Study of Marcellus and Utica Well Borehole Stability in Longwall Mining Areas

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• Over 33 years of experience in mapping, CAD and GIS
• 12 years within the oil and gas exploration industry
  • 2 years with a GIS consulting firm
• 10 years in the environmental engineering industry
• 3 years in the coal mining / exploration industry
• 6 years at Range Resources - Marcellus Shale GIS department
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Where I Hail From...
A Bit on Home...
American Shale Plays & The Marcellus & Utica Shales

Lower 48 states shale plays

Appalachian Basin

Devonian (Ohio)

Marcellus

Utica

Source: Energy Information Administration based on data from various published studies.
Location of Range Resources
Southern Marcellus Shale Division AOI

Range Resources Southern Marcellus Division Focus Area

Pittsburgh
Marcellus Shale vs. The Coal Fields of Pennsylvania
Historic Mining and Drilling Techniques
Modern Mining and Drilling Techniques
Conflict of Modern Mining and Drilling Techniques

• Over 95% of mineral estates in Southwestern Pennsylvania, have their mineral rights privately owned.

• The bulk of the tracts leased for gas drilling have their coal and natural gas rights severed. Those coal rights are often owned or leased by coal mining companies.

• Pennsylvania state law insures that both the coal and gas companies have an equal right to access and enjoy their respective mineral estates.

• The safety and stability of the wellbores drilled in and adjacent to mines is a major concern to both the gas and coal companies.
Coexistence – Mining and Drilling

Panels & Pillars

Potential Well Bores
Overview & Detail of Mining / Drilling Conflict
Alternate casing and temporary plugging procedures would need to be proposed to Pennsylvania and then proven viable via modeling and in-situ testing.
Proposed Study:

1. To use a finite element analysis modeling to simulate the complex ground condition in longwall mining areas and to quantify the factors affecting the wellbore stability.

2. To carry out an in-situ testing of various well bore construction regimens in order to evaluate current and proposed well bore casing designs.
Subsidence Modeling

Surface subsidence due to longwall mining has been extensively studied by various parties including British Coal Board, USBM, NIOSH, .. through long term monitoring / surveying of the surface settlements. Several models are available to calculate subsidence.

Source: Gutierrez 2010, PhD thesis
Predictive Model for Wellbore Damage

ABAQUS 3D Finite Element Model

Based on Actual Site Geology
- Detailed Geology from Core samples or Gamma Ray Logs
- Rock Properties: Strength, Young’s Moduli and Poisson’s Ratio

Rock Interfaces
Cohesion
- Strong Interfaces at: Limestone / Sandstone, Sandstone / Sandy Shale
- Weak Interfaces at: Coal / Limestone, Coal / Sandstone, Coal / Sandy Shale
  Limestone / Claystone, Etc. = Zero Cohesion.

Study to be Based on True Mining and Site Geometry
- Underground Longwall Panel Development Entry
- Detailed Test Well / Monitoring Well Geometry
Typical Subsidence – Perpendicular View
Typical Subsidence – Parallel View

Potential Well Bore

- **Surface Zone**
  - Thickness varies depending on depth of cover

- **Constrained Zone**
  - Interface possibly forms at plane of weakness (Vales Point Seam)

- **Fractured Zone**
  - 2-10t depends on depth of cover and geological factors

- **Caved Zone**
  - 10t (probably about 5t)

- **Extracted coal seam - thickness = t**

**Rib Area**

- **Goaf Area**
  - Variable - mostly not detected due to presence of weathered surface layer or alluvial deposits. Surface effects only noted in areas with small depth of cover
Typical Long Wall Subsidence and Stress vs. Nearby Wells

Modified after Peng and Chiang, 1984
Borehole Displacement and Stresses on Well Casing

Displacement field (shear distributed over a short length in this illustration)
Predicted Casing & Tubing Damage Due to Subsidence
Typical Current Casing Regimen

Rigid Cement Required for Borehole Stability, Coal and Aquifer Protection
Proposed Alternative Casing Regimen

Alternate Casing Method

- 20" water string at 300'
- 13-3/8" coal string at 700'
- Cement top on 9-5/8" below base of coal
- Cement top on 5-1/2" below base of coal
- 9-5/8" intermediate casing at 1,800'
- 5-1/2" production casing to total depth

Proposed Use of Compressive Cement, Bentonite or Open Annular Spaces

- Leave top of cement on intermediate casing below base of target coal seam. This will require a variance from the current Chapter 78 requirement to cement intermediate casing to surface.
- Leave cement on production casing below base of target coal seam.
- Open annular spaces around production and intermediate casings will allow outer casings to shift while protecting production casing.
Proposal for In-Situ Testing of Current and Alternate Casing Methods
Proposed Procedure for Maintaining Wells Within Long Wall Mining Areas

