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Study on characteristics of grease flow resistance by element test

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ABSTRACT: Recently, stresses in segments during construction tend to increase and therefore the segment damage during construction has increased. One of the predominant components of construction loads is force acting around a shield tail, which is composed of the force caused by the wire brushes, the force due to the grease flow resistance, and the force due to the contact between skin plate and segment. In this study, to make clear the flow resistance characteristics of grease filled up in-between wire brushes quantitatively, the element tests using grease and wire brush were carried out, using a test equipment which can press grease in front of the wire brush and apply water pressure behind the wire brush. As a result, it was found that the excess grease pressure appears under the conditions of small tail clearance and large decrement rate of grease volume.

1 INTRODUCTION

Recently, shield tunnels have been constructed in deeper underground with sharp curve, as the underground in urban areas becomes congested. Furthermore, segments become thinner and wider for saving cost. Consequently, stresses in segments during construction tend to increase and the segment damage during construction has increased.

According to the existing research on construction loads (Japan Society of Civil Engineering 2006, Sugimoto 2006), it is pointed out that one of the predominant components of the construction loads is the force acting around a shield tail as shown in Figure 1, which is composed of the force caused by the wire brushes, the force due to the grease flow resistance, and the force due to the contact between skin plate and segment. This study focused on the eccentric force due to grease flow resistance shown in Figure 2. Therefore, to make clear the flow resistance characteristics of grease filled up in-between wire brushes quantitatively, the element tests using grease and wire brush were carried out. In this study, the following test parameters were adopted: 1) the hydraulic water pressure behind wire brush, σ_w; 2) the grease flow through wire brush per wire brush unit width, q, which is represented by piston speed, V; and 3) the tail clearance, T_c (Hirai et al. 2011a, b).

This paper shows the test results using three wire brushes with a total width of 300 mm and discusses the influence of each test parameter on the grease flow resistance represented by grease pressure, σ_g.

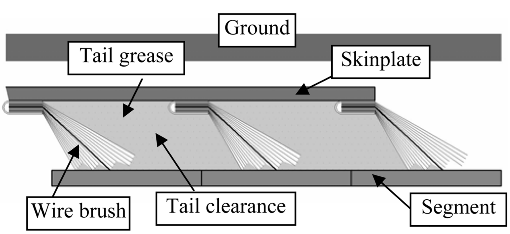

Figure 1. Detail of shield tail.

2 METHODOLOGY

2.1 *Test equipment*

The test equipment is shown in Figure 3 and 4. The equipment can press grease in front of the wire brush and apply water pressure behind the wire brush. As grease, the tail sealer #8000N and #8000NP (Matsumura Oil Chemical 2013) were used. Considering the temperature dependency of grease viscosity shown in Figure 5, the tests were carried out in a constant temperature room (20°C). Three wire brushes (hereafter referred to as WB), which are a standard

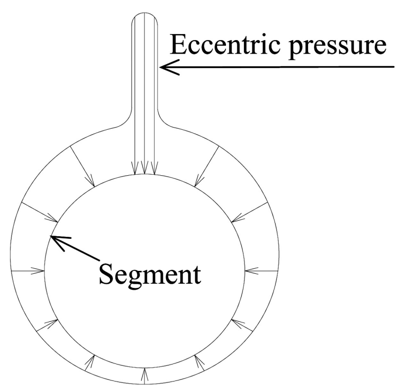

Figure 2. Eccentric grease pressure at shield tail.

