Focus on Ground Control: Horizontal Stress

BY CHRISTOPHER MARK

A SUCCESSFUL GROUND CONTROL PLAN USUALLY ALLOWS FOR A HORIZONTAL STRESS COMPONENT

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Researchers now believe that cutter roof formations, such as the one shown above, are the result of horizontal stress.

The purpose of ground control is to create a stable rock structure that can withstand the stresses that nature applies to it. Traditionally, coal mine operators have been primarily concerned with stress caused by the weight of the rock itself. The pillars, however, carry most of the vertical gravity load from the overburden, leaving only the weight of the immediate roof to be carried by the supports.

In the early 1970s, researchers began to actually measure stresses underground. They made a surprising discovery—in nearly every case, the horizontal stress was greater than the vertical stress, often several times greater. Although this unexpected finding caused quite a bit of head scratching, it explained many ground control phenomena that were commonly observed underground, such as cutter roof and long-running roof falls.

The mystery was finally solved by the theory of plate tectonics (sometimes called continental drift). Plate tectonics explains that the earth's crust is segmented into enormous rigid plates. Earthquakes, volcanism, and mountain building are caused when the plates collide with one another, generating tremendous forces that are transmitted thousands of miles through the earth's crust. Geophysicists have created a World Stress Map based on their current understanding of plate tectonics. After studying all the available stress measurement data, the U.S. Bureau of Mines (now NIOSH) confirmed the relevance of the World Stress Map to U.S. coal mines. Some of the most significant conclusions were:

- In the eastern United States, the greatest horizontal stresses are usually ENE (See Figure 1);
- There is no clear major direction for horizontal stress in the western United States;
- The horizontal stresses in the eastern United States are usually 2 to 3 times as great as the vertical stresses;

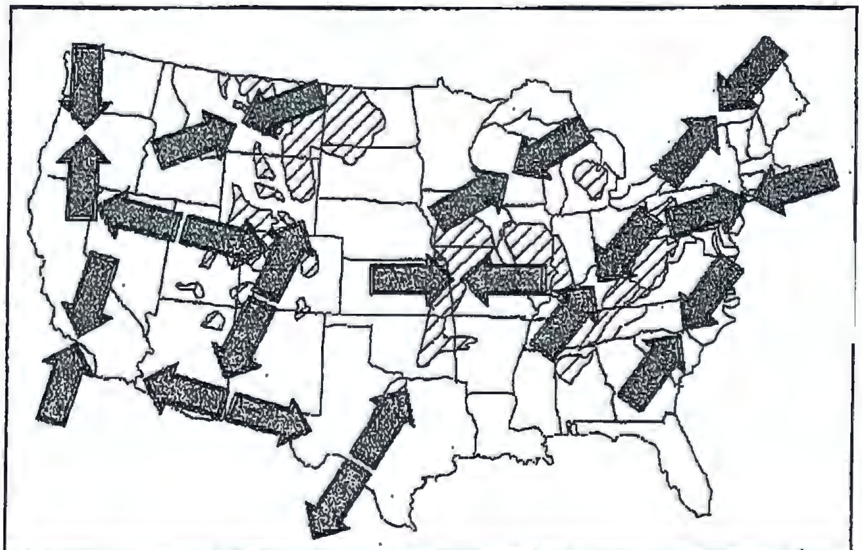


FIGURE 1—After years of data collection, scientists have mapped the direction of horizontal stress. In the northeastern United States, where most of the underground mining takes place, it's oriented in an ENE direction.

