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# Study on the Relation between Mineral Compositions of Rock and Construction Characteristics of Tunnel in Cold Regions: A Case

(Kajian tentang Hubungan antara Komposisi Mineral Batuan dan Ciri Pembinaan Terowong di Kawasan Sejuk: Suatu Kes)

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ABSTRACT

*Mineral composition of rock has a very important influence on the physical and mechanical properties of tunnel surrounding rock. Take Dangjianshan tunnel in cold regions for example, the rock specimens in different parts of tunnel were taken to carry out the detection test of mineral composition. By the detail qualitative and quantitative analysis, the relationship between mineral composition and surrounding rock engineering properties was explored. First of all, the composition and content of minerals contained in in the rock specimens were detected by X ray fluorescence spectrometer and X ray powder diffraction. The detection results show that rock of tunnel contains high hardness minerals such as quartz and feldspar which were proven by initial engineering geological investigation report, in addition, it also contains several kinds of low hardness minerals including inclined chlorite and illite which may exhibit large deformation characteristic of soft rock after the tunnel excavation in case of meeting water and weathering conditions. The total content of inclined chlorite and illite accounted for a considerable component in main tunnel, inclined shaft and parallel pilot respectively and the influence on surrounding rock engineering properties cannot be ignored. Therefore, mineral composition detection must be paid attention to after tunnel excavation. Secondly, the effects of mineral composition on surrounding rock were analyzed in aspects of rock strength, weathering resistance, water softening property and excavation deformation through comparing the rock samples in different parts of tunnel. The comparative results showed that when the mineral contents is high with high hardness and poor hydrophilicity, tunnel surrounding rock plays a better performance of physical and mechanical properties, vice versa. Finally, according to the specific geological and construction parameters of the tunnel, the correlation analysis was studied about the vault settlement after tunnel excavation and the hydrophilicity mineral content in main cave. The logarithmic relationship between them was found and the correlation coefficient was 0.98. It can provide a useful reference for the settlement prediction of Dangjinshan tunnel construction.*

*Keywords: Engineering properties; mineral composition; relation, surrounding rock; tunnel*

ABSTRAK

*Komposisi mineral batuan mempunyai pengaruh yang amat penting pada sifat fizikal dan mekanik batuan sekitar terowong. Mengambil terowong Dangjianshan di rantau sejuk sebagai contoh, spesimen batuan di bahagian berbeza dalam terowong telah diambil untuk menjalankan ujian pengesanan komposisi mineral. Berdasarkan analisis perincian kuantitatif dan kualitatif, sifat hubungan antara komposisi mineral dan sifat kejuruteraan batuan sekitar telah diterokai. Pertama sekali, komposisi dan kandungan mineral yang terkandung di dalam spesimen batu telah dikesan melalui spektrometer pendarfluor sinar X dan pembelauan serbuk sinar X. Keputusan pengesanan menunjukkan batu terowong mengandungi mineral berkepadatan tinggi seperti kuarza dan feldspar yang telah terbukti melalui laporan kajian geologi kejuruteraan awal. Di samping itu, ia juga mengandungi beberapa jenis mineral berkepadatan rendah termasuk cenderung klorit dan ilit yang boleh menyebabkan perubahan bentuk yang besar kepada ciri batuan lembut selepas penggalian terowong jika berlaku pertembungan keadaan air dan cuaca. Jumlah kandungan cenderung klorit dan ilit merupakan komponen besar dalam terowong utama, masing-masing cenderung penggerudian dan rintis selari serta pengaruh pada sifat kejuruteraan sekitar batuan tidak boleh diabaikan. Oleh itu, pengesanan komposisi mineral perlu diberi perhatian selepas penggalian terowong. Kedua, kesan komposisi mineral di sekitar batuan dianalisis dalam aspek kekuatan batu, rintangan cuaca, sifat pelembutan air dan canggaan penggalian dengan membandingkan sampel batuan di bahagian berbeza dalam terowong. Keputusan perbandingan menunjukkan apabila kandungan mineral tinggi dengan kepadatan dan rendah hidrofilisiti, batuan di sekitar terowong menunjukkan prestasi sifat fizikal dan mekanik yang lebih baik dan sebaliknya. Kesimpulannya, mengikut parameter khusus geologi dan pembinaan terowong, analisis korelasi telah dikaji untuk penempatan kubah selepas penggalian terowong dan kandungan mineral hidrofilisiti dalam gua utama. Hubungan logaritma antara mereka diperoleh dan pekali korelasi ialah 0.98. Ia mampu memberi rujukan yang berguna untuk ramalan penempatan pembinaan terowong di Dangjinshan.*

*Kata kunci: Batuan sekitar, komposisi mineral; perhubungan; sifat kejuruteraan; terowong*

## Introduction

In the construction process of mountain tunnel, how to control the stability and deformation of surrounding rock in the excavation process is an important issue. There are many factors affecting the deformation and stability of surrounding rock, such as the rock engineering properties, initial geostress field, tunnel cross-section shape, buried depth and construction methods but rock engineering properties has very close relationship with mineral composition, rock structure, groundwater and weathering factors (Cui et al. 2011; Diamantis et al. 2014; Li et al. 2013; Johansson 2011; Luukkonen 2005; Manap et al. 2010; Pappalardo et al. 2015). Zhang et al. (2013) points out that mineral composition and structure of rock are important factors affecting its mechanical properties and the uniaxial compressive strength and elastic modulus of the rocks will increase due to the content of quartz. Lin et al. (2010) determined the rock mineral composition by X-ray diffraction analysis and by observing the rock meso-structure with scanning electron microscopy (SEM), they points that the feldspar will increase rock brittle and the increment of calcite content will reduce the compressive strength and elastic modulus of rock. Li et al. (2011) analyzes the influence of mica content, particle shape and size, cracks and porosity in the rock and other factors on the rock engineering properties.

