# Breakthrough of a Long Tunnel by Geological Evaluations Combined with Various Types of Forward Exploration

## — Hokuriku Shinkansen New Hokuriku Tunnel (Okunono Construction Area)—

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## 1. Introduction

The Hokuriku Shinkansen is a 690 km-long line that starts in Tokyo and ends in Osaka City via Nagano, Toyama, and Obama. The Okunono section of the New Hokuriku Tunnel is a 4,880-meter-long middle section of a 20 km-long mountain tunnel located in Fukui prefecture. Construction was done using a working pit (inclined shaft). The cross-section of the excavation was approximately 70 $m^2$, using the full-sectional method with an auxiliary bench. Digging was done by blasting method, with continuous belt conveyor method used for shedding. Eleven faults were expected in the construction area (shown in Fig. 1), with widths ranging from a couple of meters to maximum 80 m. The natural ground was expected to be fragile with many fractures developed along the faults, with concerns of sudden water inflow especially in the area of chert.

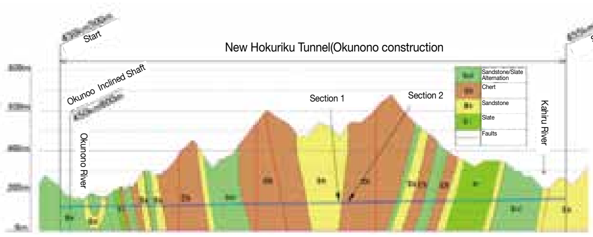


Fig. 1 Longitudinal Profile of the Geology

## 2. Overview of Exploration Methods

As shown in Table 1, three types of forward exploration were carried out to understand the geological conditions in front of the cutting face.

Tab. 1 List of Forward Probe

| List of Forward Probes | | | Notes |
|---|---|---|---|
| Name | Probe depth/number | Results | |
| medium-length non-core exploration drilling | 150-180m/time<br>34 times (full length) | Index-value of energy | Down-the-hole method<br>Water-pressure hammer boring |
| short-length non-core exploration drilling | 30-50m/time<br>120 times (full length) | Speed ration of normalized drilling<br>Prediction of water inflow | Percussion drilling |
| Seismic Survey | 150-180m/time<br>33 times (full length) | Prediction of water inflow | TSP203 |
| | | Reflection surface | |
| | | $V_p/V_s$ ratio | |

## 3. Prediction of Natural Ground using Forward Exploration Results and Actual Digging Results

Conditions of the natural ground 150 m ahead were predicted by combining result from the non-core exploration drillings and in-pit elastic wave survey described above. The results showed multiple sections of fragile terrain including fault fracture zones, fracture concentration zones, and stratigraphic boundaries, as well as sections with high risk of sudden and heavy water inflow. Among the potentially bad sections, the following two (Fig. 1) were unique in the way they clearly showed the characteristics from the forward exploration results.

Section 1: 453km185-215m (L=30m)
Section 2: 453km250-265m (L=15m)

Table 2 is a comparison between predicted and actual natural ground conditions for sections 1 and 2.

Tab. 2 Expected and Actual Conditions of Natural Ground

| | Kilometrage | Short to Medium-scale non-core drilling logging | Seismic Survey | Condition of Natural Ground | |
|---|---|---|---|---|---|
| | | | | Expected | Actual |
| Section 1 | 453km 185 ~ 215 m | Chert dominated ground<br>Equivalent to IS - IN-1 Water: 1,000L/min<br>Water pressure: 0.75MPa | VP downward<br>Focus on reflection surface<br>$V_p/V_s$ reduce | Mainly chert<br>Cracks, exfoliation, and other surface discontinuities is significant<br>Possibility of water high due to being a valley | Mainly fragile chert<br>Face of digging had a lot of sediment and caused much exfoliation<br>Digging face had 40L/min water at maximum |
| Section 2 | 453km 250 ~ 265 m | Chert and Alternation mix<br>Equivalent to Is to IN-2<br>Water: 450L/min | Lot of change in $V_p$<br>Dense reflection surface<br>$V_p/V_s$ slightly changed | Mix of chert and sandstone/slate alternation<br>A lot of cracks, exfoliation, and other discontinuities<br>Low possibility of high-level water inflow | Mainly chert with many cracks<br>Excavation face could not stand alone<br>Digging face had water 20L/min at maximum |

### 3-1 Section 1: 453km185 ~ 215m

This section raised concern of sudden water inflow. The water inflow rapidly increased to 1,000 L/min. during logging. Additional measurements of the inflow rate and inflow pressure were done. Judging from the results, due to the predominantly fractured chert soil, there was a very high possibility that a large amount of water inflow would occur when the tunnel face was reached.

The actual site was dominated by fragile chert, and the maximum water inflow was 40 L/min. at the mirror surface. A lot of the dirt showed sedimentation especially on the face of the excavation with many fission exfoliation shown in Photo 1.

The water inflow from drilling and logging holes decreased from 1,000 L/min. to 500 L/min. as the face progressed, and the water inflow on the mirror surface during excavation was minimized by draining water in the forward ground using medium-scale non-care drilling and logging.

### 3-2 Section 2: 453km250 ~ 265m (L=15m)

This section was feared to be fractured ground. Combining results of various tests, unstable ground was expected to be located near the boundary between the multi-fractured chert and the soft sandstone/slate alternation.

The actual ground was a multi-fractured chert ground with small water inflow, but as seen in Photo 2, the small amount of water caused the face to be very unsustainable.

In the actual construction, the core was left during excavation to stabilize the mirror surface. The water inflow at the face was minimized by draining water during drilling.

## 4. Conclusion

Bad ground conditions were predicted in advance with a high degree of accuracy by evaluating the ground using a combination of various types of frontal surveys. The excavation was conducted safely without any delays by considering appropriate support patterns and auxiliary construction methods beforehand as well.

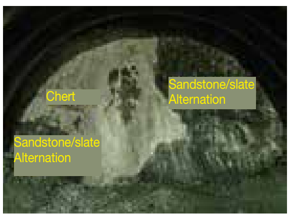


Photo 1 Face Condition (453km200m)

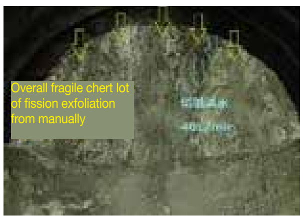


Photo 2 Face Condition (453km260m)