Lateral Resistance Characteristics of Sleepers in Railway Ballasted Tracks from Laboratory Model Tests

Kimitoshi Hayano (Yokohama National University)

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1) Effects of sleeper shape on lateral resistance of sleepers in railway ballasted tracks

2) Lateral resistance of sleepers in railway ballasted track subjected to angular folding at structure boundaries

Effects of sleeper shape on lateral resistance of sleepers in railway ballasted tracks

Outline

1) Background, objective and methodology

2) Model test conditions

- Sleepers, ballast
- Single-sleeper pullout test
- Track panel pullout test

3) Model test results

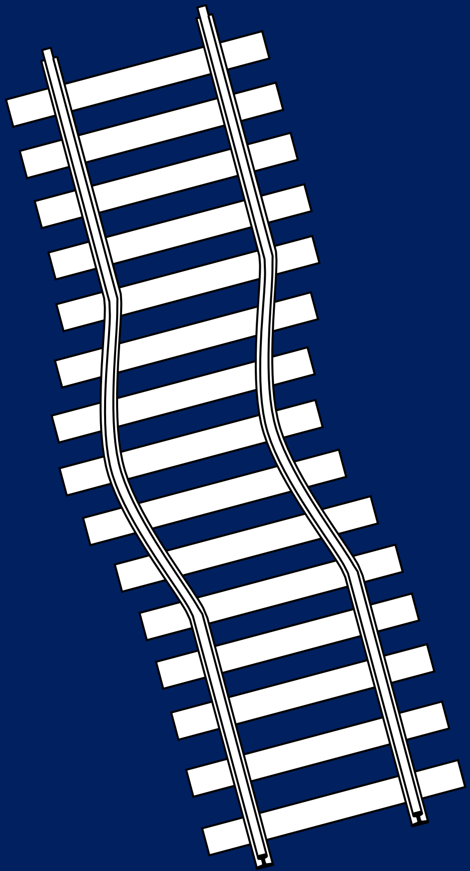
- Lateral resistance obtained from single-sleeper pullout tests
- Lateral resistance obtained from track panel pullout tests using five sleepers
- Lateral resistance obtained from pullout tests using different number of sleepers

4) Summary

Background

Ballasted track sleepers have the important function of providing sufficient *lateral resistance* to prevent lateral movement of the rails. If the lateral force induced by the thermal expansion of the steel rails overcomes the lateral resistance of the sleepers, rail buckling may occur.

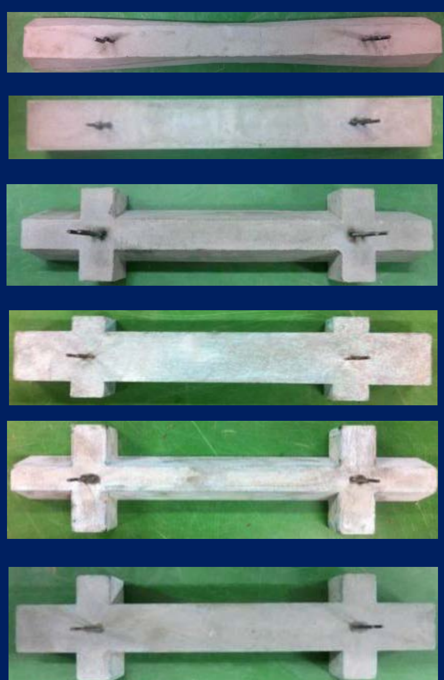
However, there is a high degree of uncertainty in the prediction of the lateral resistance of various shapes of sleepers.



Objective and Methodology

Single-sleeper pullout tests and *track panel pullout tests* were conducted in the laboratory on 1/5-scale models to evaluate the lateral resistance of various shapes of concrete sleepers .

Effects of sleeper shape, sleeper spacing and number of sleepers on the lateral resistance were investigated.



Sleepers prepared for model tests

Track panel pullout test (1/5-scale models)

Outline

1) Background, objective and methodology

2) Model test conditions

- Sleepers, ballast
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- Track panel pullout test

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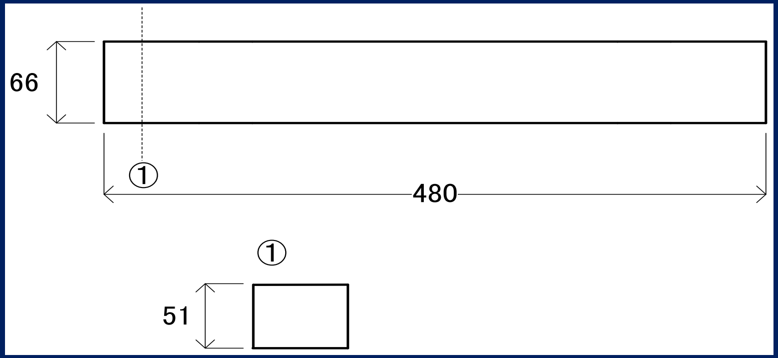
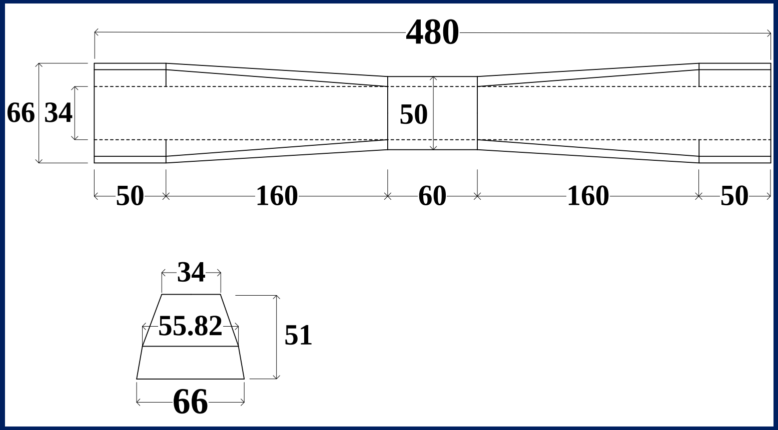
4) Summary

Sleepers

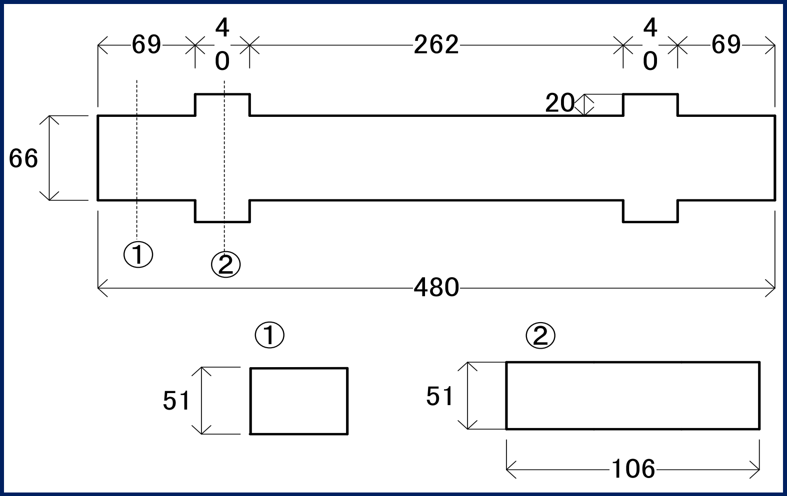
Six types of sleepers were prepared for model tests.



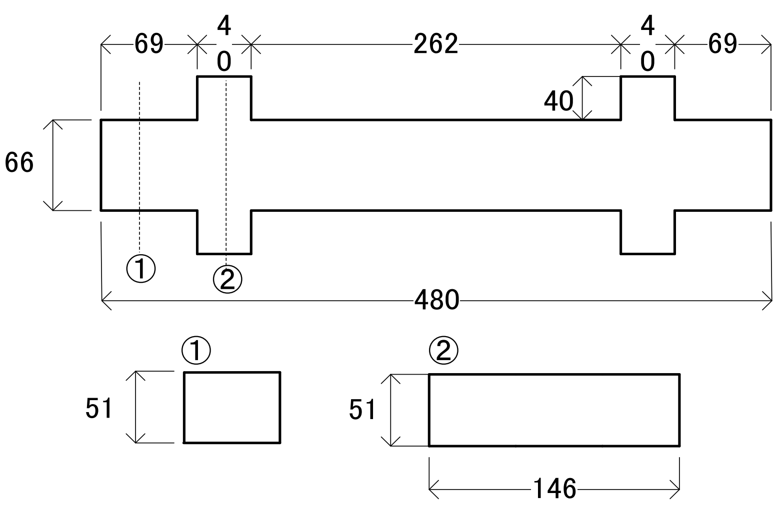
(a) Rectangular parallelepiped sleeper



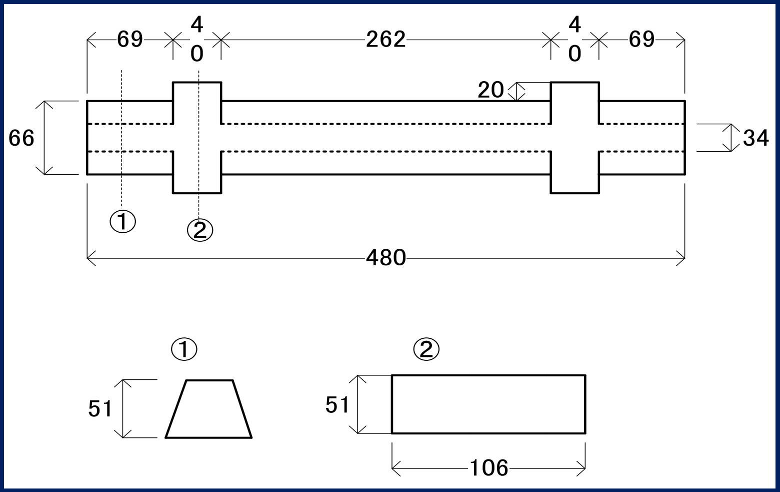
(b) 3H sleeper



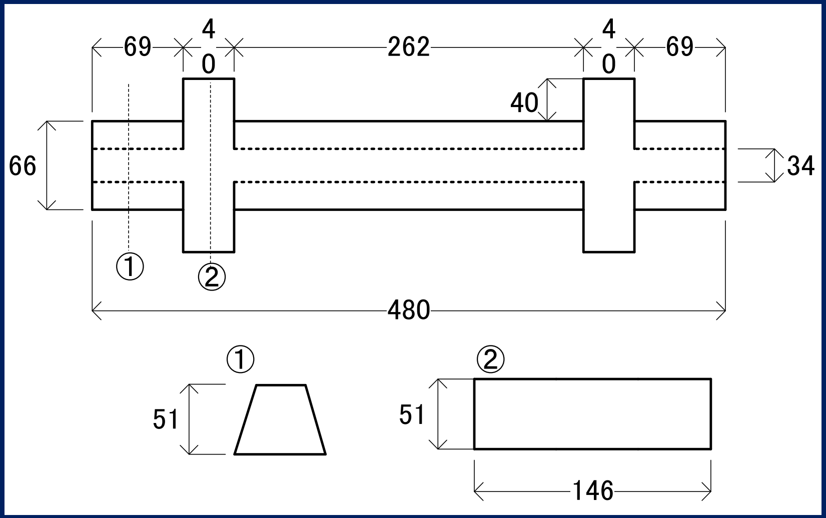
(c) 20-mm-winged sleeper with rectangular ends



(d) 40-mm-winged sleeper with rectangular ends

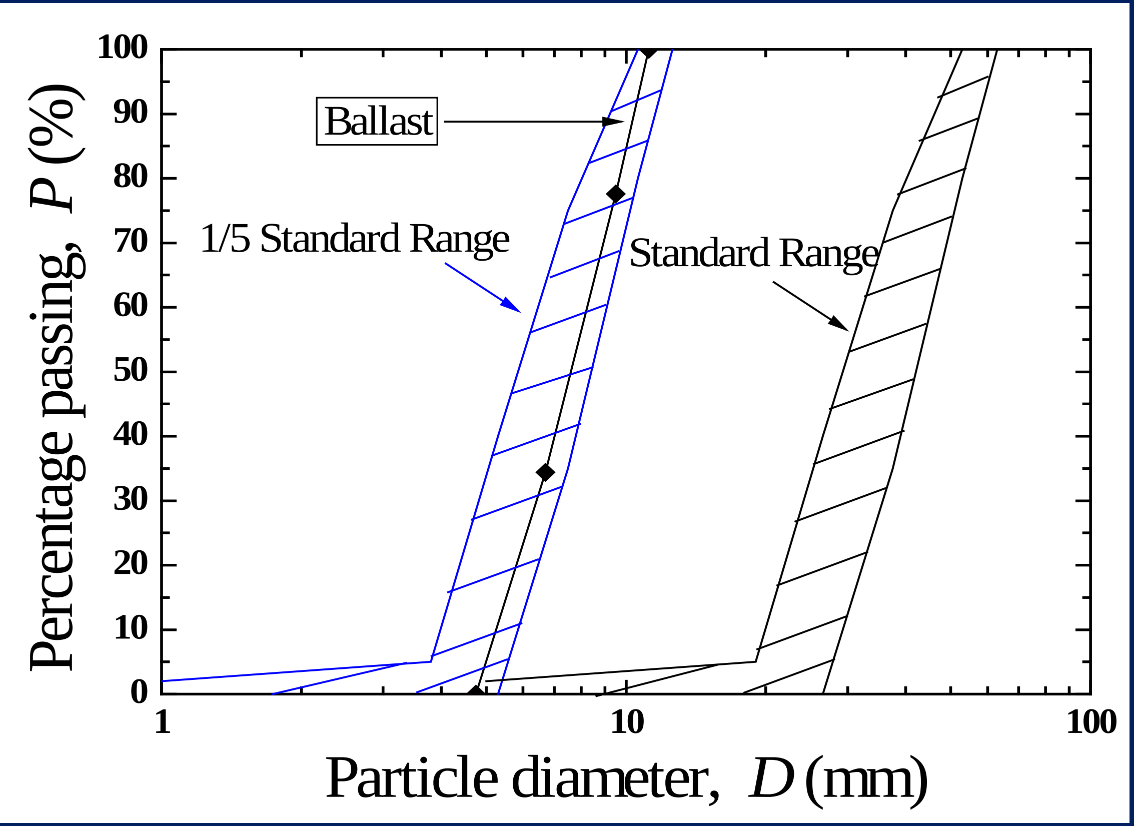


(e) 20-mm-winged sleeper with trapezoidal ends



(f) 40-mm-winged sleeper with trapezoidal ends

Ballast used for model tests

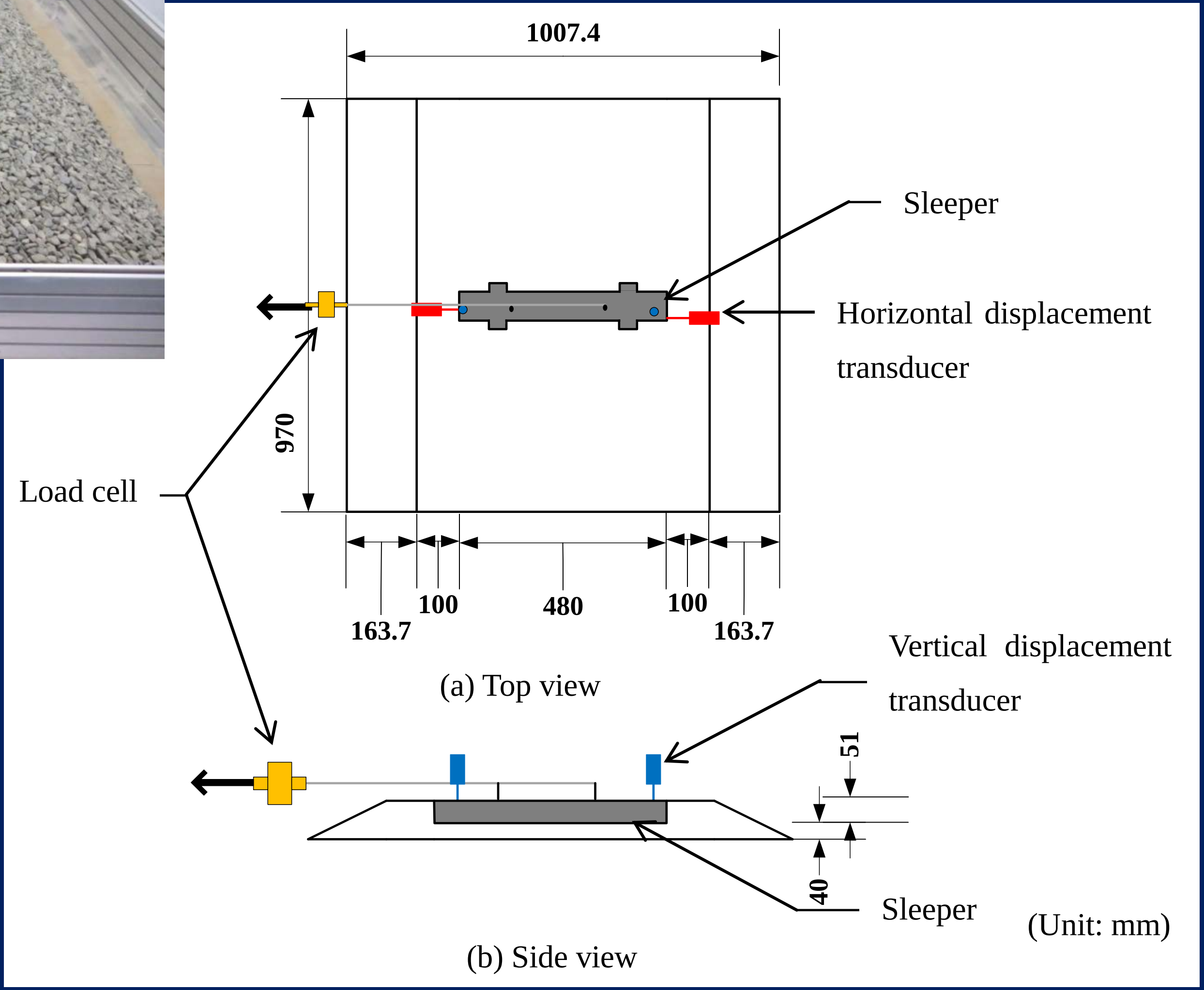


Particle size distribution

Track beds of model tests were constructed from ballast using tamping and vibration methods to achieve a dry density of 1.60 g/cm^3.

