Development of "T-DrillPacker" measurement system for groundwater inflow rate and pressure in advanced boring

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ABSTRACT: Large groundwater flow into the tunnel during construction of a mountain tunnel can cause crucial problems. It is therefore important to investigate the location, flowrate, and hydraulic pressure of the flow paths ahead of the tunnel face in advance to tunnel excavations. One of the effective ways to characterize the flow paths is measurement of flowrate and pressure in the advanced horizontal boreholes using a packer system. However, with the conventional method, it is often difficult to carry out the installation of packer systems due to the risks of borehole collapse and delay in the construction schedule caused by pulling out the drilling string before packer installation. Therefore, the authors have developed a new measurement system that can be installed packer without pulling out the drilling tools. This paper describes the concept of this system, and a result of its successful application to a mountain tunnel construction site.

Keywords: NATM, Advanced boring, Groundwater inflow rate, Hydraulic pressure, Packer system.

1 INTRODUCTION

Large groundwater flow into the tunnel during construction of a mountain tunnel could cause a risk of tunnel face collapse or workability reduction, which may have a serious impact on ensuring construction safety, schedule, and costs. For this reason, it is important to accurately detect the location of flow paths (*e.g.*, high hydraulic conductivity zones such as fractured zones) with high water pressure ahead of a tunnel face. Information on the flow paths such as inflow rate and hydraulic pressure is necessary to consider in advance the measures against groundwater inflows such as grouting and drainage boreholes. In the groundwater investigation, it is desirable to conduct advanced boring from the tunnel face and install a packer to the tip of the borehole to measure the flowrate and hydraulic pressure (Liu 2022). However, with the conventional method, as shown in Figure1, it is necessary to pull out the whole drilling string (*i.e.*, rods and a drilling bit) before packer installations, which can lead to the risk of borehole collapse. In addition, it takes a lot of time and labor to pull out the string, so it is difficult to investigate groundwater conditions using a packer, especially when drilling more than 100m long. Except for borehole for grouting (*e.g.*, Wannenmacher et al., 2022), there are only a few reports on packer tests using advanced boring from the tunnel face during construction (Taki et al., 2017).

Recently, a method has been developed in which the packer is installed through the drilling rods and the bit is pushed forward. With this method, hydraulic pressure can be monitored without pulling out the drilling string (Okada et al., 2018). However, this method still has some issues such as difficulty in resuming the drilling operation after flowrate/pressure measurement and being limited to non-core boring (not compatible with core boring). In this case, only one section can be measured in each borehole, therefore additional boring is required to investigate possible multiple flow paths hidden ahead of tunnel face. A large number of borehole survey has a significant impact on the construction schedule and costs.

Therefore, the authors have developed a new measurement system called "T-DrillPacker", which solves the problems such as borehole collapse caused by pulling out the drilling string and the continuity of drilling after measurement (Hiratsuka et al., 2022). And we have been verifying the validity of the system in field applications. This paper presents an overview of the developed system.