These literatures are limited to the experimental stage, but the relation between the mineral compositions and the deformation of the surrounding rock in practical engineering is not analyzed. The mineral composition of rock is an important factor which affecting the engineering properties of surrounding rock directly and even if the surrounding rock are in the same environmental conditions, the engineering properties of rock tunnel will show larger differences due to the change of mineral composition in the surrounding rock. Therefore, this paper uses X-ray fluorescence spectrometer and polycrystalline X-ray powder diffraction to detect and analyze the type and content of mineral elements in the tunnel surrounding rock, and combining with field monitoring of the surrounding rock vault settlement value, analyzes the influence of mineral composition on the engineering properties and deformation of surrounding rock. It will provide a basis for reducing surrounding rock deformation and maintaining the stability of the surrounding rock effectively after excavating the tunnel.

## PROJECT OVERVIEW AND FIELD SAMPLING

Dangjianshan tunnel is located in GanSu Province. Its total length is 20,140 m and the mileage of tunnel spans from DK194+980 to DK215+150. Sampling location passes through the Great Wall strata, rock grade is III~IV and the main minerals are mica quartz schist. The mica quartz schist is black color mainly, with tremolite schist, biotite schist, occasionally marble thin layer rock. The main minerals include quartz (19%~37%), feldspar (9%~24%), mica (8%~ 38%) and little amphibole mineral and the rock is hard. The tunnel is located in the alpine region, seasonal temperature difference is large, the average temperature is 3.1℃, and the minimum temperature is -34.3℃. The main groundwater is bedrock fissure water. The rock schistosity, bedding and rock joint fissures provide the channels and space for migration and storage of the groundwater. The tunnel is drilled with blasting method and excavated by step method or full section method.

The sampling sites for detection located in main cave, inclined shaft and parallel pilot. Six sampling points is set in main cave and the interval is 10 m between any two-sampling point. Five groups of samples are taken at each sampling point, samples are loose broken bulk mainly and the diameter is less than 2 cm. The retrieved samples are shown in Figure 1, the buried depth of sampling locations

TABLE 1. Sample specific information

| | Main cave | Inclined shaft | Parallel pilot |
|---|---|---|---|
| Samples | ZD-1~ZD-30 | XJ-1~XJ-5 | PD-11~PD-5 |
| Sampling sites | DK205+188.6~238.6 | DK207+20 | DK205+200 |
| Buried depth | 55m～60m | 300m～310m | 69m～74m |
| Surrounding rock grade | III | Ⅳ | Ⅳ |
| Rock mass structure | The rock mass of sampling sites is affected by the structure movement seriously, joint fissures are developed, rock mass is crushing, and the overall engineering geological conditions is poor. | | |

(a) main cave (b) inclined shaft (c) parallel pilot

FIGURE 1. Rock samples

and the surrounding rock grade are shown in Table 1.

## Test equipment and Method

### TEST EQUIPMENT

Rock elements were analyzed by Japan Shimadzu XRF-1800 scanning type X-ray fluorescence spectrometer of Shanghai Jiaotong University analysis and test center. X-ray tube uses copper target, the tube voltage is 40 kV and the tube current is 70 Ma. The instrument has many merits such as high sensitivity, wide range of elements analysis (5 B - 92U), simple sample and rapid analysis, especially the analysis will be convenient.

Rock mineral analysis used Bruker D8 advance polycrystalline X-ray diffraction of Shanghai Silicate Research Institute of Chinese Academy of Sciences. X-ray tube uses copper target, the pipe pressure is 40 kV, tube current is 40 Ma and scanning range of the 2θ angle is 4º~90º (full score). The divergence slit and anti-scatter slit are both 1.0 mm, the narrow receiving is 0.1 mm, the step is 0.03º per step and the scanning speed is 0.4 s per step.

## Test method

### SAMPLE ELEMENT TEST METHOD

Test principle  When a beam of X-ray photons with high enough energy hit the material, the inner electrons of the constituent elements atoms are excited and a hole is formed on track. Now atoms are in an unstable excited state, outer high energy electrons transit to the inner spontaneously and characteristic fluorescence X-ray radiate and the optical system of the X-ray fluorescence spectrometer will separate different wavelength characteristic fluorescence X-ray. The wavelength of characteristics fluorescence X ray and atomic number Z of the element accord with Moss's law, and the mathematical equation is:

$$\lambda = K\,(Z-s)^{-2} \tag{1}$$

In which K and s are constants. For the X ray fluorescence of different elements have specific wavelength, elements types can be determined by (1). X ray fluorescence intensity of the elements $I_i$ is proportional to the element content $W_i$ in the sample:

$$I_i = I_s W_i \tag{2}$$

when $I_i$ is 100%, according to the intensity of characteristics X ray fluorescence, elements content can be obtained by (2) (Usman et al. 2017; Wang et al. 2010).