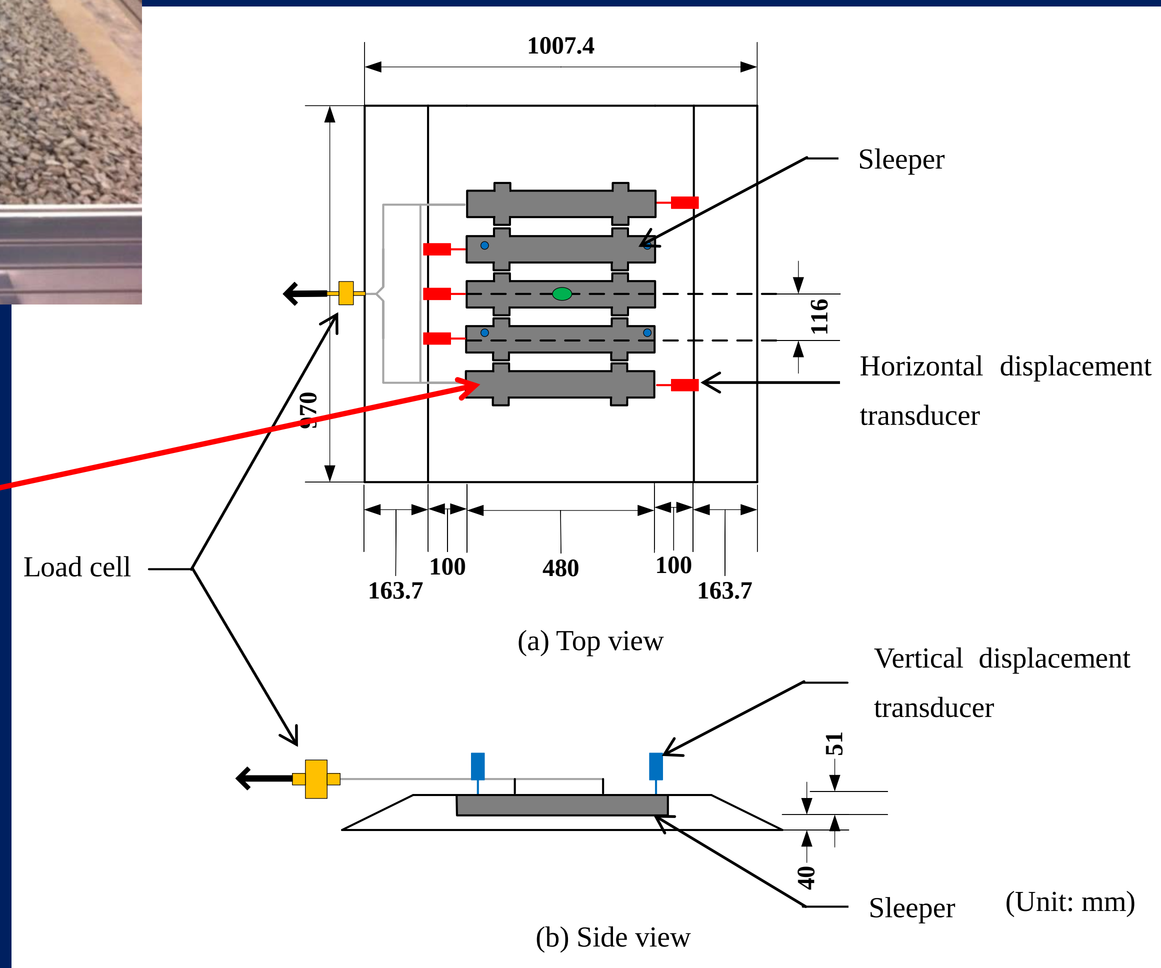
Single-sleeper pullout tests

Horizontal loadings were conducted at a constant displacement rate of 0.4 mm/min.



Ballasted track for single-sleeper pullout tests

Track panel pullout tests



Number of sleepers used were *three, five and seven*.

The sleepers were spaced at 116 mm.

Ballasted tracks for track panel pullout tests for five sleepers

Outline

1) Background, objective and methodology

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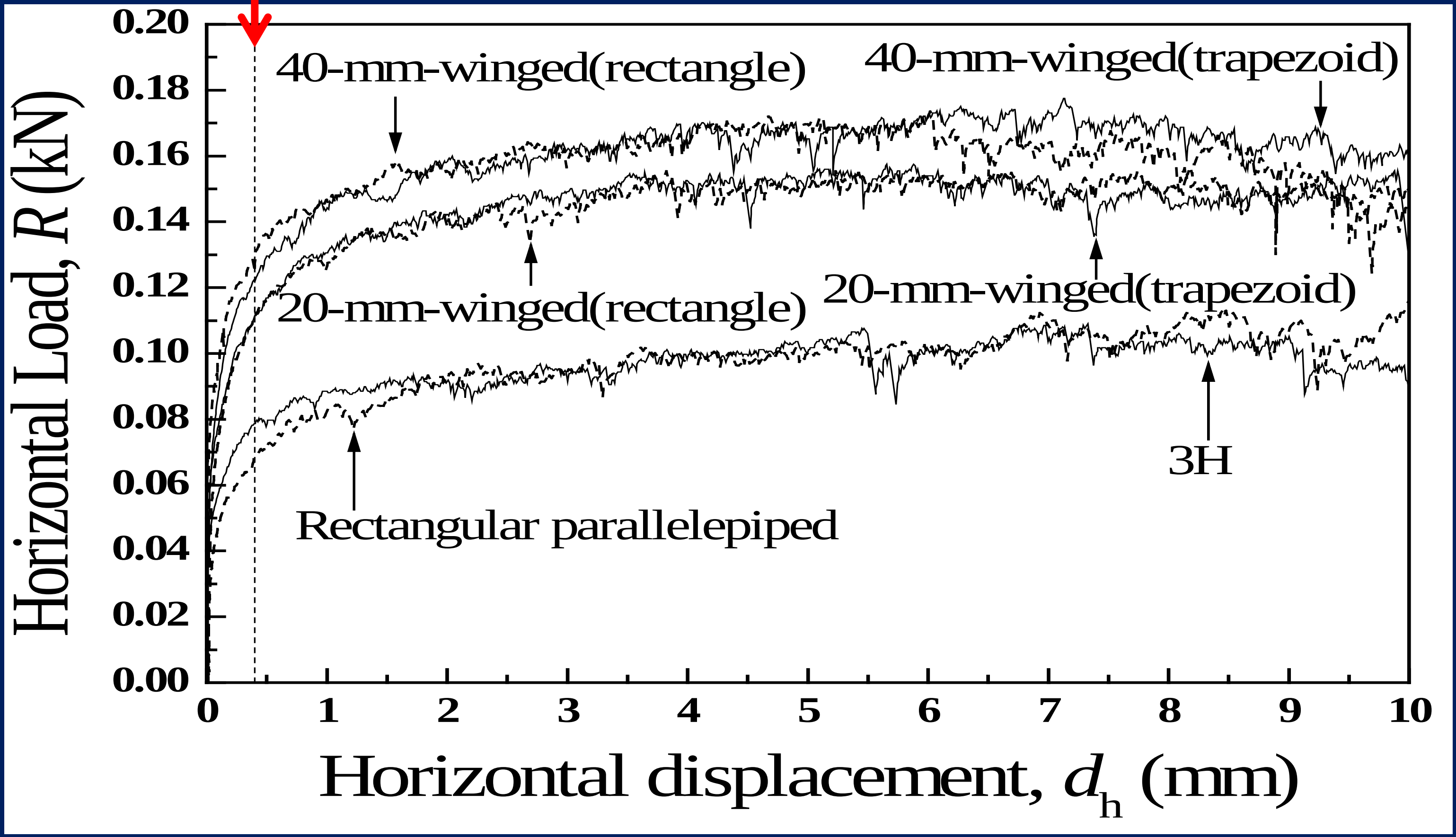
4) Summary

Lateral resistance obtained from single-sleeper pullout tests

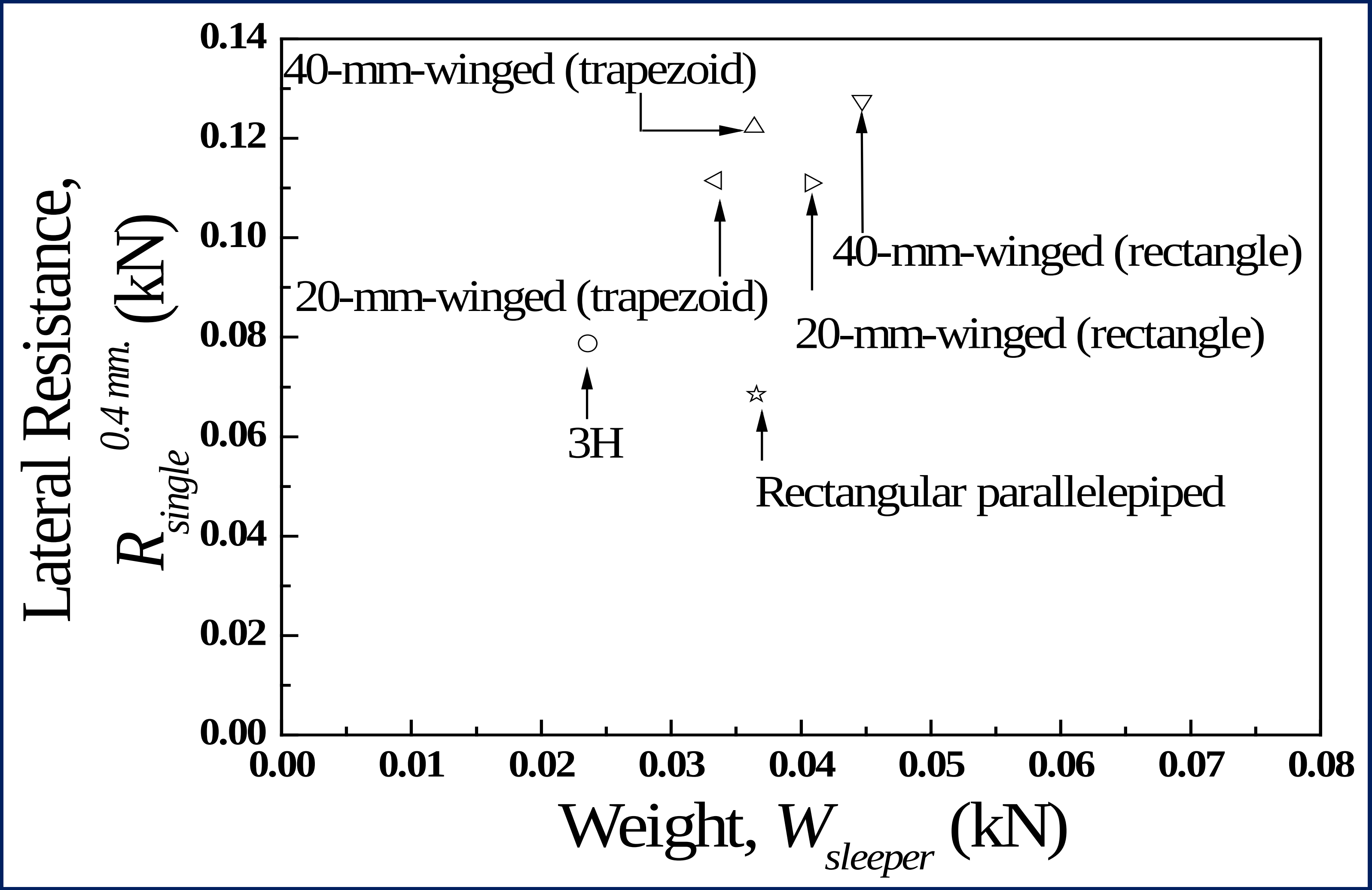
RTRI (2012) suggested the following relationship,

$R_{panel} \cong R_{single}^{2.0\ mm}$ (in full scale)

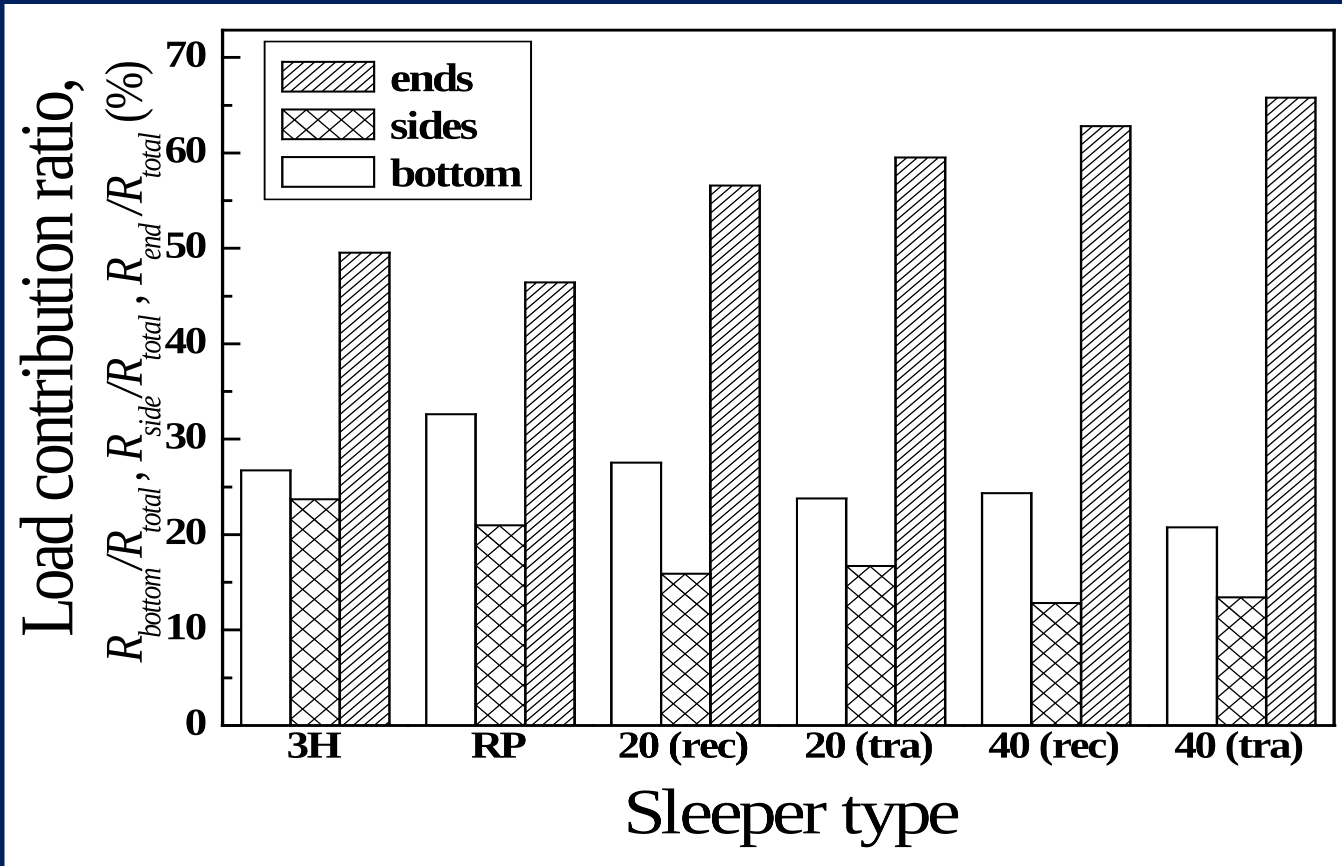
$R_{panel} \cong R_{single}^{0.4\ mm}$ (in 1/5-scale)



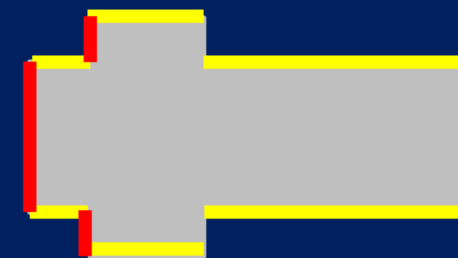
Horizontal loads and horizontal displacements relationships



Relationship between lateral resistance and weight obtained from *single-sleeper loading tests*



Rectangular parallelepiped sleeper



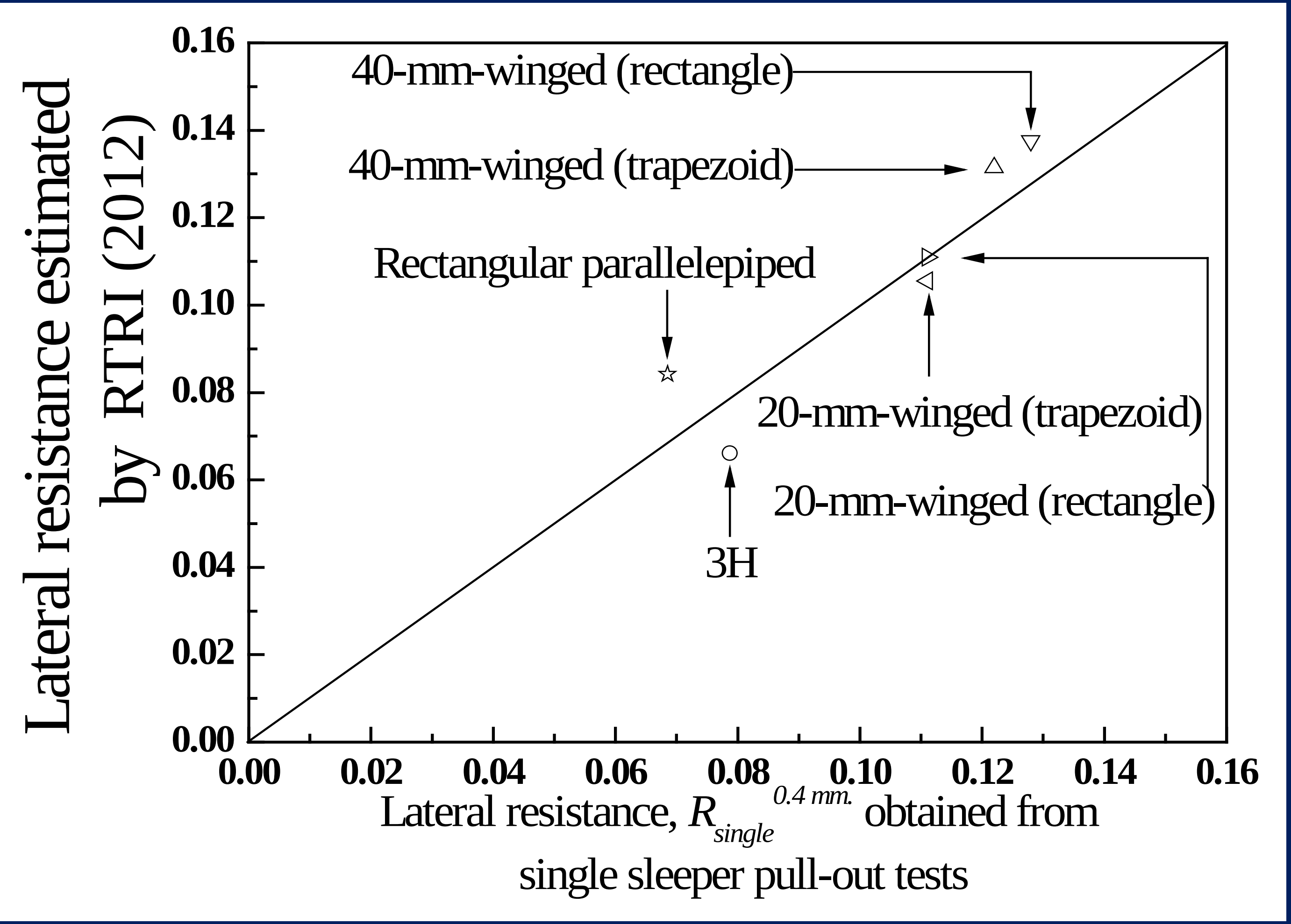
Winged sleeper

Contributions of bottom resistance, side resistance, and end resistance to total resistance

$R_{\text{total}} = aW_{\text{sleeper}} + b\gamma_{\text{ballast}}S_{\text{end}} + c\gamma_{\text{ballast}}S_{\text{side}}$ (RTRI, 2012)

