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Numerical Analysis and Experimental Study on Dynamic Construction Disturbance Effects of Deep Mine Shaft Connection Caverns

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ABSTRACT

Deep mine shaft connection caverns are most prone to deformation and fracture in its excavation and support, which poses a serious threat to production safety of coal mining enterprises and life safety of underground coal miners. To solve such problems, the paper starts from construction design source of deep mine shaft connection caverns, and considers the impact of the whole process of dynamic excavation on surrounding rock deformation of caverns. Four different construction programs are designed and numerical simulation software FLAC3D is simulated to analyze influence of different dynamic construction orders on displacement and deformation of ingate and surrounding cavern. Meanwhile, disturbance impact of dynamic construction is objectively reflected by dynamic excavation similar model test of two-dimensional deep mine shaft connection caverns. Finally, the above research results are applied to construction design of a mine site connection caverns. Site monitoring shows that steel stress after stabilization is 61.8MPa, less than 40% of design value; maximum of concrete micro-strain is 369.3με, only 18.5% of the design value; relative displacement of monitoring section is less than the value of early warning. It demonstrates that optimal dynamic construction sequence and support structure obtained in the research results are feasible, with some reference value for design and construction of deep mine shaft connection caverns.

KEYWORDS: deep mine shaft connection caverns; coal mining; dynamic construction disturbance effects; numerical simulation; similar model test

INTRODUCTION

Mine shaft connection caverns refer to ingate that connecting portion of shaft and shaft station roadway, ingate upper and lower sections, surrounding caverns and connection tunnel, such as waiting room channel, substation channel, manipulation cavern, tape transport lane, skip loading cavern and so on (Chen, 2011).Since ingate is located in the throat of the mine, the design section is large, resulting in that surrounding rock is repeatedly disturbed in the construction process, which not only affects surrounding rock stress, breakage area, surrounding displacement of caverns, but also threatens stability of shaft and connection caverns during their service (Wang, 2012). In recent years, with depletion of shallow coal resources and increase in coal consumption, mining depth of new mine is generally close to kilometers, such as Anhui Huainan Zhuji coal mine, Gansu Walnut Valley mine, Shandong Xinwen coal mine (Zhang, 2013). Because of deep burial depth, high ground pressure and complex geological conditions (Zhang, 2015; Bock, 2015) of mine shaft, absence of proper theoretical guidance and blind construction design will not only result in destruction of deep mine shaft connection caverns, but also cause casualties, bringing great economic losses and safety hazards to coal mine enterprises and underground coal miners.

In recent years, with the increase in mining depth, deep mine shaft ingate and surrounding caverns support design become a topic of great interest to scholars. A large number of research results have also been reported. M·Bill introduced that new lublin coal mine shaft, due to deep burial depth, soft surrounding rock, large ingate section and other reasons, its ingate supporting design encounters great difficulties, and it is difficult to guarantee that ingate doesn't need repair and reinforcement during the service. Ultimately, Buduokepu Mine Construction Research and Development Center devised a new steel frame ingate support structure which was successfully applied to the field engineering practice (Bill, 1992). Yee Sur Cerenkov studied rock stress distribution of mine shaft ingate with three-dimensional photoelastic model test. However, because of the smaller size of the model and the elastic medium, real situation of deep mine shaft connection cavern of weak rock can not be simulated. Thus, the research result faces greater resistance in application (Sun, 2015). Zhang Xiangdong et al. used FLAC3D numerical simulation software to numerically simulate surrounding rock structure of auxiliary shaft ingate cavern based on engineering geological conditions, rock physical properties with auxiliary shaft ingate cavern of Inner Mongolia Hongqinghe coal mine as the study object. At the same time, surrounding rock convergence deformation of ingate cavern is monitored, and based on the above research results, optimal reinforcement design is done for initial support structure of ingate cavern (Zhang, 2016). Given the situation that new auxiliary shaft ingate of Huaibei Haizi coal mine is of one thousand meters depth with large section size and very broken rock, etc., Cai Haibin used ABAQUS finite element numerical software for ingate surrounding rock stability analysis under original support design program, studied distribution rule of ingate surrounding rock displacement field, stress field and plastic zone as well as stress characteristics of support structure, and accordingly conducted optimization design of ingate support structure. Site monitoring shows that optimized ingate support structural safety stock is relatively high and the design proposal is reasonable (Cai, 2015). In order to prevent damage to second auxiliary shaft deep mine ingate of Panyi mine with soft rock and poor stability under complex conditions, on the basis of analyzing stress mechanism, Yao Zhishi et al. proposed application of single cone shaft crib and SFRC50 steel fiber reinforced concrete with good mechanical properties in wall structure of upper port at ingate (Yao, 2009). Zhai Gaofeng studied repair technology for ingate with especially big section in weak broken coal shale combination, proposed the general idea for support of ingate caverns with especially big section, introduced characteristics of deep - shallow hole grouting surrounding rock, and explored advantages of integrated control system from support from, coordinated control, etc. (Zhai, 2014). Targeting at deeply buried composite soft jointed rock with high stress and expansion of damage section of auxiliary shaft ingate of Jiaozuo Zhaogu second mine, and according to the geological conditions and destruction, Xu Yu et al. analyzed ingate mechanism of deformation and damage, developed the repair and treatment program which was successfully applied to the construction site (Xu, 2012). Aiming at that kilometers deep shaft ingate surrounding rock is repeatedly subjected to construction disturbance, stress concentration is severe, ingate cavern surrounding rock instability may occur at any time, Xu Tao carried out ingate monitoring of convergence and deformation of surrounding rock, and conducted optimized reinforcement design of ingate support structure based on deformation monitoring results of surrounding rock (Xu, 2014).

