Rail Fastening Systems and Buckling of Continuous Welded Rails

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Today's topics

1. Rail fastening systems

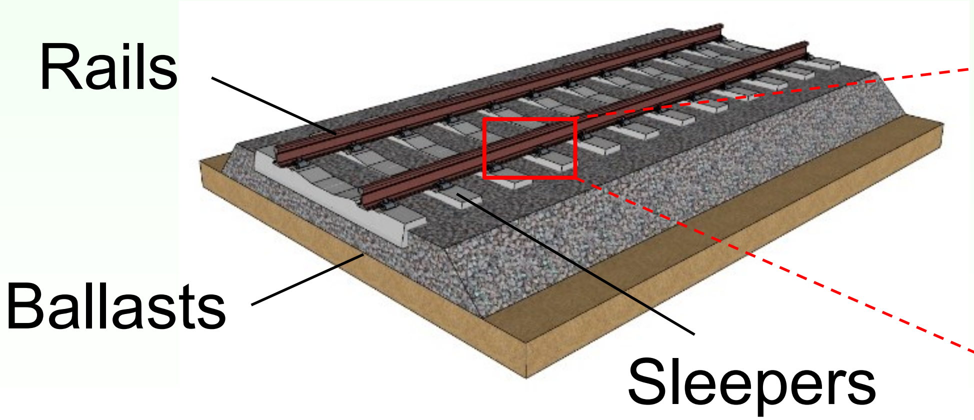
2. Buckling of continuous welded rails

1. Rail fastening systems

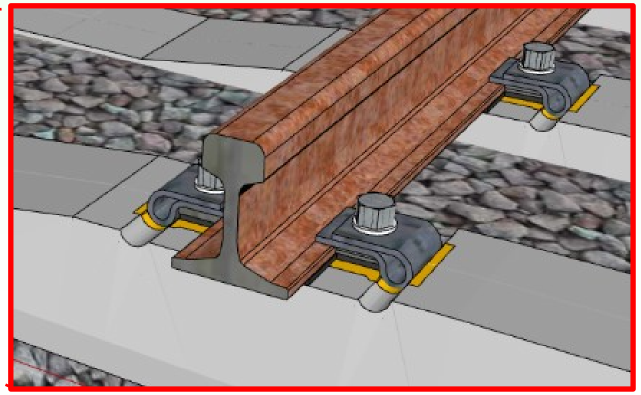
What are rail fastening systems?

Rail fastening systems are the devices

- used to fasten two rails to sleepers.
- that keep the gauge (distance between rails).
- that resist various loads and vibrations from the trains, and transfer them to the supporting structures.

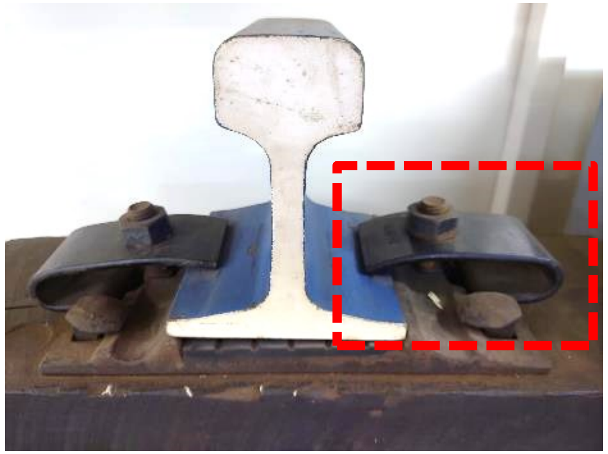


Rail fastening systems

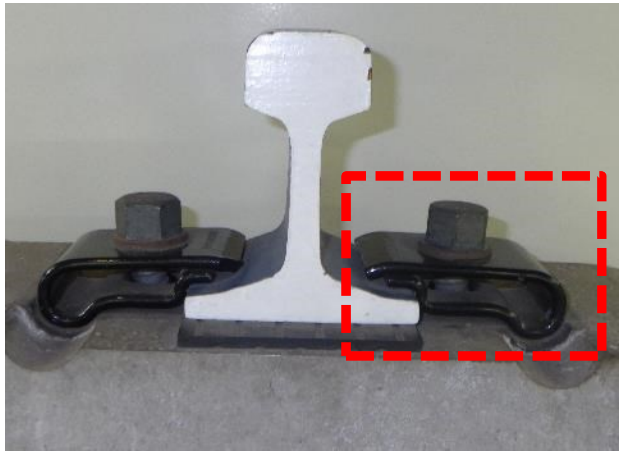


Major rail fastenings (Domestically developed in Japan)

Ballasted tracks

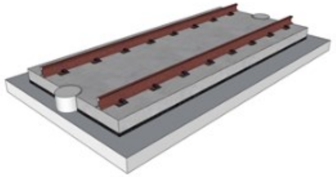


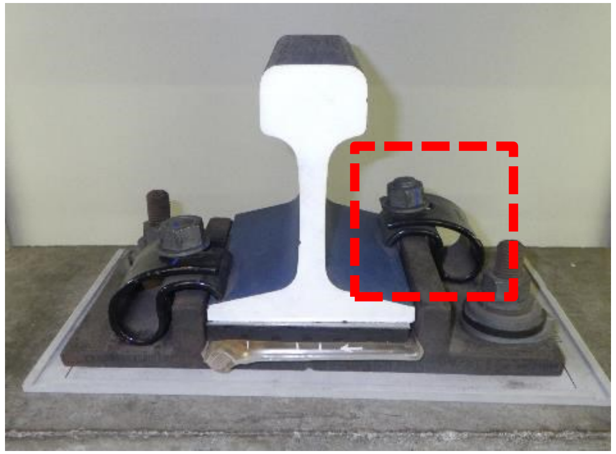
Wooden sleepers
(Type F)



PC sleepers
(Type 5N)

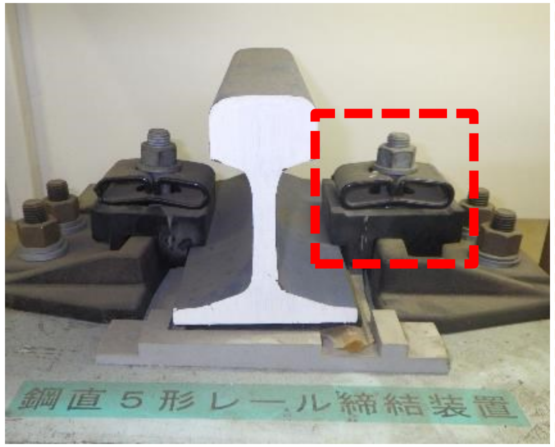
Slab tracks





Slabs
(Type 8 for slab)

Tracks on Steel bridges

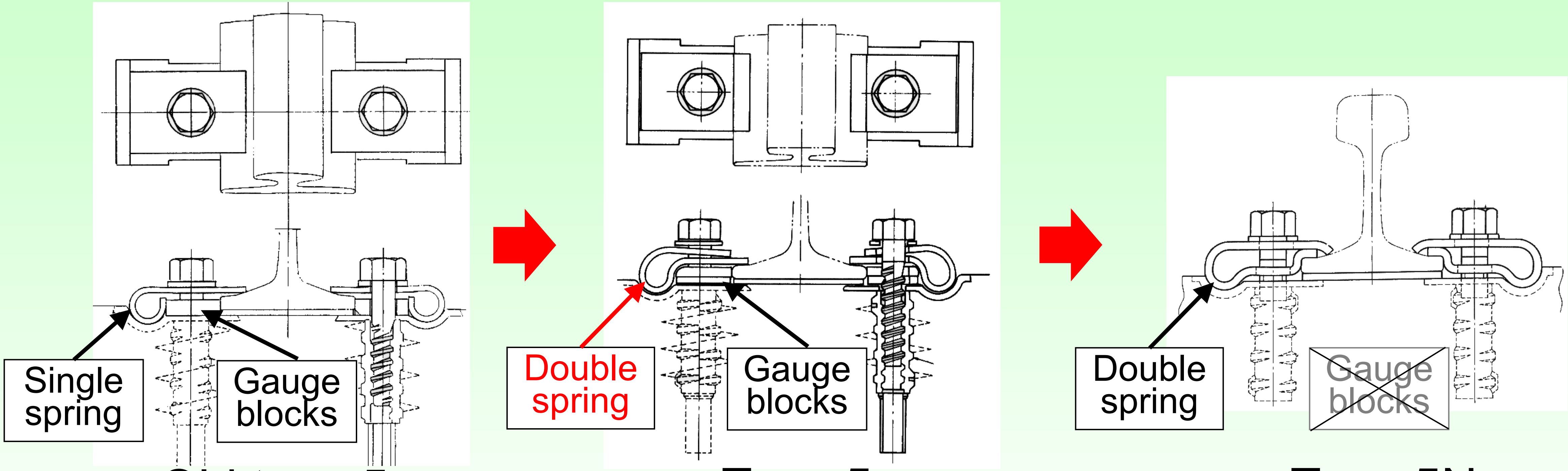


Steel bridges
(Type 5 for bridge)

In domestic products, it is common to use plate spring-type rail clips for rail fastenings.