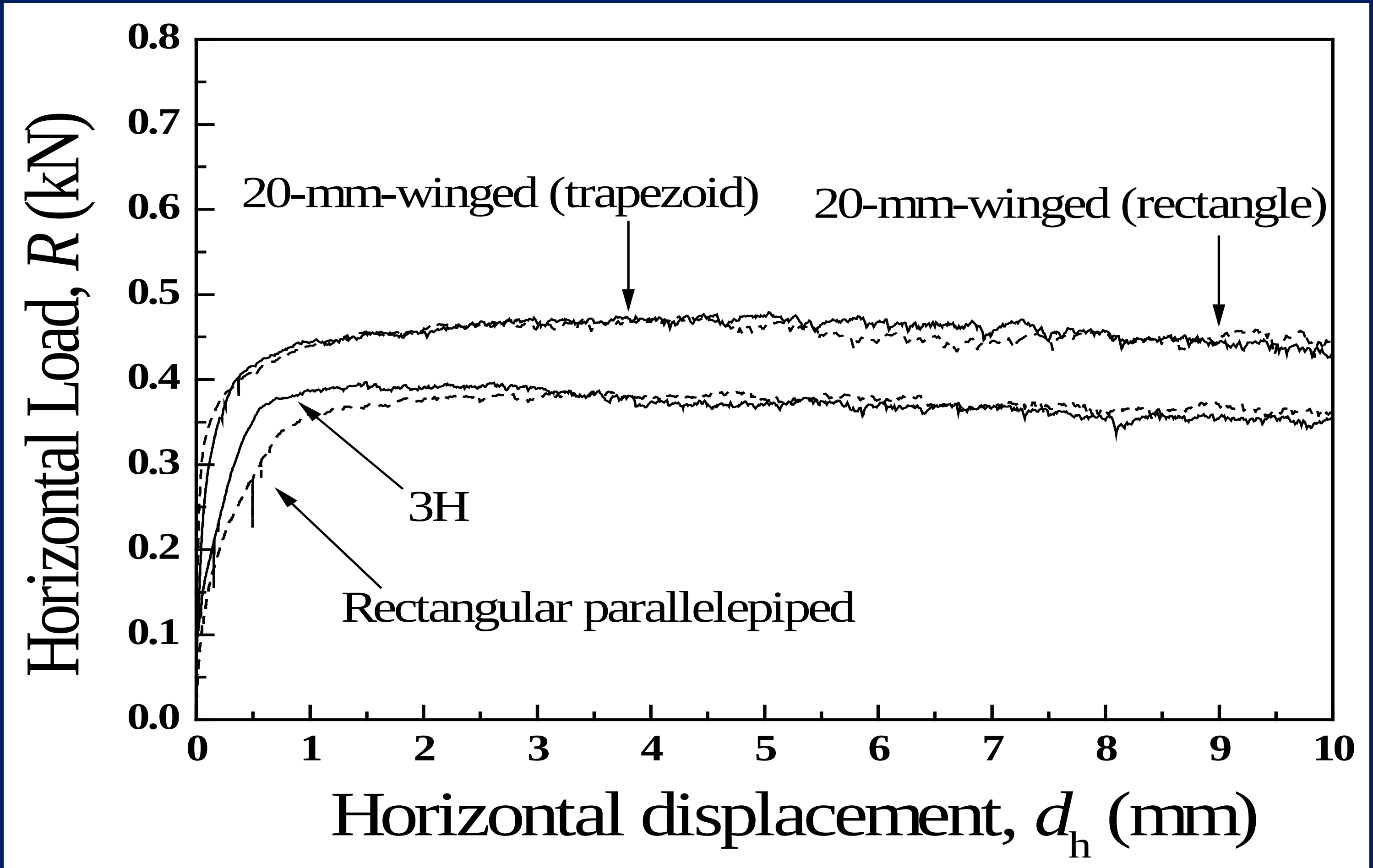
where a, b, and c are constant parameters. S_{side} is the first moment on the side face of the sleepers with respect to the upper edge, and S_{end} is the first moment on the end face of the sleepers with respect to the upper edge.

The prediction method proposed in RTRI 2012 is valid not only for conventional sleepers, but also for winged sleepers.



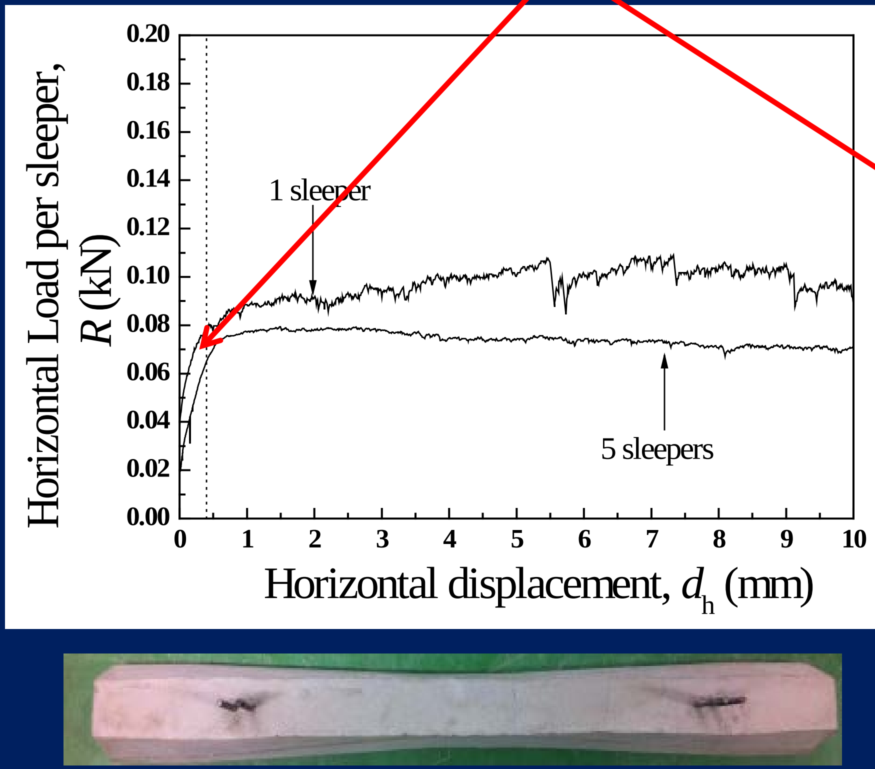
Relationship between lateral resistance obtained from model test with that estimated by RTRI (2012)

Lateral resistance obtained from track panel pullout tests using five sleepers

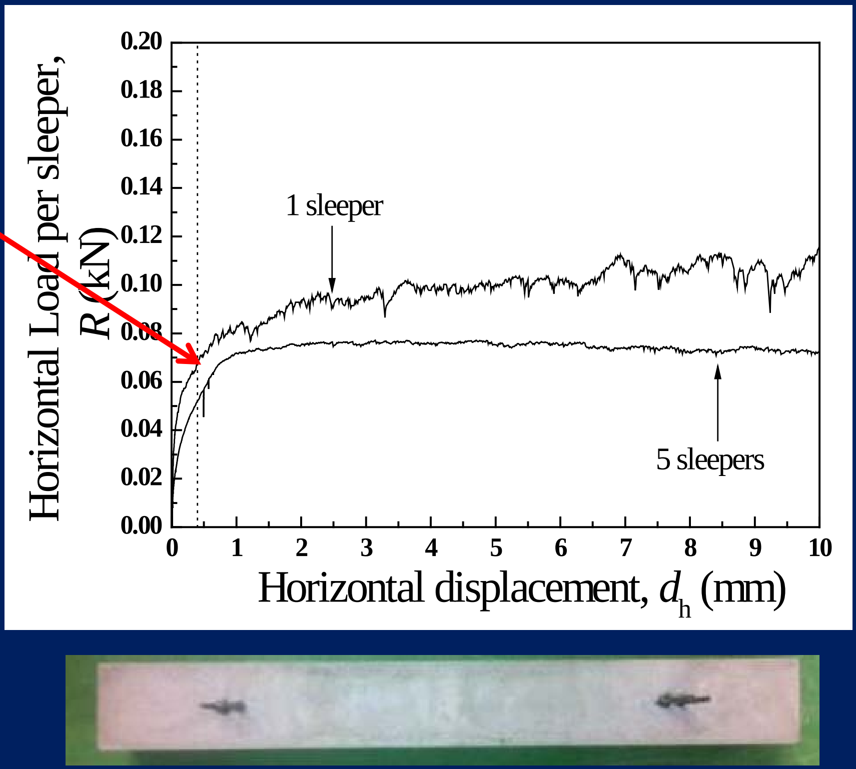


Horizontal loads and horizontal displacements relationships

$R_{panel} \cong R_{single}^{0.4\ mm}$ (in 1/5-scale)



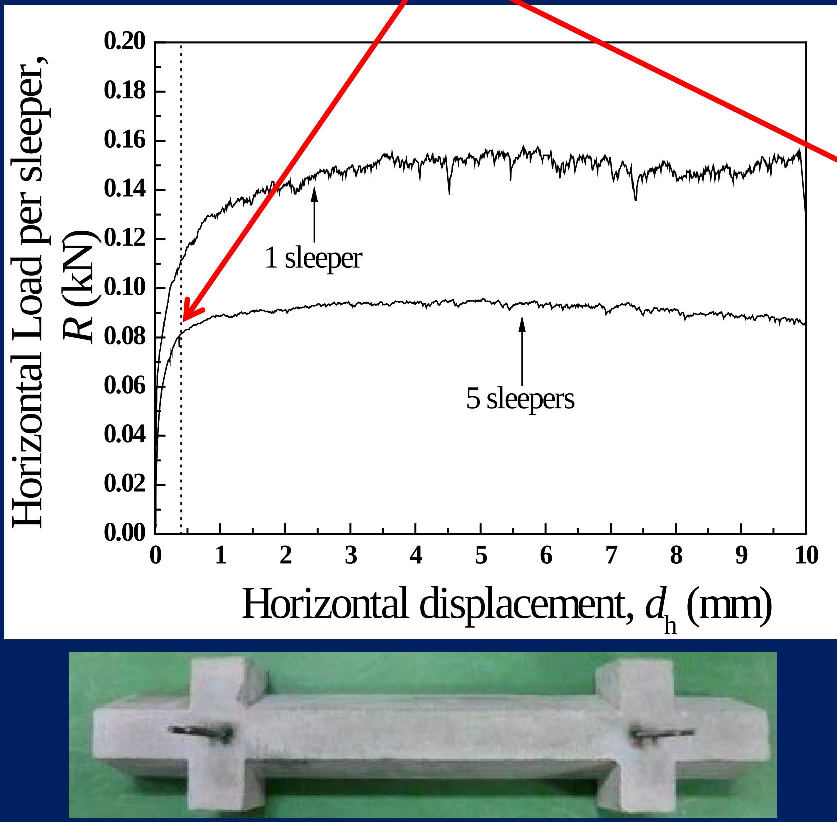
(a) 3H sleeper



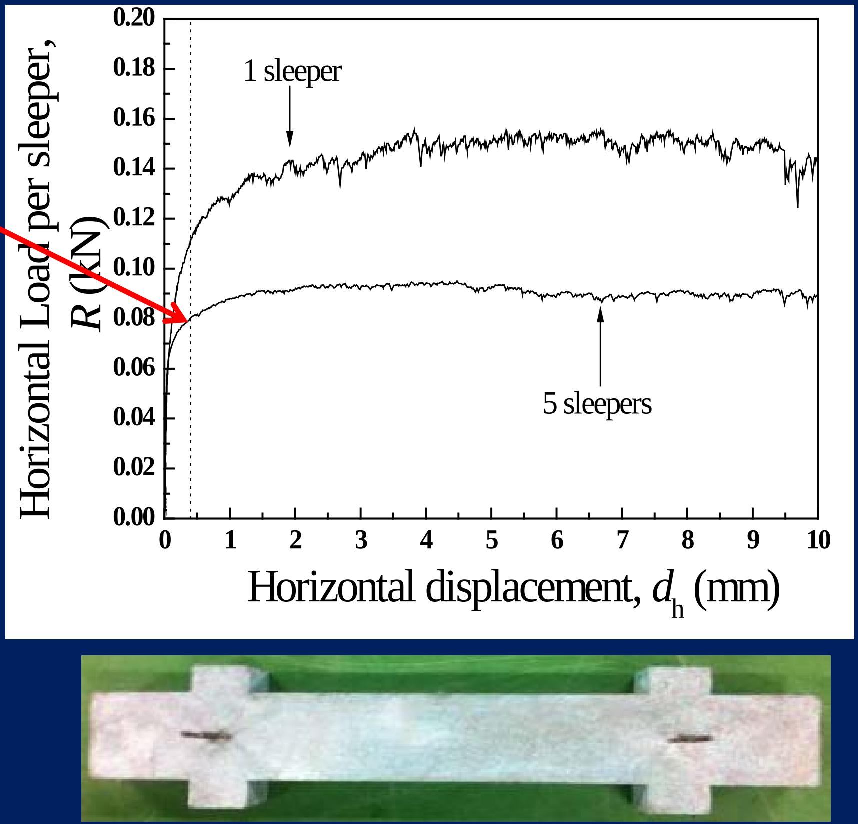
(b) Rectangular parallelepiped sleeper

Relationship between lateral resistance per sleeper and horizontal displacement obtained from *single-sleeper pullout tests* and *track panel pullout tests*

$R_{panel} \neq R_{single}^{0.4\,mm}$ (in 1/5-scale)



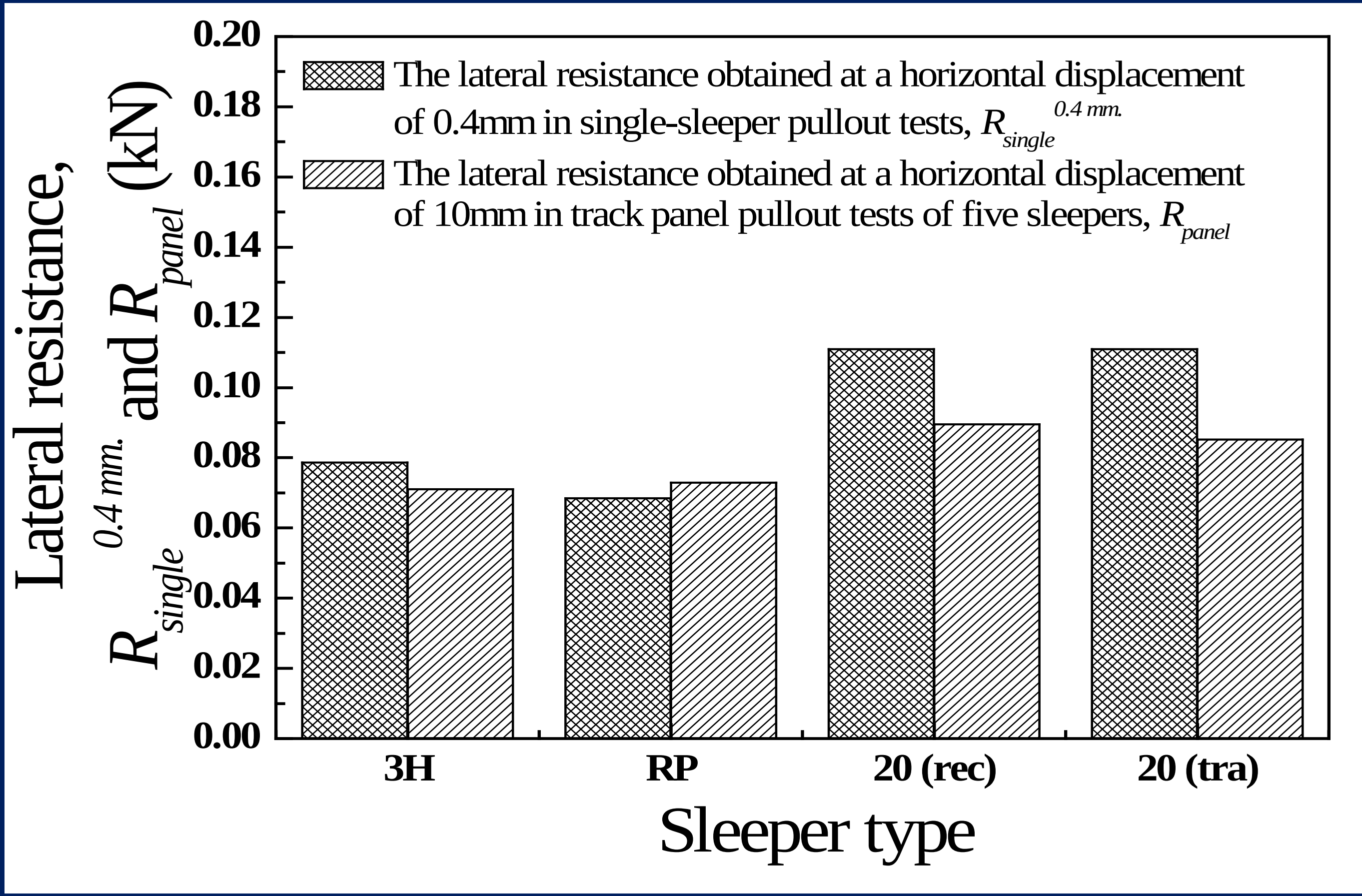
(c) 20-mm-winged sleeper with trapezoidal ends



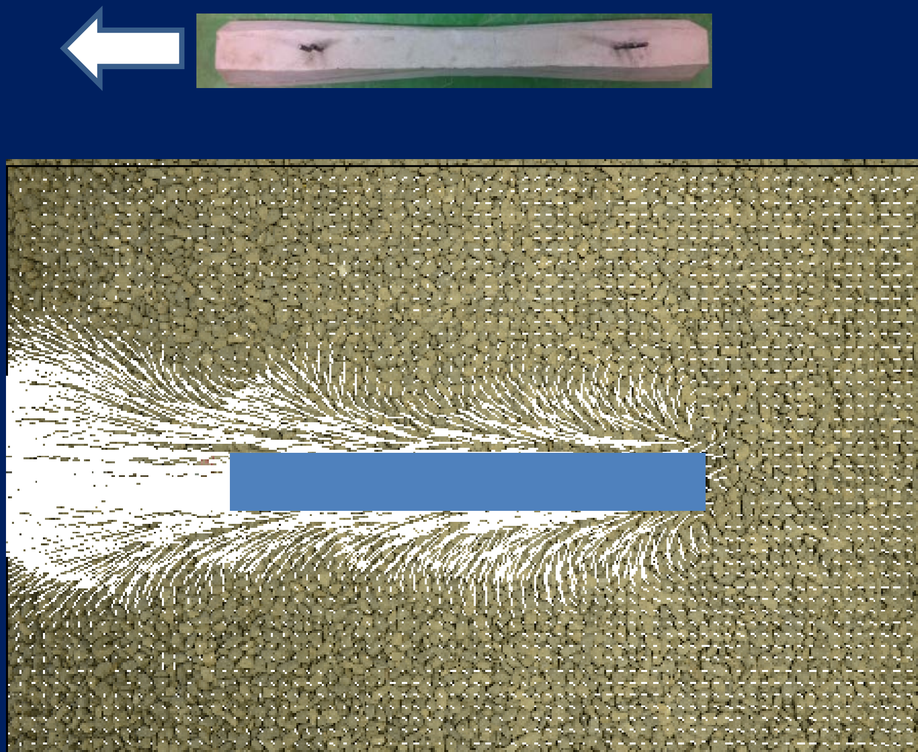
(d) 20-mm-winged sleeper with rectangular ends

Relationship between lateral resistance per sleeper and horizontal displacement obtained from *single-sleeper pullout tests* and *track panel pullout tests*

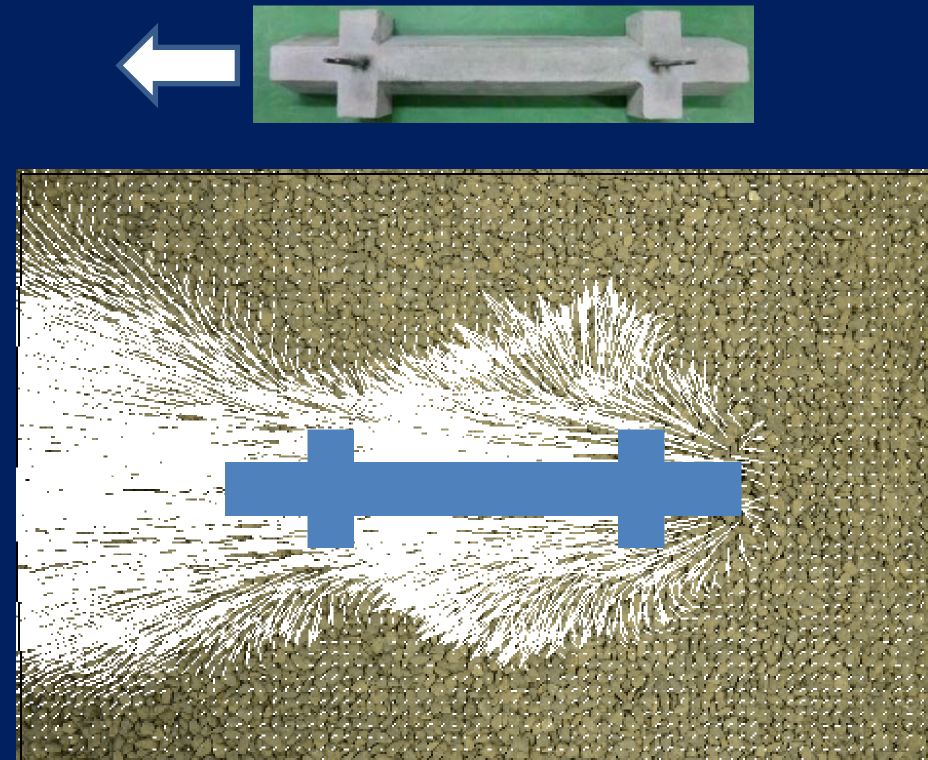
The idea that the lateral resistance measured at a horizontal displacement of 2.0 mm in full-scale (or 0.4 mm in 1/5-scale) single-sleeper pullout tests corresponds to that in track panel pullout tests is only valid for limited conditions.