Former research results reveal that stability of deep mine shaft ingate and connection caverns is essential for safe production of coal mine enterprises (Li, 2010; Liu, 2015). It is also found that current research is mainly aimed at support technology of particular complex structure of ingate, which focuses on repair technique and optimization after failure of support structure, or research on surrounding rock deformation properties and stability control of single cavern of deep shaft caverns, failing to include upper and lower shaft of ingate and surrounding small caverns in the study (Wang, 2015; Meng, 2013). As construction of shaft connection caverns is an ongoing dynamic systematic engineering, staged excavation and construction of ingate and excavation and construction of other caverns or roadway in ingate sidewall are a complex process of loading and unloading of different parts of rock mass. For nonlinear rock, it means that stress way and stress history acting on various parts of surrounding rock differ, which will have a serious impact on surrounding rock stability of deep mine shaft connection caverns. Therefore, the author believes that study of stability of ingate and surrounding caverns can not be regarded as an independent static problem, but a dynamic system consisting of mine shaft, ingate and its associated caverns, which not only need take into account influence of natural geological conditions, but also impact of human factors in the construction process, such as impact of cavern construction sequence on surrounding rock stability of shaft connection caverns. Based on the above analysis, this paper designs different dynamic construction programs by numerical calculation method, analyzes mechanical properties and deformation characteristics of deep shaft ingate and caverns, while supplementing numerical simulation with two-dimensional similar simulation experiment, to intuitively reflect disturbance effects of deep mine shaft connection caverns under dynamic construction.

DYNAMIC NUMERICAL SIMULATION OF DEEP SHAFT INGATE AND ITS CONNECTION CAVERNS

Model establishment

Because of the complexity of the ingate structure, first use finite element software ANSYS to establish three-dimensional model, and then import FLAC3D for calculation (Zhang, 2015; Walton, 2015). It is worthy of note that as this paper mainly considers the impact of different excavation sequence of shaft, cavern and roadway on stability of underground caverns surrounding rock, structure surface is left out; In addition, the numerical simulation only studies early dynamic change rule of ingate, and therefore post-excavated cavern is left out.

The model takes 19.6m vertically downward shaft bottom centerline as origin of coordinates, straight up as Z-axis positive direction, western ingate along the X-axis negative direction, eastern ingate along the X-axis positive direction, due north direction as Y-axis negative direction, and the model is symmetric to surface XOZ. The model is divided into 100,252 units and 99,291 nodes. Wherein, western ingate is 15m long, roadway is 45m long, eastern ingate is

13m long, roadway is 27m long. Two caverns are set at 8m of western side of shaft and 15m of eastern side of shaft, respectively named as M and N cavern. Taking into account dynamic influence range of deep shaft connection caverns, the model boundary is set outside 5 times of the radius of caverns, with model structure shown in Figure 1. The selected fine sandstone's elastic modulus is 11.3GP, Poisson's ratio is 0.25, and density is 2550kg / m3. Meanwhile, apply Mohr-Coulomb constitutive relation for calculation (Bejarbaneh, 2015; Lee, 2012).

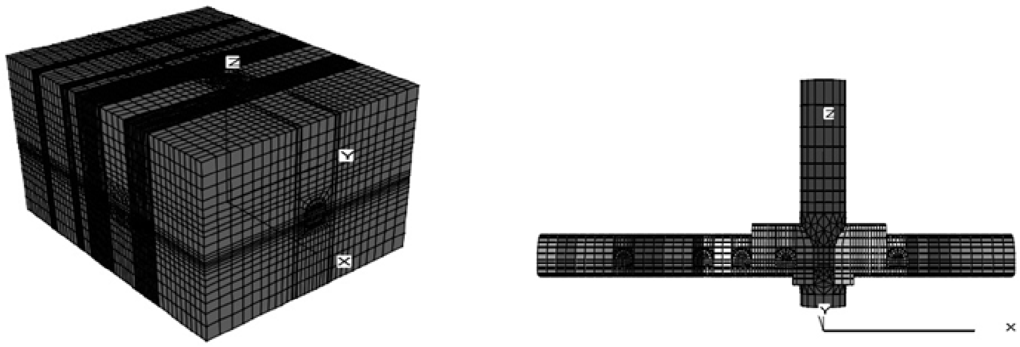

(a) (b)