Transition of plate spring-type rail fastenings

※Using the type 5 as an example



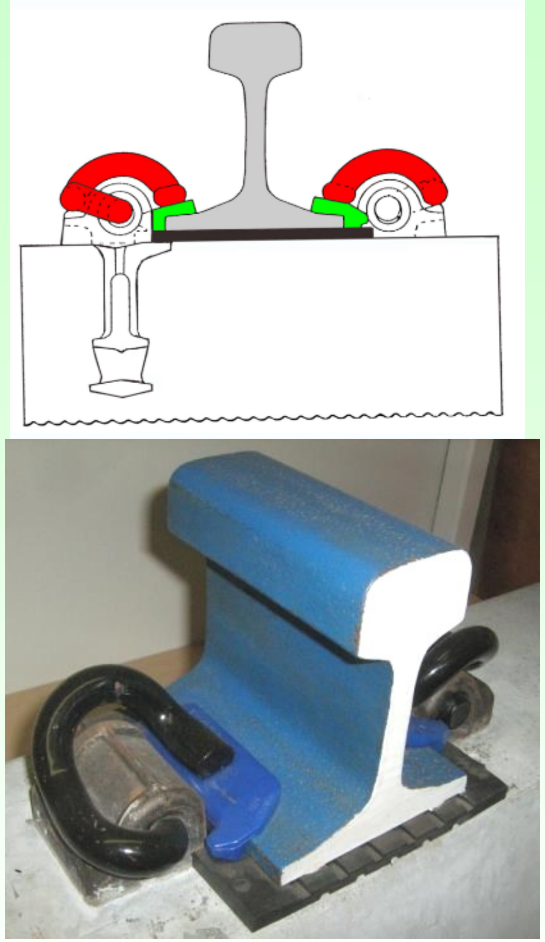
Old type 5 | Type 5 | Type 5N

Strengthen plate spring (Double springing)

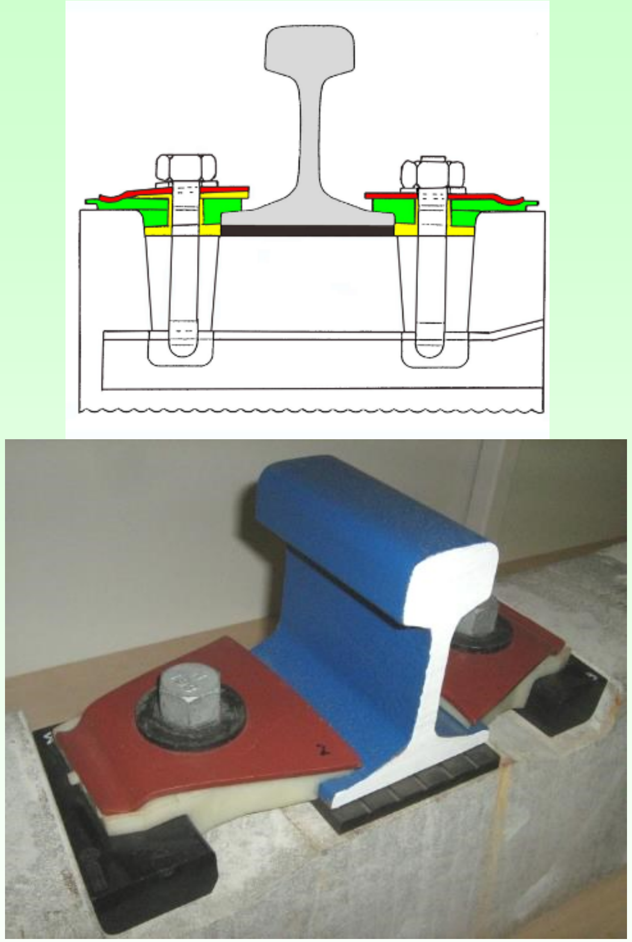
Simplification of components

After multiple improvements, it has evolved into its current form.

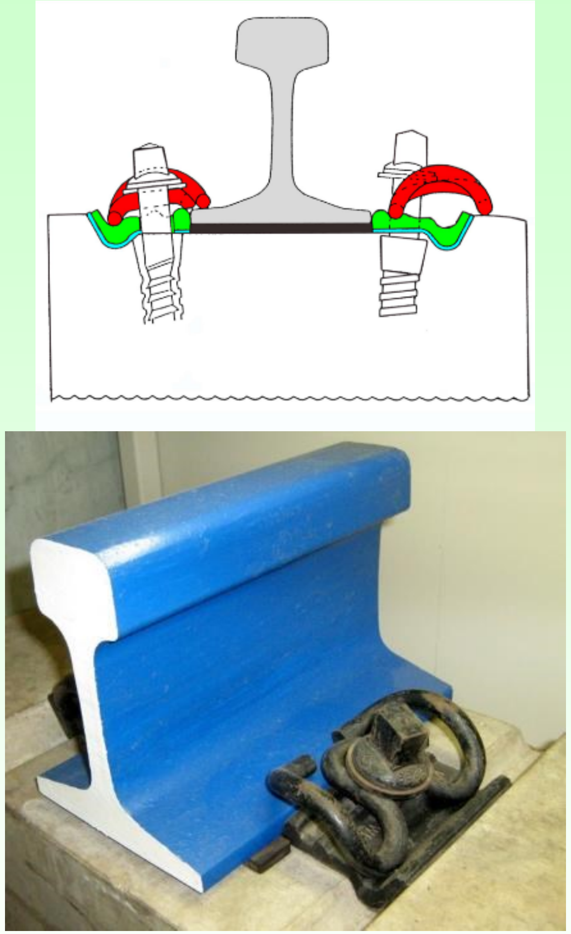
Major rail fastenings (Developed outside of Japan)



Pandrol



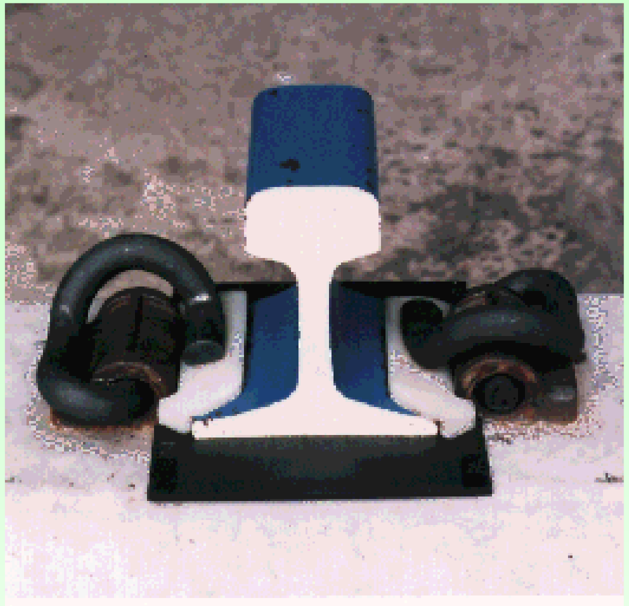
Nabla

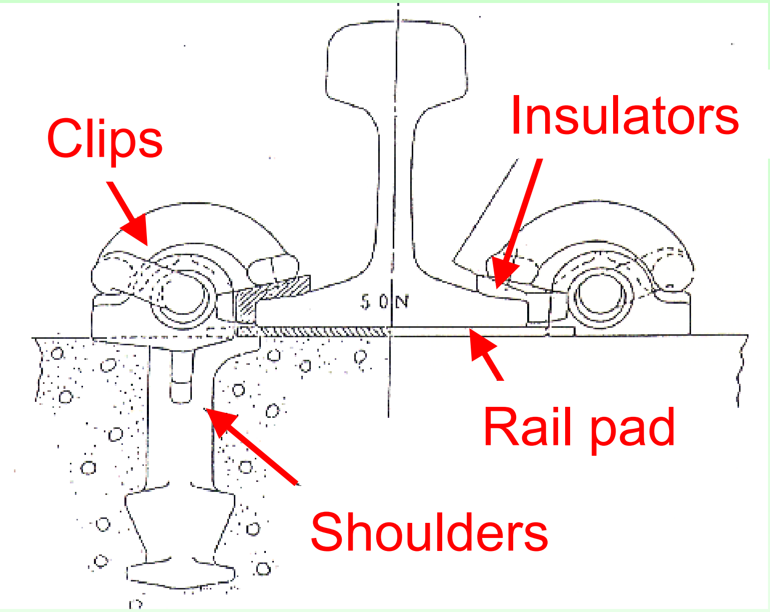


Vossloh

For decades, rail fastenings developed outside of Japan have been widely used in Japan.

