Geotechnical Impacts of Ballast Fouling on Track Design and Maintenance in Japan

Session 3: Improvement and Maintenance

17:15-17:45, 28 August 2017, Main conference room

Tatsuya ISHIKAWA

Hokkaido University, Sapporo, Japan

Co-authors: Singo MATSUTANI, Hokkaido University
Tetsuya TOKORO, Tomakomai national college of technology
Takahisa NAKAMURA, Railway Technical Research Institute
Yoshitsugu MOMOYA, Railway Technical Research Institute

Table of contents

Track Design and Maintenance in Japan

Design standard of ballasted track in Japan

Design Standards for Railway Structures and Commentary (Track Structures)

- Published in 2012 under the supervision of the Ministry of Land, Infrastructure and Transport.
- First design standard for various types of track structures including ballasted tracks.
- Performance-based design method instead of specification-based design method.
- For the performance verification, limit state design method is introduced instead of allowable stress state design method.

Track condition of ballasted track

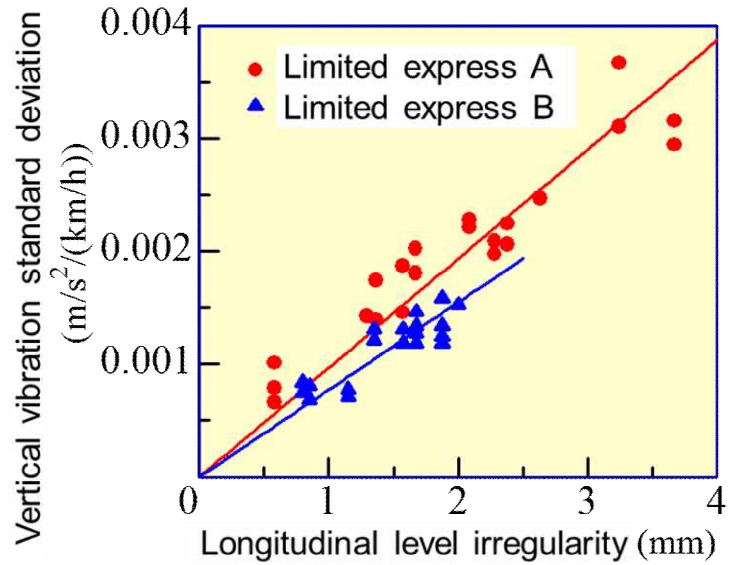
Design criteria of ballasted track

- Train vibration should be smaller than threshold limit value.
  - Traveling safety
  - Riding comfort
- Train vibration increases along with the increase in track irregularity.
- Train vibration can be estimated by

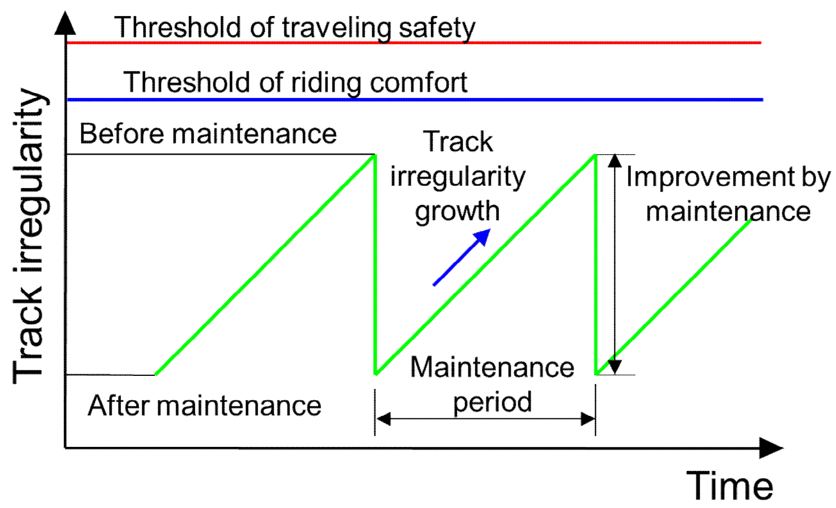
$$\alpha = a \cdot V \cdot \sigma$$

α: train vibration
V: train speed
σ: track irregularity

- Precise prediction of track irregularity growth is important for rational design & maintenance works of ballasted track.



Train vibration and track irregularity



Change in track irregularity with time

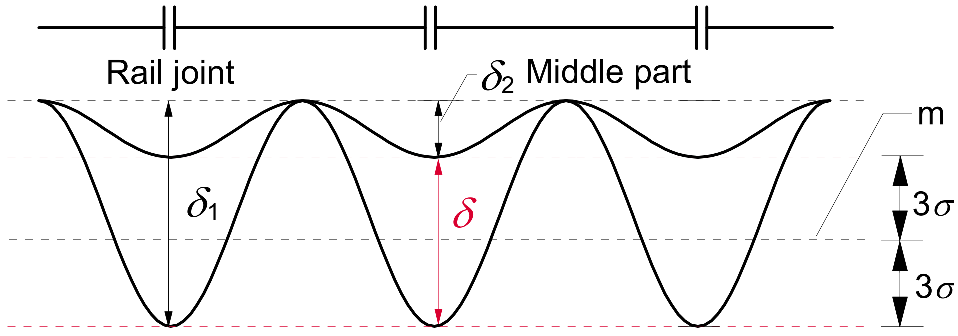
Design procedures of ballasted track

KEY POINTS : How do we calculate track irregularity using settlement?

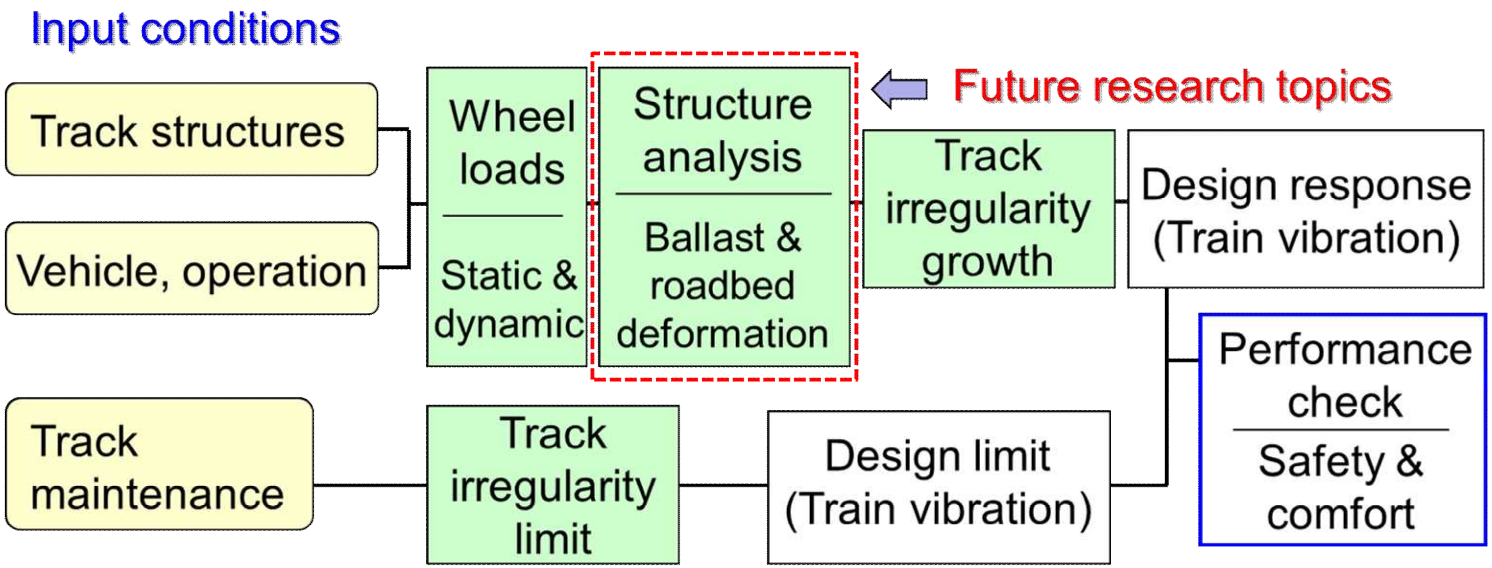
Assumption

- Track irregularity is defined by the difference between rail settlement at rail joint and that at middle part.
- Standard deviation of track irregularity can be estimated by

