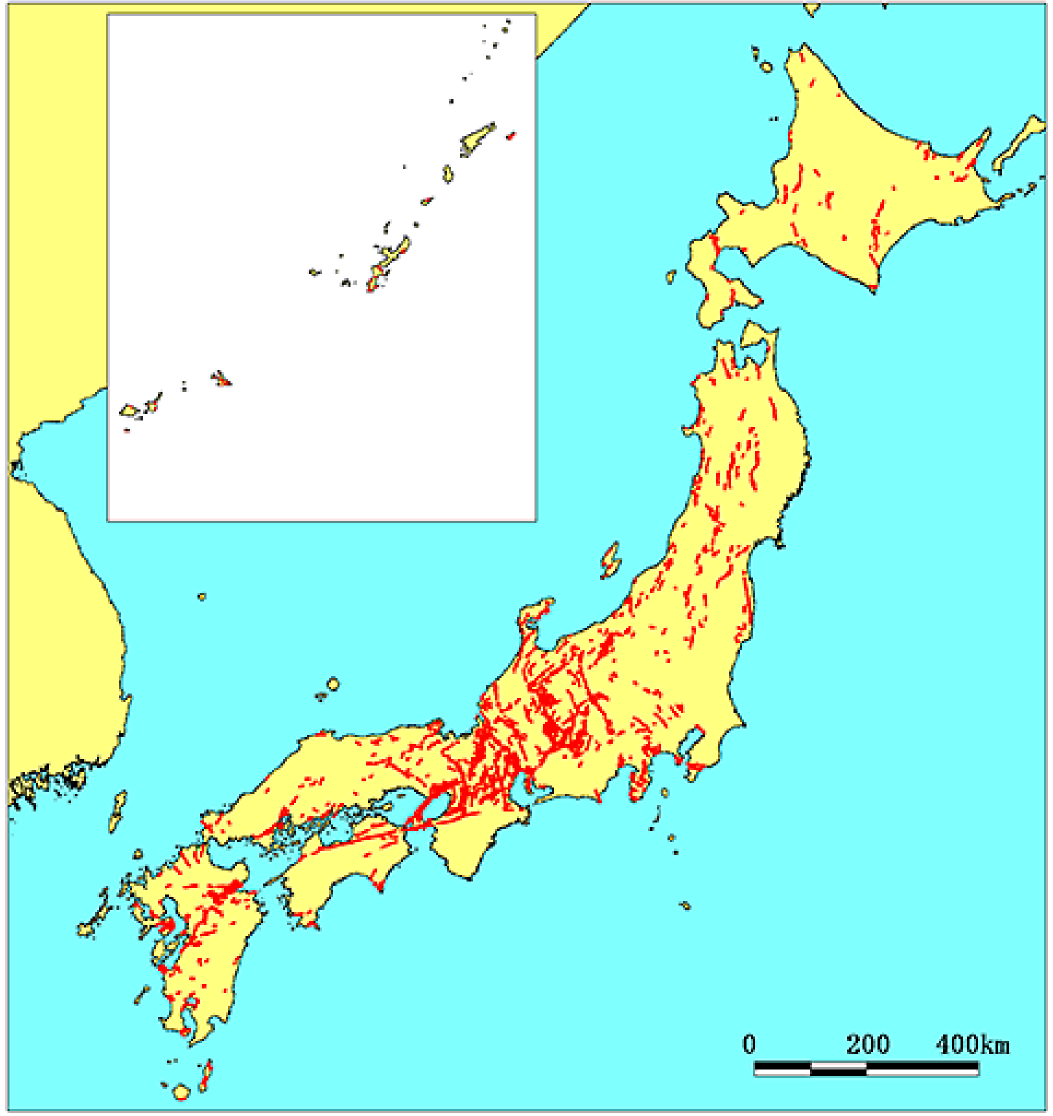
Comparison of DEM and experimental results for evaluation of ground surface displacement due to fault movement below architectural structures

ITOCHU Techno-Solutions Corporation, Tokyo, Japan
Ayaka Oya, Norihiko Hashimoto, Kaoru Kawaji, Guoqiang Cao

Railway Technical Research Institute, Tokyo, Japan
Akihiro Toyooka, Tatsuya Doi

Research Background

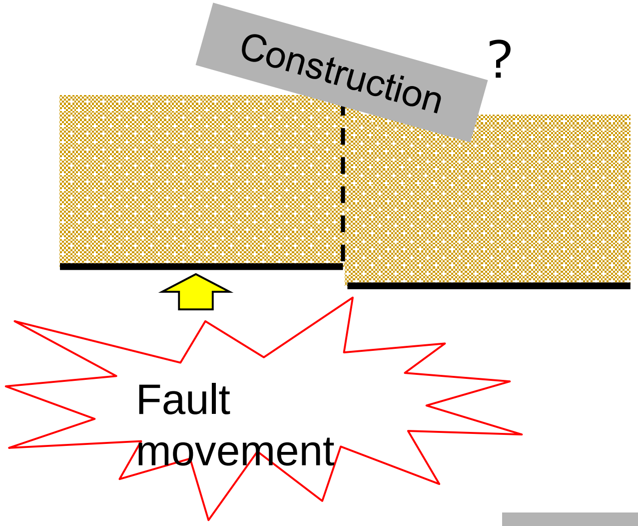
◆ **Active fault and railway around Japan**