Figure 1: Numerical simulation model. **(a)** Entire model; **(b)** Partial model

Combining the study objective, namely to clarify disturbance effect on deep shaft ingate and connection caverns in dynamic construction process, a variety of construction solutions are designed, different excavation and support sequences are selected for comparison. Wherein, ingate and connection caverns support structure applies first support, shaft applies secondary support. Difference of various programs is mainly reflected in difference in follow-up related construction sequence after excavation and support stability of upper section shaft of ingate, with specific programs as follows. Program 1, after excavation and support stability of upper section shaft of ingate, simultaneously conduct stepwise excavation of ingate and roadway in the east and west, apply first support→excavate roadway→simultaneously excavate two caverns at the south and north and apply first support→ excavate lower shaft of ingate and apply lining; program 2, after excavation and support stability of upper section shaft of ingate, simultaneously conduct stepwise excavation of ingate and roadway in the east and west, apply first support→excavate to cavern position→excavate two caverns at the south and north of the location and apply first support→continue to excavate support structure of ingate and roadway→excavate lower shaft of ingate and apply lining; program 3, simultaneously excavate upper and lower sections of ingate and apply lining→simultaneously conduct stepwise excavation of ingate and roadway in the east and west, apply first support→excavate roadway→simultaneously excavate two caverns at the south and north and apply first support; program 4, simultaneously excavate upper and lower sections of ingate and apply lining→simultaneously conduct stepwise excavation of ingate and roadway in the east and west, apply first support→ excavate to cavern location→excavate two caverns at the south and north of the location and apply first support→continue to excavate support structure of ingate and roadway.

As can be seen from Figure 2, the maximum principal stress of ingate support structure occurs in connecting position of arch ring and vertical way, corner at both wall ends, which constitute the stress concentration area. Secondly, the maximum horizontal stress is 19.58MPa, the maximum vertical stress is 14.51MPa, the maximum principal stress is 22.86MPa.

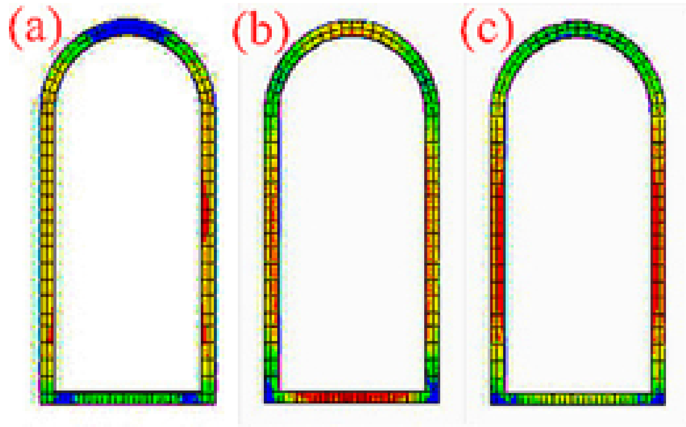


Figure 2: Ingate support structure stress diagram. **(a)** Horizontal stress; **(b)** Vertical stress; **(c)** Maximum principal stress

Figure 3 shows that general trend of ingate surrounding rock displacement is crown settlement, with side wall at both sides open, arch bottom moving upward, while surrounding rock forming a "V" shaped groove at crown portion. Range of influence of ingate excavation on surrounding rock displacement level is about twice of cavern width, while range of influence of ingate excavation on surrounding rock vertical displacement is one time of cavern width. Combining the above stress analysis results, in general, the selected numerical calculation model is reliable, and calculation meets the requirements.

