Segmented enlarged-diameter borehole destressing mechanism and its influence on anchorage support system

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Abstract

Large-diameter borehole destressing technology is one of the main technical measures for the prevention and control of coal mine rock burst. In engineering practice, there is generally a contradicting problem due to the presence of excess destressing which damages support system and insufficient destressing which results in high stress hardly transfer. In this paper, the mechanism of large-diameter borehole destressing technology and its influence on anchorage support were simulated and analyzed. Based on this, a segmented enlarged-diameter borehole destressing technology was proposed. The destressing effect at deep part and anchorage strength changing at shallow part of the coal rib were studied under different borehole parameters. Numerical simulation results show that the destressing effect increases with the increase of the borehole diameter, while borehole with oversize diameter increases the deformation of the roadway and weakens the strength of the anchorage support. The diameter-enlarging point in segmented enlarged-diameter borehole destressing technology is best placed between the anchorage end and the vertical stress peak point. The anchorage strength is inversely correlated with the diameter of the small-diameter section, and the destressing effect is positively correlated with the diameter of the large-diameter section. Based on its advantages in destressing, the segmented enlarged-diameter boreholes and anchorage support are applied together, and a system of destressing-support cooperative control of rock burst is presented. The roles in rock burst control of "zone of strong anchorage support" and "zone of low stress and energy dissipation" are described.

KEYWORDS
anchorage support, borehole parameters, large-diameter borehole destressing, segmented enlarged-diameter borehole destressing, vertical stress
INTRODUCTION

After the coal resources enter deep mining, the surrounding rock of the roadway is exposed to high stress, high temperature, and high osmotic pressure. In addition, with the influence of the strong dynamic disturbance generated during the coal mining, rock burst happens frequently, which is a main dynamic disaster that seriously restricts the safety and efficiency of deep coal resource mining.

As a means to prevent and control rock burst in deep coal mines, many scholars have extensively researched the main factors affecting the rock burst, including the physical properties, stress distribution, and support strength. It is difficult to effectively prevent rock burst only by increasing support strength. Therefore, adjustment in the stress distribution of the surrounding rock has become an effective way to maintain the stability of the roadway. The theory of stress transfer has received extensive attention as an important point in rock burst prevention and control. At present, the common rock burst local prevention technology based on the theory of stress transfer includes large-diameter borehole destressing technology, blasting destressing technology and coal seam water infusion technology. Among them, large-diameter borehole destressing technology has been widely used because of its advantages such as construction convenience and low cost. Many scholars have also studied the principle and influencing factors of large-diameter borehole destressing technology.

In theoretical research, Li et al. analyzed the elastoplastic state of a circular borehole in elastic-strain softening coal seams. Tambovtsev has developed an approximate analytical model to find energy input required to initiate main crack depending on diameter of drillholes. In terms of laboratory testing, Zhao et al. studied the influences of drilling arrangements on the mechanical behavior of models. Geng et al. determined the boring diameters of a two-stage TBM cutterhead to prevent rock burst. In field research, Zhang et al. investigated effective pressure relief drilling for reducing rock bursts. The above research indicates that the essence of roadway stress transfer is the artificial reduction and change in the distribution of the mining-induced stress. These changes result in vertical stress reduction at the shallow part of the coal rib and transferring the high stress into the deep part to maintain the long-term roadway stability.

Many scholars have made certain achievements in large-diameter borehole destressing technology research, of which a certain application system has initially been formed. However, because of the complicated geology and engineering conditions, accurate technical parameters of large-diameter borehole destressing are difficult to determine. There is generally a contradicting problem due to the presence of excess destressing which results in high stress hardly transfer in some rock burst prevention applications.

This paper first analyzed the effect of large-diameter borehole on the destressing effect and support system of the surrounding rock. Then segmented enlarged-diameter borehole destressing technology was proposed, and the influence of its key parameters on the destressing effect was analyzed. This paper may provide a theoretical basis for the destressing-support interaction design for rock burst prevention in deep mine roadway.

DESTRESSING MECHANISM OF LARGE-DIAMETER BOREHOLE AND ITS INFLUENCE ON ANCHORAGE SUPPORT

The borehole diameter is one of the key technical parameters that determine the degree of destressing level for large-diameter boreholes and is the basis for determining the spacing between boreholes. A numerical simulation method was used to analyze the influence of different borehole diameters on the vertical stress in the coal rib and anchorage strength of the roadway.

