

# Study on the technology of grouting and reinforcing the foundation of a railway bridge above shallow old mine goaf

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**Abstract.** The city fast track railway bridge studied in this paper is located above an old mined out area. There is a 1500m<sup>2</sup> underground goaf in the construction site with a depth of 30.8~53.2m, the seam thickness is 2.0~2.5m and the dip angle is 50~63 degrees. Although the mine has been abandoned for many years, there are still a lot of underground cavities. Collapse pits occurred on the surface occasionally till this day, especially during the rainy season. In order to make the design safe and reliable, drilling pressure grouting technique is proposed to fill and reinforce the foundation of the site. Proposed technique is tested by several experiments in simulated underground mined out area for the foundation treatment. The technical design, construction technology, grouting and reinforcement effect of the project are studied and summarized. The results of the experiment showed a stable and safe bridge foundation has been achieved. The proposed technique was then applied to on site experiment and passed all tests.

## 1 Engineering background

A city fast track railway bridge to be designed is located on an old goaf area of an abandoned asbestos mine. This bridge is designed as a continuous span reinforced concrete slab bridge, with a length of 300 meters and a width of 8.8 meters. The main bridge adopts a single-box double-chamber reinforced concrete box girder structure, with a one shape abutment and a Y shape pier. The bridge foundation adopts excavated cast-in-place pile; the pier foundation pile diameter is 3.20m, with design load value of 15000kN. Abutment pile diameter is 2.0m, with a design load value of 6000kN. The bridge is designed to match A Class safe building classification.

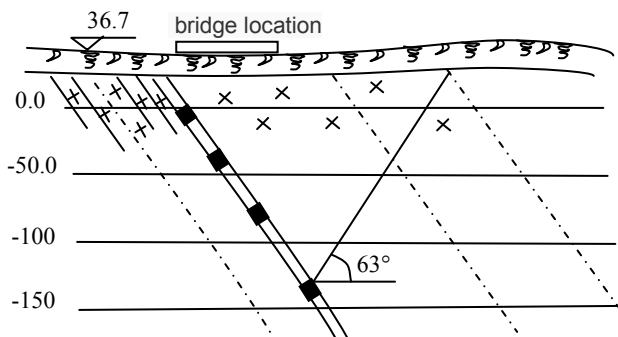
The major issue facing in this project is the foundation part, the bottom of the site directly on an abandoned asbestos mine which was mined with well lane mining technique. The ground depth of the original mining area is relatively small (33.0m~200m), which belongs to the shallow mining class. The asbestos mine was operated with lane well technique in the upper area, and the dry filling method was used in the deep area. Although mining operation has been ceased for many years, due to the existence of the shallow mined out area, collapsing pits still occurs till this date, especially during rainy season. In order to make the design safe and reliable, drilling pressure grouting technique is proposed to fill and reinforce the foundation of the site.

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## 2 Site condition

The structure of the abandoned mine area is illustrated in Figure 1. As shown can be seen, the designed bridge is directly above the mine out area. There is a 1500m<sup>2</sup> underground goaf in the construction site with a depth of 30.8~53.2m, the seam thickness is 2.0~2.5m and the dip angle is 50~63 degrees. Lane column mining technique was used, mining ratio is around 7:3, and mining range is 230 meters.



**Figure 1.** The relative position of the proposed bridge and the goaf.

The formation of the site is analyzed from top to bottom with on-site drilling technique, the results show as following:

- Filling soil (*Q4ml*), loose structure, mainly consists of quartzite fragments, slag and silty clay composition, the thickness is around 2.8~3.8m.
- Gravel Soil (*Q3dpl*), medium density structure, mainly consists of quartzite rock gravel cracks filled with silty clay component; the thickness of this layer is around 1.8 meters.
- All Weathered diabase ( $\beta\mu$ ), loose structure, this layer is very dry and could be affected by water, the thickness is around 2.3 meters to 4.4 meters.
- Strongly weathered diabase ( $\beta\mu$ ), fractured structure, joint fissure development, the thickness of this layer is around 2.5 meters to 6.8 meters.
- Medium weathered diabase ( $\beta\mu$ ), the structure is relatively complete, joint fissure development, the thickness of this layer is around 9.5 meters to 14.9 meters.
- Micro-weathered diabase ( $\beta\mu$ ), the structure of this layer is hard with fine grain, medium joint fissure development, the thickness of this layer around 7.0 meters to 28.3 meters.
- Ore layer (*Py1*), the layer consists of granular and block structure, the lower part has been mined and the structure is heavily broken. The thickness of this layer is around 1.5meters to 7.8 meters.
- Dolomite (*Zg*), this layer is the bottom of the mine out area, the integrity of the structure is maintained. The main physical and mechanical properties of the overlying mine out area is demonstrated in Table 1 as following:

**Table 1.** The main physical and mechanical properties of the overlying mine out area

Lithology	Density (g/cm <sup>3</sup> )	Elastic modulus (103Mpa)	Compressive strength (Mpa)	Tensile strength (Mpa)	Poisson's ration ( $\mu$ )	Cohesion (Mpa)	Internal friction angle ( $\varphi$ )	Wave Speed vp(m/s)
Diabase	2.9	12.33	78.04	13.33	0.34	16.18	63	5637
Ore	2.6	6.62	65.98	4.51	0.34	8.63		4626
Medium-weathered Diabase	2.86	8.7	37.75	2 · 25	0.313	4.61	45	4008

### 3 Similar material simulation tests

In order to analyze the stability and physical property of the structure of the mine out area, similar material is used in the simulation experiment, including quartz sand, barite and mica as aggregate, gypsum as compound. Water and other appropriate retarder were also added. In addition to the physical and mechanical properties of the mining area, Newton similarity criterion was also considered to reconstruct an experimental model with a 1:30 ratio. The deformation pattern of surrounding rock and ground surface are simulated after mining of underground seam. The stability of overlying strata and the suitability of building are evaluated, providing technical support for grouting reinforcement construction.

#### 3.1 Mined out area surface deformation analysis

- Surface slab damage: Surface slab damage mainly occurs within the mined out area, it is caused by the alteration between the diabase layer and dolomitic limestone layer. This alteration deteriorates the physical integrity of the structure, which makes the layer brittle. With the mining layer been mined out, displacement and deformation occurs in surrounding rock and the roof layer. New balance formed between remained layers with a pressure arch structure. Any damage or fractured of the roof or the pressure arch will produce a wide range of further fragmentary damage. [1-5]
- Surface slab fall off. Surface slab falls off occurs when the direct and indirect roof of the mined out area reaches a certain value and the roof bent the limit.
- Roof fissure damage: the fissure zone located above the fall off zone, and is mainly consist of cracking damage and fracture damage. The thickness of the fall off zone and fissure zone is calculated based on following formula. Consider the Height of the fall of zone and fissure zone is H, then

$$H = \frac{hM}{Rh + S} \tag{1}$$

Where: h---Vertical Height of the Mined out area,  
 M---Mining layer Thickness,  
 R&S----Coefficient related to rock formation.

R,S Value for each related formation is shown in following Table2.

**Table 2.** R and S values of caving zone and fracture zone

R		S	
Falling zone	Fissure zone	Falling zone	Fissure zone
0.103~0.082	0.041	3.325~2.660	1.330

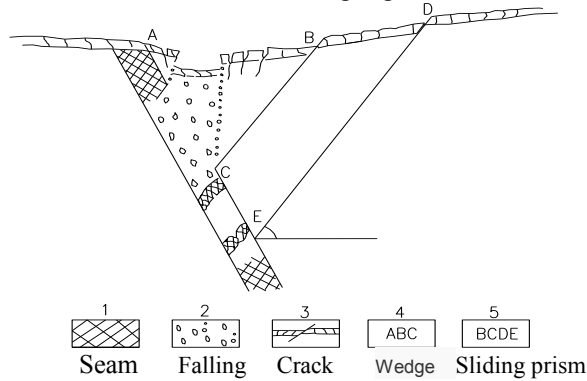
#### 3.2 Non-continuous deformation on the surface of mined out area

Non-continuous deformation on the surface occurs in the mining area where the mining depth is less than 45 meters. These deformations usually happened in two different types as following.

- Surface Cracks : This type of deformation often takes place above the tensile deformation zone above the mining area. Surface cracks can extend from a few meters to tens of meters with a width of 1-2 meters, depth of 20 meters.
- Bead-like collapse pit : Bead-like collapse pit usually occurs within the shallow mining area. When underground cracking reaches the surface, surface rock deforms under pressure. As a consequence, a series of funnel shape rock deformation take places. This type of deformation happens along the mining track with a diameter of 1 to 2 meters.

#### 3.3 Formation principles of cracks and movement in the shallow surface

Two major aspects are considered as the main cause of the deformation: First, the mining depth is relatively shallow, exposed rocks are highly weathered. And the integrity of supporting layer is compromised. In the mined out area, the roof fall off occurs due to lack of support. This type of deformation extends to the surface in an arc form. When it reaches the surface, a wedge body takes places. During rainy season, the shallow rock mass is saturated with water, the wedge body gradually sinks with this change. The weathered rock layer can not support the sinking wedge body, thus collapsing pits will occurs on the surface. Second: when the mined out area becomes large enough, the lack of support will cause the roof rock to bend and deform. Collapse pits will also take place in these areas. These two principles are demonstrated in following Figure 2.