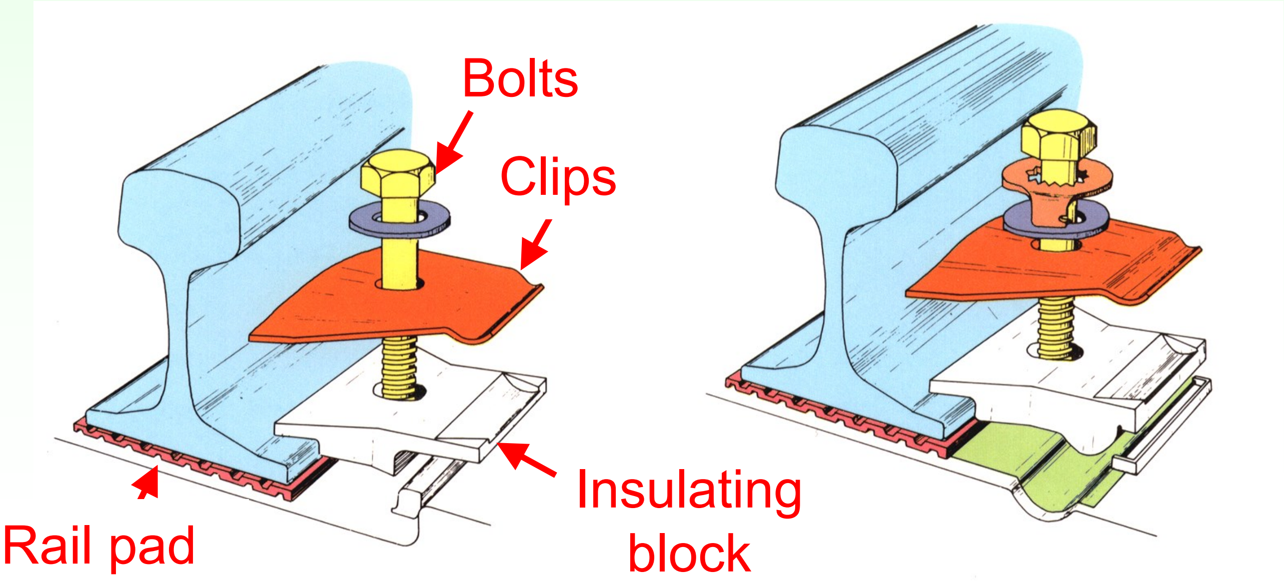
Pandrol





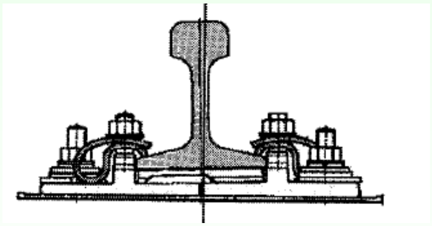
- Developed by Pandrol, UK
- Introduced to Japan in the 1990s
- Using bar-type rail clip
- Clip stands out for not loosening

Nabla



- Developed in France for TGV use
- Using plate-type rail clips and insulating block
- High tightening torque and less bolt loosening
- High electrical insulation

An example of classification for rail fastenings

Lateral loads supports	Wooden sleeper	PC sleeper	Slab	Steel bridge
Others				
Resin				
Double spring				
Base plate				

Rail supports

There are more than 100 types in use within Japan !

Why are there so many types of rail fastenings ?

This is because

- they are developed in response to the transition of track structures.

Combinations

- Rails: 30kg, 37kg, 40kgN, 50kgN, 60kg
- Supporters: Wooden or PC sleepers, Slabs, Steel bridges
- Line: High-speed line(Shinkansen), Conventional line
- Alignment: Sharp curve, Gentle curve, Straight
- Others: Rail joints (EJ, IJ), Level crossings, etc.

- different functions are required for them depending on track structures.

Required functions of rail fastenings

① **Fixing the rails to the support structures**

② **Buffering impact forces transmitted from the rails**

③ **Dispersing loads transmitted from the vehicle to the rails**

④ **Resisting horizontal forces transmitted from the rails**

⑤ **Resisting rail inclination**

⑥ **Resisting horizontal plate rotation of the rails**

⑦ **Resisting rail creep**

⇨ This function is completely different between ballasted track and slab track.

⑧ **Allowing vertical and lateral adjustment of the rails**

⑨ **Electrically insulating between the rail and the support structure**

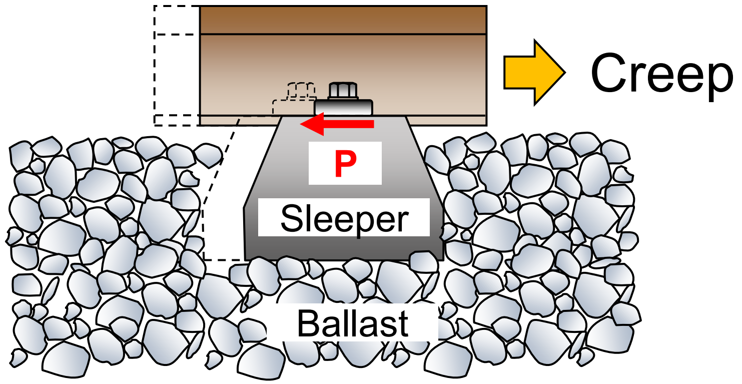
⑩ **Capable of mass production and cost-effective**

⑪ **Reducing vibrations transmitted from the rail to the support structure**

Differences in creep resistances of rail fastenings between ballasted tracks and slab tracks

Ballasted tracks

Rail creeps with sleepers



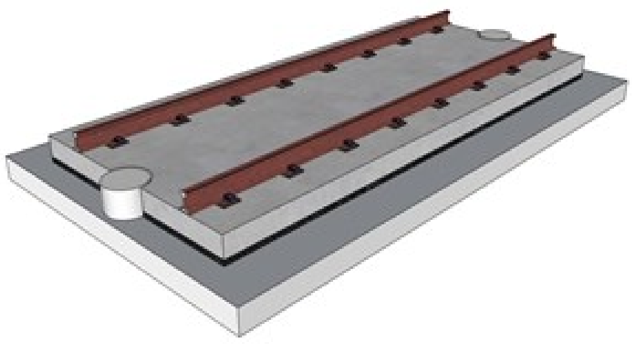
【Creep resistance P】

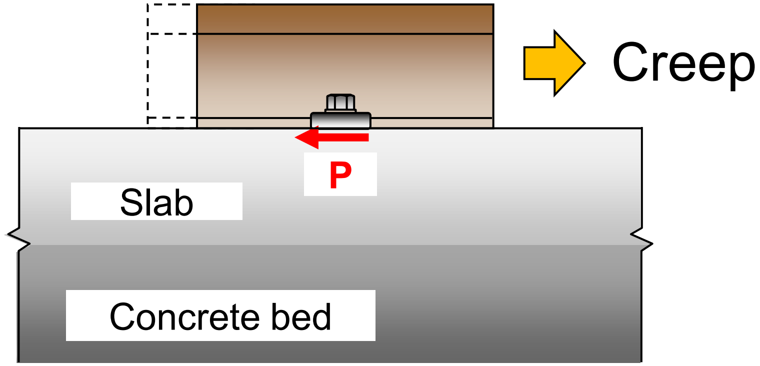
- Greater than longitudinal ballast resistance