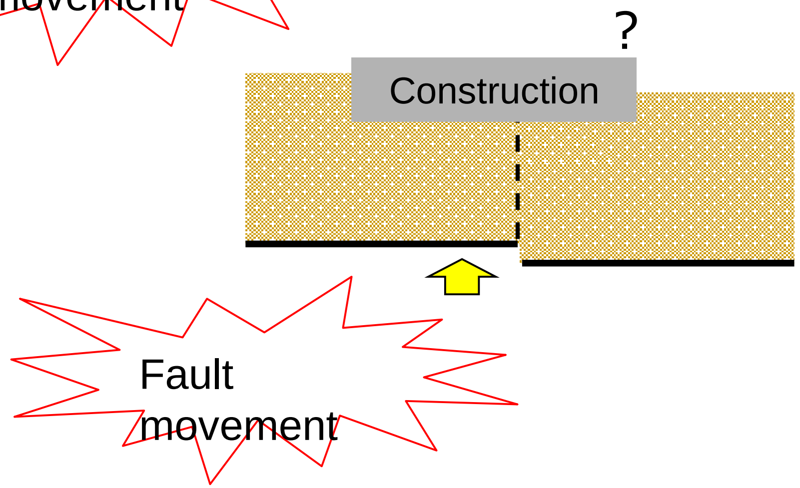
http://www.hinet.bosai.go.jp/about_earthquake/sec6.2.html

https://roote.ekispert.net/ja/rmap/fullscreen

What is happening when fault movement occurs below architectural construction ?



Evaluation method to reveal the effect of fault movement to the ground surface is needed.



- Distinct Element Method code *PFC* can simulate the discontinuity of displacement on a fault surface and a large deformation of the ground.
- Possible to estimate the influences of soil characteristics and properties around the ground surface when the fault displacement occurs and then propagates to the ground surface.

Conventional Research

◆ Ground surface displacement in elastic region due to fault movement

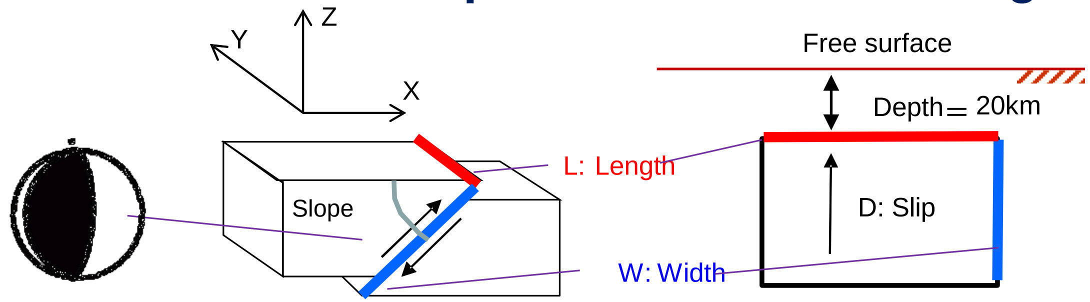


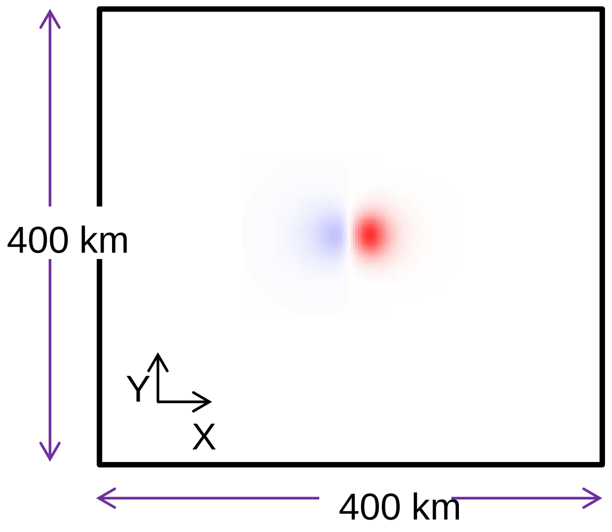
Table 1. Fault parameters of earthquake fault model.

Fault Type	Mw	Depth (km)	Strike (°)	Dip (°)	Rake (°)	Length, L (km)	Width, W (km)	Slip, D (m)
Reverse Fault	7.4	20	180	20	90	30.00	20.00	10.00