Test method  Put the rock sample into the X-ray fluorescence spectrometer, x-ray produced by x-ray tube in the instrument irradiates on to the rock surface, characteristic fluorescence x-ray of the sample elements is stimulated. Optical system separates different wavelength characteristic fluorescence X-ray and detector system records different characteristic x-ray fluorescence intensity, therefore, 2θ-fluorescent X-ray intensity curve (X-ray fluorescence spectrum) is taken (Wang et al. 2010). The X-ray fluorescence spectrum of ZD-2 is shown in Figure 2.

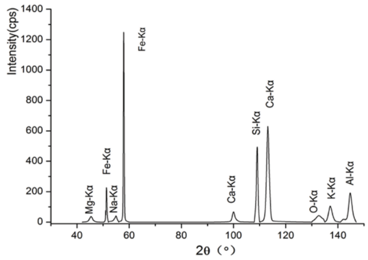


FIGURE 2. X-ray fluorescence spectrum of ZD-2

### TEST METHOD OF THE ROCK MINERAL COMPOSITION

Test principle  The vast majority of mineral belongs to the crystal. Because X-ray has the character of penetrating, when a beam of monochromatic X-ray with the wavelength λ project onto the parallel atomic planes with a neighbor space D by the incident angle manner, atomic electrons vibrate synchronously because of stimulating and the oscillating electrons radiate secondary X-ray to the surrounding as a new radiation source with the same wavelength of the original incident X-ray. When the optical path difference of adjacent crystal surface X-ray (2dsinθ) is an integer multiple of the wavelength and angle meets to Bragg equation $2d\sin\theta = n\lambda$ for an arbitrary orientation θ, the two adjacent X-ray will send diffraction. Different substances have different lattice constants, spacing, atomic species and unique diffraction spectrum line under a certain X-ray irradiation, therefore, the type of minerals in the rock can be determined. Each phase diffraction intensity of the mixed spectrum is proportional to its content in the mixture, therefore, the diffraction of X ray can be used for quantitative analysis (Li et al. 2013).

Qualitative analysis method of rock mineral  First of all, put the rock sample into the diffraction spectrum for scanning to get the X-ray diffraction specimen. Then, use the software of MID-JADE to open the X-ray diffraction of samples, input the main elements analyzed by X-ray fluorescence into the software, limit the search range of rock minerals contained in the rock sample and compare the standard diffraction pattern of each mineral with the scanning specimen. When they meet the diffraction, peaks will appear in the same diffraction angle and the corresponded number is more than or equal to 3, the mineral can be determined. The X-ray diffraction patterns of rock sample in ZD-2 and the detected mineral composition are shows in Figure 3. Finally, compare the standard diffraction patterns of mineral in retrieval range using scanning diffraction patterns one by one to determine the main mineral contained in the samples (Li et al. 2014).

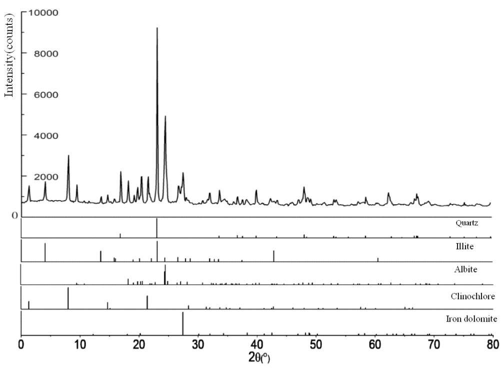


FIGURE 3. X ray diffraction pattern of ZD-2

Quantitative analysis method of rock mineral X-ray fluorescence spectrometer detects the main elements and content of sample, X-ray diffraction (XRD) detects the main mineral in samples and the main minerals of rock sample contains most of the elements. When the element exists in a mineral only, the content of mineral in the sample can be determined in accordance with the element contents of samples (Li et al. 2013; Wu et al. 2017). For example, when sodium elements only exists in albite of ZD-2, the content of sodium feldspar in the sample can be determined in accordance with the sodium contents of samples detected.

## Test results and Analysis

### TEST RESULTS OF ELEMENTS

The 15 groups of rock samples locating at main cave (DK205+188.6), inclined shaft and parallel pilot are carried out qualitative and quantitative element analysis in turn by X-ray fluorescence spectrometer. The analysis results are shown in Table 2 and Figure 4. (In order to facilitate the discussion and analysis of the relation between tunnel vault settlement and the rock mineral compositions, the other 25 groups rock samples retrieved from main cave locating at DK205+198.6~238.6 will be tested subsequently.)

