# Field verification test for buried bend with lightweight thrust restraint using geogrid

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ABSTRACT: Thrust forces are generated at bend pipes due to internal water pressures. Generally concrete blocks are installed at bends to resist thrust forces. However, it has been reported that concrete blocks were one of the weak spots of the pipe system during earthquake. To improve the pipe system during earthquake, we previously proposed to replace concrete blocks with a lightweight thrust restraint technique using geogrids. In this study, the field test on the lightweight thrust restraint for buried bend pipe was carried out in order to examine the behavior of the bend pipe in the field. From the test results, it was found that the steel bend pipe with the proposed method performed satisfactorily under internal water pressures.

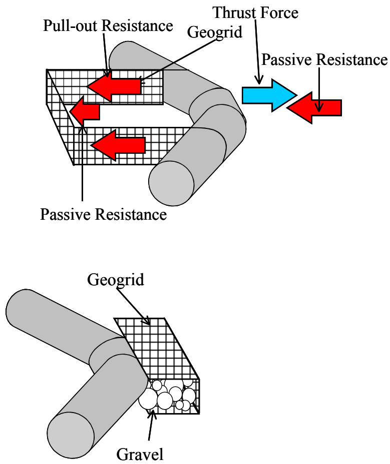
## 1 INTRODUCTION

Generally, pipelines for irrigation are subjected to internal water pressure. In the bend pipes of such pressure pipelines, unbalanced forces, which are called thrust forces, develop depending on the magnitude of internal pressure and the bending angle. Thrust forces act outward on the bend pipes and that tend to move the bend pipes. Passive earth pressures acting on the bend pipes resist thrust forces. If thrust forces are larger than passive forces, thrust restraints are required. Commonly, concrete blocks are installed at the bend pipes.

However, it has been reported that concrete blocks were one of weak points in the pipe system during earthquakes. In the 1993 Hokkaido-Nansei-Oki earthquake in Japan, the concrete block at a bend displaced largely in liquefied ground due to the thrust force, leading to the slipping out of an adjacent pipe as shown in Figure 1 (Mohri et al, 1995).

In our previous study, a thrust restraint technique using geogrid was proposed as shown in Figure 2(a) (Kawabata et al, 2005). Geogrid was connected at the back of a bend pipe. In the proposed method, the tensile force in the geogrid develops with the movement of the bend pipe. It was considered that the thrust force was supported by passive earth pressure, pull out resistance and passive resistance in the proposed method as shown in Figure 2(a). In order to verify the effectiveness of this proposed method as thrust restraint, laboratory model tests, large-scale

Figure 1. Damage to buried bend in the 1995 Hokkaido-Nansei-Oki Earthquake




(b) Using geogrid with front of bend
Figure 2. (a)Using geogrid with back of bend

tests (Sawada et al, 2008), numerical analysis and shaking table tests (Kawabata et al, 2008) were carried out. From these results, it was found that the lateral resistance against thrust force was increased whereas the lateral displacement of the bend pipe was reduced using proposed method. The mechanism of restraining was understood through numerical analyses. The design aspect of proposed method was then established. In addition, it was found that the bend pipe with proposed method was extremely stable in liquefied ground.

On the other hand, a new backfill method using geogrid was suggested (Kawabata et al, 2008) as shown in Figure 2(b). Geogrid was wrapped at the front of a bend pipe. Lateral loading tests were conducted to examine the behavior of the pipe with proposed method. The results indicated that passive resistance acting at the front of the pipe was increased.

In this study, field tests were carried out to examine the behavior of the bend pipe with a lightweight thrust restraint using geogrid (Figure 3). The test field was one of branch canals at the Gunma prefecture in Japan. The repair work, which replaced the water pipe bridge with the buried pipeline, was carried out in this branch in March 2008.

## 2 GROUND CONDITIONS AND TESTING PROCEDURES

Figure 4 shows the schematic diagram of the field testing. Two geogrid layers were used. Figure 5 shows the result of tensile test of geogrid. During the test, water supply was stopped for 24 hours. Field soil was excavated from the ground to the level of existing concrete pipe. After the concrete pipe was removed, a geogrid and a steel bend pipe were set as shown in Figure 6. The steel bend pipe had a diameter of 800 mm and a bend angle of 56°. In addition, the pipe has two poles for connecting the geogrid as shown in Figure 7. Geogrid was connected at the back of bend pipe.

