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DEVELOPMENT OF MULTI-LAYERED SEWER PIPE PLUG -1ST REPORT: RUPTURED TEST AND STRESS ANALYSIS OF PROTECTIVE SHEET

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In recent years, the sewer system in Japan is becoming obsolete. It is, therefore, necessary to reinforce or repair without stopping sewer functions by applying a suitable water stopping method. In this study, a multi-layered sewer pipe plug consisting of the protective sheet and two rubber balls is focused since it can be installed and removed at the construction site in a short time conveniently. This sewer pipe plug has several advantages dealing with various diameters compared to the conventional type. In this study, the rupture test is conducted to improve the water stopping performance. The fractured position of the protective sheet of the sewer pipe plug was investigated experimentally. It was clarified that the maximum stress around the flange portion can be reduced by decreasing the flange inner diameter.

Keywords: Sewer Pipe Plug; Protective Sheet; Ruptured Test; Stress Analysis

1. Introduction

Sewers occupy a considerable large amount of underground space compared to underground tunnels and subways. Japan's sewer system is becoming obsolete and has to be updated, reinforced, and repaired after 2020. During the repair, it is necessary to apply a suitable water stopping method without stopping the sewer function. An air injection type pipe plug with one layer is used to stop water conventionally although the critical pressure is about critical pressure p_{cr} =0.3 MPa or less with a risk of a rupture. Therefore, to stop high-pressure water for deep underground over 40m, higher pressure resistance is required.

Fig. 1 shows a three-layered sewer pipe plug to be developed.[1-2] The first inner layer is an inner ball made of natural rubber to keep airtight. The second layer is a protective sheet made by ultra-high molecular weight polyethylene fiber (Izanas fiber) to support the high internal pressure. The third outer layer is made of natural rubber to provide frictional resistance from the pipe wall. In this study, by performing a rupture test of the protective sheet, the strength and the fracture origin will be clarified. The stress analysis is also performed to improve the protective sheet performance.

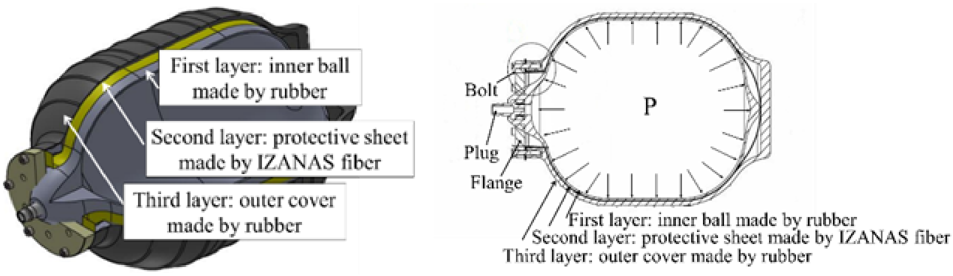

Fig. 1. Development of multi-layered sewer Pipe Plug

2. Rupture test for protective sheet made by ultra-high molecular weight polyethylene fibers (UHMWPE)

2.1. *Description of the protective sheet*

The protective sheet used in the pipe plug in Fig. 1 is made by the seamed cloth knitted by the thread composed of ultra-high molecular weight polyethylene fibers (UHMWPE). The UHMWPE fiber has a molecular weight of 15 times or more that of ordinary polyethylene having extremely high strength, excellent wear resistance, weather resistance, and water resistance. This fiber has the highest level of strength and elastic modulus as an organic fiber. Table 1 shows the mechanical properties of UHMWPE fiber named IZANAS fiber. One thread is made by spinning 1170 UHMWPE fibers and the band cloth with 200 mm length and 100 mm width dimensions is made by plain weaving the thread. Finally, the protective sheet is made by sewing four-band clothes with Kepler thread composed of Aramid fibers.

Table 1. UHMWPE fiber named IZANAS used in the protective sheet

Material	Diameter [μm]	Strength [MPa]	Elastic modulus [GPa]
Polyethylene	12	$2.6 \sim 4.0 \times 10^6$	79

* One thread is made by spinning 1170 fibers

2.2. *Experiment method*

Fig. 2 illustrates the ruptured test of a two-layered sewer pipe plug consisting of an inner ball and a protective sheet. The strength of the protective sheet is discussed identifying the fracture origin. Air is injected into the inner rubber ball until the protective sheet ruptures. The fracture origin is clarified by examining the protective sheet after it ruptured.

2.3. *Experimental results and discussion*

Fig. 3 illustrates an example of a ruptured protective sheet. The rupture occurs under the $p_{cr} = 0.53$MPa, which is lower than the target pressure $p = 2$ MPa to be used for the deep underground. Observation shows that the protective sheet is fractured near the inner corner of the flange shown in R_2 in Fig. 4. Note that the fracture origin is at the seamed portion near the inner corner of the flange. Since the seamed portion is constrained in deformation, the smaller deformation compared to the other portion may increase the risk of fracture.

