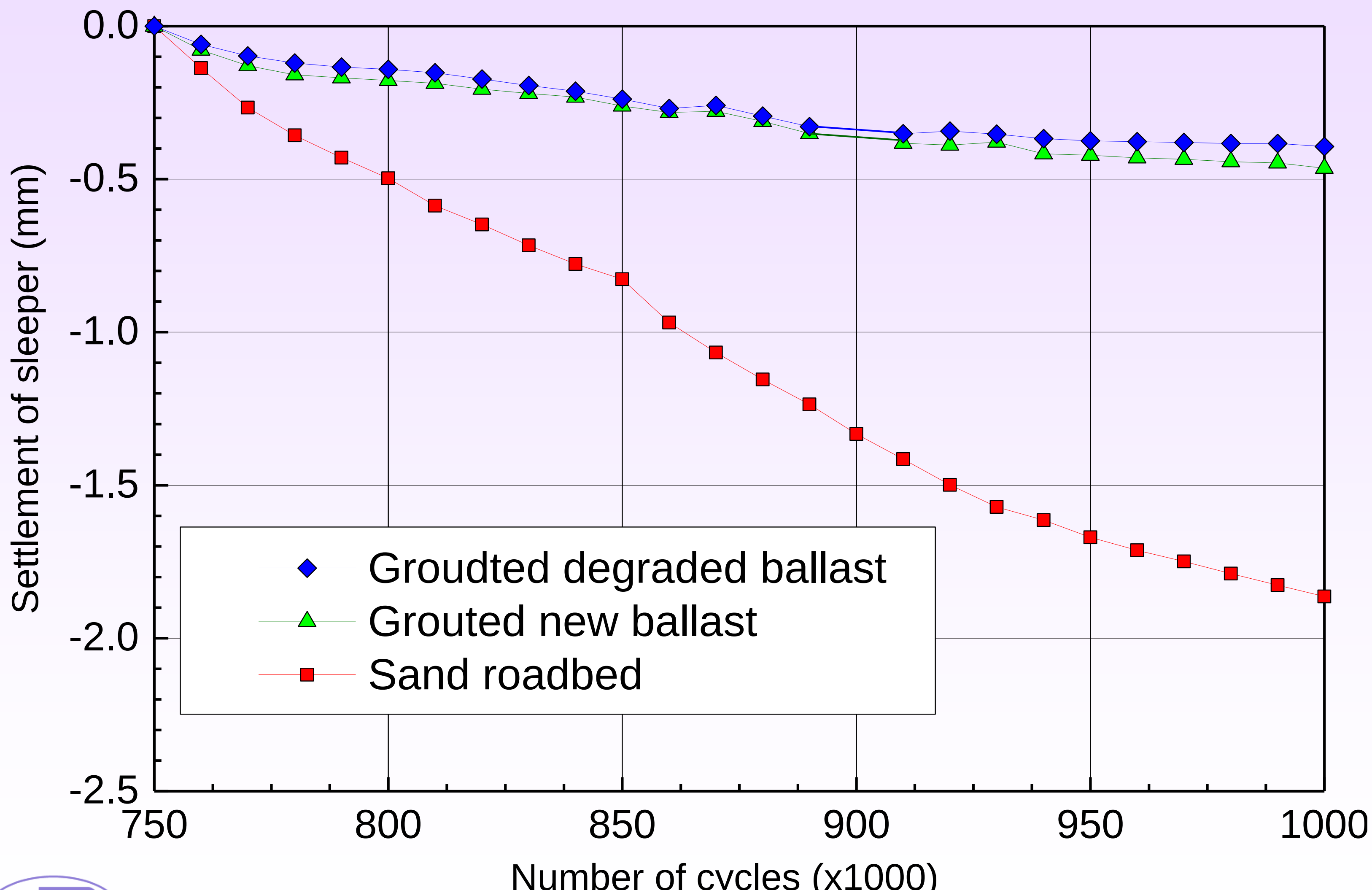


◆ Cyclic loading test results



◆ Cyclic loading test results

☐ Settlement after 750,000 cycles

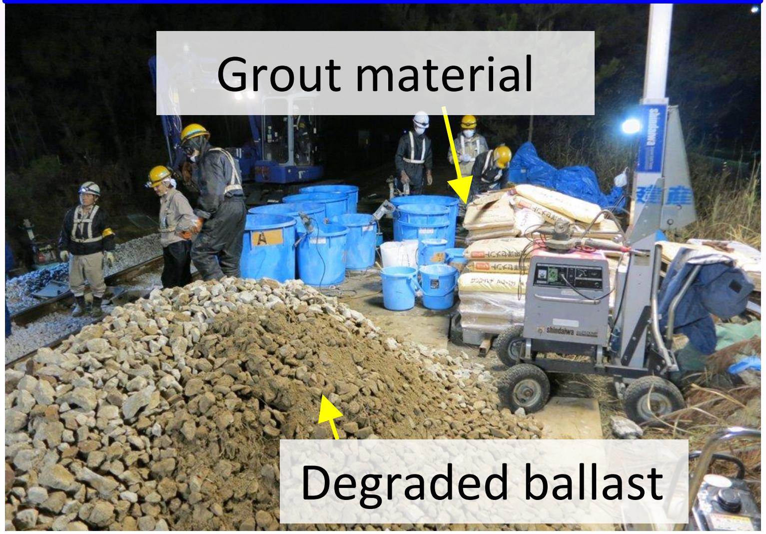


◆ Application at site

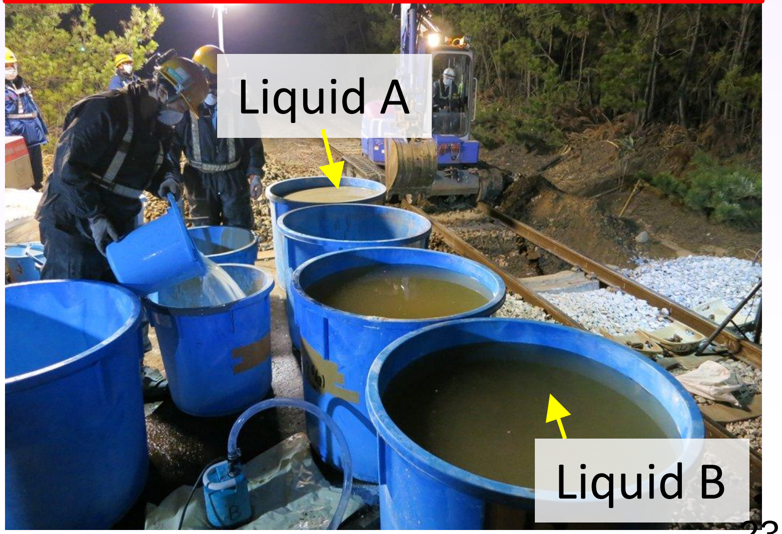
Before roadbed improvement

Excavation of ballasted track

Degraded ballast

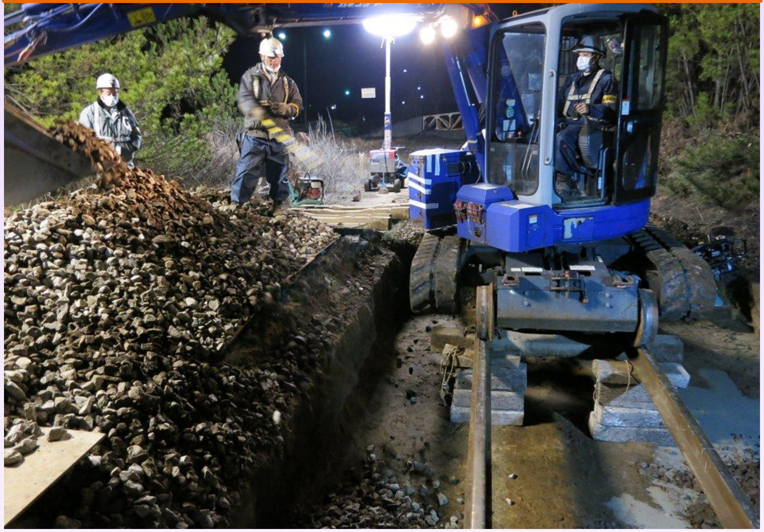


Preparation of grout

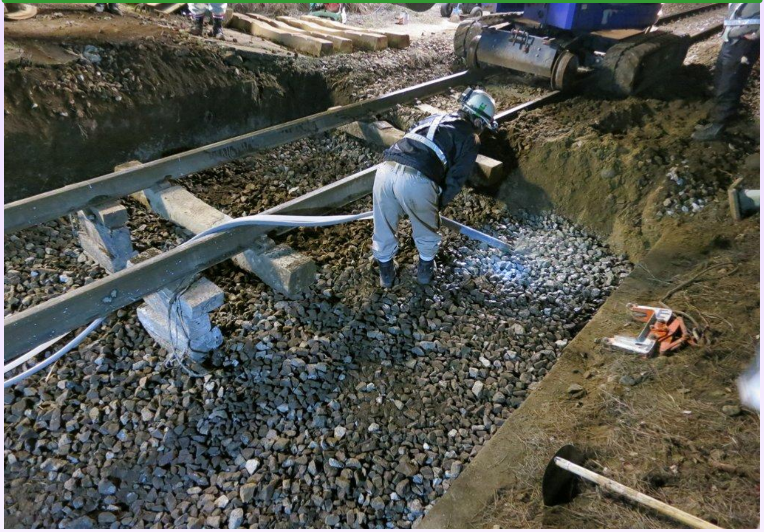


◆ Application at site

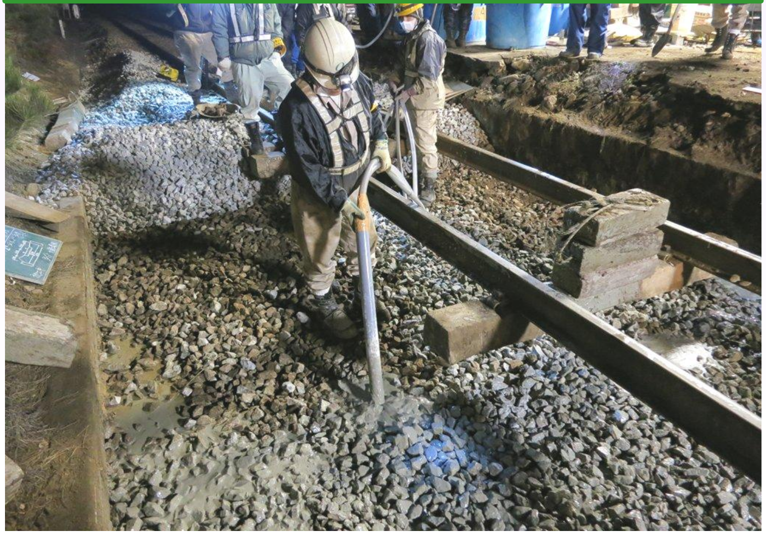
Laying degraded ballast



Injection of grout

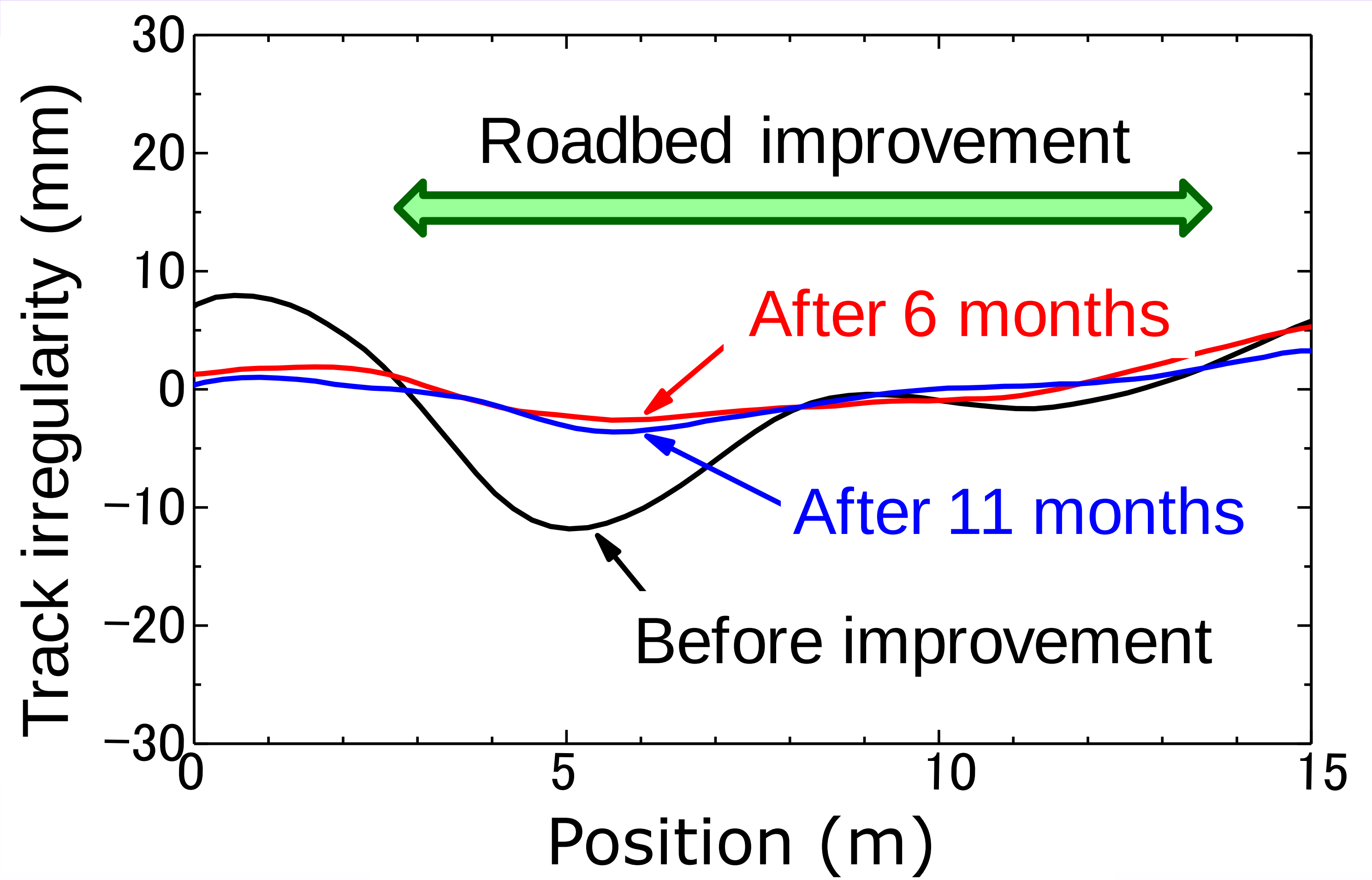


Injection of grout

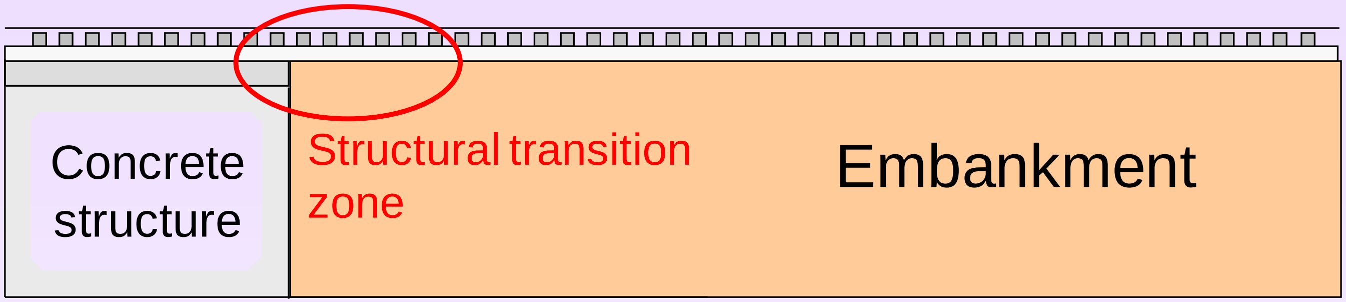


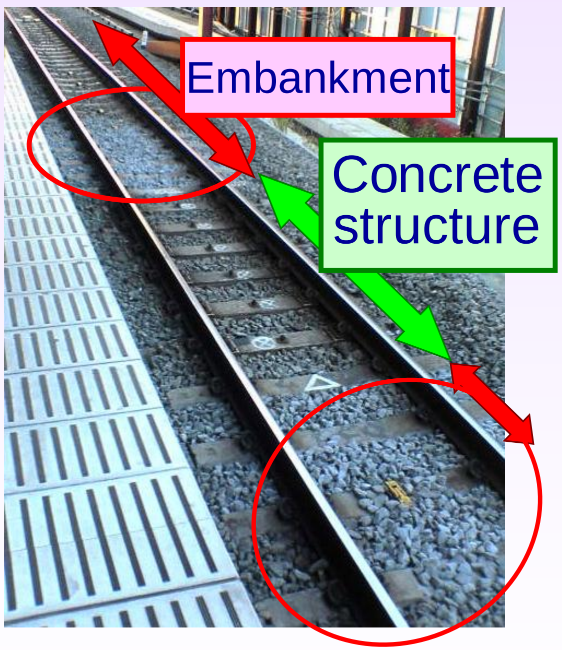
After roadbed improvement