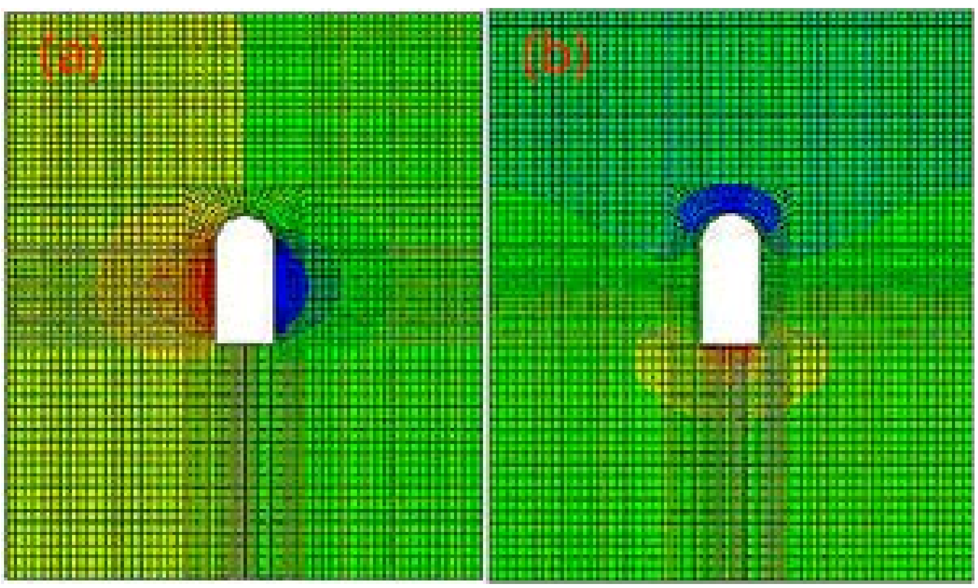


Figure 3: Surrounding rock displacement at the west side of ingate supporting structure. **(a)** Horizontal displacement; **(b)** Vertical displacement

Comparison of various construction programs

Effect of dynamic construction on ingate deformation

Conduct simulation calculation according to the above described four different construction programs, with results shown in Table 1.

Table 1: Effect of dynamic construction on ingate displacement

Monitoring section	Monitoring location	Study object	Program 1	Program 2	Program 3	Program 4
West side of ingate section	Top	M cavern	4.72mm	2.87mm	4.7mm	2.84mm
		Total displacement	56.65mm	56.74mm	56.55mm	56.64mm
	Bottom	M cavern	4.68mm	2.34mm	4.67mm	2.38mm
		Total displacement	88.92mm	89.88mm	89.11mm	90.19mm
East side of ingate section	Top	N cavern	2.94mm	1.66mm	2.18mm	1.67mm
		Total displacement	46.07mm	46.60mm	45.90mm	46.43mm
	Bottom	N cavern	4.70mm	1.26mm	3.90mm	1.25mm
		Total displacement	81.58mm	82.87mm	77.76mm	78.90mm

In study object column of Table 1, M cavern/N cavern respectively refers to displacement change of M cavern/N cavern corresponding to ingate section at east and west before and after excavation and support, the total displacement refers to displacement change of ingate section at east and west after excavation of M cavern and N cavern. Comparison of top sink and bottom upward displacement of ingate at east and west reveals that program 1 is larger than program 2, program 3 is larger than program 4, indicating that program 2 and program 4 are advantageous for overall ingate deformation in timely excavation of ingate and roadway in early excavation process. But seen from overall amount of displacement of ingate at both sides, program 1 and 3 are slightly less than program 2 and program 4. Thus, early excavation of cavern may not be conducive to stability of deep shaft connection caverns system.

Effect of successive cavern excavation on cavern deformation

As shown in Table 2, in program 3, cavern is excavated after ingate excavation and roadway excavation and support, but in program 4, cavern is excavated during excavation of ingate and roadway. Comparison reveals that displacement before and after excavation and support of two caverns in program 4 is 3-4mm smaller than that in program 3, particularly N cavern, of which difference in bottom upward displacement of the two programs is 9.38mm. It can thus be seen that impact of dynamic construction process on cavern in program 4 is smaller than that in program 3. However, the overall displacement of program 4 is 1-2mm larger than that of program 3. See from overall caverns, program 3 is slightly superior to program 4. Total displacement data in the table is above 30mm, with part over 65mm. Displacement is relatively large. Thus, dynamic process of cavern has a greater disturbance on deep shaft connection caverns system.

Table 2: Effect of dynamic construction on cavern displacement

Monitoring cavern	Monitoring location	Dynamic process	Program 3	Program 4
M cavern	Top	Before and after excavation	25.93mm	22.32mm
		Total displacement	34.20mm	34.71mm
	Bottom	Before and after excavation	27.18mm	24.41mm
		Total displacement	33.13mm	35.45mm
N cavern	Top	Before and after excavation	25.23mm	21.12mm
		Total displacement	41.84mm	42.19mm
	Bottom	Before and after excavation	62.66mm	53.28mm
		Total displacement	66.76mm	67.87mm

Effect of successive excavation of lower shaft of ingate on wall deformation

As shown in Table 3, difference of the two programs: in Program 1, excavation and support of lower shaft of ingate occur after excavation and support of ingate, roadway and cavern, but in program 3, excavation and support of lower shaft is done after support of upper shaft of ingate. Comparison reveals that displacement amount before and after dynamic construction of northern side wall of lower shaft in program 3 and total displacement amount of caverns are less than those in program 1, which demonstrates that prior excavation of lower shaft of ingate exerts relatively little disturbance on deep shaft caverns system.