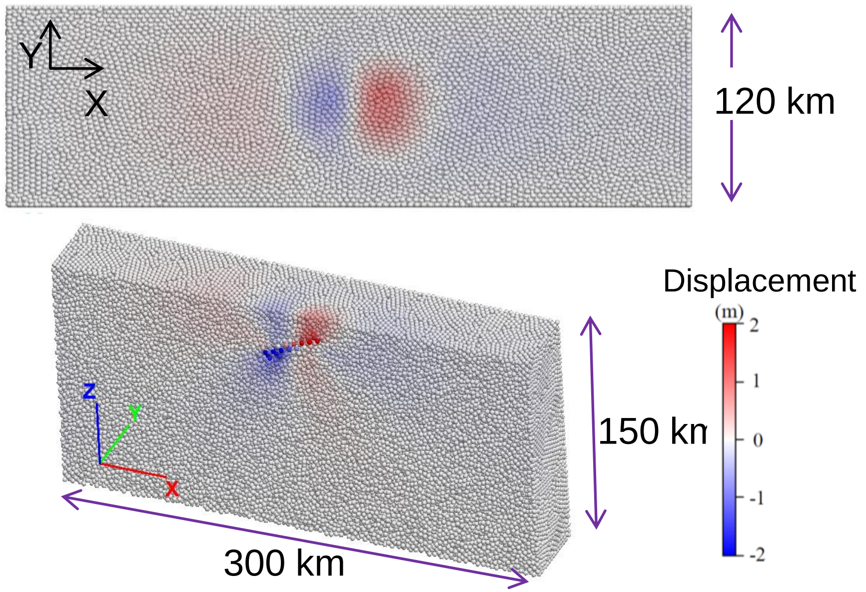
Table 2. Parameters for DEM simulations (Parallel bonding).

Effective Modulus	Normal-to-shear stiffness ratio	Tensile strength	Cohesion	Friction angle	Normal critical damping ratio	Shear critical damping ratio
1.0 GPa	4.0	100 GPa	100 GPa	30°	0.5	0.5

(a) Analytical solution by Okada Model



(b) DEM by *PFC*

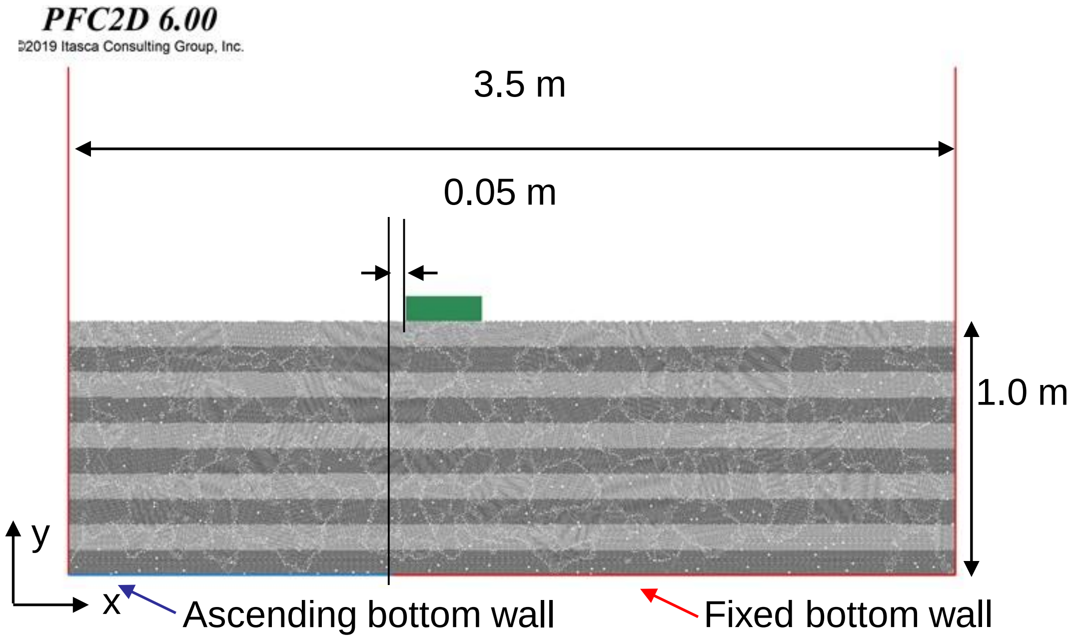


- ☐ Comparison of analytical solution and DEM
- ☐ Same tendency between them.
- ☐ Possible to be applied to static problem.

⇨ Demonstrating the first attempt in simulating ground deformation using the DEM due to fault movement that occurred below the structure, based on the preceding experiment to examine the effect of the structure on the ground.

Outline of the analyses

◆Model



◆Input parameters[1)2)]

Contact	Ball-Ball	Ball-Wall
Density[3)]	2560 (kg/m^3)	-
Stiffness（Nomal)	6.24×10^7 (N/m)	6.24×10^7 (N/m)
Stiffness（Shear)	2.08×10^7 (N/m)	2.08×10^7 (N/m)
Friction coefficient	0.67 (-)	0.00 (-)
Ball badius	0.004 (m)	-

① Contact model: Linear contact model
② Stiffness estimation[4)] : $ks = \frac{1}{4}\pi\rho Vs^2$
③ Friction coefficient：Estimated from friction angle

- Particle radius is homogenous in entire model.
- Bottom and side boundary is modeled by walls. Construction is by Convex rigid block.
- After packing is completed to stabilize the model, the bottom wall vertical velocity is set to 0.005 m/s in both analysis cases. The velocity is applied until the bottom wall vertical displacement reaches 120 mm.