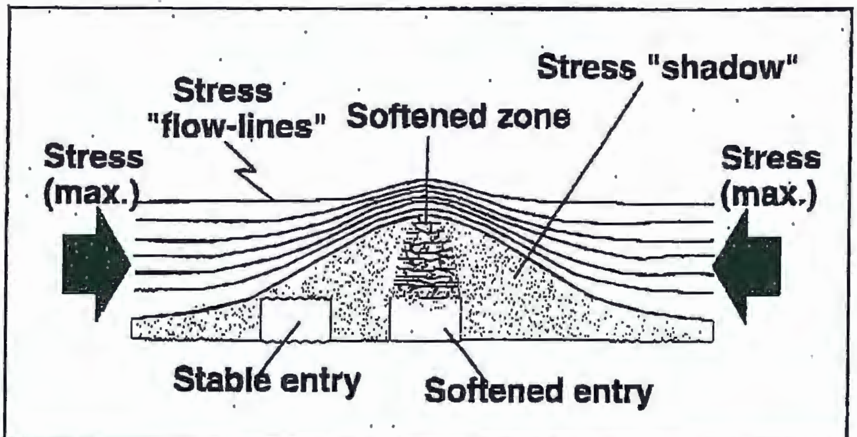


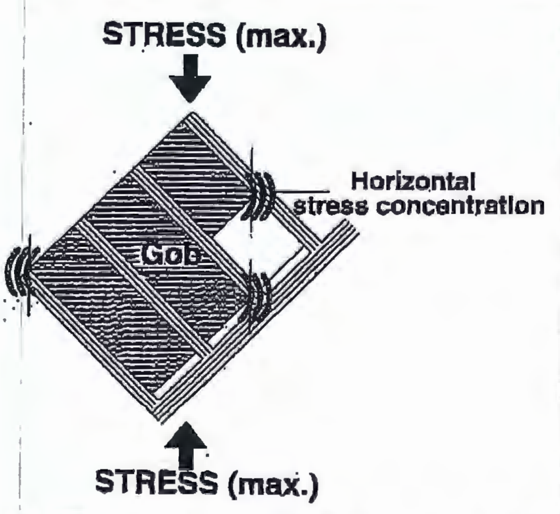
FIGURE 2—Stress relief principles explain why one entry experiences ground control problems while the adjacent entries remain intact.

- Horizontal stresses in the west are generally about equal to the vertical stresses, though some western mines have encountered very high stresses; and
- In general, the deeper the mine, the greater the horizontal stress.

It is now widely accepted that horizontal stress is nearly always present underground. The only likely exceptions are some small hilltop drift mines. Studies have also shown that:

- Weak rocks, particularly those containing many weak bedding planes or laminations, are more likely to be damaged by horizontal stress than strong, massive rocks; and
- Stream valleys can concentrate horizontal stresses, and also re-direct them.

FIGURE 3—Stress concentrations contribute to ground control problems for longwall gate entries.



What are the Effects of Horizontal Stress?

Now that we are aware of how widespread horizontal stress is, it is easier to see its effects. Three examples that illustrate the types of problems that can be encountered in different stages of mining include:

Development—A small drift mine in western Virginia was advancing into a new, deeper portion of their reserve. Large chunks of roof began to fall on continuous miners, forcing cut lengths to be reduced. These roof pots were up to 3-feet (ft) thick. Roof cutters also developed along the rib and through the intersections. The problems were most often experienced in the belt entry, which was normally kept approximately one break ahead of the other entries.

Outby Roof Falls—A Pennsylvania room-and-pillar mine was driving panels to the north. Conditions in the faces were excellent and the roof looked perfect. Several breaks outby, however, roof falls occurred with little warning. Once initiated, usually in an intersection, the falls could extend for more than 1,000 ft. The roof falls generally ran down an entry, and could not be stopped by cribbing. Several panels were abandoned prematurely.

Longwall—At a longwall mine in southern West Virginia, gate entries were developed beneath a stream valley in an easterly direction. Many

COMMON MISCONCEPTIONS ABOUT HORIZONTAL STRESS

"It is unusual for horizontal stress to exceed the vertical stress." Years ago, it was thought that the normal horizontal stress was about one-third the vertical stress. We now know that there is no normal horizontal stress, it depends entirely on factors such as the current state of plate tectonics, rock stiffness, and surface topography.

"Our mine doesn't have horizontal stress." Few mines are free of horizontal stress. If you have a strong, massive roof, however, you may not see any effects from horizontal stress.

"All my roof control problems are caused by horizontal stress." Roof control problems are generally caused by a combination of factors, including weak roof, wide spans, pillars that are too small, and/or inadequate roof support. While horizontal stress may be the most significant problem at some mines, it is seldom the only one.

"Horizontal stress only acts in one direction." Rock underground is stressed in all directions, not just horizontal and vertical. Every entry is subjected to some degree of horizontal stress, but those perpendicular to the maximum horizontal stress see the highest level.

"Pillar design can help me control horizontal stress." Unfortunately, pillar design is seldom much help. Larger pillars can handle more vertical loads, but have little effect on horizontal ones. Small yield pillars have been used to control horizontal stress in very deep salt mines where the ground is highly deformable, but they would have to be very thin (5 to 10 ft) to have any affect on horizontal stress in a coal mine. In any case, many horizontal stress problems occur right at the face, before the ground knows what size pillar is coming anyway.