Fig. 2. Two-layered pipe plug used in the ruptured test

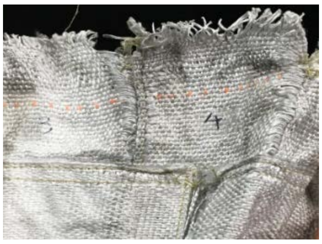

Fig. 3. Protective sheet after rupture

3. Analytical results and discussion

3.1. *Analytical method*

Since the rigidity of the rubber ball is smaller and negligible compared to the protective sheet, only the protective sheet is analyzed by applying axisymmetric shell elements using general finite element method analysis software Marc/Mentat 2012. Fig. 4 shows the analysis model. In Fig. 4, the circular arc R_1 is divided into 30 elements, R_2 is divided into 60 elements, R_3 is divided into 60 elements, straight line l_1 is divided into 34 elements and l_2 is divided into 146 elements. In this analysis, the flange inner diameter d_f =80mm, diameter d =180mm, thickness t = 1 mm, the elastic modulus $E = 3.4$GPa, Poisson's ratio $\nu = 0.3$. The circumferential stress σ_θ, tangential stress σ_t , and normal stress $\sigma_n$are obtained under the internal pressure p = 1 MPa.

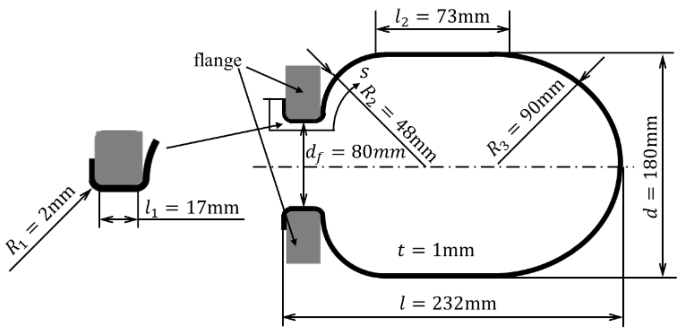

Fig. 4. FEM model for protective sheet when d_f =80mm

3.2. *Analytical results and discussion*

Fig. 5 and Fig. 6 show the analysis results for the flange inner diameters $d_f = 80$mm and $d_f = 20$mm. The solid line denotes the circumferential stress σ_θ, the dashed line denotes the tangential stress σ_t, and the normal stress σ_n=0. From Fig. 5, the maximum tensile stress σ_t = 93MPa at the seamed portion coincides with the fracture origin at the flange part in the ruptured test. Since the fracture occurred at an internal pressure of critical pressure $p_{cr} = 0.53$MPa, the tensile strength of the seamed part of the protective sheet can be estimated as $\sigma_t = 93 \times 0.53 = 49$MPa.

From the comparison of Fig. 5 and Fig. 6, it is seen that the maximum stresses σ_θ and σ_t around the flange portion decrease with decreasing the flange inner diameter d_f.

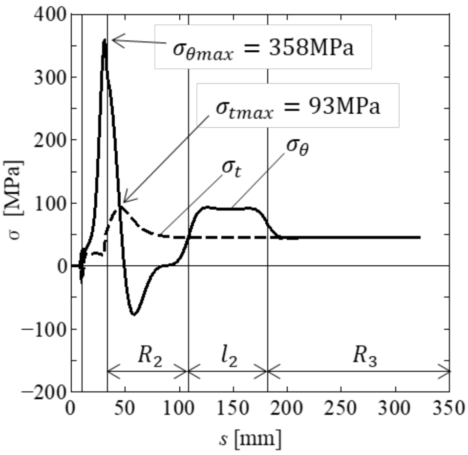

Fig. 5. Stress distribution of protective sheet under p=1MPa when $d_f = 80$mm

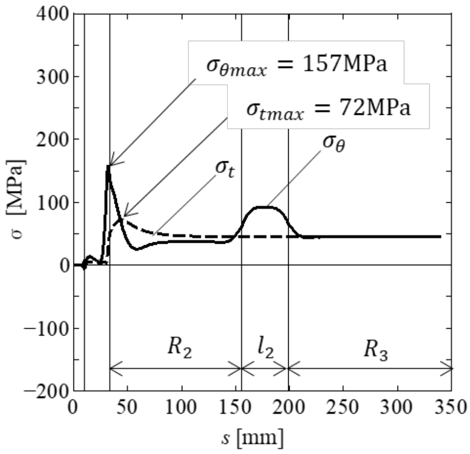

Fig. 6. Stress distribution of protective sheet under p=1MPa when $d_f = 20$mm

4. Conclusions

In this study, a rupture test was conducted for the multi-layered pipe plug to investigate the strength of the protective sheet. The stress analysis is also performed to clarify the fracture origin. The conclusions can be summarized in the following way.

(1) From the rupture test, it was found that the fracture originates from the seemed portion of the protective sheet is near the inner corner of the flange.

(2) From the stress analysis for the protective sheet, it was found that the maximum stress appears around the flange portion. The maximum stress can be estimated as σ_t =49MPa when fractured.

(3) It was clarified that the maximum stress around the flange portion can be reduced by decreasing the flange inner diameter.

References

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