◆Analysis Case

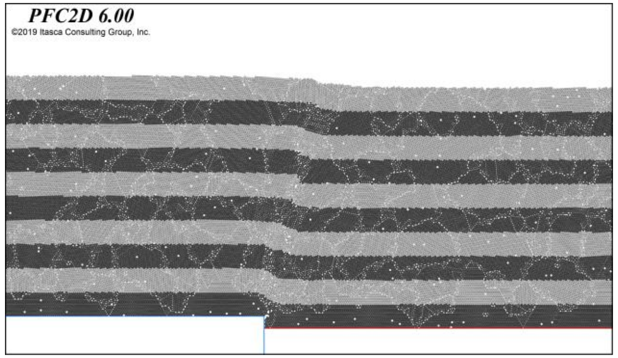
Case 1 ：Without construction on the ground
Case 2 ：With construction

1) Public Works Research Institute, 2014. Jibanbussei no baratsukiga kuikisono jisinji jiban outou hyouka ni ataeru eikyou ni kansuru kenkyu, Public Works Research Institute (In Japanese).
2) Hakuno, Motohiko, 2004, Hakai no simulation: Kakucho kobetsyuyousohou de hakai wo ou, Morikita Publishing (In Japanese).

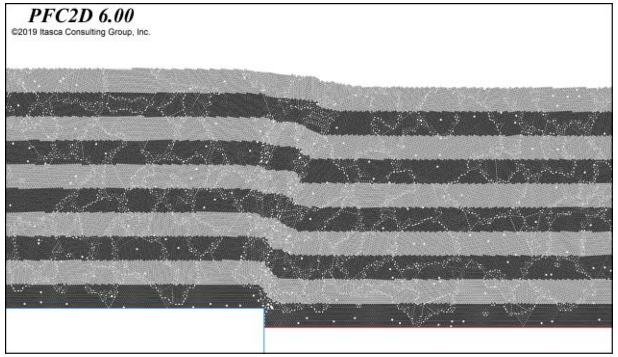
Results Case-1（1）

Case１：Comparison with the experiment

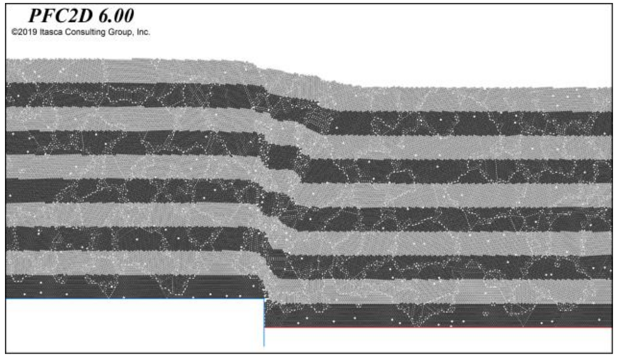
◆ Analysis



Bottom displacement 50 mm

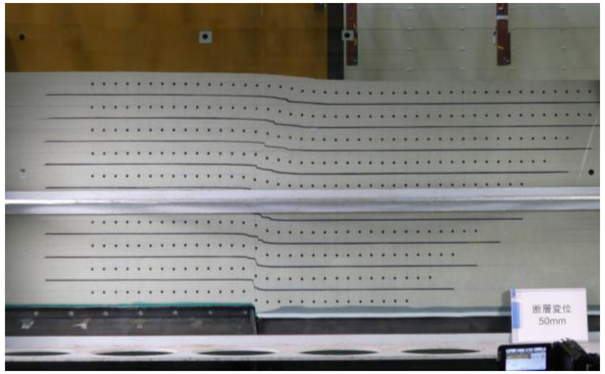


Bottom displacement 80 mm

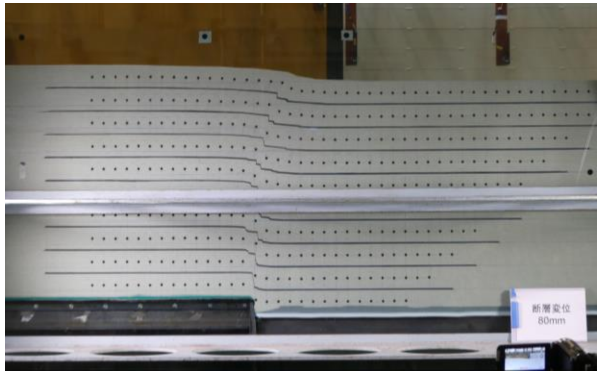


Bottom displacement 120 mm

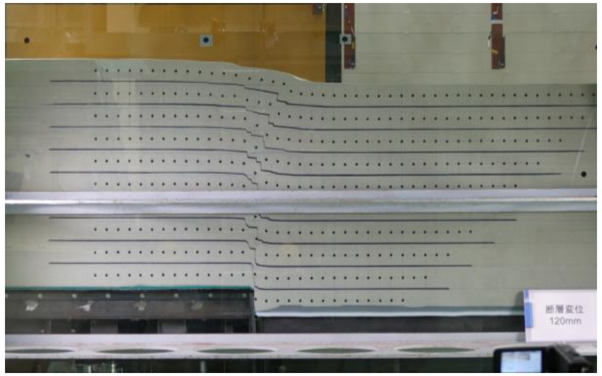
◆ Experiment[1)]



