# A Fundamental Study on Inelastic Behavior and Mechanical Characteristics of Rainwater Storage and Infiltration Facility

Kenta Aoki and Takumi Ito
Department of Architecture/ Tokyo University of Science, Tokyo, Japan
Email: kenta.aoki.handball@gmail.com, t-ito@rs.kagu.tus.ac.jp

***Abstract*— In recent years, urban disasters such as depleting groundwater and urban floods are increasing due to an increase in paved roads using asphalt and the like in Japan. As a countermeasure, rainwater storage and infiltration facilities (RSIF) that's able to prevent flood by suppressing rainwater flowing into rivers and use the stored rainwater as domestic water by storing rainfall in the underground are being adopted in many cities. If these facilities are collapsed by earthquake motions, it is concerned that most buildings or people are affected by the damage. In order to prevent such a situation, it is desirable that RSIF has sufficient seismic resistant performance. In this study, the cyclic loading tests are conducted to investigate the seismic behavior and resistant mechanism. From the test results and observation record during loading test, a frictional behavior and the development of shear and bending load bearing mechanism were confirmed.**

***Index Terms*— Rainwater storage and infiltration facilities, Horizontal cyclic loading test, mechanical characteristics, deformation followability**

## I. Introduction

Recently, in Japan, the paved roads using asphalt are increasing on urban cities because the advanced use of land accompanying rapid urbanization has progressed. For this reason, water-holding function and penetration capability of rainwater in cities and surrounding areas are markedly deteriorated. Additionally, in urban areas, the occurrence of torrential rain has become prominent due to radiant heat from buildings and reflected heat from paved roads (Fig.1) [1]. Therefore, the depletion of groundwater and floods are recognized as severe social issue. Natural rivers or traditional infrastructure such as sewers encounter their limitation of ability for sewerage treatment, and it is necessary to improve the management ability of rainwater all the city. In the Portland, United States, the rainwater management by green infrastructure using plants and soil is being promoted [2]. On the other hand, in many Japanese cities have adopted rainwater storage and infiltration facility (RSIF). RSIF is buried under the ground (see Fig. 2), storage rainwater in the facility or gradual infiltrate rainwater into the underground. By preventing rainwater from rapidly flowing into rivers and sewer systems, it is possible to prevent flooding and to accept effective utilization of stored rainwater.

In recent years, various RSIF have been developed in Japan, this study focuses on RSIF made from plastic shown in Fig.3, which has been adopted in urban areas in Japan. This facility is composed of plurality of members, and basic unit can be constructed merely by fitting the members as show in Fig. 3.Combining plural units results in one large facility. This facility has the following features: 1) It is lightweight because made from plastic. 2) construction period can be shorten because special tools and heavy construction machine are unnecessary.

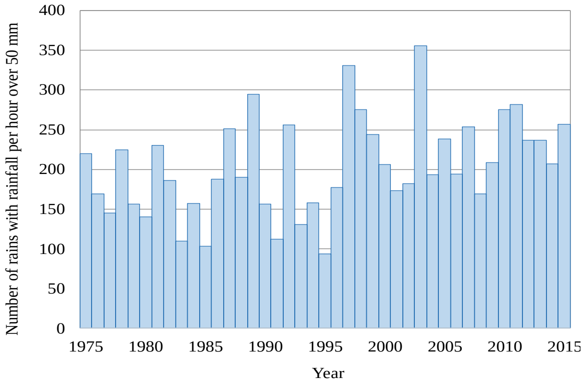


Figure 1. Number of rains with rainfall per hour over 50 mm in Japan [1]

