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VISUALIZATION OF FRICTION MECHANISM AROUND JOINT PART OF PIPE USING SOIL PARTICLE MODEL

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Abstract

In the seismic design guidelines for buried pipes, the relationship between the shear stress and relative displacement is important to show the performance of buried pipe under the seismic load and it is shown by a bilinear model, which explains the slip between the pipe and soil occurs when the shear stress exceed the limit. By the way the buried pipe has joint and fitting part, the friction between the pipe and the ground in the direction of the pipe axis includes frictional resistance due to the convex part. The friction model of the joint part have not examined well so far. The objective of this study is to clarify the friction mechanism microscopically from the movement of soil particles around the joint by conducting a model experiment in which the behavior of the pipe and soil particles is replaced with a two-dimensional section.

The test equipment is a two-dimensional cross-section of the ground soil particles that are covered with an aluminum rods on a vinyl chloride plate that looks like the upper part of the axial section of the buried pipe. The experiment was conducted changing the loading pressure and the shape of joint part plate. The overloading force is set to a load equivalent to 0.5m, 0.75 m, and 1.0 m of ground depth. In setting shape of the joint part plates, the homothetic ratio of the pipe thickness to the sand particle diameter is referred.

The trajectory of soil particles was obtained from the captured images of the experiment. Specifically, images of marker soil particles randomly placed at regular intervals were compared. From the particle trajectory, the vertical displacement of the soil particles at the top of the joint is small, and when the front of joint passes, it is displaced in the direction opposite to the traveling direction. It can be seen that the soil particles move in a spiral manner in front of the joint. In particular, the vortex is large at the front of the joint, and a large vertical displacement occurs accordingly. From this, it is considered that the friction due to the convex part of the joint increased due to the increase of the restraining pressure of the ground due to the vertical displacement of the particles at the front part of the joint.

Keywords: friction, pipe-soil interaction, soil particle model, joint

1. Introduction

In the current seismic design guidelines of buried pipeline in Japan, the relationship between shear stress and the relative displacement of pipe is modeled in a bilinear form [1]. The fact that the frictional force acting between the buried pipe and the ground is a constant value regardless of the moving speed of the buried pipe indicated that the dynamic frictional force is not taken into account. However, when the relative displacement occurs between the buried pipe and the ground, the soil particles around the pipeline are relocated. The relocation of soil particles varies according to the moving speed of the pipeline and the soil compaction condition. In general, in soil materials, the more compacted the ground is, the more positive dilatancy is applied to shear deformation, and accordingly the pipeline receives greater frictional force. On the other hand, if the ground is loose, the higher the shearing speed, the lower the generated frictional force. In order to correctly evaluate the frictional force acting between the ground and the buried pipe, it is necessary to clarify the mechanism of soil particle relocation [2][3].

By the way the buried pipe has joint and fitting part, the friction between the pipe and the ground in the direction of the pipe axis includes frictional resistance due to the convex part. The friction model of the joint part have not been examined well so far. Some studies on the pipe pulling tests in the soil tank were carried out and friction restraining due to the joint were obtained by experiencing [4][5]. The friction force due to the convex part of pipeline is not taken into account well in the seismic design.

The objective of this study is to clarify the mechanism of the frictional force generated between the ground and the pipe around the joint part from the point of the movement of soil particles. A model experiment in which the behavior of soil particles around the pipe joint part is replaced with a two-dimensional section is conducted. The soil particles movement as well as the relationship between the frictional force and relative displacement are paid attention to. Imaging analysis of soil particles makes clear the effects of frictional force due to difference of convex shape at the joint part.

2. Shear test equipment and experimental cases

2.1 Testing equipment

The testing equipment lays only aluminum rods in a steel frame, facing a vinyl chloride plate at the bottom (hereinafter referred to as the bottom plate). The bottom plate looks like the buried pipe and aluminum rods reproduces the soil particles of the ground in a two-dimensional cross section. Fig.1 shows a schematic diagram of the test equipment. The area of the constructed two-dimensional cross section is 500 mm in length, 100 mm in height, and 50 mm in depth (see Fig.2). The spread aluminum rods are cylindrical, 1.6 mm in diameter and 50 mm in length as shown in Fig.3. In order to perform image analysis, the central part was fixed at 400 mm in length and 80 mm in height with an acrylic plate to make it a visible region. Turning the handle in the right side of figure gives shear displacement to the bottom plate. The bottom plate moves from right to left. Small vinyl chloride plates in the various shape can be attached on the bottom plate as the convex of joint part.