TAB LE 2. Sample elements content (%)

| Sample | O | Si | Ca | Fe | Al | Mg | K | Na |
|---|---|---|---|---|---|---|---|---|
| ZD-1 | 48.3 | 37.6 | 3.3 | 3.3 | 5.5 | 1.1 | 0.4 | 1.1 |
| ZD-2 | 47.6 | 28.5 | 4.1 | 4.5 | 10.5 | 1.6 | 1.3 | 1.5 |
| ZD-3 | 47.0 | 27.9 | 3.5 | 5.5 | 11.1 | 2.1 | 1.6 | 1.6 |
| ZD-4 | 48.5 | 26.4 | 5.2 | 5.6 | 8.5 | 2.2 | 1.3 | 1.3 |
| ZD-5 | 48.6 | 36.9 | 3.6 | 3.4 | 6.2 | 1.4 | 0.5 | 1.2 |
| Mean content | 48.0 | 31.5 | 3.8 | 4.5 | 8.3 | 1.6 | 1.0 | 1.3 |
| XJ-1 | 45.0 | 22.7 | 6.7 | 11.2 | 8.4 | 3.1 | 0.5 | 1.8 |
| XJ-2 | 44.6 | 24.5 | 7.6 | 10.1 | 7.2 | 3.6 | 0.6 | 1.2 |
| XJ-3 | 45.1 | 22.3 | 7.4 | 11.5 | 7.7 | 3.9 | 0.9 | 1.4 |
| XJ-4 | 46.2 | 23.4 | 5.6 | 10.3 | 8.0 | 4.2 | 0.7 | 1.2 |
| XJ-5 | 42.2 | 23.0 | 7.4 | 10.7 | 8.5 | 5.6 | 1.5 | 1.3 |
| Mean content | 44.6 | 23.2 | 6.9 | 10.8 | 8.0 | 4.2 | 0.9 | 1.4 |
| PD-1 | 46.4 | 26.4 | 4.2 | 7.6 | 9.6 | 2.4 | 1.5 | 1.4 |
| PD-2 | 47.2 | 22.6 | 8.8 | 8.5 | 7.5 | 3.0 | 1.2 | 1.1 |
| PD-3 | 45.8 | 21.6 | 8.5 | 10.1 | 9.3 | 3.2 | 1.3 | 1.3 |
| PD-4 | 41.6 | 21.5 | 5.4 | 13.3 | 9.6 | 4.4 | 1.4 | 1.4 |
| PD-5 | 42.3 | 20.4 | 8.5 | 12.5 | 9.9 | 4.6 | 1.4 | 1.4 |
| Mean content | 44.7 | 22.5 | 7.1 | 10.4 | 9.1 | 3.5 | 1.4 | 1.3 |

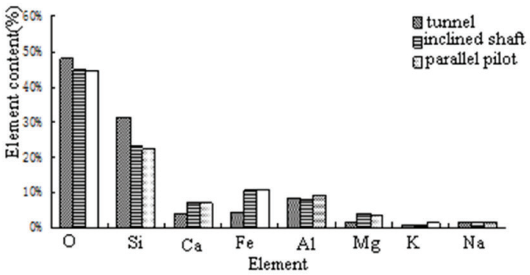


FIGURE 4. Mean content of rock elements

As shown in Table 2 and Figure 4, each element contents of the sample in ZD-1 and ZD-5 are similar and rock elements of ZD-2, ZD-3 and ZD-4 are similar. But the contents of Si, Al and K have greater difference between the former two groups of samples and other three groups and the five groups of samples in main cave contain the same type of minerals. Because elements content affect the mineral content directly, the different mineral content will change obviously in main cave. The elements content of parallel pilot and inclined shaft have relatively small fluctuations, so fluctuations are smaller in mineral content.

Nonmetallic element in rock specimen is mainly O and Si. The mean content of these two elements in main cave, inclined shaft and parallel pilot are 79.5%, 67.8% and 67.2%, respectively. The main metal elements are Al, Fe, CA, Mg, K and Na and the mean proportion of the six elements in main cave, inclined shaft and parallel are 20.5%, 32.2% and 32.8%, respectively, namely, the nonmetal elements content in main cave is higher than inclined shaft and parallel pilot and the metal element content is low. Generally speaking, the opportunity of elements formatting minerals is more in the continuous migration process if the number of atomic is more. Therefore, according to the measured content of major element in rock, it is concluded that the rock is mainly oxide and contains mineral salts composed of Si, Al, Fe, CA, Mg, K and Na. Quartz content of main cave is higher than the inclined shaft and parallel pilot, and the corresponding mineral salt content is low. The content of metal and nonmetal element in inclined shaft and parallel pilot is similar as shown in Figure 4 and sampling sites are both located in the Great Wall mica quartz schist zone, therefore, their mineral species and content are similar.

## TEST RESULTS OF ROCK MINERAL COMPOSITION

The rock mineral composition of three working faces in main cave is shown in Table 3. The minerals contain albite, calcite, feldspar, quartz, hastingsite, clinochlore, illite and iron dolomite mainly. Compared with engineering geological investigation report of design, the main cave adds clinochlore and illite, the inclined shaft and parallel pilot add clinochlore, illite, hastingsite and calcite. Clinochlore and illite were detected in rock of the three working face both. The two minerals have large differences with quartz and feldspar in aspect of engineering properties under the conditions of water and weathering, so the tunnel may exhibit large deformation characteristics of soft rock after excavation.