◆ Track irregularity after the roadbed improvement

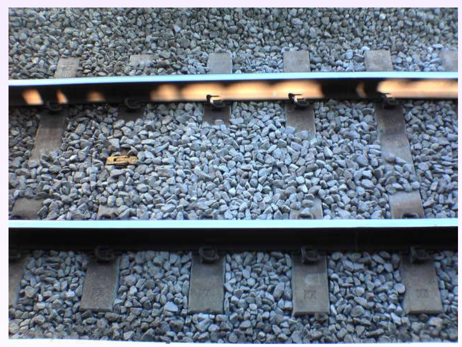


Issues around transition zone





Structural transition



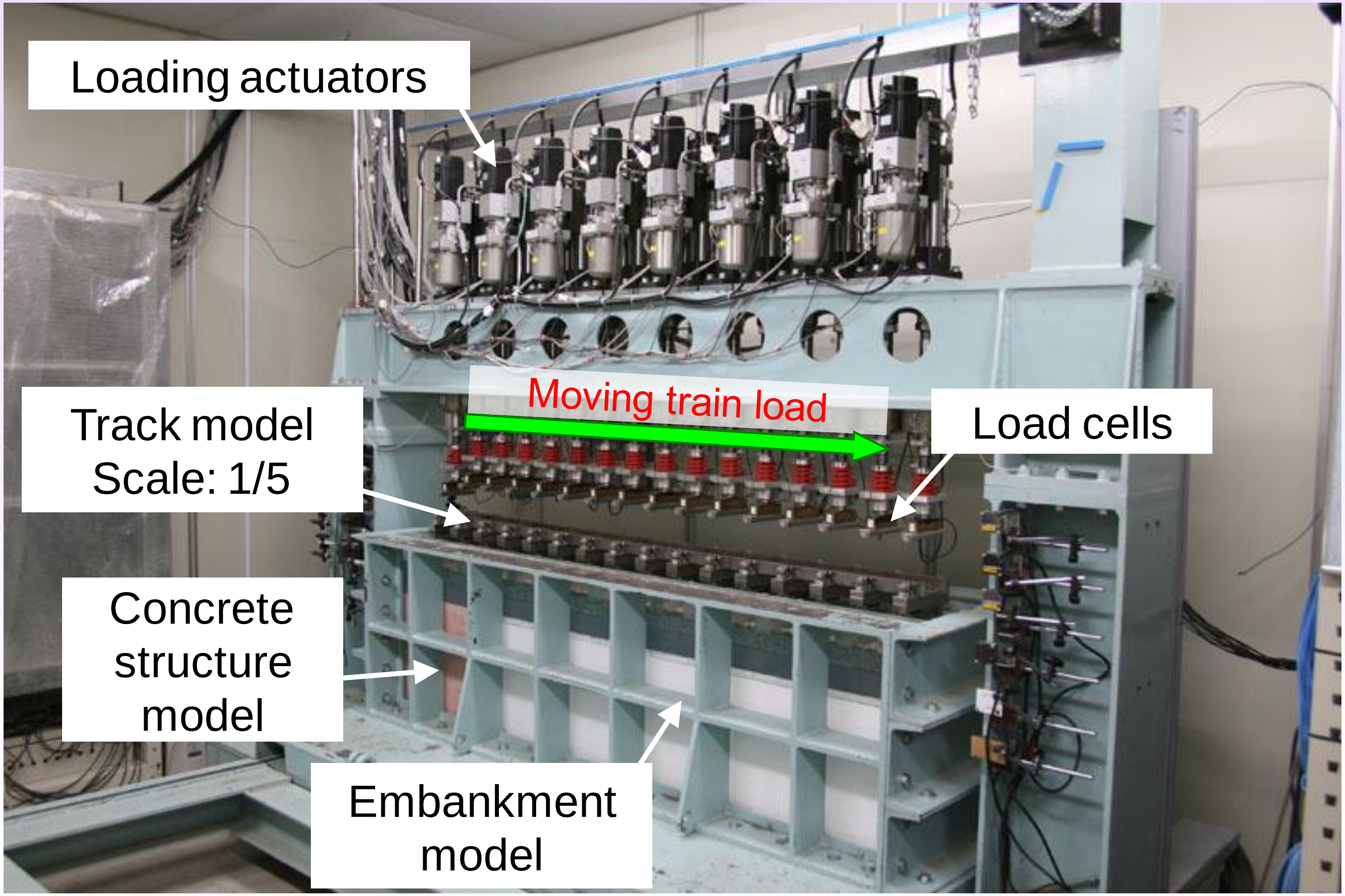
Floating sleeper
→ large settlement

General section

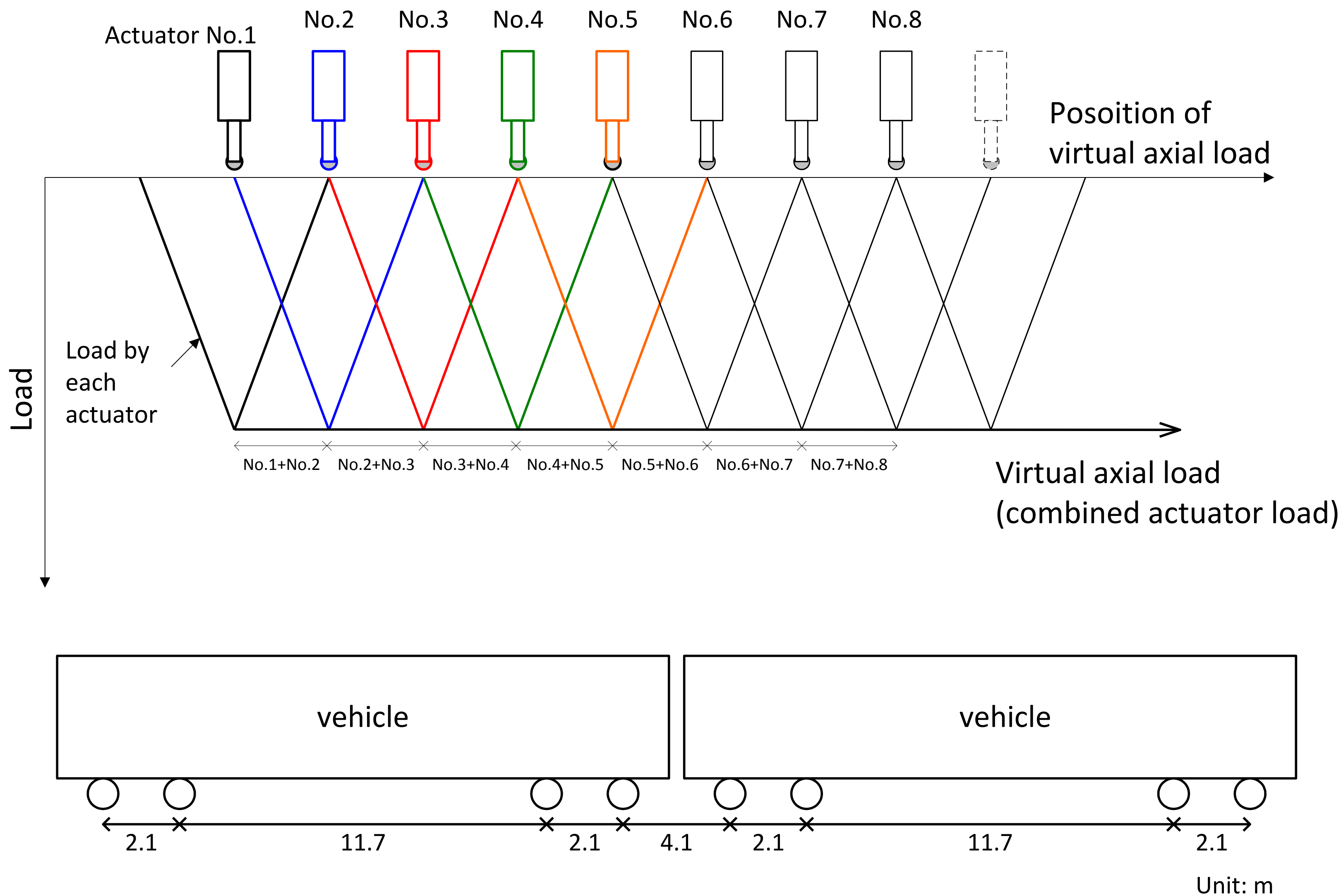
No floating sleeper

Moving loading test

◆ Multi-actuator moving loading test apparatus

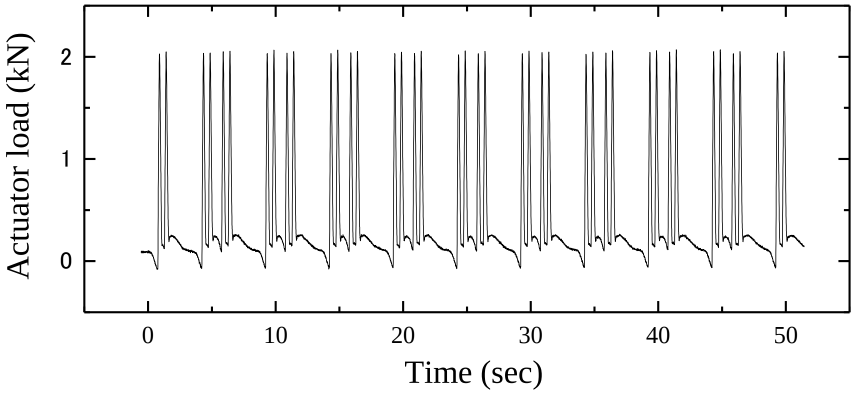


◆ Multi-actuator moving loading test apparatus

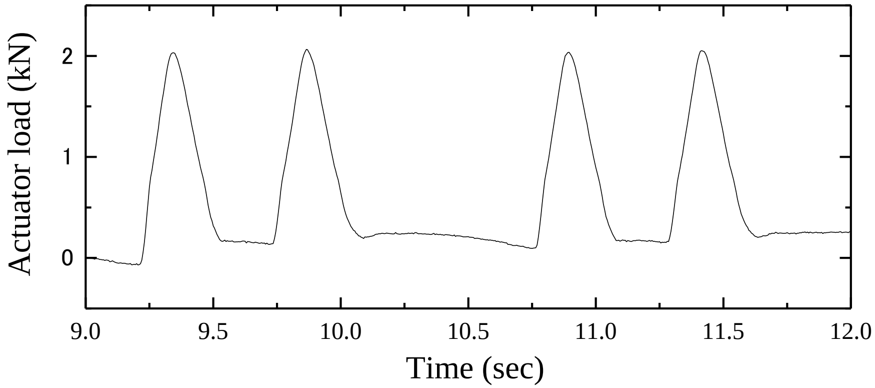


◆ Multi-actuator moving loading test apparatus

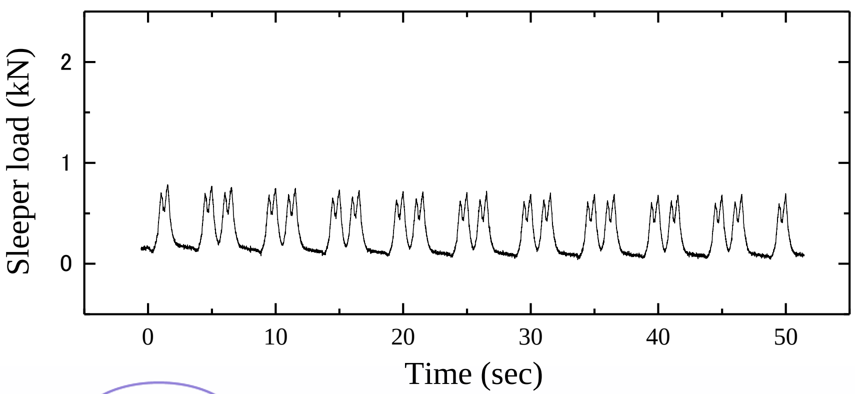
Actuator load



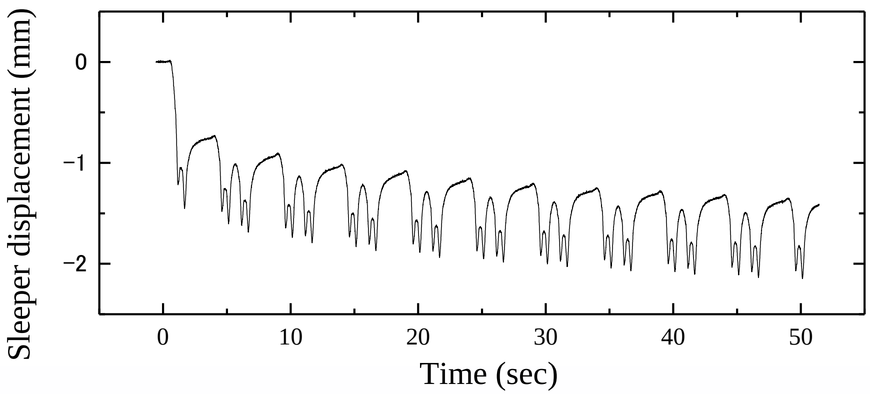
Actuator load



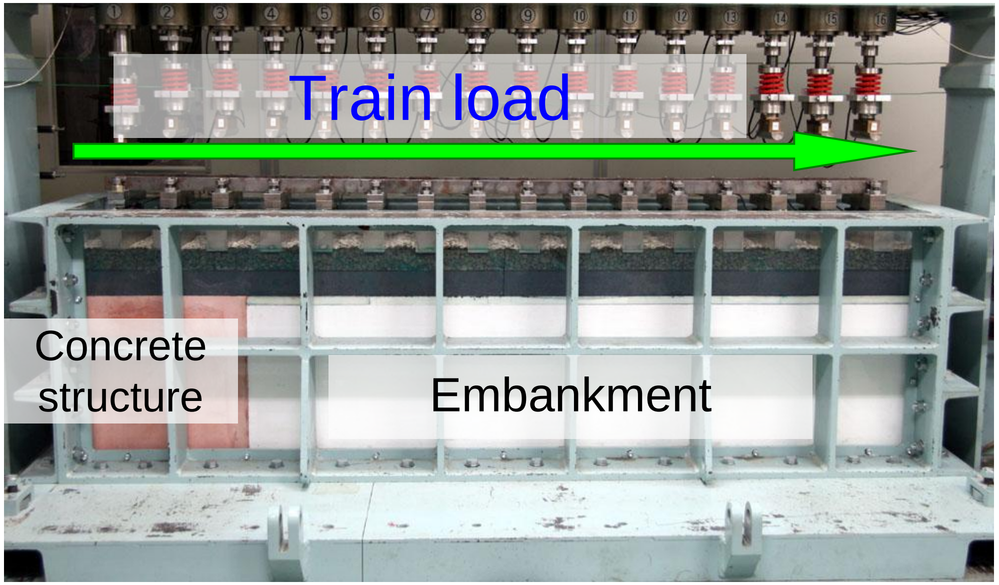
Sleeper load