2.2 Measuring equipment

One of the compression-type load cells was installed on top of the soil particles via a steel material, the loading pressure was measured and adjusted, and the other was installed between the bottom plate and the handle to measure the shear load. The shear load measured here is evaluated as the frictional force acting on the bottom plate surface. Spring-type displacement gauges (CDP-25, Tokyo Sokki) are installed at both ends of the bottom plate to measure the displacement of the bottom plate.

2.3 Experimental case

The experiment was carried out three times for each case, changing the loading pressure and joint parts. The loading pressure is set to a load equivalent to 0.5 m, 0.75 m, and 1.0 m depth of covering ground when the density of the ground is assumed to be 1.7 g/cm^3. Hereafter, the case of overloading pressure is expressed by this assumed ground depth. The pushing speed shall be manually adjusted by turning the handle, and adjusted so as to be approximately the same speed as 5mm/s. When setting the joint parts (see as Fig.4), two types; a rectangular shape and a trapezoidal shape (the angle at both ends is 45 degree) are considered. For the size, the homothetic ratio of the pipe thickness to the sand particle diameter is referred. The plate with 21 mm thickness was set in consideration of the 5 times as the diameter of the aluminum rods used in the experiment. The plate with 14 mm thickness was also prepared to clarify the difference in friction force due to the joint thickness. Hereafter, the one with a thickness of 21 mm is called as large plate and the one with a thickness of 14 mm is called as small plate. Table-1 lists the cases conducted in this study.