$$\delta = m + 3\sigma = 6\sigma$$

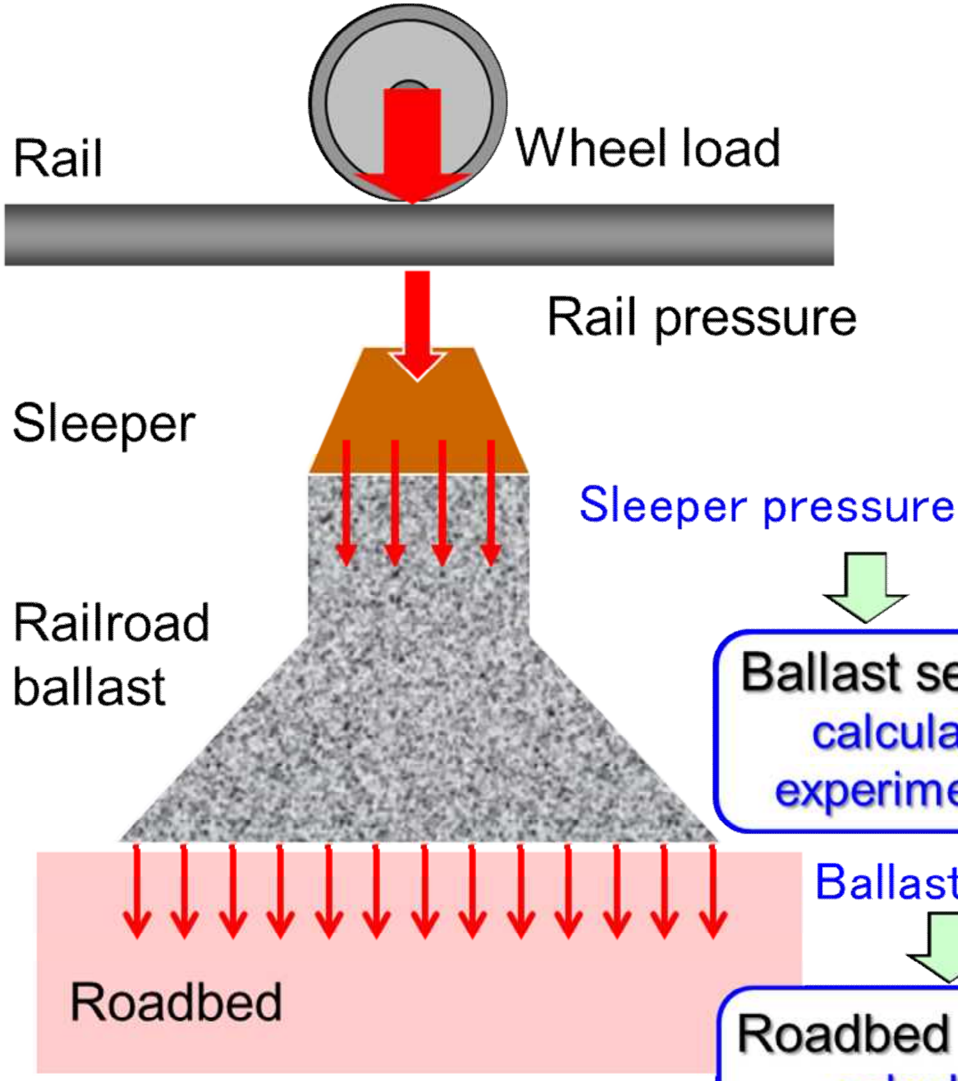


Rail settlement and track irregularity



Flow of design procedures for ballasted track

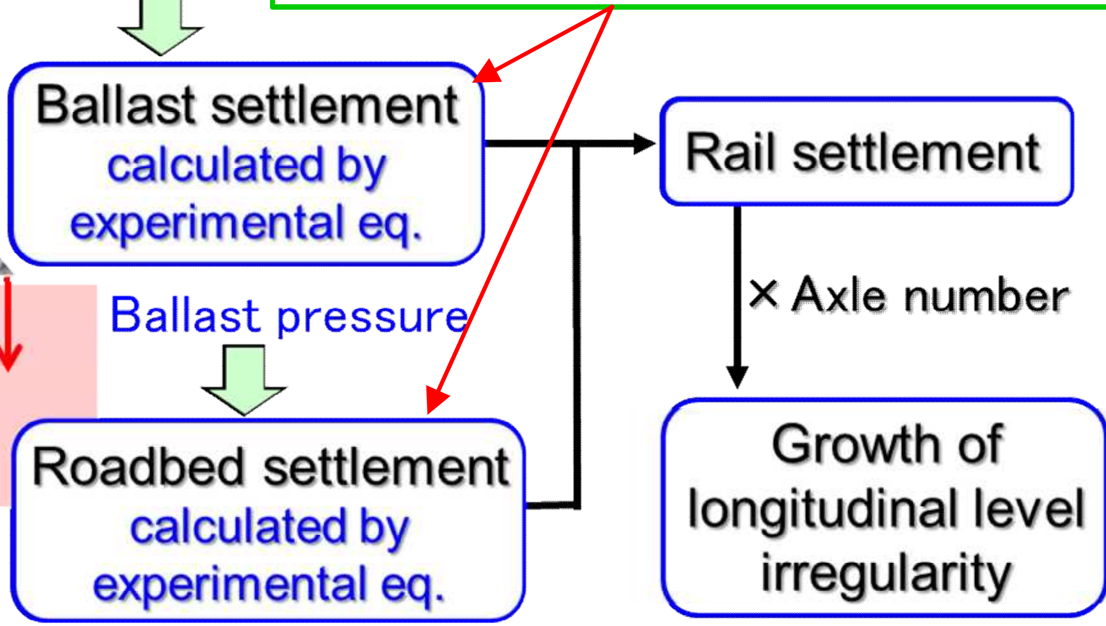
Improvement of design standard



Key Point

- Does a factor not considered in design standard have a serious impact on the development of track irregularity?

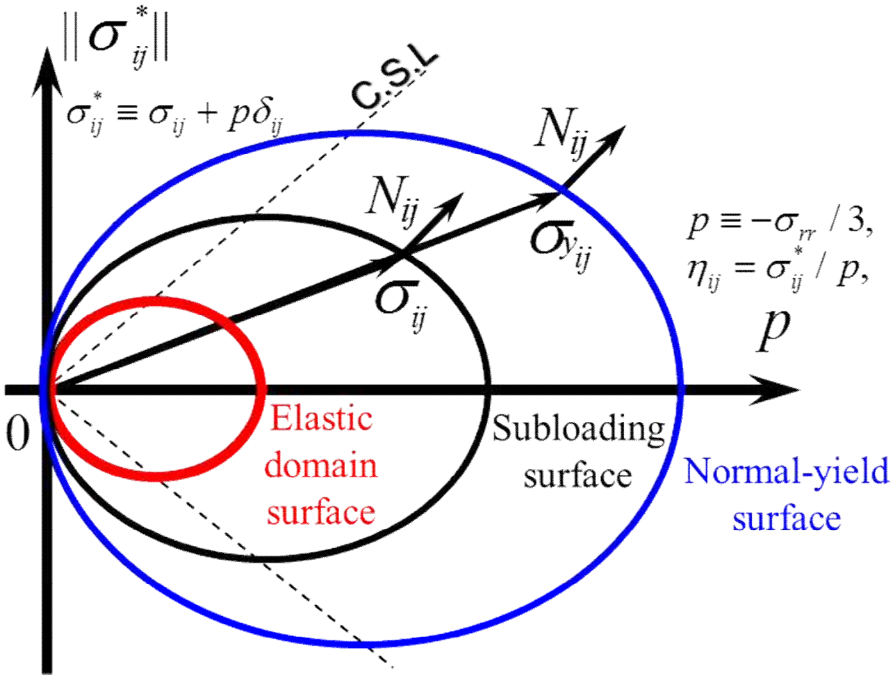
e.g. moving wheel load, water content, fine content, high speed loading, etc.

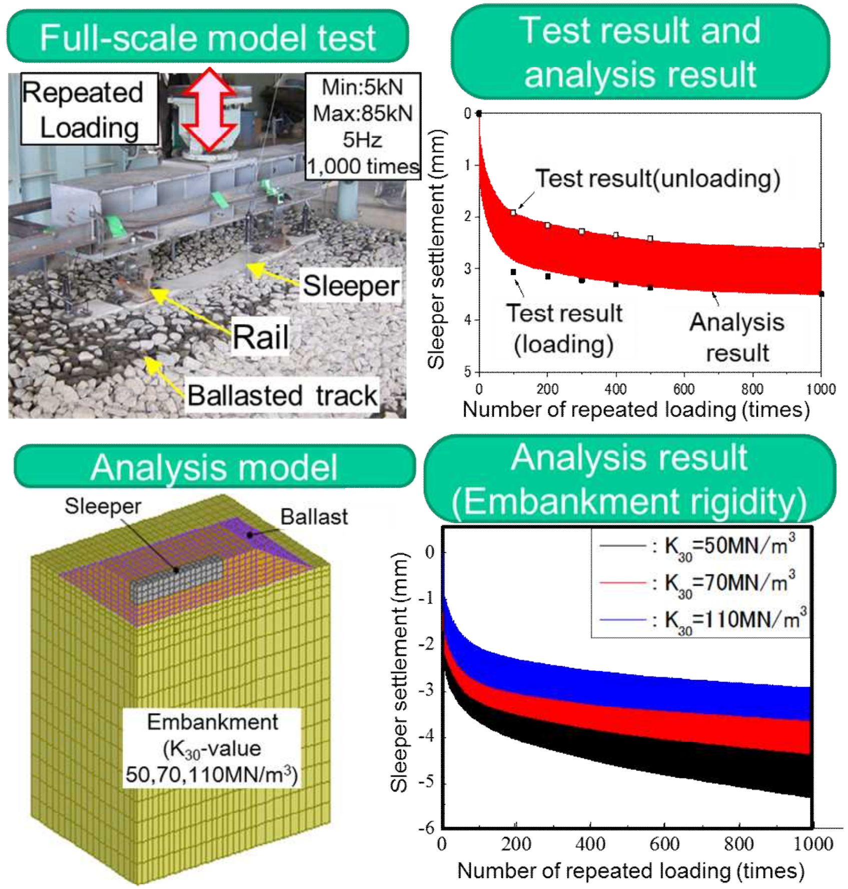


Calculation of rail settlement in Japanese design standard

Introduction of new constitutive law

Subloading Surface Extension Model





Okayasu et al. (2016)