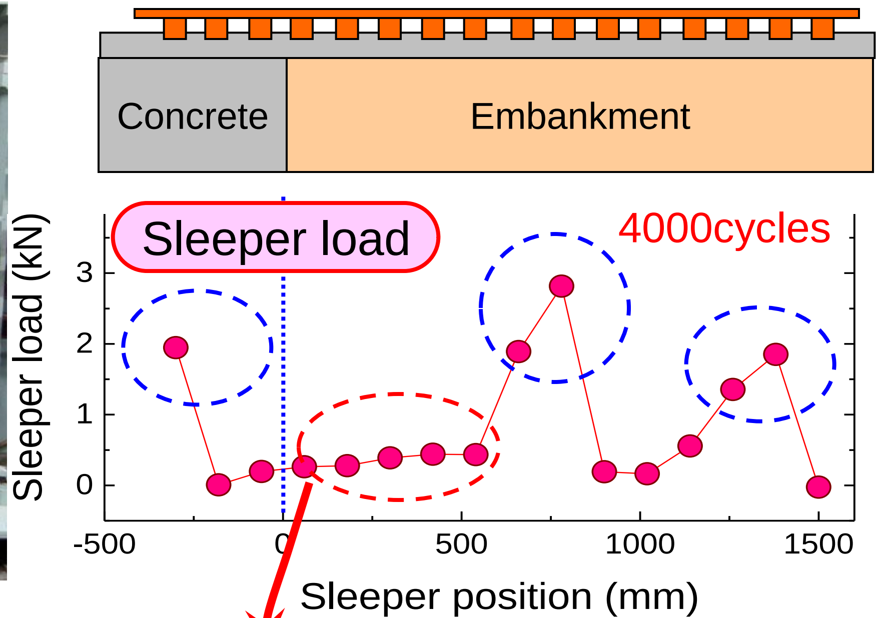


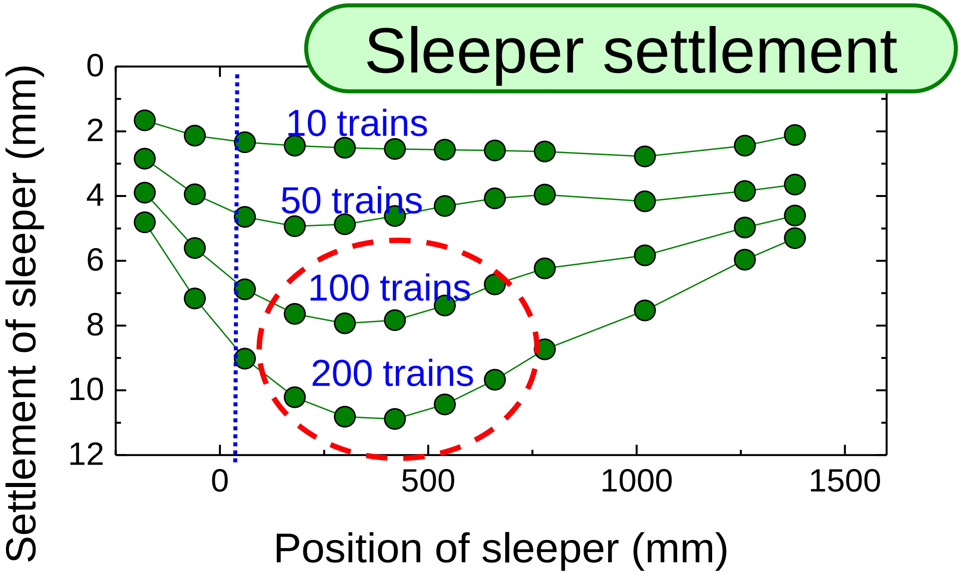
Sleeper settlement



◆ Moving loading test results







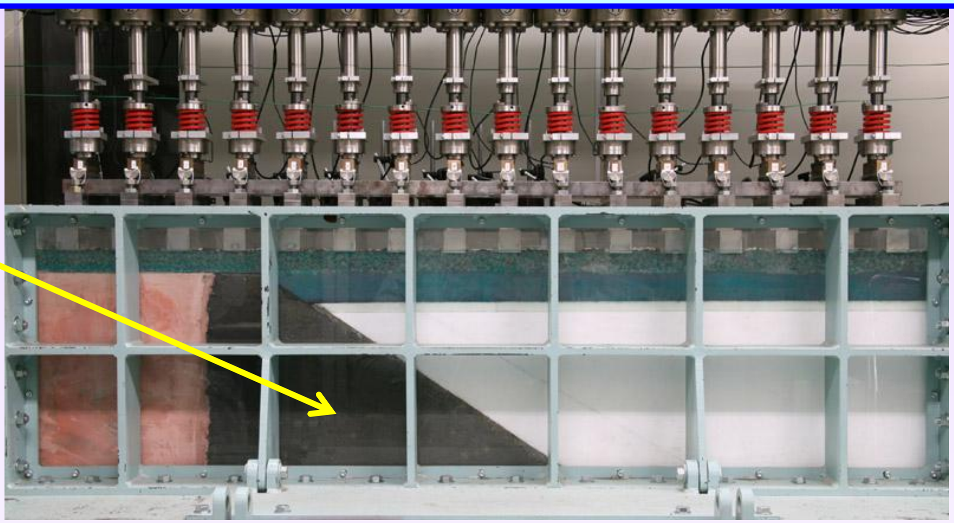
Those sleepers are not supporting wheel load (Floating sleeper)

Accelerate local settlement

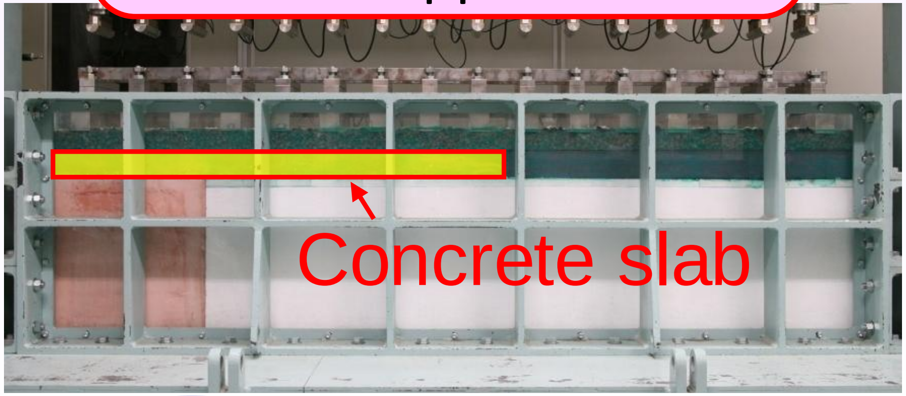
◆ Moving loading test results

Approach block (Design standard)

Approach block

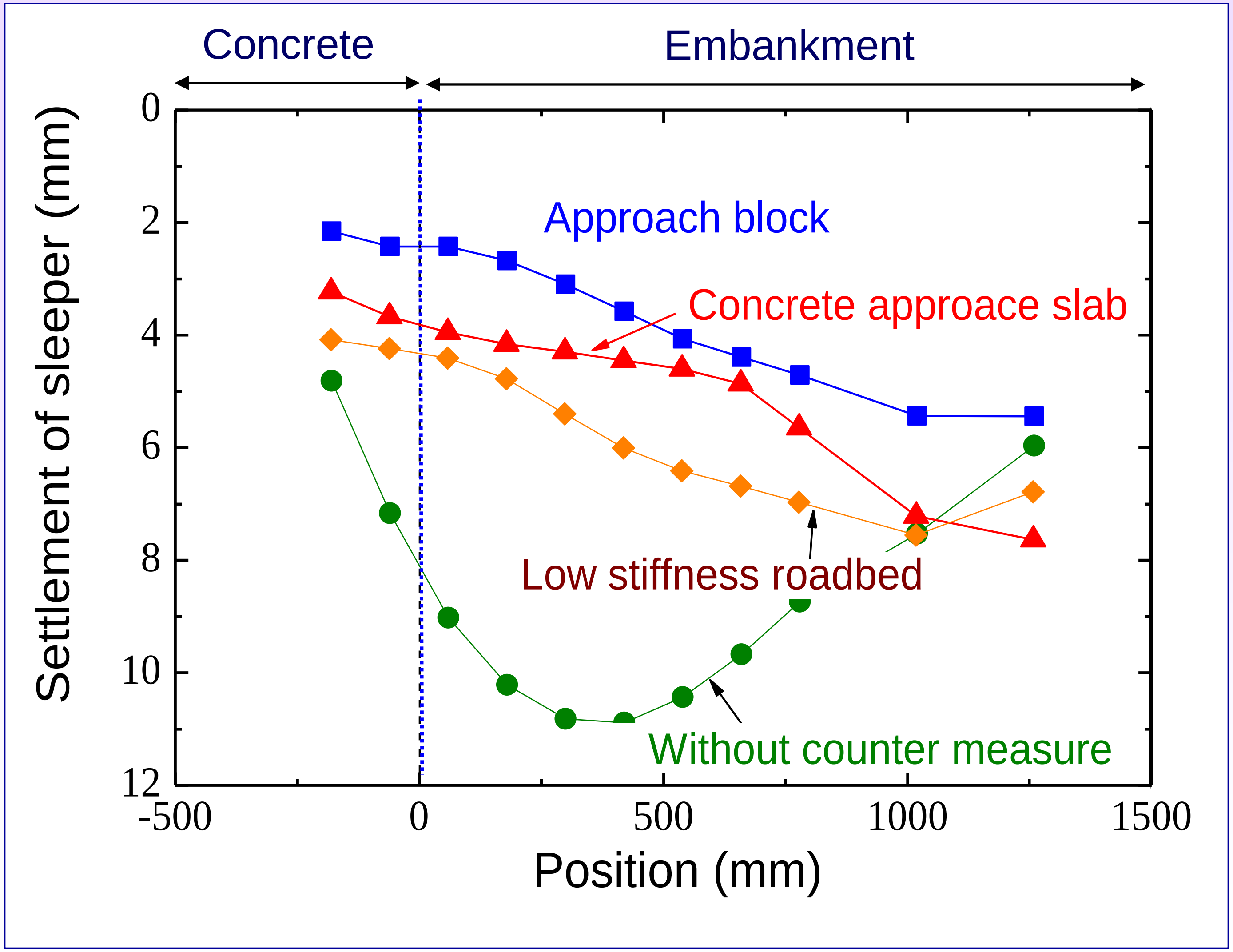


Concrete approach slab



Low stiffness roadbed

◆ Moving loading test results

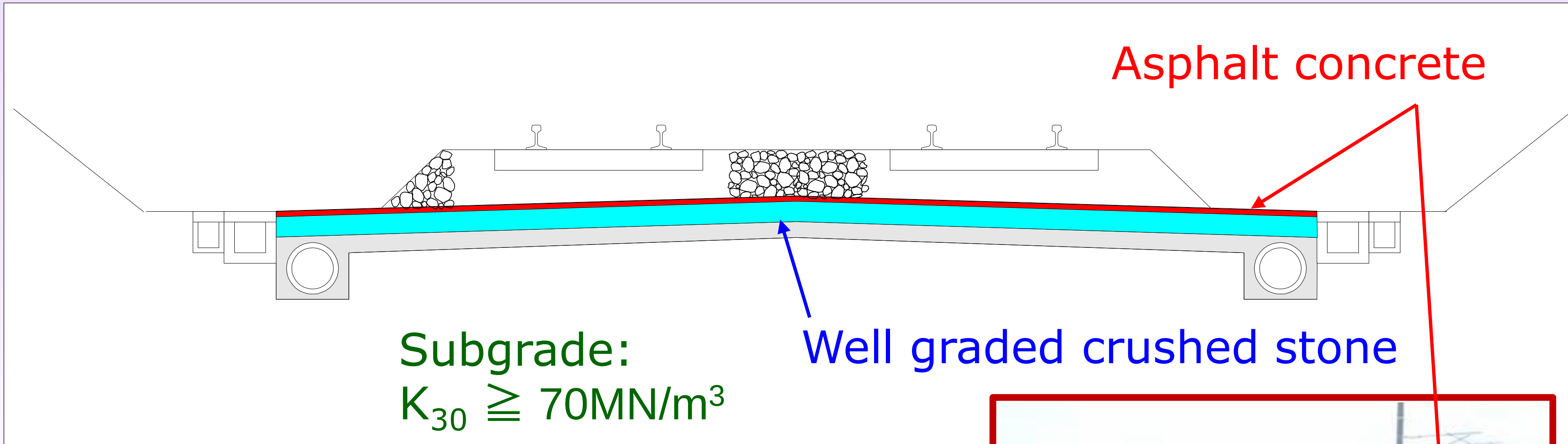


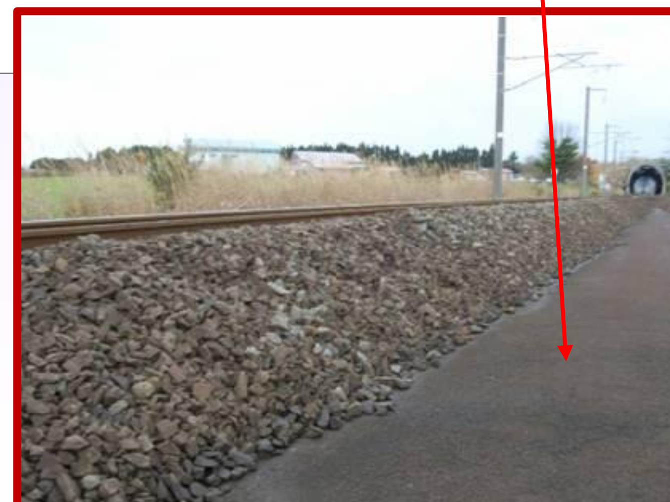
Contents

- Introduction
- Ballasted tracks in existing line
- Asphalt roadbed in design standard
- Slab track on earth structure

