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# Effects of longwall-induced stress and deformation on the stability and mechanical integrity of shale gas wells drilled through a longwall abutment pillar

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ABSTRACT

This paper presents the results of a comprehensive study conducted by CONSOL Energy, Marcellus Shale Coalition, and Pennsylvania Coal Association to evaluate the effects of longwall-induced subsurface deformations on the mechanical integrity of shale gas wells drilled over a longwall abutment pillar. The primary objective is to demonstrate that a properly constructed gas well in a standard longwall abutment pillar can maintain mechanical integrity during and after mining operations. A study site was selected over a southwestern Pennsylvania coal mine, which extracts 457-m-wide longwall faces under about 183 m of cover. Four test wells and four monitoring wells were drilled and installed over a 38-m by 84-m centers abutment pillar. In addition to the test wells and monitoring wells, surface subsidence measurements and underground coal pillar pressure measurements were conducted as the 457-m-wide longwall panels on the south and north sides of the abutment pillar were mined by. To evaluate the resulting coal protection casing profile and lateral displacement, three separate 60-arm caliper surveys were conducted. This research represents a very important step and initiative to utilize the knowledge and science obtained from mining research to improve miner and public safety as well as the safety and health of the oil and gas industries.



## 1. Introduction

Due to a recent shale gas boom, one which may enable the United States to become more energy independent, approximately 800 gas wells have been drilled through active and future coal reserves in Pennsylvania, West Virginia, Ohio, Virginia, and Tennessee over the past 10 years. These shale gas wells have penetrated many coal seams, such as the Sewickley, Pittsburgh, upper/lower Freeport, and upper/middle/lower Kittanning seams, which are either actively mined or planned to be mined in the near future. Also, these shale gas wells, whether tapped into the Marcellus or Utica formations, contain very high (approximately 2.41–20.7 MPa) gas pressure. Longwall and high-extraction-induced stresses and strata deformations could induce high stresses and deformations in the shale gas well casings, which may seriously compromise the mechanical integrity of the production, intermediate and coal protection casings. Such a compromise of mechanical integrity of the well casings would potentially introduce high-pressure, explosive gas into underground mine workings or into surface dwellings and water wells, which could seriously jeopardize underground miners as well as public safety and health. Plugging these gas wells ahead of mining not only incurs substantial cost for the mining operators, it also represents substantial loss of income for gas operators.

In 2012, upon recognizing that the 1957 Pennsylvania Gas Well Pillar Regulations were formulated without data from modern-day longwall mining, the Pennsylvania Department of Environmental Protection (PA DEP) initiated a call for research to update the outdated regulations, which have been widely used by the Mine Safety and Health Administration (MSHA) and other states to govern gas well pillar stability issues over the past 60 years. In response to this call for research, the John T. Boyd Mining and Geological Consultants Company was commissioned to conduct an analytical study to produce a preliminary safeguard distance table [1,2]. This table, by the nature of its overly simplified analytical approach, cannot take into account detailed subsurface strata deformations. In 2013 and 2014, a study was conducted in a southwestern Pennsylvania coal mine under shallow cover by the coal and gas industries, which focused primarily on the effect of strata deformations on the well casings above the mining horizon. This paper presents the results of a suite of detailed 3D finite element analyses and some

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of the field instrumentation results (about 75% of the field instrumentation results are not able to be included pending consent from the project partners).

## 2. Site description and geotechnical instrumentations

The study site was located over a southwestern Pennsylvania coal mine employing longwall panels to extract from the Pittsburgh Seam. A three-entry longwall gate road system of 18.3 m × 38.1 m centers was employed at the mine. Fig. 1 illustrates the layout of the longwall panels, which are oriented approximately in the east-west direction. Fig. 1 also shows the locations of the surface and subsurface instrumentation layout, which includes four test wells designed similarly to real shale gas wells, three subsurface inclinom stations and one subsurface extensom station. Test wells were drilled to a depth of 196 m, which was about 12.2 m below the Pittsburgh Seam. The inclinom holes were drilled to different depths below the surface (0–61, 61–122 and 122–183 m), while the extensom hole was drilled to 192 m below the surface. In addition to the surface subsidence measurements, underground instrumentation consisting of borehole pressure cells (BPCs) and entry convergence meters was also installed to corroborate surface responses with subsurface and underground responses to provide a clear picture of strata reaction to longwall mining. The first panel mined by the test site in August 2013 and the second panel mined by the test site in May 2014.