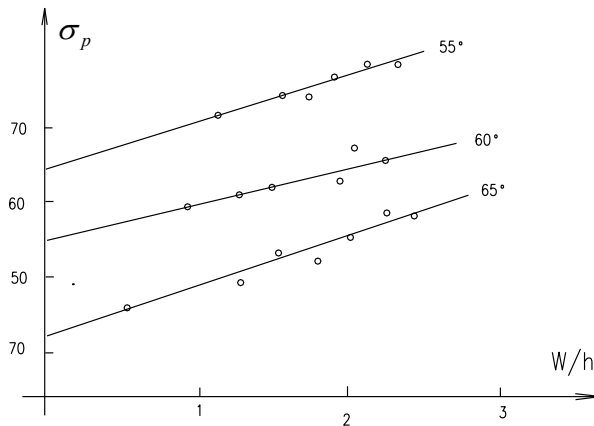


**Figure 2.** Formation principles of cracks and movement in the shallow surface

Lane column mining, pillar strength is the main factor affecting the ground collapse and destruction. The main forms of pillar failure include shear failure and tensile failure, i.e. tension fracture produced by pillar compression, which is similar to the split failure of uniaxial compression test. The strength of the pillars is calculated according to the following formula:

$$\sigma_p = \sigma_{p1}(C + D \cdot W/h) \tag{2}$$

Where:  $\sigma_{p1}$ --- when  $w/h = 1$ , pillar strength  
 $w/h$ ---the pillar width / height



**Figure 3.**  $\sigma_p$ - $W/h$  regression curve

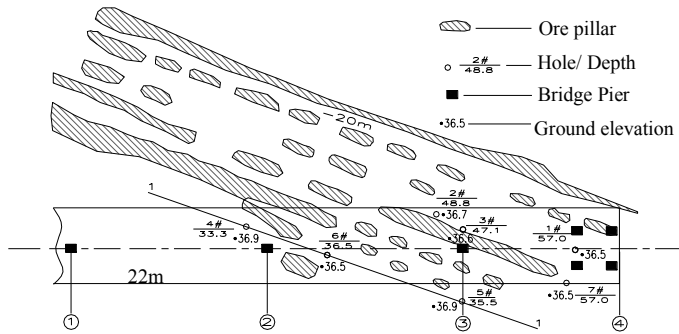
According to the data of experimental and field observation, the linear regression analysis can be carried out to calculate the coefficient of the formula(2) for strength of the pillar under the corresponding dip angle, as shown in Figures 3 and Table 3.

**Table 3.** Results of regression analysis

group	n	$\sigma_{p1}(Mpa)$	C	D	standard deviation	correlation coefficient	$t_{0.06}$	correlation
65°	7	49.1	0.875	0.144	1.04	0.972	2.015	significantly
60°	6	60.3	0.933	0.082	1.304	0.880	2.132	significantly
55°	6	71.9	0.888	0.10	0.687	0.973	2.132	significantly

### 4 Field experiment

Based on the comprehensive analysis of the data of surface movement, combined with the observation and the results of the simulation experiment, it is concluded that the influence of surface subsidence and the deformation is basically stable for mining area with a depth greater than 45 meters. In the shallow area where the depth is less than 45 meters, the rock formation is less stable, and grouting reinforcement techniques need to be used to support the area.



**Figure 4.** Floor plan of grouting hole layout

Seven grouting hole are designed as shown in Figure 4. The hole 4#、5#、6# are along a straight line above the mined out area, and is relatively higher than the other four grouting holes. As the goaf is full of water, in order to improve the effect of grouting, to achieve the function of drainage and diversion, the detailed grouting procedure is as following: when grouting in hole number 4#、5#、6#, drainage is carried out in the hole number 2#. When grouting in drill hole number 2#、3#、1#, drainage is carried out in the hole number 7#. And when above procedure finishes, grouting the last drill hole number 7#.The intermittent injection method is used; each grouting hole is injected in three different stages. In the first stage, slurry with a water-cement ratio of 2:1 is used. In the second stage, the ration changed to 1.5:1, and in the last stage, the ration is 1:1. By dividing the procedure to three stages can expand the slurry diffusion radius, improve the slurry transport distance and also improve the filling reinforcement effect. The total injection amount of seven grouting holes is 1528 m<sup>3</sup>.