2.1 Different diameter borehole destressing simulation scheme

This study quantitatively examined the influence of borehole destressing on the vertical stress and anchorage support system in a 1000-m-depth roadway by using FLAC3D...
software. The simulation model is shown in Figure 1. The model's size was 60 m × 5 m × 60 m. In addition, stress boundary condition was applied on the upper of the model with a load of 25 MPa, and the lateral pressure coefficient was set as 0.8 on the front and behind. The model was fixed at the bottom, and roller boundaries were applied at the lateral surface. The Mohr Coulomb model embedded in FLAC was used for simulating the roof and floor rocks’ mechanical behaviors, and the parameters are listed in Table 1.33 The strain softening model embedded in FLAC was used for simulating the coal’s mechanical behavior, and the parameters were obtained via back analysis. Basic mechanical parameters of coal specimens from Tangkou Coal Mine were tested in laboratory. A uniaxial compression specimen model was built, and its postpeak stress-strain curve was compared with the laboratory test. Using trial-and-error modeling, the strain softening model’s input parameters were obtained, as listed in Table 2.

The roadway cross section size was 4 m × 5 m. A pile element was selected to simulate the bolt with 3 m length, and full-length anchorage was chosen, the parameters are listed in Table 3.34 The row-line space of the bolts in the coal rib and roof were set to be 0.9 × 1.2 m and 0.7 × 1.2 m, respectively.

Large-diameter boreholes were drilled after the roadway excavated and surrounding rocks anchored. The depth of the boreholes was set to be 20 and 2 m above the floor. Boreholes were arranged in a single row along the axial direction of the roadway.

The diameter was designed for ten schemes, which were 40, 80, 120, 160, 200, 240, 280, 320, 360, and 400 mm. The vertical stress distribution and deformation of coal rib were monitored, and the stress monitoring points were 2 m above the borehole.

2.2 | Influence of the borehole diameter on the destressing effect

The relation curves between the vertical stress in the coal rib and the borehole diameters are shown in Figure 2. The peak stress (38 MPa) point of the coal rib was 5.4 m far from the coal wall. The vertical stress distribution of the coal rib was different due to the different borehole diameters. When the borehole diameter was smaller than 160 mm, the vertical stress before the original peak point (only 1.2 m away) was decreased by a little value. The decreased stress transferred into the nearby deeper area, and the peak value increased slightly (smaller than 0.5 MPa). But the stress changing was little, and destressing effect was not obvious. When the borehole diameter reached 200 mm, the peak stress point transferred obviously. The value of the peak stress was decreased by 34.4%, and the destressing range was 5-10 m from the coal wall. When the borehole diameter larger than 240 mm, the peak stress point moved to the location where was 20 m further from the coal wall. The borehole exhibited destressing effect within the entire borehole length, and the stress at the original peak point was decreased by 60.6%. The degree of destressing increased with the increasing of the borehole diameter.

The relation curve between the coal rib deformation and the borehole diameters is shown in Figure 3. The coal rib deformation increased with the increasing of the borehole diameter. The deformation value was increased by 46.6% when borehole diameter was 320 mm, comparing with no borehole. Based on the above analysis, destressing effect can be improved by increasing borehole diameter, while coal rib deformation increased too.
Influence of the borehole diameter on the anchorage support

The relation curve between the effective confining stress on bolt and the borehole diameter is shown in Figure 4. The effective confining stress on bolt is the average value of the normal stress of the surrounding rock applying on the bolt. Generally, lower the effective confining stress, lower the shear strength at the anchorage interface, that is, lower the anchorage strength of the support system. The effective confining stress on bolt was >5.3 MPa and decreased linearly and slowly when the borehole diameter was <280 mm. When the borehole diameter was larger than 320 mm, the effective confining stress decreased deeply to 3.2 MPa, which resulted in easier anchorage failure.