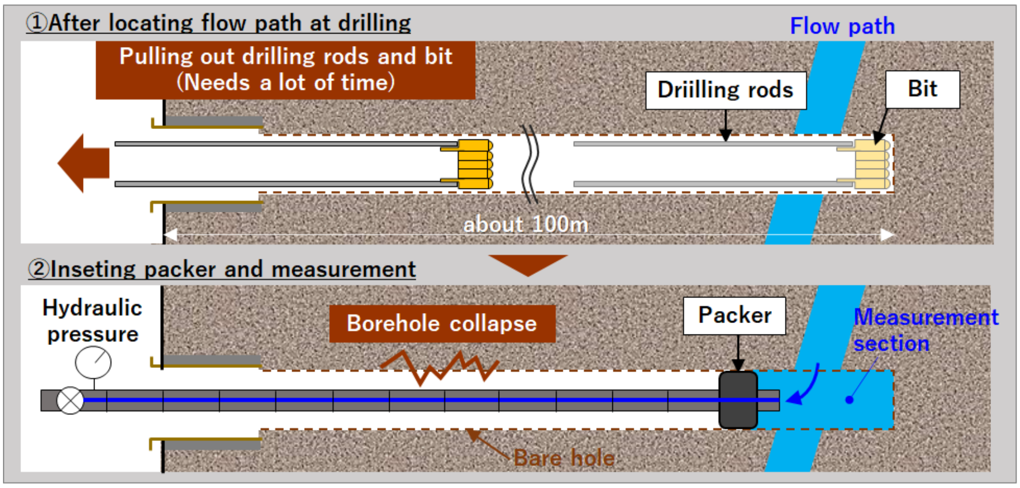

Figure 1. Conventional method with inserting packer into a bare hole.

2 OVERVIEW OF THE SYSTEM

With this system, the packer can be installed without pulling out the drilling string, and the groundwater investigation can be performed quickly while reducing the risk of borehole collapse. Furthermore, after the measurement, the packer can be retrieved, and drilling can be resumed immediately. Therefore, it is possible to investigate groundwater regime at multiple locations over a long distance in one borehole, which was previously difficult. The features of the system are described below together with the workflow:

1. **Quick measurement for inflow rate and hydraulic pressure:** Drilling is done with a double bit (Figure 2 (a)) consisting of the outer and inner bits (Figure 3 (a)). During drilling, when a flow path is encountered, only the inner bit is retrieved at high speed with a wire line (Figure 3 (b)). The packer can be installed quickly without pulling out the drilling string.
2. **Reduced risk of borehole collapse during packer installation:** Packer can be inserted from the inside of the outer bit and placed in front of the bit (Figure 3 (c)). The risk of borehole collapse during packer installation is low, as the drilling rods protect the hole wall. After the packer is expanded, the flowrate and hydraulic pressure in the measurement section can be measured (Figure 3 (d)).
3. **Repeatable measurement at any point:** After the measurement, the packer can be retrieved, and the inner bit can be pumped to the borehole tip by water and reset to the outer bit easily. It is possible to resume drilling quickly (Figure 3 (e)).

4. **Compatibility with both non-core and core drillings:** By changing the double bit to a core bit with a core barrel, it can also be applied to core boring (Figure 2 (b)). It has versatility to suit a wide range of drilling needs in construction.
5. **Large expansion packer to enable the above:** Since the packer must be inserted through the narrow inner diameter of the outer bit and expanded to the hole wall, it was difficult to implement with the expansion width of the normal packer. With this system, we have newly developed a large expandable packer (Figure 2 (c)) that can be expanded up to about three times the initial diameter (from initial outer diameter 40mm to 120mm).

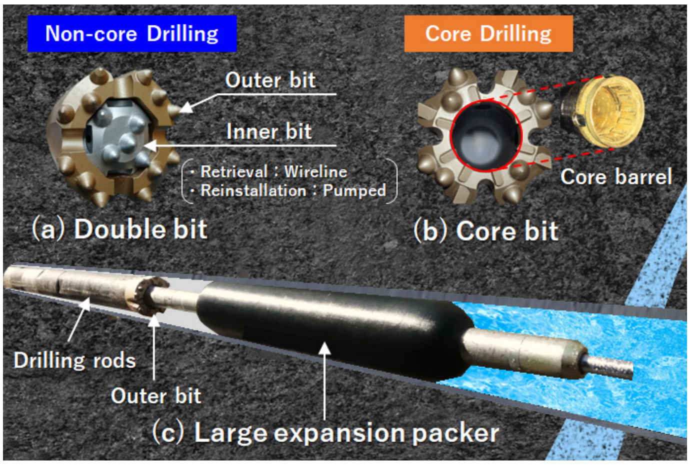

Figure 2. Overview of T-DrillPacker.