- Subloading Surface Extension Model can predict cyclic plastic deformation of full-scale model test with new railroad ballast in air-dried condition.
- When using this numerical simulation, the material properties which do not consider in laboratory element tests carried out cannot be reproduced.

Background & Objectives of Research

Background of Research (1)

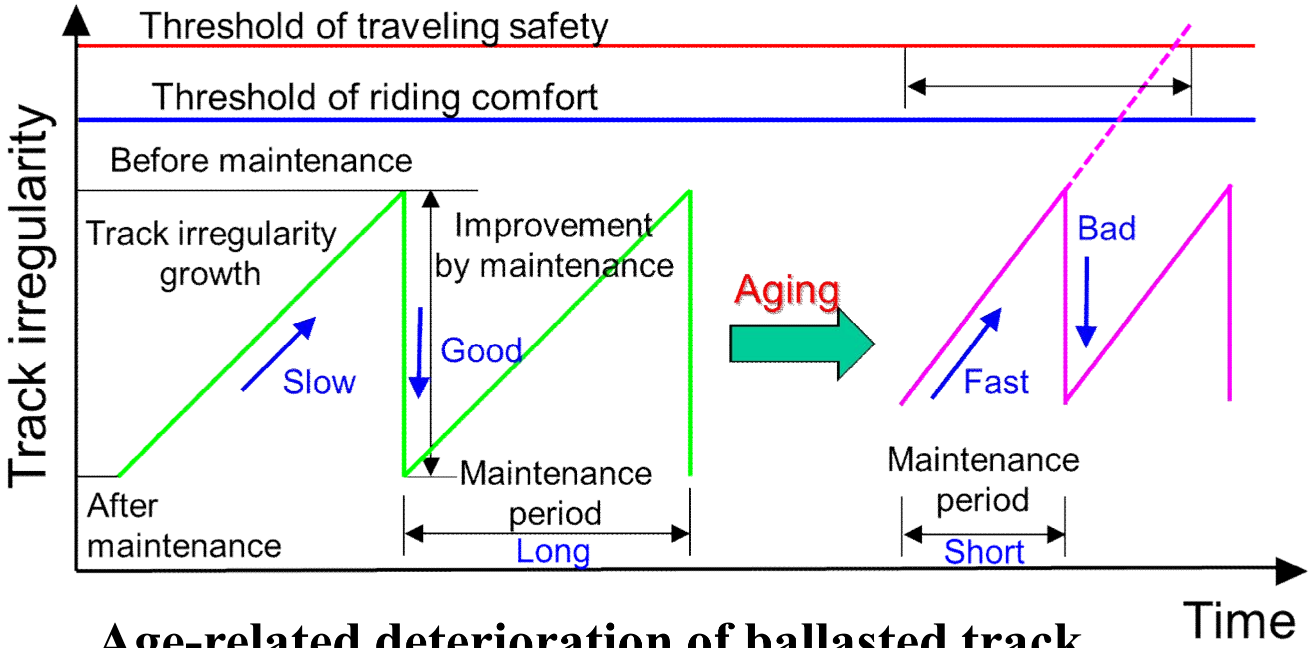
KEY POINTS :

- **How long is service life of track structures designed in present design standard?**
- **Does present design standard apply to maintenance for aged existing line?**

Fouled ballasted track in existing line

ANSWER :

- Japanese design standard does not consider age-related deterioration.
- **To improve the applicability, what kinds of research topics should be examined?**



Age-related deterioration of ballasted track

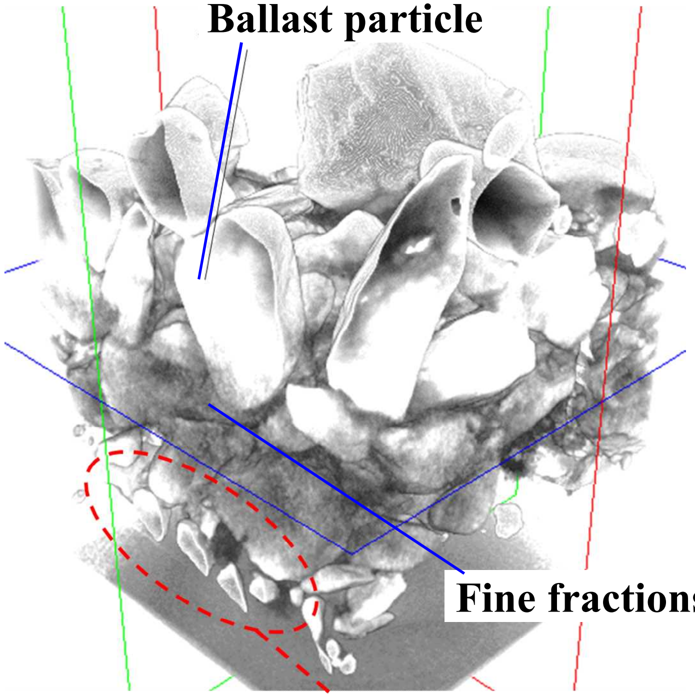
Age-deteriorated railroad ballast

Fouled ballasted track
in aged existing line

Sampling

Ballast sample by Wax–coating method

X-ray CT observation



Particle structure of fouled ballast

Features of fouled ballast

- **Fine fractions, and crushed or split small ballast particles exist between ballast particles.**
- **We should simulate this particle structure with a triaxial specimen in the future.**

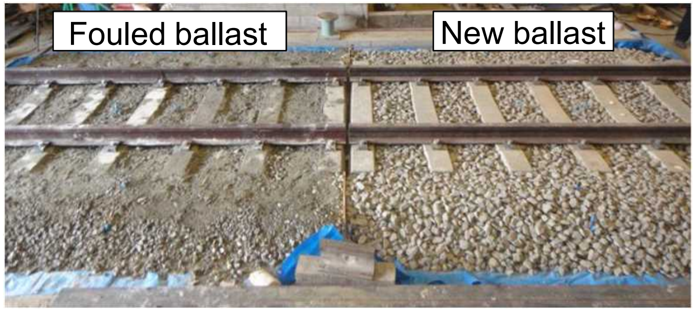
Background of Research (2)

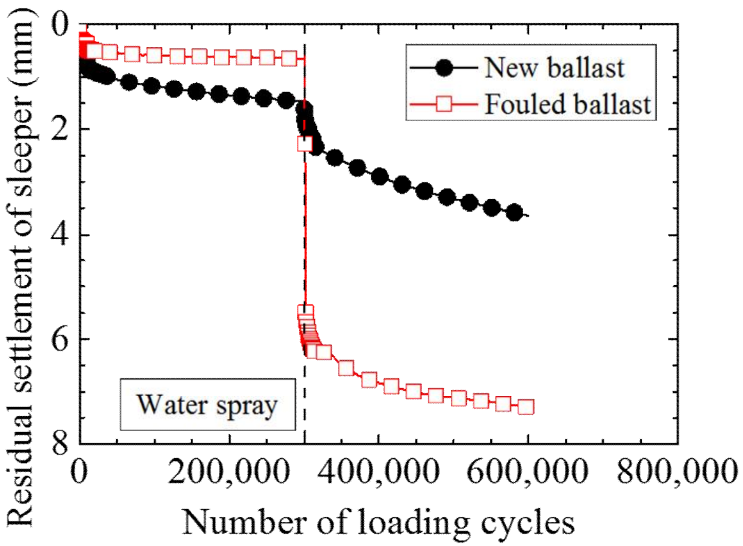
QUESTION :