P is about 15 kN/m

Slab tracks

Rail creeps on slabs



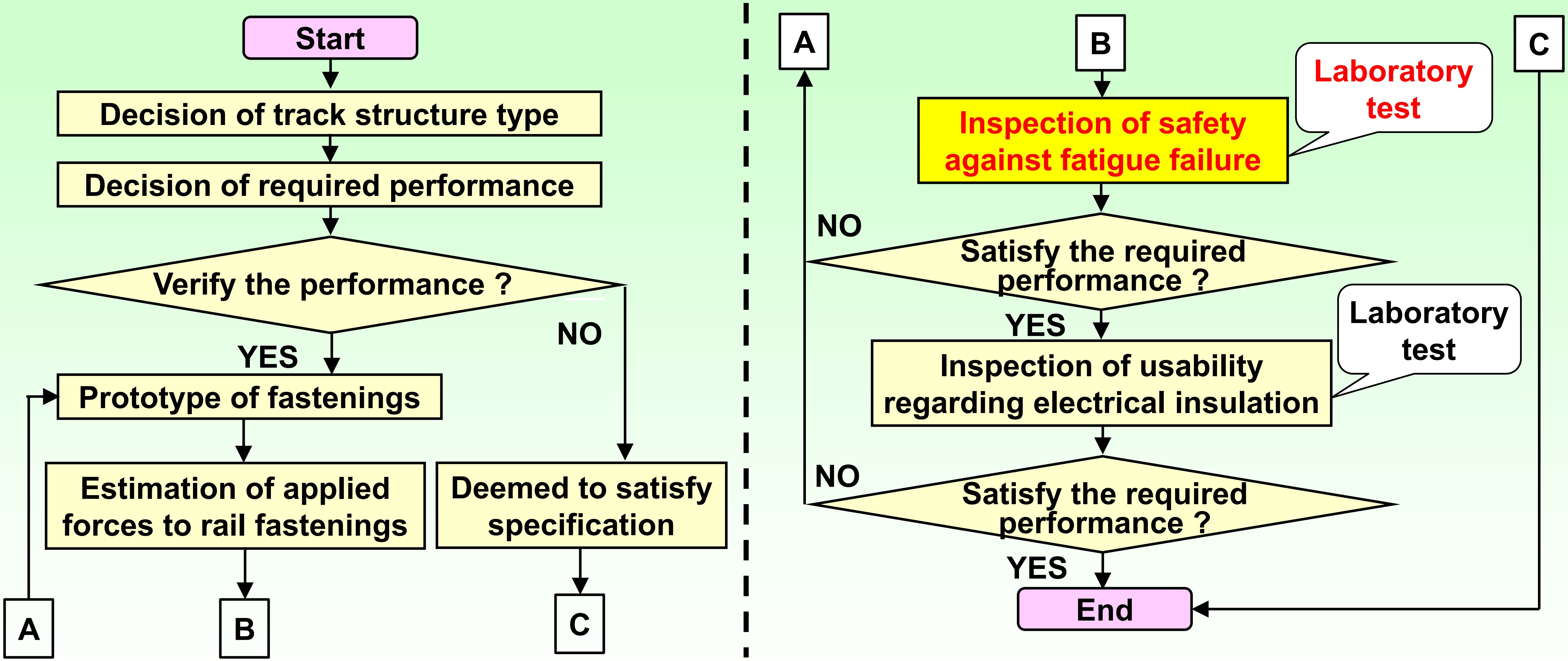


【Creep resistance P】

- Reducing the forces transmitted to the support structures

P is about 5 kN/m

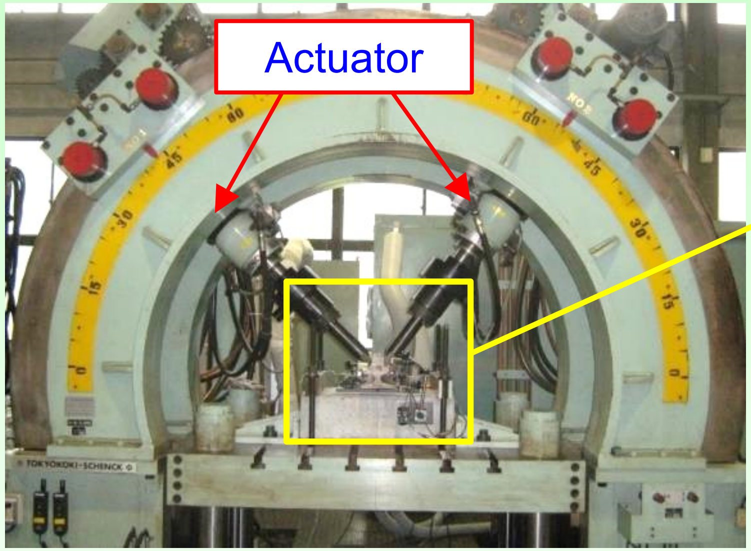
Basic flow of design for rail fastening systems



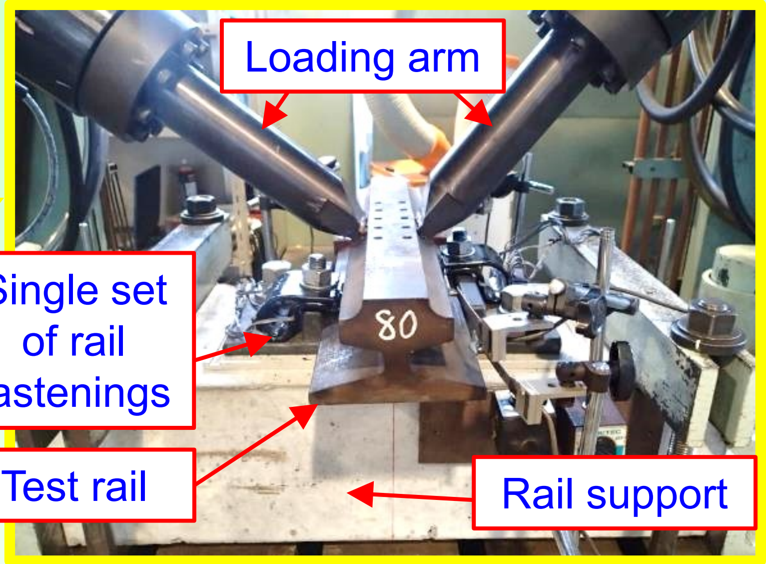
The Japanese design standard for railway structures requires the safety to be verified by the laboratory test.

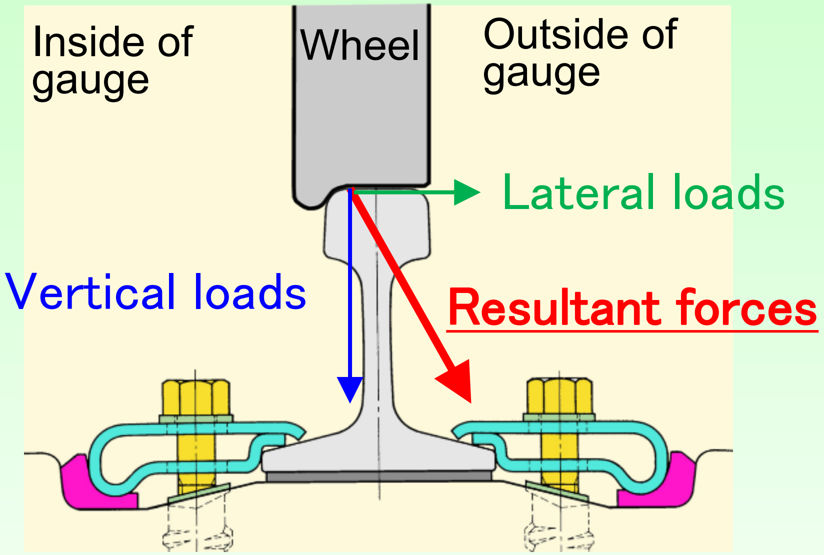
Laboratory test to inspect the safety against fatigue failure

Two directional load test



Inside of gauge　Outside of gauge



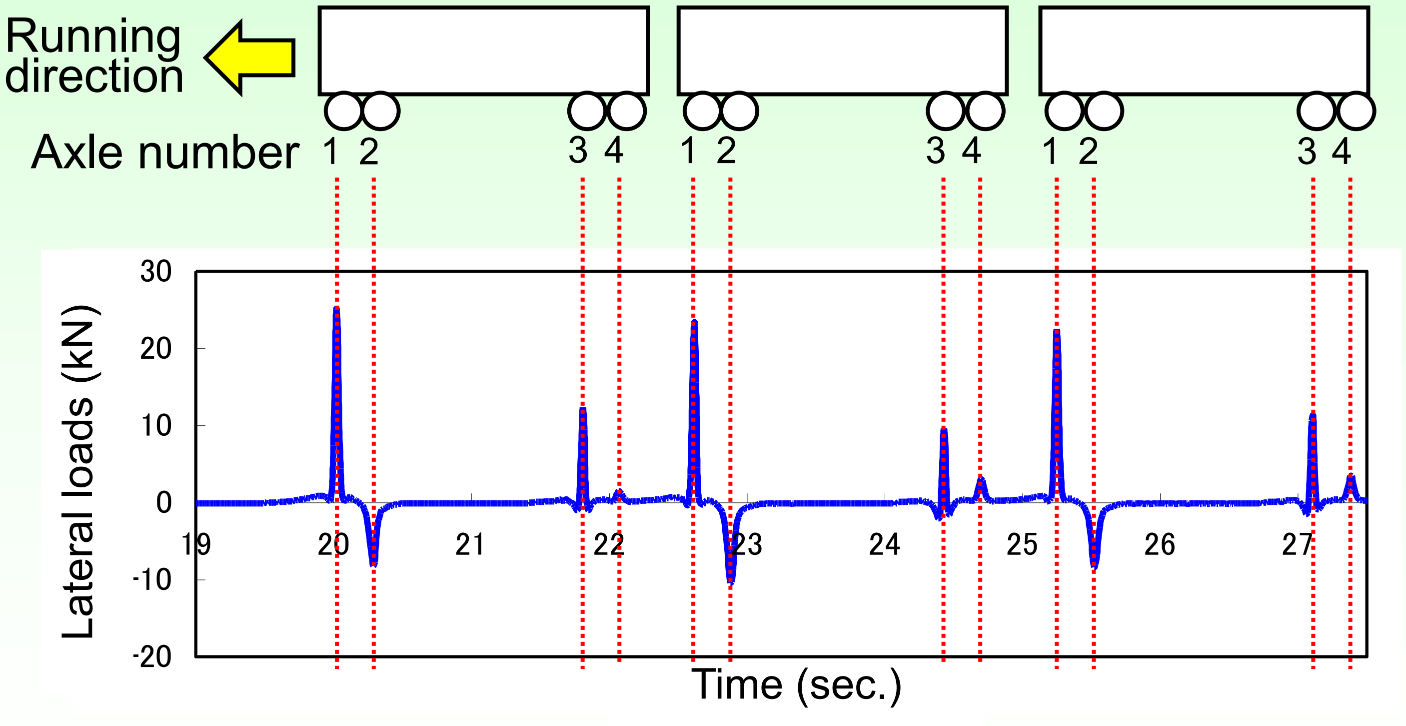


Resultant forces of vertical and lateral loads are alternately applied to the test rail from inside and outside directions of the gauge.

