

# 采空区下综采工作面开切眼一次成巷支护技术

吴 昕

(平顶山天安煤业股份有限公司 四矿 河南 平顶山 467093)

**摘 要:**为实现采空区下 $E_{9,10}$ -19070开切眼一次成巷支护,采用弹塑性力学理论分析了开切眼顶板稳定性,通过模糊综合评判得出其围岩类别,从围岩应力、围岩强度、巷道支护及设备选型方面探讨了 $E_{9,10}$ -19070开切眼一次支护可行性,根据工程类比法确定了开切眼一次成巷支护方案,并对围岩变形进行了监测。研究结果表明: $E_{9,10}$ -19070开切眼上覆 $E_8$ -19070采空区底板最大破坏深度为8 m,其煤层以上10 m顶板为完整岩层,开切眼围岩属Ⅲ类中等稳定,支护形式为锚网索;经分析确定 $E_{9,10}$ -19070开切眼一次支护是可行的,并确定了一次成巷支护具体支护参数和施工顺序;一次成巷支护后,开切眼顶板最大离层量21 mm,顶底板最大移近量170 mm,两帮最大移近量80 mm,实现了采空区下开切眼一次成巷支护,经济效益和社会效益明显。

**关键词:**采空区下综采工作面;开切眼一次成巷;开切眼支护;围岩稳定性

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## One driving completed gateway support technology applied to open-off cut in fully-mechanized coal mining face under goaf

Wu Xin

(No.4 Mine Pingdingshan Tian'an Coal Company Limited Pingdingshan 467093 China)

**Abstract:** In order to realize one driving completed gateway support of  $E_{9,10}$ -19070 open-off cut under goaf, a elastic-plastic mechanics theory was applied to analyze the roof stability of the open-off cut. The surrounding rock type was obtained from a fuzzy comprehensive judgment. From surrounding rock stress, surrounding rock strength, gateway support and equipment selection aspect, a feasibility on one support of open-off cut in  $E_{9,10}$ -19070 seam was discussed. According to the engineering analogy method, one driving completed gateway support plan of the open-off cut was determined and the monitoring and measuring was conducted on the surrounding rock deformation. The study results showed that a goaf in  $E_8$ -19070 seam was above the open-off cut in  $E_{9,10}$ -19070 seam, a max failure depth of the floor was 8 m, the roof with 10 m above the seam was an integrated strata, the surrounding rock of the open-off cut was in Ⅲ type medium stable and support mode was a bolt/steel mesh/anchor. The analysis showed that the one support of the open-off cut in  $E_{9,10}$ -19070 seam would be feasible and certain support parameters and construction sequence of the one driving completed gateway were set up. After the one driving completed gateway support conducted, a max value of the roof bed separation above the open-off cut was 21 mm, the max value of the roof and floor convergence was 170 mm and the max convergence of the two sidewalls was 80 mm. The one driving completed gateway support of the open-off cut under the goaf was realized and the economic and social benefits were obvious.

**Key words:** fully-mechanized coal mining face under goaf; one driving completed gateway of open-off cut; open-off cut support; surrounding rock stability

## 0 引 言

目前,传统的开切眼施工工艺为二次成巷,即先

掘进单开切眼,再二次扩开切眼,形成安装支架的条件。一次成巷的施工方式未能得到应用,其主要原因是一次成巷开切眼跨度大,支护困难<sup>[1-2]</sup>。随着

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作者简介:吴昕(1969—),男,河南西峡人,高级工程师,硕士,现任平顶山天安煤业股份有限公司四矿矿长。