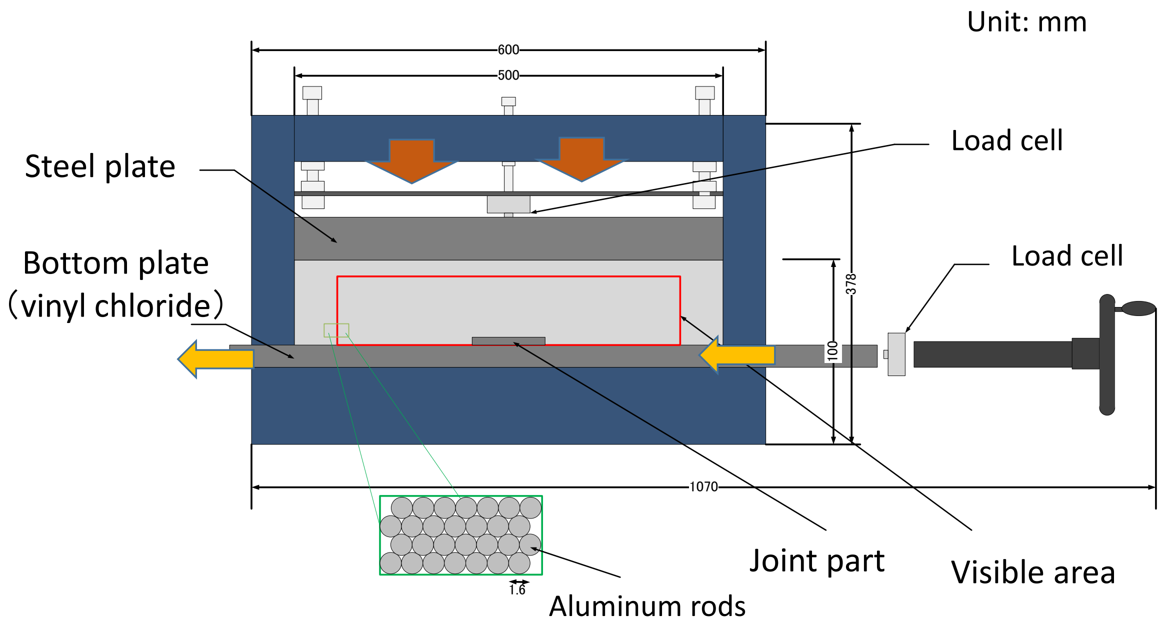


Fig.1–Test equipment drawing

Fig. 2 – Capther of test equipment

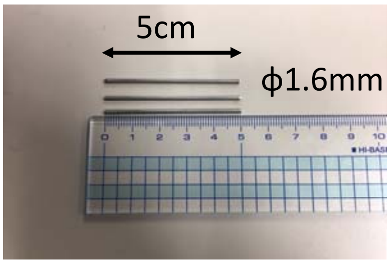


Fig.3 – Aluminium rod

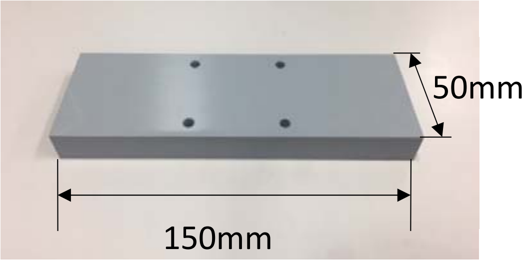


Fig. 4 – Joint part plate (Rectangle large)

Table-1 Experimental cases

Case #	Shape of plate	Thickness of plate	Number of sampling
1	Rectangle	Large: 21 mm	3 for each overload pressure
2	Rectangle	Small: 14 mm	
3	Trapezoid	Large: 21 mm	
4	Trapezoid	Small: 14 mm	

2.4 Angle of repose

In order to make clear the friction between the aluminum rods, the angle of repose of aluminum rods was measured when the aluminum rods were piled up with restraint in the horizontal direction and then the restrain was removed, as shown in Fig. 5. The results showed that the angle of repose was 15 deg. on average and 22 deg. at maximum.

Fig. 5 – Angle of repose of alminium rods

2.5 Friction coefficient between aluminum rods and bottom plate

The friction coefficient between the aluminum rods and PVC bottom plate was measured by the shear force to the overloading force when the joint part plate was not attached. 3 samplings for three cases of overloading forces were taken. Fig. 6 shows the relationship between the relative displacement and friction coefficient. When the displacement is given less than 2 mm, the slippage between the aluminum rods and bottom plate occurs. The friction coefficient without the joint part plate was about 0.3 to 0.4 regardless the overloading forces. The reason why the coefficient increases and decreases in a range to the displacement is considered that there is small gaps between aluminum rods and their relocations makes the shear force large and small. In the case the aluminum rods were piled up tightly, the slip occurred by the rotation of rods and the shear force became more constant.

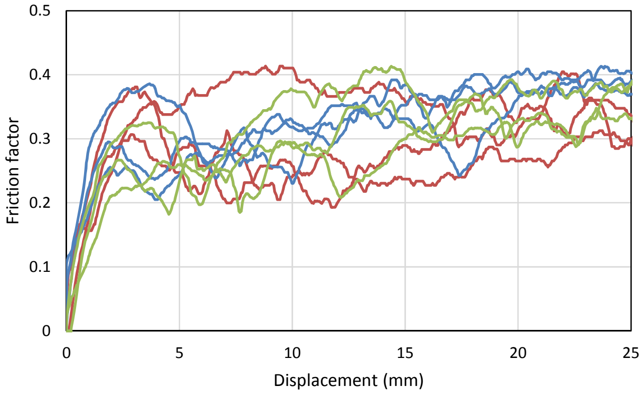


Fig. 6 – Friction coefficient between aluminum rods and PVC bottom plate.