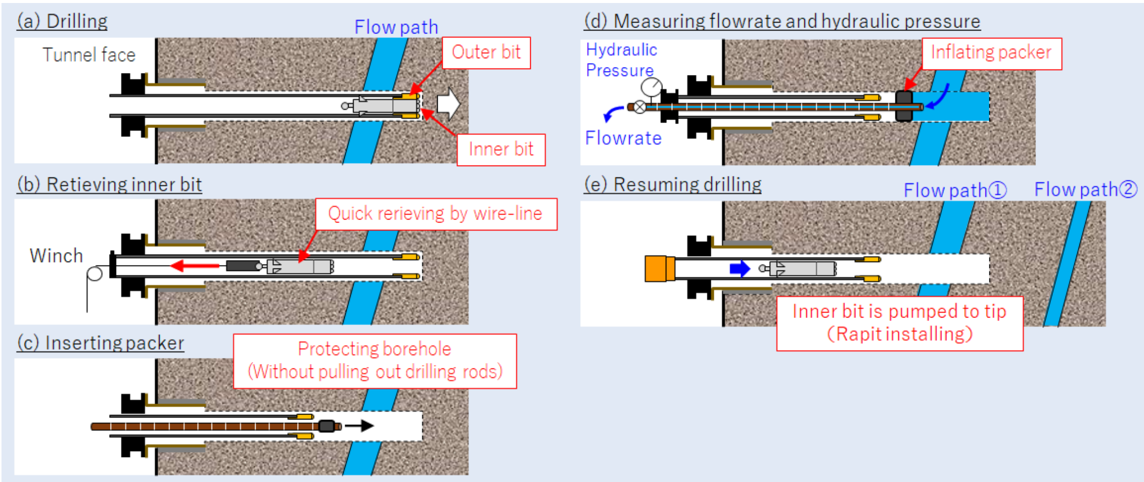

Figure 3. Workflow for measurement (non-core drilling).

3 FIELD APPLICATIONS

3.1 Geology and groundwater condition of test site

A demonstration test of this system was conducted in a road tunnel construction site in Japan. In this tunnel, the groundwater level was about 300m above the tunnel, and the ground consisted of fractured granodiorite. Increase in groundwater inflow was expected upon tunnel excavation. At the start of advanced boring, groundwater inflow was already visible at the tunnel face, and drilling of drainage boreholes was drilled from the tunnel face and the side walls (Left figure in Figure 4).

Fractured zones over a distance of 28m from the borehole head were confirmed in the core samples obtained by advanced boring, and the groundwater inflow was thought to take place mainly in these zones. Except a small zone of fractured rocks at about 70m from the borehole head, intact rock zone was distributed at larger depths. The groundwater inflow rate measured at the borehole head reached 1,000L/min (Right figure in Figure 4).

Figure 4. Photos showing the drilling operations and groundwater inflow near the tunnel face.
(Left: Drilling drainage and advanced boreholes; Right: groundwater inflow from the borehole head)

3.2 *Overview of test*

Hydraulic pressure was measured using a packer for a small section of fractured rocks at a drilling depth of 70m, which had been confirmed during drilling (Figure 5). After drilling to a depth of 82.5m through this fractured section, the drilling was interrupted. The drilling rods were retrieved for 13.5m, and a packer was installed in an intact rock zone (drilling depth: 68-69m) where no fractures were confirmed in the core samples. The length of measurement section was therefore 13.5m from the packer to the drilled tip at that time.

