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# Analysis of the failure of primary support of a deep-buried railway tunnel in silty clay

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ABSTRACT

This paper analyses the mechanism for the failure of primary support of a deep-buried tunnel whose side wall collapses during construction. The main focus is on discussion and comparison of the soil engineering aspects of the incident, and on the lessons that may be learnt from the case. Empirical and numerical analysis have been carried out for the collapse. The mechanisms of failure of tunnel are analyzed during tunnel excavation and the parameters of support are revised according to the results of analysis. Results have shown that the collapse of tunnel is mainly attributed to abundant joint fissures on surrounding soil. The changed support makes tunnel drive through the section of collapse successfully, and similar dangerous situation does not take place in the following construction.



## 1. Introduction and description of the problem

In 2010 Yang Jialing tunnel began to be constructed as the passage to transport coal in the vicinity of Lv Lin, a town in Shanxi province in China. Yang Jialing tunnel is 3012 m in length and is located in Loess Plateau of western Lvliang Mountain. Its terrain slopes from east to west in general and its upside tends to be covered with thick loess.

Yang Jialing tunnel is driving through silty clay, fine gravel soil, coarse gravel soil and mudstone. Starting from DK27 + 260, silty clay is met with anisotropic geomaterials and lens, such as thick pellet soil, sand and ginger like stone, accompanied by tight tectonic joints with strike parallel to the tunnel axis and dip angle approximate to 90°. The detailed geological condition is showed in Figs. 1 and 2.

Yang Jialing tunnel collapses at DK27 + 371–DK27 + 401.5 (buried depth: 80 m). The designed support parameters are given by reference to Code for design on tunnel of railway in China (2005). The detailed primary support parameters are shown in Table 1.

The tunnel is excavated as three-step bench method. The heights of top heading, middle bench and lower bench are 3.0 m, 3.2 m and 3.0 m respectively. Its cross section is u-shaped, as shown in Fig. 3, and the distances of inverted arch of primary support and secondary lining from tunnel face are 30 m and 70 m respectively when the tunnel collapses, as shown in Fig. 6.

At November 27th, 2011, Yang Jialing tunnel collapsed. The detailed situation was as follows:

At 00:00–00:30, the top heading between DK27 + 398.5 and DK27 + 401.5, the middle bench between DK27 + 384 and DK27 + 387 and the lower bench between DK27 + 381 and DK27 + 384 was excavated and not supported. At 0:45 the operator on duty noticed that large-scale spalling occurred on the surrounding soil mass of tunnel face and left side wall. Until 01:00, large-area deformation occurred on the primary support at left side wall between DK27 + 371 and DK27 + 387. With the gradual

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**Fig. 1.** Geo-condition in the section of collapse (tunnel face).

deformation and collapse of soil mass on the left side wall, the deformation of primary support between DK27 + 388.5 and DK27 + 401.5 was further enlarged, and the surface of shotcrete spalled and cracked, as shown in Fig. 4. At 03:39, the left side of primary support between DK27 + 388.5 and DK27 + 395.5 collapsed completely, accompanied by a loud bang. Soil mass in the range of 2 m–3.5 m on left side wall collapsed next, as shown in Fig. 5.

The eventual conditions were as follows: between DK27 + 371 and tunnel entrance, primary support showed no deformation; between DK27 + 371 and DK27 + 387, the left side of primary support was severely strained and some soil mass behind it collapsed; between DK27 + 388.5 and DK27 + 395.5, the left side of primary support collapsed and soil mass on the left side wall were severely collapsed in the range of 2 m–3.5 m(shown as Fig. 5); Between DK27 + 395.5 and DK27 + 398.5, primary support on vault roof was stable; Between DK27 + 398.5 and DK27 + 401.5, it was also collapsed, as shown in Fig. 6. Actual situation when tunnel collapsed is shown in Fig. 7.

In order to prevent the collapse of the tunnel, two measurements were used to stabilize the tunnel. The first was to backfill the soil. The second was to install 10 Φ200 steel tube transverse braces as the temporary inverted arch.

## 2. Laboratory test of silt clay(soil mass)

Analysis of the mineral samples from the collapse section reveals the detailed mineral composition as shown in Table 2.

Seen from Table 2, soil mass only contains few Swelling mineral and it presents weak expansibility. Laboratory tests have been carried out according to Code for Soil Test of Railway Engineering [5]. Cohesion and internal friction angle are determined by the direct sheer test. Table 3 shows the properties of the samples from the section of collapse, According to the laboratory tests, the plasticity index of the samples is 15 and the content of clay is greater than 40%. As a result, soil mass in this project is mainly comprised of silt clay in China.

## 3. Details of tunnel's collapse should be noticed

Through detailed analysis of collapse process, the following details should be noticed:

(1) Tunnel's collapse took place at the position where buried depth is 80 m;
(2) The strength of surrounding soil mass is relatively low, and its uniaxial compressive strength by laboratory tests is only 0.45 MPa. Furthermore, joint fissures of surrounding soil mass at the section of collapse is particular abundant, weakening its strength.
(3) Primary support on left side wall cracked and collapsed, and soil mass in the range of 2 m to 3.5 m behind tunnel's side wall collapsed. And primary support on right side wall did not collapse. Besides, its displacement between DK27 + 371 and DK27 + 384 was relatively small.
(4) After the completion of excavation on the left side of middle bench between DK27 + 384 and DK27 + 387, a large area spalling happened at surrounding soil mass, leading to tunnel's collapse then.
(5) Between DK27 + 395.5 and DK27 + 398.5, top heading only was excavated, primary support did not collapse.

## 4. Numerical simulations

### *4.1. Description of numerical model*

The finite difference software, FLAC3D [6], has been used for numerical simulation of the Yang Jialing case. The X-axis and Y-axis are in the cross-section perpendicular to the tunnel alignment (*Z*-axis). The dimension of the model is