Bottom displacement 50 mm



Bottom displacement 80 mm



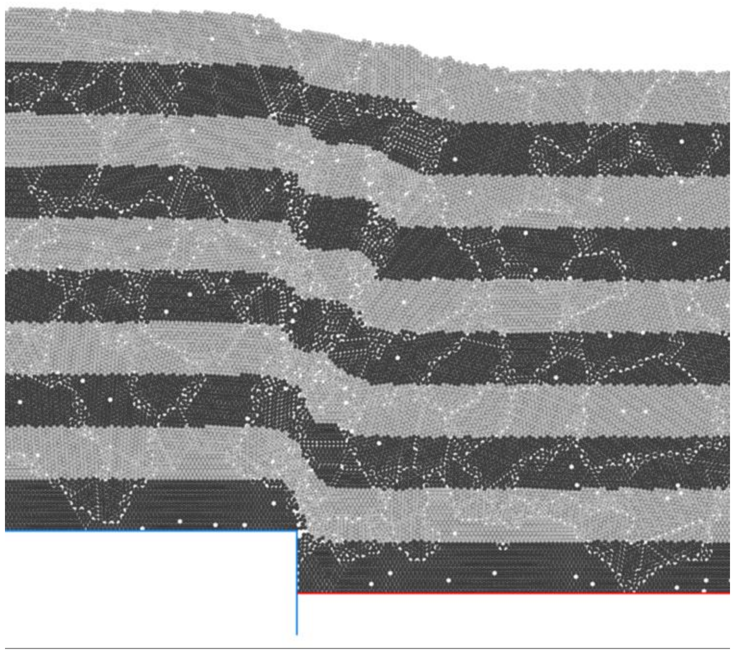
Bottom displacement 120 mm

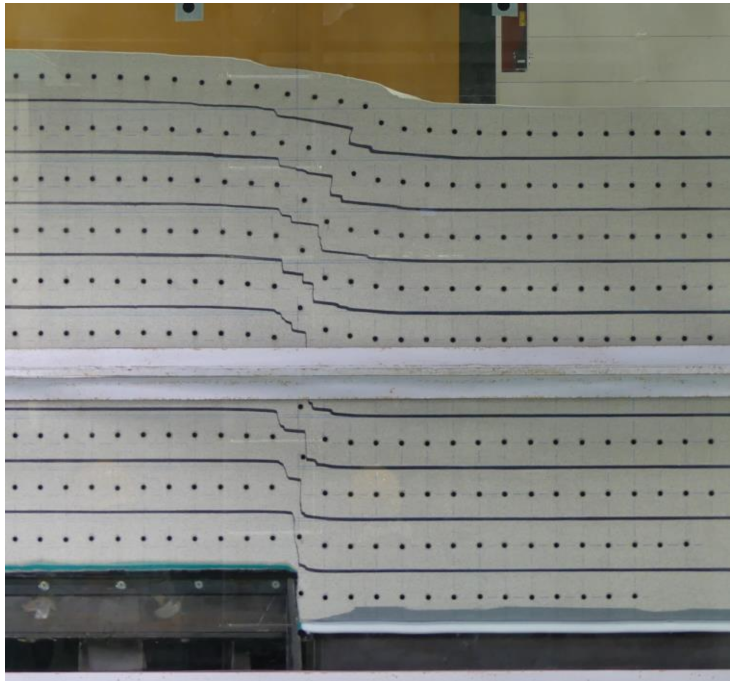
- ☐ The ground is deformed and the ground surface is tilted as the bottom wall rises.
- ☐ Ground surface is gradually deformed in both the analysis and the experiment.

1）Oshida, Naoyuki et al. 2019. Model test on dip slip fault displacement affected by railway structure foundation, Journal of structural engineering. A, Japan Society of Civil Engineers (In Japanese).

Case１：Comparison with the experiment

◆ **Bottom dispacement 120 mm　Zoomed**

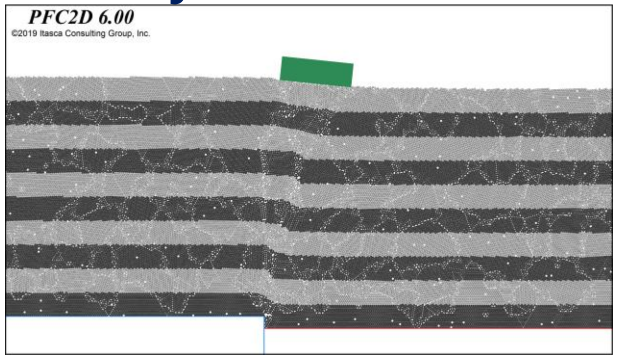




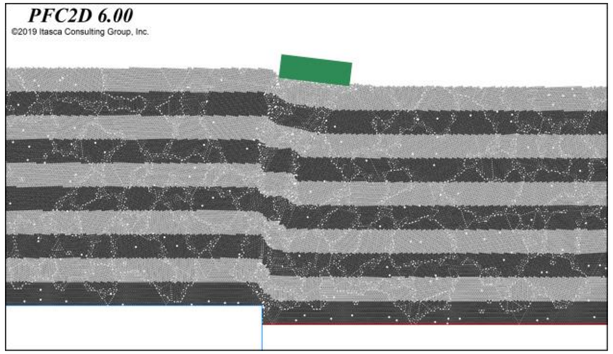
- Slip lines are observed from the boundary of the ascending bottom wall and the fixed bottom wall.
- The slip lines also develop nearly vertically from the bottom, and then branch off near the ground surface which draws arcs from side-to-side near the ground surface
; as is similar to the experimental results.