### 5 Grouting effect

The total grouting operation takes 18 days. 7 days after the finishing date, drill method is used to test the out come of the grouting operation. Leak test and cross-hole in-situ acoustic velocity measurement are both carried out to test the integrity of the grouting part. [6-8]

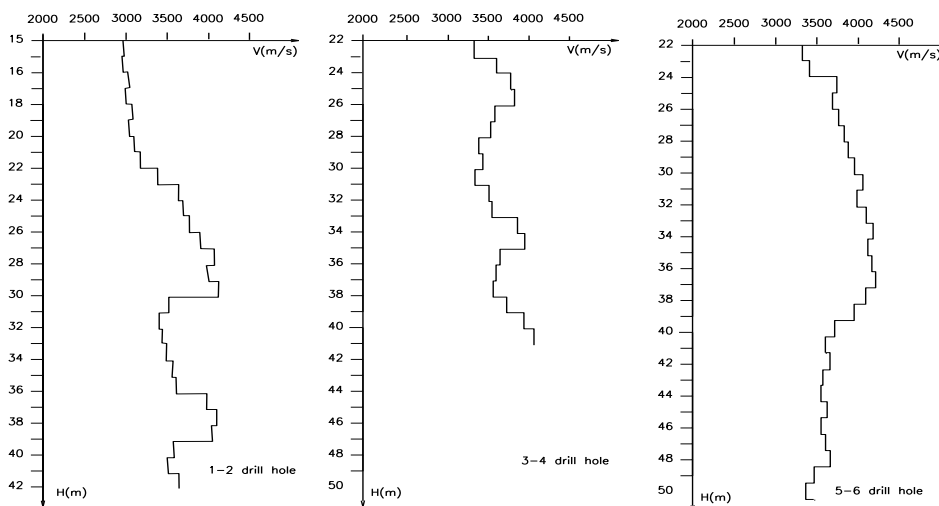
According to the results of the drilling in-situ wave velocity test, it is not difficult to see there are two abnormalities in hole1#~2#, 3#~4#, and 5#~6# hole has an anomaly. The curve reflects the obvious of the recess, the value of the low wave velocity and abnormal wave velocity can be seen in

the following Table 4. The velocity of sound in goaf area is about 3000/s~3500/s which is close to the velocity of surrounding rock, as shown in Figure 5.

According to the drilling data, the upper anomaly area is the main leakage section of the micro-weathered diabase, and the lower part is mainly the mined-out area.

**Table 4.** Comparative analysis of wave velocity

Test group	Abnormal band (m)		Lithology		Wave velocity (m/s)	
	I	II	I	II	I	II
1#~2#	31~37	40~42	diabase	Mined out area	3250~3500	3260~3370
3#~4#	26~33	35~38	diabase	Mined out area	3250~3510	3510~3520
5#~6#	39~50		diabase		3250~3520	



**Figure 5.** Cross-hole sound velocity V-H curve

The test result of DPT and SPT on site in the typical rock strata is shown in Table 5.

**Table 5.** The test result of DPT&SPT

Name of rock and soil	Standard values of bearing capacity of rock and soil layer (kPa)
Plain Filling Soils ( $Q_4^{ml}$ )	80
granular soil ( $Q_3^{dpl}$ )	280
Fully weathered diabase ( $\beta \mu$ )	240
Strongly weathered diabase ( $\beta \mu$ )	320
Moderately weathered diabase ( $\beta \mu$ )	2500
weak weathered diabase ( $\beta \mu$ )	4200

Through the observation of the core of the borehole, the collapse of the mined out area has been formed with surrounding pillar. No excess gap in the grouting area, core surface and gap already been filled with injection material. The result shows that the fissures are contained and the filling effect is good. The drilling sampling rate is between 50%~80%, including a large quantity of grouting materials, which reflects the successful of the grouting procedure. Therefore, the grouting reinforcement project achieves desired effect.

## 6 Discussion and Conclusions

The study shows that the underground layout and rock formation in a mined out area is not stable enough to support new construction project. Therefore, a thorough stability analysis is carried out and following reinforcement approach is proposed. The proposed grouting reinforcement technique is first tested in similar material simulation experiment for physical and mechanical parameters. With the test results and the consideration of surface crack and collapse pit in the construction site, 7 different grouting holes with precise positions are selected. And in order to provide support for the construction site, the intermittent injection method is used; each grouting hole is injected in three different stages with filling slurry in different water to cement ratio.

It is also concluded that in mined out area, due to the hollow space from the mining operating Non-continuous deformation of the surround rock such as surface cracking and roof rock fall off will take places, especially in rainy season. This poses a threat to buildings and personal safety. Therefore, foundation reinforcement is vital for construction project directly above mined out area.

Further filed experiment, filed operation and following up drilling test shows that the proposed grouting reinforcement technique achieves expected filling and reinforcement objective. The drilling sample test results also shows that the fissures are contained and the filling reinforcement can provide sufficient and safe support for the city rail bridge project.

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