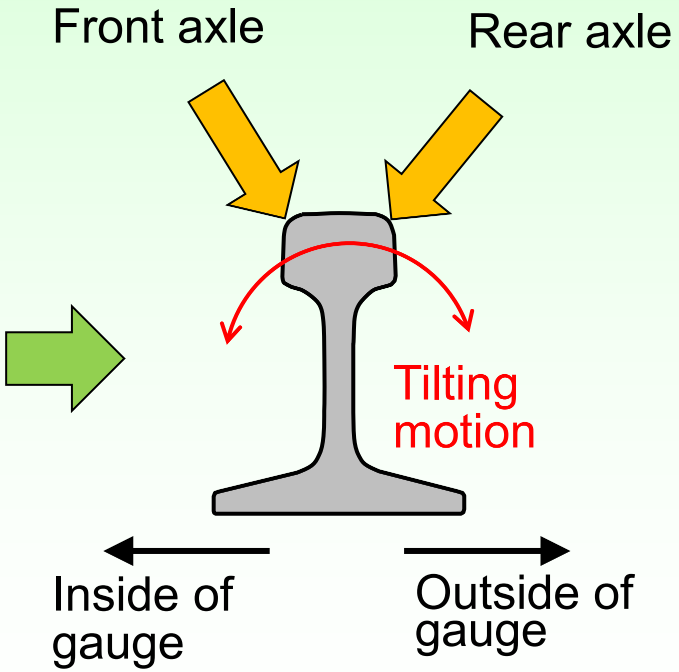
※Two directional loading is a unique approach in Japan.

Why loading from two directions?

Past on-site measurements in curved sections show that lateral loads occur that tilt the rail alternately to the outside and inside of the gauge, when the front and rear axles of the train's bogie pass.

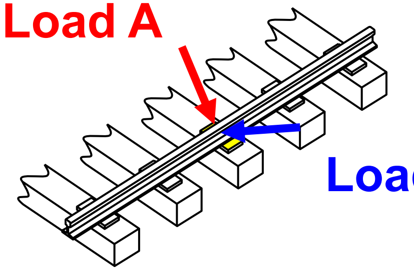


Measured lateral force at sharp curve (R=160m)



Estimation of applied loads used in the test

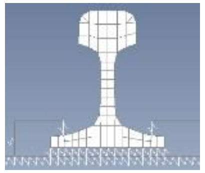
Design loads

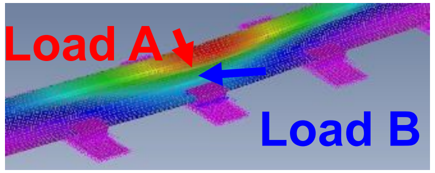


Load type	Alignment	Values	
		Load A (Max, rarely)	Load B (Avg, often)
Vertical loads	Tangent, Curved	98 kN	86 kN
Lateral loads	Tangent, R≧800m	30 kN	15 kN
	600m≦R＜800m	45 kN	23 kN
	R＜600m	60 kN	30 kN

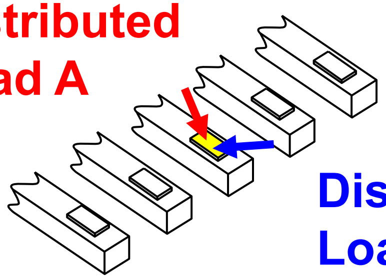
Values are for meter-gauged railway line

FEM analysis

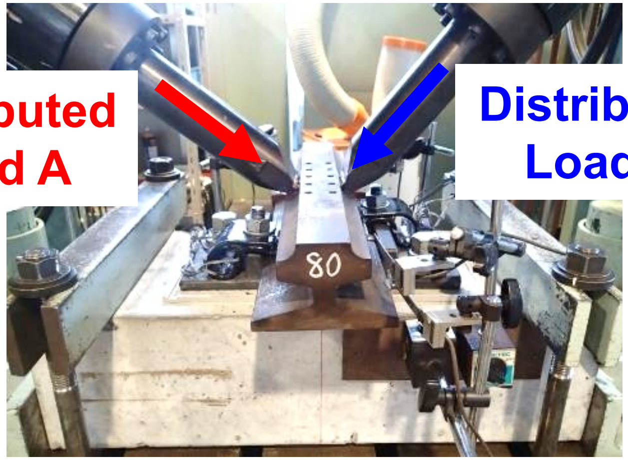




Distributed design loads



Applied loads on a single set of fastenings

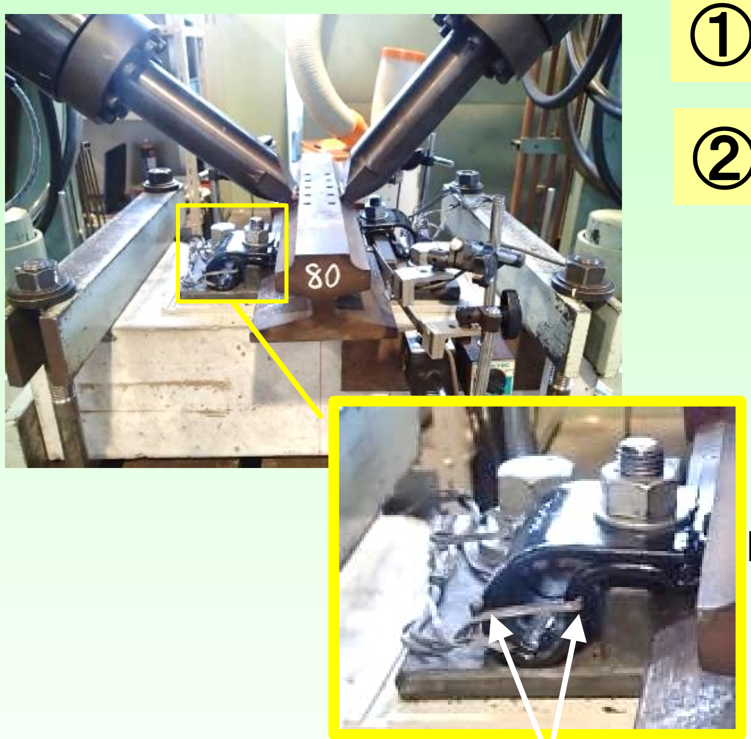


Inspection of safety against fatigue failure

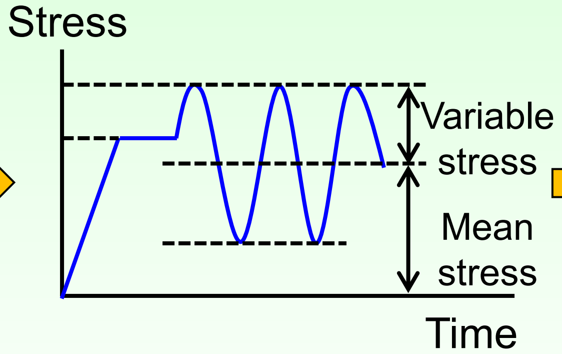
The following three items are verified by the load test.

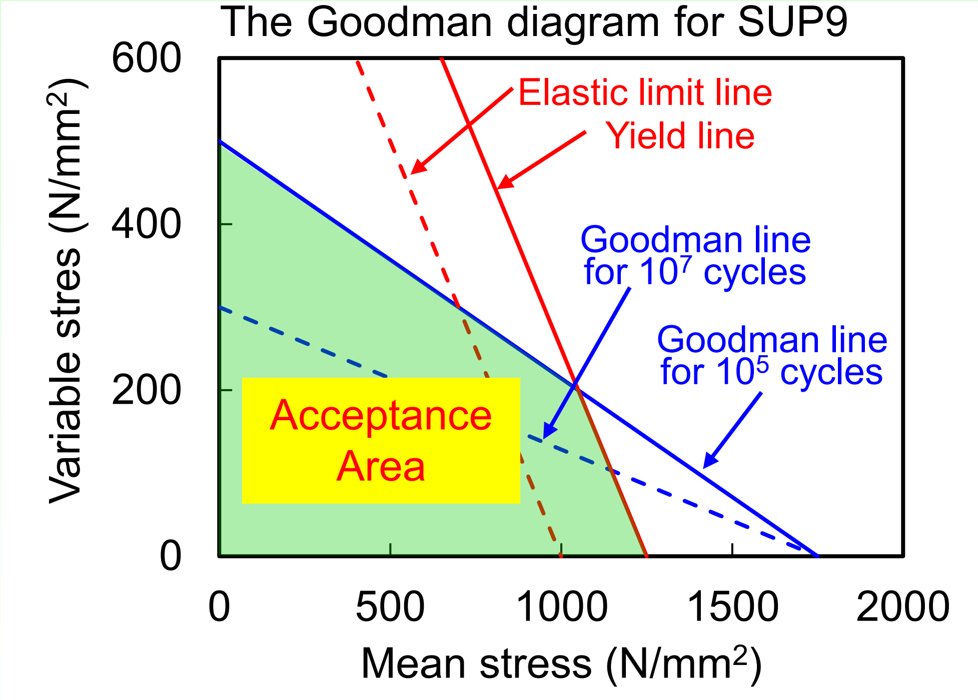
① Rail head lateral displacement

② Stress of rail clips



Strain gages





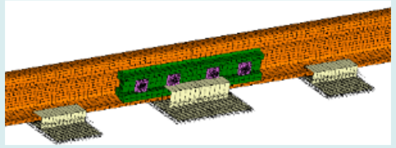
③ The overall condition of the rail fastening systems after 1 million load cycles

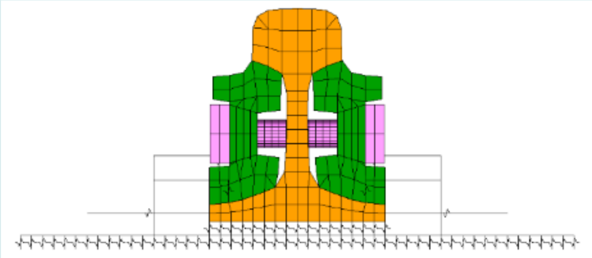
Rail fastenings currently used in Japan have passed this inspection.