The gravel was used as backfill material in the area from the bottom to the top of the pipe. Gravel was compacted in 0.2-m layers by a 80 kg – vibratory compacter as shown in Figure 8. Optimum moisture content of the gravel was 12.33 % and the maximum dry density was 1.95 g/cm$^3$. After the gravel reached the top of the pipe, geogrid that was set under the bend pipe was wrapped as shown in Figure 3. Field soil was filled and compacted at0.3 m interval in the area from the top of the pipe to the ground. The steel bend pipe was buried at the depth of the cover of 1.2 m. The field soil was a sand layer having boulders of diameter ranging from 0.2m to 0.5m. The ground water level was below the bottom of the pipe. After backfilling, the water supply was started.

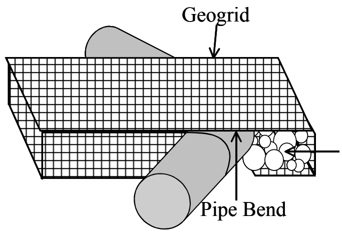



Figure 3. Lightweight thrust restraint

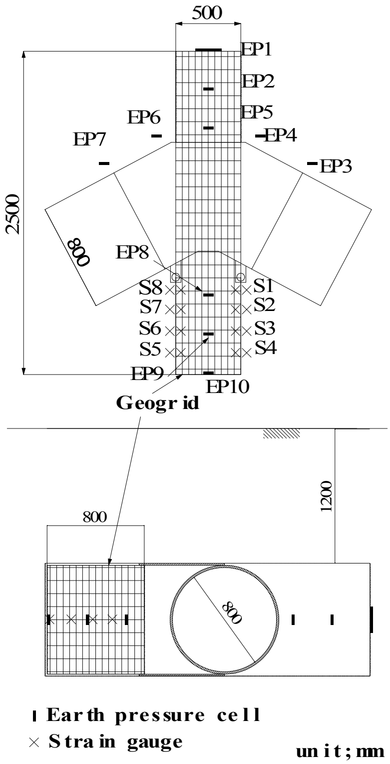



Figure 4. Schematic diagram of field test

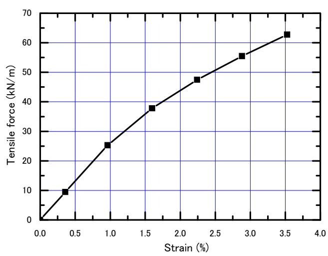



Figure 5. Result of tensile test of geogrid

## 3 MEASUREMENTS

The instrumentation scheme consisted of several types of measurements. The internal water pressure was measured. Earth pressure around the bend pipe was measured for observing the behavior of the surrounding ground around the bend pipe as shown in Figure 4. In addition, strain gauges were attached on both faces of geogrid to measure the axial strain of geogrid.

## 4 TEST RESULTS

### 4.1 *Time History of Internal Water Pressure*

Figure 9 shows the time history of internal water pressure. After the water supply was started, the internal water pressure reached 73 kPa. It was founded that the internal water pressure fluctuated from day to day depending on the use of water. Compared with the range of fluctuation of the internal water pressure per day from March to June, the range from June to August was small. It was found that the water supply increased for midnight in the irrigation period. The inner water pressure decreased from mid-October. It was considered that after the harvesting season, the use of water supply decreased.

### 4.2 *Time History of Earth Pressure Acting on Bend Pipe*

Figure 10 shows the time history of the internal water pressure and horizontal earth pressure of EP5. The internal water pressured increased in the morning and decreased at night. The behavior of the earth pressure was similar to that of the internal pressure. The fluctuation of earth pressure was associated with the fluctuation of the internal water pressure. It was considered that passive earth pressure acting on the front of the bend pipe was generated depending on the magnitude of the internal water pressure.