Table 3: Effect of dynamic construction on lower shaft of ingate wall displacement

Monitoring object	Monitoring location	Dynamic process	Program 1	Program 3
Lower Shaft of Ingate	North side of shaft wall	Before and after excavation	7.67mm	4.95mm
		Total displacement	12.37mm	11.52mm

The above analysis reveals that excavation and support of cavern exert a greater impact on ingate section and caverns, excavation sequence of cavern directly affects stability of deep shaft caverns system. Macro effects of successive excavation of cavern on ingate are substantially similar, but prior excavation of cavern exerts smaller disturbance on ingate section, with relative ease displacement change; while later excavation of cavern exerts larger disturbance on ingate section, with rapid displacement changes, which will bring great difficulty for construction. In deep shaft caverns, construction sequence of lower shaft of ingate has greater difference in effect on side wall. In the whole process of dynamic construction, for later excavation of lower shaft of ingate, wall displacement is large, displacement rate is also fast, which will bring adverse effect on actual construction process.

DYNAMIC TWO-DIMENSIONAL PHYSICAL MODEL TEST OF DEEP SHAFT CAVERNS

In order to intuitively reflect disturbance of deep shaft connection caverns under dynamic construction, now two-dimensional similar physical model test method is adopted for excavation of lower shaft (Li, 2011), ingate and roadway of longitudinal section of auxiliary shaft of a coal mine. The visual, intuitive way is used to seek general characteristics and laws of deep shaft caverns system in the dynamic process, especially stress and displacement changes of upper surrounding rock of ingate in excavation of ingate.

Experimental model is determined based on actual size of auxiliary shaft, rock and shaft parameters, and construction work of a coal mine (Zhang, 2010), with specific parameters shown in the following Table 4.

Table 4: Model material parameters

Object	Size /m	Volume weight /g·cm^{-3}	Strength /MPa	Load /MPa	Construction progressm/d
Engineering example	240×24×96	2.55	82.3	18.52	2
Similar model	3×0.3×1.2	1.5	0.61	0.14	0.2232

Model material ratio and mechanical properties of similar simulation test is shown in the following Table 5. Test shows that strength of this kind of material coincides with strength of calculation material.

Table 5: Ratio of similar materials and mechanical properties

Sand proportion	Lime proportion	Gypsum proportion	Water proportion	σ_c	σ_t
80.81%	3.03%	7.07%	9.09%	0.614	0.553

Drying time of the above proportional material is 7 days, moisture control after drying is controlled within 2%, with unit weight at about 1.5g/cm3. Similar simulation experimental model independently developed by our school is used to make experimental model (Gao, 2007). Measure required amount of materials in accordance with Table 5 before the start of the test, pour sand, gypsum, lime into a blender and stir evenly, then add predetermined amount of water and stir about 5 minutes. Then pour the mixed material into a mould and tamp to achieve the requirement for experimental material strength. Then pour it to the predetermined position, and bury in a pressure cell. The model needs to set aside shaft, and shaft model should be embedded in a predetermined position (Sumitra, 2013). During pouring process, intermittently throw in mica powder as soft surface to enhance the compression effect of the model. After pouring process of model, dry for 24 hours, remove constraint channel steel at both sides, wait for the model to dry for more than 7 days, restore channel steel at both sides before the experiment. Experimental model is shown in the Figure 4.

(a) (b)

Figure 4: Model making. **(a)** Pre-reserved shaft; **(b)** Whole model

Wherein, load applies hydraulic jack pressure with the pressure kept. Set 4 monitoring sections at each side of shaft for monitoring, with four monitoring sections of western ingate and roadway 140mm, 260mm, 360mm and 460mm away from ingate, while four monitoring sections of eastern ingate and roadway 120, 90 , 360 and 460mm away from ingate. Wherein, pressure cell on roadway and ingate faces upward to monitor the pressure at the top of the roadway; the lower pressure cell faces downward to monitor floor heave pressure of roadway; pressure cell on the side faces inward to monitor lateral pressure. Arrangement position of pressure cell is shown in Figure 5.