- **Does rainfall affect settlement of unsaturated railroad ballast?**

Literature Review

- Deformation modulus of coarse granular materials decreases with the increase in water content. (Coronado et al. 2005, Ekblad & Isacsson 2006)
- Plastic deformation of ballasted track during cyclic loading suddenly increase due to water spray, especially in case of fouled ballast. (Itou et al. 2014)





Results of full-scale model test

ANSWER :

- **We should evaluate the synergistic effects of water content and fine fraction content on shear behavior of unsaturated fouled ballast.**

Background of Research (3)

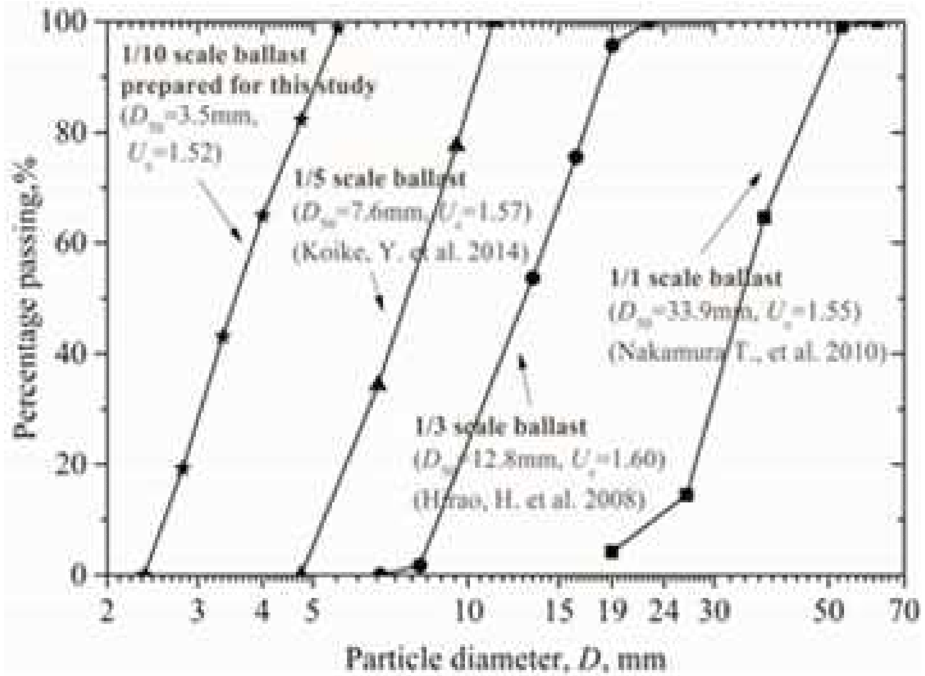
- Most appropriate way to investigate the material properties of ballast is to perform laboratory element tests using full-scale ballast.
- Since triaxial compression tests for unsaturated soils is very time-consuming, it is not easy to handle large triaxial specimens with full-scale ballast.
- Instead, we often adopt small-scaled ballast with parallel gradation of full scale ballast

QUESTION :

- **Does a small-scaled ballast reproduce the mechanical behavior of full-scale ballast in unsaturated condition?**

ANSWER :

- **We should discuss the validity and usefulness of parallel gradation technique from the viewpoints of particle size effects.**



Parallel gradation technique (after Tomita et al. 2017)

Objectives of Research

Research Objectives

- **To examine the synergistic effects of parallel grading and water content on the hydro-mechanical characteristics of unsaturated fouled ballast.**

Discussion Points

- Soil water characteristics by water retention tests
  - Effects of fine fraction content on water rententivity
  - Effects of particle size on water rententivity
- Deformation – strength characteristics by triaxial compression tests
  - Effects of fine fraction content on shear strength and cyclic deformation
  - Effects of water content on shear strength and cyclic deformation
  - Effects of particle size on shear strength and cyclic deformation

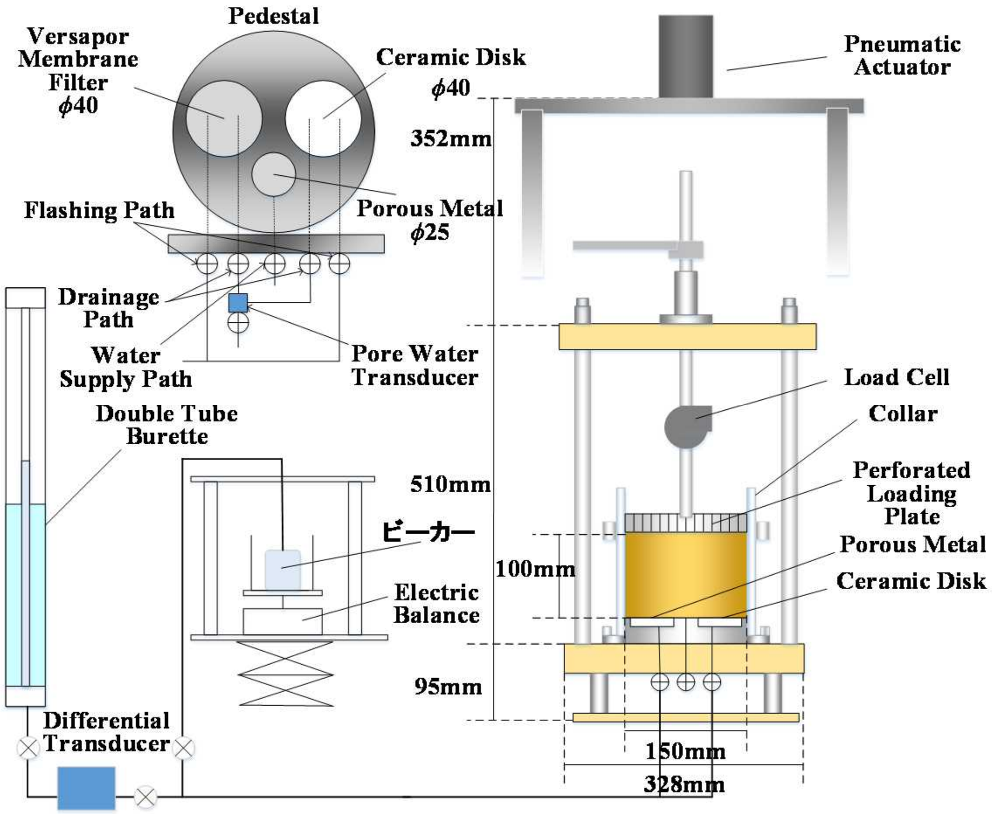
Test apparatuses

Freeze-thaw water retention test apparatus

- Specimen size

  D : 150mm
  H : 100mm

- Test condition
  - Suction method under low suction range
  - Pressure plate method or pressure membrane method under high suction range



- Remarkable Features
  - It can subject a test specimen to a one-dimensional desired freeze-thaw history at a constant freezing rate.
  - It can perform water retention tests under wide range of matric suction.
  - It adopts a small-height test specimen for coarse granular materials and two drainage paths with both ceramic disk and membrane filter to reduce total testing time.