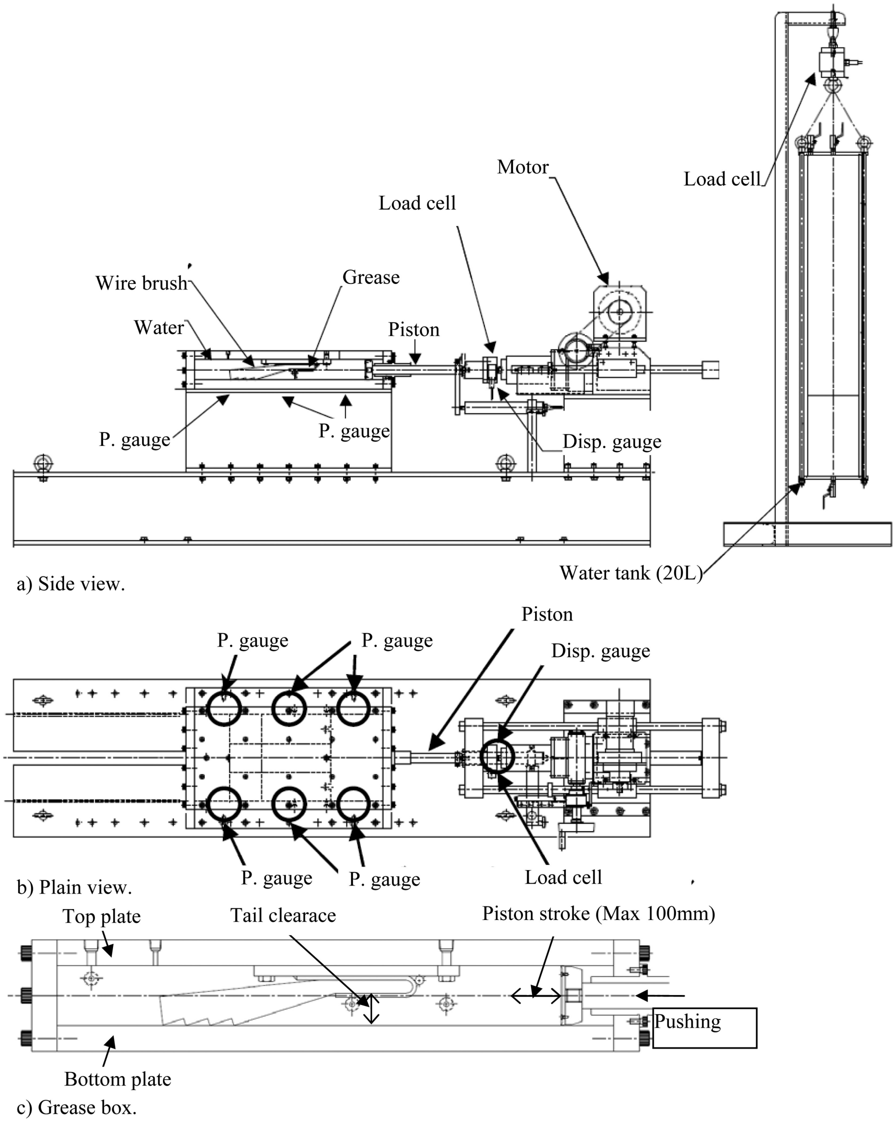

Figure 3. Test equipment.

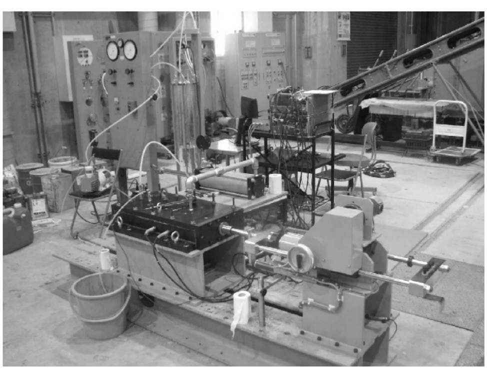

Figure 4. Overview of test equipment.

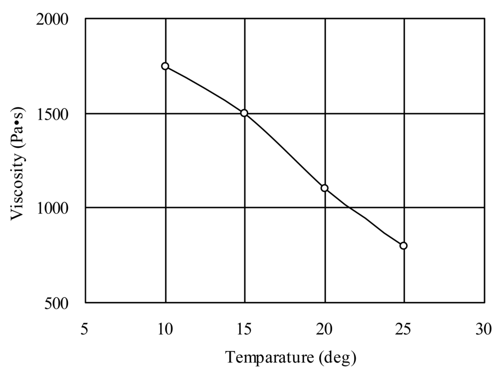

Figure 5. Temperature dependent viscosity of grease. (#8000N) (Matsumura Oil Chemical 2013).

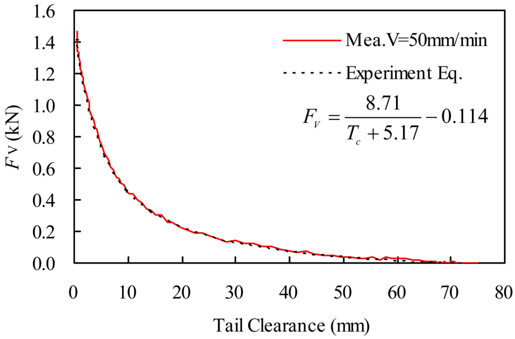

Figure 6. Deformation characteristics of wire brush. (Width = 0.1 m) (Hoshino et al. 2009).