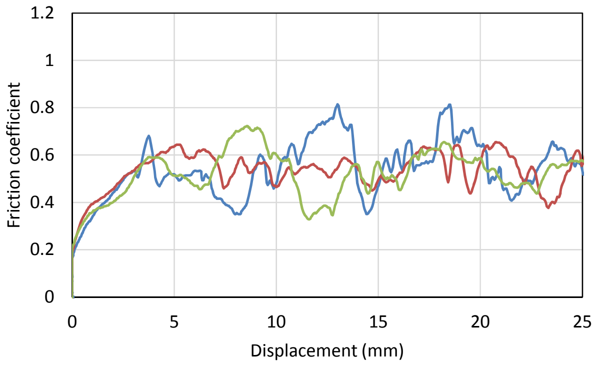
3. Result of shear test of convex part

Total of 36 samplings of experiments for 4 types of joint part plates for three cases of overloading force were obtained. The analysis is conducted based on the relationship between the displacement of the bottom plate and the friction coefficient. Fig. 7 to 10 show the experimental results in each case when the shape of the joint part plate was changed. The figures are summarized by each conversed buried depth, *d*. As the buried depth is large, the shear force increases for each joint part plate. In terms of the friction coefficient, the coefficients in the same plate is almost same. After the displacement reaches the slip, the shear force increases and decreases in a certain range and it does not keep to be constant. The reason is that the diameter of aluminum rods are comparative large for this experimental setting and when the gap between the aluminum rods is sifted, the shear force changes from increase to decrease or from decrease to increase.

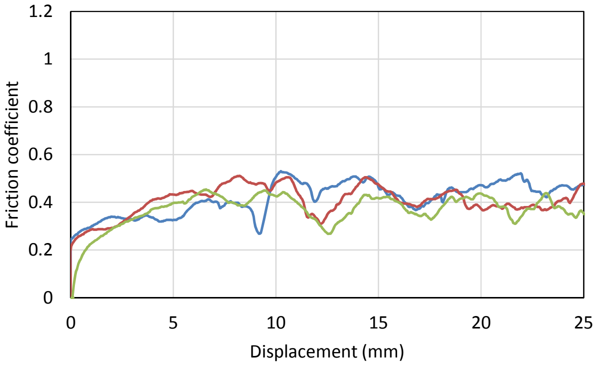
By the way in the most of cases, the relationship between the displacement and friction coefficient shows the bi-linear relation. Comparing with the case without the joint part plate, the initial displacement does not increase until the shear force increases somehow. The joint part plate makes aluminum rods not to slip. However, once the slip starts, the shear force gradually increases.

In the cases of rectangle joint part plates with large thickness (see Fig.7), there is first peak around the distance of 5 to 10 mm then the coefficient overshoots and then increase gradually. It is considered that because the soil particles are large relative to the thickness of joint part plate, the upward restraint pressure is applied when the soil particles pass over the joint part plate, while the restraint pressure is rapidly released when the gap is large. The friction coefficient at first peak is around 1.0, equal to three times of the case without the joint part plate.

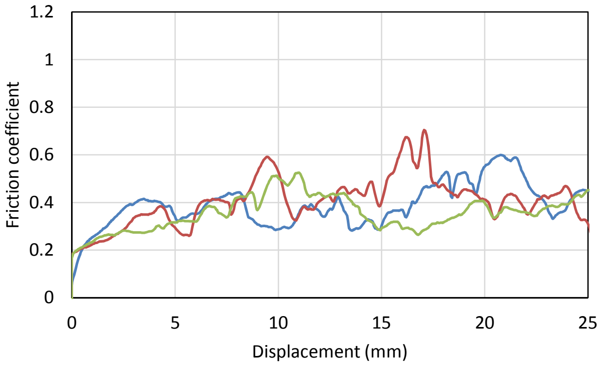
On the other hand, in the case of trapezoid joint part plate, the friction coefficient increases as the joint becomes thicker. The friction coefficient is around 0.4 in case of the small plate and 0.5 in case of the large plate. However, the shear force gradually increases according to the displacement and there is no peak like that seen in the rectangle joint part plate. It was confirmed that the shear force increases simply according to the overhang area of the joint part plate compared to the case without the joint.