Medium-size triaxial apparatus

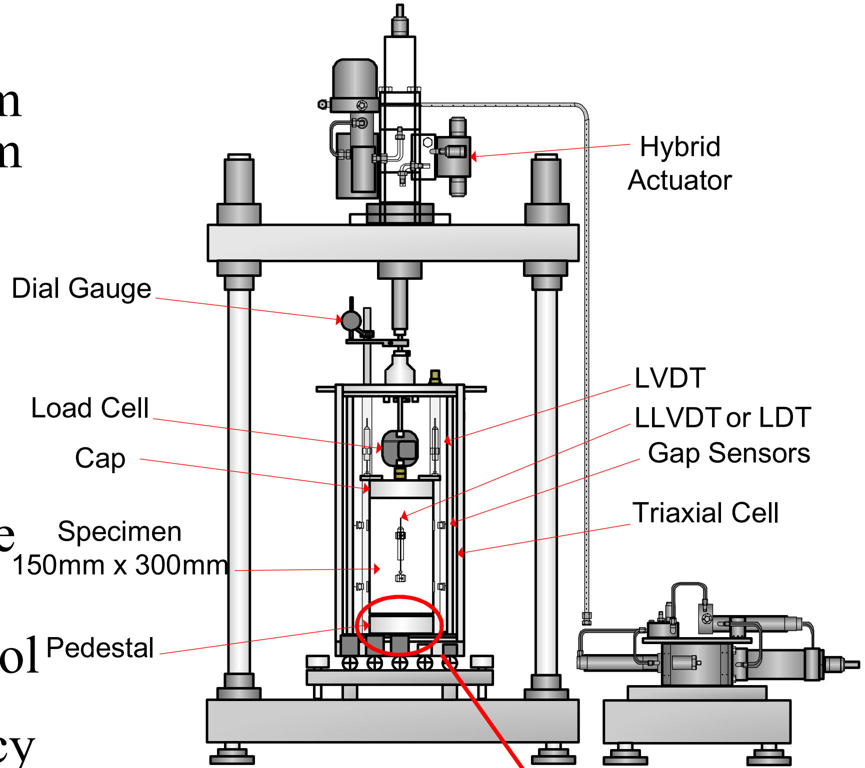
- **Specimen size**

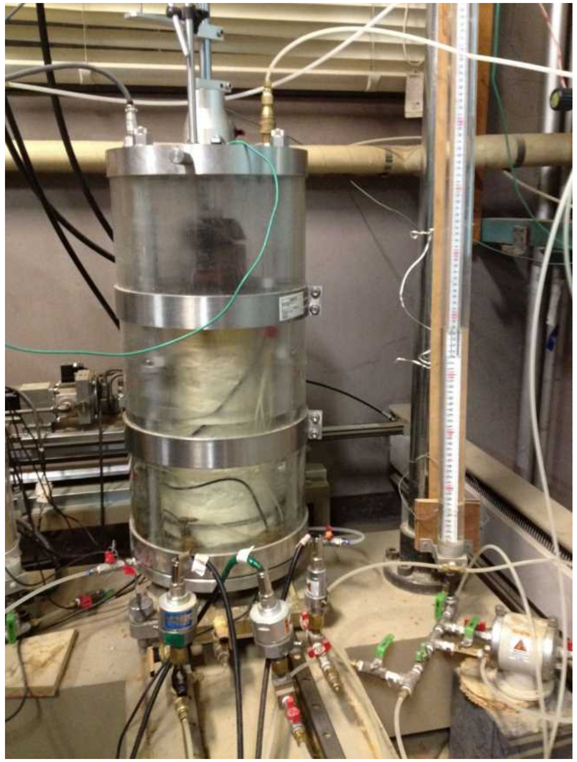
  Diameter : 150mm
  Height : 300mm

- **Test condition**

  Suction-controlled

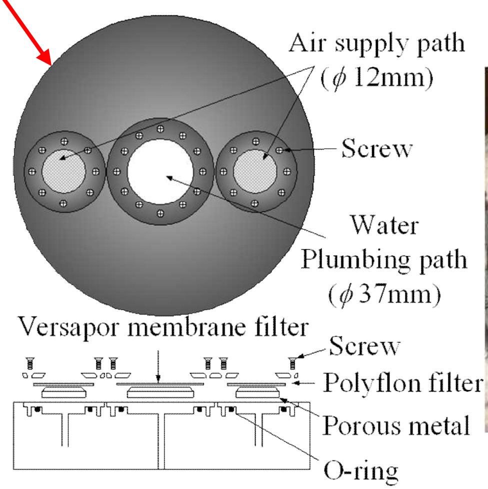
  - Monotonic loading with strain control method at very slow loading rate
  - Cyclic loading with stress control method at high loading frequency





- **Remarkable Features**

  - The apparatus can perform water retention tests, triaxial compression tests and resilient modulus test (MR test) for unsaturated soils to evaluate the deformation-strength characteristics of coarse granular materials.
  - The apparatus adopts pressure membrane method for reducing total testing time.



Large-size triaxial apparatus

- Specimen size

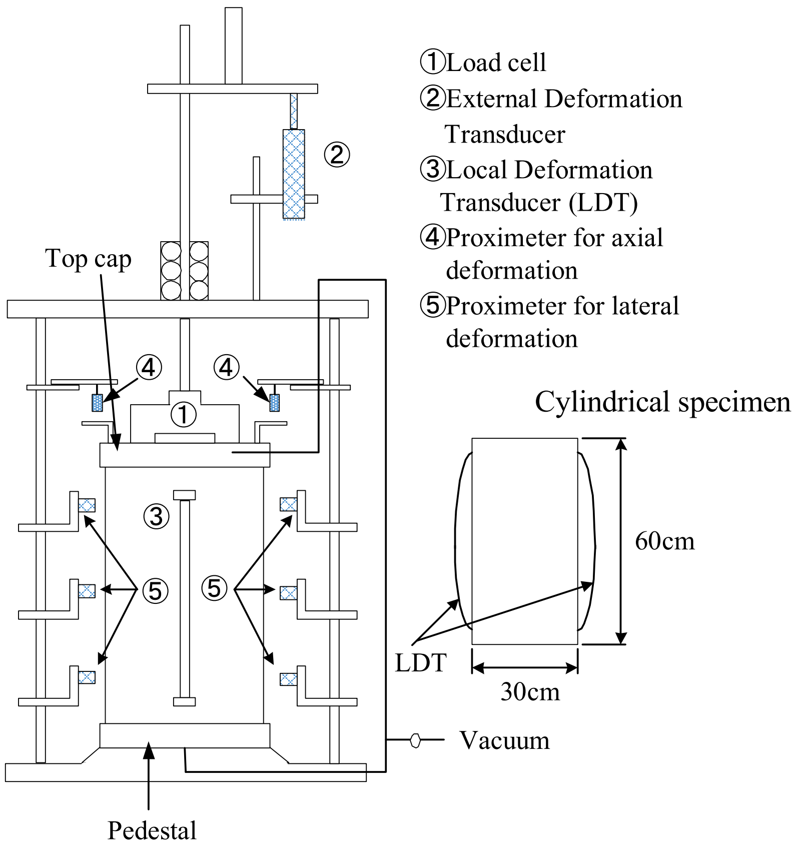
  Diameter : 300mm
  Height : 600mm

- Test condition

  Non suction-controlled

  - Monotonic loading with strain control method at very slow loading rate
  - Cyclic loading with stress control method at high loading frequency

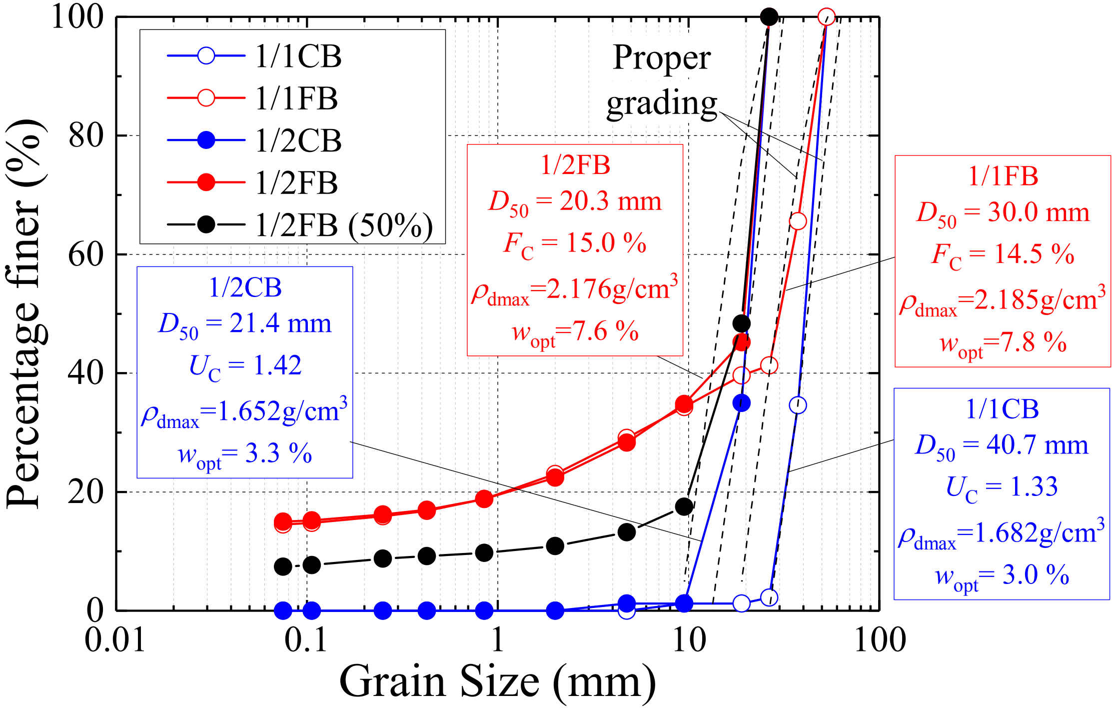
- Remarkable Features
  - The height and diameter of large-size triaxial specimen is twice of medium-size triaxial specimen while keeping the ratio of mean grain size against specimen size constant.



