Restoration of a Mountain Tunnel Damaged in the 2016 Kumamoto Earthquake

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When an earthquake of magnitude 7.3 occurred in April 2016 in Kumamoto (the Kumamoto Earthquake), the Tawarayama Tunnel suffered damage and was undermined along the entire tunnel length and became impassable. This was a tunnel constructed by conventional method where was located about 17 kilometers from the epicenter and within 300 meters of the closest active fault. The tunnel was opened for service in July 2002. This restoration project included inspection of damage over the whole length of the tunnel, designing of countermeasures and restoration of its function.

1. Conditions of the disaster (ground change)

The tunnel was wholly observed and cracks and openings at the joints between the spans of permanent lining were found over the concrete. At several locations, lining concrete had collapsed (Photo 1), and there were cracks and heaving under compressive forces (Photo 2), openings of cracks under shearing force (Photo 3) as well as transversal slippages at the joints, spalling of concrete etc.

2. Selection and implementation of restoration methods

The condition of permanent lining of the tunnel was investigated in detail for damage, and the rehabilitation methods adopted are classified into the following three categories:

1) Removal of the existing lining and replacement of new lining (approx. 160 m)
2) Countermeasure for spalling (injection into cracks, rehabilitation of section walls, carbon fiber sheet attachment, spalling prevention net, application of steel arched support) (about 1,150 m)
3) No countermeasure due to slight or no damage (about 750 m)

For the sections in category 1), after the removal of permanent lining, steel arched support, shotcrete, rockbolt, etc. were visually checked. Buckling deformation was confirmed for a length of about 20 meters (Photo 4). For this section, all existing steel supports, etc., were removed to install new supports (Photo 5). In other sections, steel arched supports were kept as they were, cracked shotcrete was taken away to cast additional shotcrete and rockbolts. For replacement of lining concrete, reinforcement bars were assembled at the site, and then lining concrete, with high fluidity, mixed with plastic fibers was cast.

Of the section of category 1), about 100 meters where the inverted arch concrete had been installed was visually checked for the status of concrete. Along the 60 meter length, at places where there were differences (Photo 6), resulting from destruction of inverted concrete under axial pressure, old inverted arch concretes were removed and new ones were cast. For a stretch of 30 meters with cracks 5 mm or more, non-shrinking mortal was injected.

3. Overview

We started inspection and design in June 2016 while aftershocks continued and traffic was paralyzed, and started construction after this. A maximum manpower exceeding 200 per day was allocated.

Restoring the function of the whole tunnel course in a short period of six months was achieved, with making full use of the technology and management expertise. To meet the needs from the project owner and local residents, the Tawarayama tunnel reopened in December 2016.

Photo 1 Collapse of lining concrete

Photo 2 Compressive destruction and earth heaving

Photo 3 Openings and cracks caused by shearing force

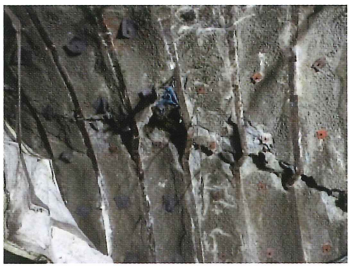

Photo 4 Buckling of steel supports

Photo 5 Reconstruction of a collapsed area

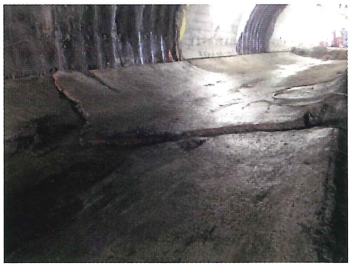

Photo 6 Differences in grade of invert concrete