Example of temporary plugging method

- 20" water string at 300'
- Annular space filled with bentonite gel or other acceptable fluid
- Pittsburgh Coal Seam
- 13-3/8" coal string at 3,000'
- Cement top on 9-5/8" below base of coal
- Cement top on 5-1/2" below base of coal
- 9-5/8" intermediate casing at 1,800'
- 5-1/2" production casing to total depth
- 300' of cement on top of bridge plug
- Drillable bridge plugs

Temporary plugging of gas well during mining operations

- In advance of mining:
  - Temporarily plug production casing above the curve to isolate the gas formation from the coal seam.
- Following removal of panels on both sides of well:
  - Pressure test production casing to insure integrity
  - Perform remedial work if required
  - Drill out or remove plugs
  - Return well to production
- If placing well back in production is not possible, the well is already plugged adequately.
- Industry will work with DEP on specific details to insure safety and environmental protection.
In-Situ Testing
Layout of In-Situ Sample Well Drill Pad

E-24 Panel
- Gas Wells
- Monitoring Wells

E-25 Panel
Layout of In-Situ Test Site Subsidence and Lateral Movement Monitoring Stations
ABAQUS Predicted Shifting and Subsidence vs. Actual Results of In-Situ Wells

Computed Results:
• Center Panel Surface Subsidence: 4.606’ after E24 (South Panel)
• Center Panel Surface Subsidence: 4.618’ after E25 (North Panel)
• Well Site Vertical Subsidence: <0.2044’
• Well Site Horizontal Movement: <0.1313’
• Coal Pillar Pressure: 469 psi after E24 (South Panel)
• Coal Pillar Pressure: 917 psi after E25 (North Panel)

Actual Results:
• Center Panel Surface Subsidence: 4.6’ after E24 (South Panel)
• Center Panel Surface Subsidence: 4.6’ after E25 (North Panel)
• Well Site Vertical Subsidence: <0.2’
• Well Site Horizontal Movement: <0.2’
• Coal Pillar Pressure: 375 psi after E24 (South Panel)
• Coal Pillar Pressure: 833 psi after E25 (North Panel)
Process for Determining In-Situ Wellbore Damage

- Casing Evaluation (all 4 test wells)

- Ran multi finger caliper log inside the mine string casing prior to any mining and after each long wall pass
Results of Caliper Logging - 48” Drift (Roundness)

Summary of 60-arm caliper logging in Test Wells – 48” drift diameter

- Maximum deformation occurs in all wells in the interval from 390 – 400 feet
- Minimum 48” drift diameter indicates smallest I.D. after mining over a 48” pipe section
- Maximum observed diameter reduction of just under 2 inches.
Summary of 60-arm caliper logging in Test Wells – Minimum I.D.

- Maximum deformation occurs in all wells in the interval from 390 – 400 feet
- Minimum inside diameter
- Comparing both the 48” drift diameter and the measured inside diameter, the maximum observed diameter reduction is less than 2 inches.
Down Hole Shifting of ABAQUS Model vs. In-Situ Wellbores @ Elevation 390’

Predicted Results:
• MW-4 : 4.17” after E24 (South Panel)
• MW-4 2.81” after E25 (North Panel)
• Test Well 1 4.29” after E24 (South Panel)
• Test Well 1 2.68” after E25 (North Panel)
• Test Well 2 4.08” after E24 (South Panel)
• Test Well 2 2.99” after E25 (North Panel)
• Test Well 3 4.19” after E24 (South Panel)
• Test Well 3 2.96” after E25 (North Panel)
• Test Well 4 4.10” after E24 (South Panel)
• Test Well 4 3.10” after E25 (North Panel)

Actual Results:
• MW-4 5.8” after E24 (South Panel) via inclinometer
• MW-4 4.7” after E25 (North Panel) “
• Test Well 1 4.9” after E24 (South Panel) via 60 Arm Caliper Log
• Test Well 1 3.3” after E25 (North Panel) “
• Test Well 2 5.4” after E24 (South Panel) “
• Test Well 2 5.0” after E25 (North Panel) “
• Test Well 3 2.0” after E24 (South Panel) “
• Test Well 3 4.6” after E25 (North Panel) “
• Test Well 4 4.1” after E24 (South Panel) “
• Test Well 4 3.0” after E25 (North Panel) “
Based Upon the Successful Results of In-Situ Testing
The Industry Consortium Is Requesting:

1. That the Pennsylvania DEP approve alternate casing plans and cementing methods for new wells located on planned gate road pillars

2. When mining approaches, grant permits for mining around wells located in gate road pillars

3. The consortium recommends that the down hole temporary plugging of the wells be implemented and approved by the DEP to avoid any risk to miners.

4. This same down hole plugging process should apply to existing wells on planned pillars that have casing cemented to the surface.

Thank You! – Questions??