Recent researches on rail fastening systems

Testing methods for a single set of rail fastening systems for rail joints

Establish the FEM model for rail joints





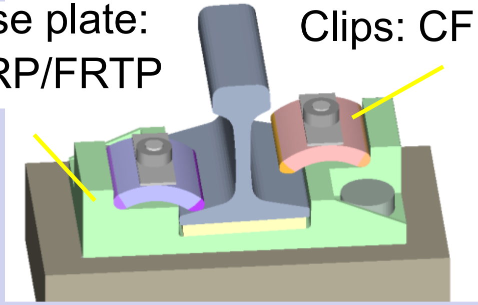
Determination of load conditions for a single set of rail fastenings for rail joints

Rail fastenings for rail joints

Examination of rail fastenings with non-metallic materials as the main component

Prototype rail fastening systems

Base plate: GFRP/FRTP



Clips: CFRP

CFRP: High anti-corrosion

FRTP, GFRP: High electrical insulation

Verified high electrical insulation

Test of electrical insulation

We will continue to take on challenges related to rail fastening systems!

2. Buckling of continuous welded rails

What are continuous welded rails?

In Japan, continuous welded rails (**CWRs**) are defined as rails without rail joints and with a length of 200m or more.

[Advantages]

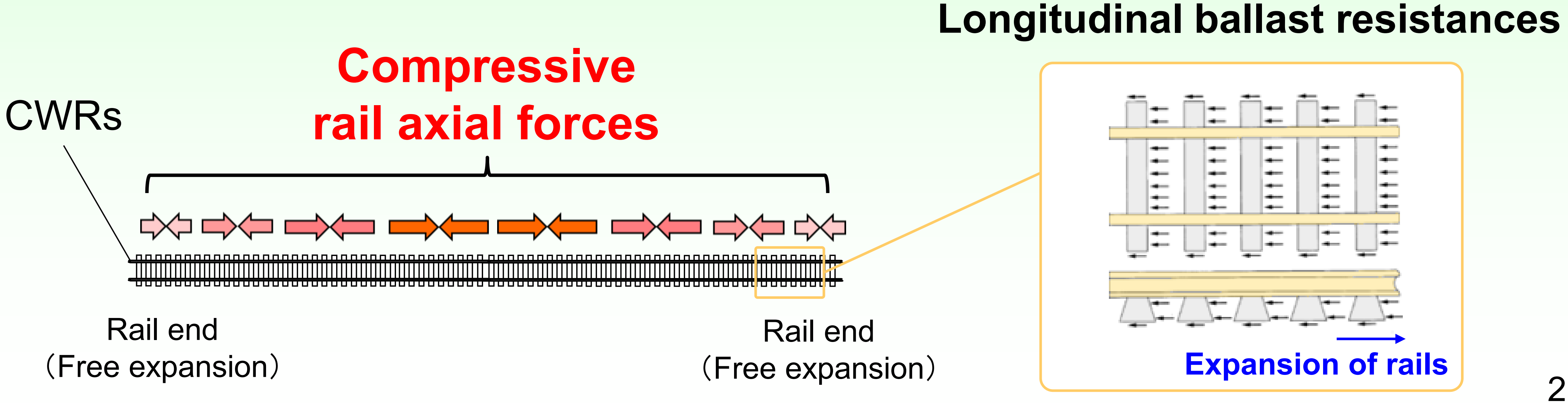
- Improved ride comfort
- Reduced vibrations and noise
- Decreased track maintenance works

Characteristics of CWRs

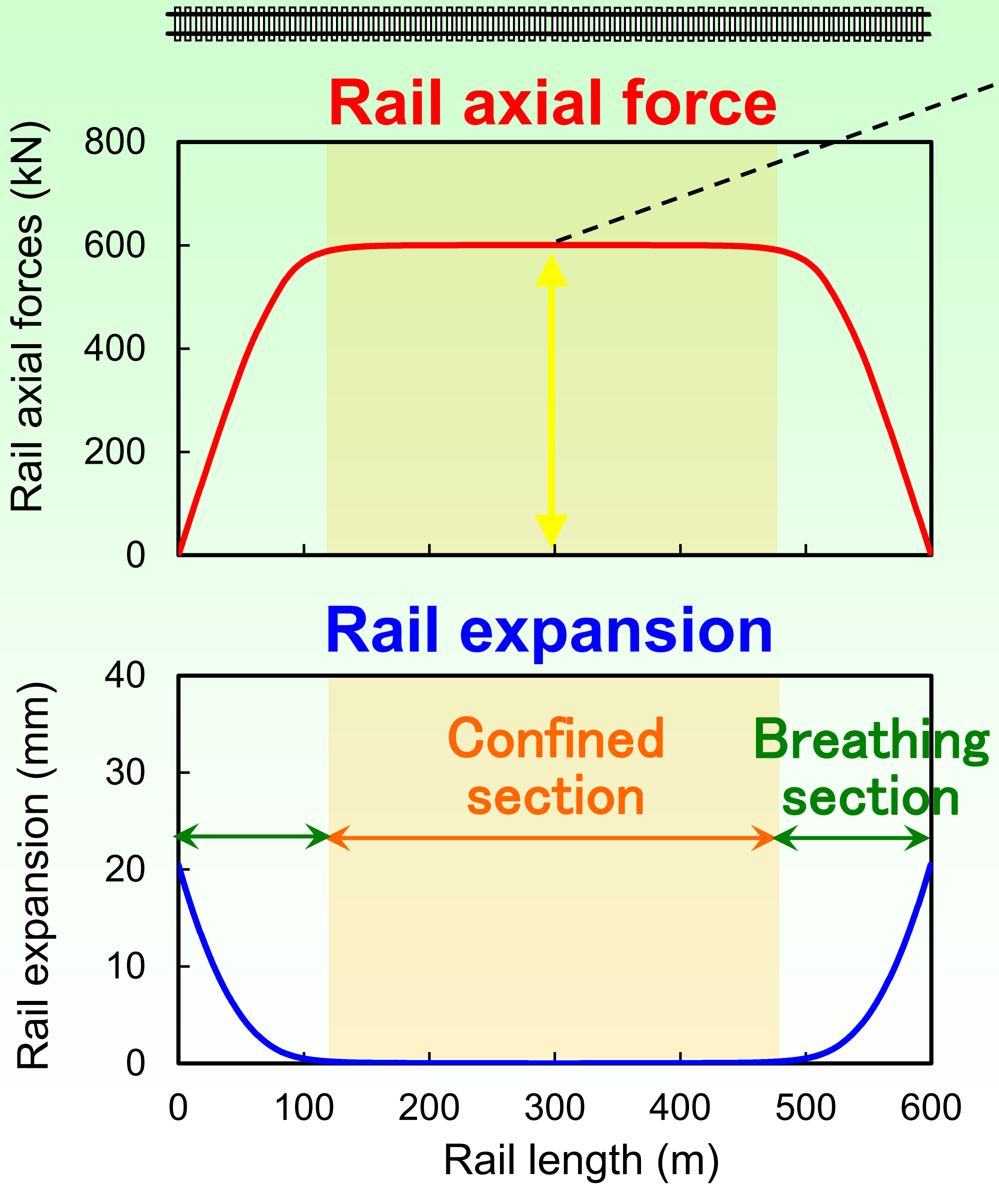
The expansion of rails due to temperature increase is constrained.

⇓

Significant compressive rail axial forces are generated.



Rail axial force and rail expansion



$$P = EA\beta\Delta t$$

P: Rail axial force (compressive)