■ Asphalt roadbed for newly constructed lines

◆ Asphalt roadbed became standard structure in Japan after 1978

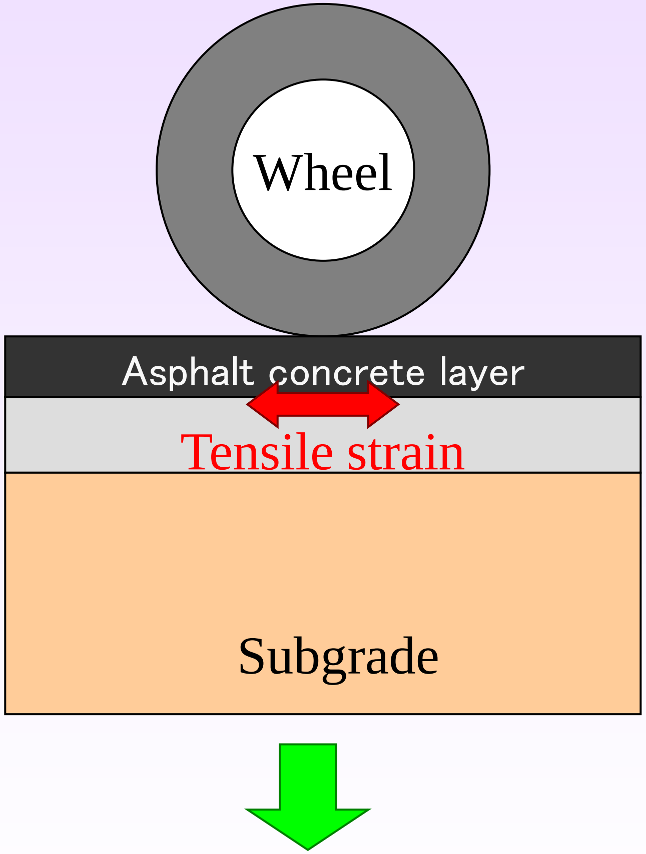




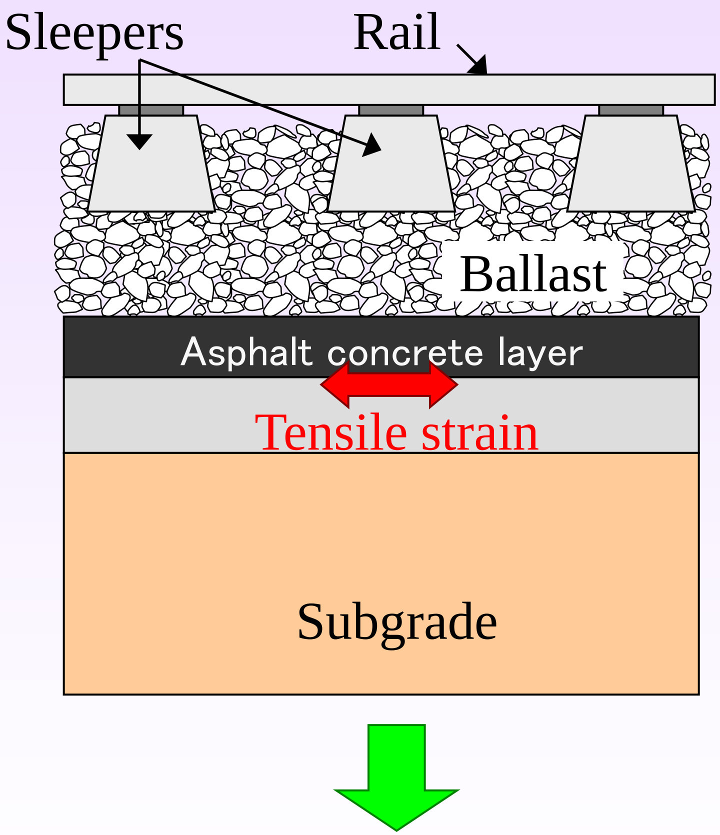
- Sufficient bearing capacity.
- No ballast penetration.
- Good drainage.

■ Design of asphalt roadbed

Road



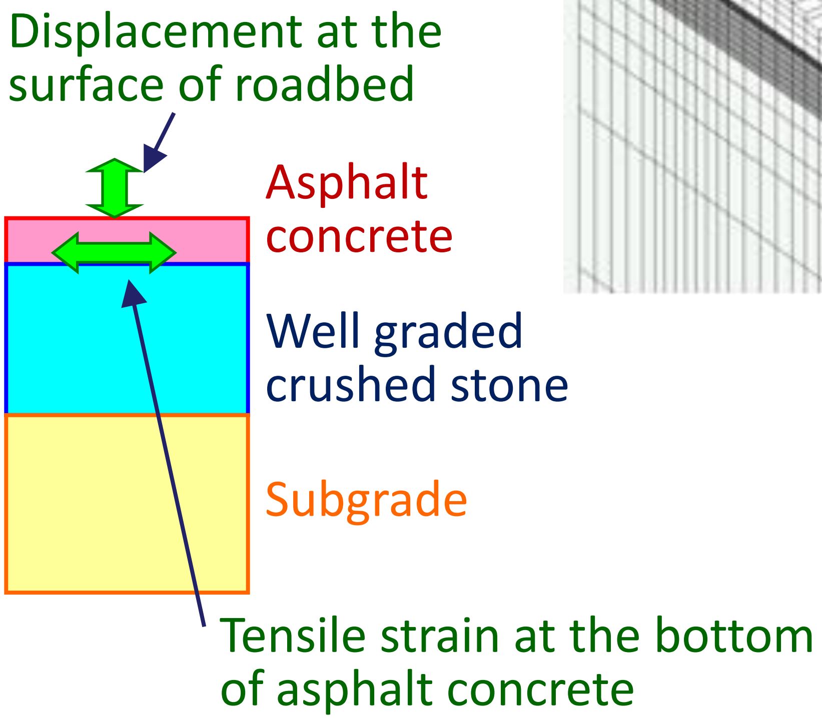
Railway

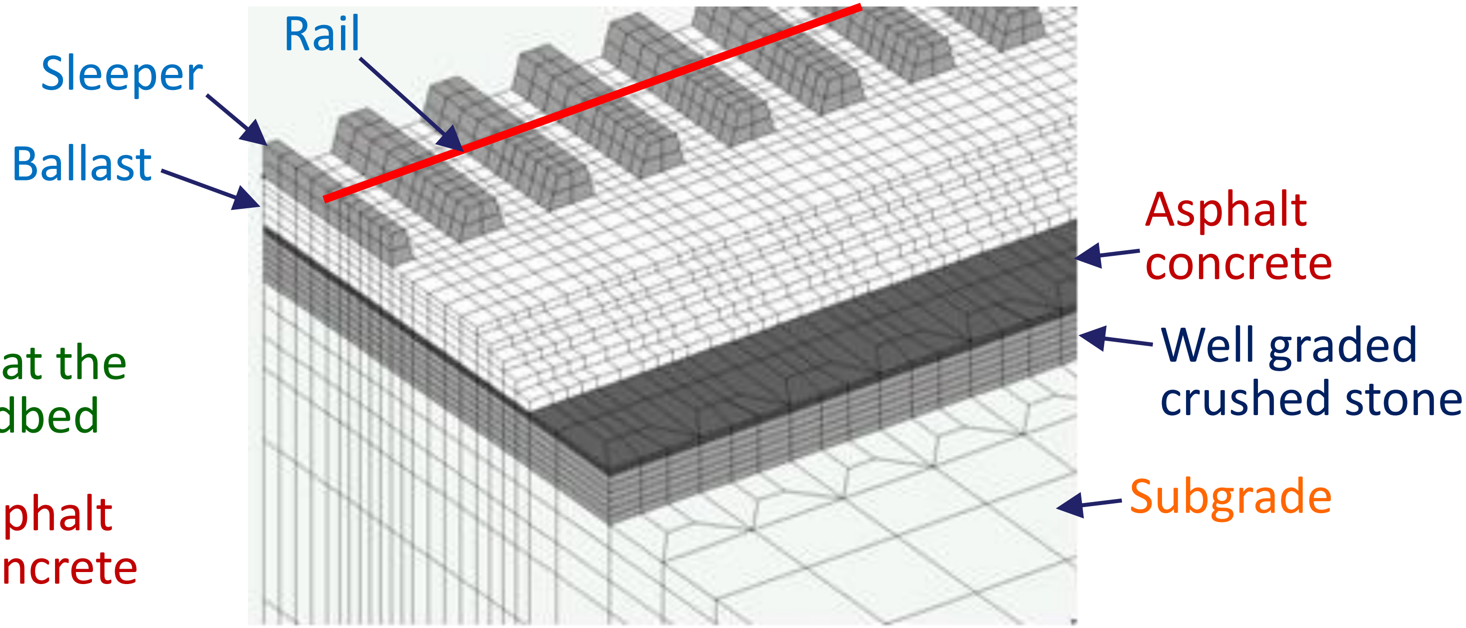


Multi-layered elastic analysis

FEM analysis

Design of asphalt roadbed

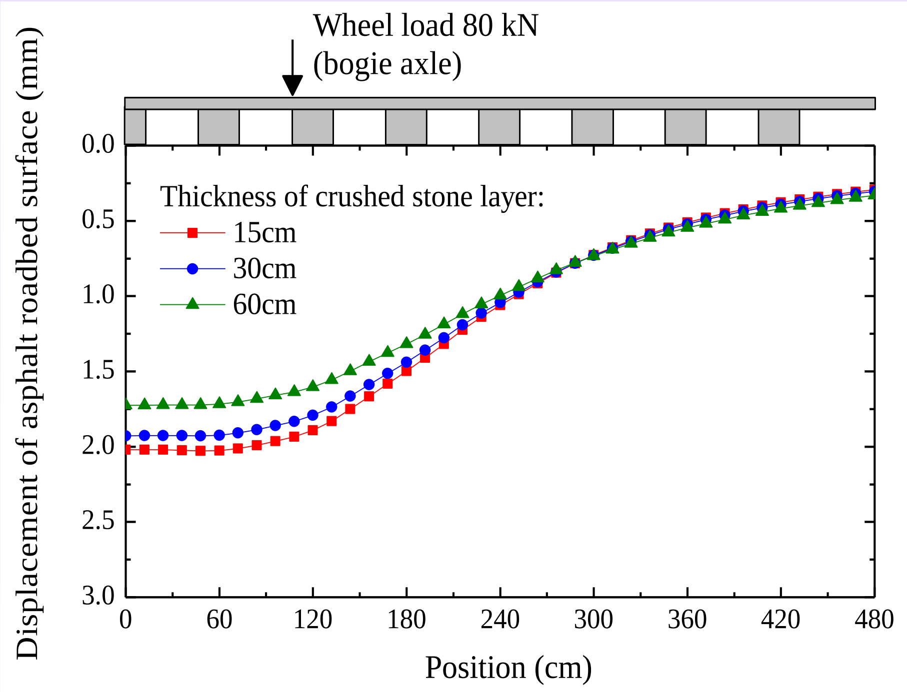




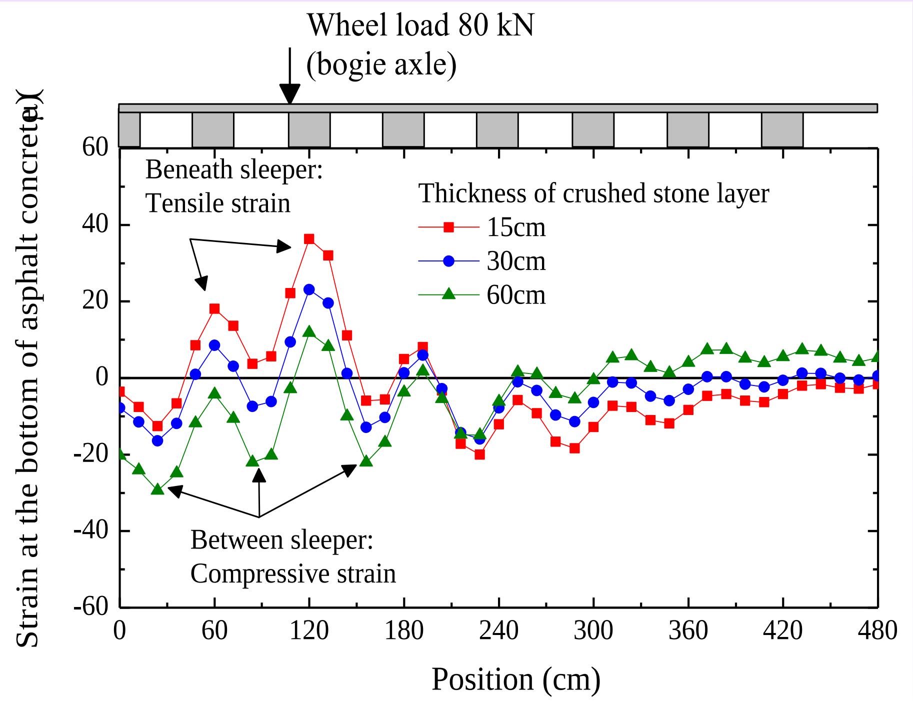
1/4 symmetric model

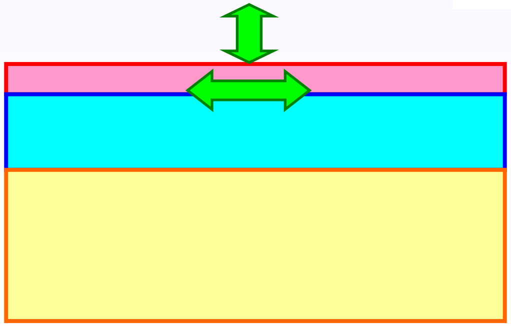
Design of asphalt roadbed

Settlement



Strain





Design of asphalt roadbed

- Tensile strain at the bottom of asphalt concrete ε_t

  → Allowable number of cyclic loading for Fatigue failure

$$N_A = 0.6 \times 18.4 \times C \times 6.167 \times 10^{-5}\ \varepsilon_t^{-3.291} E_A^{-0.854}$$

Where

N_A	:	Allowable number of cyclic loading for Fatigue failure
ε_t	:	Tensile strain
E_A	:	Young's modulus (MN/m^2)
V_v	:	void ratio
V_b	:	asphalt volume

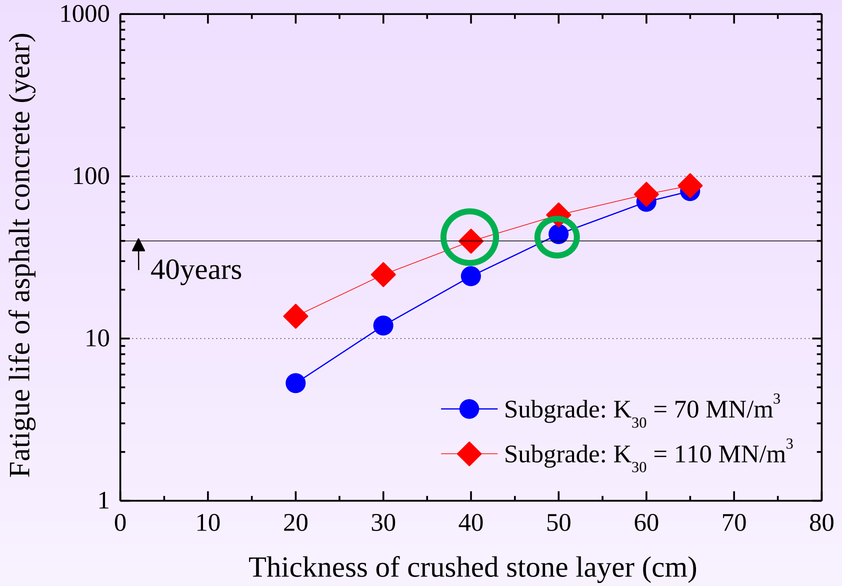
$C = 10^M$ $\quad M = 4.84\ (V_b / (V_v + V_b) - 0.69)$