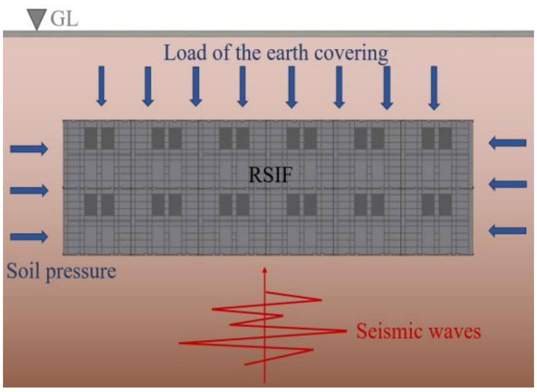


Figure 2. A state of RSIF buried in the ground

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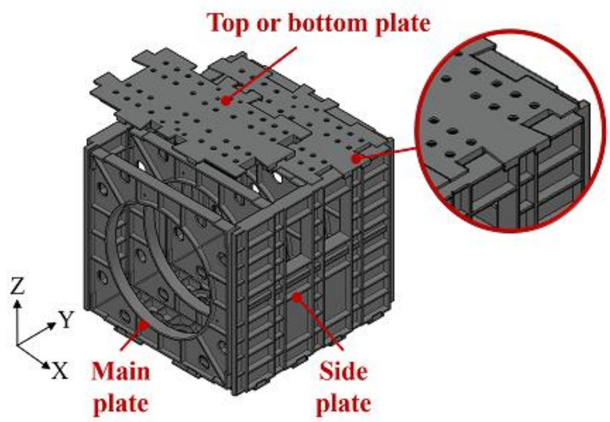



Figure 3. Basic unit of RSIF

Japan is one of the countries with high-risk by earthquake, it is required to evaluate seismic capacity of RSIF correctly. Regarding the durability and safety of RSIF, "Technical Guideline for Plastic Underground Storage and Infiltration Facilities" (TGPUSIF) has been published by "Association for Rainwater Storage and Infiltration Technology" [3]. From this guideline, to estimate the seismic performance, the experiment method is presented by cyclic loading tests. And also, this guideline shows analytical methods with seismic response simulation to confirm the response deformation followability. However, it is necessary to clarify the fundamental mechanical characteristics and resistant performance of the basic unit. In this paper, we conduct an experimental study due to comprehend the elastoplastic behavior and the mechanical characteristic of basic unit, and the resistant mechanism is clarified.

## II. Summary of Evaliation Methpd of Sesimic Capacity

### *A. The Outline of Evaluation Method*

If the facility is collapsed by earthquake motions, it is concerned that most buildings or people are affected by the damage. In order to prevent such a situation, it is desirable that RSIF has sufficient seismic resistant performance.

The seismic response behavior of the underground structure is greatly affected by the behavior of its surrounding ground. It is predicted that the shear deformation exceeds because RSIF has lower rigidity compared with surrounding ground. So it is desirable that its seismic resistant performance is investigated with consideration of the situation which RSIF is buried under the ground. However, it is practically difficult from the viewpoint of behavior confirmation in the ground, time, and cost for experiment investigations. Therefore, the guideline suggests the pseudo-experiment method as assumption with load of the earth covering.

And also, it is expected that the strength of RSIF decreases due to unstable phenomenon such as buckling, blushing, and peeling during loading test. So these resistant behavior is verified by observation, and the effect of strain and stress are checked.

### *B. Method of the Horizontal Cyclic Loadind Test*

First, to consider the situation of actual use of RSIF, the underground depth is estimated from 0.5m – 2.0m. So these estimated weight is equipped with steel weights on test specimen.

To obtain the restoring force characteristics of RSIF, the shear deformation angle and shear force are measured. From test results, the fundamental seismic performance can be discussed. Furthermore, the analytical model of restoring force characteristics can be assumed from the test results.

### *C. Evaluation of Seismic Capacity by Shear Deformation Angle*

In the previous section, it is explained how to measure the shear stress and shear deformation angle of RSIF during cyclic loading behavior. On the other hand, shear deformation angle of RSIF under the ground during earthquake motions is obtained by dynamic analysis using finite element method. Specifically, we obtain the allowable shear deformation angle (it is defined as 80% of the shear deformation angle at maximum stress of the test specimen.) by the horizontal cyclic loading test, and the shear deformation angle by dynamic analysis. When the shear deformation angle by dynamic analysis is less than the allowable shear deformation angle obtained by the test, it is judged that it has seismic capacity.