Comparison of lateral resistances per sleeper obtained from track panel pullout tests and single-sleeper pullout tests



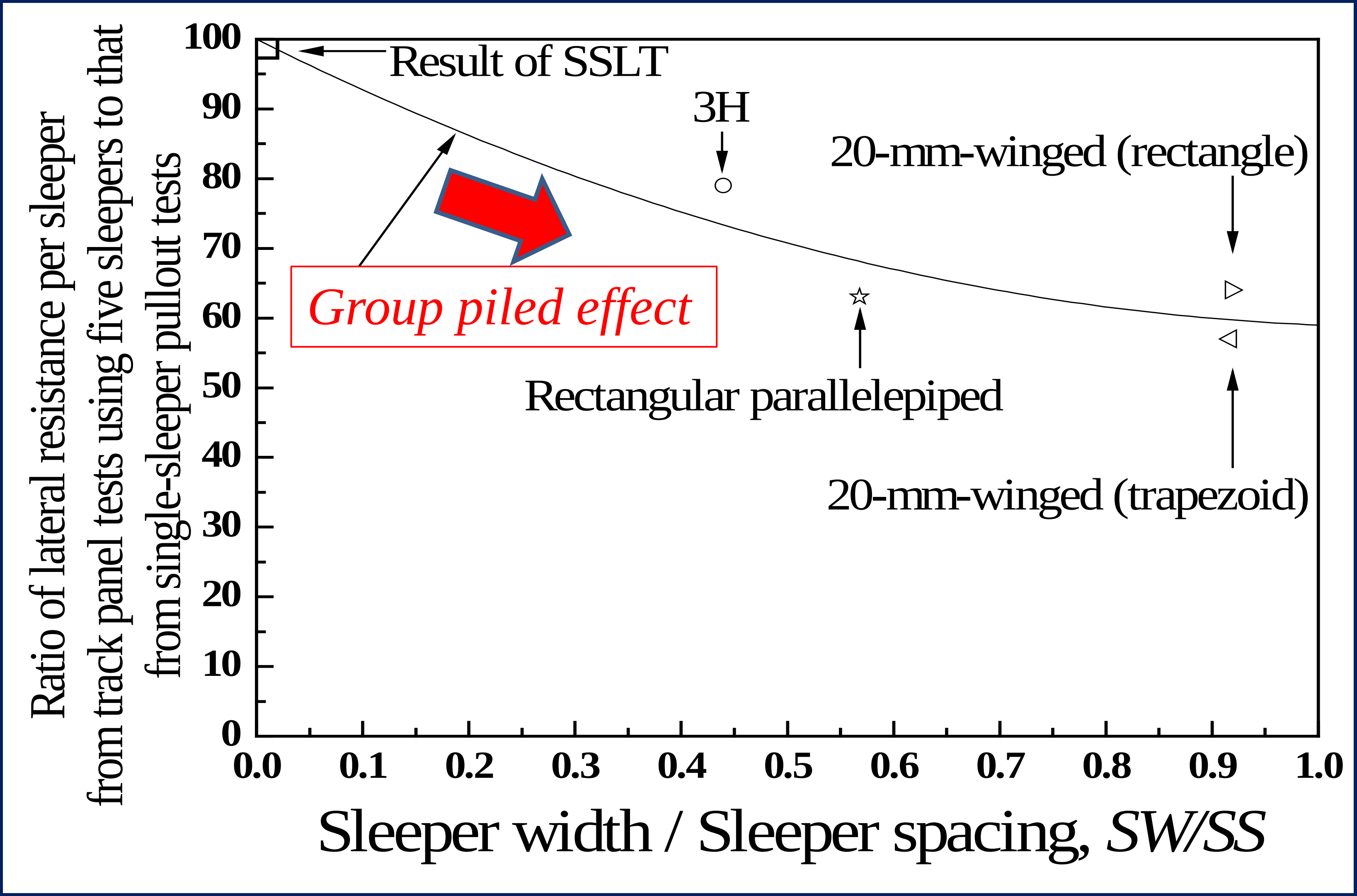
(a) 3H sleeper



(b) 20-mm-winged sleeper with trapezoidal ends

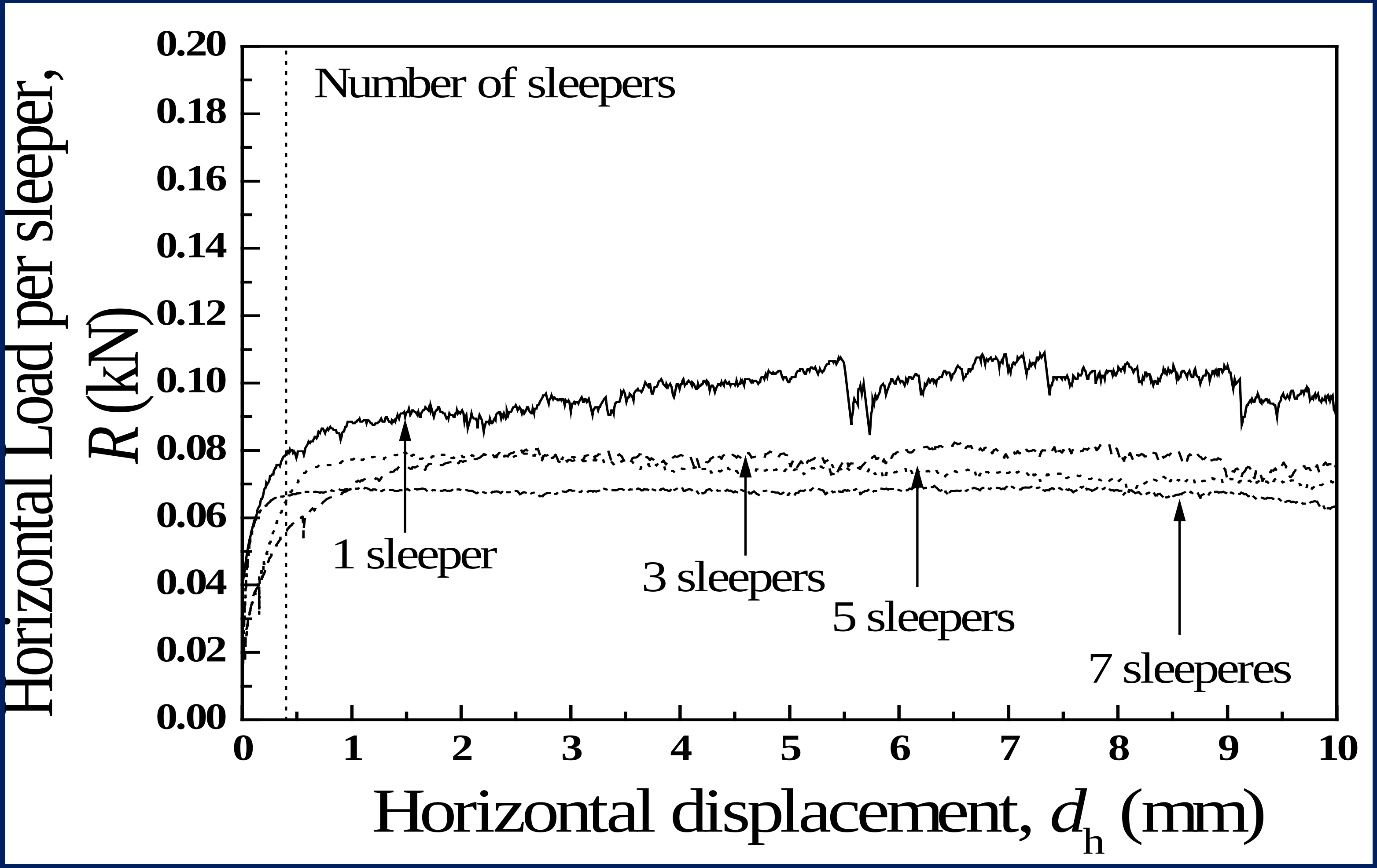
Displacement of ballast analyzed by *PIV* at 10 mm horizontal displacement of sleeper in single-sleeper pullout tests

Group piled effect

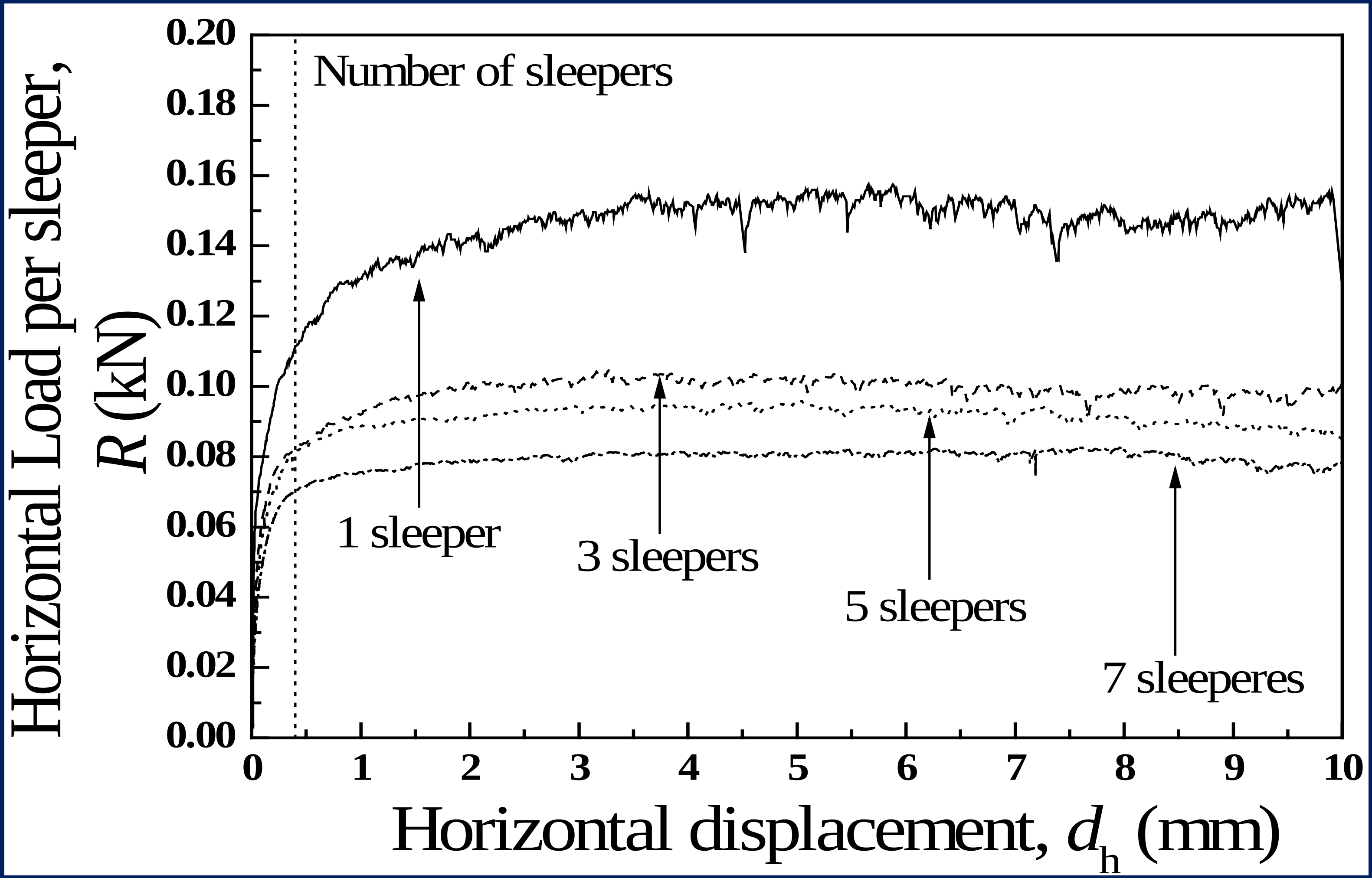


Relationship between ratio of lateral resistance obtained from *track panel pullout tests* to that obtained from *single-sleeper pullout tests* and normalized sleeper width

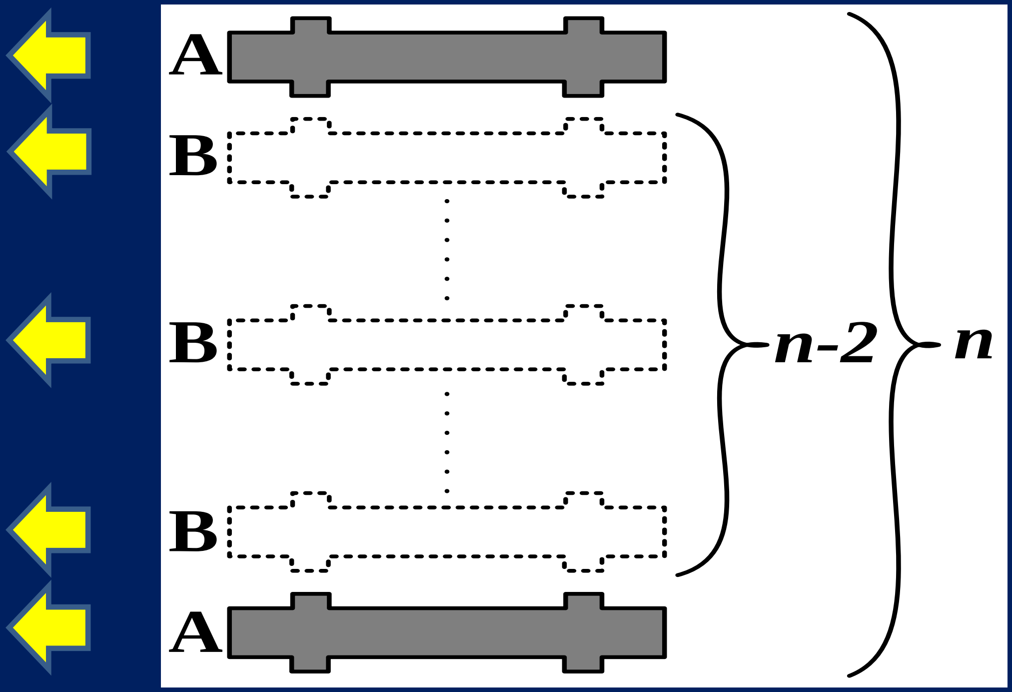
Lateral resistance obtained from pullout tests using different number of sleepers



(a) 3H sleeper



(b) 20-mm-winged sleeper with trapezoidal ends

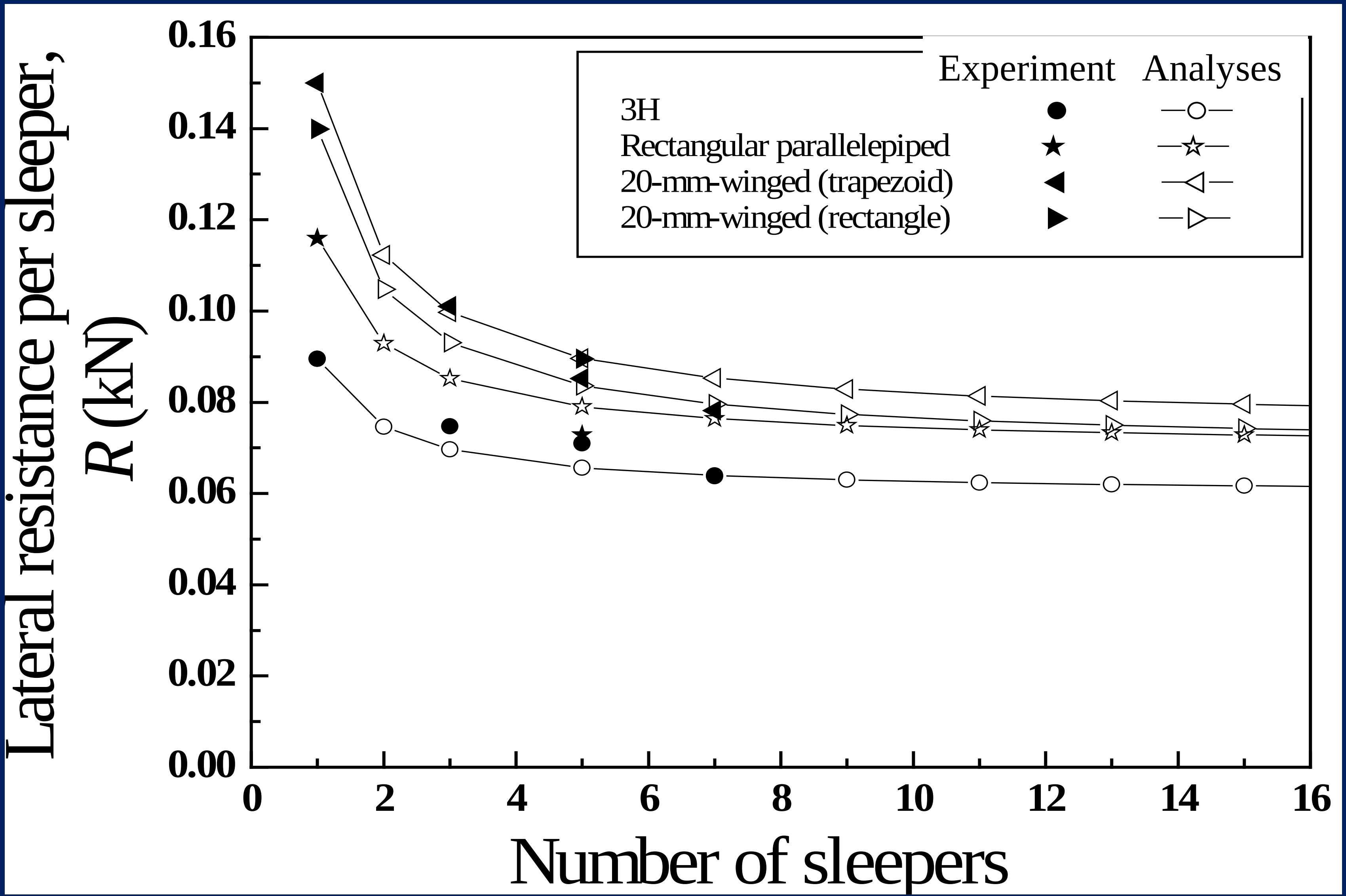


Simple calculation method for estimating the lateral resistance of sleepers in pullout tests for a wide range of numbers of sleepers;

$$R_n = 2R_A + (n - 2)\, R_B$$

$$= 2\alpha R_{single} + (n-2)\beta R_{single} \quad (n > 2)$$

$\alpha = (1 + \beta)/2$ is assumed.