The relation curves between the bolt axial force and the borehole diameters are shown in Figure 5. The axial force along the bolt first increased and then decreased. When the borehole diameter was smaller than 240 mm, the axial force changed from 7 to 12 kN along the bolt. With increasing of the borehole diameter, the axial force distribution curve's curvature increases, and the difference between the peak and low point value increased. When the borehole diameter was 400 mm, the maximum value of the axial force was 2.2 times of the minimum value. Existing literatures indicate that for the same anchorage structure, higher the axial force of the bolt, lower the redundant anchorage strength, and easier damage when the external load increases. Therefore, with increasing of the borehole diameter, the subsequent supporting capacity of the bolt decreased.

### TABLE 3 Parameters of the bolt simulated in the model

| Young’s modulus/GPa | Poisson ratio | Cross-section area/m² | Perimeter/m | Tensile-yield/N | Moi-y/m⁴ | Moi-z/m⁴ | Moi-polar/m⁴ | Coupling-cohesion/(N/m) |
|---------------------|--------------|-----------------------|------------|----------------|-----------|-----------|-------------|------------------------|
| 200                 | 0.2          | 3.8e-4                | 0.0942     | 2.47e-5        | 1.15e-8   | 1.15e-8   | 2.3e-8      | 4.37e5                 |

**FIGURE 2** Relation curves between the vertical stress in the coal rib and the borehole diameters

**FIGURE 3** Relation curves between the coal rib deformation and the borehole diameters

**FIGURE 4** Relation curve between the effective confining stress on bolt and the borehole diameters
In the radial cross section of the borehole, there is a destressing annular area, including the fracture zone and the plastic zone. Larger borehole diameter results in larger destressing area and meanwhile provides a larger bulking and energy release space for the surrounding rock under high stress.

When multiple boreholes’ destressing annular area connected, a destressing through zone forms in the coal rib along the roadway, and the high stress region transfers into deeper part, as shown in Figure 6A. Sufficient destressing effect can be guaranteed. But on the other hand, when the destressing through zone extends to the anchorage zone, rocks around the bolt’s anchorage section may be excessively damaged, as shown in Figure 6B. Surrounding rock’s confining force on the bolt will decrease, and anchorage strength decreases accordingly. More seriously, the supporting structure of the roadway may lose efficacy easily under dynamic load.

3 | DESTRESSING EFFECT OF SEGMENTED ENLARGED-DIAMETER BOREHOLE DESTRESSING TECHNOLOGY

3.1 | Technical introduction

According to the analysis of the influence of borehole diameter on the destressing effect and anchorage support, it can be concluded that with increasing of the borehole diameter, the destressing effect of the roadway increases, while the strength of the anchorage support decreases. In roadway design, the anchorage zone is the shallow part of the coal rib, where the stress is low, and destressing is not need. The high stress zone is deeper than the anchorage zone generally, and measures need to be taken to reduce the stress. According to the stress distribution and anchorage position of the coal rib, a segmented enlarged-diameter borehole destressing technology is proposed, which is to drill a small-diameter borehole in the shallow part of the coal rib, and drill a large-diameter borehole in the deep part, as shown in Figure 7.
The key parameters of segmented enlarged-diameter borehole destressing technology include the length ratio of segmented sections, the diameter of the small-diameter section, and the diameter of the large-diameter section. The length ratio of segmented sections is length ratio of the small-diameter section to the large-diameter section, and the point between these two sections is defined as diameter-enlarging point. The influences of these three key parameters on the destressing effect and anchorage support were analyzed by using the same numerical model presented in Section 2.1.

In scheme 1, the diameters of the small-diameter section and large-diameter section were set as 120 and 320 mm. The total length of the borehole was 20 m, and the length ratios of segmented sections were designed for six values, as listed in Table 4.

In scheme 2, the length ratio of segmented sections was set as 5:15, and the total length was 20 m. The diameter of the large-diameter section was set as 320 mm, and the diameters of the small-diameter section were designed for six values, as listed in Table 5.

In scheme 3, the length value was same as scheme. The diameter of the small-diameter section was set as 120 mm, and the diameters of the large-diameter section were designed for six values, as listed in Table 5.

3.3 Simulation results

3.3.1 Influence of the length ratio of segmented sections

The relation curves between the vertical stress in the coal rib and the length ratio of segmented sections are shown in Figure 8. The peak point of the vertical stress before destressing was 5.4 m from the coal wall. When the diameter-enlarging point was located deeper than the stress peak point (ie, the length ratio was higher than 8:12 in this simulation), the
stress around the peak point changed little, though the stress in the deeper part of the coal rib decreased. When the diameter-enlarging point was located in the shallow part of the coal rib, the vertical stress decreased obviously, and the peak value is reduced by 82%. To get better destressing effect, the diameter-enlarging point should be shallower than the stress peak point.