### 4.3 *Distribution of Earth Pressure*

Figure 11(b) shows the distance from the center of the bend pipe to earth pressure cells. Figure 11(a) shows the distributions of horizontal earth pressure in X-axis direction at the internal water pressure of 63 kPa and 78 kPa. From Figure 11(a), it was found that the earth pressure around the center of bend pipe was peak and they were small as the distance from center of bend pipe was far (Sawada et al, 2008). This implied that the thrust force was concentrated at the center of the bend pipe.

Figure 6. Geogrid and a steel bend pipe

Figure 7. Installation of geogrid

Figure 8. 80 kg – vibratory compacter

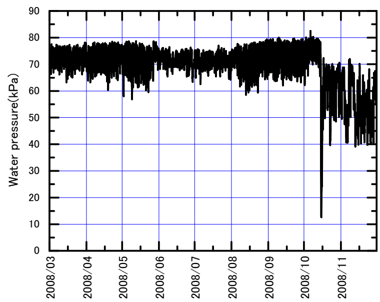



Figure 9. Time history of internal water pressure

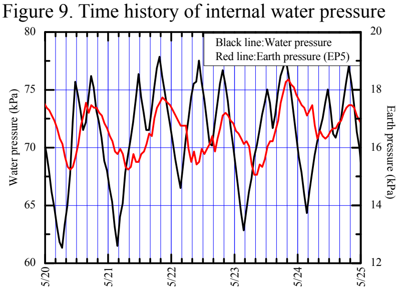



Figure 10. Relationship between inner water pressure

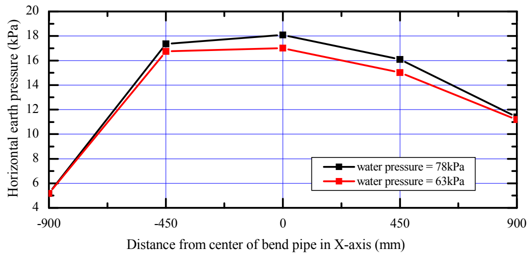
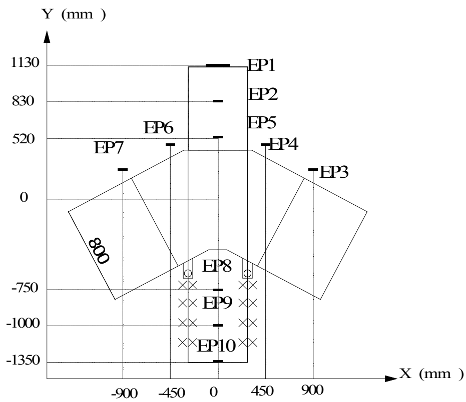
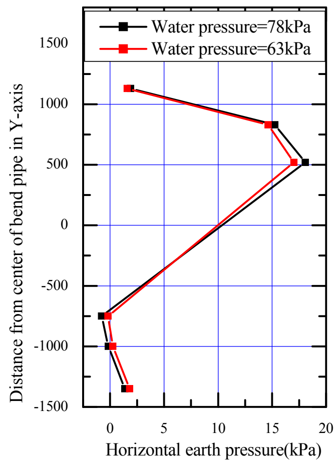


Figure 11. (a) Distribution of horizontal earth pressure in X-axis



(b) Distance from center of bend pipe to earth pressure cell



(c) Distribution of horizontal earth pressure in Y-axis

Compared with the earth pressures at the inner water pressure of 63 kPa, that at 78 kPa was large. It indicated that the earth pressures increased depending on the magnitude of the inner water pressure.

Figure 11(c) shows the distributions of horizontal earth pressure in the Y-axis direction at the internal water pressure of 63 kPa and 78 kPa. By comparing the earth pressure of EP2 and EP5, the passive earth pressure at EP1 was small. It means that the passive earth pressure was not effective for the lateral resistance against thrust force as the distance from center of the bend pipe was far.

Figure 11(c) shows that the earth pressure of EP10 approached 2.5 kPa. It was caused by lateral movement at the back of the geogrid.