Relationship between lateral resistance per sleeper and sleeper number in pullout tests

Outline

1) Background, objective and methodology

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- Sleepers, ballast
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4) Summary

Summary (1/2)

- The side frictional resistance, end resistance, and bottom resistance significantly affect the total lateral resistance of the sleepers. The prediction method proposed in RTRI 2012 is valid not only for conventional sleepers, but also for winged sleepers.

- However, the idea that the lateral resistance measured at a horizontal displacement of 2.0 mm in full-scale (or 0.4 mm in 1/5-scale) single-sleeper pullout tests corresponds to that in track panel pullout tests is only valid for limited conditions. This is because of the piled group effect in track panel pullout tests.

Summary (2/2)

- Because the degree of the piled group effect is controlled by the ratio of the sleeper width to the sleeper spacing, a significant reduction of lateral resistance may be observed in track panel pullout tests depending on the sleeper type.

- The lateral resistance per sleeper in track panel pullout tests reduces with increasing number of sleepers. This is due to the effects of boundary conditions and loading width.

- Based on the results of the model tests, a simple calculation method for estimating the lateral resistance of sleepers in pullout tests for a wide range of numbers of sleepers is proposed.

Contents

1) Effects of sleeper shape on lateral resistance of sleepers in railway ballasted tracks

2) Lateral resistance characteristics of sleepers in railway ballasted track subjected to angular folding at structure boundaries

Lateral resistance characteristics of sleepers in railway ballasted track subjected to angular folding at structure boundaries

Outline

1) Background and Objective

- Earthquake effects
- Differential displacement and angular folding at structure boundaries

2) Methodology

- Modelling of angular folding in the experiment
- Cyclic behavior of angular folding during earthquake

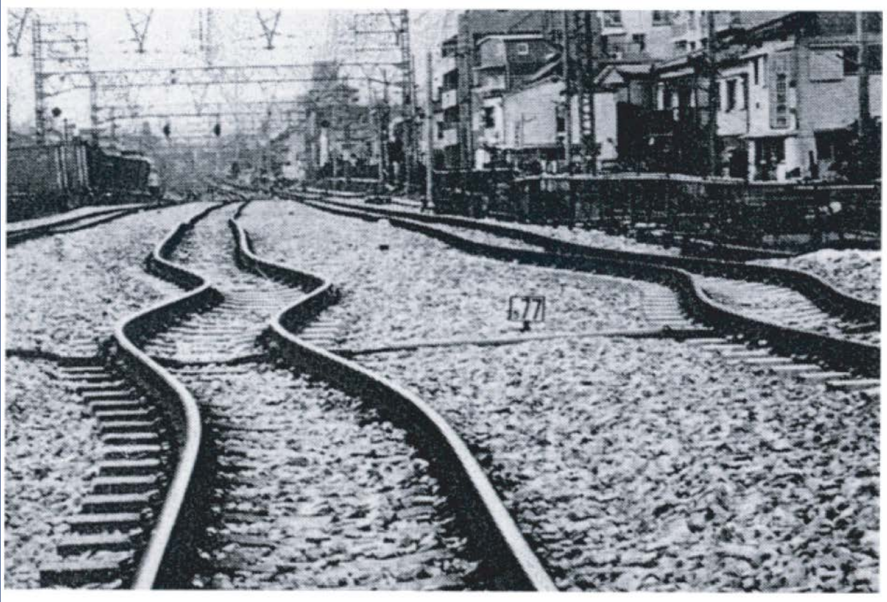
3) Single sleeper pull-out test

- Effect of open or close state on the lateral resistance
- Effect of number of cyclic angular folding on the lateral resistance
- Effect of angular folding angle on the lateral resistance

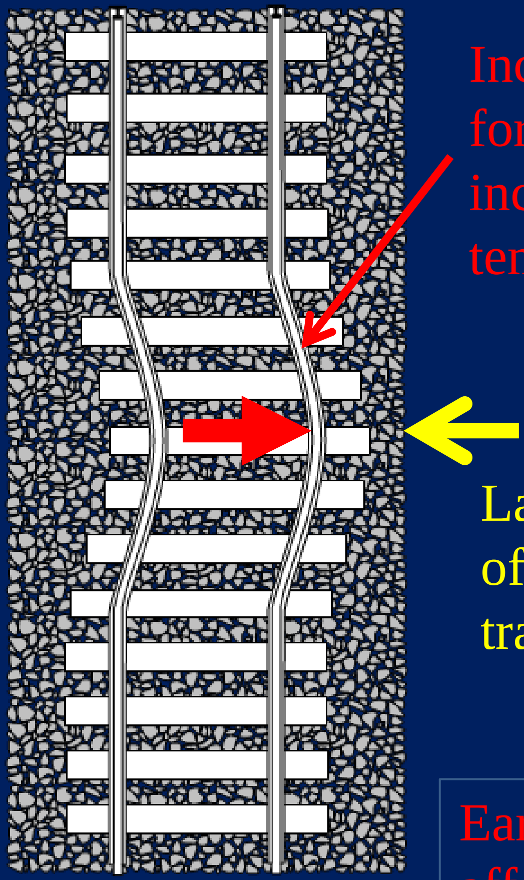
4) Track panel pull-out test

5) Summary

Background



Damage observed after an earthquake
(Momoya et al. 2013)



Increase of axial force with the increase of rail temperature

Lateral resistance of ballasted tracks

Earthquake may affect.

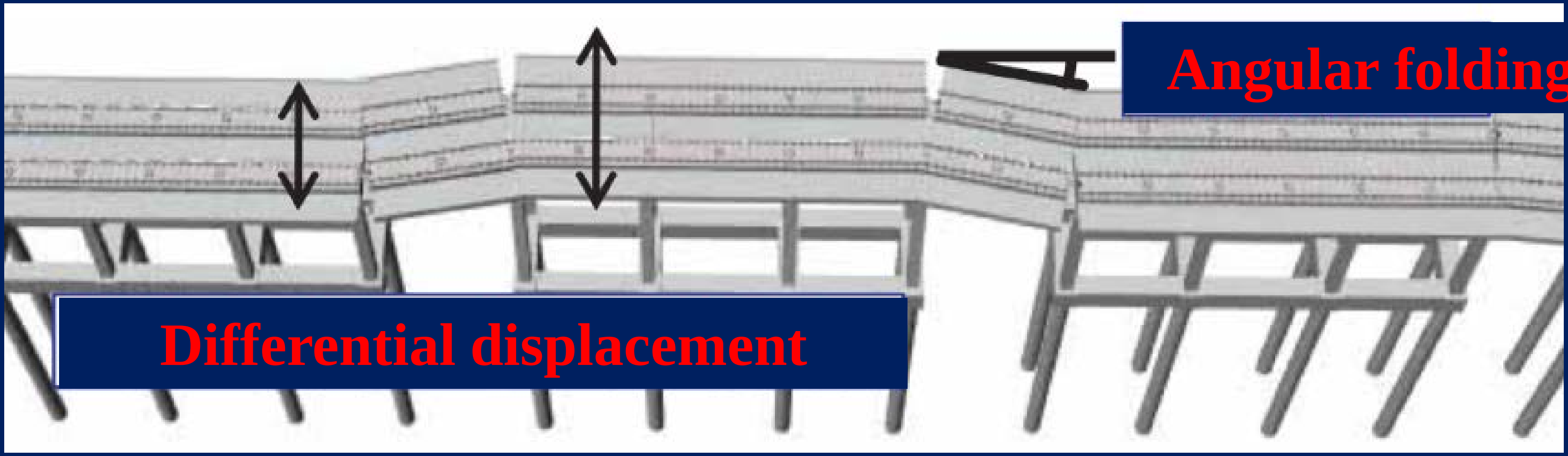
Lateral resistance characteristics subjected to earthquakes should be clarified so that appropriate countermeasures can be implemented.

Nakamura et al. (2014) conducted a series of shaking table tests on full-scale ballasted tracks. They found that lateral resistance was reduced during and after seismic motions.

Shaking table tests on a full-scale ballasted track

(Nakamura et al. 2014)

Railway tracks at structure boundaries have other problems.



Elevated railway bridges subjected to earthquakes

(Takahashi et al., 2008)

In addition to seismic vibration, local differential displacement or folding at structure boundaries may reduce the lateral resistance of ballasted tracks.

Objective

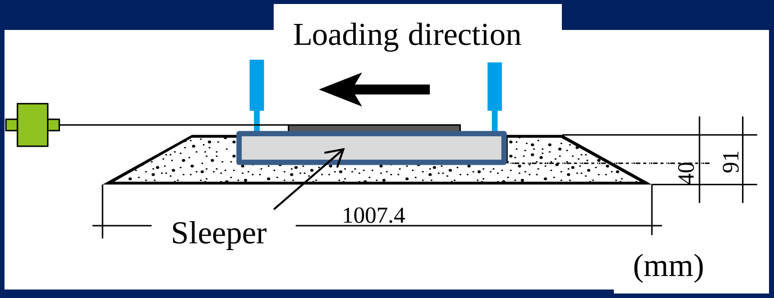
- To investigate lateral resistance characteristics of railway ballasted tracks subjected to angular folding at structure boundaries.

Outline

1) Background and Objective
   - Earthquake effects
   - Differential displacement and angular folding at structure boundaries
2) Methodology
   - Modelling of angular folding in the experiment
   - Cyclic behavior of angular folding during earthquake
3) Single sleeper pull-out test
   - Effect of open or close state on the lateral resistance
   - Effect of number of cyclic angular folding on the lateral resistance
   - Effect of angular folding angle on the lateral resistance
4) Track panel pull-out test
5) Summary

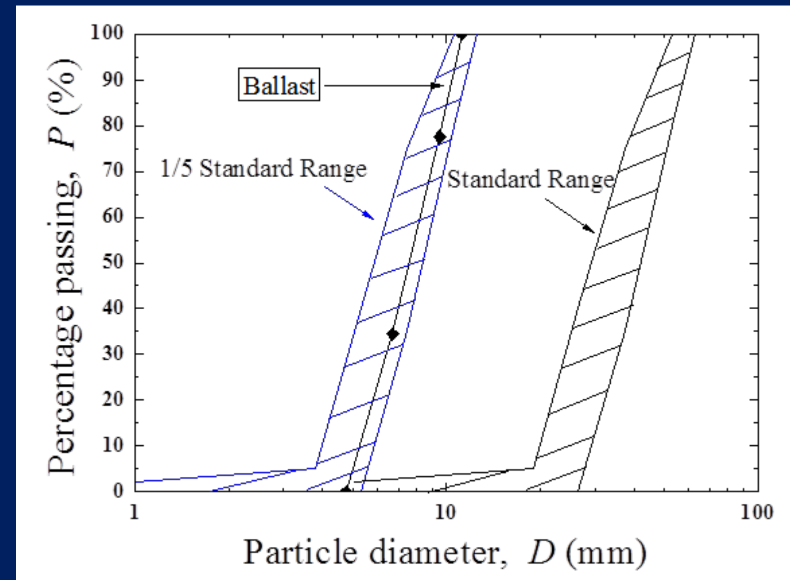
Methodology

- To conduct sleeper pull-out tests on small scale (1/5 scale) models.



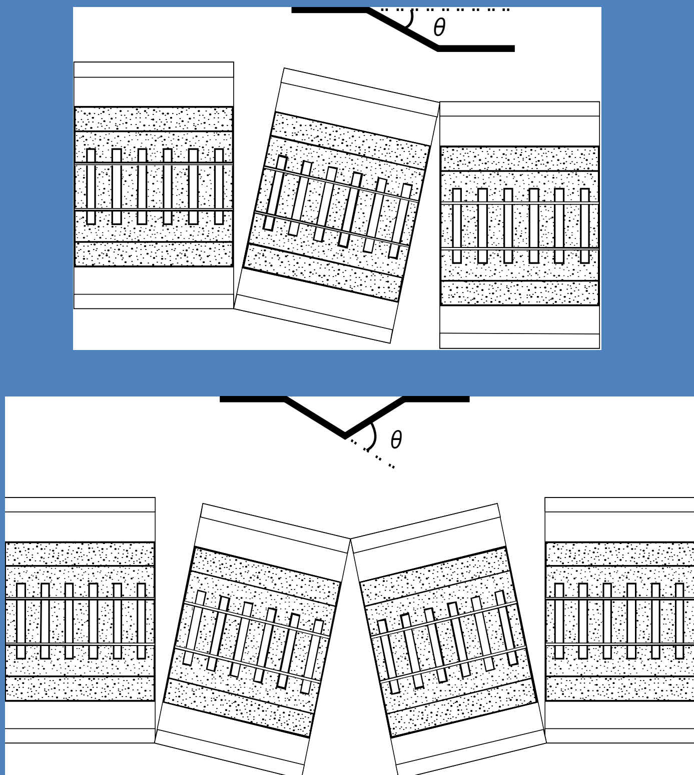
Track panel pull-out test on a 1/5 scale model

3H sleeper (1/5 scale)
(Mainly used for Shinkansen)

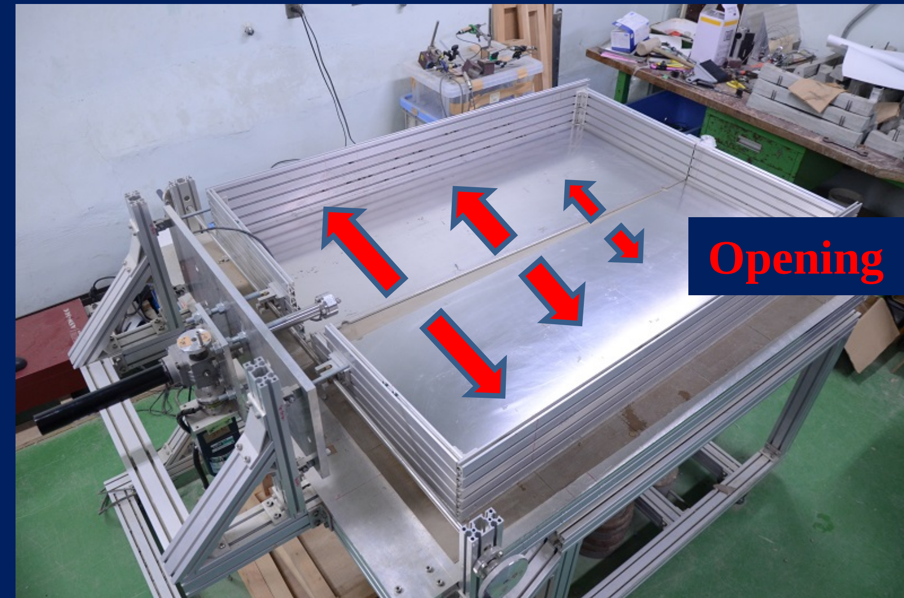


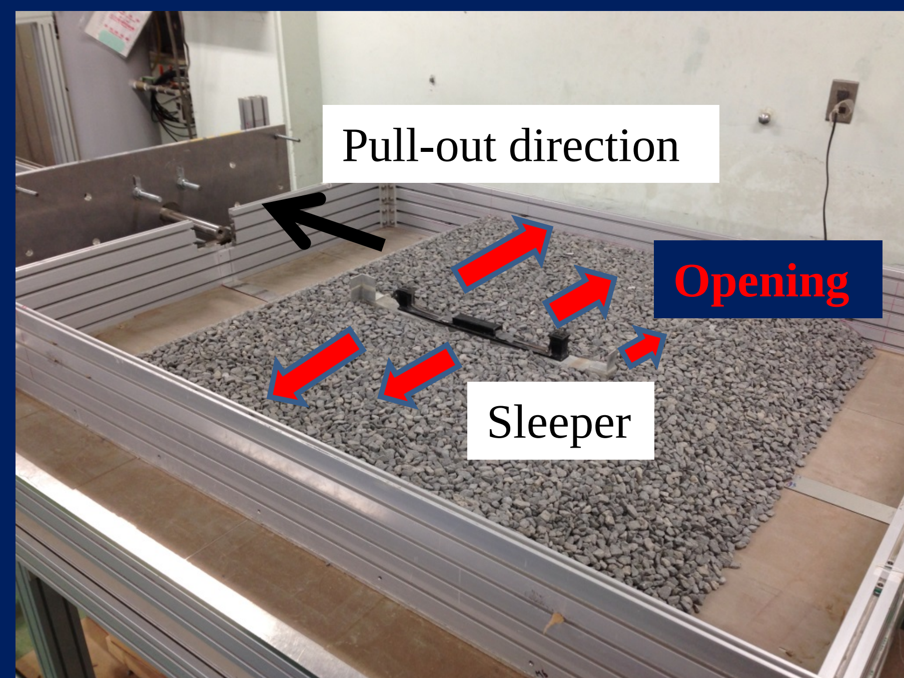
Crushed stones
(Andesite)