The relation curve between the effective confining stress on bolt and the length ratio is shown in Figure 9. When the length ratio was 4:16 (ie, the diameter-enlarging point was 1 m deeper than the anchorage end), the effective confining stress on bolt was increased by 46.35% compared with the value when length ratio was 0:20. When the length ratio was higher than 8:12, the effective confining stress on bolt was larger than 5.4 MPa and changed little. Therefore, in order to maintain the strength of the support system, the diameter of the small-diameter section should be as small as possible.

3.3.2 | **Influence of the diameter of the small-diameter section**

The relation curves between the vertical stress in the coal rib and diameters of small-diameter section are shown in Figure 10. Because the diameter-enlarging point was 0.4 m shallower than the vertical stress peak point, diameter of small-diameter section had little influence on the vertical stress.

The relation curve between the effective confining stress on bolt and diameters of small-diameter section is shown in Figure 11. With decreasing of the diameter, the effective confining stress on bolt increased. Therefore, in order to maintain the strength of the support system, the diameter of the small-diameter section should be as small as possible.

3.3.3 | **Influence of the diameter of the large-diameter section**

The relation curves between the vertical stress in the coal rib and diameters of large-diameter section are shown in Figure 12. When the diameter was larger than 200 mm, there was no obvious stress peak point, and the vertical stress within the length of the borehole was lower than 26 MPa. With increasing of the diameter, the vertical stress decreased.

The relation curve between the effective confining stress on bolt and diameters of large-diameter section is shown in Figure 13. Because the diameter-enlarging point was 2.4 m deeper than the anchorage end, diameter of large-diameter section had little influence on the anchorage support.

4 | **DISCUSSION**

Compared with large-diameter borehole destressing technology, the destressing effect of the segmented enlarged-diameter borehole destressing technology is better, and it has little influence on the anchorage support system. But its drilling operation is more complicated. A hydraulic variable-diameter bit with a pop-up blade should be used, as shown in Figure 14. At the beginning, the pop-up blade is retracted into the bit, and the small-diameter borehole...
When reaching the diameter-enlarging point, increase the hydraulic pressure, and the pop-up blade is pushed out by the water. Then, a larger diameter borehole is drilled in the deep part of the coal rib. The cutting is removed from the borehole by water washing and spiral drill rod.

Besides the diameter parameters researched in the simulation, the spacing is another important parameter in destressing borehole design. The segmented enlarged-diameter borehole can cause larger destressing zone in the deep part of the coal rib. The small-diameter section of boreholes has little damage on anchorage support system, so the anchorage support and the surrounding rock can form a reinforcement arch structure with a higher bearing strength, which is called "zone of strong anchorage support." In large-diameter section of the borehole, high stress is transferred to the deep part of the coal rib. There forms a "zone of low stress and energy dissipation" by reducing the stress and strength of the coal. This zone can effectively buffer the strong dynamic load and dissipate the impact energy caused by hard roof fall and so on Ref. 38–41.

5 | CONCLUSION

Based on the principle of borehole destressing, the paper puts forward the destressing technology of segmented enlarged-diameter borehole. The following conclusions can be drawn:

1. In large-diameter borehole destressing technology, increasing the borehole diameter can achieve a better destressing effect, while a borehole with oversize diameter will increase the deformation of the roadway, reduce...
2. The segmented enlarged-diameter borehole destressing technology is to construct small diameter boreholes in the shallow part of the coal rib and large diameter borehole in the deep part. The diameter of small-diameter section does not affect the destressing effect, while the diameter of large-diameter section has a great effect on the destressing effect. The best location of the diameter-enlarging point is between the anchorage end and the vertical stress peak point.

3. Segment enlarged-diameter boreholes and anchorage support can constitute a destressing-support cooperative system for rock burst control. The "zone of strong anchorage support" has a higher bearing strength. The "zone of low stress and energy dissipation" can effectively buffer the strong dynamic load and dissipate the impact energy.

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CONFLICT OF INTEREST
None declared.

