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Mechanism of tunneling-induced cave-in of a busy road in Fukuoka city, Japan

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Abstract

A road cave-in accident caused by tunneling is described, and the possible mechanism of failure is analyzed. The cave-in measured about 30 m × 27 m in plane, and about 15 m in depth. At about 19 m below the ground surface at the site, a tunnel construction was underway. Immediately above the tunnel, there was a weathered shale layer approximately t 2.66 m thick; above this layer, there were sand and gravel layers. The groundwater level was estimated to be about 5 m below the ground surface. By arch analysis, it is shown that the most likely cause of the accident was the low strength of the weathered shale layer and the high water pressure above the tunnel, which resulted in tensile failure of the weathered shale layer. The All Ground Fasten (AGF) pre-support measure was adopted, but it might make very limited contribution to the increase in the tensile strength of the shale layer in the cross-sectional direction of the tunnel.

Keywords: Tunneling; Road cave-in; Arch analysis; Tensile failure

Road cave-in accident

The information presented in this section is obtained from Fukuoka Transportation Bureau (FTB) (2017).

(1) At 5:15 AM (local time), November 8, 2016, several cracks appeared in a busy five-lane road in front of Hakata Station, Japan Railways (JR), Fukuoka city, Japan. The road is called Hakata-ekimae-tori. The cracks gradually widened, and sink holes started to appear thereafter.

(2) At around 7:20 AM, a large cave-in occurred with the size of approximately 30 m × 27 m and approximately 15 m in depth, as shown in Fig. 1 (produced based on the information from FTB (2017)).

It appears that the water level in the cave was at a depth of about 5 m (the depth of the water level was more than the height of one story of the adjacent building) from the ground surface. As can be seen from Fig. 1, the cave-in broke the underground gas, water, and sewer lines, and snapped the electricity and telecommunication cables.

Immediately below the cave-in area, construction of the extension of the Nanakuma subway line was underway. At the zone where the accident occurred, the designed tunnel had a cross-section close to an ellipse, with a maximum

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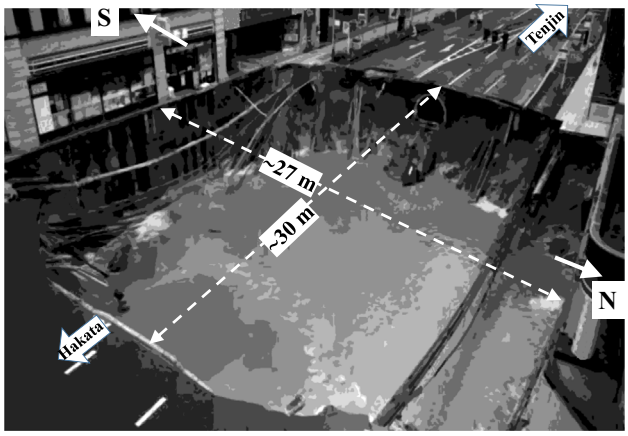

Fig. 1. Road cave-in in Hakata-ekimae-tori.

width of 15.77 m and height of 11.50 m, as shown in Fig. 2 (b). At this section, the construction method adopted was the New Austrian Tunneling Method (NATM). The All Ground Fasten (AGF) method was used as a pre-support measure. The AGF steel tubes had a diameter $\phi = 114.3$ mm; the wall thickness of the tube was 6 mm, and the length of each tube was 9.5 m. There were 33 tubes installed in approximately 120° range around the crown on the cross-section, but the lap length in the longitudinal direction is not known. The inclination angle between the tubes and the horizontal was approximately 10°. The designed excavation procedure was pilot excavation

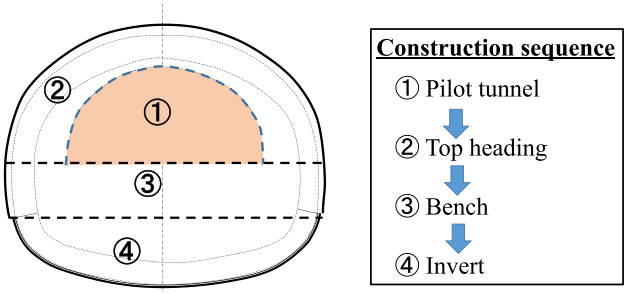

Fig. 3. Illustration of the tunnel construction sequence.

followed by top heading, bench, and invert excavations, as illustrated in Fig. 3. At the time when the accident occurred, the top heading excavation had been completed. Inside the tunnel, the following events happened at dawn on November 8, 2016.