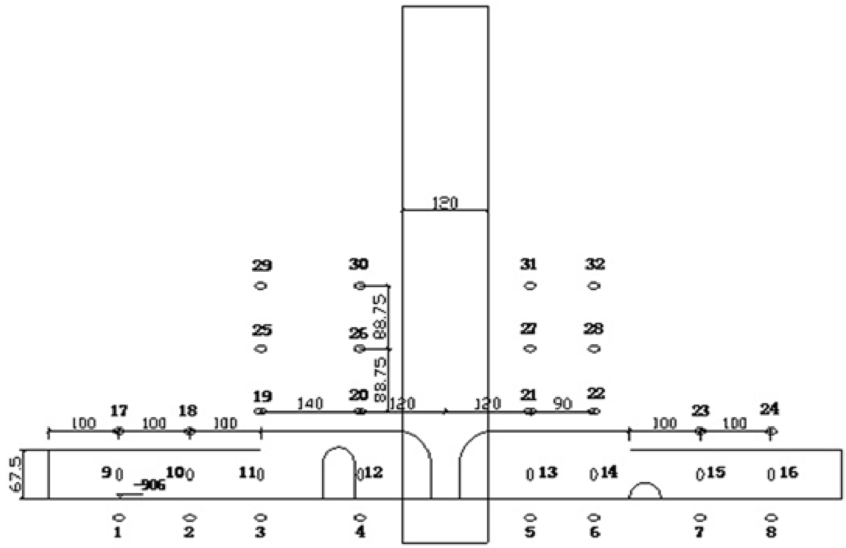


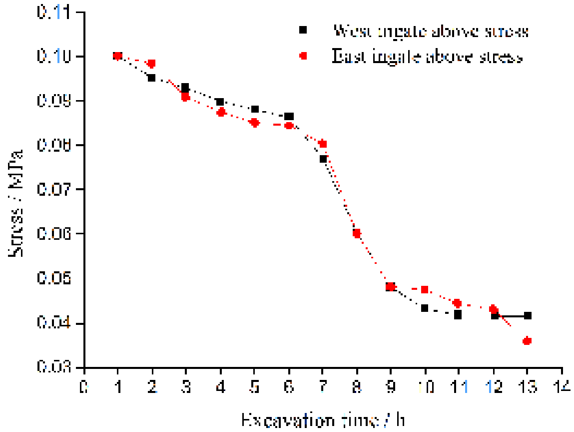
Figure 5: Arrangement position of pressure cell

In the experiment, reserved shaft scheme is adopted, which means it is in initial state before excavation of ingate. The test follows according to similar quasi-experimental time steps, which excavates nearly 1cm per hour and makes timely measurement, and conducts intensive measurement at excavation of key parts. Pre-process and test results are shown in Figure 6.

(a) (b)

Figure 6: Model of excavation schemes. **(a)** Prior process of experiment; **(b)** Later process of experiment

Conduct stress analysis on several key points on upper part of ingate at east and west, to study stress displacement change rule in the process of excavation and unloading, with stress variation as shown in Figure 7 and displacement change shown in Figure 8.



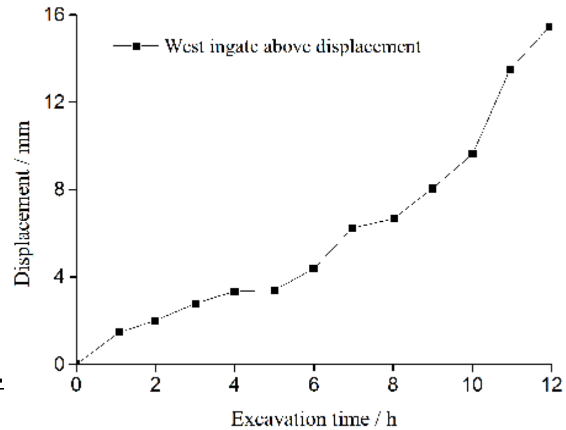


Figure 7: Ingate above the stress curve **Figure 8:** Ingate above the displacement curve

A comparison of stress curve of upper part of ingate at east and west reveals that pressure change rule of the two is substantially the same. The initial stress is 0.1MPa, at the beginning of the excavation, i.e. the first 6 hours, stress release is slow. By excavation of lower ingate of No.20 pressure cell, upper pressure releases fast, dropping by about 0.04MPa and then gradually tending to balance, which is consistent with the actual working condition. Due to data missing during the test of eastern side ingate, displacement map of upper western ingate in the model reveals that ingate experiences change process from steady development to sharp decline.

This two-dimensional physical similar model experiment conducts relatively accurate sinking simulation of the top of deep mine shaft ingate in excavation process, which reflects that disturbance on surrounding rock during excavation of deep shaft ingate causes upper stress relief and sharp sinking phenomenon. As there is no simulated support structure in this experiment, collapse is inevitable. In addition, external bulge of two-dimensional model experiment is also an unfavorable factor for collapse, which is likely to be well controlled in three-dimensional experiment.