- Vertical displacement at the surface of asphalt roadbed

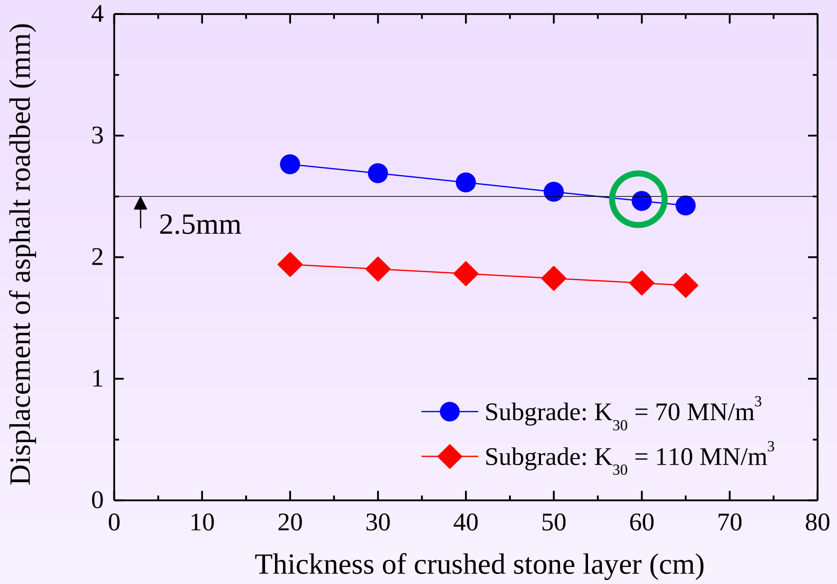
  → Less than 2.5mm considering impact load

Design of asphalt roadbed

Fatigue life



Displacement

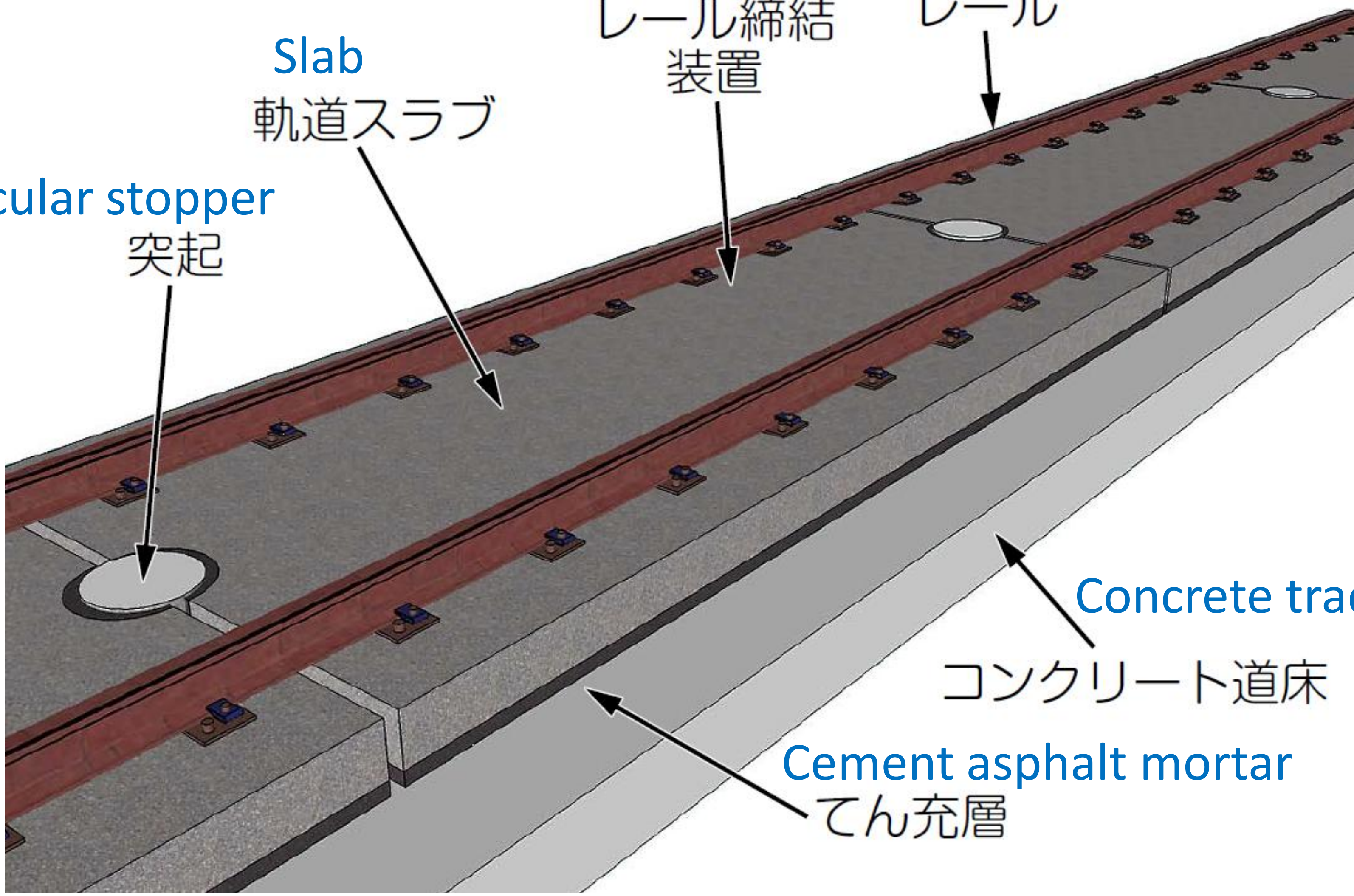


Subgrade	Thickness of crushed stone layer for high speed line
K_{30} = 70 MN/m^3	60 cm (Settlement)
K_{30} = 110 MN/m^3	40 cm (Fatigue life)

Contents

- Introduction
- Ballasted tracks in existing line
- Asphalt roadbed in design standard
- Slab track on earth structure

Slab track



Rail Fastener
レール締結
装置
Rail
レール
Slab
軌道スラブ
Circular stopper
突起
Concrete trackbed
コンクリート道床
Cement asphalt mortar
てん充層

History of slab track

Tokaido Shinkansen (1964):

Ballasted track on embankment

Bearing capacity of embankment was not very high. (using clay, compaction control etc)
Settlement of ballasted track became very large after the start of train operation.

http://www.jrtt.go.jp/02Business/Construction/const-seibi.html

Sanyo Shinkansen
Okayama-Hakata (1975):

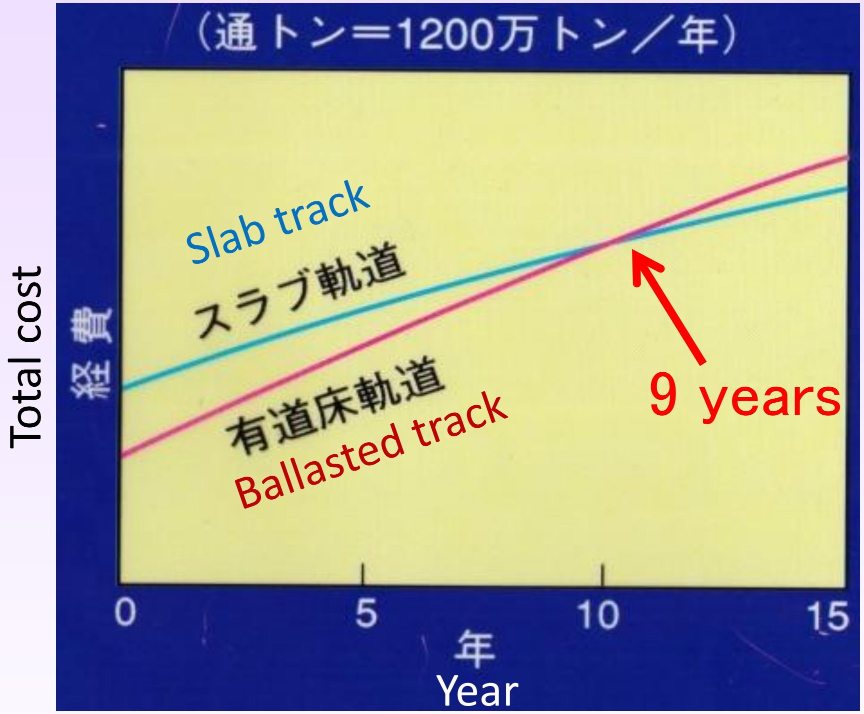
Slab track on viaduct.

Hokuriku Shinkansen
Takasaki-Nagano (1997):

Slab track on high quality embankment

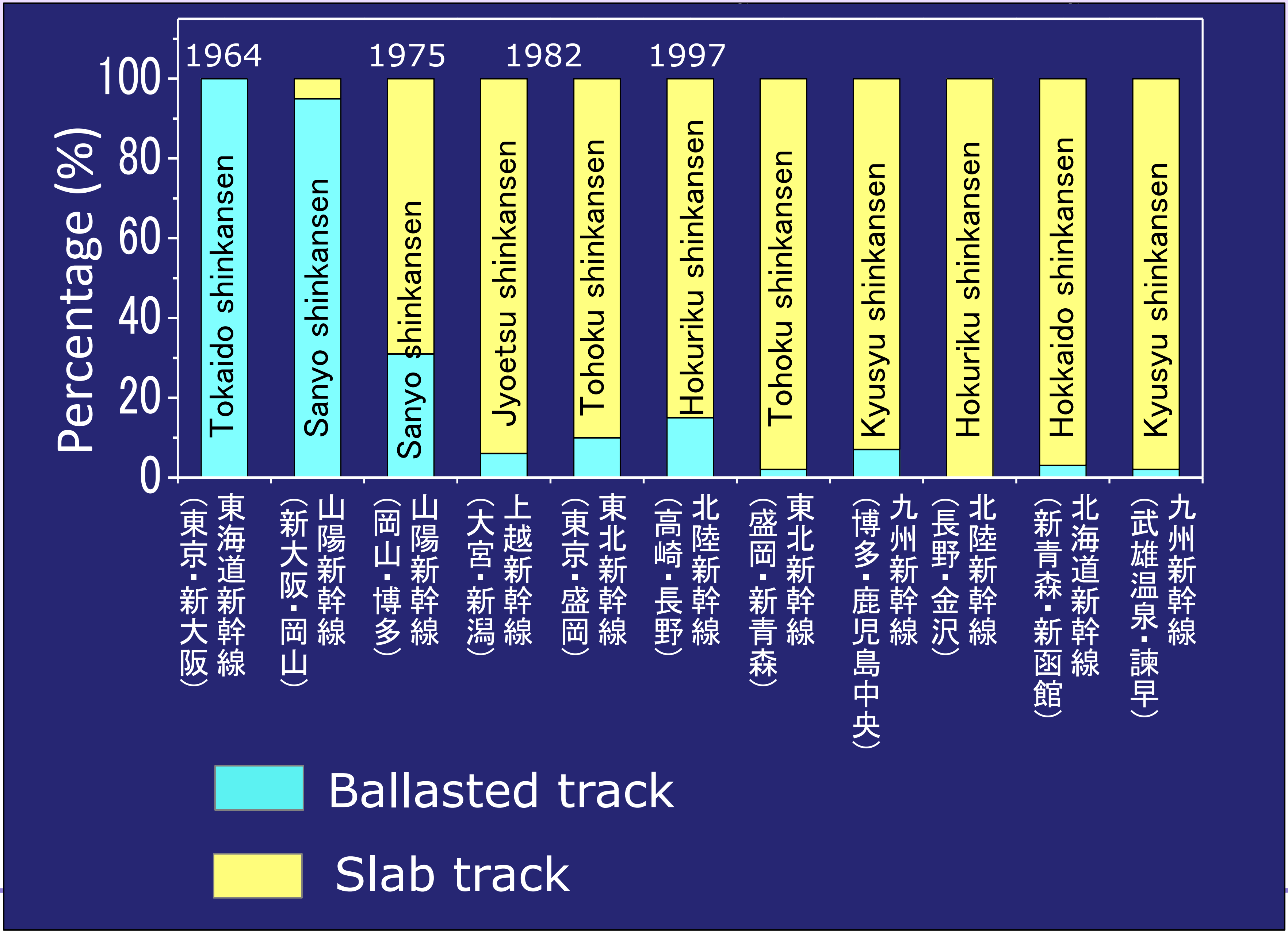
■ Cost of slab track

Annual tonnage 1.2 million ton / year



Life cycle cost of slab track is lower than that of ballasted track.

Percentage of slab track in Shinkansen



Slab track on earth structure

Required specification for subgrade

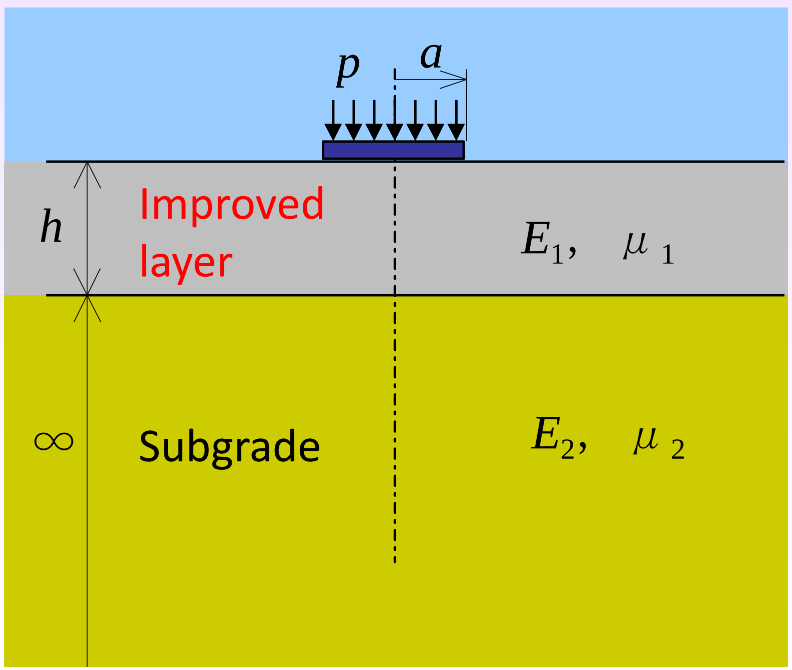
Stiffness: $K_{30} \geqq 110 MN/m^3$

Density: Higher than 95% of maximum dry density

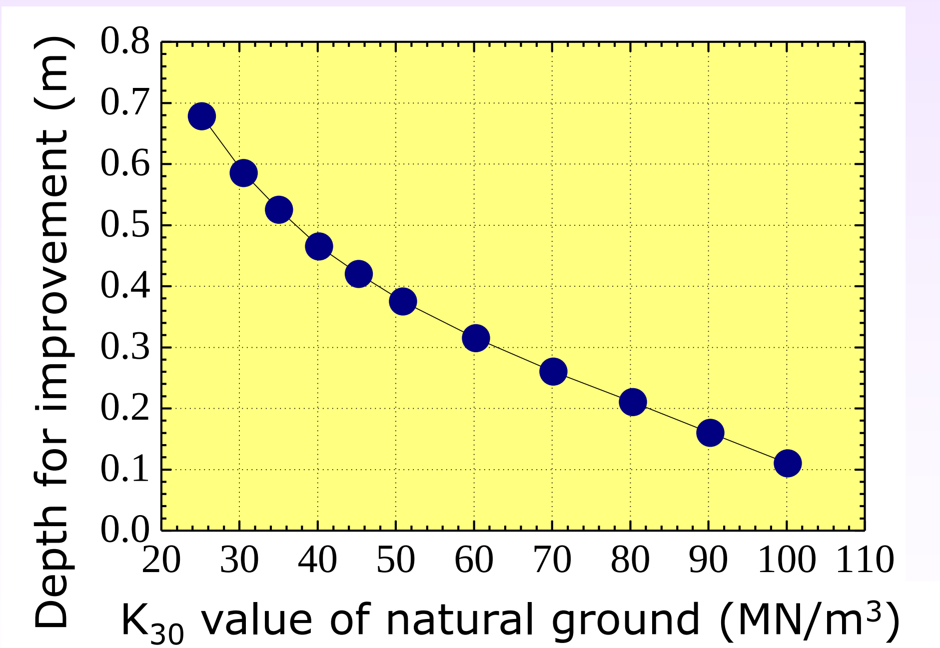
Material for embankment:
Gravel, Sandy gravel, Gravelly sand, sand