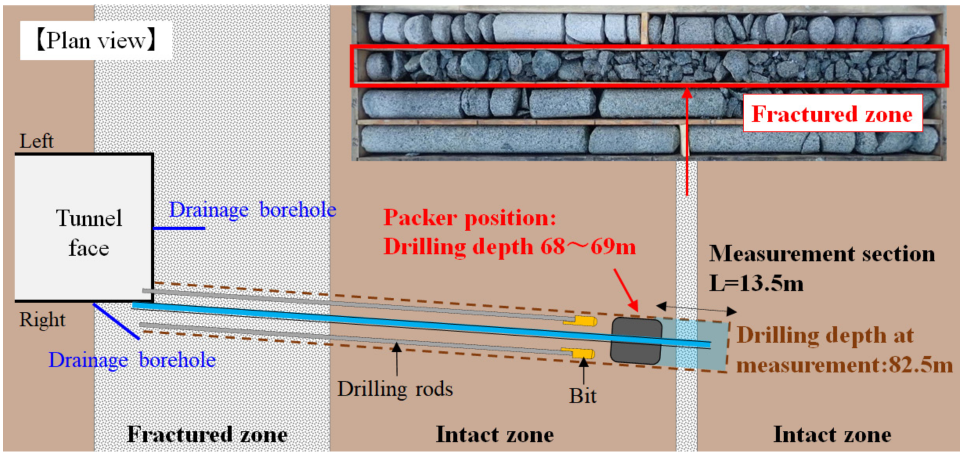

Figure 5. Measuring section for hydraulic pressure.

3.3 *Test results*

After the packer was expanded, the pressure gauge (Figure 6 (a)) attached to the head of the packer rods was used to measure the hydraulic pressure in the measurement section (hereafter referred to as section hydraulic pressure). In addition to the section hydraulic pressure, the borehole head hydraulic pressure was measured with another pressure gauge (Figure 6 (b)) installed in the preventer at the head of the drilling rods. This hydraulic pressure is considered to be the average value of the entire borehole in near side from the packer. Figure 7 shows the measurement results of section hydraulic pressure and borehole head hydraulic pressure. First, all the valves were closed before expanding the packer, and it was made sure that both gauges registered almost the same hydraulic pressure. After that, the packer was expanded, and when the packer was pressed to the hole wall, the section hydraulic pressure increased. As a result, we were able to confirm the hydraulic separation between the measurement section and the other section with the packer functioning appropriately.

Next, we opened the valve at the head of the packer rods and measured the flowrate from the measurement section. After that, the valve was closed again and the pressure measurement was continued until the section groundwater pressure became almost stable. Since there is a clear difference between the section pressure and the borehole head pressure, it is considered that the hydraulic pressure in the fractured zone itself, which cannot be obtained only by borehole head pressure, could be measured accurately. Figure 8 shows a comparison between the borehole head pressure measured every 10m during advanced boring drilling and the measured section pressure. Note that borehole head pressure is the average value of the entire borehole drilled up to that point. In this boring, its value is about 0.5 MPa at any measured depth. On the other hand, the section pressure measured using a packer is clearly higher than the borehole head pressure. As in this case, under the condition that groundwater inflow takes place from around the tunnel face at the start of advanced boring or there is a drainage borehole nearby, hydraulic pressure of the targeted flow paths cannot be obtained by measuring it only at the borehole head. It is thought that the water pressure of the flow path at depths in the borehole cannot be accurately measured due to leakage to the surrounding area, and in many cases it is underestimated. In such cases, it is considered effective to measure the section hydraulic pressure using the developed packer system.

There was no trouble such as borehole collapse during the series of operation from packer insertion to retrieval, and the investigation time was reduced approximately 40% compared to the conventional method. After the measurement, the core barrel was reset at the tip of the borehole, and drilling was resumed promptly, and completing the planned drilling length of 90m.

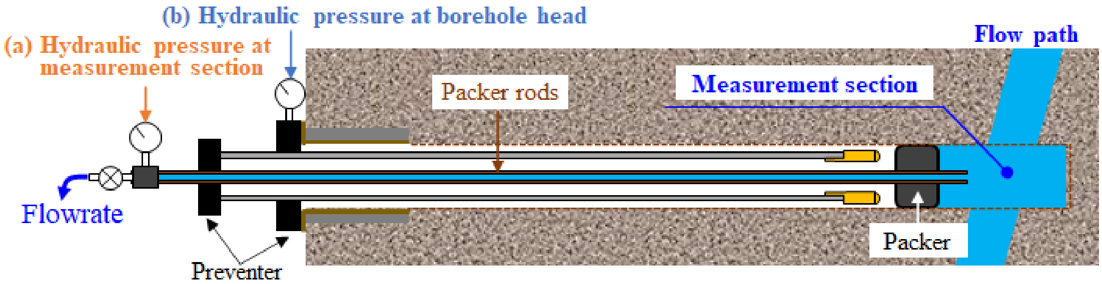

Figure 6. Positions of water pressure gauges.