"The direction of horizontal stress can be determined by studying the regional pattern of faults and folds." This may or may not be true. Where faults are currently active, as in the western United States, they are responding to the current state of plate tectonics. Where geologic features were caused by ancient stressfields, as is generally the case in the eastern United States, any relationship to the current state of stress is probably coincidental.

WHAT ABOUT STRESS MEASUREMENTS?

A number of techniques are available to measure ground stress. With overcoring methods, a hole is drilled into the roof, a sensitive measuring device is installed, and then a second, larger hole is drilled around the first one. The overcore relieves the stress, allowing the rock to relax.

By measuring the expansion of the rock, the original stressfield can be reconstructed. Some overcoring techniques can define the complete 3-D state of stress, while others provide information just about the horizontal stresses.

Hydrofracturing methods use only a single hole. A section of the hole is isolated with packers, and then pressurized with fluid until the rock fractures. Measurements of the fracture pressure, subsequent re-opening pressures, and the orientation of the fracture are used to define the horizontal stressfield.

Both techniques are difficult, time-consuming, and can be expensive. Fortunately, a precise value of the magnitude of the horizontal stress is seldom necessary.

A simple alternative is stress mapping, which uses features such as pots, cutters, shifts in bolt holes, etc.

Stress mapping does not provide a numerical value for the stress level, but it usually provides information on the direction of the major horizontal stress.

By rating the intensity of the stress features, it also indicates whether the magnitude of the stress exceeds the strength of the roof rock.

large roof pots fell out during development, particularly in the crosscuts and intersections. The longwall had retreated only 100 ft when a major roof fall occurred on the headgate. It was cleaned up, but 200 ft later the stageloader was again trapped by a broken roof. To regain ground control, the belt was removed, the floor was shot, and the roof supported with cable bolts for a distance of 200 ft.

The observations at these mines may be explained by two basic principles of horizontal stress:

- Entries driven perpendicular to major horizontal stress are more likely to suffer damage than those driven parallel to it; and
- Horizontal stress cannot pass through a broken or collapsed roof, so roof falls and gob areas create zones of both stress relief and stress concentration.

The second principle has several applications. It explains why one entry may be heavily damaged, while its neighbor is perfectly intact (See Figure 2). It also explains why a roof fall can begin to run, and why it can be so hard to stop. And it explains the horizontal stress concentrations that can be so troublesome for longwalls (See Figure 3).

How Can Horizontal Stress Be Controlled?

Mine design is the first line of defense against horizontal stress. Some basic mine design principles are listed below:

- Try to maximize the drivage parallel to the maximum horizontal stress, and minimize the drivage perpendicular to it. A Stress Design Diagram (See Figure 4) can be helpful in laying out main entries, panel entries, and crosscuts;
- Orient longwall panels so that the headgates are stress relieved; and
- In room-and-pillar mining, try to develop panels within the stress shadows of previously mined gob areas. Advance-and-relieve mining, where a gob zone is created during development, can be another option.

Another group of techniques can be used during development to minimize horizontal stress problems. The basic principle is to minimize the damage inflicted on critical entries, so that they are more likely to remain standing over the long term. The techniques include:

- Advancing the least critical entry first;
- Turning crosscuts away from the maximum horizontal stress;
- Minimizing entry widths and intersection spans, particularly in critical entries;
- Minimizing cut lengths and the time between cutting and roof bolting; and
- In some cases, leaving top coal can help.

Even the best design and mining practice is often not enough to control severe horizontal stress, however. Roof support is still the main control technique. Un-

Signs of Horizontal Stress

How many of the following signs of horizontal stress have you observed?

On development, do you see that roof cutters and pots are more frequent:

- When you drive in one particular direction?
- On one side of the entry?
- In one particular entry or entries?
- When you turn a crosscut in one particular direction?
- When you are mining beneath a stream valley?
- When you are mining under deeper cover?

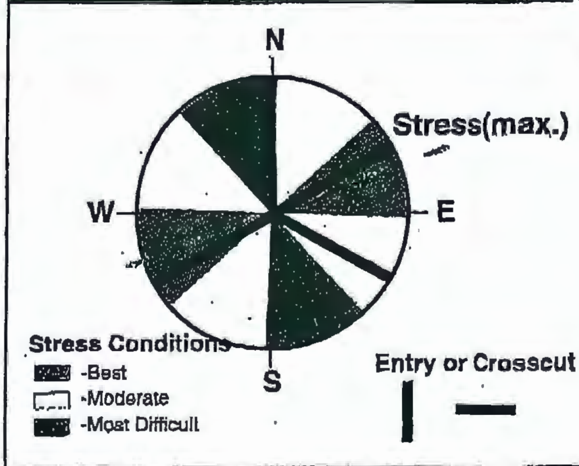
When you have outby roof falls, do they:

- Tend to be more than an intersection in length?
- Tend to run (grow) over time?
- Preferentially occur in one direction?
- Seldom occur in two adjacent entries?
- Occur more often beneath stream valleys?
- Occur more often under deeper cover?