## 3. Site geology

The overburden depth at the test site was about 183 m. Fig. 2 shows the detailed geology at the test site, which was interpreted by correlating a test site gamma log and a nearby core hole. Clearly, the overburden geology was a typical Pittsburgh Seam geology and was highlighted by many strong and weak rock interfaces, which were demonstrated to have major influences on longwall-induced stresses and deformations from ground control research conducted over the past 30 years.

## 4. 3D finite element simulations

Prior to the instrumentation program, which commenced in June 2013, a series of ABAQUS 3D finite element simulations were conducted and analyzed to evaluate the effect of longwall excavations on the induced stresses and deformations within the gate road abutment pillars and their effects on the stability of shale gas wells drilled through the abutment pillars. Specifically, the concerns centered on the stability of the production, intermediate and coal protection casings, since any stability compromise of these casings may potentially introduce high-pressure shale gas into mine workings, which would seriously jeopardize underground miner safety and health. The ABAQUS finite element program was selected over a number of numerical models, since it has been calibrated and verified with field data from the Pittsburgh, Pocahontas #3, and Illinois #6 seams over the past 25 years.

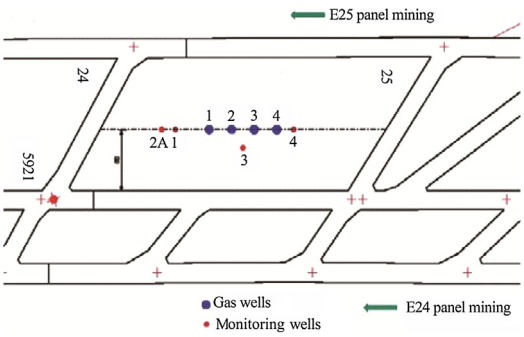


**Fig. 1.** Surface instrumentation layout at the test site.

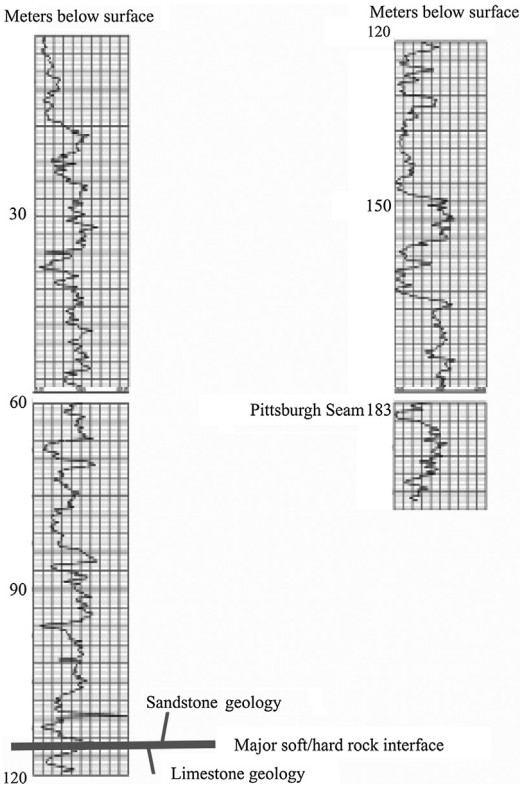


**Fig. 2.** Test site overburden geology as interpreted from an on-site gamma log and a nearby core hole.

## 5. Results of geotechnical instrumentation and 3D finite element analyses

### 5.1. Geotechnical instrumentation

Surface subsidence surveys were conducted as the first panel approached within 305, 153, 61, and 0 m of the test site, and 61, 153, and 305 m past the test site, which occurred in August 2013. A similar survey schedule was also implemented for mining of the second panel, and the survey was completed in June 2014. The inclinom and extensom readings were recorded continuously over the same time frame. Three 60-arm caliper surveys were conducted to evaluate the casing profile of the four test wells, and they were conducted one month prior to mining of the first panel, one month after mining of the first panel, and one month after mining of the second panel.

Fig. 3 shows the results of surface subsidence and surface horizontal movement measurements after completion of the first and second panels, respectively. Fig. 4 illustrates the plastic casing profile of one of the inclinom holes, which indicates the magnitude of movement after the first and second panel extractions. Results from the extensom monitoring are not presented, since due to the relatively shallow overburden, less than 1.3 cm of vertical movement was detected. Results from the 60-arm caliper surveys are not presented in this paper pending consent from the project partners, although the well casing profiles mimic the inclinom casing profile shown in Fig. 4.