TABLE 3. Rock mineral composition

| Mineral | Chemical formula | Main cave | Inclined shaft | Parallel pilot |
|---|---|---|---|---|
| Quartz | $SiO_2$ | √ (●) | √ (●) | √ (●) |
| Albite | $(Na,Ca)Al(Si,AL)_3O_8$ | √ (●) | √ (●) | √ (●) |
| Clinochlore | $(Mg,Fe)_6(Si,Al)_4O_{10}(OH)_8$ | √ | √ | √ |
| Illite | $(K,H_3O)Al_2Si_3\ AlO_{10}(OH)_2$ | √ | √ | √ |
| Calcite | $CaCO_3$ | √ | √ | |
| Hastingsite | $(Na,Ca)_2(Fe_2,Mg)_5(Si,AL)_8O_{22}(OH)_2$ | √ | √ | |
| Feldspar | $KAlSi_3O_8$ | √ (●) | | |
| Iron dolomite | $Ca(Fe,Mg)(CO_3)_2$ | √ | | |

√ is the minerals containing in rock after analysis and detection by X-ray diffraction, ● is the minerals containing in rock given by the engineering geological prospecting report

## THE TEST RESULTS OF ROCK MINERAL CONTENTS AND ANALYSIS

The content of elements in sample can be calculated with the mineral content in samples and take ZD-2 for an example, the calculation process is shown below.

Element of K is only in illite of ZD-2 and the mass fraction of K is 1.3% in rock. Assume the mass fraction of illite is a in rock samples, therefore,

$$9.3\times a\% = 1.3,\quad a = \frac{1.3}{9.3}\times 100\% = 13.9\%\,. \tag{3}$$

Similarly sodium feldspar content can be get according to the sodium content:

$$\frac{1.5}{6.0}\times 100\% = 25\%\,. \tag{4}$$

The calcium element content in iron dolomite is equal to the total calcium content minus the calcium element content in albite ferrodolomite, therefore, the content of iron dolomite is

$$\frac{4.0\% - 25\%\times 0.104}{0.166} = 8.4\%. \tag{5}$$

TABLE 4. Rock mineral content of ZD-2

| Mineral | Mineral | The mass fraction of elements in the chemical formula |
|---|---|---|
| Quartz | $SiO_2$ | Si: $\frac{28}{60}\times 100\% = 46.7\%$ O: $\frac{32}{60}\times 100\% = 53.3\%$ |
| Albite | $(Na,Ca)Al(Si,Al)_3O_8$ | Ca: 10.4%; Na: 6.0% ; Al:28.0% |
| Clinochlore | $(Mg,Fe)_6(Si,Al)_4O_{10}(OH)_8$ | Mg: 14.4%; Fe: 33.7%; Al: 10.8% |
| Illite | $(K,H_3O)Al_2Si_3\ AlO_{10}(OH)_2$ | K: 9.3%; Al: 19.3% |
| Iron dolomite | $Ca(Fe,Mg)(CO_3)_2$ | Ca: 16.6%; Fe: 23.3%; Mg: 10% |
| Element content of ZD-2 | O:47.6%; Si:28.5%; Ca:4.1% Fe:4.5%; Al:10.5%; Mg: 1.6% ; K:1.3% ; Na:1.5% | |

The iron element content in clinochlore iron is equal to the total iron content minus the iron content in ferrodolomite, therefore, the content of clinochlore is,

$$\frac{4.5\% - 8.4 \times 0.233\%}{0.337} = 7.5\% . \quad (6)$$

The content of quartz is

$$100\% - 13.9\% - 25\% - 8.4\% - 7.5\% = 45.2\% . \quad (7)$$

According to the relative content of the above minerals, it is concluded that the Al content of sample is equal to,

$$13.9\% \times 0.193 + 25\% \times 0.28 + 7.5\% \times 0.108 = 10.4\% . \quad (8)$$

But the element of Al measured by experiment content is 10.5%. With regard to instrument error, sampling error and error produced in the process of sample preparation, the calculation result is reasonable. The mineral content in samples is calculated by element content as shown in Tables 5 to 7.

TABLE 5. Mineral content of main cave

| Rock sample | Quartz | Albite | Clinochlore | Illite | Iron dolomite |
|---|---|---|---|---|---|
| ZD-1 | 64.7% | 16.7% | 4.2% | 5.5% | 8.9% |
| ZD-2 | 45.2% | 25% | 7.5% | 13.9% | 8.4% |
| ZD-3 | 41.5% | 26.9% | 12.9% | 16.5% | 2.2% |
| ZD-4 | 42.5% | 22.9% | 6.7% | 13.2% | 14.7% |
| ZD-5 | 62.8% | 18.0% | 4.8% | 6.9% | 7.5% |
| Average content | 51.3% | 21.9% | 7.2% | 11.3% | 8.3% |

TABLE 6. Mineral content of inclined shaft

| Rock sample | Quartz | Albite | Feldspar | Clinochlore | Hastingsite | Calcite | Illite |
|---|---|---|---|---|---|---|---|
| XJ-1 | 37.8% | 15.2% | 2.5% | 4.5% | 30.6% | 9.4% | — |
| XJ-2 | 39.2% | 11.9% | 4.5% | 8.0% | 22.2% | 14.2% | — |
| XJ-3 | 35.9% | 13.3% | 5.2% | 11.4% | 23.0% | 11.2% | — |
| XJ-4 | 41.4% | 14.9% | 4.7% | 12.0% | 18.5% | 8.5% | — |
| XJ-5 | 27.0% | 10.4% | 4.4% | 8.5% | 25.0% | 14.5% | 10.2% |
| Average content | 36.3% | 13.1% | 4.3% | 8.9% | 23.9% | 11.6% | 2.0% |