## III. The Outline of Experiment

### *A. Mechanical Properties*

Table I shows the name, size and weight of the test specimen, and Table II summarizes the mechanical properties of material. The young's modulus and the yield strength is shown with values considering the standard deviation of the material test result. Poisson's ratio is shown as general value of polypropylene copolymer.

TABLE I The Name, Size and Weight of the Test Specimen Member

| | X(mm) | Y(mm) | Z(mm) | Weight(kg) |
|---|---|---|---|---|
| Main plate | 1,000 | 63 | 1,000 | 9.0 |
| Top or bottom plate | 1,049 | 547 | 50 | 7.3 |
| Side plate | 80 | 1,165 | 1,000 | 17.8 |

TABLE II Mechanical Properties of Material

| Yield strength ($N/mm^2$) | Poisson's ratio | Young's modulus ($N/mm^2$) | Mass density ($kg/m^3$) |
|---|---|---|---|
| 21.5 | 0.41 | 804 | 1,020 |

### *B. Test Setup and Measurement Plan*

Test setup is shown in Fig.4. Loading test is carried out with vertical load which is assumed as covering ground or soil on RSIF under the ground, so a steel plate is placed on the top of test specimen and a portable jack is attached via a jig. Out-of-plane deformation is restrained by linear guide equipment. Rocking behavior of the test specimen is restrained by the jig pillar. Slip of the test specimen is suppressed by inserting a rubber sheet between the bottom of the basic unit and the reaction frame. The horizontal load is detected from the load cell built in the portable jack. The retractable displacement gauge is installed at the top of the test specimen, and the shear deformation angle is obtained by dividing the measured displacement by the height of the test specimen.

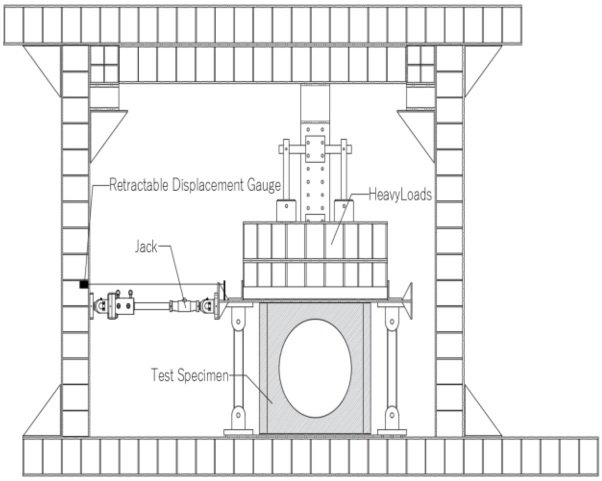



Figure 4. Test set up

### C. *Experiment Variables*

Experimental variables are load weight and loading direction. The name of the test specimen and the experimental variables are shown in Table 3.

TABLE III THE NAME OF THE TEST SPECIMEN AND THE EXPERIMENTAL VARIABLES

| Test specimens name | Loading direction | Heavy loads (kg) | Assumed load of the earth (mm) |
|---|---|---|---|
| PU-XL | X | 851 | 0.46 |
| PU-XH | X | 1357 | 0.75 |
| PU-YH | Y | 1357 | 0.75 |