■ Subgrade improvement for slab track

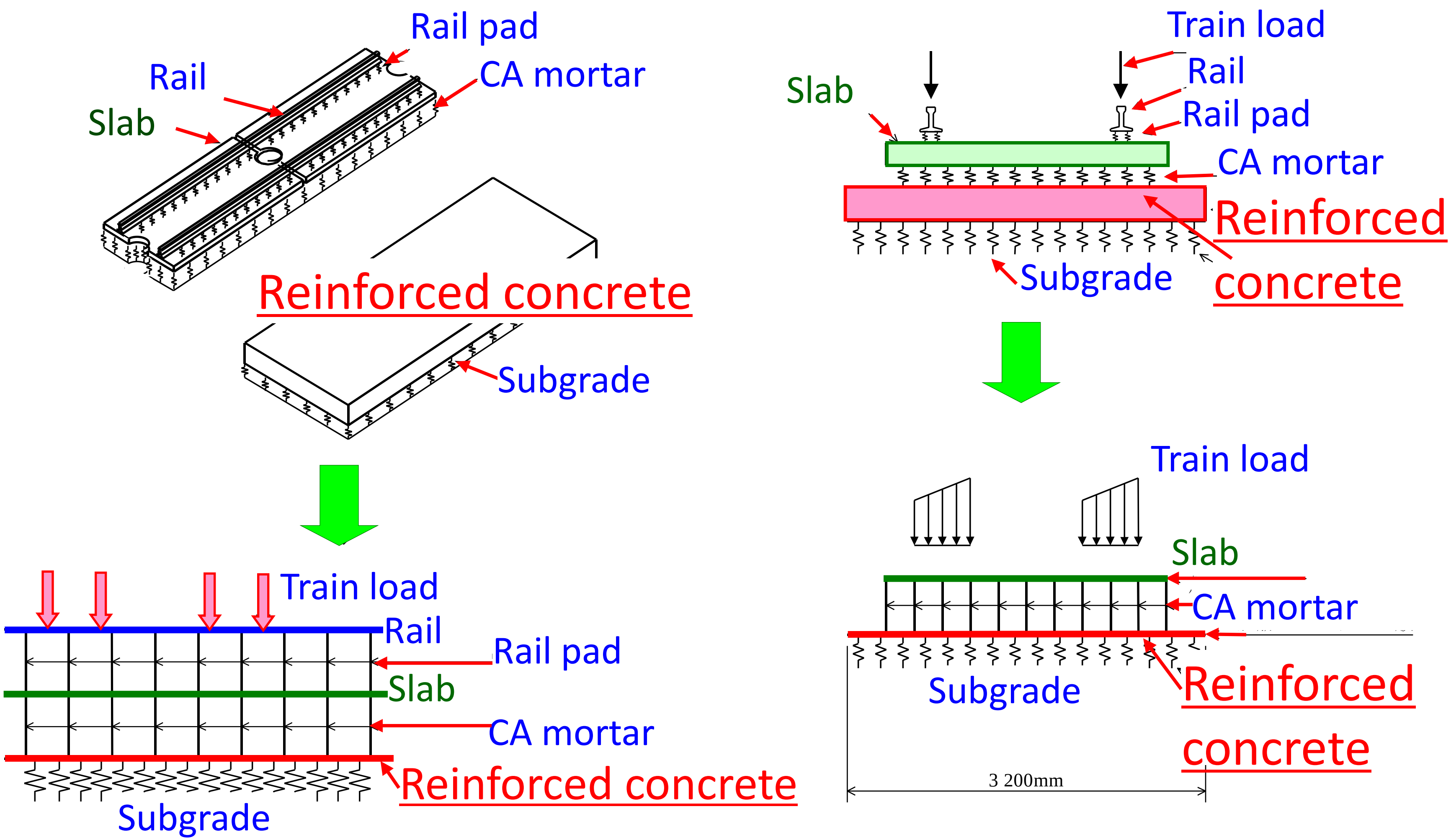
- Subgrade of natural ground should be improved to satisfy K_{30} value.



Multi-layered elastic analysis



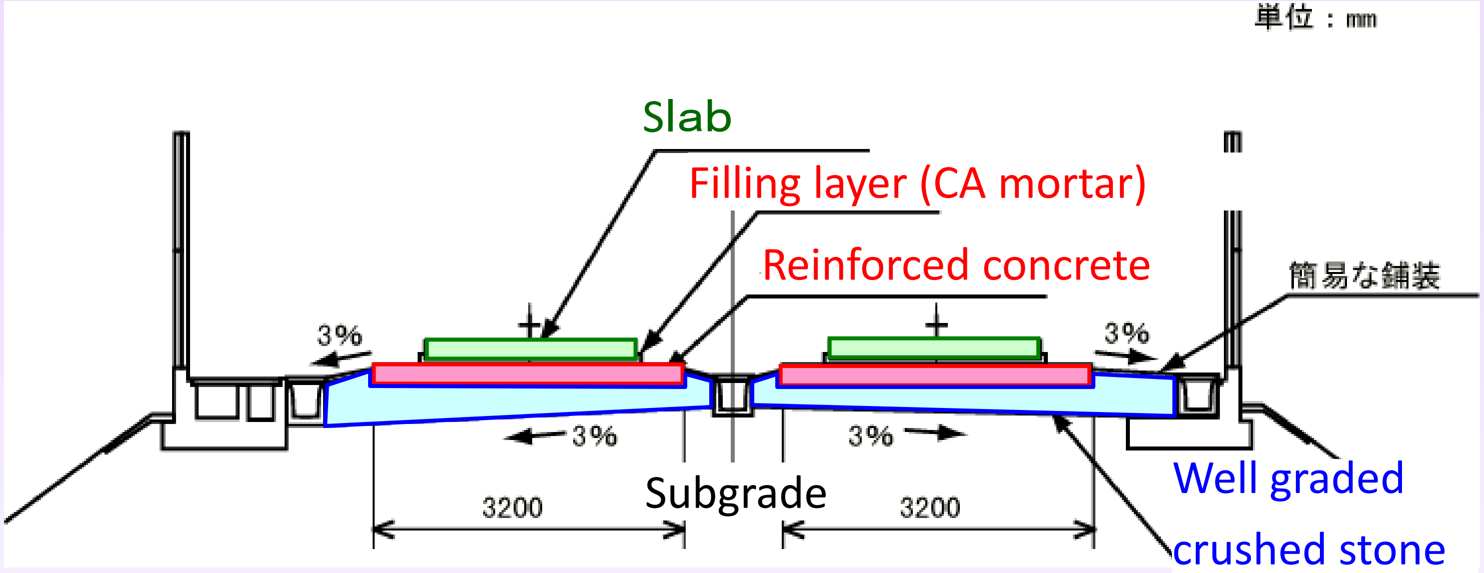
Numerical analysis for the design

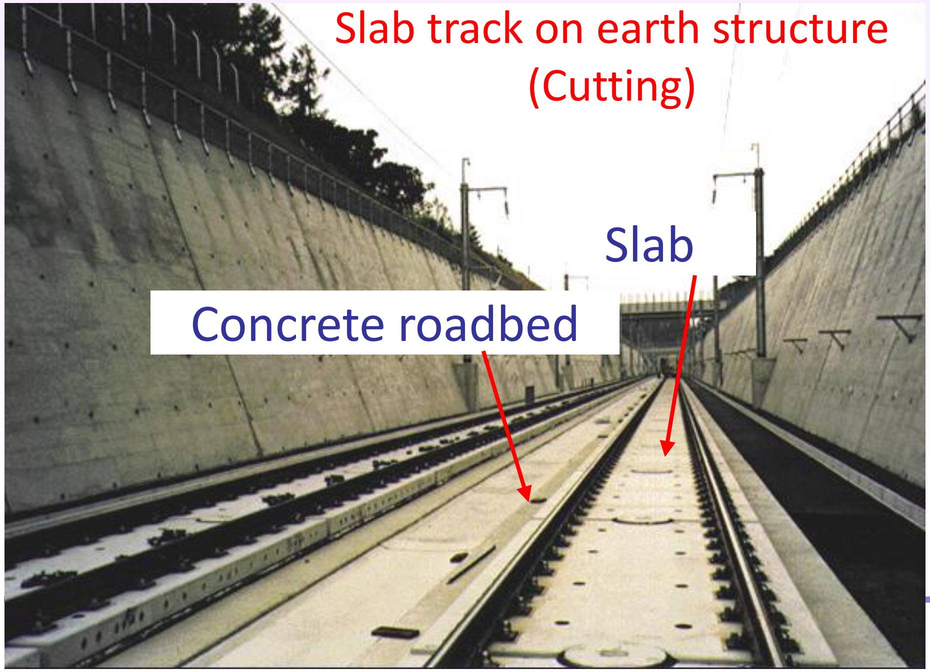


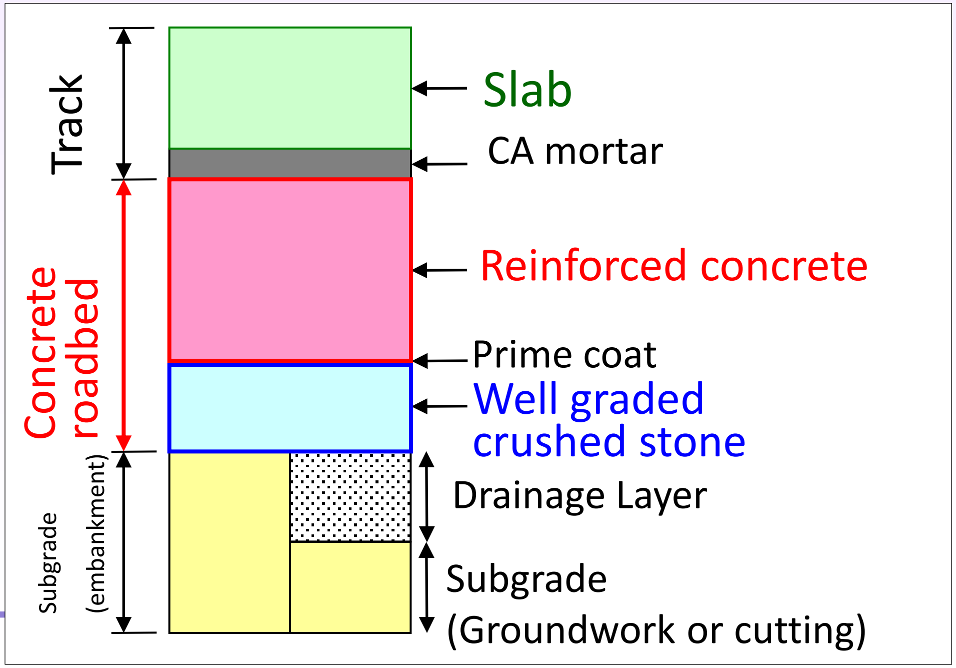
(a) Parallel to rail direction

(b) Perpendicular to rail direction

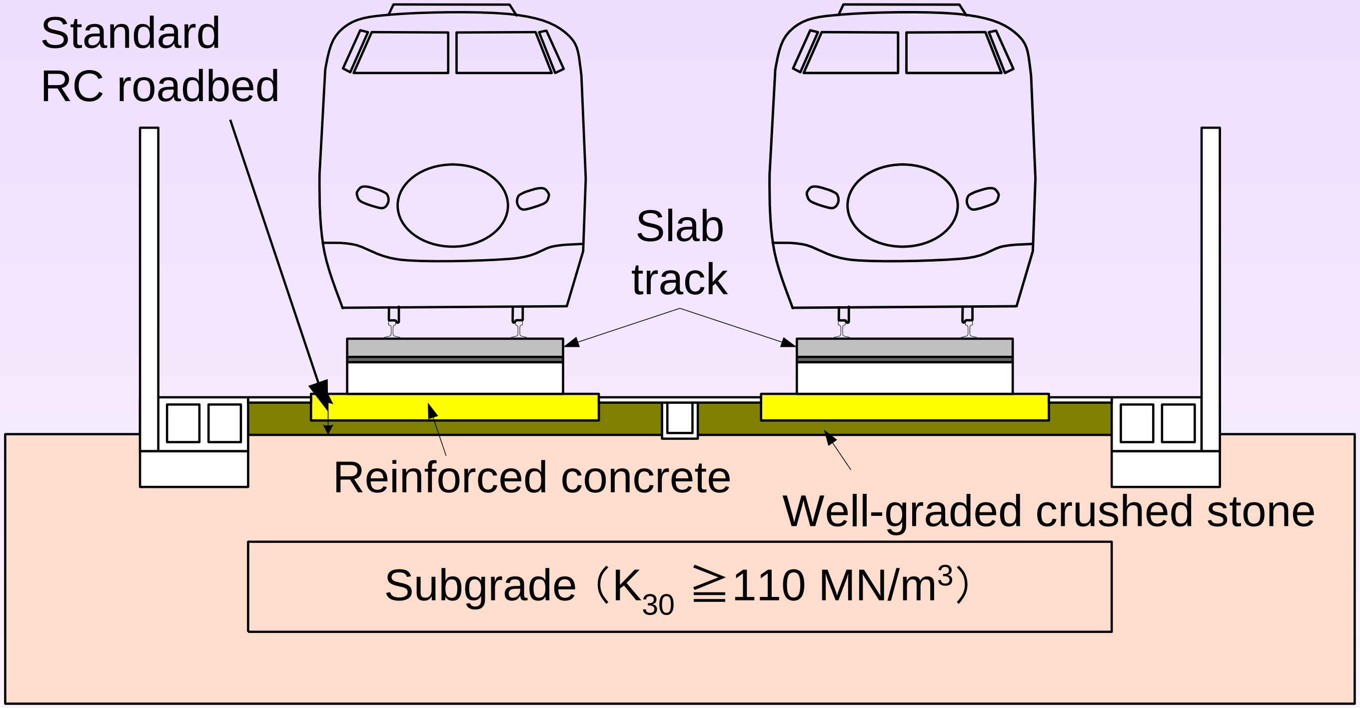
Cross section of slab track on earth structure





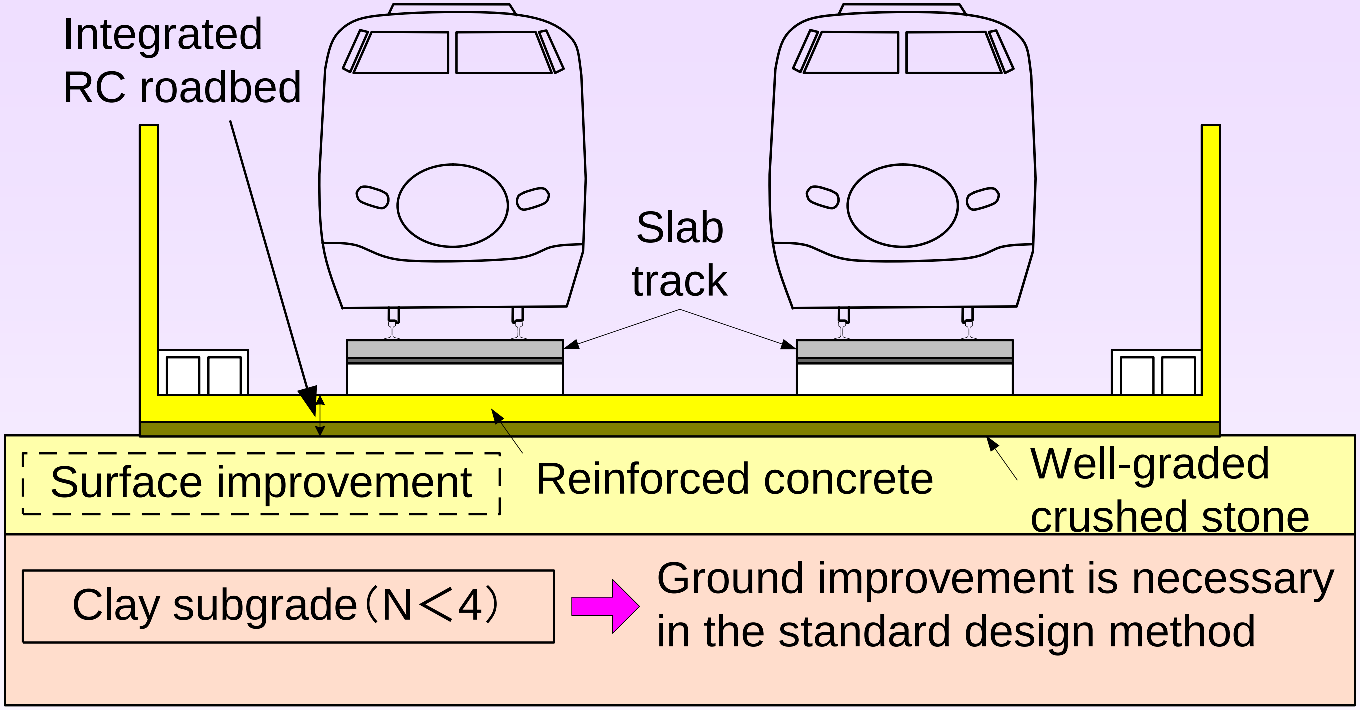


Subgrade with N value less than 4



- If N value of subgarad by SPT test is less than 4, ground improvement is required.