CONSTRUCTION SCHEME DESIGN AND MONITORING OF ENGINEERING SITE

By comparative analysis of different simulated construction schemes, as well as supplement of numerical simulation with two-dimensional similar model test, disturbances of deep shaft caverns system under dynamic action are visually and intuitively reflected. To this end, the above research results are applied to construction design of ingate and connection caverns of a coal mine. Comparison reveals that program 4 in numerical simulation achieves the best effect. Therefore, site construction of auxiliary shaft ingate and connection caverns of a coal mine is conducted in accordance with dynamic process in program 4, with joint support forms of primary rockbolt mesh shotcrete support and secondary cast-in-place reinforced concrete support for ingate and caverns, with specific parameters as follows: anchor rod: $\Phi 22 \times 2500$mm, inter-row spacion 800×800mm, plum-shaped layout; anchor cable applies $\Phi 17.8$mm steel stand, design length 8.0m, row spacing 2.0m, with preload not less than 100KN, and foot bolt set at straight wall feet of roadway within certain range (eastern ingate 48m, western ingate 23m) at both ends; anchor rod is designed as high strength anchor rod with 22mm diameter, 3.0m length, 800mm row spacing and horizontal angle of 30 °. A combination of deep and shallow bore is used for grouting reinforcement of surrounding rock of ingate support. After rockbolt mesh shotcrete support of ingate within subsection, secondary support can be done, with concrete strength grade at C50. Following the above-described construction scheme and support design, site monitoring of ingate structure can be done. The monitoring content involves lining structure reinforcement stress and concrete strain measurement of ingate of auxiliary shaft, as well as lining structure displacement of ingate at east and west sides, with section arrangement and monitoring points as shown in Figure 9-10. B section is arranged with three measuring points, with a reinforcement meter and concrete strain meter for each point. C section is arranged with three vertical and two tangential concrete strain meters.

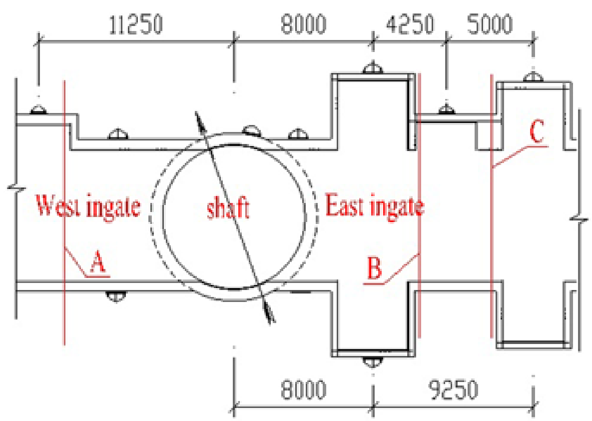


Figure 9: Site monitoring section layout

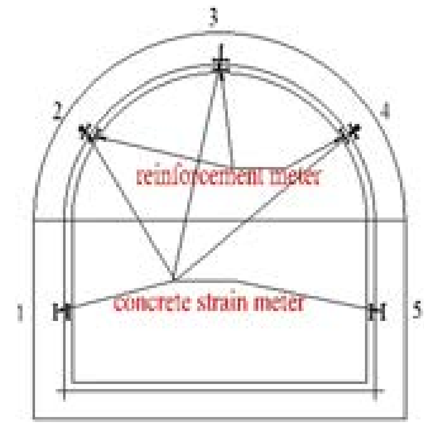


Figure 10: Monitoring points layout

Due to the complex construction site environment and poor protection, testing cable is cut. After remediation, most B section is repaired, while A and C section only has one remaining valid position. Therefore, this paper only analyzes B section monitoring results, as shown in Figure 11-12. Reinforcement stress of reinforcement meter of existing monitoring orientation is 61.8MPa, less than40% of the design value; maximum of concrete micro-strain is 369.3με, design value is 2000με, so micro-strain maximum is only 18.5% of the design value. Currently, strain - time curve tends to flatten, indicating that construction scheme and support design plan at the site are feasible, which is beneficial for stability of deep shaft connection caverns system.