In your longwall panels, are roof problems more likely to occur:

- On the first panel of a group than in subsequent panels?
- In the headgate than the tailgate?
- In a repeating pattern, for example, near every intersection?
- Beneath stream valleys?

FIGURE 4—Stress Design Diagram.



fortunately, no magic bullet roof support has been found that works every time. To improve the effectiveness of roof bolts, two concepts have been found to be important:

Longer is better, because long bolts are more likely to anchor above the zone that has been broken by the horizontal stress. Longer bolts are particularly effective in narrow entries, and where the rock becomes sandier and stronger higher up.

Stronger is better, because strong bolts can carry more broken rock, and they can withstand more horizontal shear loading. Stronger bolts are made from larger diameter and higher grade steel. It is critical, however, that the anchorage capacity of any bolt be greater than its breaking strength.

Some studies also have found that it can be effective to install bolts with high levels of tension, or to use denser bolt patterns.

FIGURE 5—Close-up of horizontal stress damage.

Rate Your Horizontal Stress Potential

To determine whether you are at risk for horizontal stress, take the following simple test.

What is your typical depth of cover?	Points	Score
Less than 300 ft	0	
300 to 600 ft	3	
600 to 1,000 ft	6	
Greater than 1,000 ft	8	____
Note: Mines in western U.S., divide depth rating by 2.		
What best describes your roof rock?	Points	Score
Massive sandstone or limestone	0	
Siltstone, beds >8 inches thick	4	
Coal or slickensided, weak shale	8	
Thin bedded sandstone (stackrock)	8	
Thinly laminated shale	12	____
Is your main direction of drivage:	Points	Score
Parallel to the major horizontal stress?	2	
45° to the major horizontal stress?	4	
Perpendicular to the major horizontal stress?	6	____
What retreat mining do you plan to do?	Points	Score
No retreat mining	0	
Longwall, with headgate in stress shadow	3	
Pillar recovery	3	
Longwall, with headgate in stress concentration	10	____

Add your ratings in each of the four categories to get your Horizontal Stress Potential: .... ____

If your HSP is:	Then you:
Greater than 20	Should expect serious horizontal stress problems, and probably should implement horizontal stress control techniques.
Between 15 and 20	May or may not see damage from horizontal stress. Should be prepared to implement control techniques if they become necessary.
Less than 15	Probably don't need to be concerned about horizontal stress.

Secondary support is the last line of defense. In general, secondary supports do not prevent the roof from failing. Instead, they work to control the rock that has already been broken.

Roof-to-floor standing supports, particularly the modern engineered wood cribs and posts, can be effective second supports. Standing supports are usually inconvenient in development entries and longwall headgates, however, where horizontal stress most often strikes. For these applications, cable trusses and cable bolts have become the most popular secondary supports.

Cable bolts have the advantage of being stiffer than trusses, meaning that they will resist the movement of the roof sooner. Roof bolts are even stiffer, so cable bolts are generally more compatible with them. Cable bolts also use more of their strength to resist vertical loads than do trusses, and they can obtain better contact in an uneven roof. Cable bolts greatest drawbacks are that they must be long enough to obtain solid anchorage above the broken rock, and they can be sheared by horizontal roof movements. Skin support, such as heavy steel mats, should also be used to prevent the roof from unravelling between the cable bolts.

Cable trusses anchor over the solid coal, so their anchorage is more likely to remain intact. They can also withstand downward roof movements in excess of 1 ft. For these reasons, they can survive in high deformation environments where other supports would fail. Their greatest drawbacks are that even tensioned cable trusses provide little support until large roof movements have already occurred, and their vertical load carrying capability is reduced because they are installed on an angle. CA

A leading ground control expert with NIOSH, Dr. Chris Mark will teach an afternoon workshop at Longwall USA 2001 (June 14, 2001) titled, "New Software for Ground Control." For more information on the workshop, contact Steve Fiscor (steve_fiscor@intertec.com). And, to reach Mark, contact cnm7@cdc.gov; Tel: 412/386-6522.

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