(a) d=0.5m

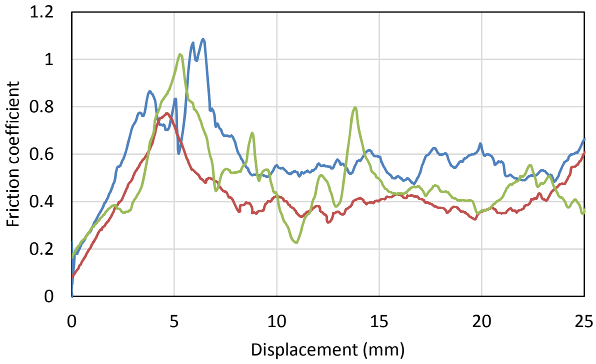


(b) d=0.75m

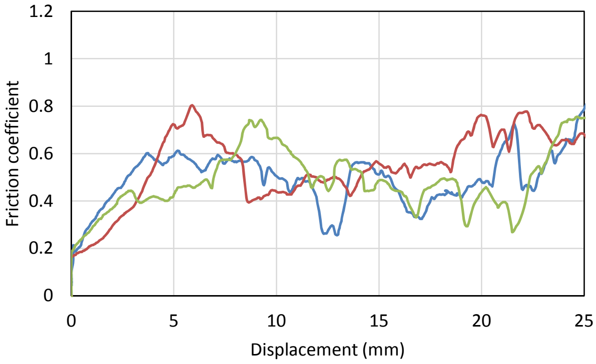


(c) d=1.0m

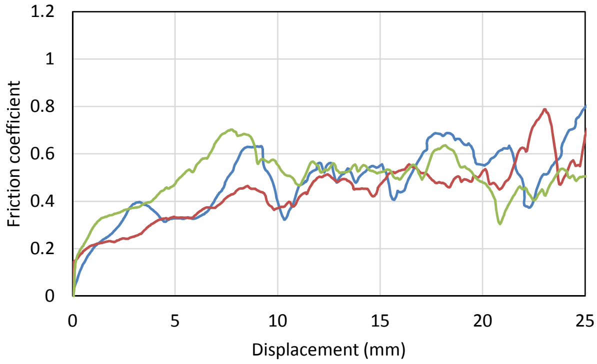
Fig.7 – Friction coefficient and displacement relationship for rectangle small joint



(a) d=0.5m

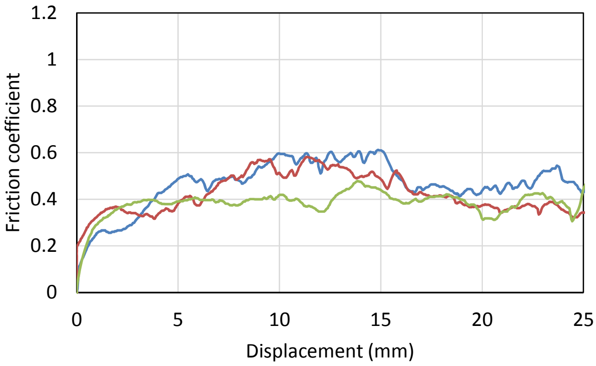


(b) d=0.75m

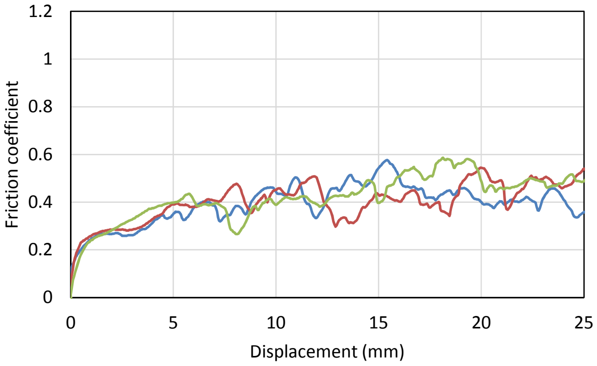


(c) d=1.0m

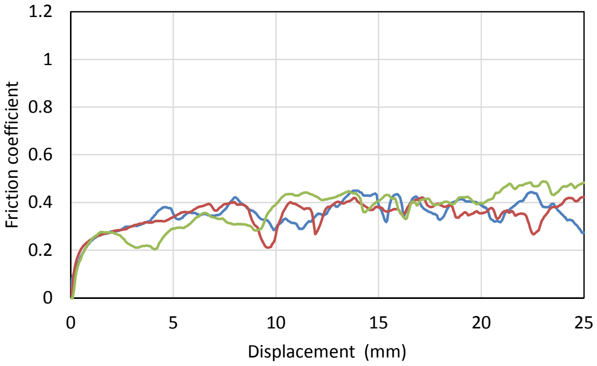
Fig.8 – Friction coefficient and displacement relationship for rectangle large joint