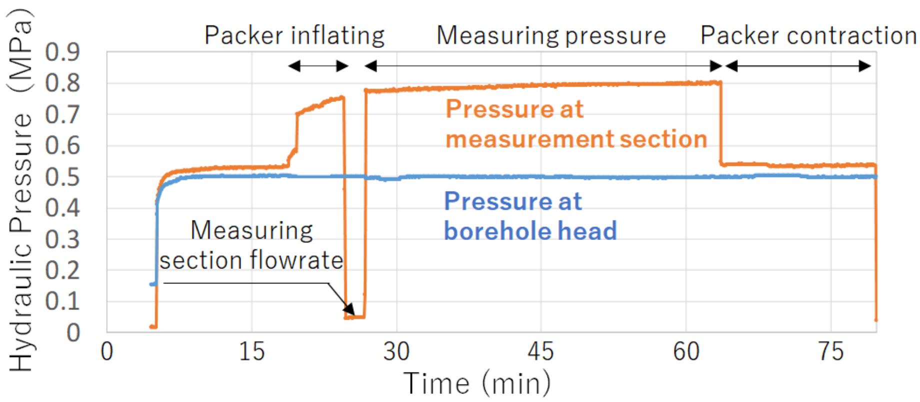

Figure 7. Results of hydraulic pressure measurement.

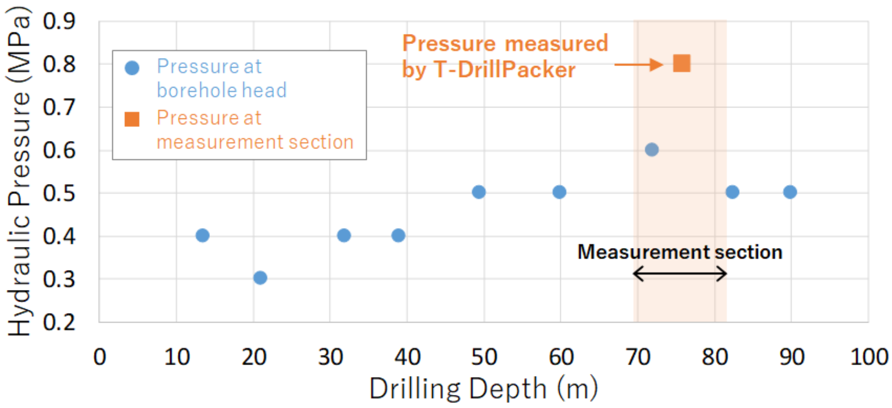

Figure 8. Comparison between hydraulic pressures observed at head of borehole and at measurement section.

4 CONCLUSIONS

We have developed a new system to quickly measure the flowrate and hydraulic pressure of groundwater inflow at the tip of the borehole in the middle of drilling. On-site demonstration tests in a mountain tunnel construction site successfully verified that the obtained hydraulic pressure was clearly higher than the pressure measured at the borehole head, confirming necessity and effectiveness of hydraulic pressure measurement with a packer system. In addition, it was confirmed that the hydraulic pressure can be measured by installing a packer at the tip of the bit without pulling out the drilling string. The investigation time can be reduced by about 40% compared to the conventional method. Furthermore, it was confirmed that resuming drilling after pressure/flowrate measurement, which was previously difficult, is now possible.

Advanced boring has to be conducted, temporarily suspending tunnel excavation, so the investigation time is limited. Groundwater investigation using packers was difficult to implement because it would involve the risk of borehole collapse and time-consuming, and in many cases measures were implemented ex-post. With the developed system, on the other hand, it is possible to conduct detailed investigation with less impact on the tunnel construction schedule, greatly lowering the hurdles for implementing investigation, and greatly improving investigation frequency and accuracy. For a safe and effective groundwater measures, we intend to actively use the system in future tunnel constructions where high-pressure and large groundwater inflow are expected.

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