1/5 scale beds

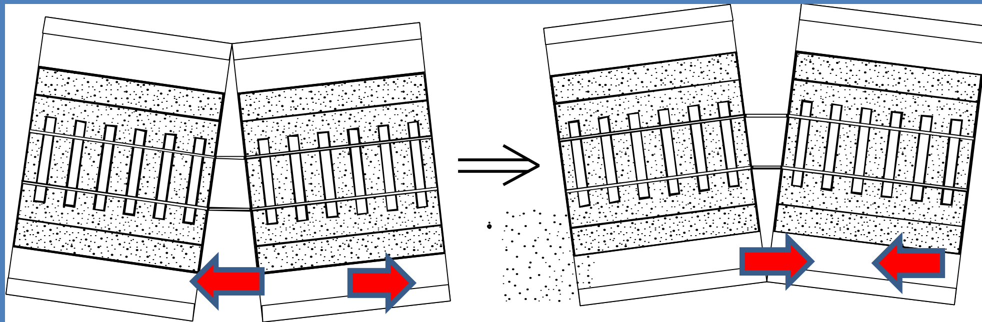


Ballasted tracks subjected to angular folding



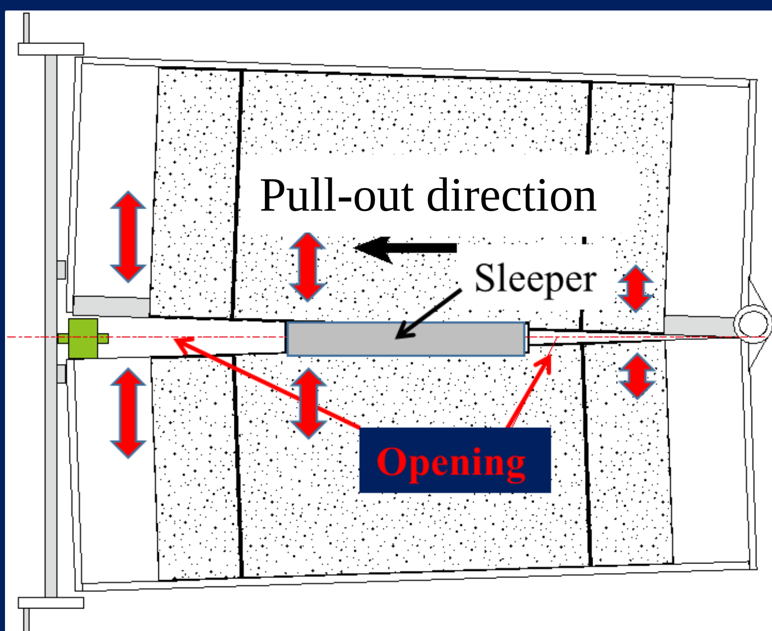


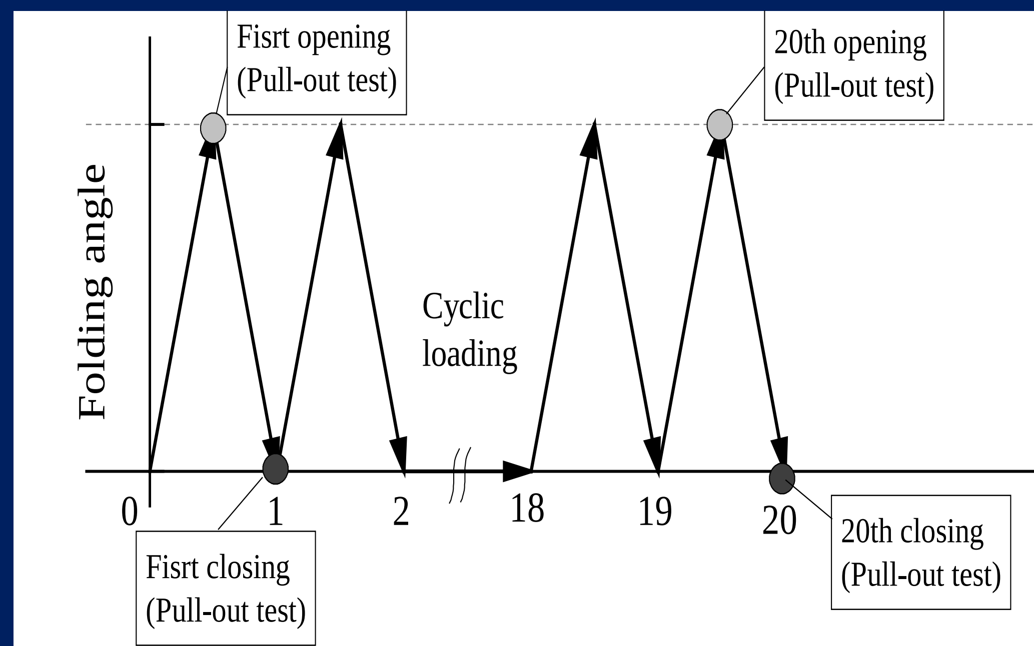
Modeling of angular folding in the experiment



Opening   Closing

Angular folding is repeated during an earthquake.
Opening or closing situation can be cyclically expected at boundaries.





Cyclic behavior of angular folding in model test and sleeper pull-out tests under opening or closing situation

Outline

1) Background and Objective

- Earthquake effects
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- Cyclic behavior of angular folding during earthquake

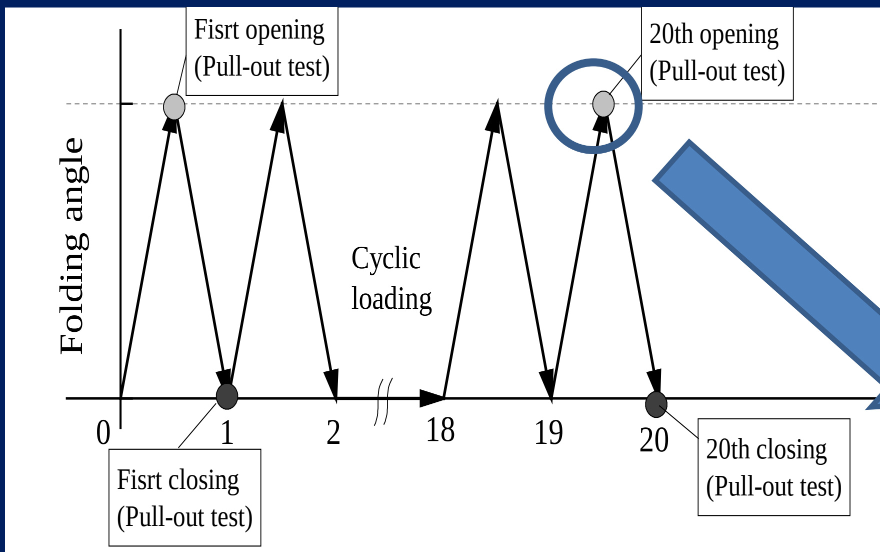
3) Single sleeper pull-out test

- Effect of open or close state on the lateral resistance
- Effect of number of cyclic angular folding on the lateral resistance
- Effect of angular folding angle on the lateral resistance

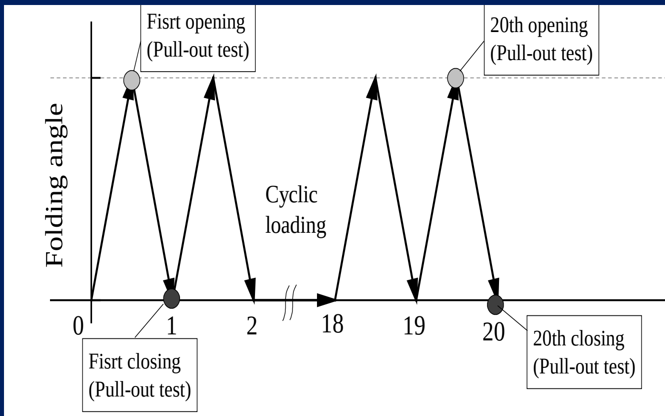
4) Track panel pull-out test

5) Summary

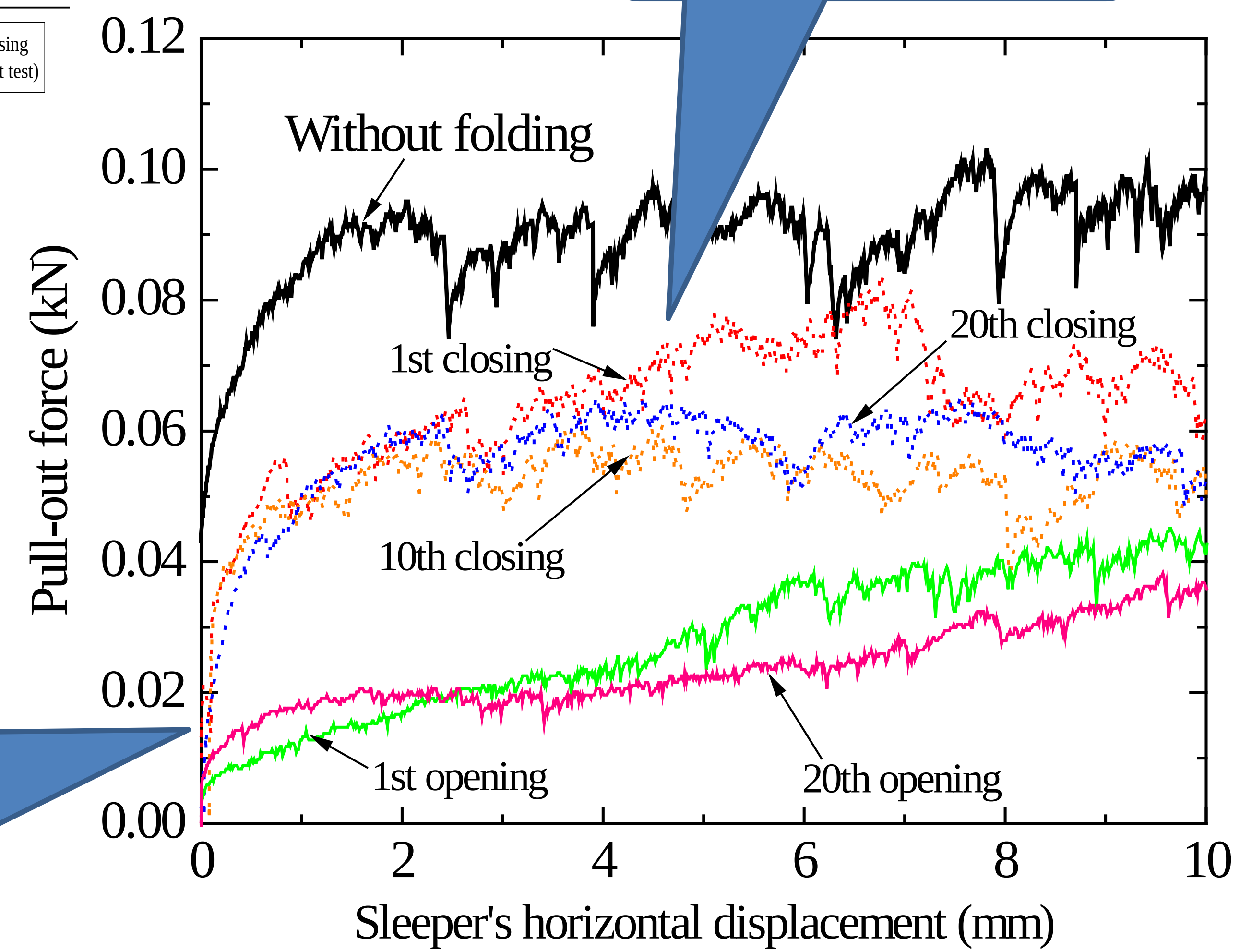
Single sleeper pull-out test



Single sleeper pull-out test at 20th open state

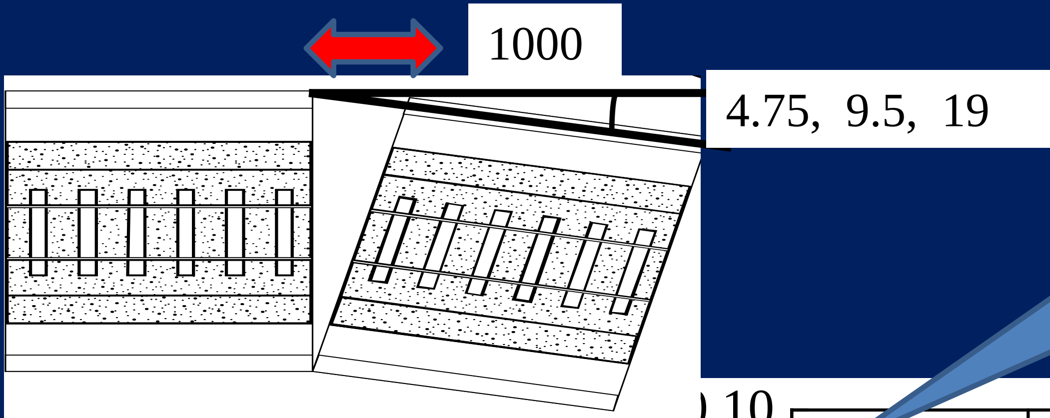


Angular folding experience reduced the lateral resistance.

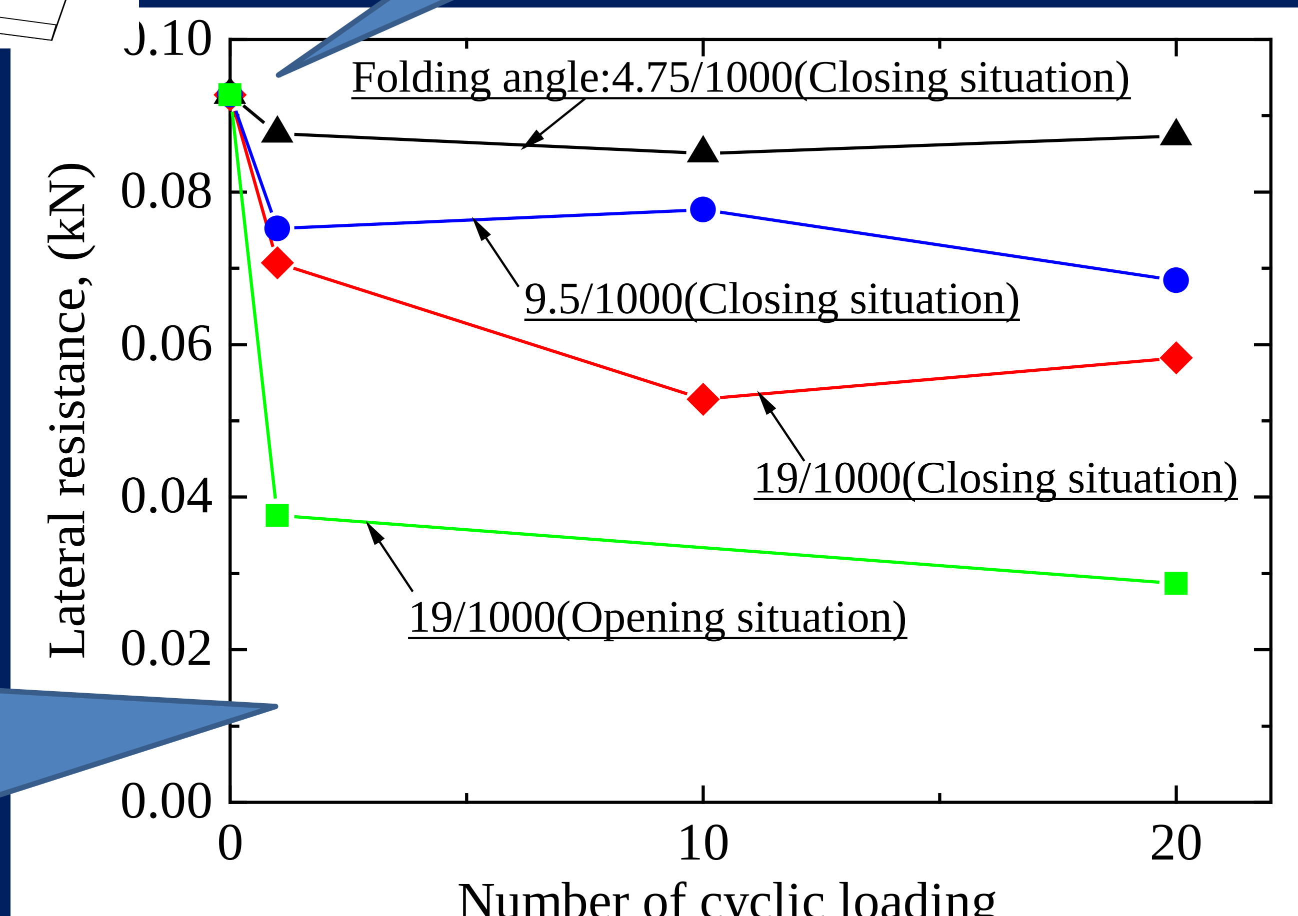


The lateral resistance was drastically reduced under the open situation.

Single sleeper pull-out test results(folding angle: 19/1000)



Lateral resistance might be reduced little beyond 1st loading (folding).

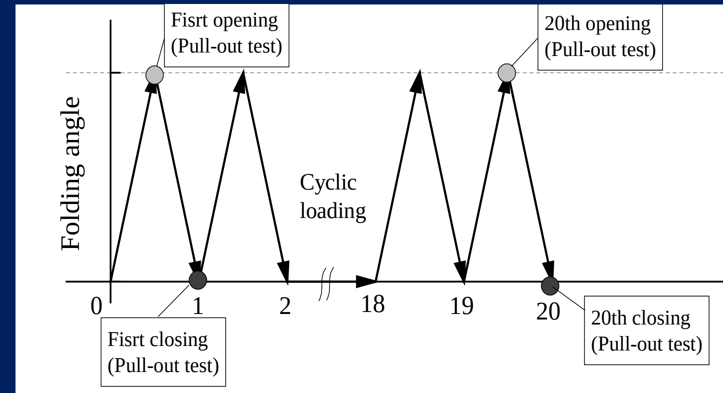


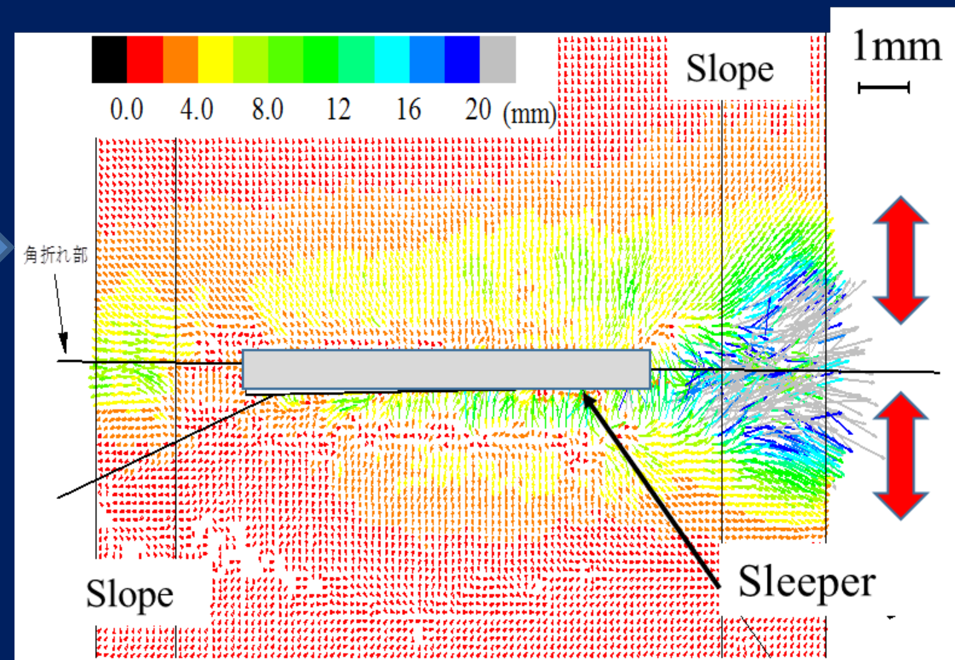
With increase of the folding angle, the lateral resistance was decreased.