(a) d=0.5m

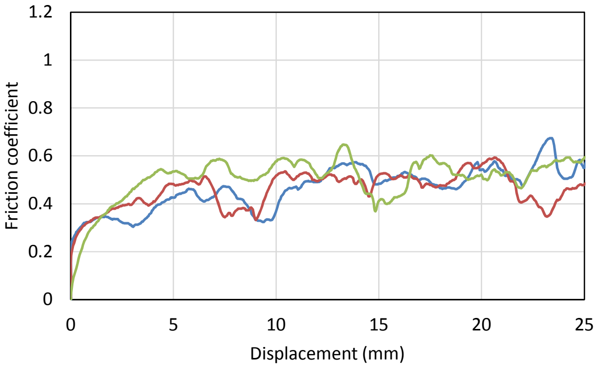


(b) d=0.75m

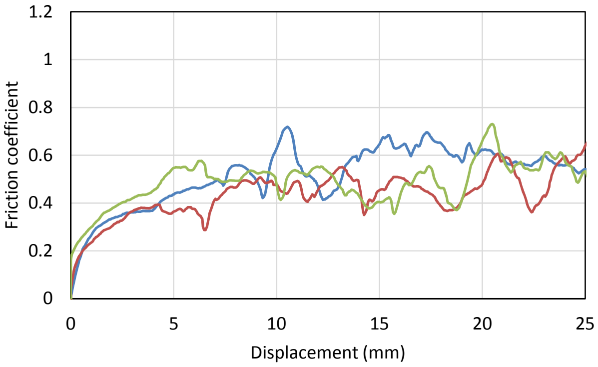


(c) d=1.0m

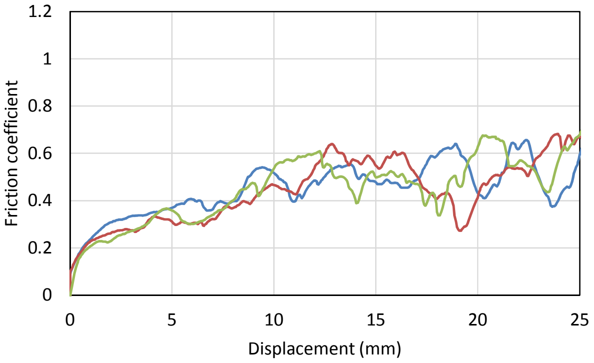
Fig.9 – Friction coefficient and displacement relationship for trapezoid small joint



(a) d=0.5m



(b) d=0.75m



(c) d=1.0m

Fig.10 – Friction coefficient and displacement relationship for trapezoid large joint

4. Trajectories of soil particles

The trajectories of soil particles were obtained from the snaps taken by the experiment. Specifically, images of marker soil particles randomly arranged at regular intervals were compared. Fig. 11 and Fig. 12 show the results in the cases of rectangle joint and trapezoid joint for both small thickness, respectively. The displacement of the joint plate is shown at the boundary point with the bottom plate. The joint plate moves from the right side to the left side. The colors filed in the circle indicates the location of rods by taken at the same time.

From the particle trajectory, both the vertical displacement and the horizontal displacement of the soil particles at the upper part of the joint plate were small in both cases using the rectangle joint and the trapezoid joint. Also, it can be seen that the soil particles were swirling in front of the joint. In particular, the vortex was large at the front of the joint, causing a large vertical displacement. From this, it is considered that the cause of the increase in the frictional force due to the convex part of joint was that the ground constraint pressure increased due to the vertical displacement of the particles at the front of the joint.

Comparison between the case of trapezoid joint part and the case of rectangle joint part shows a difference of the displacement of rods closer to the front of the joint. The movement of rods in the front of the rectangle joint part shows large circle. The shape of rectangle joint part makes the vertical movement hard and after a rod passes over the other rods the gap reminds.

