Influence of Longwall Mining on the Stability of Shale Gas Wells in Barrier Pillars



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Introduction

- Over the last 15 years, about 1,400 shale gas wells have been drilled through coal reserves in PA, WV, and OH
- These shale gas wells have penetrated through many coal seams which are either currently being mined or will be mined in the near future
- Shale gas wells are drilled deeper and have higher gas pressure
- Marcellus shale wells are 7,000–9,000 ft deep, and gas pressure is as high as 3,000 psi
- Safety concerns arise when shale gas wells are influenced by longwall mining







Introduction

- Longwall mining induces surface and subsurface subsidence and stress changes in the overburden
- When gas wells are influenced by subsurface ground movements, their mechanical integrity can be compromised
- If gas well casings are damaged or ruptured, high pressure gas can migrate into underground workings, potentially causing a fire or explosion
- Gas wells through coal seams are protected by coal pillars
- Chain pillars and barrier pillars are left during longwall mining
- The risk of gas well failures still exists even though barrier pillars are larger and farther away from longwall gob







PA 1957 Gas Well Pillar Study

- The current gas well pillar regulations are based on the PA 1957 gas well pillar study
- The study included 77 gas well failure cases that occurred over 25 years in room-and-pillar mines with full and partial pillar recovery in the Pittsburgh and Freeport coal seams
- Mining depth in those seams ranged from 55 ft to 770 ft
- The 1957 study provided guidelines for pillar sizes around gas wells under different overburden depths up to 770 ft
- Without specific guidelines for gas well pillars for longwall mining, the 1957 study has been used for assessing gas well pillars in longwall mines

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JOINT COAL AND GAS COMMITTEE GAS WELL PILLAR STUDY EXAMPLES OF PILLAR PLANS FOR VARIOUS DEPTHS OF COVER



(MIN. 10,000" BEARING AREA) (MIN. 15,000" BEARING AREA)(MIN.22,000" BEARING AREA)







NOTE: NO PLACE TO EXCEED IS' IN WIDTH. PILLARS TO BE AMINIMUM OF TWICE THE WIDTH OF THE EXCAVATION DRIVEN. SCALE I INCH = 200 FEET



PA 1957 Gas Well Pillar Study

- For longwall mining with an overburden depth of 650 ft or more, the regulation requires a solid pillar area of 10,000 square ft with a minimum total bearing area of 40,000 square ft
- The 1957 study is not applicable to assessing longwall gas well pillars especially under deep cover
- Generally, barrier pillars meet the requirement by the 1957 study, but risk of gas well failure still exists
- A thorough evaluation of gas well stability is still needed



COVER 650'To 700'+

(MIN. 40,000" BEARING AREA)





Potential Gas Well Failure Locations

- Three potential failure locations
 - In the coal seam
 - In the overburden strata
 - In the immediate floor



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Causes of Gas Well Failures

- Subsurface movements induced by longwall mining
 - Conventional subsidence
 - Unconventional subsidence

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- Coal seam convergence
- Weak floor movement
- Subsurface movements associated with surface features
 - > Steep slope
 - Stream valley
- Gas wells are likely to be subjected to vertical/horizontal compression, shear, or bending in response to these movements
- Gas wells could fail if the induced stresses or deformations in the casings exceed the permissible values





Gas Well Stability Influenced by the Pillar Stability Factor

- Pillars have to be stable to protect gas wells
- Gas wells could fail even when the pillars are stable
- The pillar stability factor, especially for barrier pillars, does not indicate gas well stability



Gas Well Stability Influenced by Distance from the Gob

- There is severe influence when wells are within 40–50 ft of the gob
- Influence is much less 80 ft away from the gob



Gas Well Stability Influenced by Unconventional Subsidence

- Unconventional subsidence refers to horizontal movements not associated with conventional vertical subsidence
- Unconventional subsidence is controlled by overburden geology, overburden depth, and surface features
- Large horizontal movements could occur at the interfaces of weak claystone layers and massive strong sandstone/limestone layers
- High horizontal movement occurs under shallow cover
- High horizontal movement also occurs under a steep slope or stream valley

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Distance from the edge of the barrier pillar, ft



Gas Well Stability Assessment in Barrier Pillars

- Failures are likely to be in the coal seam horizon, roof strata, or floor
- Gas well location from gob is important to minimize any influence from longwall mining
- Potential high horizontal movements could occur under shallow cover or near a steep slope or near a stream valley
- An evaluation is needed even when the risk of failure is perceived to be low

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A Case Study on Shale Gas Wells in Barrier Pillars

- Two Marcellus shale gas wells are located within a barrier pillar between two longwall bleeders
- The first longwall panel was mined before the gas wells were drilled and installed
- The gas wells were drilled within the center of a 145-ft wide barrier pillar
- The bleeders for the second panel were developed later, and then the second panel was mined about 350 ft away from the gas wells
- The panels are 1,150 ft and 1,100 ft wide
- The overburden depth at the gas well site is 850 ft
- Average mining height is about 7 ft