■ Integrated RC roadbed



- Investigation was carried out to apply integrated RC roadbed on soft diluvial clay subgrade.

Diluvial clay: Ageing effect, pre-loaded(cutting)

■ Ground investigation method

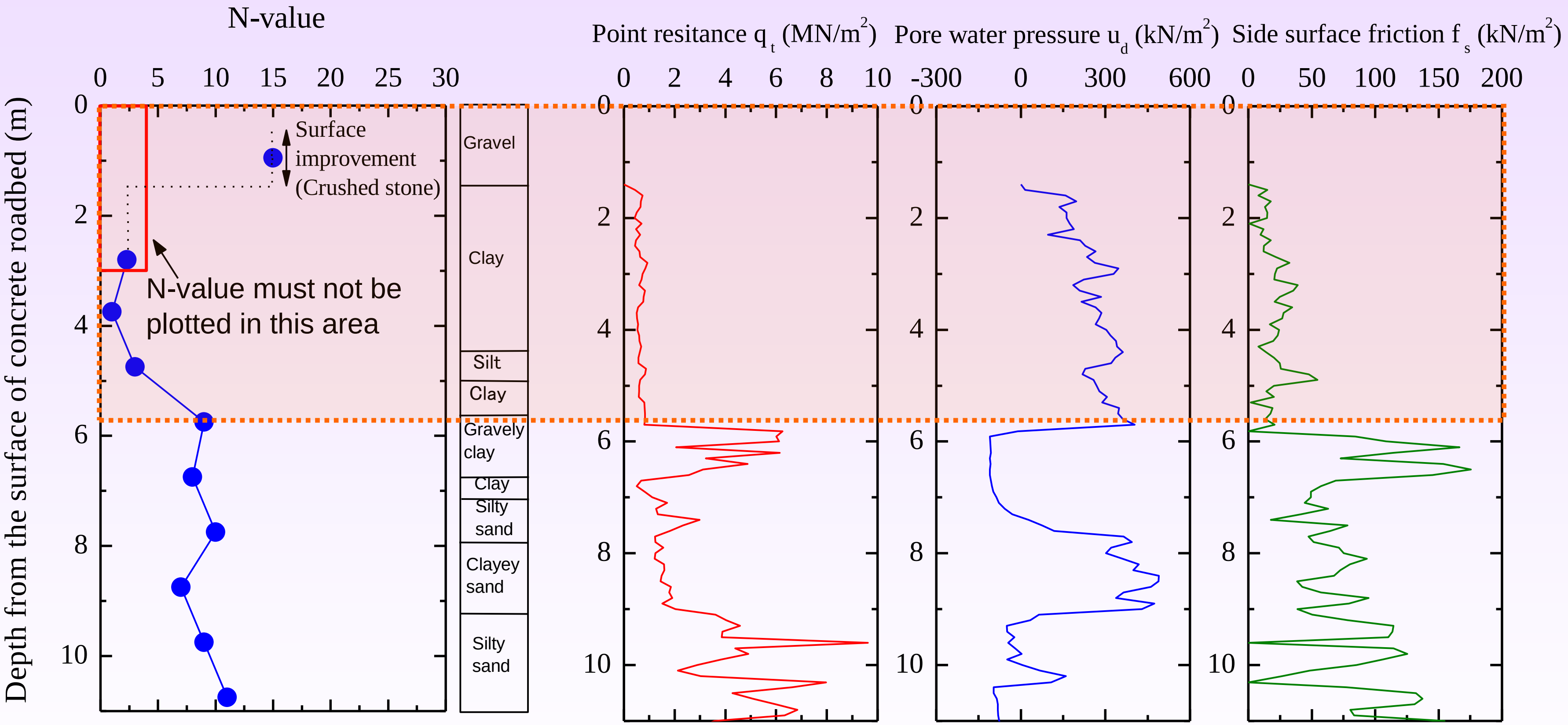
Standard penetration test

Electric cone penetration test

Ground investigation result

SPT

Electric cone penetration test



N value

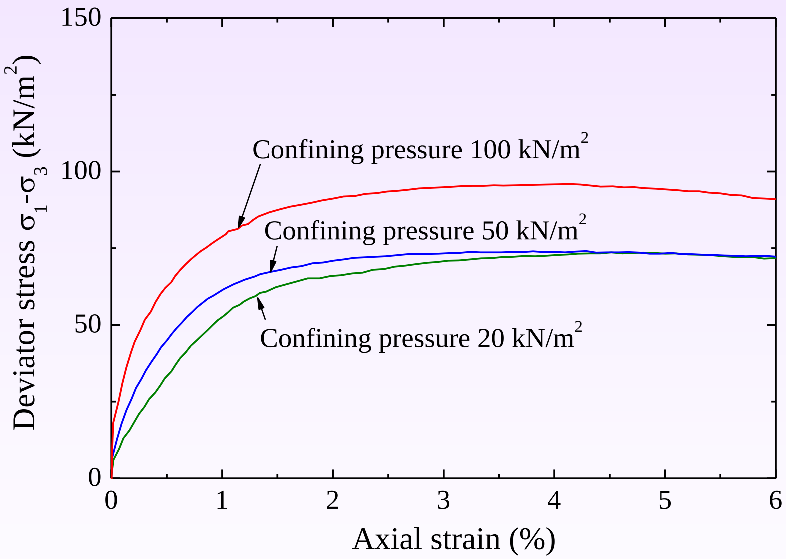
Point resistance

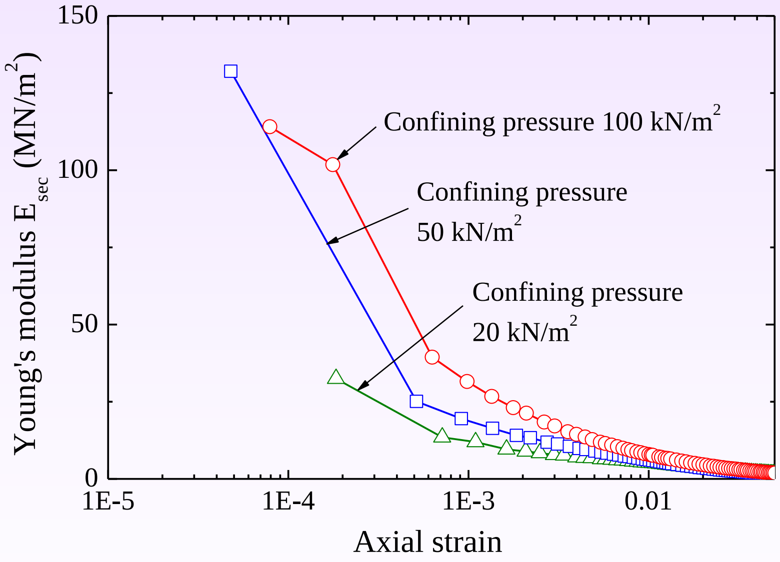
Pore water pressure

Side friction

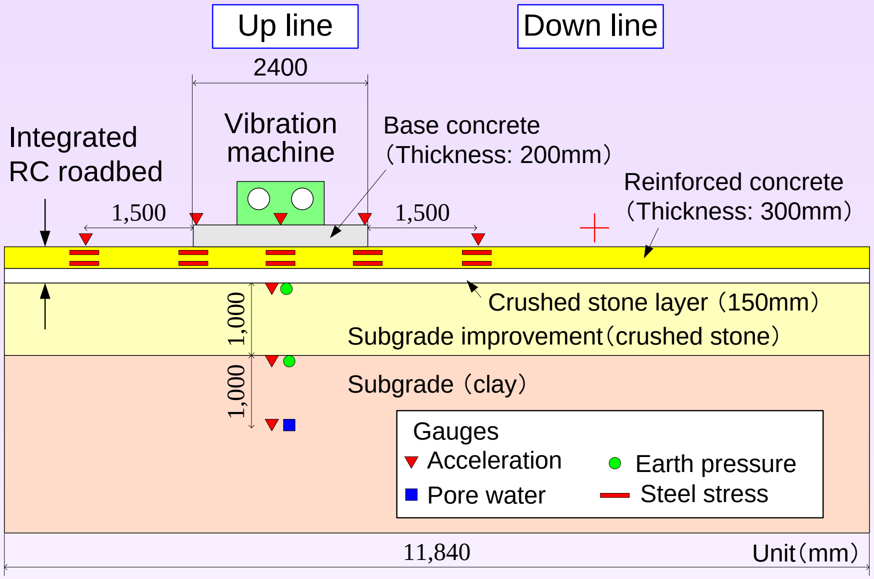
Railway Technical Research Institute

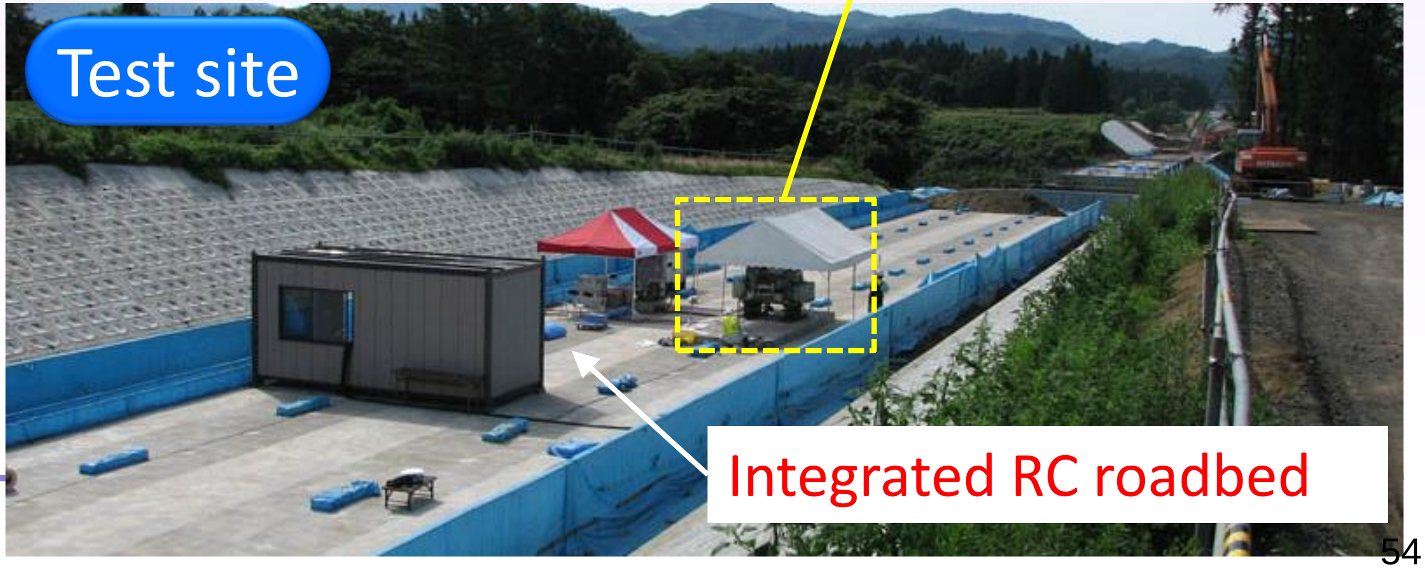
Triaxial test





In-situ cyclic loading test



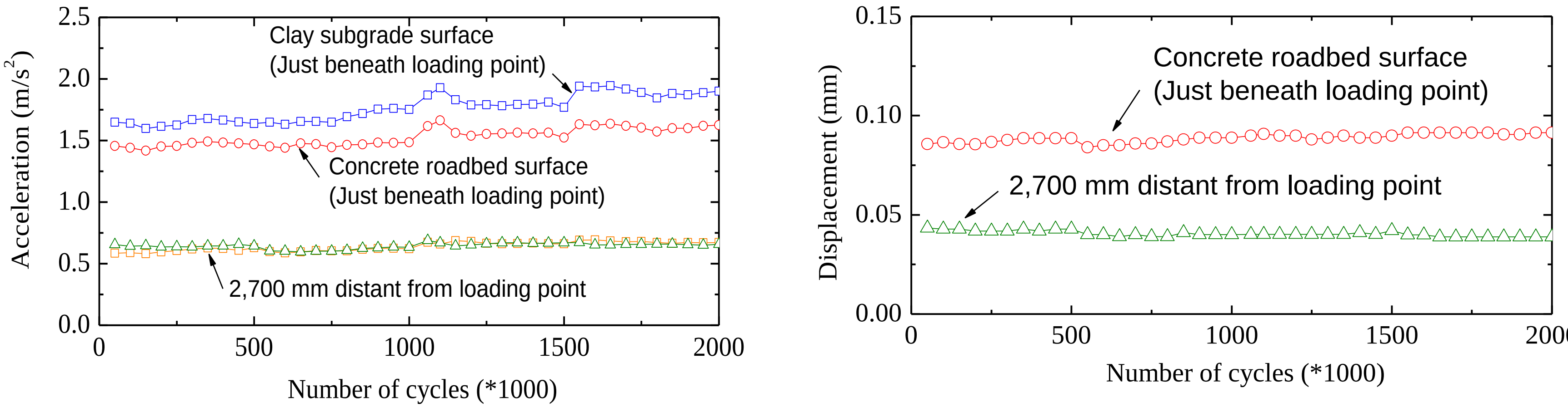


■ Loading test results

120kN, 20Hz, 2x10[6] times loading

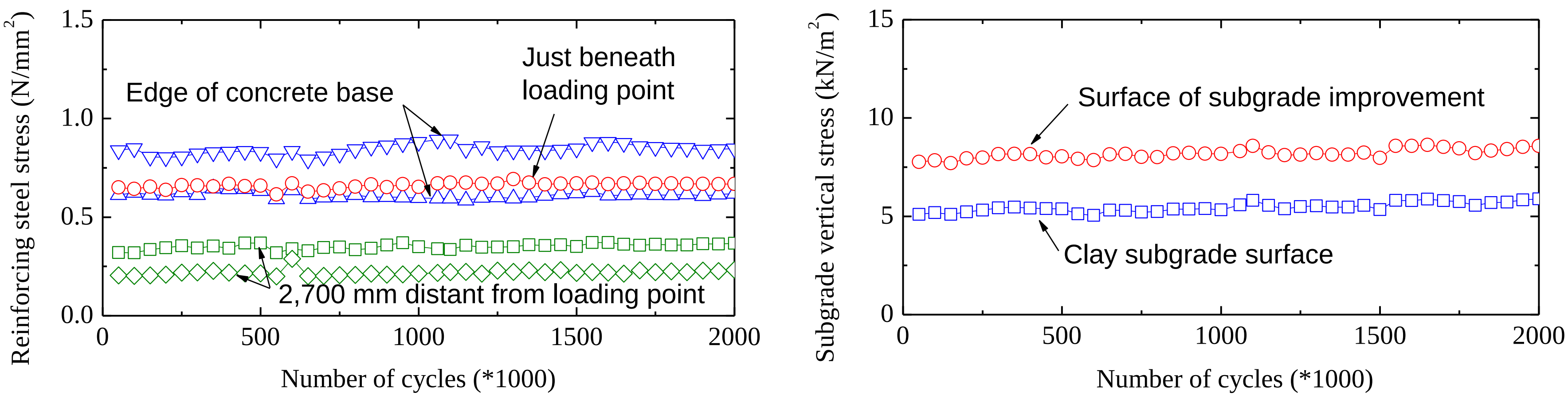
Acceleration

Displacement

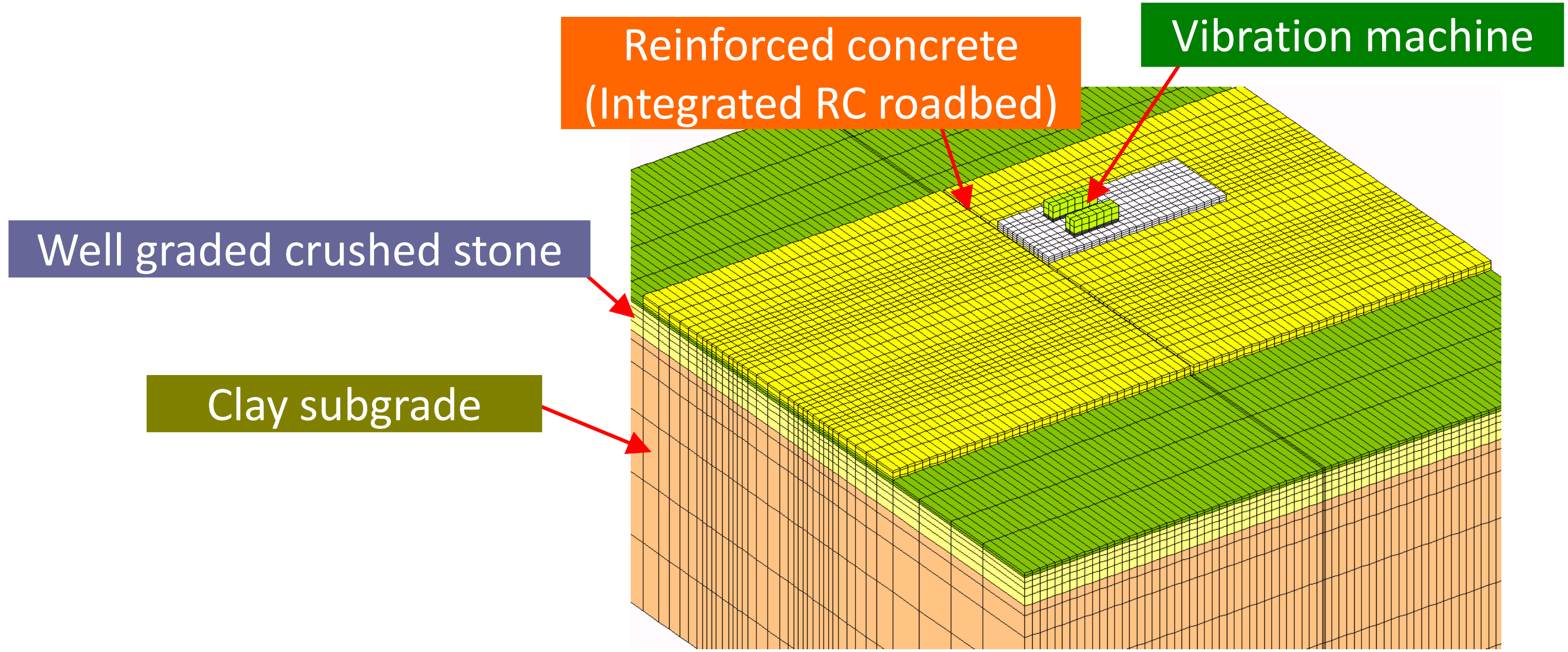


Reinforcing steel stress

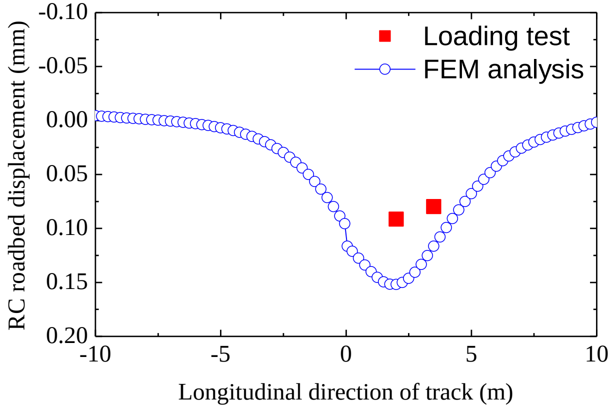
Subgrade vertical stress



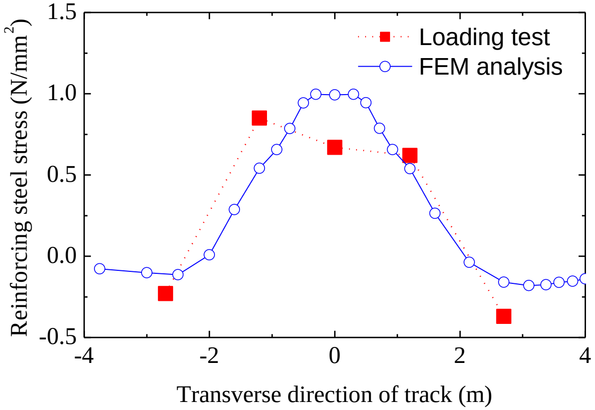
FEM to simulate the loading test



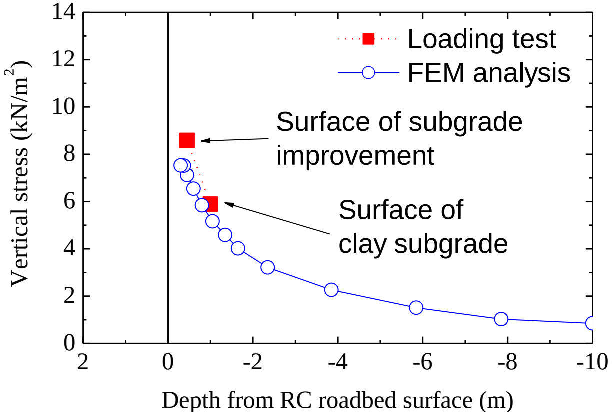
Displacement



Reinforcing steel stress

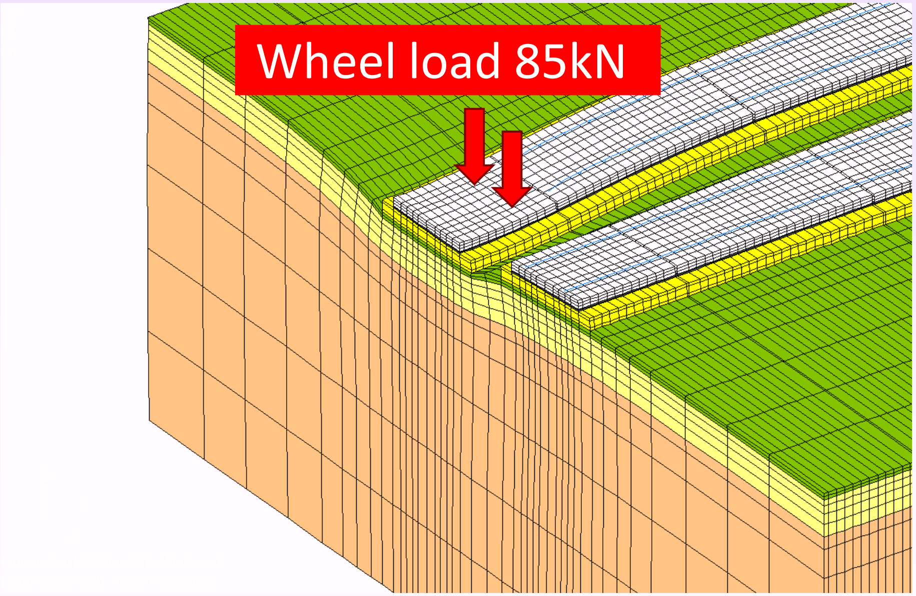