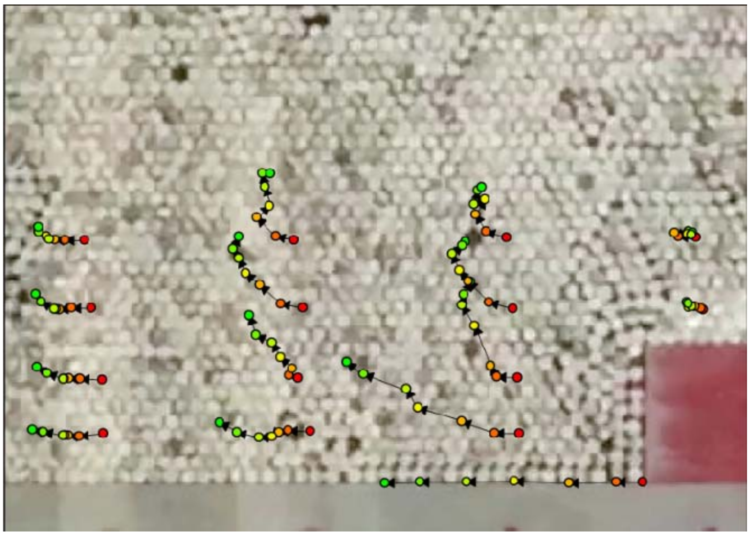


Fig. 11 – Trajectories of soil particles in case of reqtangle joint part with small thickness

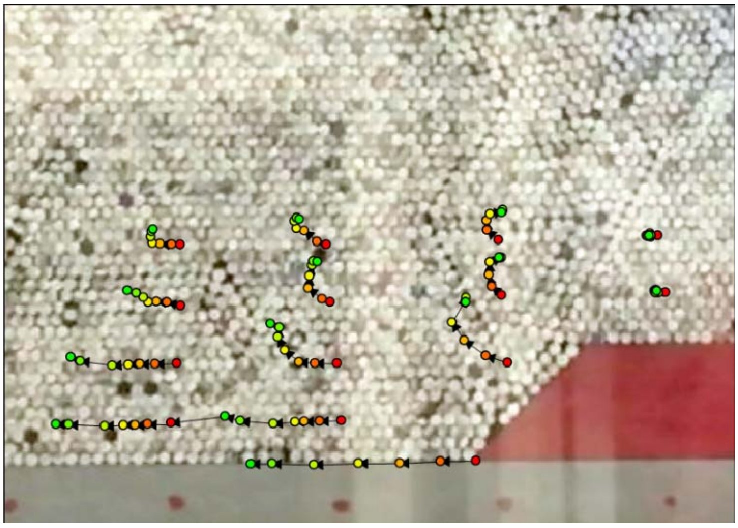


Fig.12 –Trajectories of soil particles in case of trapezoid joint part with small thickness

In this study, the convex shape used two patterns. Even though the same thickness, the friction coefficient is different by the shape. By devising the shape of the joint convex portion, it is possible to propose a frictional force acting on the pipeline. In this study, only aluminum rods with a uniform diameter were used. It is thought that the frictional force will be different if aluminum rods with different particle sizes are mixed, so it is necessary to consider various cases in the future. It is also necessary to clarify these model experiments analytically by numerical simulation.

5. Conclusive remarks

This study tried to clarify the mechanism of the frictional force generated between the ground and the pipe around the joint part from the point of the movement of soil particles. A model experiment in which the behavior of soil particles around the pipe joint part is replaced with a two-dimensional section is conducted. Followings cam be summarized as conclusive remarks.

- With the joint part on the shear furface, the friction coefficient increased 3 times at maximum when the shape of joint part plate is rectangle with large thickness.
- Even though the same thickness of joint part plate, the friction coefficient is different by the shape of joint convex.
- As the shear movement of joint part plate, the aluminum rods moves as a vortex. The cause of the increase in the frictional force due to the convex part of joint was that the ground constraint pressure increased due to the vertical displacement of the particles at the front of the joint.

6. References

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