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REFERENCES
1. Ranjith PG, Zhao J, Ju MH, De Silva RVS, Rathnaweera TD, Bandara AKMS. Opportunities and challenges in deep mining: a brief review. Engineering. 2017;3:546-551.
2. Tan YL, Fan DY, Liu XS, Song SL, Li XF, Wang HL. Numerical investigation on failure evolution of surrounding rock for super-large section chamber group in deep coal mine. Energy Sci Eng. 2019;7:3124-3146.
3. Keneti A, Sainsbury BA. Review of published rockburst events and their contributing factors. Eng Geol. 2018;246:361-373.
4. Zhao T-B, Guo W-Y, Tan Y-L, Lu C-P, Wang C-W. Case histories of rock bursts under complicated geological conditions. B Eng Geol Environ. 2018;77:1529-1545.
5. Zhao TB, Guo WY, Tan YL, Yin YC, Cai LS, Pan JF. Case studies of rock bursts under complicated geological conditions during multi-seam mining at a depth of 800 m. Rock Mech Rock Eng. 2018;51:1539-1564.
6. Guo WY, Gu QH, Tan YL, Hu SC. Case studies of rock bursts in tectonic areas with facies change. Energies. 2019:12.
7. Wang CJ, Yang SQ, Yang DD, Li XW, Jiang CL. Experimental analysis of the intensity and evolution of coal and gas outbursts. Fuel. 2018;226:252-262.
8. Chen XJ, Li LY, Wang L, Qi LL. The current situation and prevention and control countermeasures for typical dynamic disasters in kilometer-deep mines in China. Safety Sci. 2019;115:229-236.
9. Guo WY, Yu FH, Tan YL, Zhao TB. Experimental study on the failure mechanism of layer-crack structure. Energy Sci Eng. 2019;7:2351-2372.
10. Lu CP, Liu Y, Wang HY, Liu PF. Microseismic signals of double-layer hard and thick igneous strata separation and fracturing. Int J Coal Geol. 2016;160:28-41.
11. Li Y, Jiang Y, Zhang B, Song H, Dong W, Wang P. Investigation on the pore characteristics of coal specimens with bursting proneness. Sci Rep. 2019;9(1), Article number: 16518.
12. Zhu J, Zhang B, Zhang Y, Tang J, Jiang YD. Coal pore characteristics in different coal mine dynamic disasters. Arab J Geosci. 2018;11:499.
13. Wang CJ, Yang SQ, Li XW, Yang DD, Jiang CL. The correlation between dynamic phenomena of boreholes for outburst prediction and outburst risks during coal roadways driving. Fuel. 2018;231:307-316.
14. Tan YL, Gu QH, Ning JG, Liu XS, Jia ZC, Huang DM. Uniaxial compression behavior of cement mortar and its damage-constitutive model based on energy theory. Materials. 2019;12:1309.
15. Chen D, Cheng JL, Wang AM. Numerical simulation of drill-hole transient electromagnetic response in mine roadway whole space using integral equation method. Chin J Geophys-CH. 2018;61:4182-4193.
16. Zhang YB, Zhao TB, Taheri A, Tan YL, Fang K. Damage characteristics of sandstone subjected to pre-peak and post-peak cyclic loading. Acta Geodyn Geomater. 2019;16:143-150.
17. Li YY, Zhang SC, Zhang X. Classification and fractal characteristics of coal rock fragments under uniaxial cyclic loading conditions. Arab J Geosci. 2018;11:201.
18. Hu SC, Tan YL, Zhou H, et al. Anisotropic modeling of layered rocks incorporating planes of weakness and volumetric stress. Energy Syst. 2020;8:789-803.
19. Wang J, Ning JG, Qiu PQ, Yang S, Shang HF. Microseismic monitoring and its precursory parameter of hard roof collapse in longwall faces: a case study. Geomech Eng. 2019;17:375-383.
20. Wang GF, Gong SY, Li ZL, Dou LM, Cai W, Mao Y. Evolution of stress concentration and energy release before rock bursts: two case studies from Xingan Coal Mine, Hegang, China. Rock Mech Rock Eng. 2016;49:3393-3401.
21. Jiang BY, Gu ST, Wang LG, Zhang GC, Li WS. Strainburst process of marble in tunnel-excitation-induced stress path considering intermediate principal stress. J Cent South Univ. 2019;26:984-999.