TABLE 7. Minerals content the parallel pilot

| Rock sample | Quartz | Albite | Clinochlore | Hastingsite | Illite | Calcite |
|---|---|---|---|---|---|---|
| PD-1 | 39.8% | 14.9% | 5.8% | 19.4% | 17.3% | 2.8% |
| PD-2 | 36.9% | 9.7% | 7.9% | 17.9% | 12.7% | 14.9% |
| PD-3 | 31.5% | 13.0% | 9.6% | 20.8% | 11.0% | 14.1% |
| PD-4 | 25.9% | 10.4% | 14.9% | 25.1% | 15.4% | 8.3% |
| PD-5 | 23.1% | 10.0% | 14.9% | 25.6% | 13.1% | 13.3% |
| Average contents | 31.4% | 11.6% | 10.6% | 21.8% | 13.9% | 10.7% |

It can be seen from Tables 5 to 7 that the main mineral (content ≥10%) of main cave is quartz, sodium feldspar and illite the total content of quartz and feldspar is 73.2%, the total content of clinochlore and illite is 18.4% and the content of iron dolomite is 8.3%, respectively. Because there are great differences between the silicon and potassium, the content of quartz and illite have greater volatility.

The main mineral in inclined shaft is quartz, albite, hastingsite and calcite. The total content of quartz and feldspar is 53.7%, the total content of clinochlore and illite is 10.9% and the content of hastingsite and calcite are 23.9% and 11.6%, respectively. Each mineral contents in the inclined shaft has small wave.

The main minerals of parallel pilot are quartz, albite, clinochlore, hastingsite, illite and calcite. The total content of quartz and feldspar is 43.0%, the total content of clinochlore and illite is 24.5% and the content of hastingsite and calcite is 21.8% and 10.7%, respectively. The fluctuation of each mineral contents of parallel pilot is small.

The content of illite and calcite in inclined shaft and parallel heading has great difference, but other mineral content is close. Compared to the main cave, the content of quartz and ankerite in inclined shaft and parallel decrease, but the content of clinochlore, hastingsite and calcite increase as shown in Figure 5.

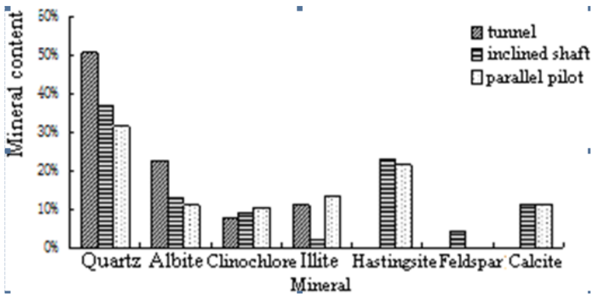


FIGURE 5. The mean content of rock mineral

Samples of the main cave, inclined shaft and parallel pilot contain feldspar, quartz, clinochlore and illite, but the content of these four kinds of minerals is greatly different. The total content of quartz and feldspar in main cave, inclined shaft and parallel pilot account for 73.2%, 53.7% and 43.0%, respectively and the total content of clinochlore, illite and calcite accounts for 18.5%, 22.5%, 35.2%. Compared to the main cave, the content of quartz and feldspar reduce in inclined shaft and parallel pilot, but the content of illite, clinochlore and calcite increase.

Compared to the engineering geological survey report, minerals of main cave add clinochlore, illite and ankerite and the total content is 26.8%. Minerals of inclined shaft add clinochlore, hastingsite, calcite and illite and the total content is 46.4%. Minerals of parallel pilot add clinochlore, hastingsite, illite and calcite and the total content is 57.0%. Because the proportion of new mineral is large, the effects of minerals on the engineering properties of rock is cannot be ignored.

## THE RELATIONSHIP BETWEEN ENGINEERING PROPERTIES OF ROCK AND MINERAL COMPOSITION

With regards to the given samples of this test, it can be drawn that the main minerals of the rock are quartz, feldspar, illite, hastingsite, clinochlore and calcite through X-ray diffraction. Mineral composition and groundwater have direct influence on the properties of engineering rock mass both.

### EFFECTS OF MINERALS ON ROCK STRENGTH

Analyze the strength of rock by mineral composition. Mineral components affect the rock strength directly. In general, if the content of hardness mineral is higher, the strength of rock is higher (Li et al. 2006), such as quartz, feldspar, hastingsite and other minerals. In contrast, if the content of hardness mineral is lower, rock strength is lower, such as illite and clinochlore. For the whole block of rock, the strength of rock determines the strength of rock mass directly. If rock strength is high, the surrounding rock is stable easily after the excavation of tunnel. But for joints and surrounding rock with fractured rock mass, rock strength only affects the strength of rock mass partly.

Analyze the surrounding rock strength from the perspective of the mineral content. The total content of quartz and feldspar in main cave, inclined shaft and parallel pilot are 73.2%, 53.7% and 43.0%. Hastingsite content in inclined shaft and parallel pilot are 23.9% and 21.8%, respectively, therefore, the surrounding rock strength in main cave is the highest and the minimum in parallel pilot.