Full-scale Ballast

Test Samples and Testing Method

Test samples



Grain size distribution of test samples

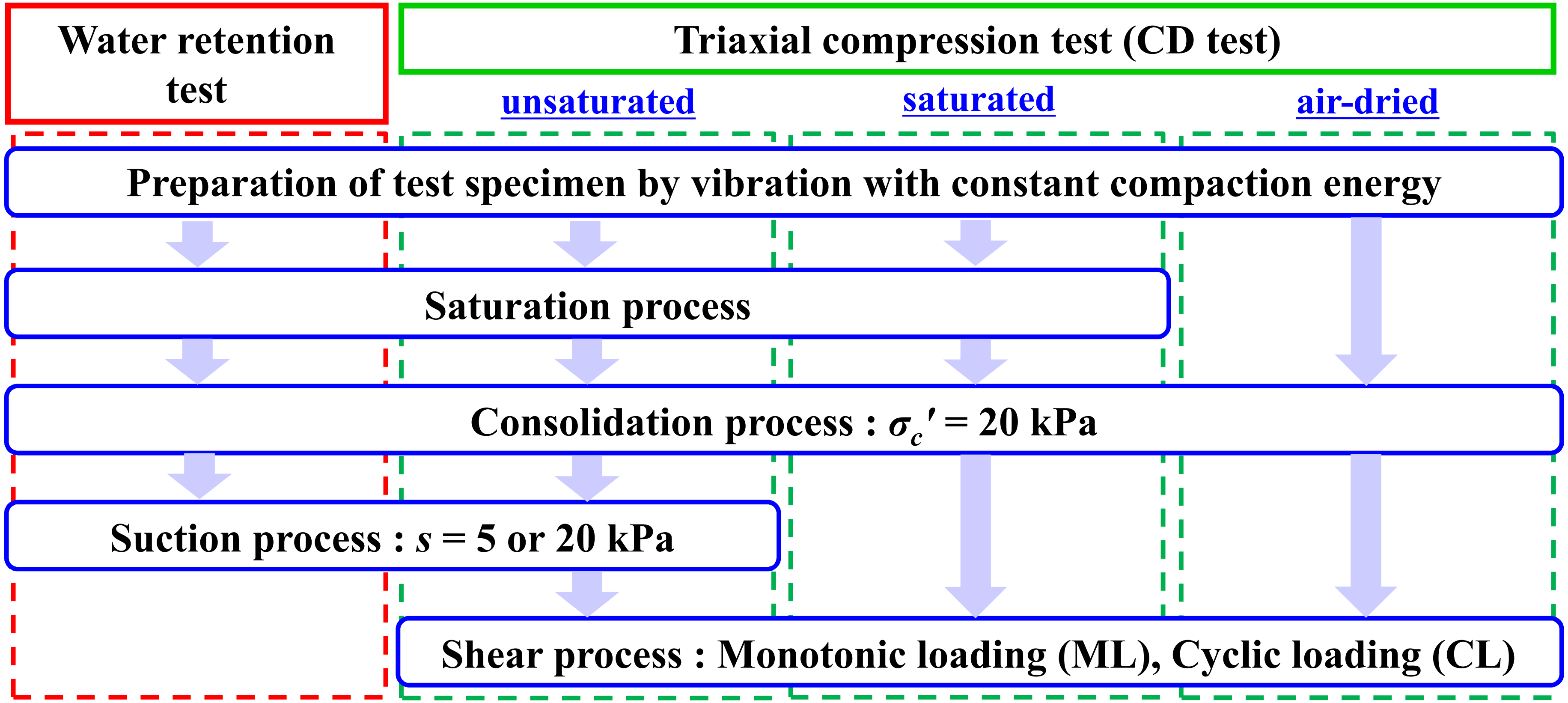
- Small-scaled ballasts have one-half parallel grading of full-scale ballasts extracted from actual railway track, in order to ensure experimental accuracy in terms of specimen size.
- FB is an artificial mixed soil with CB, gravel and kaolin (6:3:1 mixture in weight ratio). Fine-grained soil of FB is different from in-situ soil.

Small-scaled Ballast

Full-scale Ballast

Test procedures

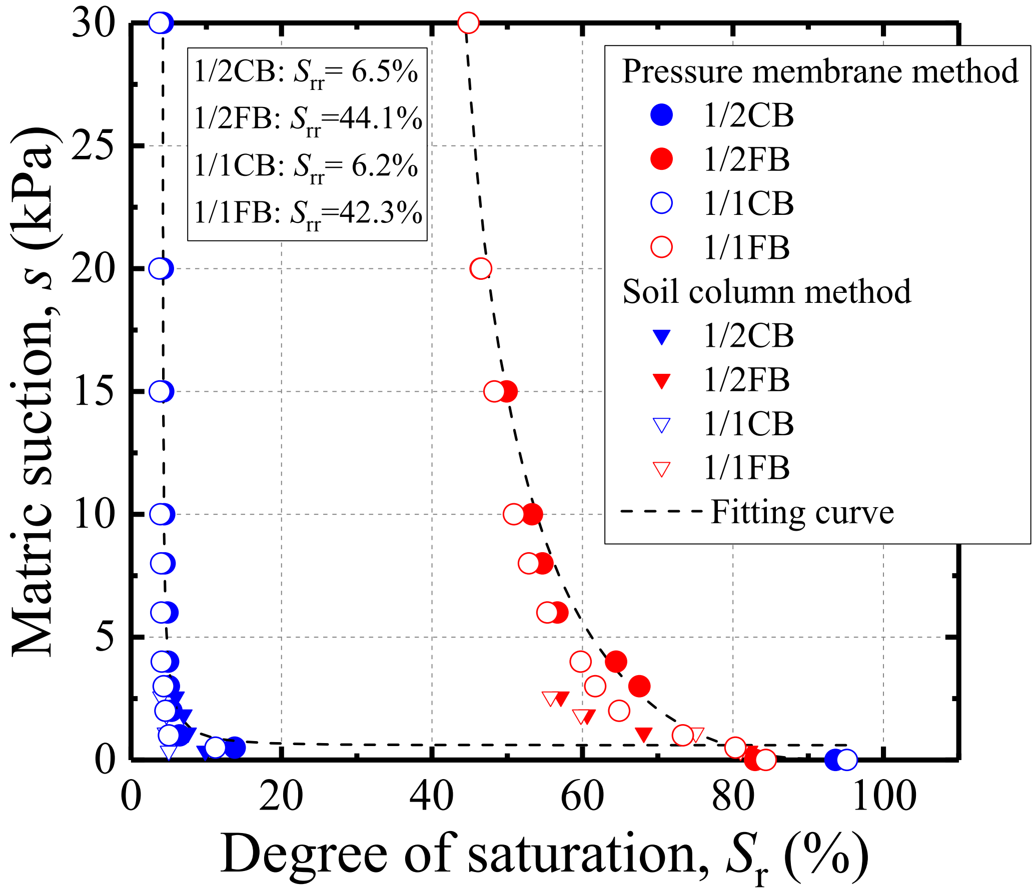
- Water retention (SWCC) tests were conducted by the pressure membrane method and the soil column method using medium-size triaxial apparatus.
- For triaxial compression tests, we prepared three kinds of test specimens with different water contents (air-dried, unsaturated, saturated).
- After the preparation, we conducted both ML and CL traiaxial compression test under fully drained conditions (CD test).



Results & Discussions

Results of water retention tests (1)

Effects of parallel grading on water retentivity

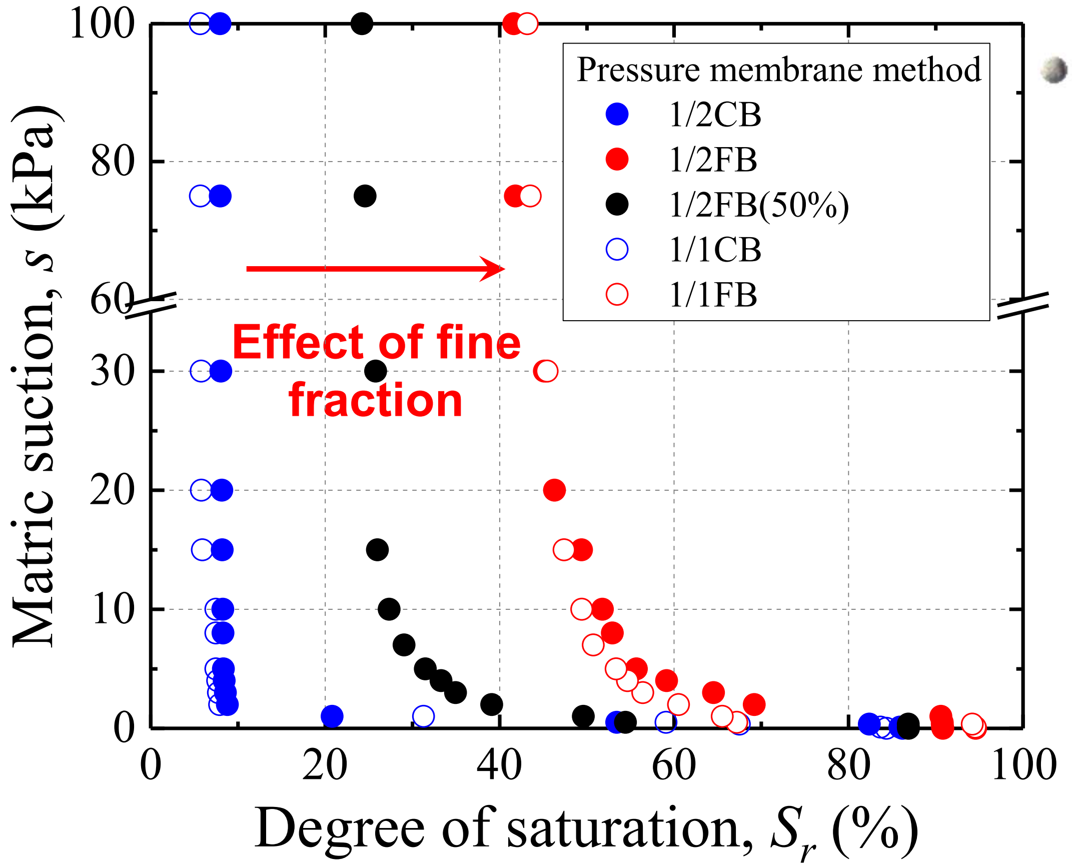


- 1/2CB has a little higher water retentivity than 1/1CB. On the other hand, the residual degree of saturation for 1/2FB is almost similar to that for 1/1FB, while the 1/2FB has higher water retentivity than 1/1FB at the transition effect zone.