Table 1. Test parameters.

Test factor	Value
Water pressure (kPa)	0, 300, 500
Piston speed (mm/min)	10, 30, 50
Tail clearance (mm)	5, 15, 25, 35

type of wire brush for shields with a width of 100 mm, were used. The deformation characteristics of the WB is shown in Figure 6.

2.2 *Test procedure*

The tests were carried out as follows:

1. Fill up the inside of the WB attached to the top plate with the grease #8000 N.
2. Fill up the space between the WB and the piston in the grease box with the grease #8000 NP by hand pressing.
3. Attach the top plate to the grease box.
4. Charge the space behind the WB in the grease box with water from the water tank.
5. Start a test by pushing the piston to the WB with a specified speed.

2.3 *Measurement*

The following items shown in Figure 3 were measured automatically by a data logging system.

1. Piston displacement: to grasp the grease flow, the piston position was measured by a displacement gauge.
2. Piston thrust: to grasp the grease flow resistance, the piston thrust was measured by a load cell.
3. Volume change behind the WB: the grease volume moving to the space behind the WB from the space in front of the WB was measured by a load cell above the water tank.
4. Grease pressure: four water pressure gauges were set in the grease box to grasp the grease pressure distribution.
5. Water pressure: two water pressure gauges were set to grasp the water pressure behind the WB.

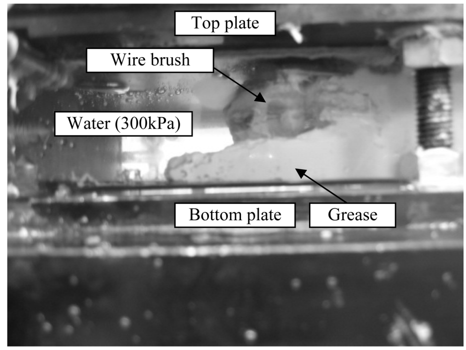

Figure 7. Grease behavior in grease box (Case333).

2.4 *Test cases*

The hydraulic water pressure behind wire brush, σ_w, the piston speed, V, and the tail clearance, T_c were adopted as test parameters as shown in Table 1. In addition, the test case was numbered as follows:

- The third digit: the third digit of water pressure (kPa);
- The second digit: the second digit of piston speed (mm/min); and
- The first digit: the second digit of tail clearance (mm).

3 TEST RESULTS

3.1 *Influence of water pressure on grease pressure*

Figure 7 shows the side view of the grease box under the test case of $\sigma_w = 300$ kPa, $V = 30$ mm/min and $T_c = 35$ mm. Figure 8 shows the influence of water pressure, σ_w, on effective grease pressure under $V = 30$ mm/min, and $T_c = 35$, 25, 15 and 5 mm. Here, to compare the influence of σ_w on σ_g, the effective grease pressure, σ'_g $(= \sigma_g - \sigma_w)$, was used. From these figures, the followings were found.

1. Grease does not penetrate in the WB, but grease pushes up the WB and passes between the WB and the bottom plate. This is because grease can seldom intrude into the WB due to the protection plate attached at the up-and-down side of WB.
2. In the case of $T_c = 35$ and 25 mm and $\sigma_w = 300$ and 500 kPa, σ'_g is less than 0 kPa at start. It is considered that this is because σ_w does not fully act to the grease due to the grease viscosity. The peak σ'_g is almost the same for $\sigma_w = 0$ kPa and 300 kPa, and the peak σ'_g with $\sigma_w = 500$ kPa is smaller than that with $\sigma_w = 0$ and 300 kPa.
3. In the case of $T_c = 5$ mm, the peak σ'_g decreases as the decrease of σ_w. It is considered that this is because the WB is forced on the bottom plate in the grease box by σ_w for small T_c since the WB becomes almost level due to small T_c, and this forcing force increases as σ_w increases.