The distribution of rock mineral is not uniform. Minerals formed by the influence of factors such as temperature and pressure, their distribution show periodic rule to make some minerals of low intensity and easy weathering present zonal distribution. After the excavation of underground cavern, stress redistributes. Stress concentration produces easily at the arch foot and waist affected by the tunnel cross-section shape and rocks occur failure from these weak structural surfaces.

### MINERAL WEATHERING EFFECT

Analyze the surrounding rock weathering from the perspective of its mineral composition. In the process of tunnel construction, due to the effects of excavation methods, excavation footage, construction operation space and other factors, the initial support cannot be done timely, the surrounding rock will expose in the air for a long time. Because of the influence of atmosphere, water and temperature, surrounding rock will accelerate the rate of weathering and the original rock mass fracture increases (Nicholson 2001; Shang et al. 2004). The weathering resistance of quartz and feldspar are strong, but the anti-weathering abilities of hastingsite, calcite, ankerite and chlorite are weak. Minerals with anti-weathering ability weather into clay minerals easily and it leads to decrease the strength and stability of rock mass.

Analyze the surrounding rock weathering from the perspective of the mineral content. The total content of hastingsite, calcite, clinochlore in main cave, inclined shaft and parallel pilot are 15.5%, 44.4%, 43.1%, respectively, therefore, the rock weathering resistance ability of main cave is stronger, the weathering resistance abilities of inclined shaft and parallel pilot are weaker. Therefore, in the process of construction, the initial support should be applied promptly for closing the rock to shorten the exposure time.

### THE RELATIONSHIP BETWEEN MINERALS & GROUNDWATER AND THE ROCK ENGINEERING PROPERTIES

Water affects the properties of mineral engineering in many aspects. DangJinshan tunnel is located in cold area, seasonal temperature difference is large, the annual average temperature is 3.1℃ and the coldest month temperature is -13.1℃. Because of jointed rock mass development, complex rock mineral composition and uneven structure, the frost resistance of rock is poor (Nicholson 2001).

For the soluble calcite mineral, it is soluble easily in flow, especially when the water contains $CO_2$. It provides conditions for karst development and water gushing, leakage and collapse may occur during construction. The content of calcite is high in inclined shaft and parallel pilot up to 11.6% and 10.7%, therefore, the advanced geological prediction should be done before tunnel excavation in order to master the geological conditions in front of tunnel face (Qu et al. 2006).

Minerals composition of illite and clinochlore bate easily in case of water to reduce the strength of surrounding rock and clinochlore has obvious creep properties due to the deformation with time (Li et al. 2013) and the volume of clinochlore can be expanded 10% ~ 30% after absorbing water. The content of these two minerals are higher in main cave, inclined shaft and parallel pilot up to 18.5%, 10.9% and 24.5%, respectively. Due to the existence of these two minerals, it may generate larger deformation of surrounding rock because of the influence of groundwater and construction water after the excavation of tunnel. It can use reasonable excavation methods, excavation footage and advanced supporting measures to reduce surrounding rock deformation (Liu et al. 2008).

Rock strength will be reduced after saturated with water. Water immerses along the rock joints and fractures, weakens the joining force between the mineral particles each other and makes the shear strength and compressive strength of rock decreased. Therefore, it is necessary to formulate corresponding measures and do a good job to prevent the ingress of groundwater according to the different geological conditions, such as the use of well point precipitation, the construction of drainage tunnel or strata grouting. Construction water should be to minimize in construction process.

## THE RELATIONSHIP BETWEEN THE MINERALS AND ROCK DEFORMATION

The main purpose of tunnel monitoring is to ensure the stability and construction safety of the tunnel structure and surrounding rock. Comparing the construction measurement results with the predicted values, the design parameters would be revised to guide the site construction and provide the basis for the optimization design. The vault settlement of tunnel surrounding rock is measured by the method of leveling (Trimble Dini03) and the instruments of leveling instrument, steel rulers or total station are equipped with. The tunnel vault subsidence curve of the three rock sample sections is shown in Figure 6.

As can be seen from Figure 6, the final vault settlement value of parallel pilot, inclined shaft and main cave is 15.3, 10.4 and 9.3 mm, namely, the vault settlement of parallel pilot is largest and the main cave's is minimum. Combined with the above analysis result of surrounding rock mineral composition, the rock mineral composition and content are the important factors that affect rock vault settlement. When the content of high hardness mineral is high in surrounding rock, such as main cave, the content of high strength of quartz and feldspar are higher, quartz content increases the elastic modulus and the strength of the rock and the deformation of main cave surrounding rock is smaller. But the content of chlorite and illite mineral with low hardness are relatively high in inclined shaft and parallel pilot, so this will reduce the rock elastic modulus. Therefore, deformation of surrounding rock in main cave is small and the deformation of surrounding rock in parallel pilot is maximum. This is corresponding with the practical engineering level of surrounding rock. It is III grade rock for main cave and IV grade rock for inclined shaft and parallel pilot.