⇨ Parallel grading hardly has a serious influence on the water retention characteristics of fouled ballast with high fine fraction content though it slightly affects those of clean ballast.

Results of water retention tests (2)

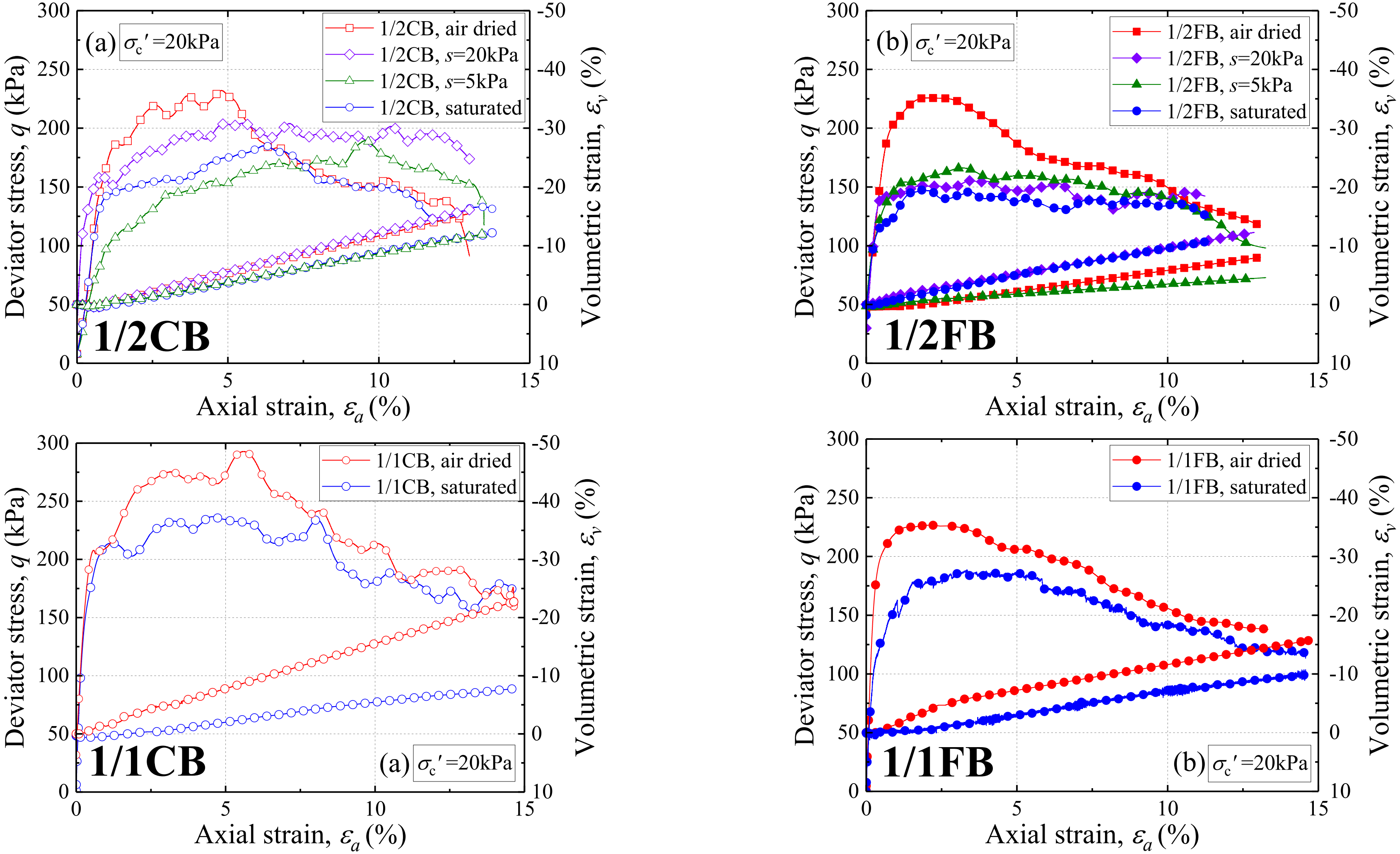
Effects of ballast fouling on water retentivity



- Ballast fouling due to the increase in fine fraction contents induces the rise in the water retentivity of ballast in accordance with the fine fraction content.

⇨ Grain refining of ballast particles by aging effect of ballasted track induces the increase in water retentivity, thus resulting the change in the mechanical behavior of railroad ballast.

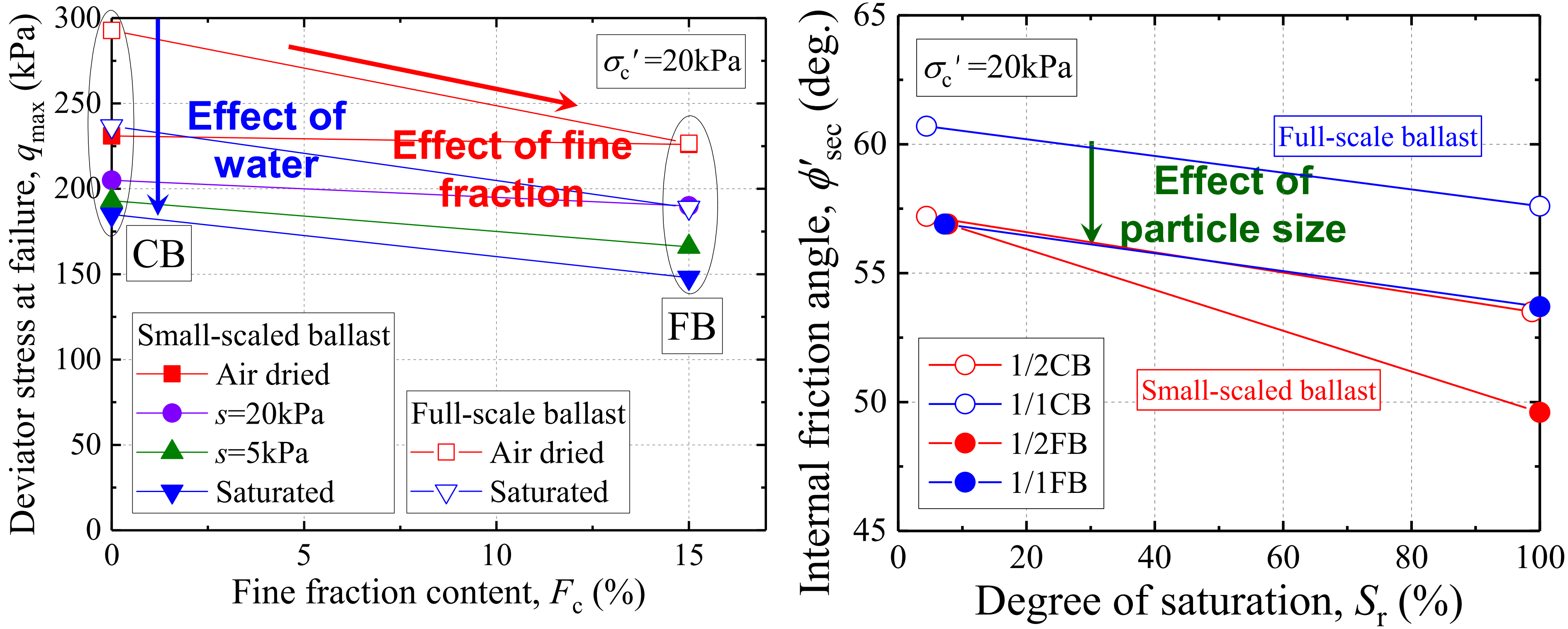
Results of ML triaxial tests (1)



- Stress-strain relationships varies depending on the test conditions, with a tendency for peak strength to decrease with the increase in water content and fine content.
- Trends of both ballasts agree well with each other, though the peak strength of full-scale ballast is a little higher than that of small-scaled ballast.