Shale Gas Wells through Coal Seams

- Shale gas wells have five casings
 - Surface casing
 - Water-protection casing
 - Coal-protection casing (250 ft below the coal seam at minimum)
 - ✤ Intermediate casing
 - Production casing
- Annuli are cemented between the rock and the outer casing and between the inner casings







Potential Risks of Gas Well Failures in the Barrier Pillar

- Known risks
 - \checkmark The risk of pillar failure is low
 - ✓ Surface subsidence is small
 - ✓ Horizontal movements at the surface could be significant if the gas wells are near a steep slope or a stream valley
- Unknown risks
 - Horizontal movement along weak layers at the subsurface (unconventional subsidence)?
 - ✓ Effect of the weak claystone floor?

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FLAC3D Modeling of Longwall-induced Stresses and Deformations

- NIOSH has developed FLAC3D modeling procedures to calculate surface and subsurface deformations and their effects on gas well casings
- The case study model is set up based on the geological and mining conditions near the gas wells
- Gas well casings are built in the model
- The actual sequence of longwall retreating and gas well installation are modeled



Final Surface Subsidence at the Gas Well

- The model predicts 4.6 ft subsidence around panel center and about 1.75 in subsidence at the gas well site
- The modeled subsidence agrees with the measured subsidence



Distance from the gas well, ft

Longwall-induced Stress in the Barrier Pillar

The longwall-induced vertical stress at the gas well in the barrier pillar is about 100 psi after the first panel is mined and another 100 psi after the second panel is mined





Distance from the gas well, ft

Vertical Displacement in the Subsurface along the Gas Well

- The maximum vertical displacement at the surface is 0.75 in after the first panel is mined and 1.75 in after the second panel is mined
- Overall, the gas well is shortened for about
 0.5 in between the surface and the coal seam



Vertical displacement at the gas well, in

Horizontal Displacement in the Subsurface along the Gas Well

- The maximum horizontal displacement at the surface is 1.25 in after the first panel is mined and -0.3 in after the second panel is mined
- Longwall-induced horizontal movement is towards the gob, so after the second panel is mined, the ground moves back towards the second panel
- Second panel mining would induce about 1.55 in horizontal movement at the surface of the gas well



Horizontal displacement at the gas well, in

The Effect of Subsurface Movements on the Stability of Gas Well Casings

- Longwall-induced subsurface movements transfer deformations to the gas well casings through back-filled cement
- As the modulus of steel is high, a small amount of subsurface movement will induce a large amount of stress in the casings
- In resisting subsurface movements, the casings are likely to experience tension, compression, bending, shear, or even torsion



Longwall-induced Vertical Stress in the Coal-Protection Casing Vertical stress in casings is induced by vertical movement *FLAC3D 6.00* ©2017 Itasca Consulting Group, Inc. *Scale* (80,80,1) Deformed Factor: 1 Calculated by: Constant

- in the subsurface and the weight of the casings
 High vertical stress occurs at claystone layer and the coal seam with larger deformations
- The highest vertical stress is at the claystone floor



Longwall-induced Shear Stress in the Coal–Protection Casing

- Shear stress is induced by differential horizontal movement along a bedding plane or a weak layer
- Shear stress is seen along the interfaces between strong limestone/sandstone and claystone layers





Casing

 Shear deformation occurs along the interfaces between strong limestone/sandstone and claystone laye

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Von Mises Stress in the Three Casings

 Von Mises equivalent stress is used to evaluate casing yielding

$$\sigma_{eq} = \sqrt{3J_2} = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}}$$

- The highest von Mises stress in the three casings is about 20% of the yield strength
- The risk of casing failure is low



Influence of Mining and Gas Well Installation Sequence

- If the gas well is installed after both panels are mined, the influence of longwall mining on the gas well is minimal
- Assuming the gas well is installed before the first panel is mined, the von Mises stress increases slightly but still less than the yield strength of the





Discussion on the Case Study

- The gas wells have been successfully mined by longwall mining without safety issues
- Can the size of the barrier pillar be reduced?
- What is the minimum distance from the gas wells to the nearest entries?
- The goal of the evaluation is to determine the risk level and how much safety precautions should be put into place during longwall retreating





- Gas wells in barrier pillars are influenced by longwall mining
- Longwall mining induces vertical, horizontal, and shear stresses in gas well casings as a result of subsurface movements
- Potential gas well failures can occur in the coal seam, weak floor, immediate roof, or in overburden
- Numerical modeling is an effective approach to quantify subsurface deformations and induced stresses in gas well casings
- Induced von Mises stress can be used to assess the stability of the gas well casings in barrier pillars
- NIOSH is working on a research project to quantify subsurface deformations, reevaluate the PA 1957 study for its adequacy and deficiency, and eventually propose the optimal safeguard distance and gas well casing design to prevent gas well failures