22. Zhang YB, Zhao TB, Yin YC, Tan YL. Numerical research on energy evolution in granite under different confining pressure using Otsu’s digital image processing and PFC2D. Symmetry. 2019;11:131.
23. Louchnikov VN, Eremenko VA, Sandy MP, Kosyreva MA. Support design for mines exposed to rockburst hazard. J Min Sci+. 2017;53:504-512.
24. Li CC, Mikula P, Simser B, et al. Discussions on rockburst and dynamic ground support in deep mines. JRMGE. 2019;11:1110-1118.
25. Prusek S, Masny W. Analysis of damage to underground workings and their supports caused by dynamic phenomena. J Min Sci+. 2015;51:63-72.
26. Li Y, Cao SG, Fantuzzi N, Liu YB. Elasto-plastic analysis of a circular borehole in elastic-strain softening coal seams. Int J Rock Mech Min Sci. 2015;80:316-324.
27. Tambodtsev PN. Estimation of main fracture initiation energy in separating stone blocks from rock mass by impact on plastic material in drillhole. J Min Sci+. 2016;52:689-697.
28. Zhao WY, Guo WY, Yu FH, Tan YL, Huang B, Hu SC. Numerical investigation of influences of drilling arrangements on the mechanical behavior and energy evolution of coal models. Adv Civ Eng. 2018;2018:1-12.
29. Geng Q, Wei ZY, Meng H. Numerical and experimental method to determine the boring diameters of a two-stage TBM cutterhead to prevent rock burst. J Mech Sci Technol. 2014;28:4613-4620.
30. Zhang SC, Li YY, Shen BT, Sun XZ, Gao LQ. Effective evaluation of pressure relief drilling for reducing rock bursts and its application in underground coal mines. Int J Rock Mech Min Sci. 2019;114:7-16.
31. Hu XC, Su GS, Shen SY, et al. Experiment on rockburst process of borehole and its acoustic emission characteristics. Rock Mech Rock Eng. 2019;52:783-802.
32. Wang M, Wang XY, Xiao TQ. Borehole destressing mechanism and determination method of its key parameters in deep road-way. J China Coal Soc. 2017;42:1138-1145.
33. Wang Z, Zhang S, Fan GW, Zhang J. Supporting stress field with different cable length in deep roadway with thick top-coal—a case study at Tangkou Coal Mine. Electron J Geotech Eng. 2016;21:6535-6543.
34. Wang XQ, Kang HP, Zhao K, Liu YD. Numerical analysis of bonding stiffness for support effectiveness of pre-stressed bolts. J China Coal Soc. 2016;41:2999-3007.
35. Liu Q, Chai J, Chen SJ, Zhang DD, Yuan Q, Wang S. Monitoring and correction of the stress in an anchor bolt based on pulse pre-pumped Brillouin optical time domain analysis. Energy Sci. 2020. https://doi.org/10.1002/ese3.644
36. Xu XL, Tian SC. Load transfer mechanism and critical length of anchorage zone for anchor bolt. PLoS ONE. 2020;15:e0227539.
37. Wang Q, Pan R, Li SC, Wang HT, Jiang B. The control effect of surrounding rock with different combinations of the bolt anchoring lengths and pre-tightening forces in underground engineering. Environ. Earth Sci. 2018;77:501.
38. Lu CP, Liu GJ, Liu Y, Zhang N, Xue JH, Zhang L. Microseismic multi-parameter characteristics of rockburst hazard induced by hard roof fall and high stress concentration. Int J Rock Mech Min Sci. 2015;76:18-32.
39. Lu CP, Dou LM, Zhang N, et al. Microseismic frequency-spectrum evolutionary rule of rockburst triggered by roof fall. Int J Rock Mech Min Sci. 2013;64:6-16.
40. Wang CX, Shen BT, Chen JT, et al. Compression characteristics of filling gangue and simulation of mining with gangue backfilling: An experimental investigation. Geomech Eng. 2020;20(6):485-495.
41. Zhang GC, Chen LJ, Wen ZJ, et al. Squeezing failure behavior of roof-coal masses in a gob-side entry driven under unstable overlying strata. Energy Sci Eng. 2020. https://doi.org/10.1002/ese3.678

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