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现代支护技术的不断进步,尤其是近年来锚网索联合支护技术的日趋成熟,综采开切眼一次成巷支护技术得到了一定的推广应用,如张东等<sup>[3]</sup>针对潘集煤矿 2141(3) 工作面断面大、深埋层、支护难的实际情况,改变传统的锚网索支护或棚式支护,采用“锚网索加挑棚和木垛联合支护”方式,较好地控制了大跨度、大高度条件下的开切眼顶板及两帮围岩的变形,黄庆国等<sup>[4]</sup>为解决塔山煤矿综放工作面跨度 10 m 开切眼的支护难题,采用高强度锚杆、组合锚索、W 钢带、金属网、混凝土联合支护,提高了支护结构的整体承载力,有效控制了开切眼巷道围岩的变形,保证了大断面开切眼的安全使用。开滦集团蔚州矿业责任公司崔家寨矿采用锚网索支护技术,成功实现了跨度 6.5 m 开切眼的一次成巷,达到了快速安全掘进开切眼的效果<sup>[5]</sup>。汾西矿业集团河东煤矿采用锚网索、W 钢带和槽钢联合支护技术实现了宽 9.2 m 的 3908 综采工作面开切眼的一次成巷<sup>[6]</sup>。然而,国内在针对近距离煤层群上覆采空区条件下的综采工作面开切眼一次成巷技术研究不多。基于此,笔者针对平顶山天安煤业股份有限公司四矿(以下简称平煤四矿)戊<sub>9,10</sub>-19070 开切眼的实际地质情况,通过理论计算其上覆戊<sub>8</sub>采空区底板破坏深度,确定其顶板完整性,从围岩应力、围岩强度、巷道支护和设备选型等方面对该开切眼一次成巷的可行性进行分析论证,最终确定戊<sub>9,10</sub>-19070 开切眼一次成巷的支护形式和支护参数。

## 1 地质概况

戊<sub>9,10</sub>-19070 开切眼位于平煤四矿戊九采区东翼上部,南部和北部均为戊<sub>9,10</sub> 实体煤,上覆戊<sub>8</sub>-19070 工作面已回采完毕,垂深 769~800 m。戊<sub>9,10</sub>-19070 开切眼综合柱状如图 1 所示,距上覆戊<sub>8</sub>-19070 采空区层 17 m,戊<sub>9,10</sub>-19070 开切眼与戊<sub>8</sub>-19070 开切眼内错 20 m(图 2)。开切眼戊<sub>9</sub> 煤层 1.2 m,直接顶粉砂质泥岩,平均厚度为 4 m,基本顶为 13 m 厚的细砂岩,底板为 7.5 m 厚的粉砂质泥岩。

## 2 开切眼围岩完整性分析

### 2.1 底板破坏深度

按照弹塑性理论,工作面底板下部一定深度内的岩体,当作用在其上的支承压力达到或超过其临界值时,岩体中将产生塑性变形,形成塑性区。当支










地层系统	层厚/m	柱状	岩石名称	岩性特征
二叠系下石盒子组	10.2		粉砂质泥岩	灰~深灰色,含沙量不均,含植物化石碎片
	2.0		细砂岩	浅灰色,成分以岩屑、石英为主,中厚层状
	7.0		粉砂质泥岩	灰~深灰色,含沙量不均,含植物化石碎片,含大个完整的还豆芽化石及少量黄铁矿鳞片
	1.8		戊 <sub>8</sub> 煤层	已回采完毕
	8.0		粉砂质泥岩及砂岩	深灰色,块状,含植物化石,下部含沙量增高,上部含镜煤包体,自西向东由 6.0 m 至 17.0 m 左右
	1.2		戊 <sub>9</sub> 煤层	黑色,碎块状,粒状,以亮煤,暗煤为主,次为镜煤
	6.0		泥岩及粉砂质泥岩	灰色,块状,含少量植物化石,多见滑面,底部含沙量偏高,近似粉砂岩,自西向东由 0.3 m 至 0.5 m 左右
	2.2		戊 <sub>10</sub> 煤层	黑色,碎块状,以亮煤,暗煤为主,底部夹有泥岩夹矸
	7.5		粉砂质泥岩	灰色,底部深灰色,块状,粉砂泥岩结构,含植物根部化石,底部有泥岩,微含炭质

图 1 戊<sub>9,10</sub>-19070 开切眼综合柱状

Fig. 1 E<sub>9,10</sub>-19070 open-off cut synthesis column



图 2 戊<sub>9,10</sub>-19070 开切眼示意

Fig. 2 E<sub>9,10</sub>-19070 open-off cut schematic

承压力达到导致部分岩体完全破坏的最大载荷时,支承压力作用区域周围的岩体塑性区将连成一片,致使采空区内底板隆起,已发生塑性变形的岩体向采空区内移动,并形成一个连续的滑动面<sup>[7]</sup>。戊<sub>9,10</sub>-19070 开切眼位于戊<sub>8</sub>-19070 工作面采空区下方,戊<sub>8</sub>-19070 工作面煤层屈服区长度  $x_a$  为