E: Young's modulus

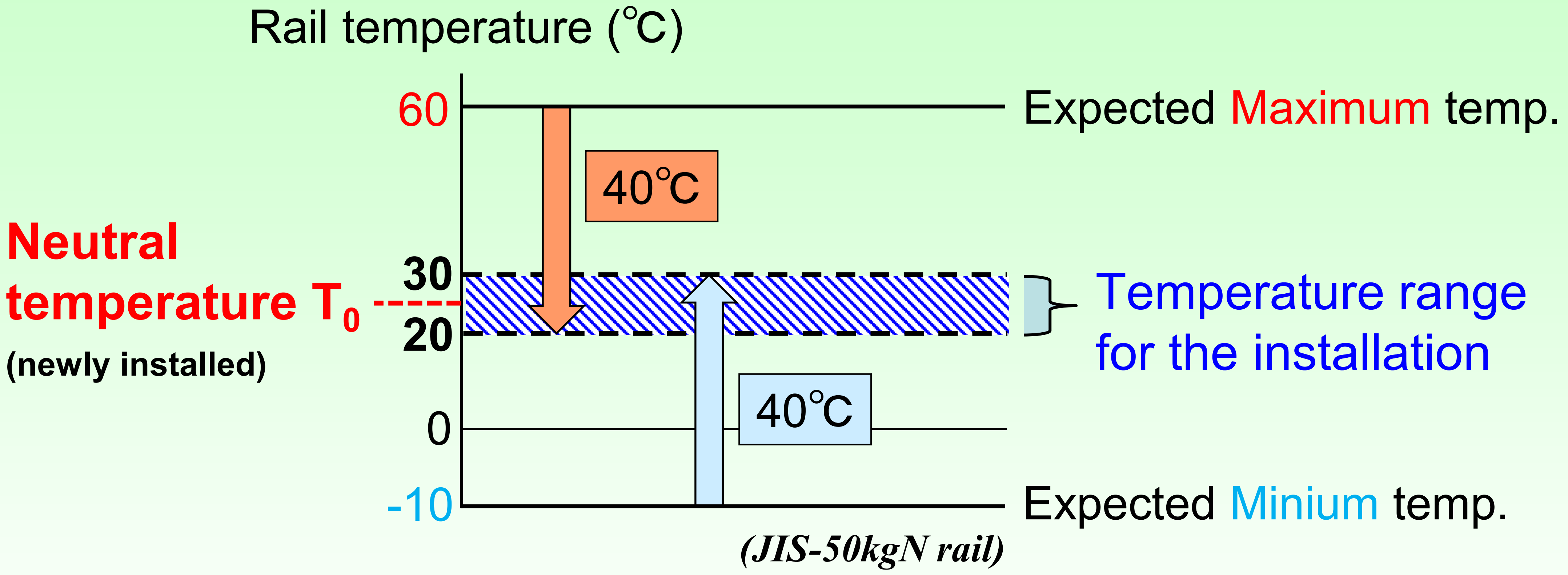
A: Cross sectional area

β: Coefficient of thermal expansion

Δt: Temperature increase from neutral temperature

Rail axial force is zero at both ends of rail, and is maximum in the middle, remaining constant.

Neutral temperature of CWRs newly installed



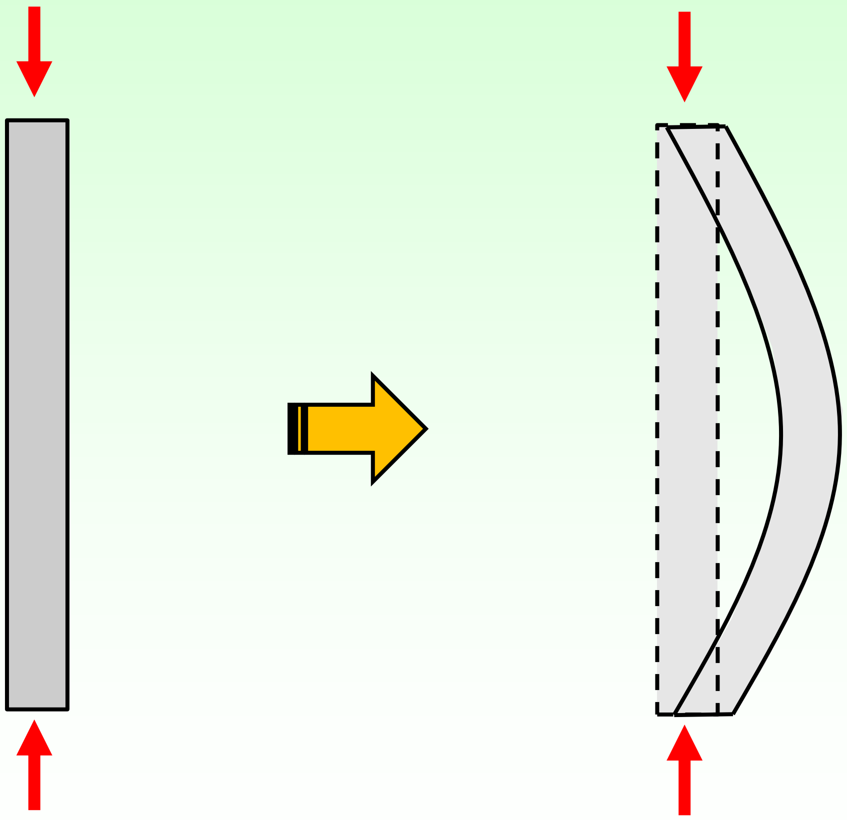
- New CWRs should be installed within a specific temperature range.
- Rail axial force is zero at the neutral temperature T_0.
- Maximum rail axial force depends on temperature increase from T_0

If rail axial force exceeds the limit, there is a risk of buckling

Photo of Buckling Test

What is buckling?

Buckling is the sudden change in shape of a structural components subjected to compressive forces.

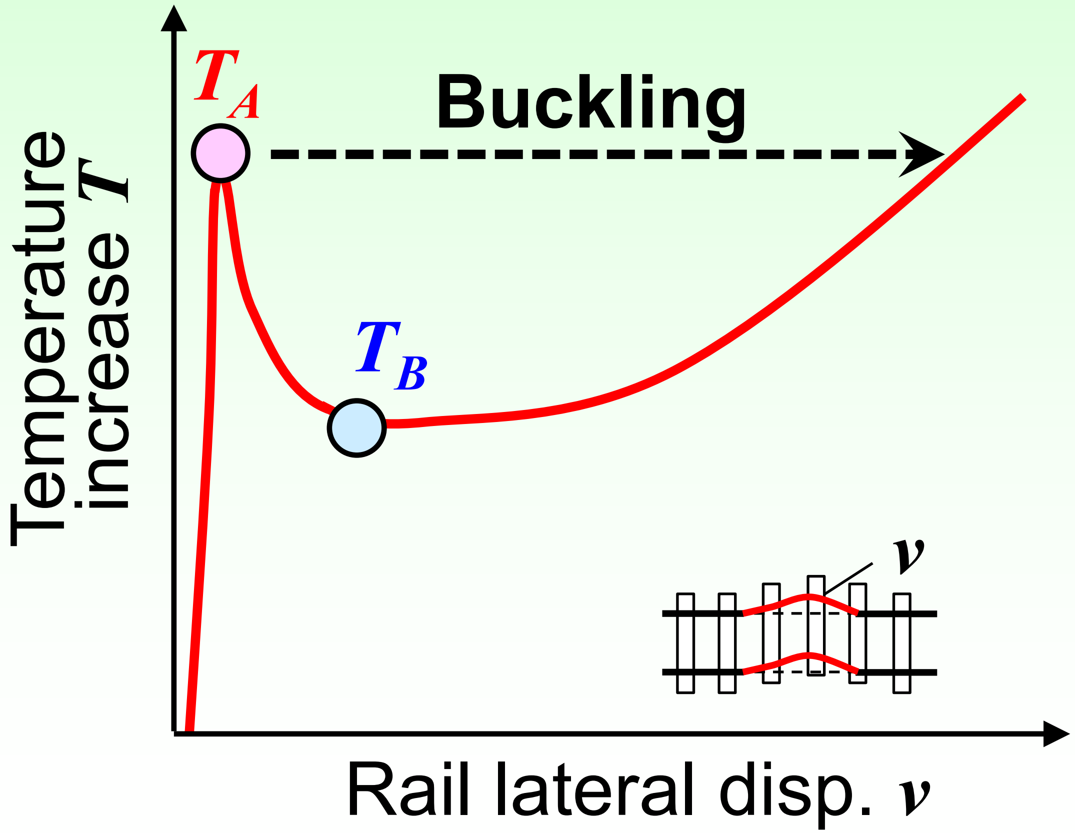


Track buckling test by RTRI (2018)

This study received funding from the MLIT's subsidy aid of railway technology development.

The relationship between rail temperature Increase and rail lateral displacement in track buckling

- Theoretically, when the rail temperature reaches T_A, buckling occurs.
- **Buckling state does not exist, at values below** T_B.



Rail axial force at T_B is defined as **"Minimum buckling strength P_t"**

P_t **is used as an evaluation index of buckling strength of CWRs.**

Calculations of minimum buckling strength P_t

Currently, the minimum buckling strength P_t is calculated by the following equations based on the energy method, in Japan.

$R \geq R_0$

$$P_t = 0.987 J^{0.388} g^{0.521}$$

$R < R_0$

$$P_t = 1.266 J^{0.374} g^{0.534} - a J^b g_0{}^c / R$$

$$R_0 = \frac{a J^b g^c}{1.266 J^{0.374} g^{0.534} - 0.987 J^{0.388} g^{0.521}}$$

(JIS-50kgN rail)

- P_t : Minimum buckling strength (kN)
- J : Parameter by multiplying track panel stiffness with rail lateral stiffness
- g : Lateral ballast resistance (kN/m)
- r : Longitudinal ballast resistance = $2g$ (kN/m)
- R : Radius of curvature (m)
- a : Proportional constant, b, c : Exponentiation of constant

Verification of buckling stability of CWRs

Buckling stability is verified by comparing the minimum buckling strength with the maximum rail axial force.

Value of safety level :

$$S = \frac{P_t}{P_{\max}}$$

P_t : **Minimum buckling strength** (kN)

$P_{\max}$: **Maximum rail axial force** (kN)

$S \geqq 1.2$ → Normal state

$S < 1.2$ → Needs actions

- ◆ Track inspection
- ◆ Restressing of CWRs
- ◆ Reinforcement of lateral ballast resistances, etc.