Single sleeper pull-out test results

Before the start of 1st folding

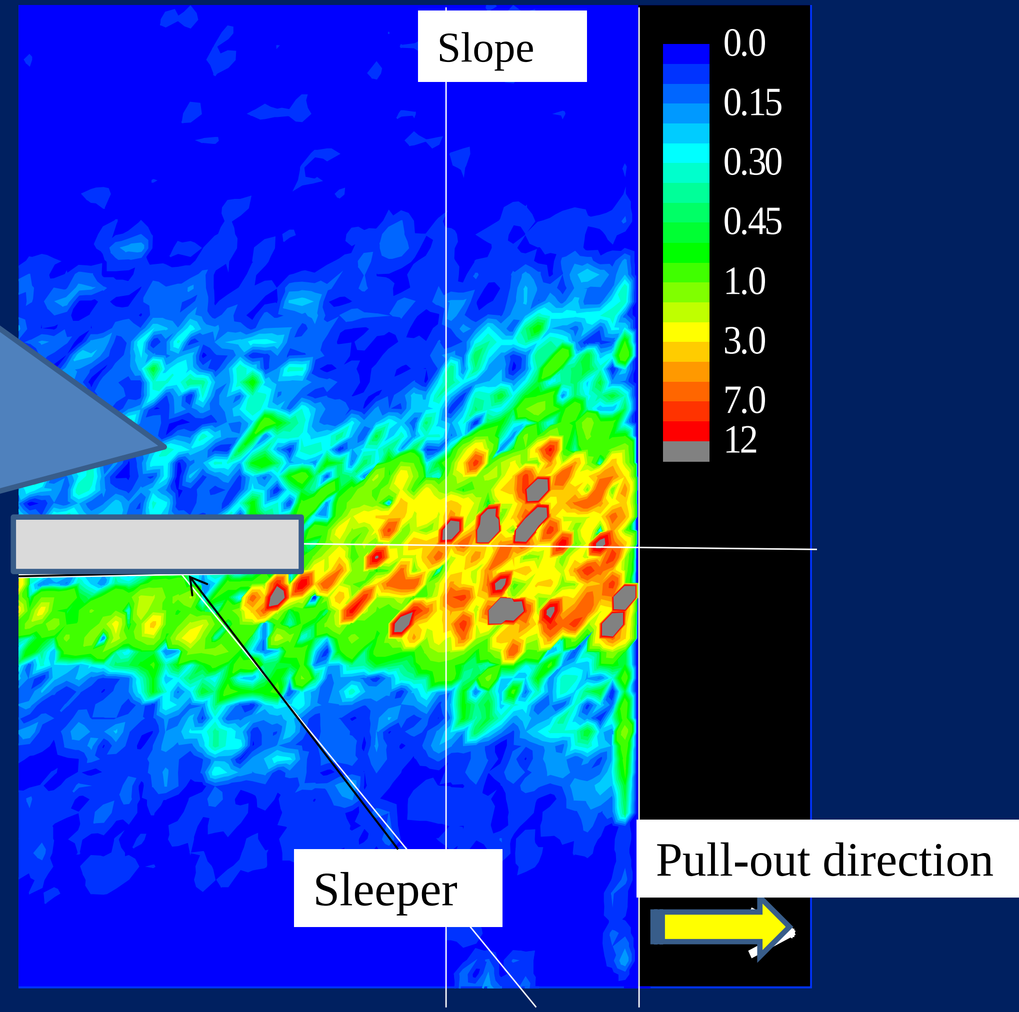
After the 20th cyclic angular folding



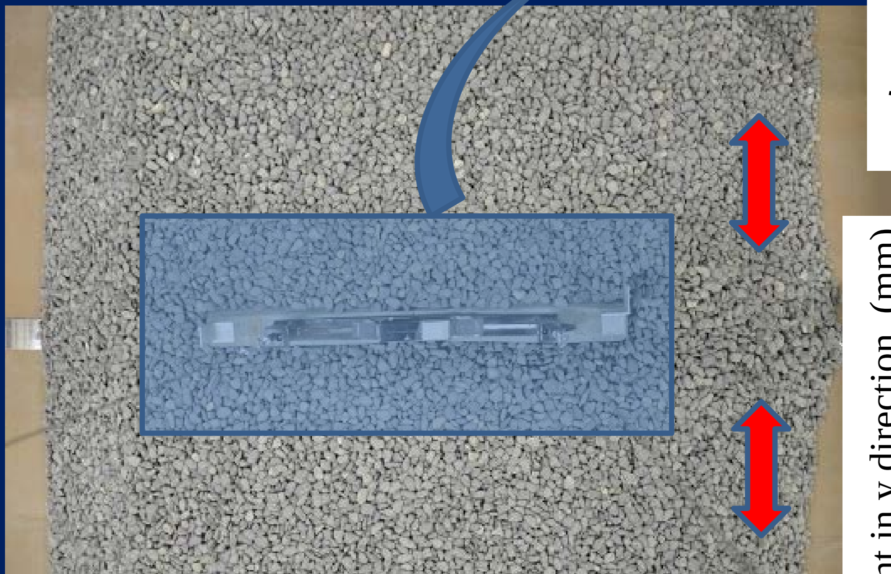


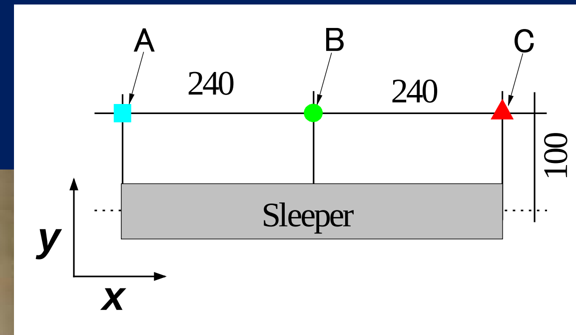
Accumulated displacements after the 20th angular folding from PIV

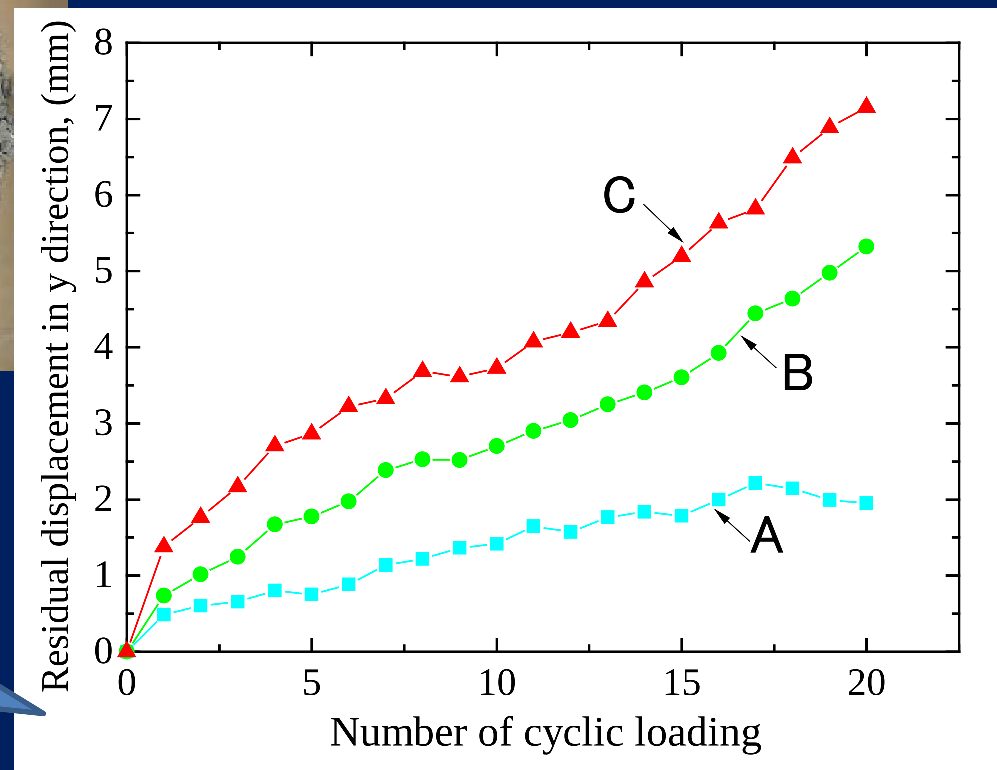
Shear strain was significantly developed near the sleeper end before pull-out loading.
The fact indicates that the bottom end resistance could be reduced before the start of pull-out tests.



Maximum shear strain distribution near the sleeper end after the 20th angular folding from PIV







Ballasts moved away from the sleeper side. The fact indicates that the side resistance could be reduced.

Residual displacements in y direction at points A, B and C near the sleeper side from PIV

Outline

1) Background and Objective

- Earthquake effects
- Differential displacement and angular folding at structure boundaries

2) Methodology

- Modelling of angular folding in the experiment
- Cyclic behavior of angular folding during earthquake

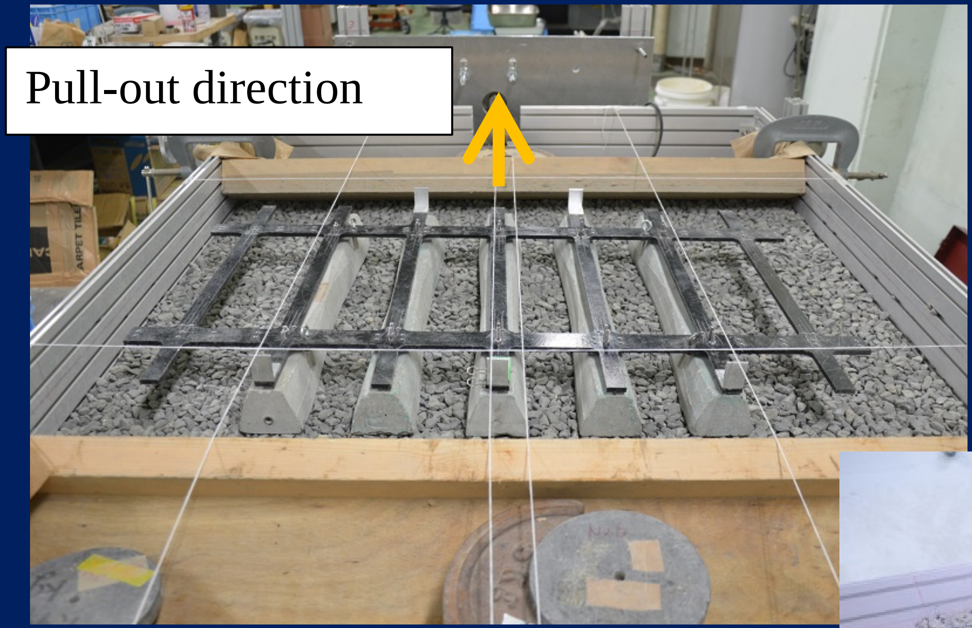
3) Single sleeper pull-out test

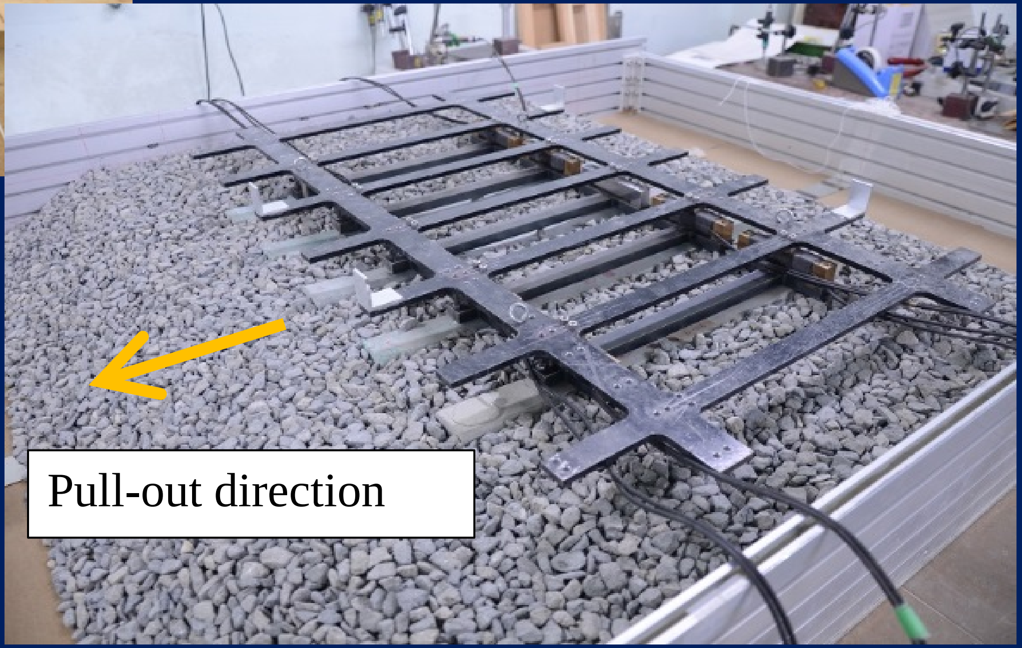
- Effect of open or close state on the lateral resistance
- Effect of number of cyclic angular folding on the lateral resistance
- Effect of angular folding angle on the lateral resistance

4) Track panel pull-out test

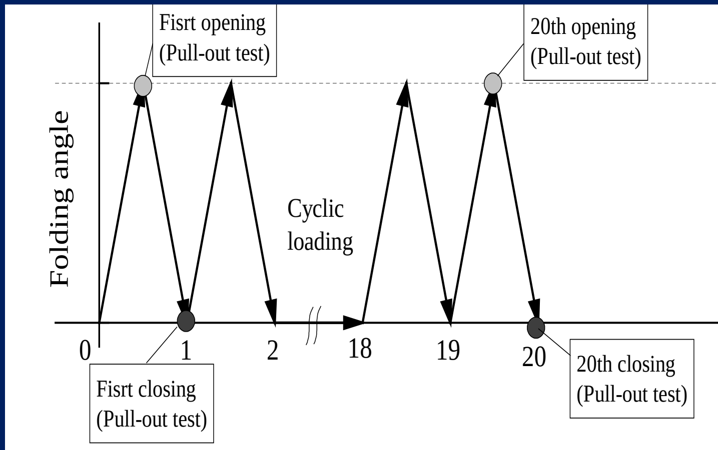
5) Summary

Track panel pull-out test

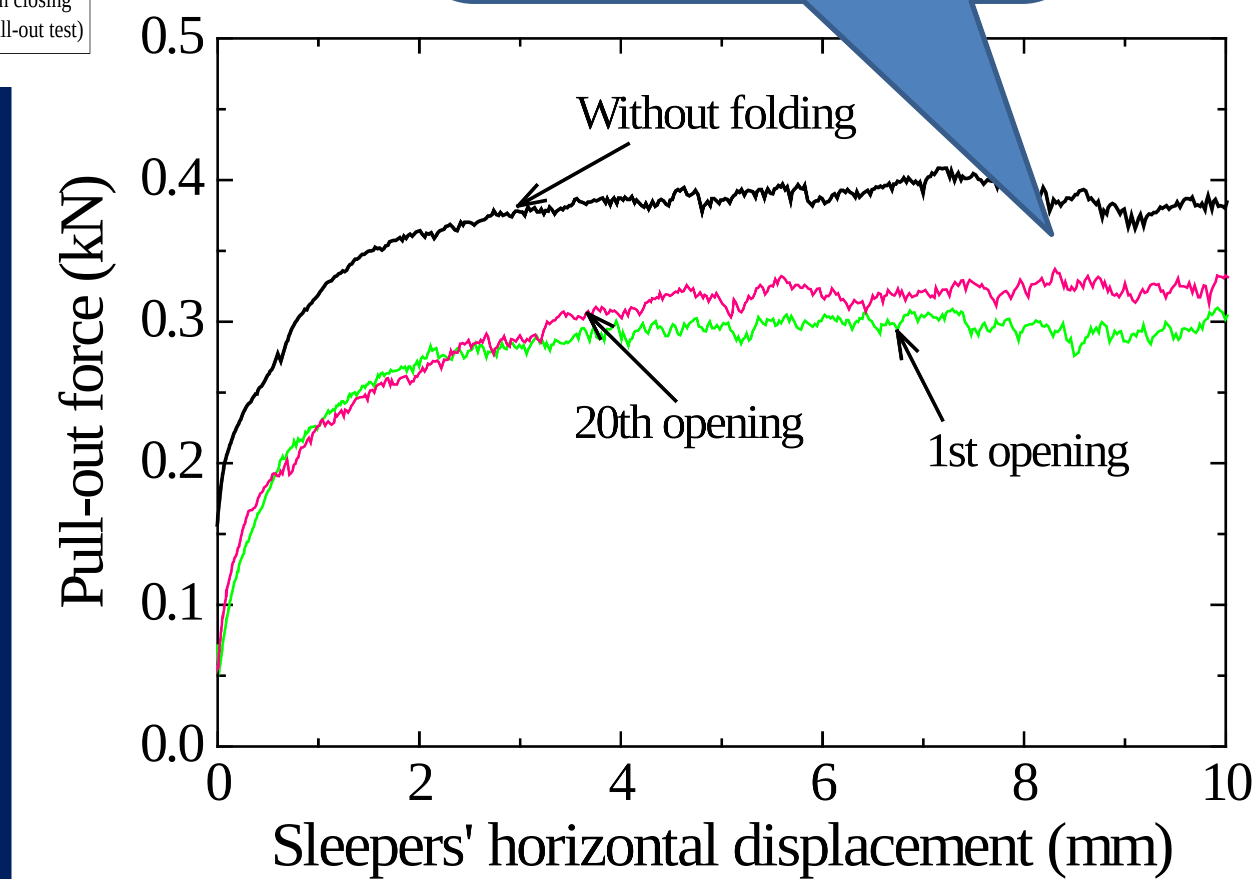




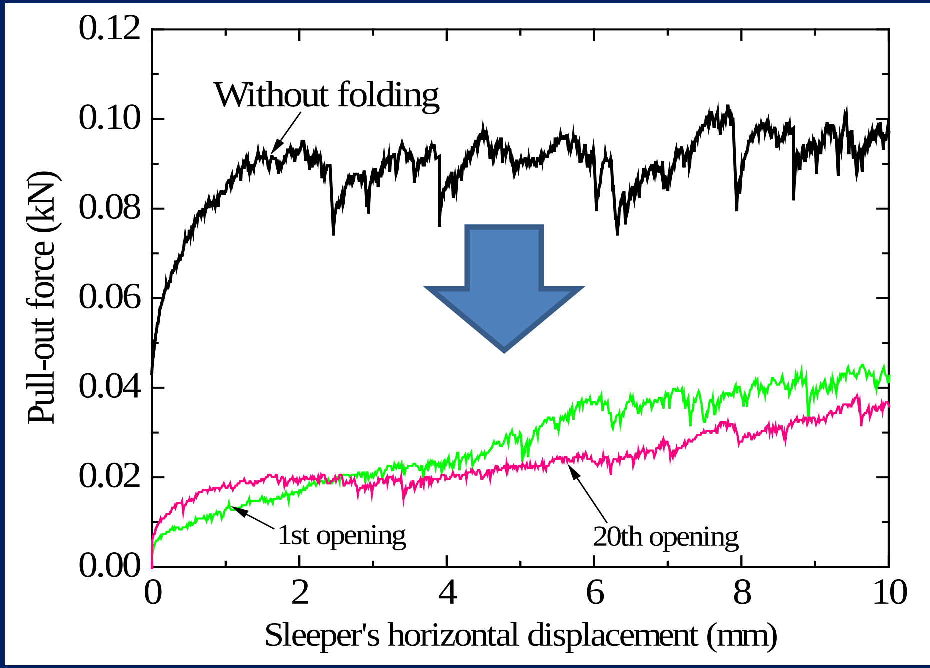
Track panel pull-out with 5 sleepers

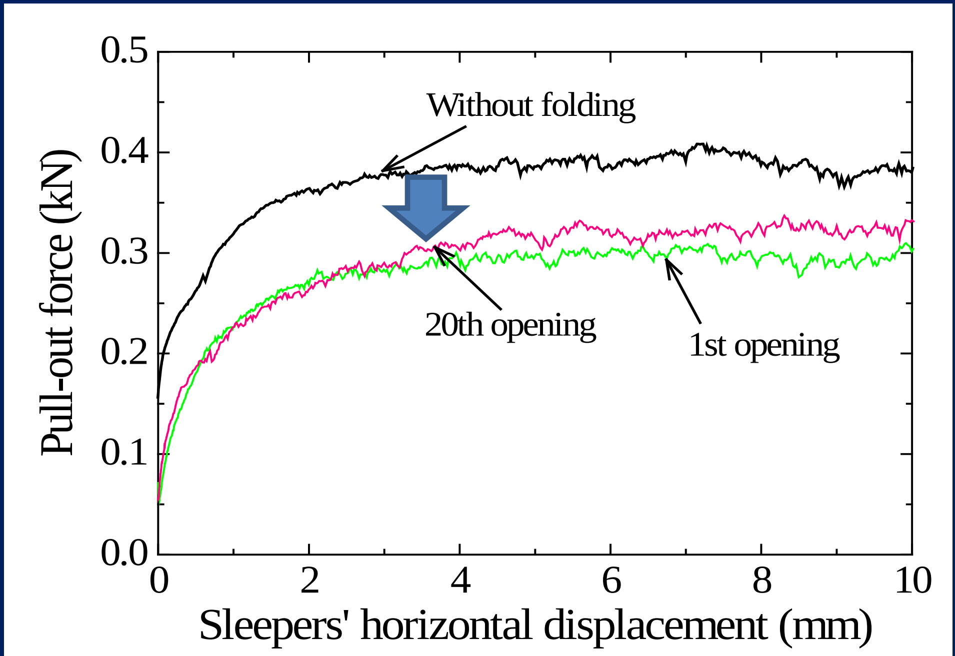


Angular folding reduced the lateral resistance.