$$x_a = m \ln(10\gamma H) / F$$

$$F = (K_1 - 1) / \sqrt{K_1} + [(K_1 - 1) / \sqrt{K_1}]^2 \tan^{-1} \sqrt{K_1}$$

$$K_1 = (1 + \sin \varphi_0) / (1 - \sin \varphi_0)$$

其中: $m$  为戊<sub>8</sub> 煤层厚度,取 2.2 m; $\gamma$  为底板岩层容重,取 25 kN/m<sup>3</sup>;  $H$  为埋深,取 800 m;  $F$  为与自然对数  $K_1$  的相关系数;  $\varphi_0$  为戊<sub>8</sub> 煤层底板岩层内摩擦角,取 47°。由此计算得出屈服区长度  $x_a$  为 2.4 m,煤层底板岩体最大破坏深度  $h_1$  为

$$h_1 = \frac{x_a \cos \varphi_0}{2 \cos(\pi/4 + \varphi_0/2)} e^{(\pi/4 + \varphi_0/2) \tan \varphi_0}$$

煤层底板岩体最大破坏深度距工作面端部的水平距离  $L_1$  为

$$L_1 = h_1 \tan \varphi_0$$

采空区内底板破坏区内沿水平方向的最大长度  $L_2$  为

$$L_2 = x_a \tan(\pi/4 + \varphi_0/2) e^{\pi/(2 \tan \varphi_0)}$$

计算得出  $h_1$ 、 $L_1$  和  $L_2$  分别为 8.000、8.579、32.300 m。

依照上述计算结果,得出戊<sub>8</sub>-19070 采空区底板破坏区曲线如图 3 所示,戊<sub>9,10</sub>-19070 开切眼距戊<sub>8</sub>-19070 采空区层间距 17 m,戊<sub>9,10</sub>-19070 开切眼所在位置处底板破坏深度 7 m,也即其顶板以上 10 m 岩层未遭到戊<sub>8</sub>-19070 工作面采动破坏,为完整岩层。

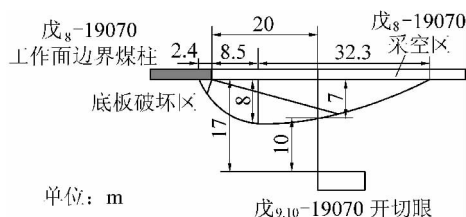


图 3 戊<sub>8</sub>-19070 采空区底板破坏区曲线

Fig. 3 E<sub>8</sub>-19070 gob floor failure curves

## 2.2 围岩稳定性分析及支护形式判定

由于戊<sub>8</sub>-19070 采空区底板最大破坏深度 7 m,戊<sub>9,10</sub>-19070 开切眼顶板以上 10 m 为完整岩层,对该围岩稳定性进行分类。通过取样计算,戊<sub>9,10</sub>-19070 开切眼围岩参数为

$$U = \{\sigma, D, KH, W\} = \{32, 0.3, 800, 10\}$$

其中:  $\sigma$  为围岩单轴抗压强度,取 32 MPa;  $D$  为围岩岩体完整性指数,取 0.3;  $K$  为应力集中系数,取 1;  $H$  为埋深,取 800 m;  $W$  为岩块干饱和吸水百分率,取 10%。参照文献[8]中采用的模糊综合聚类分析方法,得出戊<sub>9,10</sub>-19070 开切眼围岩稳定性属Ⅲ类中等稳定围岩。根据工程类比法,得出其支护形式为锚杆+W 钢带(或钢筋梁)+金属网。锚杆杆体直径为 18~22 mm;锚杆长度为 1.8~2.4 m;间排距为 0.6~1.0 m。

## 3 一次支护方案确定

### 3.1 一次支护的可行性

围岩应力、围岩强度和巷道支护是影响支护稳定性的 3 个要素<sup>[9-12]</sup>,而掘进设备选型也是实现开切眼一次支护的关键,因此从以下 4 个方面确定

戊<sub>9,10</sub>-19070 开切眼一次支护的可行性。

1) 戊<sub>9,10</sub>-19070 开切眼处于戊<sub>8</sub>-19070 采空区下,且其内错戊<sub>8</sub>-19070 开切眼 20 m 布置,依照矿压显现规律<sup>[13]</sup>,其处于应力降低区,顶板压力较小。