### 4.4 *Time History of Axial Strain*

Figure 12 shows the time history of internal water pressure and axial strain at S1 and S2. The axial strains increased with the increase in the internal water pressure. The lowest value of the axial strain per day approached about 4 hours after the lowest value of the internal water pressure. It was considered that the fluctuation of the axial strain was associated with that of the internal water pressure.

Maximum strain generated at a position closest to the bend and minimum strain generated at a position closest to the back of geogrid. However, comparing the axial strains of S1 and S2, the axial strain of S2 was larger than S1. It was considered that geogrid was curved when buried.

### 4.5 *Lateral Resistance against Thrust Force*

Thrust force $P$, depending on the internal water pressure, bending angle and cross-sectional area of the bend is calculated from

$$P = 2 \cdot Pw \cdot A \cdot \sin\frac{\theta}{2}$$

where $Pw$ is the internal water pressure (kPa), $A$ is the cross-sectional area of the bend (m$^2$) and $\theta$ is the angle of the bend (deg.). In addition, the passive resistance is calculated from observed earth pressure at the center level of the bend. The earth pressure distribution as presented in Figure 11(b) is approximated by a parabola and the total area is regarded as the passive resistance having the unit of force per unit depth. In addition, the total passive resistance $R_p$ is assumed that earth pressure distribution in the direction of depth is a trapezoid, as used in existing Japanese Standard. $R_p$ is calculated by

$$R_p = P_p \cdot D \cdot F$$

Here $P_p$ is the passive resistance acting on the center level of the bend (kN/m) and $F$ is a reduced coefficient for square object (= 0.65). It was clarified that the lateral resistance for the model pipe was approximately 65% comparing with that of a square plate by conducting lateral penetration model tests in sand (Kawabata et al., 2002).

Moreover, in the proposed method, it is considered that the geogrid contributed to an increase in the lateral resistance against lateral force. The lateral resistance is equivalent to the tensile force that was generated at the connection of the bend and geogrid as shown in Figure 4. The tensile force could be calculated from the tensile strain of both sides of geogrid, at S1 and S8 (Fig. 5).

Figure 13 shows the time history of the ratios of two lateral resistances to thrust force. One of them was the lateral resistance due to passive earth pressure acting at the front of the bend pipe and the other one was the lateral resistance due to geogrid.

From Figure 13, the ratio at the lateral resistance due to the earth pressure was about 40%. On the other hand, the rate at the lateral resistance due to the tensile force of the geogrid was about 1%. When the bend pipe was moved, tensile force due to geogrid was generated. It was considered that the bend pipe has hardly moved. It is considered that rest of the lateral resistance against thrust force was due to the frictional resistance along the circumference of the straight part of the bend.

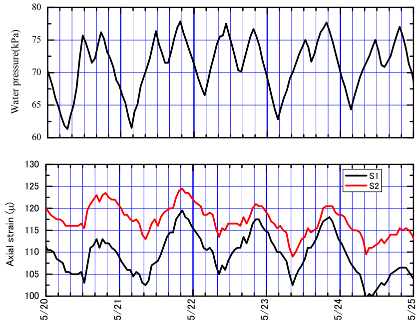


Figure 12. Relationship between internal water pressure and axial strain

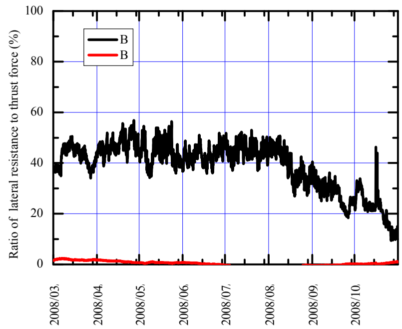


Figure 13. Ratio of lateral resistances to thrust force

## 5 CONCLUSION

Field tests were carried out to examine the behavior of the bend pipe for proposed methods. The following points were clarified from the test results:

- The fluctuation of earth pressure acting on the front of the bend and the axial strain were associated with the fluctuation of the inner water pressure.
- The lateral resistance due to tensile force of geogrid against thrust force was hardly generated. Most of the lateral resistance were due to the passive earth pressure acting at the front of the bend pipe.

## 6 ACKNOWLEDGEMENTS

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