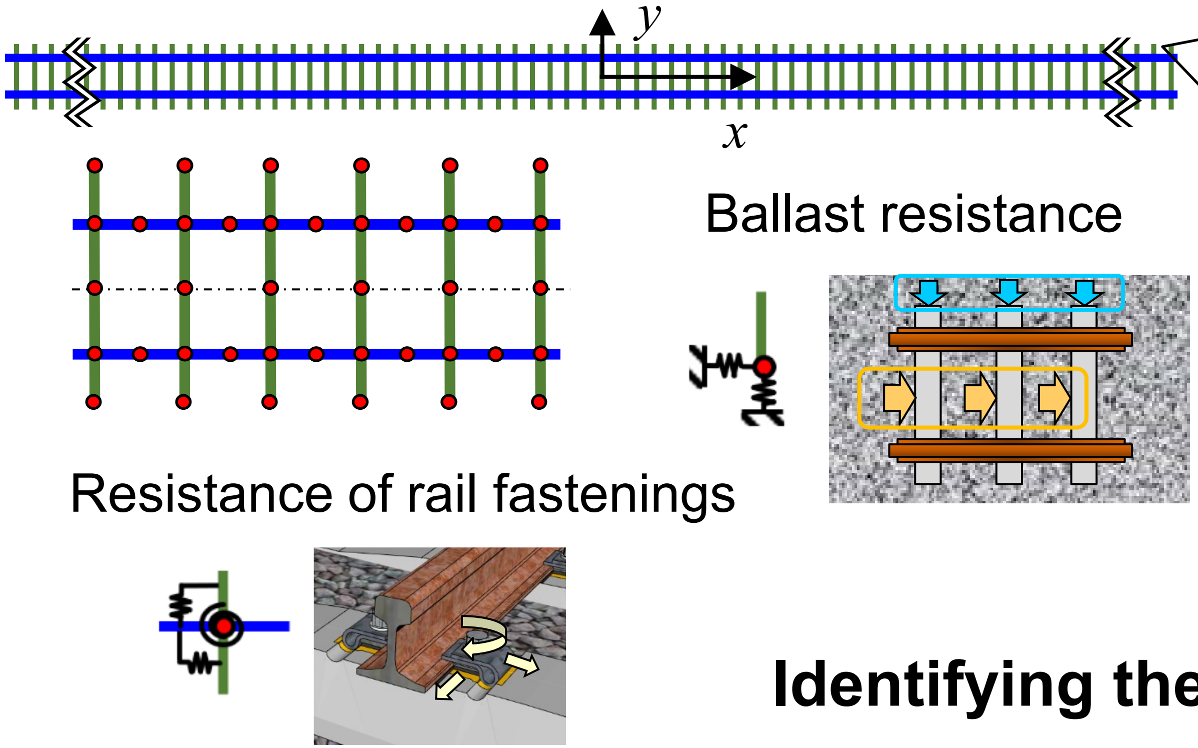
If the safety level falls below the threshold level (1.2), some form of actions are necessary.

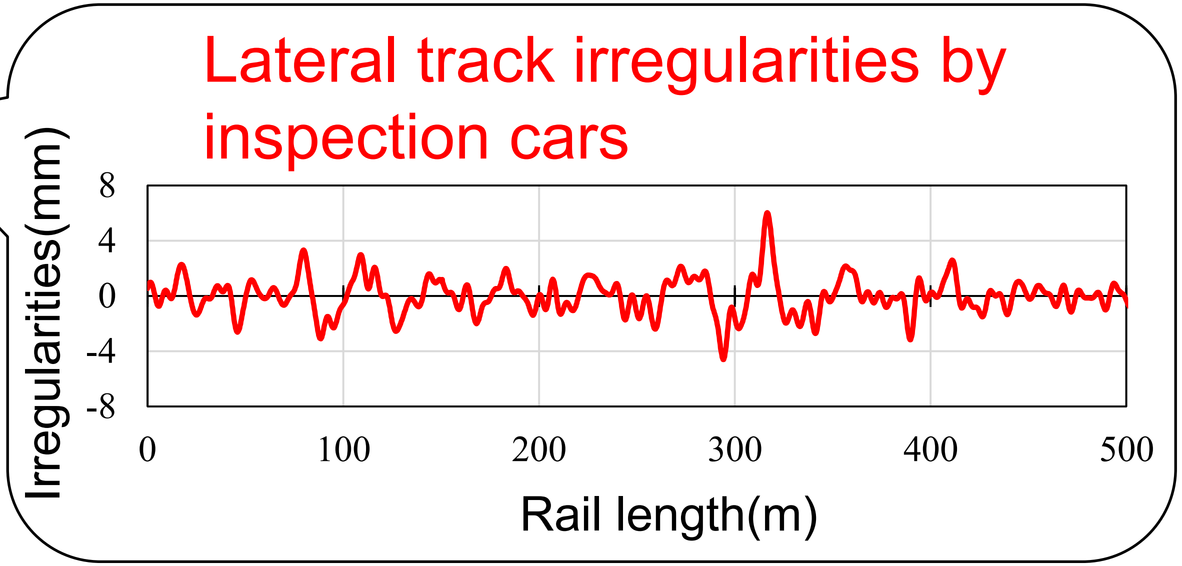
Recent researches on buckling of CWRs

Practical method for estimating buckling temperature of CWRs based on lateral track irregularities measured by inspection car

Buckling analysis by FEM using track irregularities measured by inspection cars

FEM model



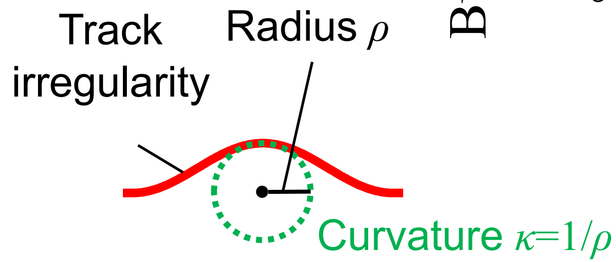


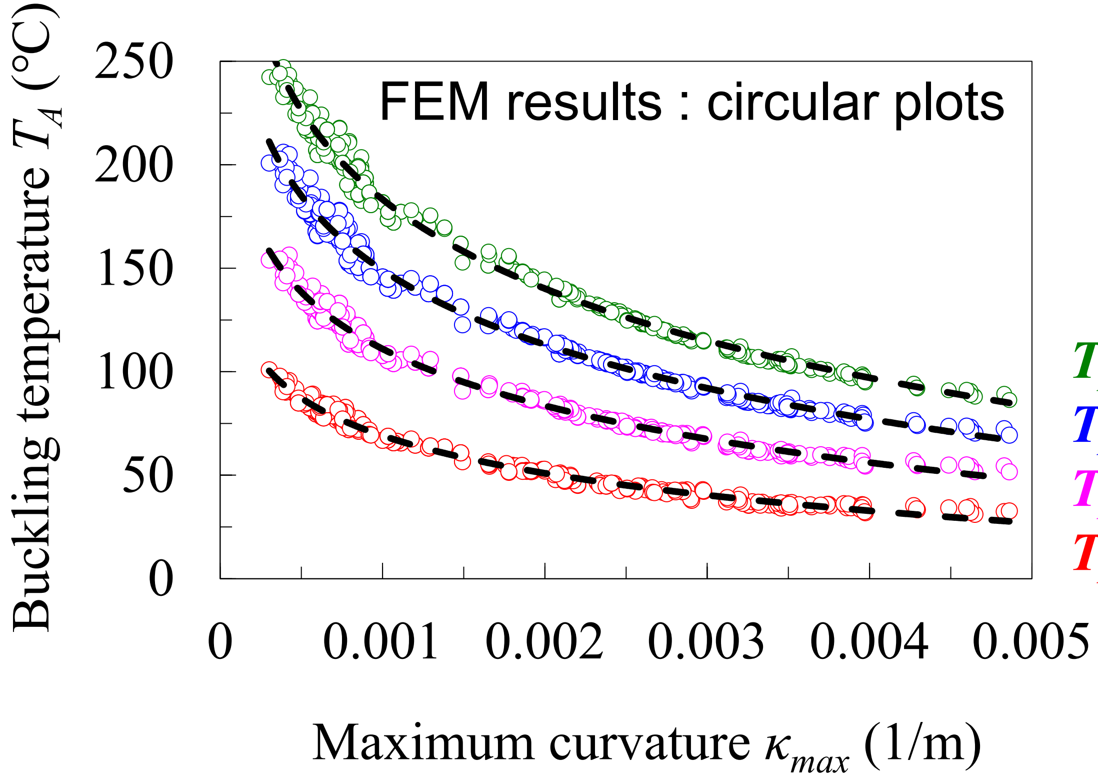
Analysis for over 250 cases

Identifying the key factor that affects track buckling

Recent researches on buckling of CWRs

Proposing formulas to estimate the buckling temperature T_A from the maximum curvature κ_{max} of the lateral track irregularities.





Regression formulas

T_A=-62.41ln(κ_{max})-247.9 ･･･ g=8 kN/m

T_A=-52.14ln(κ_{max})-211.2 ･･･ g=6 kN/m

T_A=-39.75ln(κ_{max})-163.7 ･･･ g=4 kN/m

T_A=-26.21ln(κ_{max})-112.1 ･･･ g=2 kN/m

g:Lateral ballast resistance

We will continue to take on challenges related to CWRs!

Thank you for your attention