2) 戊<sub>9,10</sub>-19070 开切眼与戊<sub>8</sub>-19070 采空区层间距 17 m,戊<sub>9,10</sub>-19070 开切眼煤层以上 10 m 顶板为完整的粉砂质泥岩及砂岩,围岩为Ⅲ类中等稳定顶板。

3) 戊<sub>9,10</sub>-19070 开切眼安装支架型号为 ZY4000-12/25,开切眼设计宽度 5.8 m,此跨度对于Ⅲ类中等稳定顶板而言,不会出现较大的变形,且国内外实践表明,锚网索联合支护的方式完全能支护此类顶板<sup>[14-16]</sup>。

4) 采用 EBZ-160TY 掘进机施工该开切眼,该型号掘进机满足一次施工宽 5.8 m 开切眼的要求。

### 3.2 一次支护方案

一次支护参数如下(图 4):①锚杆:顶板和正帮使用规格为:φ20 mm×2 400 mm 左旋高强树脂锚杆,副帮使用 φ18 mm×2 100 mm 玻璃钢锚杆。顶板锚杆间排距为 800 mm×750 mm,正帮锚杆间排距为 700 mm×750 mm,副帮锚杆间排距为 900 mm×750 mm。顶板、正帮、副帮分别布置 8、4、3 根锚杆。②锚索:φ22 mm×8 500 mm,间排距 1 500 mm×1 600 mm,每排布置 3 根。③钢带:W 钢带,顶板钢带长 5.7 m;两帮不使用钢带。④金属网:8 号冷拔丝网,根据巷道断面确定规格。⑤锚固剂:ZK2335 树脂药卷,顶板每孔 3 卷,两帮每孔锚杆 2 卷,锚索每孔 6 卷。⑥托棚:布置 2 道,一梁三柱,单体柱采用 2.8 m 铁质单体柱,上下垫长 3 m 木大梁。⑦木垛:木垛以开切眼中心以东 0.2 m 为中心搭设,每隔 15 m 布置一处,井字形搭设,长×宽×高为 1.6 m×1.6 m×2.4 m。⑧初锚力:左旋高强树脂锚杆锚固力不小于 220 kN,安装转矩不小于 180 N·m,玻璃钢锚杆锚固力不小于 60 kN,安装转矩不小于 70 N·m,锚索预应力不小于设计值 200 kN。

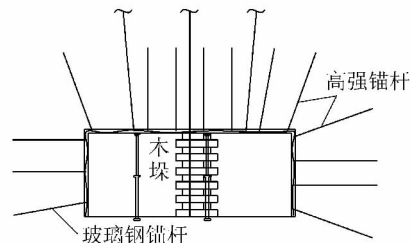


图 4 开切眼一次支护断面

Fig. 4 Once-tunneling support section of open-off cut

## 4 现场矿压观测及分析

为确保开切眼一次成巷支护的安全<sup>[17-22]</sup>,对戊<sub>9,10</sub>-19070开切眼的围岩变形进行了监测,2014年7月对开切眼顶底板及两帮移近量和顶板离层量进行观测,3次顶板离层量观测结果分别为21、15、19 mm,巷道变形量观测结果见表1。

表1 巷道变形量观测结果

Table 1 Results of roadway deformation monitor

测点布置日期	测点编号	两帮移近量/mm	顶底板移近量/mm	观测时间
5月12日	1	50	130	7月20日
5月21日	2	70	170	7月20日
6月2日	3	80	150	7月20日

戊<sub>9,10</sub>-19070开切眼在采用一次成巷支护后,开切眼顶板最大离层量为21 mm,顶底板最大移近量为170 mm,两帮最大移近量为80 mm,表明顶板未出现明显下沉,两帮移近量不大,证明该种支护条件下一次成巷开切眼施工方法是安全可靠的。

## 5 结 论

1) 根据戊<sub>9,10</sub>-19070开切眼的地质条件,通过理论计算,得出戊<sub>9,10</sub>-19070开切眼煤层以上10 m顶板为完整岩层,根据模糊综合聚类分析,确定开切眼围岩属Ⅲ类中等稳定围岩,依据工程类比法确定了支护形式为锚网索,并界定了支护参数。

2) 通过分析开切眼围岩强度、围岩应力、巷道支护、设备选型,得出戊<sub>9,10</sub>-19070开切眼采用一次成巷的施工方法是可行的,并确定了具体的支护形式、参数和施工顺序。

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