Case2：Comparison with the experiment

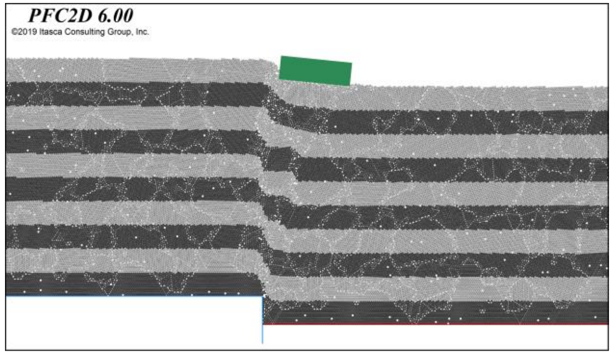
◆ Analysis



Bottom displacement 50 mm

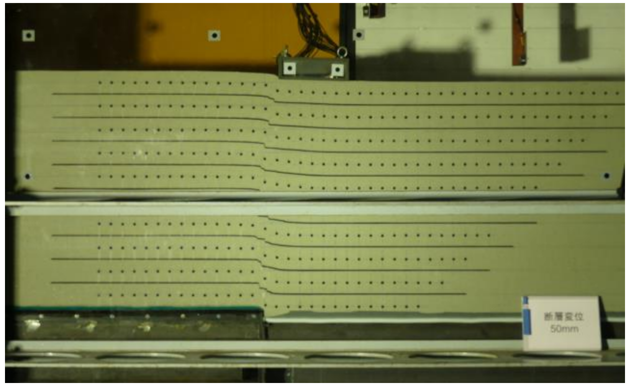


Bottom displacement 80 mm

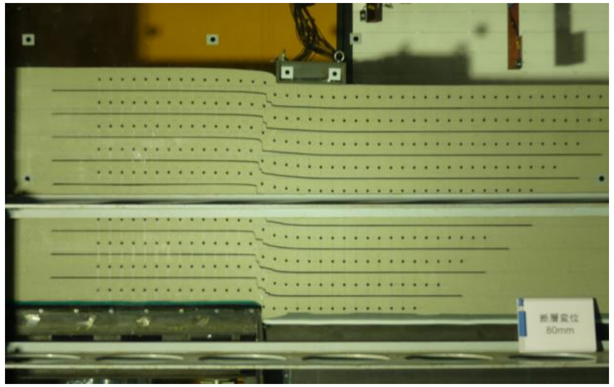


Bottom displacement 120 mm

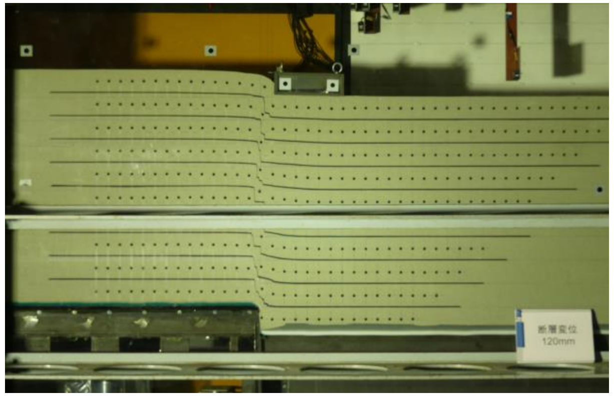
◆ Experiment[1)]