Vertical stress

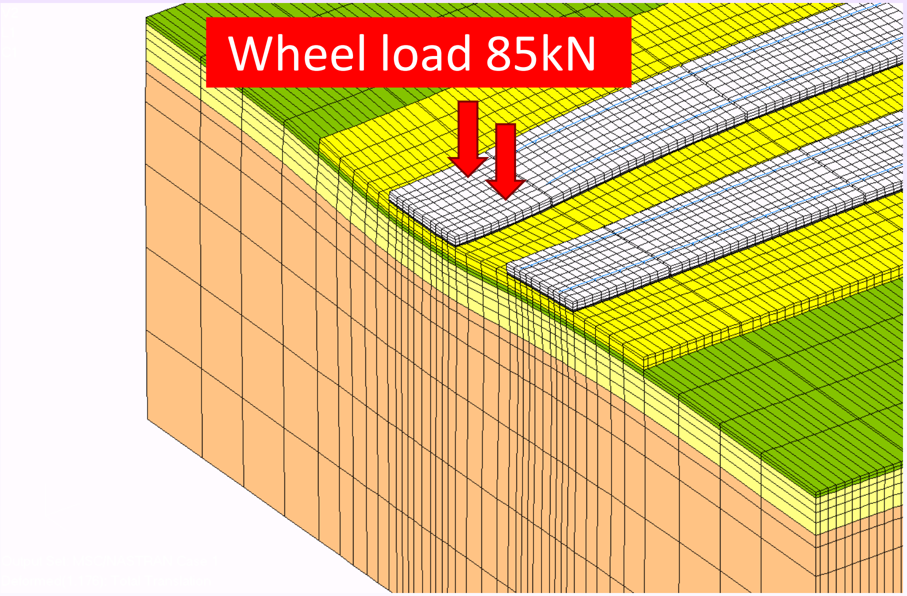


Deformation of RC roadbed

Standard RC roadbed



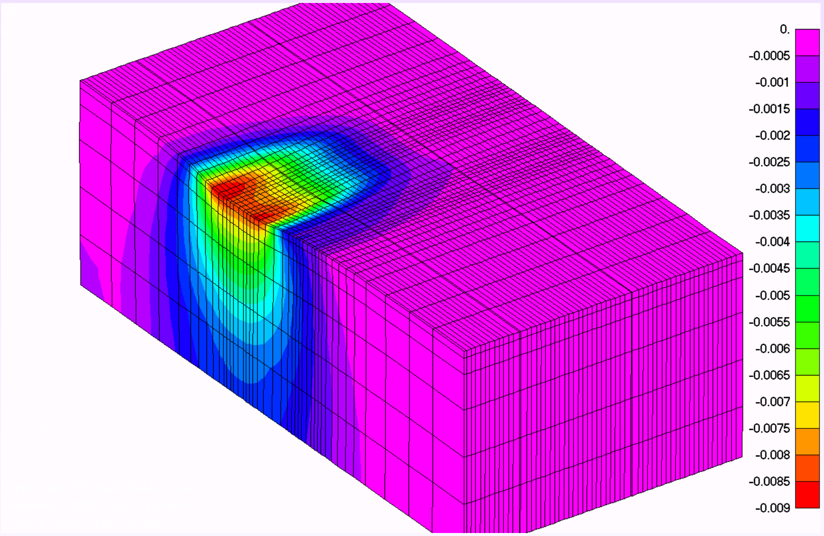
Integrated RC roadbed

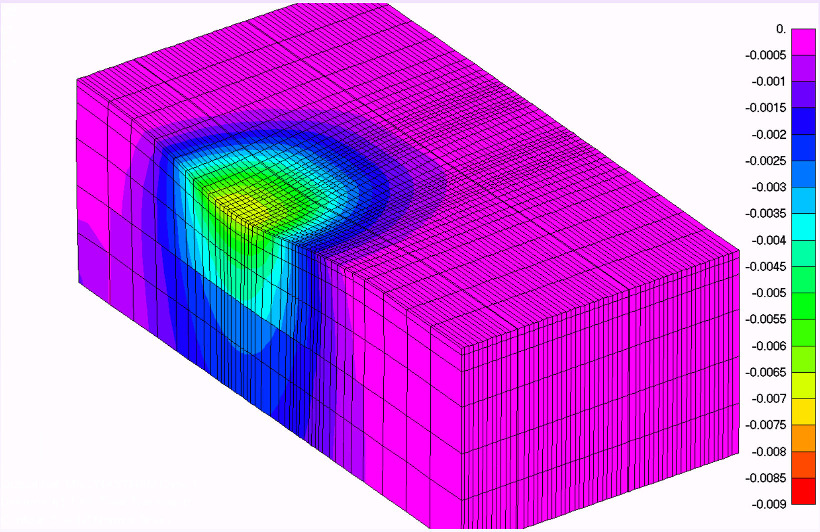


- Integrated RC roadbed distributes train load widely.

Vertical stress on subgrade

Standard RC roadbed	Integrated RC roadbed





- Integrated RC roadbed reduces stress applied on subgrade.

Comparison between Standard RC roadbed and integrated RC roadbed

	Integrated RC roadbed	Standard RC roadbed	Integrated / Standard
Vertical displacement	0.60 mm	0.71 mm	0.85
Reinforcing steel stress	2.08 MN/m^2	2.33 MN/m^2	0.89
Subgrade surface stress	10.5kN/m^2	28.6 kN/m^2	0.37
Clay subgrade surface stress	6.89 kN/m^2	9.02 kN/m^2	0.76

Summary

- Bearing capacity of roadbed and subgrade is important factor to reduce the maintenance work of ballasted track.
- To reduce the settlement of ballasted track at transition zone is an important issue.
- Asphalt roadbed is widely applied to ballasted track.
- Slab track is widely constructed on the earth structure in these 20 years.
- Integrated RC roadbed is a new method to apply slab track on relatively soft subgrade, such as aged diluvial clay.