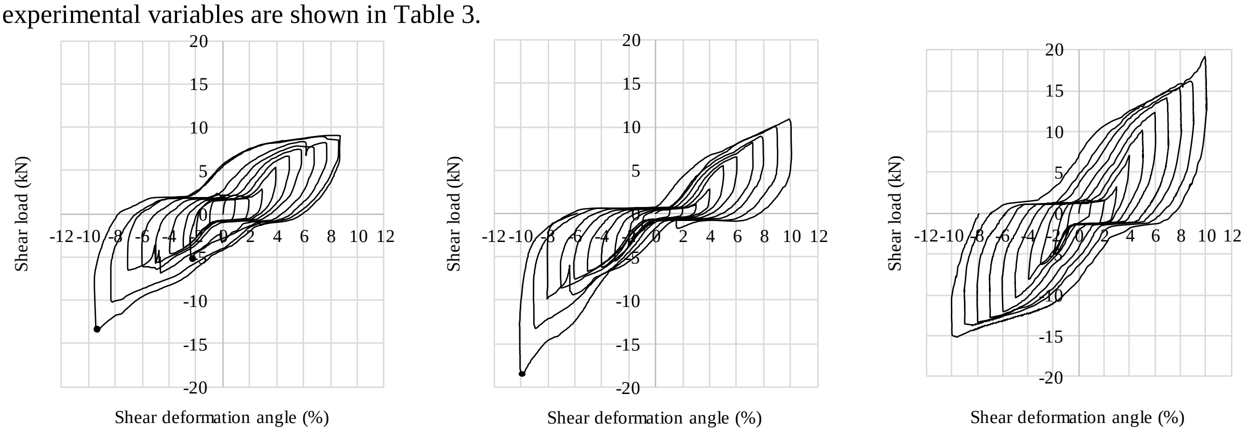
### D. *Loading Pattern*

According to TGPUSIF, the shear deformation angle is gradually increased 10% at 1% increments, and peak-to-peak alternating loading is performed. For convenience of setup, the shear deformation angle of 10% is set as the load limit.

## IV. TEST RESULTS

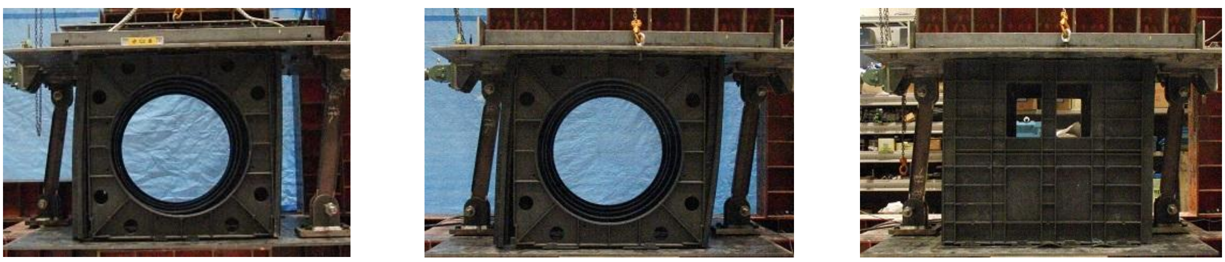
From the test results, the relation of the shear load-shear deformation angle of horizontal cyclic loading test is shown in Fig.5. When the fracture of test specimen is observed, the symbols is presented in Fig.5 are shown. The ultimate state of the test specimen is presented in Fig. 6.

The test specimen of PU-YH was not broken even if the shear deformation angle reaches to limit (10%). The average value of the maximum load at a shear deformation angle of 10% was 11.3kN, 14.9kN, 17.1kN for PU-XL, PU-XH, PU-YH. The average value of the rigidity was 0.14kN/mm, 0.19kN/mm, 0.31kN/mm, and PU-YH showed the maximum value. According to guideline of performance evaluation [4], the allowable shear deformation angle is 2.9% and 6.6% at the ground covering of 1.0m and 2.0m, respectively. In contrast, each test specimen doesn't exhibit an unstable deterioration




a. PU-XL b. PU-XH c. PU-YH

Figure 5. The relation of the shear load-shear deformation angle of horizontal cyclic loading test



a. PU-XL b. PU-XH c. PU-YH

Figure 6. The final state of the test specimen

behavior even at a shear deformation angle rate of 10%, so it can be confirmed that it has deformation following capability.

## V. Study of Test Results

### A. Comparison by Loading Direction

The loading direction corresponds to the coordinates in Fig.3. Test results show that the maximum stress of PU-YH in the Y direction loading is larger than PU-XL and PU-XH in the X direction loading from the aspect of difference in loading direction. Depending on loading direction, it shear resistance mechanism in the Y direction loading.