Bottom displacement 50 mm



Bottom displacement 80 mm

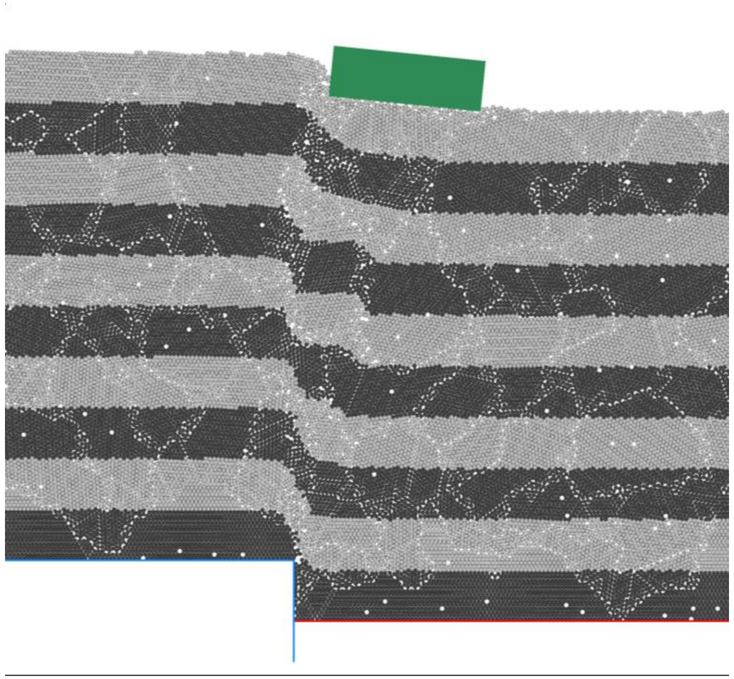


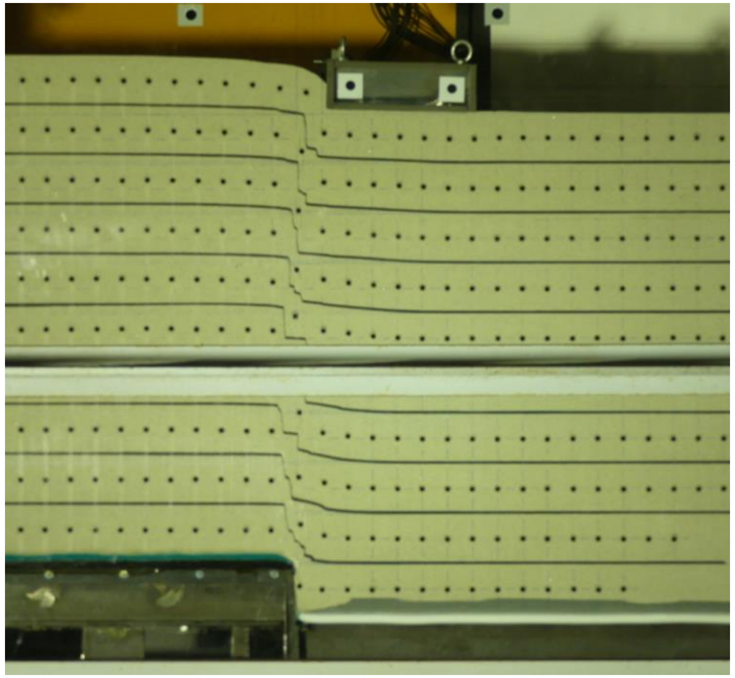
Bottom displacement 120 mm

- The tendency of the results are basically same as case1.