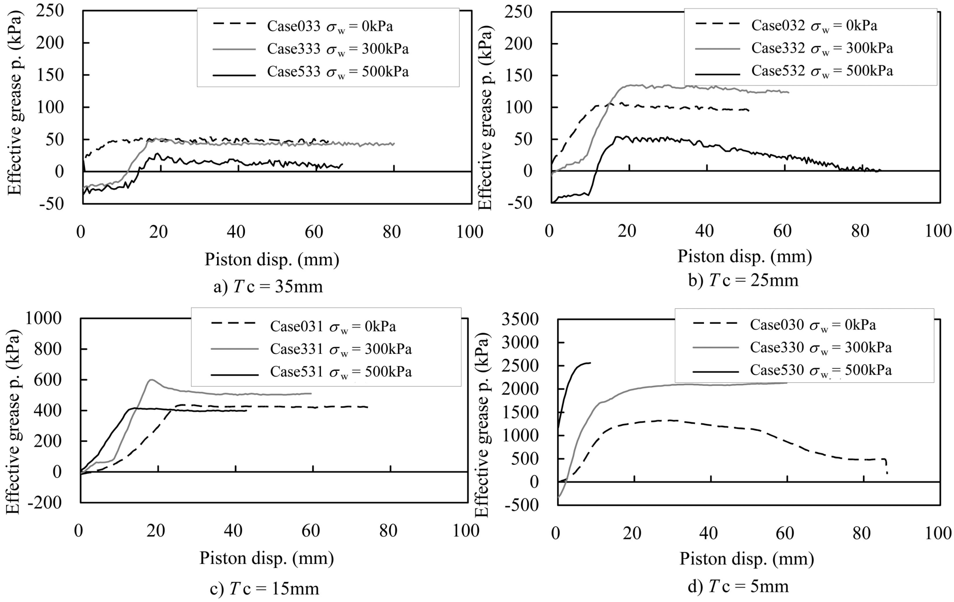

Figure 8. Influence of water pressure on effective grease pressure ($V = 30$ mm/min).

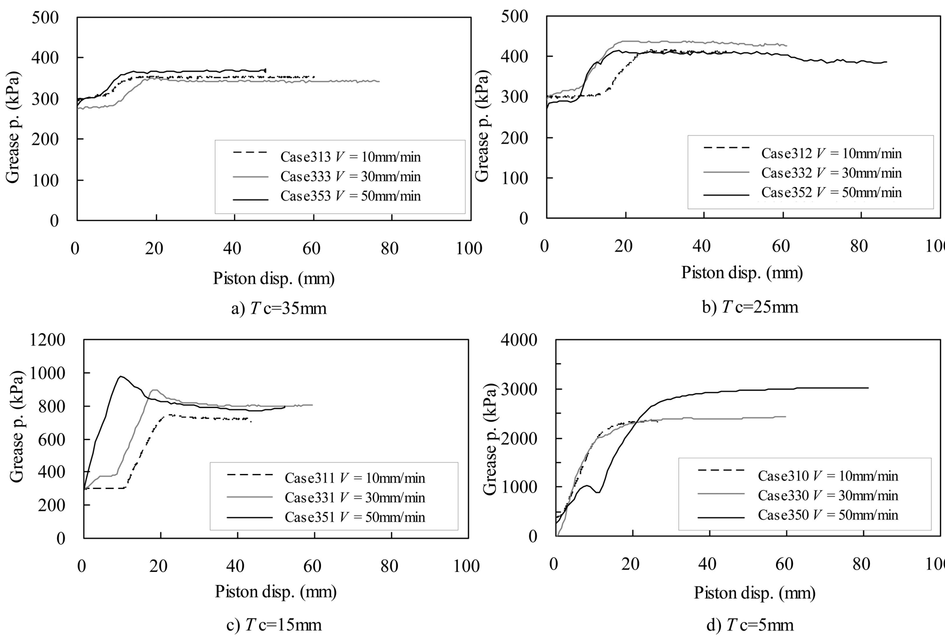

Figure 9. Influence of piston speed on grease pressure ($\sigma_w = 300$ kPa).

3.2 *Influence of grease flow on grease pressure*

Figure 9 shows the influence of grease flow on grease pressure, σ_g, with $\sigma_w = 300$ kPa and $T_c = 35$, 25, 15 and 5 mm. These figures show:

1. In the case of $T_c = 35$ and 25 mm, the peak σ_g is almost constant for $V = 10{\sim}50$ mm/min.
2. In the case of $T_c = 15$ mm, the peak σ_g increases with the increase of V. Moreover, the peak σ_g is clear irrespective of V, compared with $T_c = 35$ and 25 mm. It is considered that this is because larger force is required for grease pushing up the WB, compared with $T_c = 35$ and 25 mm.
3. In the case of $T_c = 5$ mm, the peak σ_g becomes about 3 times that of $T_c = 15$ mm. The peak σ_g for $V = 10$ and 30 mm/min is almost same, but is smaller than that with $V = 50$ mm/min.