### B. Deformation Behavior and Transition of Load-Bearing Mechanism

From the Fig.7 and the observation record during the experiment, the behavior of test specimen is as follows: phase (1) high rigidity behavior because the steel plate strongly restrict and all member remains initial condition, phase (2) slip behavior occurrence between main plate and side plate, after this behavior, each member release their deformation, phase (3) restoring force mechanism appearance which derived from contact mechanism between each panel, phase (4) rigidity deterioration because joint and member yields, finally, the joint are fractured.

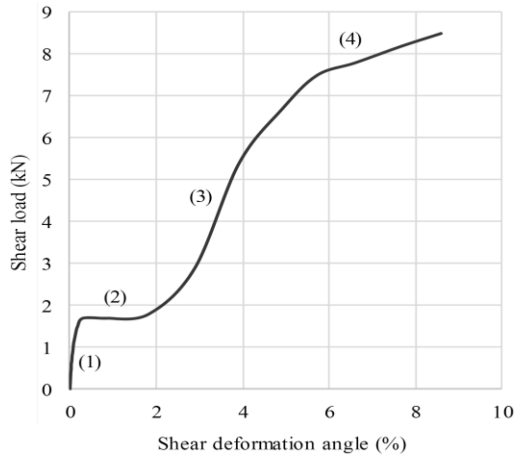



Figure 7. Skeleton curve of PU-XL

### C. Slide of Main Plate

Regard the behavior during phase (2), the slip amount in the X direction loading is about 30 mm. Moreover, a clearance of about 30 mm is set up between the main plate and the side plate, which is considered to be consistent with the slip behavior.

### D. Load-bearing Mechanism of Main Plate and Side Plate

From the Fig.8 and the observation record during the experiment, shear deformation of the main plate and bending deformation of the side plate were confirmed during phases (3), (4). From these observations, it is considered that the load-bearing mechanism by the shear resistance force of the main plate and the flexing resistance of the side plate was developed through the reaction force of the stop at the joint area by the contact between the main plate and the side plate.

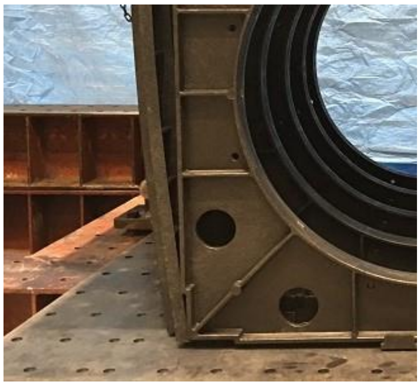


Figure 8. Contact between main plate and side plate

## VI. Conclution

In this paper, we conducted an experimental study due to comprehend the elastoplastic behavior and the mechanical characteristic of basic unit. The main conclusions of this paper are bellow.

(1) At the shear deformation angle of 10%, the restoring force characteristic does not become an unstable behavior and has sufficient deformation followability.

(2) The maximum stress and rigidity are different depending on the loading direction,

(3) The shape of the side plate influences the load-bearing mechanism.

(4) Slip behavior due to unit clearance is shown.

(5) it is considered that the load-bearing mechanism due to the flexing resistance of the main plate and the shear resistance force of the side plate was developed by contact between the main plate and the side plate.

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**Kenta Aoki** was born in Chiba of Japan in 1993. He earned the bachelor's degree, and planning to earn the master's degree from Tokyo University of Science. He belongs to the Architectural Institute of Japanese (AIJ) since 2016.

**Takumi Ito** is associate professor, Tokyo University of Science. He received the Dr. Eng. Deg. from the University of Tokyo. His research interests are building structure, experimental methodology, and numerical simulation. He has published 42 papers, 57 proceedings, and other papers or reports. He received some paper awards of Architectural Institute of Japan or Japan Society of Steel Construction in 2003, 2004, and 2006.