Case2：Comparison with the experiment

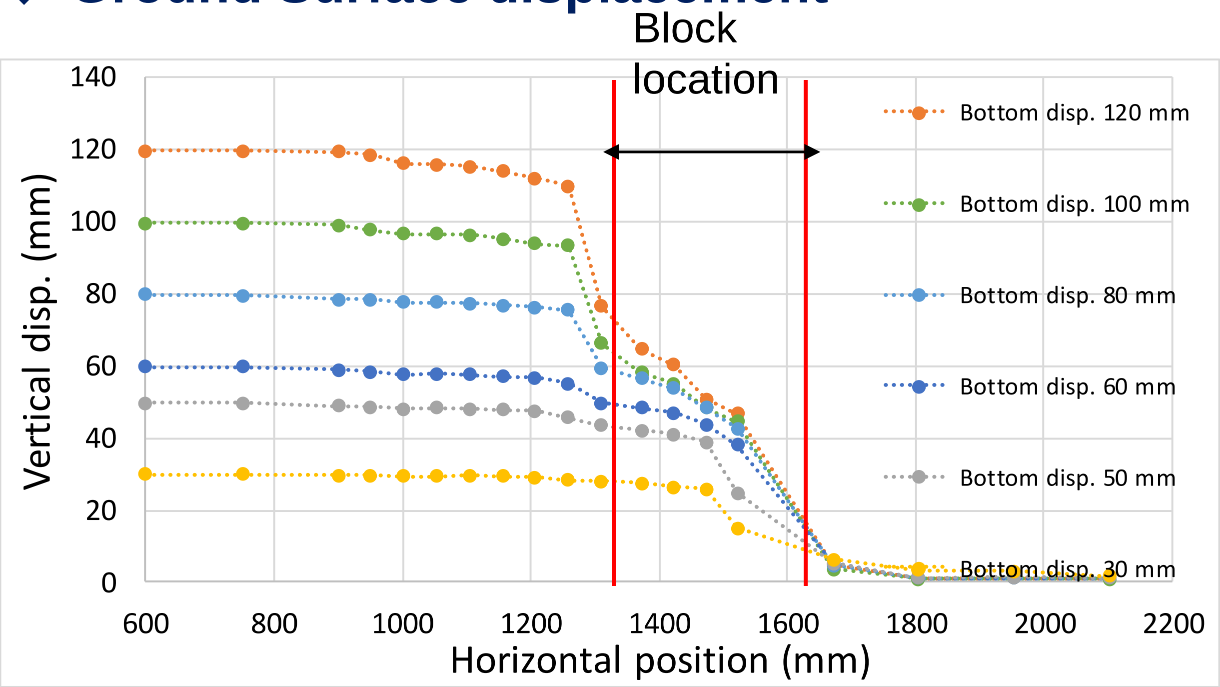
◆ Bottom dispacement 120 mm　Zoomed



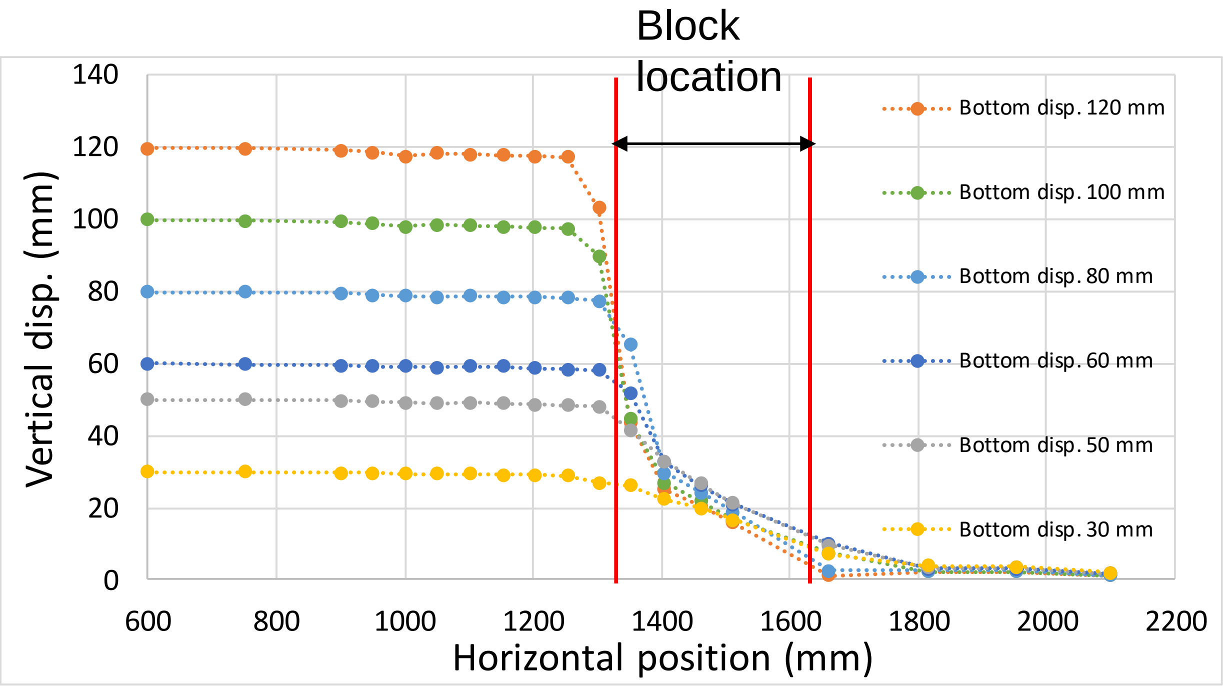


- A drastic change in ground surface displacement is observed close to the left side of the structure; this is reproduced in the experiment as well.

Ground Surface displacement

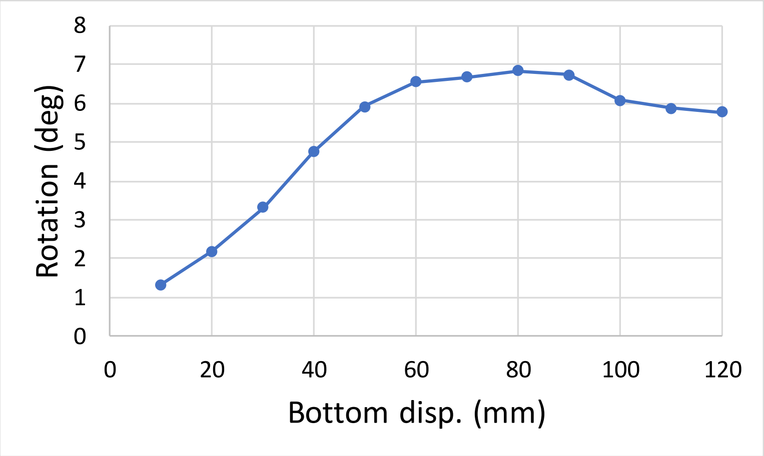


Case 1



Case 2

Rotation of the construction



- Ground surface displacement is affected by the construction.
- Drastic change of ground surface displacement is observed around the construction in Case2.
- Focusing on Case-2, the rotation of the structure is excessively estimated when compared to the experimental results.
  (1.7° in the experiment)

◆Conclusion

1. This paper demonstrates the first attempt in simulating ground deformation using the DEM due to fault movement that occurred below the structure, based on the preceding experiment to examine the effect of the structure on the ground.
2. Simulations are performed and replicated fault displacement by a simple model lab-experiment.

- ☐ The results of the analyses are in strong agreement with the experimental results and prove the applicability of using DEM to analyze these types of problems.
- ☐ The analyses can also simulate the effect of the structure on the ground surface displacement.

◆Future works

- ☐ There are some differences between the analyses results and the experimental results, such as rotation of the structure and slope of the ground surface.

⇨ Can be solved by a more detailed inspection of the input parameters, such as the friction coefficient

- ☐ Applied to more complex target of the simulation (3D, real scale etc..).
- ☐ Consider the applicability to the prediction method of the ground deformation and design method.