Track panel pull-out test results(folding angle: 19/1000)



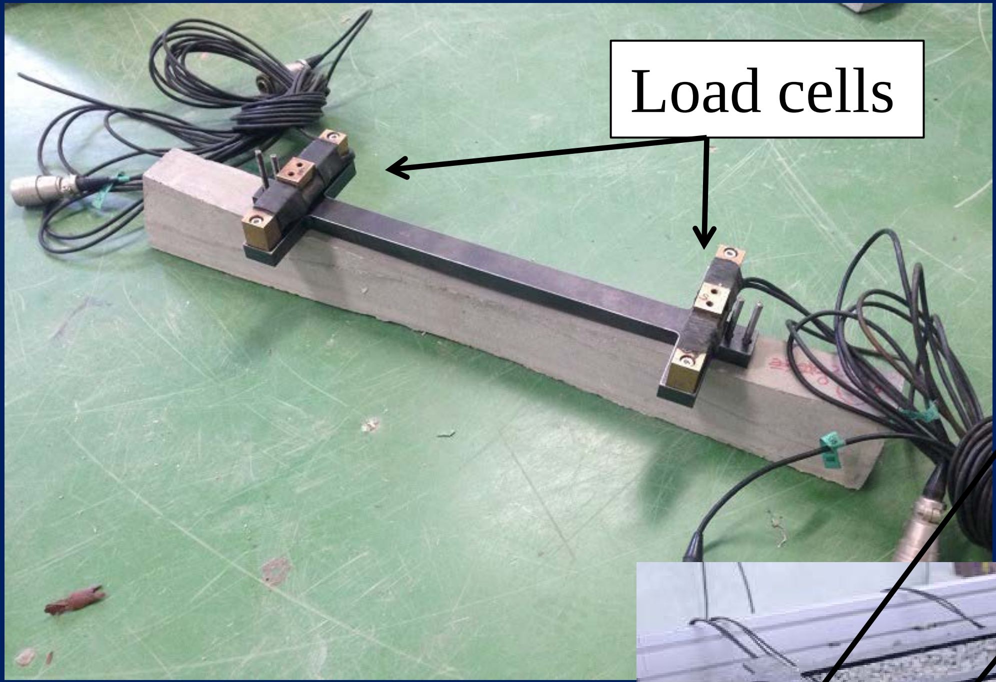


Single sleeper pull-out test results

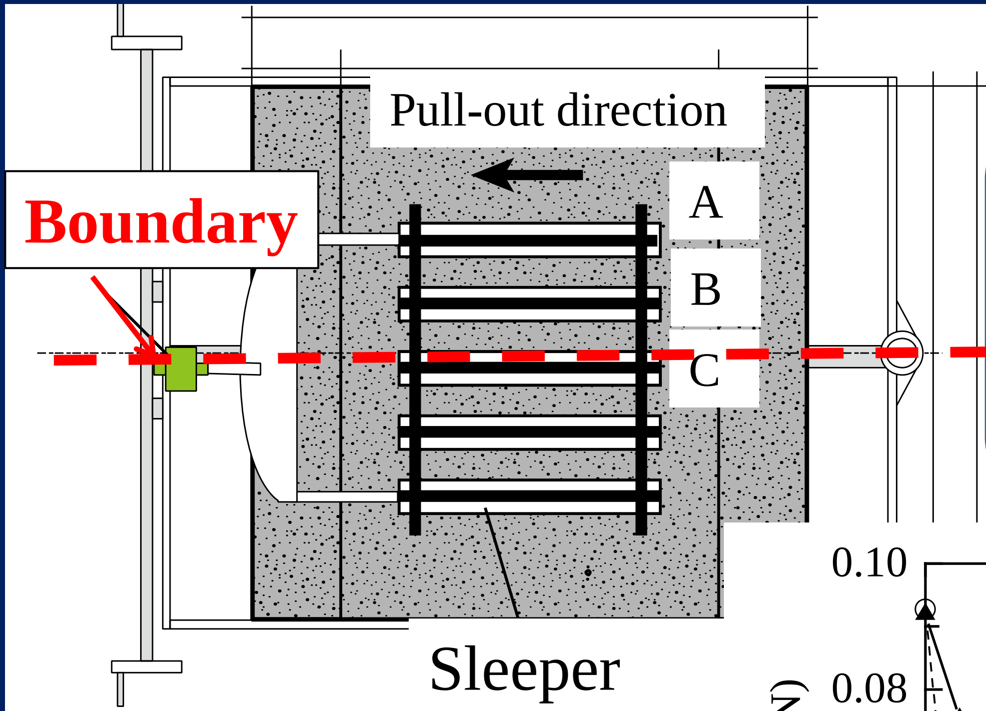
Track panel pull-out test results

(folding angle: 19/1000)

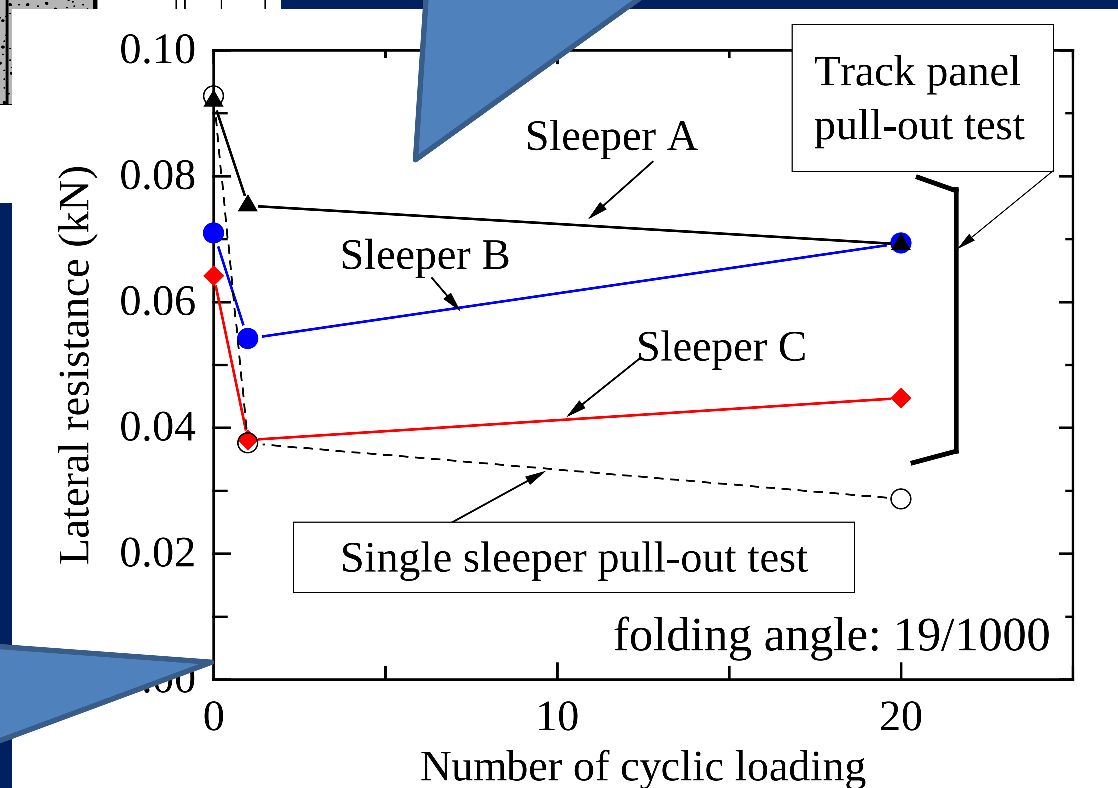
Reduction of lateral resistance was 60 -70 % in case of single sleeper pull-out tests while 20 – 25 % in case of track panel pull-out tests.



Load cells were installed on the sleepers so that lateral resistance of each sleeper could be measured in the track panel pull-out tests.

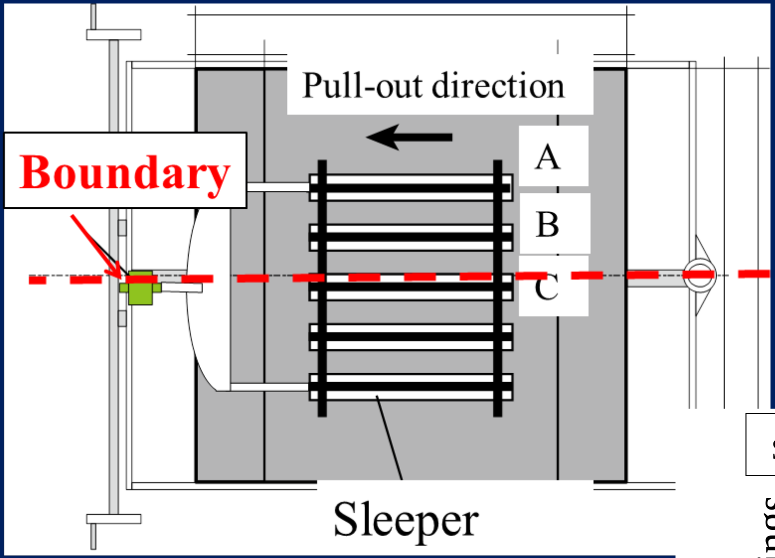


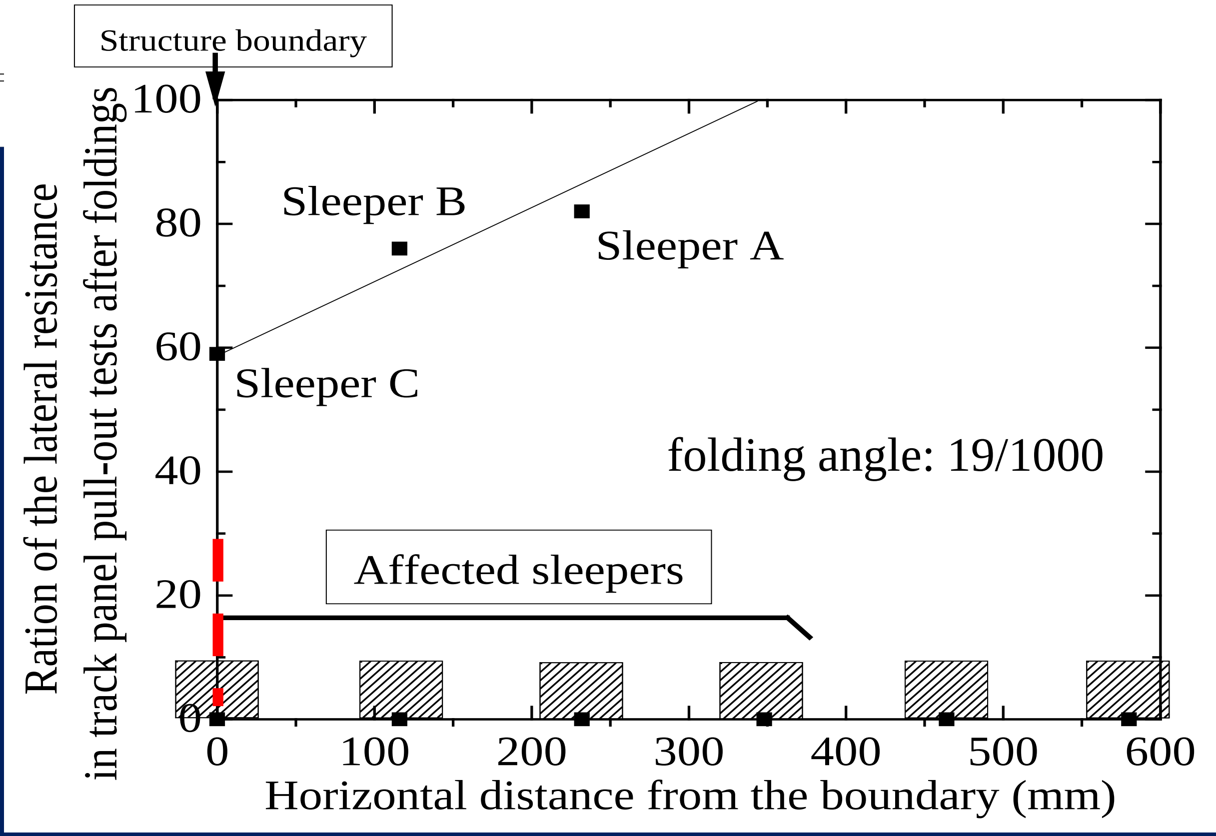
The more away from the structure boundary, reduction of the lateral resistance is less significant.



The lateral resistance of sleeper C just above the boundary is similar to that from the single pull-out test after folding.

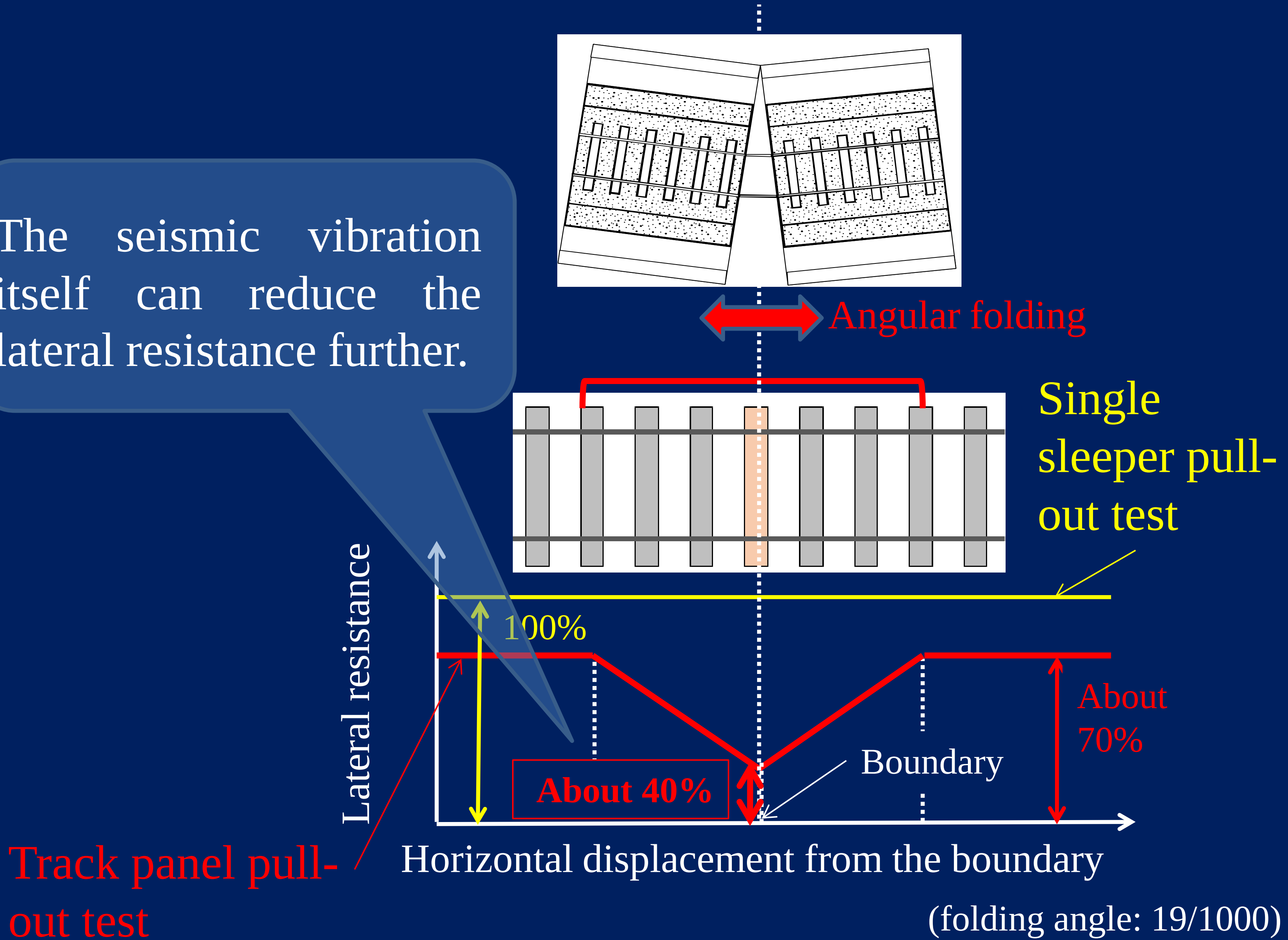
Change of lateral resistance of each sleeper





Ratio of lateral resistance of each sleeper before folding to that after folding

The seismic vibration itself can reduce the lateral resistance further.



Schematic image of the effect of angular folding on the lateral resistance in railway ballasted tracks

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- ･Effect of angular folding angle on the lateral resistance

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5) Summary

Summary

1. Physical modeling methods which simulate angular folding of ballasted tracks at structure boundaries were attempted.
2. Folding experience reduced the lateral resistance of ballasted tracks. With the increase of folding angle, the lateral resistance reduced.
3. The lateral resistance was sharply decreased by the first angulra folding, but reduced little beyond the first loading when the folding angle remained constant.
4. The more away from the structure boundary, reduction of the lateral resistance of the sleeper became less significant.
5. Based on the experimental results, track area affected by the angular folding was suggested. Reduction rate of the lateral resistance by the angular folding was also proposed.

Thank you very much
for your kind attention.

Please contact hayano@ynu.ac.jp for discussions.