Results of ML triaxial tests (2)

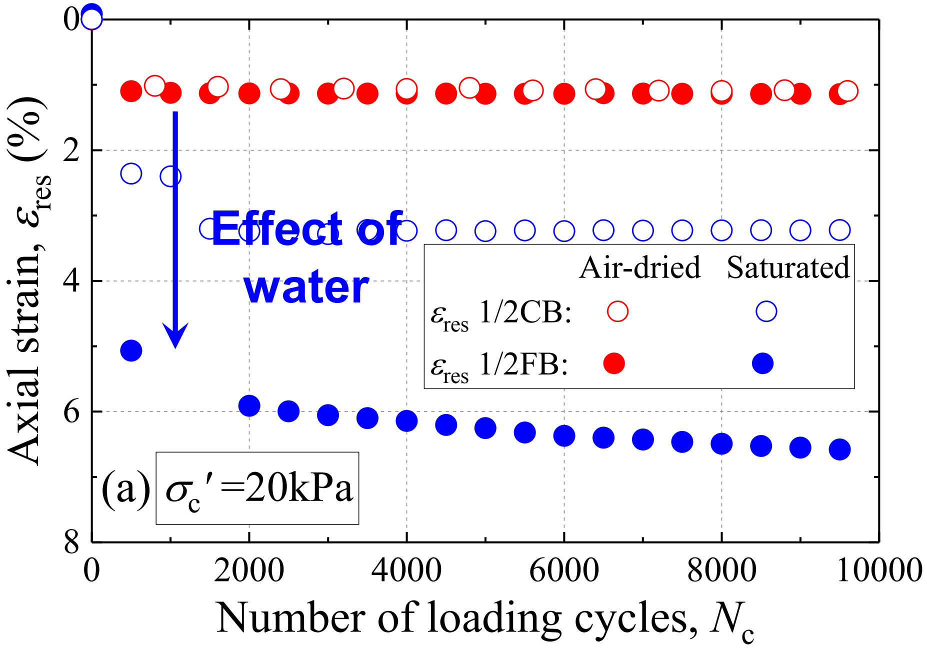
Effects on shear strength



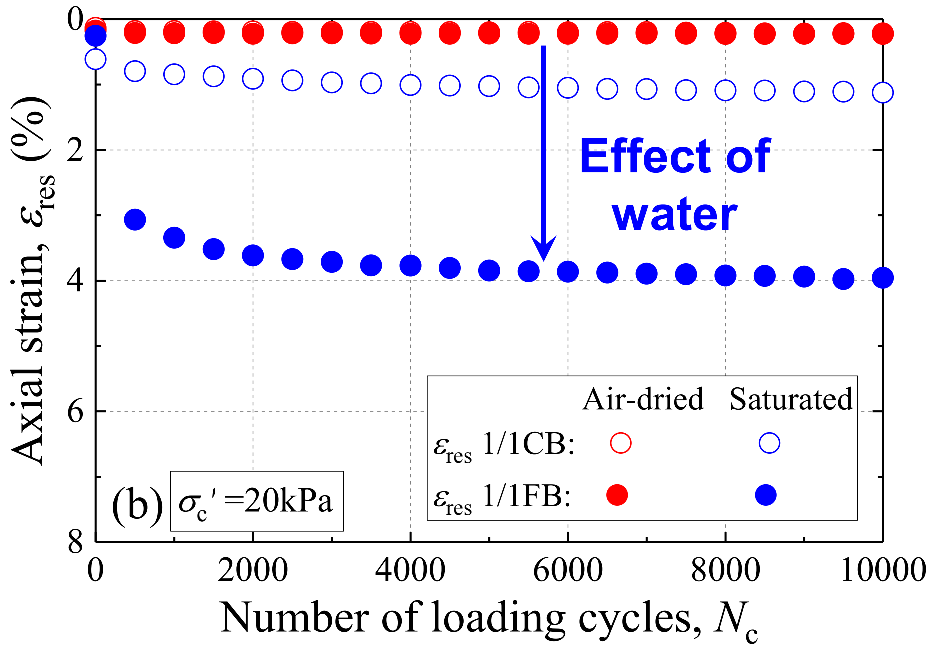
- Increase in the water content and the fine fraction content seriously influences the peak strength and the strength parameter of ballast.
- Particle size quantitatively has a serious influence on the shear behavior of ballast, irrespective of fine fraction content and water content, even when using parallel grading, though the qualitative trends are similar.

Results of CL triaxial tests (1)

Effects on cyclic deformation characteristics



Small-scaled ballast

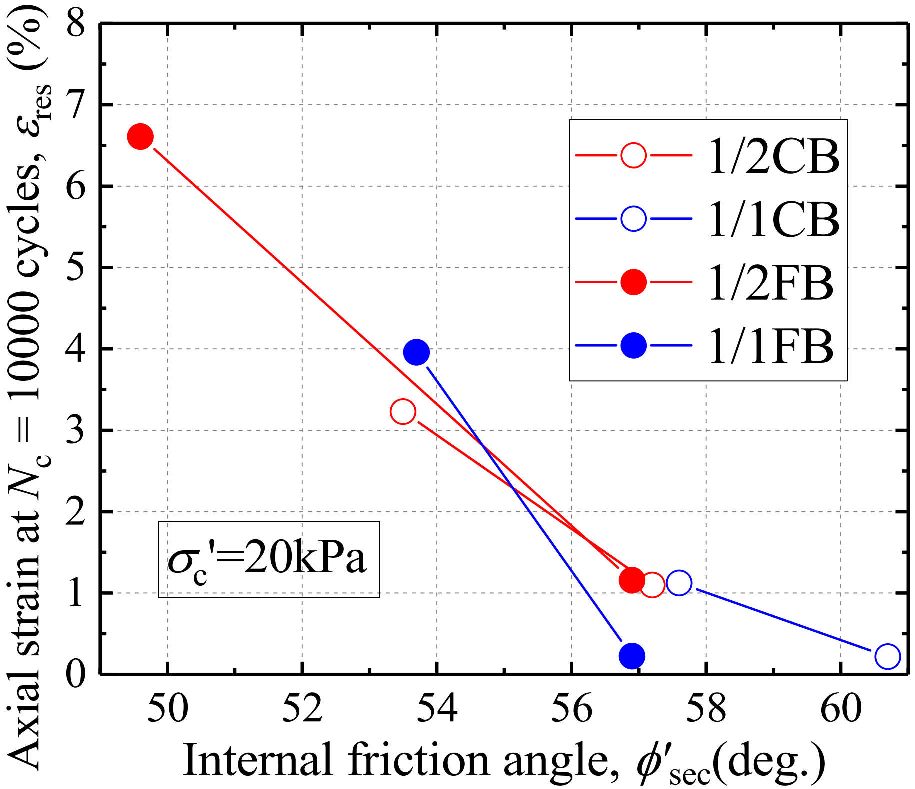


Full-scale ballast

- Residual strain of saturated specimen is larger than that of air-dried specimen, irrespective of test sample. Especially, wetting causes fouled ballast to increase residual settlement dramatically.

Results of CL triaxial tests (2)

Effects on cyclic deformation characteristics



Relations between ML tests and CL tests

- The trends in CL tests agree well with those in ML tests, and the trends in small-scaled ballast are similar to those for full-scale ballast though the residual strain of small-scaled ballast is larger than that of full-scale ballast.

- Particle size quantitatively has a serious influence on the cyclic deformation as well as shear strength of ballast, even if using parallel grading.

Conclusions

Concluding Remarks

- Soil-water characteristic curves and stress-strain relationships are seriously affected by intrusion of fouling materials and water into ballast, regardless of grain size.
- Parallel grading hardly has a serious influence on the water retention characteristics of fouled ballast with high fine fraction content though it slightly affects the water retention characteristics of clean ballast.
- Decreasing trend of peak strength becomes more remarkable in such a case where both water content and fine fraction content increase, while increasing trend of cyclic plastic deformation becomes more noticeable in case of fouled ballast with high water content.
- Particle size quantitatively has a serious influence on the shear behavior of ballast, irrespective of fine fraction content and water content, even if using parallel grading, though the qualitative trends are similar.

⇩

- For the precise evaluation of the hydro-mechanical characteristics of unsaturated railroad ballast, it is important to carefully interpret the test results using the parallel grading geomaterials by taking into account the synergistic effects of water content and particle size on the deformation-strength characteristics of ballast in accordance with the degree of ballast

Hokkaido Shinkansen (bullet train) Launched in 2016 Spring

HOKKAIDO SHINKANSEN

Thank You for Your Kind Attention