(1) 4:25 AM: At the crown, a number of rock blocks between the AGF tubes fell down.
(2) 4:50 AM: Abnormally turbid water leaked from the crown; then, rock blocks (each having a volume of approximately 0.25 m^3) fell down, followed by a debris flow. The order to move the tunneling machines away from the working excavation face was given, and the workers took shelter.
(3) 5:00 AM: All the nine workers returned to the ground level.

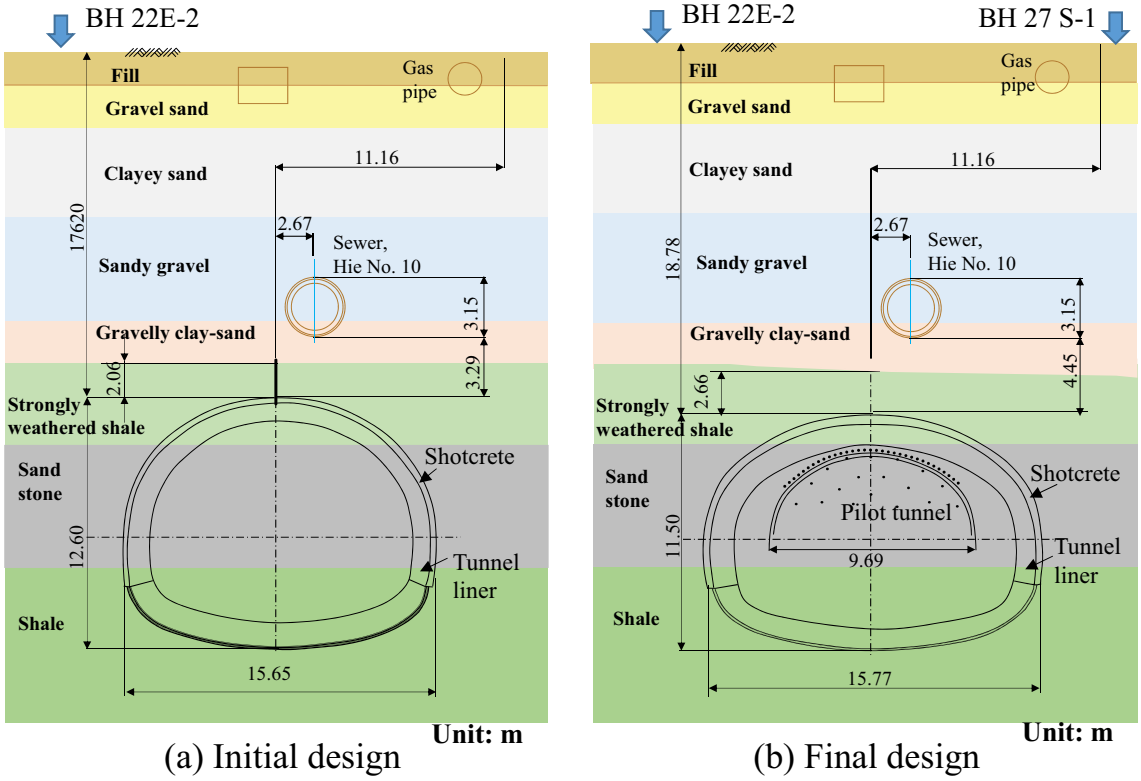

Fig. 2. Design cross-sections of the tunnel. Initial design; (b) Final design.