Mineral species and content are the internal factors which influence the engineering properties and stability of surrounding rock. The engineering properties of rock and the stability are also affected by the many external factors, such as the tunnel excavation method and cross sectional shape (Liu et al. 2008). In order to master the engineering properties of rock truly and maintenance of surrounding rock stability, it should consider the comprehensive effect of excavation method, initial crustal stress, rock structure and groundwater factors.

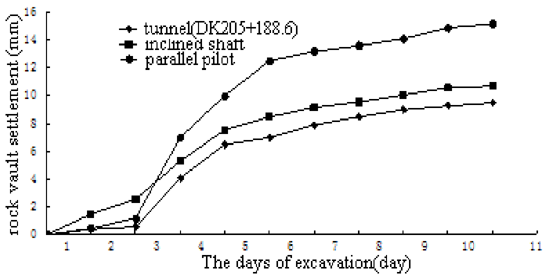


FIGURE 6. Vault settlement curve

Furthermore, using the test results of all samples in main cave and the vault settlement monitored in site, their relation is studied. Similarly, the other 25 groups rock samples are tested by X-ray fluorescence spectrometer which are taken from main cave locating at DK205+198.6~238.6. The average mineral content in samples is calculated by element content as shown in Table 8.

It can be seen that the minerals of the six sampling points in main cave are similar, but the contents are floating. It will cause some differences in the mechanics properties of rock.

The total content of clinochlore and illite in main cave and the vault settlement are shown as Table 9 and the relation curve as shown in Figure 7.

TABLE 8. Average mineral content of samples in main cave

| Samples | Sampling point | Quartz | Albite | Clinochlore | Illite | Iron dolomite |
|---|---|---|---|---|---|---|
| ZD-1~5 | DK205+188.6 | 51.3% | 21.9% | 7.2% | 11.3% | 8.3% |
| ZD-6~10 | DK205+198.6 | 50.1% | 19.7% | 7.9% | 11.9% | 8.1% |
| ZD-11~15 | DK205+208.6 | 52.3% | 23.9% | 6.8% | 11.0% | 8.5% |
| ZD-16~20 | DK205+218.6 | 50.3% | 20.7% | 7.9% | 11.7% | 7.8% |
| ZD-21~25 | DK205+228.6 | 51.0% | 21.1% | 7.4% | 12.0% | 8.0% |
| ZD-26~30 | DK205+238.6 | 52.0% | 22.9% | 6.9% | 10.7% | 8.5% |

TABLE 9. Total mineral content of clinochlore and illite in main cave

| Samples | Sampling point | Total content (%) | Vault settlement(mm) |
|---|---|---|---|
| ZD-1~5 | DK205+188.6 | 18.5 | 9.3 |
| ZD-6~10 | DK205+198.6 | 19.8 | 10.5 |
| ZD-11~15 | DK205+208.6 | 17.8 | 8.9 |
| ZD-16~20 | DK205+218.6 | 19.6 | 10.3 |
| ZD-21~25 | DK205+228.6 | 19.4 | 9.9 |
| ZD-26~30 | DK205+238.6 | 17.6 | 8.3 |

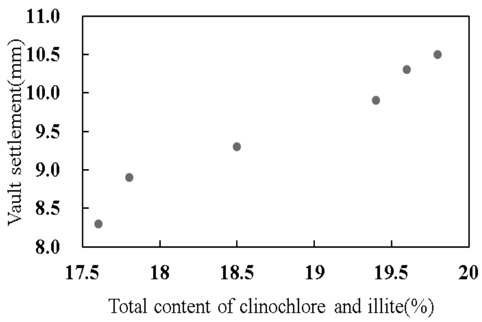


FIGURE 7. Relation curve between mineral content and vault settlement

Through regression analysis by the software SPSS, the empirical logarithmic formula is obtained between the vault settlement and the mineral total content of clinochlore and illite also and the correlation coefficient R is 0.98, that is,

$$\Delta = 16.428 \ln \alpha - 38.632 , \quad (9)$$

in which$\Delta$is the vault settlement, $a$ is the mineral total content of clinochlore and illite.

## Conclusion

The elements of surrounding rock and the composition and content of mineral were detected using X-ray fluorescence spectrometer and polycrystalline X-ray powder diffraction. Effect of minerals on rock engineering properties is analyzed qualitatively and quantitatively. The following conclusions are obtained.

The main elements in sample are oxygen, silicon, calcium, iron, magnesium, potassium and sodium. The nonmetal elements content in main cave, inclined shaft and parallel pilot are much higher than metal elements.

Rock mineral composition and content in the surrounding is one of the important factors that affect the surrounding rock strength, weathering resistance, water softening capacity and rock deformation. When the content of high hardness mineral in the surrounding rock is higher, these physical and mechanical properties of surrounding rock perform well, for example main cave. In contrast, it will result in large surrounding rock deformation in these places, such as inclined shaft and parallel pilot.

In the similar conditions f construction parameter, mineral composition, buried depth, crustal stress field and groundwater, the vault settlement and the total mineral content of clinochlore and illite accord with the laws of logarithmic formulas in main cave and the correlation coefficient R is 0.98. It can provide great help for the vault settlement prediction of main cave of Dangjinshan tunnel.

The presented analysis method in this paper can be used for other tunnel in different regions, such as gas tunnel, rich water tunnel and soft rock tunnel.

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