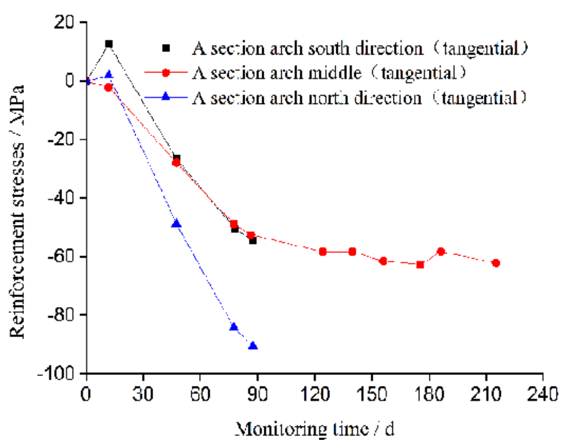


Figure 11: B section of steel stress

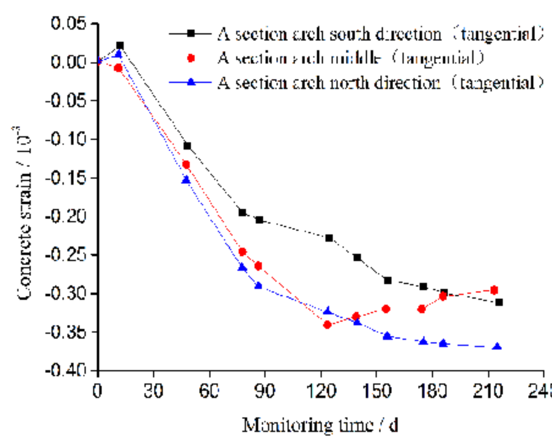


Figure 12: B section of concrete micro-strain

Lining structure deformation and convergence of ingate at east and west are shown in Figure 13-14, which indicates that arch convergence displacement of ingate lining structure is greater than that of other parts, and relative displacement of each section is less than the value of early warning. The relative displacement of different measuring points of ingate lining structure changes with the fastest rate within three months after pouring. During the grouting, the relative displacement appears abrupt increase, and then gradually stabilizes. It indicates that ingate support structure limits further deformation and fracture of broken rock with its own stiffness and strength, surrounding rock and support structure forms joint action, with support structure stabilized.

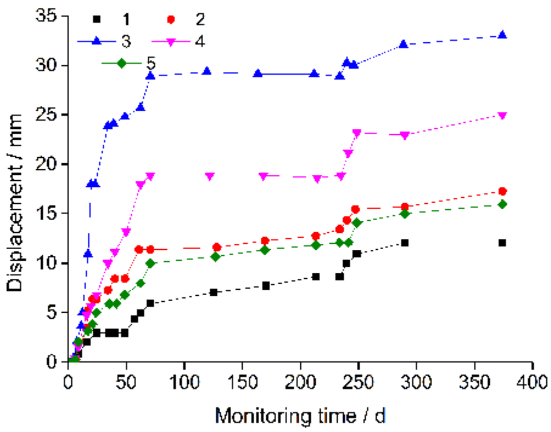


Figure 13: A cross-sectional deformation displacement

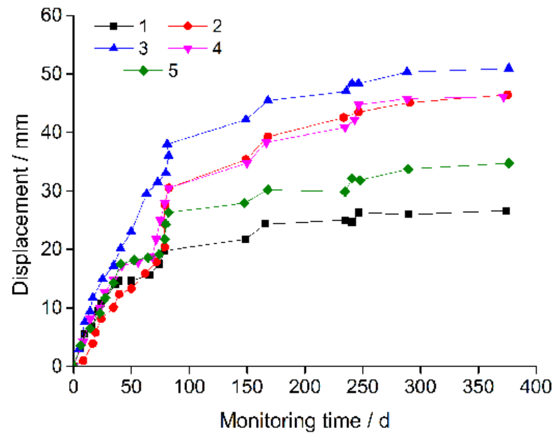


Figure 14: B cross-sectional deformation displacement

CONCLUSION

Deep mine shaft connection caverns structure is with complex stress, and different dynamic construction process have different effects. (1) Numerical simulation is used to design and calculate convergence deformation of caverns under four different dynamic construction programs, and disturbance effect of different dynamic construction programs on caverns surrounding rock deformation is learned. Successive excavation of cavern has little overall impact on ingate surrounding rock, but in the process of excavation, there is relatively large difference in influence on ingate and cavern; excavation of cavern during excavation of ingate can play a role in advance unloading of ingate; during initial excavation, sinkage of ingate sectional top and upward expansion of bottom are relatively small, but cavern excavation after excavation and support of ingate and roadway will cause a sharp convergence of cavern and ingate section, which is likely to cause accidents in the real construction process; excavation of support shaft before and after excavation of ingate and roadway have substantially the same overall effect on shaft side wall; but in the course of shaft excavation, displacement caused by later shaft excavation is greater than that caused by prior shaft excavation. (2) By combining similar model experiment, ingate top sinking phenomenon caused by unloading is visually and intuitively reflected. The test data is close to law obtained with numerical simulation and field test data, so the method can serve as effective way to study sinking law of ingate top. (3) By applying optimal dynamic construction program 4 obtained in numerical calculation to a mine site engineering practice, significant practical project benefit is achieved. The final monitoring results show that caverns are in safe construction state. In this paper, mine shaft, ingate and surrounding caverns are regarded as a dynamic system to study disturbance effect on surrounding rock under dynamic construction environment. The research results can provide guidance for overall construction design of future deep shaft connection caverns.

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Editor's note.
This paper may be referred to, in other articles, as:

Wei Jing, Chuanxin Rong, Xiang Li, and Hua Cheng: Numerical Analysis and Experimental Study on Dynamic Construction Disturbance Effects of Deep Mine Shaft Connection Caverns" *Electronic Journal of Geotechnical Engineering*, 2017 (22.01), pp 233-246. Available at ejge.com.