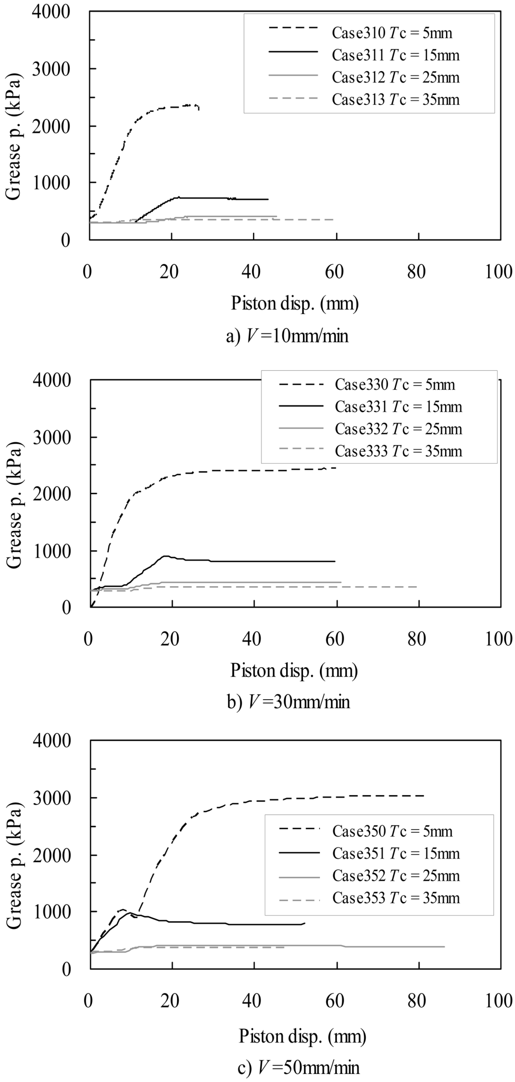

Figure 10. Influence of tail clearance on grease pressure ($\sigma_w = 300$ kPa).

3.3 *Influence of tail clearance on grease pressure*

Figure 10 shows the influence of tail clearance on grease pressure with $\sigma_w = 300$ kPa and $V = 10, 30$ and 50 mm/min. From this figure, it was concluded:

1. Irrespective of V, σ_g increases as T_c decreases. This is because a large force is required for grease pushing up the WB and therefore grease flow resistance becomes large, when T_c becomes small.

4 CONCLUSIONS

This research has led to the following conclusions.

1. In the case of $T_c = 5$ mm, the effective grease pressure, σ'_g, increases as σ_w increases.
2. In the case of $T_c = 35$ and 25 mm, the grease pressure, σ_g, is constant for $V = 10\sim50$ mm/min. On the other hand, in the case of $T_c = 15$ and 5 mm, σ_g increases with the increase of piston speed, V.
3. The grease pressure, σ_g, increases with the decrease of T_c. Especially in the case of $T_c = 5$ mm, the grease pressure, σ_g, becomes about 10 times σ_w.

Therefore, it is important to take construction loads into consideration. It is noted that the grease pressure at a shield tail has a big influence on segments especially in the case of small T_c.

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REFERENCES

Hirai Y., Yamauchi F. & Sugimoto M. 2011a. Study on Characteristics of Grease Flow Resistance by Element Test. *The 66th JSCE Proc. of annual conference*: IV-037. Tokyo Japan: JSCE. (in Japanese).

Hirai Y., Yamauchi I. & Sugimoto M. 2011b. Study on characteristics of grease flow resistance by element test. *Proc. of the 6th Japan-China conference on shield driven tunnelling, Niigata, Japan, 3–4 Aug. 2011*: 103–108. (in Japanese)

Hoshino T., Takada S. & Sugimoto M. 2009. Experimental study on deformation and friction characteristics of wire brush. *The 64th JSCE Proc. of annual conference*: III-419. Tokyo Japan: JSCE. (in Japanese).

Japan Society of Civil Engineering. 2006. *Tunnel library17: Construction loads during shield tunnelling*. Tokyo Japan: JSCE. (in Japanese)

Matsumura Oil Chemical Co. Ltd. 2013. *Catalog on TAILSEALER #8000, #9000*. (in Japanese).

Sugimoto M. 2006. Cause of shield segment damage during construction. *Proc. intern. symp. on underground excavation and tunnelling, Bangkok, 2–4 Feb. 2006*: 67–74. Bangkok Thailand: EIT.